Comparison of the Behaviour of Spilled Conventional and Non-Conventional Oils through Laboratory and Meso-Scale Testing: Full Data Report

For:

Canadian Association of Petroleum Producers

Canadian Energy Pipeline Association
(TC Energy and TransMountain)

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Scientific Advisory Committee

The Scientific Advisory Committee (SAC) provided inputs into the development of the test procedures and initial protocols used in this project. Membership of the SAC included:

- Canada Energy Regulator
- Environment and Climate Change Canada
- Fisheries and Oceans Canada
- Natural Resources Canada
- Polaris Applied Sciences, Inc.

Disclaimer

EXECUTIVE SUMMARY

There is a risk of spills associated with all oil product transportation systems, including pipelines. Spills are rare events with the consequences, to a large degree, determined by location, timing and environmental conditions. Knowledge about how different oils behave under different conditions is important in making the right decisions to select the most effective recovery strategies and equipment.

This study was commissioned with the goal of significantly enhancing the state of knowledge of oil properties and behaviour for spills of conventional and non-conventional oils in a range of environmental conditions: fresh and marine waters, with and without sediments in the water, and cold and warm temperatures. Data and findings from this study will improve response effectiveness by validating computer model predictions of oil fate and behaviour over time, and by enabling responders to make more informed decisions about choosing the most effective countermeasures.

This full data report details an extensive series of hundreds of tests conducted at different scales in a laboratory setting. The 14 oils selected for this study range from condensate to heavy oils representing a cross section of the conventional (light, medium and heavy) and non-conventional crude oil (e.g. oil sands-derived) shipped by Canadian transmission pipelines to markets in Canada and in the United States. Bunker C (Heavy Fuel Oil - HFO) and Alaska North Slope crude (ANS) were included for additional comparison, recognizing their common use and extensive knowledge base covering the characteristics of these products. This is the first time that such a broad range of Canadian oils have undergone consistent, multi-scale, rigorous analysis related to spill behaviour.

The work was divided into six main areas of research designed to study how the properties of selected oils varied over time after being released in different environments:

1. Small-scale tests using standardized protocols to determine oil physical properties relevant to oil spill response.
2. A small-scale study to evaluate different laboratory oil evaporation methods in order to confirm that physical properties measurements are largely independent of the test protocol used.
3. Small-scale tests to study oil-particle (sediment) interaction – for marine and freshwater spills.
4. Larger-scale tests performed in a recirculating flume with both fresh and marine waters to evaluate changes in oil properties under different conditions.
5. Small-scale tests to study how the oils flow through porous media (soil / sand/ pebble).
6. Larger-scale tests to evaluate adhesion of oils to shorelines – focusing on the effects of wave action on stranded oil.

No laboratory test can fully simulate the complexity of the natural environment. Small scale tests such as evaporating samples in a wind tunnel, provide valuable benchmarks of oil properties at a specific point of mass loss. Recirculating flume tests come closer to replicating real world conditions where oil on water is able to spread and weather in the presence of winds, currents, UV light, varying temperatures, and mixing energy (waves/currents).

The main conclusions drawn from the six different research areas are summarized here:

- A common misconception about oil sands-derived crudes is that they tend to separate into their original bitumen and diluent quickly after they spill. This is not possible because the hydrocarbons in both the diluent and bitumen are infinitely soluble in each other and do not form separate phases after mixing together.
- Oil weathering processes including spreading, evaporation, dispersion, emulsification, dissolution, photooxidation, sedimentation, and biodegradation will all impact a slick to varying degrees. Of these processes, evaporation has the highest impact at the beginning of a spill of most oils, including oil sands-derived crudes, and can result in a substantial reduction in the mass of oil remaining to be recovered from the environment. With condensates, most of the oil naturally evaporates and disperses from the water surface very soon after a spill. Light to medium oils can lose up to 40 percent of their volume due to evaporation within a few days. Heavy conventional crudes and oil sands-derived crudes experience evaporative losses in the order of 20 percent, still a significant factor in reducing the quantity of spilled oil available for recovery in the environment.
- Oil sands-derived products demonstrated changes to physical properties (viscosity and density) more rapidly due to weathering than conventional heavy crudes in the first few hours, especially at warmer temperatures. Over longer periods (days, weeks), these products ultimately weathered to densities and viscosities comparable to conventional heavy crudes.
- Many oils form water-in-oil emulsions that greatly increase the spill volume and viscosity. Data from this study showed that heavy conventional oils and oil sands-derived products are very likely to form emulsions while in a fresh state, but these oils quickly become too viscous to emulsify any further. The two lightest products tested, condensate and synthetic, were the only oils unlikely to emulsify in either a fresh or weathered state. Light to medium crudes are unlikely to begin to emulsify until they reach a moderately weathered state after a few days. Even then, they may only form entrained water or unstable emulsions.
- The oil-particle interaction study showed that at moderate levels of turbulence and moderate-to-high sediment particle concentrations in the water, a small percentage of the spill (on average) was removed from the surface of fresh water and transferred into the water column. There was no clear correlation between oil type and density, and oil mineral aggregate (OMA) formation.
- The addition of sediments during the flume tank runs did not cause bulk submergence or sinking in fresh water for the conventional heavy crude or for the oil sands-derived crude. The only oil substantially affected by the addition of sediments to the flume tank was HFO during the low water temperature run (0°C), which saw noticeable submergence by the 1-hour mark.
- Porous media tests showed that the most viscous oils (e.g. HFO) had the lowest penetration and the least viscous oils (e.g., condensate, SYN) penetrated the furthest.
- The artificial soil, with its clay and organic material, retained selected chemical compounds and showed reduced BTEX concentrations in the run-off water when compared with the sand or gravel test results.
- Shoreline adhesion tests showed that light and medium oils are more easily self-cleaned from shoreline sediments through wave action meaning they are more susceptible to remobilization. In contrast, higher viscosity oils were more persistent and likely to remain in place.

The likelihood of oil sinking after a spill is a concern in any response. Response plans are prepared using emergency response strategies and equipment that consider the potential for some oil to submerge, be over washed by wave action, entrained in the water, or possibly sink.

Results from the small-scale and recirculating flume tests (run for a minimum of five days) showed:

- All of the oils floated in marine (saltwater) experiments regardless of the degree of weathering.
- Light and Medium Oils floated in freshwater regardless of the degree of weathering.
- Conventional and non-conventional heavy oils reached densities close to or equal to neutral buoyancy in freshwater (e.g. 0.98 to 1.02) within a few hours to days in the flume tests. This makes them susceptible to temporary submergence/over washing and entrainment but not inevitably to sinking. The increased viscosity associated with weathering contributed to the formation of weathered oil mats with entrapped bubbles that were observed to remain floating for extended periods of time in the recirculating flume.
- The HFO run at low water temperature (0°C) resulted in some blobs of oil submerging and sticking to the walls of the flume tank by 6 hours into the run. By the 24 hour mark, a large portion of the oil slick was submerged. This oil remained floating in fresh water at the warm water temperature (20°C) and in tests with seawater at both tested temperatures.
- The partially upgraded oil sands product (AHS) also showed some submergence with a few blobs of oil being stuck to the walls and settling to the bottom of the tank at the 24 hours point of the flume testing in freshwater at 20°C. It remained floating in tests with fresh water at the lower temperature and tests with seawater at both tested temperatures.
- The uptake of sediments depends on a number of factors, including the mixing energy, particle types and sizes, and the pour point and viscosity of oils that might make them more conducive to mineral aggregate (OMA) formation. The potential for entrainment in the water column through an uptake of sediments is not unique to oil sands-derived crudes and can occur for many crude and fuel oils. Notably, the addition of suspended sediment in the flume tests in this study did not cause gross submergence or sinking for the conventional heavy crude, or oil sands-derived crudes.

Data generated in this project covers the full spectrum of expected behaviours for a wide range of oils. The results demonstrate that oil sands-derived crudes do not exhibit unusual characteristics that would substantially affect the applicability of current oil spill response strategies to a wide range of spill scenarios and oil types. Any heavy oil, whether conventional or oil sands-derived, can become highly viscous and increase in density as it weathers, emphasizing the importance of rapid response using proven recovery systems designed to handle very viscous products.

Industry remains committed to being prepared to respond to the full range of possible spill events originating from its facilities or transportation systems. Mitigating the consequences of oil spills is accomplished through proven and practiced emergency response plans (including remediation and restoration) mandated by regulatory agencies and required financially by law under the Pipeline Safety Act. This study is part of maintaining and strengthening that commitment to environmental protection through ongoing research.

The well-known statement that "speed is the key for oil spill response" holds for all oil spills including spills of oil sands-derived products. Industry and government understand this and work together to continuously improve response capabilities, as evidenced by programs such as the federal Canadian Multi-Partner Research Initiative (2019 ongoing) under the Oceans Protection Plan.

TABLE OF CONTENTS

Executive Summary ii

1 Introduction 1

1.1 Project Objective 1

1.2 Project Description 2

2 Oils Used During Testing 3

3 Standardized Oil Analysis 5

3.1 Introduction 5

3.2 Methods 5

3.2.1 Physical properties 5

3.2.2 Evaporation 6

3.2.3 Density 6

3.2.4 Viscosity 7

3.2.5 Interfacial Tension 7

3.2.6 Pour Point 7

3.2.7 Flash Point 8

3.2.8 Emulsification Tendency and Stability 8

3.3 Oil Analysis Results 9

3.3.1 Albian Heavy Synthetic (AHS) 10

3.3.2 Alaskan North Slope (ANS) 14

3.3.3 Access Western Blend (AWB) 18

3.3.4 Conventional Heavy Crude (CHV) 22

3.3.5 Cold Lake Blend (CLB) 26

3.3.6 Condensate Blend (CRW) 30

3.3.7 Heavy Fuel Oil – Bunker C (HFO) 34

3.3.8 Light Sour Blend (LSB) 38

3.3.9 Medium Sour Blend (MSB) 42

3.3.10 Mixed Sweet Blend (MSW) 45

3.3.11 North Dakota Bakken (NDB) 50

3.3.12 Synbit Blend (SYB) 54

3.3.13 Synthetic Sweet Blend (SYN) 58

3.3.14 Western Canadian Select (WCS) 62

3.4 Discussion....66
3.5 References....66
4 Artificial Weathering Methods Comparison....67
4.1 Introduction....67
4.2 Background....67
4.3 Results....69
4.3.1 AHS Weathering Comparison Results....69
4.3.2 ANS Weathering Comparison Results....71
4.3.3 AWB Weathering Comparison Results....72
4.3.4 CHV Weathering Comparison Results....73
4.3.5 CLB Weathering Comparison Results....75
4.3.6 CRW Weathering Comparison Results....76
4.3.7 HFO Weathering Comparison Results....77
4.3.8 LSB Weathering Comparison Results....79
4.3.9 MSB Weathering Comparison Results....80
4.3.10 MSW Weathering Comparison Results....81
4.3.11 NDB Weathering Comparison Results....83
4.3.12 SYB Weathering Comparison Results....84
4.3.13 SYN Weathering Comparison Results....85
4.3.14 WCS Weathering Comparison Results....87
4.4 Weathering Comparison Discussion....88
5 Oil-Particle Interactions....90
5.1 Background....90
5.2 Protocol variables....90
5.3 Test Protocol....92
5.4 Observations and Discussion....93
5.4.1 General....93
5.4.2 Mineral Type....93
5.4.3 Mineral Concentration....94
5.4.4 Brackish Water....94
5.4.5 Oil Type....95
5.4.6 Overall Summary....97

6 Flume weathering Tests 98
6.1 Test Method 98
6.2 Sampling Protocol 101
6.3 Flume Results and Discussion 102
7 Porous Media Tests 109
7.1 Background 109
7.2 Protocol Review 109
7.2.1 Small Bench Scale Materials: 109
7.2.2 Procedure for Producing Artificial Soil 110
7.3 Small Bench Scale Test Procedures 111
7.3.1 The small bench scale test procedure for sand 111
7.3.2 The small bench scale test procedure for artificial soil 111
7.4 Small Bench Scale Shakedown Test Results 112
7.5 Large Bench Scale Materials 113
7.6 Large Bench Scale Test Procedure 113
7.6.1 The procedure for sand 114
7.6.2 The procedure for small pebble (3/8" pea gravel) 114
7.6.3 The procedure for artificial soil 115
7.7 Large Bench Scale Results 116
7.7.1 Penetration results in different media 116
7.7.2 Analysis of water effluent 117
7.8 Discussion 120
7.8.1 Small Bench Scale Tests 120
8 Shoreline Adhesion Tests 122
8.1 Test Matrix 123
8.2 Testing and Analytical Procedure for beach plots using *small* substrate 124
8.2.1 Preparation 124
8.2.2 Test Procedure for Small Substrate 124
8.2.3 Sampling Plots for Small Substrate 125
8.2.4 Analytical Procedure for Small Substrate 125
8.3 Sampling and Analytical procedure for beach plots using *large* substrate 125
8.3.1 Preparation 125

8.3.2 Test Procedure for Large Substrate 126
8.3.3 Sampling Plots for Small Substrate 126
8.3.4 Analytical Procedure for Large Substrate 126
8.4 Test Results 126
8.5 Discussion 147
9 Overall Conclusions and Recommendations 149
9.1 Standardized analysis of physical properties 149
9.2 Comparison of different laboratory evaporation methods 150
9.3 Oil-Particle interactions 151
9.4 Flume Weathering Tests 151
9.5 Porous Media Tests 152
9.6 Shoreline Adhesion Tests 153
10 References 154
APPENDIX A – Oil Property Test Methodology and Relationship to Spill Behavior 156
APPENDIX B – Oil Model Inputs and Chemical Analysis 160
B.1 AHS Oil 160
B.2 ANS Oil 168
B.3 AWB Oil 176
B.4 CHV Oil 183
B.5 CLB Oil 191
B.6 CRW Oil 199
B.7 HFO Oil 207
B.8 LSB Oil 215
B.9 MSB Oil 223
B.10 MSW Oil 231
B.11 NDB Oil 239
B.12 SYB Oil 247
B.13 SYN Oil 255
B.14 WCS Oil 263
APPENDIX C – Flume Tank Run Details 270
C.1 AHS in Flume Tank 270
C.2 ANS in Flume Tank 278

C.3 AWB in Flume Tank ... 283
C.4 CHV in Flume Tank ... 291
C.5 CLB in Flume Tank ... 298
C.6 CRW in Flume Tank ... 305
C.7 HFO in Flume Tank ... 309
C.8 LSB in Flume Tank ... 321
C.9 MSB in Flume Tank ... 330
C.10 MSW in Flume Tank ... 333
C.11 NDB in Flume Tank ... 342
C.12 SYB in Flume Tank ... 345
C.13 SYN in Flume Tank ... 353
C.14 WCS in Flume Tank ... 358
APPENDIX D – Flume Tank Density and Viscosity Data ... 369
APPENDIX E – Porous Media Test Data ... 381
APPENDIX F – Beach Adhesion Testing Protocol Development ... 453
APPENDIX G – Oil Fact Sheets ... 463

1 INTRODUCTION

In 2014 the Royal Society of Canada (RSC) established an Expert Panel in response to a request from the Canadian Energy Pipeline Association (CEPA) and the Canadian Association of Petroleum Producers (CAPP). The Expert Panel, composed of international specialists on spilled oil chemistry, behaviour and toxicity, reviewed the current science relevant to crude oils spilled into Canadian marine waters, lakes, waterways and wetlands. The report on their findings was released in late fall of 2015. The report, entitled "Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments" highlights research needs related to the behaviour of crude oils, including unconventional oils such as diluted bitumen and shale oil, and how they affect ecosystems and communities in the event of spilling into marine and inland waters.

Spills of crude oil during transportation across Canada have the potential to impact lakes, rivers and wetlands. These types of spills can have different ecological impacts and behavioural characteristics than spills in marine environments. Specific short term (High Priority) research needs were identified in the RSC report to address a lack of information involving the chemical composition, properties and behaviour of spilled oils including diluted bitumen blends. These concerns include research needs in the following areas:

- Evaporation and how weathering processes will affect crude oil properties and spill behaviour, particularly the evaporation behaviour of bitumen blends (e.g., dilbit, synbit, dilsynbit);
- Emulsion formation, particularly of weathered diluted bitumen in fresh water;
- Effectiveness of chemical dispersants on spills of diluted bitumens; and,
- Submerging behaviour, including interactions with suspended particulates.

It is important that this information be available to spill responders before an incident. The primary focus during a spill event is on public and worker health and safety, spill cleanup, environmental protection and restoration. Information on oil property variation over time and other oil fate and transport metrics are often not gathered during spill events due to more pressing issues. As a result, pertinent data is often not available from actual spill incidents. Furthermore, no two spills are alike and there are always oil-type, environmental, geographic or oceanographic factors that will ultimately result in unique oil behaviour and fate for a specific release.

1.1 PROJECT OBJECTIVE

The objective of this body of work has been to try to further improve knowledge of the most pressing data gaps in the state of knowledge of the behaviour and response options for spills of selected conventional and unconventional crude oils presently being transported in North America. Since tests with oils could not be carried out in the real-world environment, the objective was accomplished by conducting laboratory- and meso-scale tests under simulated real-world conditions instead which determined the following information:

- Oil properties and how those properties change with evaporation and exposure to a range of environmental conditions;

- Spill behaviour such as emulsion formation, submergence, and interactions with suspended particulates (sediment) in the water and on shorelines;
- Differences between bitumen blends, and their significance towards spill behaviour.

These laboratory tests were performed under a range of environmental conditions to provide ample data for comparison of the results to inform spill responders on the expected properties and oil behaviour over the first few days of a spill.

1.2 Project Description

Knowledge and understanding about the physical properties of an oil, and how they change with exposure to the environment (i.e., weathering), are critically important to spill responders in order to understand how the oil will behave if spilled primarily on water. Physical and chemical properties will affect the fate and behaviour of spilled oil and how it interacts with the environment (e.g., disperse or submerge in water, penetrate into porous media, adhere to surfaces and shorelines). These physical properties often define how the oil will react to its surrounding environment and the window-of-opportunity for specific spill countermeasures. Weathering and property information is also required for all oil-spill models, along with forecasts of weather and oceanographic conditions, to provide better predictions of property changes and slick impacts.

The project was completed as a series of many experiments. A short description of the experiments based upon the scale of the work is shown as follows:

Bench Scale Studies	Standardized bench-scale testing of selected conventional crude oils, shale oils, diluents, and diluted bitumen products of interest. Testing measured oil composition and physical properties and how those changed with artificial weathering, and the effects of interactions with suspended particulates.
Meso Scale Studies	Meso-scale testing to measure the effects of weathering on water with the selected oils at a larger scale. Testing assessed the effects of temperature, waves, current, air flow, salinity, UV rays and suspended particulates in water, adhesion on beach sediments, and oil penetration in simulated soils.

Six separate laboratory investigations were undertaken using a total of 14 oils to investigate the behavioural similarities or differences between conventional oils and bitumen products. These investigations included:

1. <u>Standardized Analysis</u> of the physical properties of fresh and artificially weathered oils (through evaporation) to provide data needed to model oil behaviour under varying conditions consistent with Canadian environments. This analysis involved wind-tunnel evaporation weathering of each oil and measurements of their fresh and weathered physical properties.
2. <u>Comparison of three commonly used laboratory evaporation methods</u> utilizing controlled heat and/or wind (air movement) to accelerate evaporative losses. This was done to verify that results were independent of the test protocol used.
3. A study of <u>oil-particle interactions</u> in a small-scale apparatus to determine the propensity of each oil to bind with sediment and possibly sink in a standardized test.

4. Long-term Flume Weathering Tests using on-water weathering at a meso-scale to determine the change in key physical properties of the oil as it weathered over a period of days. This test series used a recirculating flume to create conditions that better simulate a dynamic natural environment, including exposure to UV light, wind shear, surface water agitation, sub-surface water movement, suspended sediments and two temperature regimes.
5. Porous Media Tests to determine the penetration characteristics of each of the oils when spilled onto three soil types: small pebbles, sand, and loamy soil.
6. Shoreline Adhesion Tests to determine the propensity of the oil to adhere to two different beach types after being subjected to an array of waves configured to impact a sloped shoreline test section.

The overall goal of this project is to better understand the characteristics of different oils in a variety of conditions, including fresh and marine water with and without sediments, and cold and warm temperatures. Information from this project will provide responders with information to develop effective response plans and make informed decisions, and modellers with data needed to better predict oil behaviour over time. The oils selected and the specifics of the tests are described below.

A Scientific Advisory Committee (SAC) was formed to review and provide feedback on the proposed scope of the study; the proposed matrix of tests including methods to be performed; the relevance of proposed studies and their results and the list of crude oil types to be selected. The SAC included representatives from Environment and Climate Change Canada, Department of Fisheries and Oceans, Natural Resources Canada, National Energy Board and a world renowned spill expert.

2 OILS USED DURING TESTING

An independent consultant was hired to make a recommendation on the crude oil types to be included in the study. A total of 14 oils were selected representing a broad range of Canadian and foreign crude oil types. These oils range in composition from very light condensate, very light crude, medium crude and heavy crude, a range of “unconventional” diluted bitumen blends and Bunker C heavy fuel oil. The eleven Canadian crude oils selected represent a significant percentage of the volumes shipped by major pipelines. The selected oils are listed below in *Table 2–1*.

Table 2–1: Oils Selected for Testing

	Name	Type	Testing					
			Bench Scale			Meso Scale		
			Standard Property Analysis[1]	Comparison of Evap Methods	Oil-particle interactions	Flume Tank Weathering	Porous Media Penetration	Shoreline Adhesion
1	Condensate (CRW)	Blended Condensate/Crude, Extremely Light	x	x	x	--	x	x
2	Light Sour Blend (LSB)	Crude, Very Light	x	x	x	--	x	x
3	U.S. Bakken (NDB)	Crude, Very Light	x	x	x	x	x	x
4	Mixed Sweet Blend (MSW)	Crude, Light-Medium	x	x	x	x	x	x
5	Alaska North Slope (ANS)	Crude, Light-Medium	x	x	x	x	x	x
6	Medium Sour Blend (MSB)	Crude, Medium	x	x	x	x	x	x
7	Conventional Heavy (CHV)	Crude, Heavy	x	x	x	x	x	x
8	Bunker C – Heavy Fuel Oil (HFO)	Refined, Heavy	x	x	x	x	x	x
9	Western Canadian Select (WCS)*	Dilbit	x	x	x	x	x	x
10	Access Western Blend (AWB)*	Dilbit	x	x	x	x	x	x
11	Cold Lake Blend (CLB)*	Dilbit	x	x	x	x	x	x
12	Albian Heavy Synthetic (AHS)*	Partially upgraded oil sands product	x	x	x	x	x	x
13	Synbit Blend (SYB)*	Synbit	x	x	x	x	x	x
14	Synthetic Sweet Blend (SYN)*	Synthetic	x	x	x	x	x	x

* Oil sands-derived crudes
1 – Standard Property Analysis include traditional weathering incorporating fresh, Weathered Mode 1 (2 days in wind tunnel), Weathered Mode 2 (2 weeks in wind tunnel). An extended Weathered Mode 3 (6 weeks in wind tunnel) was incorporated in this study.

3 STANDARDIZED OIL ANALYSIS

3.1 INTRODUCTION

Understanding key spill related properties of oils is an important component of pre-spill planning and readiness. Physical and chemical properties of an oil will not only affect its fate and behaviour but may also impact the selection of appropriate countermeasures for clean-up efforts. The physical properties will often evolve over time and provide defined Windows of Opportunity[1] for various spill response techniques to be applied. As an example, in-situ burning is generally difficult to initiate and sustain once stable emulsions are formed.

Our normal weathering protocol includes splitting an oil sample into multiple subsamples to obtain:

1) a fresh sample,
2) short term weathered sample, and
3) a mid-term weathered sample.

One additional weathered sample was added to the analysis – 4) a long term weathered sample. Evaporative trays are used to weather the oil samples for discrete periods of time in a calibrated wind tunnel. At the end of the weathering process we are left with one fresh oil sample, plus samples of three artificially weathered states for each oil for Standardized Oil Analysis.

3.2 METHODS

3.2.1 Physical properties

The oils were subjected to the analyses outlined in *Table 3–1*. Test temperatures were chosen to represent a range of values encompassing typical values for regions across Canada for temperature sensitive tests, including density and viscosity.

Table 3–1: Test procedures for oil analysis

	Property	Test Temperature(s)	Equipment	Procedure
1	Evaporation	Room Temperature	Wind Tunnel Distillation Apparatus SIMDIS	D7169/D7900 blended, Modified ASTM D86
2	Density	0°C, 15°C, 20°C, and 30°C	Rudolph Research Analytical DDM 2911	ASTM D5002
3	Viscosity	0°C, 15°C, 20°C, and 30°C	Brookfield DV III+ Digital Rheometer c/w Cone and Plate and/or Brookfield R/S-CPS+ Rheometer	Brookfield M/98-211 and/or M/01-213-A0706
4	Interfacial Tension	Room temperature	CSC DuNouy Ring Tensiometer	ASTM D971

[1] Period during which a specific countermeasure is expected to successfully remediate spilled oil. As a spill weathers over time, physical properties change which will hinder the effectiveness of said countermeasure.

5	Pour Point	N/A	ASTM Test Jars and Thermometer/Thermocouple	ASTM D5853
6	Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
7	Emulsification Tendency and Stability	0°C and 20°C	Rotating Flask Apparatus	Zagorski and Mackay 1982, Hokstad and Daling 1993
8	Composition	N/A	Saturates, Aromatics, Resins, and Asphaltenes BTEX, Detailed hydrocarbon analysis PAHs, alkyl-PAHs, metals	D2007 + D6560 or D4124. GC/FID/MS GC/MS, other

3.2.2 Evaporation

Each oil was divided into four aliquots. Three aliquots were weathered in a wind tunnel: one for two days, one for two weeks, and one for six weeks. Depending upon conditions at a spill site, this is typically equivalent to a few hours, a few days, and many days on water. This helps address the lack of information in the scientific literature identified in the RSC report on the long-term weathering behaviour of unconventional oils. In addition, fresh oil samples were subjected to a modified distillation procedure (ASTM D86-17, modified in that both liquid and vapour temperatures are measured) in order to obtain two oil-specific constants for evaporation prediction purposes. Evaporation is correlated using Evaporative Exposure (θ), a dimensionless time unit calculated by:

$$\theta = kt/x$$

where: k = a mass transfer coefficient [m/s] (determined experimentally in the laboratory wind tunnel or by an equation related to wind speed for spills at sea)
t = elapsed time [s]
x = oil thickness [m]

The distillation information is used in conjunction with the wind tunnel data to predict evaporation rates for oil spills on water.

In addition, a sample of each fresh oil was sent to an outside oil analytical laboratory to be subjected to a SIMDIS analysis (depending upon the properties of an oil, typically using a blend of the ASTM D7169/D7900 procedures) that is required by some oil spill models to predict evaporation. These may be found in Appendix B for each oil.

3.2.3 Density

Density is the mass per unit volume of the oil (or emulsion), and determines how buoyant the oil is in the water. The common unit of density is grams per cubic centimetre (g/cm^3), although sometimes g/mL is used. The SI unit is kg/m^3, which is numerically 1000 times the value in g/cm^3. The density of spilled oil increases with weathering and decreases with rising temperatures. Density can have an impact on the following spill processes

- Potential for submergence – if the density of the oil approaches or exceeds 1 g/mL the oil becomes subject to temporary submergence and possible sinking in fresh water (generally SG=1);

- Spreading – in the early stages of a spill, more dense oils spread faster;
- Natural dispersion – more dense oils stay dispersed more easily in the water column; and,
- Emulsification stability – dense oils form more stable emulsions (typically due to their chemical composition)

3.2.4 Viscosity

Viscosity is a measure of the resistance of oil to flow, once in motion. The common unit of measurement of dynamic viscosity is the centi-Poise (cP); the SI unit is the milli-Pascal second (mPas) which is numerically equivalent to the centi-Poise. The common unit of kinematic viscosity (calculated by multiplying the dynamic viscosity by the density) is the centi-Stoke (cSt); the SI unit is the square millimeter per second (mm^2/s), which is numerically equivalent to the centi-Stoke. The viscosity of spilled oil increases as weathering progresses and decreases with increasing temperature. Viscosity is one of the more important properties from the perspective of spill behaviour and affects the following processes:

- Spreading – higher viscosity oils spread more slowly;
- Natural and chemical dispersion – highly viscous oils are difficult to disperse;
- Emulsification tendency and stability – viscous oils typically form more stable emulsions; and,
- Recovery and transfer operations – more viscous oils are generally harder to skim and more difficult to pump.

3.2.5 Interfacial Tension

Interfacial tension is a measure of the surface forces that exist between the interfaces of the water and oil, and the oil and air. The common unit of interfacial tension is the dyne/cm; the SI unit is the milli-Newton/meter (mN/m), which is numerically equivalent to the dyne/cm. Chemical dispersants work by reducing the oil/water interfacial tension to allow a given mixing energy (i.e., sea state, breaking waves) to produce smaller oil droplets). Emulsion breakers also work by lowering the oil/water interfacial tension; this weakens the continuous layer of oil surrounding the suspended water droplets and allows them to coalesce and drop out of the emulsion. Interfacial tensions (oil/air and oil/water) are fairly insensitive to temperature, but are affected by evaporation. Interfacial tension affects the following processes:

- Spreading – interfacial tensions determine how fast an oil will spread and whether the oil will form a sheen;
- Natural and chemical dispersion – oils with high interfacial tensions are more difficult to disperse naturally, chemical dispersants work by temporarily reducing the oil/water interfacial tension;
- Emulsification rates and stability; and,
- Mechanical recovery – oleophilic skimmers (e.g., rope-mop, belt, disk, drum skimmers) work best on oils with moderate to high interfacial tensions.

3.2.6 Pour Point

The pour point is the lowest temperature (tested to the nearest multiple of 3°C) at which crude oil will still flow. Near, and below this temperature, the oil develops a yield stress and, in essence, gels. The pour point of an oil increases with weathering. Pour point affects the following processes:

- Spreading – oils at temperatures below their pour points will not spread on water;
- Viscosity – an oil's viscosity at low shear rates increases dramatically at temperatures below its pour point;
- Natural and chemical dispersion – an oil at a temperature below its pour point may be difficult to disperse; and,
- Recovery, transfer and storage – crude oil below its pour point may not flow towards skimmers or down inclined surfaces in skimmers, and at temperatures significantly below its pour point may present storage/transfer challenges.

3.2.7 Flash Point

The flash point of crude oil is the temperature at which the oil produces sufficient vapours to ignite when exposed to an open flame or other ignition source. Flash point increases with increasing evaporation and is an important safety-related spill property, especially in the early stages of a spill when the oil is fresh.

3.2.8 Emulsification Tendency and Stability

The tendency of crude oil to form water-in-oil emulsions (or "mousse") and the stability of the emulsion formed are measured here by two numbers: the Emulsification Tendency Index (Zagorski and Mackay 1982, Hokstad and Daling 1993) and the Emulsion Stability (adapted from Fingas *et al.* 1998). The Emulsification Tendency Index is a measure of the oil's propensity to form an emulsion, quantified by extrapolating back to time = 0 the fraction of the parent oil that remains (i.e., does not cream out) in the emulsion formed in a rotating flask apparatus over several hours. If a crude oil has an Emulsification Tendency Index between 0 and 0.25 it is unlikely to form an emulsion; if it has a Tendency Index between 0.25 and 0.75 it has a moderate tendency to form emulsions. A value of 0.75 to 1.0 indicates a high tendency to form emulsions. The Emulsion Stability assessment has been changed to reflect the four categories originally suggested by Fingas *et al.* 1998. Emulsion types are selected based on water content and the visual appearance of the emulsion after 24 hours settling. The four categories used to describe emulsification are defined as follows:

1. **Unstable** – looks like original oil; water contents after 24 hours of 1% to 23% averaging 5%; viscosity same as oil on average.
2. **Entrained Water** – looks black, with large water droplets; water contents after 24 hours of 26% to 62% averaging 42%; emulsion viscosity 13 times greater than oil on average.
3. **Meso-stable** – brown viscous liquid; water contents after 24 hours of 35% to 83% averaging 62%; emulsion viscosity 45 times greater than oil on average.
4. **Stable** – the classic "mousse", a brown gel/solid; water contents after 24 hours of 65% to 93% averaging 80%; emulsion viscosity 1100 times greater than oil on average.

Both the Tendency Index and Stability generally increase with increased degree of evaporation. Colder temperatures generally increase both the Tendency Index and Stability (i.e., promote emulsification). Emulsion formation results in large increases in the spill's volume, enormous viscosity increases (which can reduce dispersant effectiveness), and increased water content (which can prevent ignition of the slicks and *in situ* burning).

It is generally believed that oils that have relatively high concentrations of asphaltenes, resins, and/or waxes are the most likely to form stable water-in-oil emulsions. Some oil spills do not form emulsion immediately, but once evaporation occurs and the relative asphaltene, resin, and wax concentrations increase, the emulsification process begins and usually proceeds quickly thereafter.

3.3 Oil Analysis Results

The physical oil properties measured by SL Ross are presented in individual sections below. Each section consists of the following:

1. The name of the oil;
2. A summary table of the physical properties of the fresh and three weathered samples of the oil as measured by SL Ross;
3. A graph comparing the measured evaporation in the wind tunnel (for the three samples weathered for two days, two weeks, and six weeks) with the prediction of the evaporation model derived for the crude, at the average temperatures in the wind tunnel over the six-week period.
4. Three graphs that illustrate how the oil density (at 0°C, 15°C, 20°C, and 30°C), viscosity (at 0°C, 15°C, 20°C, and 30°C), and pour point change as the oil evaporates.

3.3.1 Albian Heavy Synthetic (AHS)

A summary of AHS spill-related physical properties is listed below in Table 3–2.

Table 3–2: Spill-related properties of AHS

Spill-related properties		Fresh	2D	14D	6W
AHS	API Gravity =	19.6 °			
Evaporation (Volume %)		0	16.2	20.6	23.8
Density (g/cm^3)					
0 °C		0.948	0.991	1.010	1.022
15 °C		0.937	0.980	0.999	1.012
20 °C		0.933	0.977	0.996	1.008
30 °C		0.926	0.970	0.989	1.001
Dynamic Viscosity (mPa.s)	at approx 100 s^{-1} except at 0°				
0 °C		809	40,838	310,285	1,660,148
15 °C		229	6,428	31,028	90,889
20 °C		172	4,301	16,130	50,844
30 °C		104	1,910	5,699	26,814
Kinematic Viscosity (mm^2/s)					
0 °C		854	41,195	307,305	1,624,781
15 °C		245	6,556	31,046	89,847
20 °C		184	4,403	16,194	50,431
30 °C		113	1,970	5,762	26,776
Interfacial Tension (dyne/cm)					
Oil/ Air		30.0	32.5	33.5	NM
Oil/ Seawater		24.6	23.4	28.8	NM
Pour Point (°C)					
		-33	-6	0	12
Flash Point (°C)					
		<-10	1	17	30
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Very Likely	Very Likely	Too Viscous	Too Viscous
Stability		Meso-stable	Entrained	Unstable	Unstable
Water Content		60%	NM	NM	NM
Emulsion Formation-Tendency and Stability @ 20°C			18 °C		
Tendency		Very Likely	Very Likely	Too Viscous	Too Viscous
Stability		Stable	Meso-stable	Entrained	Unstable
Water Content		72%	26%	0%	0%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)	
		IBP	55.6	25.7	
		5	91.3	44.8	
		10	129.2	61.8	
		15	184.3	46.7	
		20	270	50.1	
		25	407	60.3	
		30	434	106.6	
		40	450	210	
		50	460	277	
Weathering Model					

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta\exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 12770

C_2 = 9.60

C_3 = 4761

NM - not measured due to high viscosity

3.3.1.1 Evaporation

Approximately 16% of the oil volume evaporated after two days in the wind tunnel; about 21% evaporated after two weeks; and, around 24 % evaporated after 6 weeks of exposure.

Figure 3-1 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-2, Figure 3-3, and Figure 3-4 show the effect of evaporation on the properties of oil density, viscosity, and pour point.

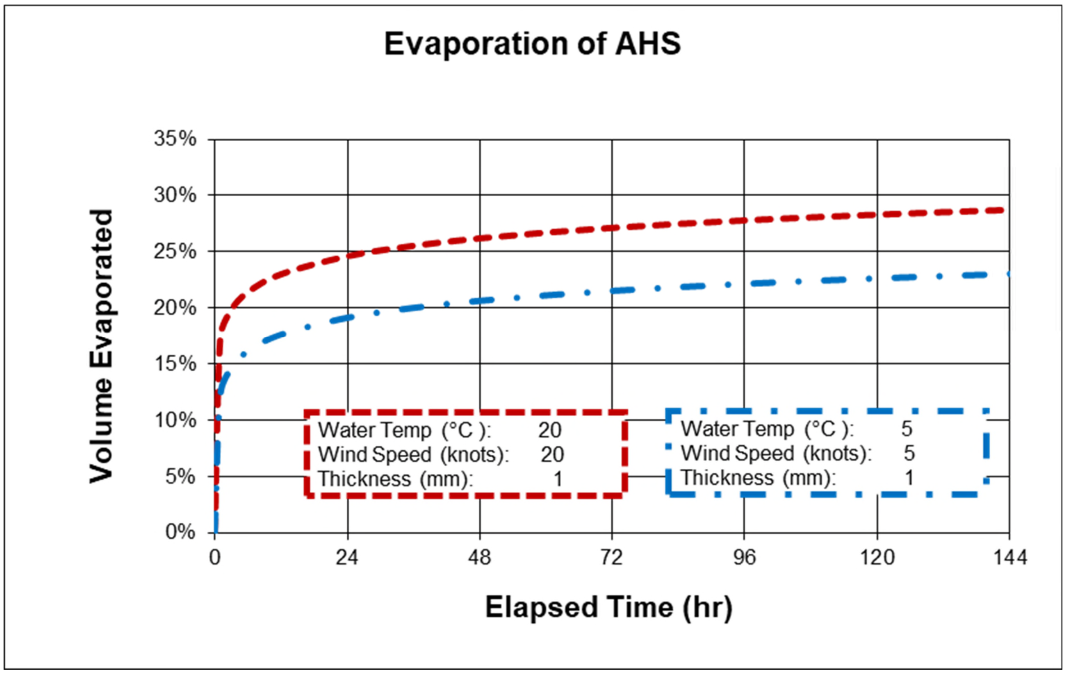


Figure 3-1 Evaporation of AHS

3.3.1.2 Density

AHS has a density of 0.937 g/cm³ at 15.5°C (API gravity of 19.6°). After 6 weeks in the wind tunnel, the density of the oil sample increased to 1.022 g/cm³ when measured at 0°C, very close to the density of seawater (about 1.027 g/cm³ at 0°).

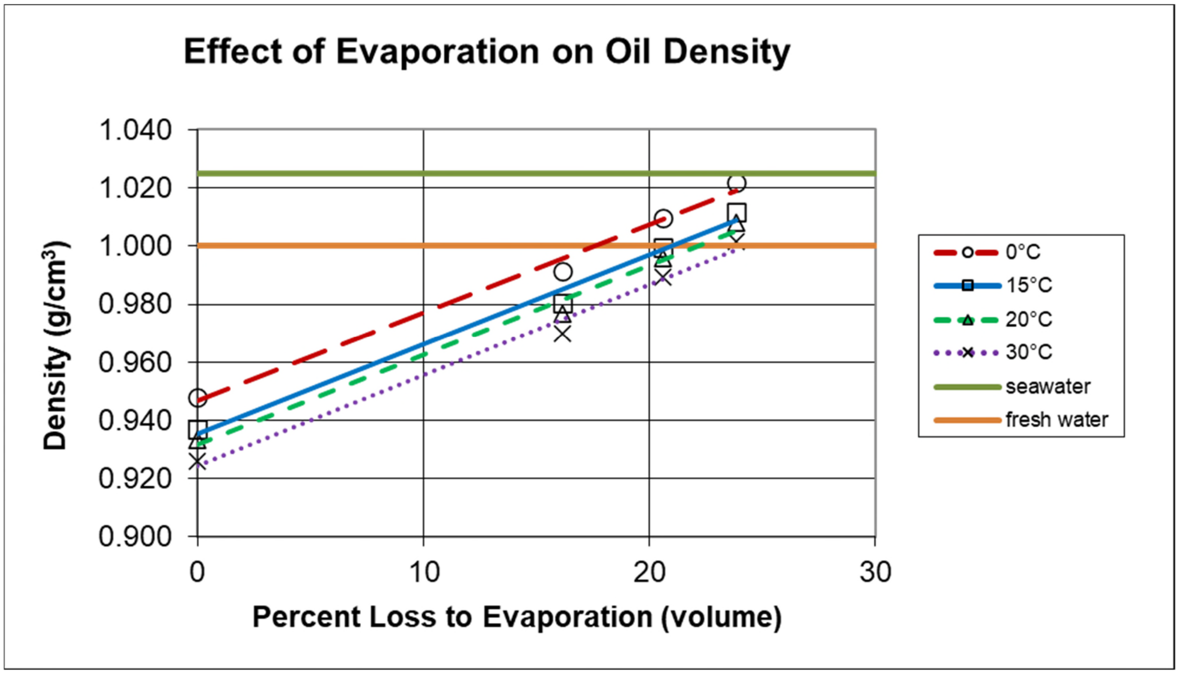


Figure 3-2 Effect of Evaporation on AHS Oil Density

3.3.1.3 Viscosity

The fresh oil has moderately high viscosity that is typical of partially upgraded bitumen. At 20°C the viscosity of the fresh oil is about 172 cP (mPa.s). The viscosity increases to 4,301 cP after 16% evaporation; to 16,130 cP after 21% evaporation; and, to 50,800 cP after 24% evaporation.

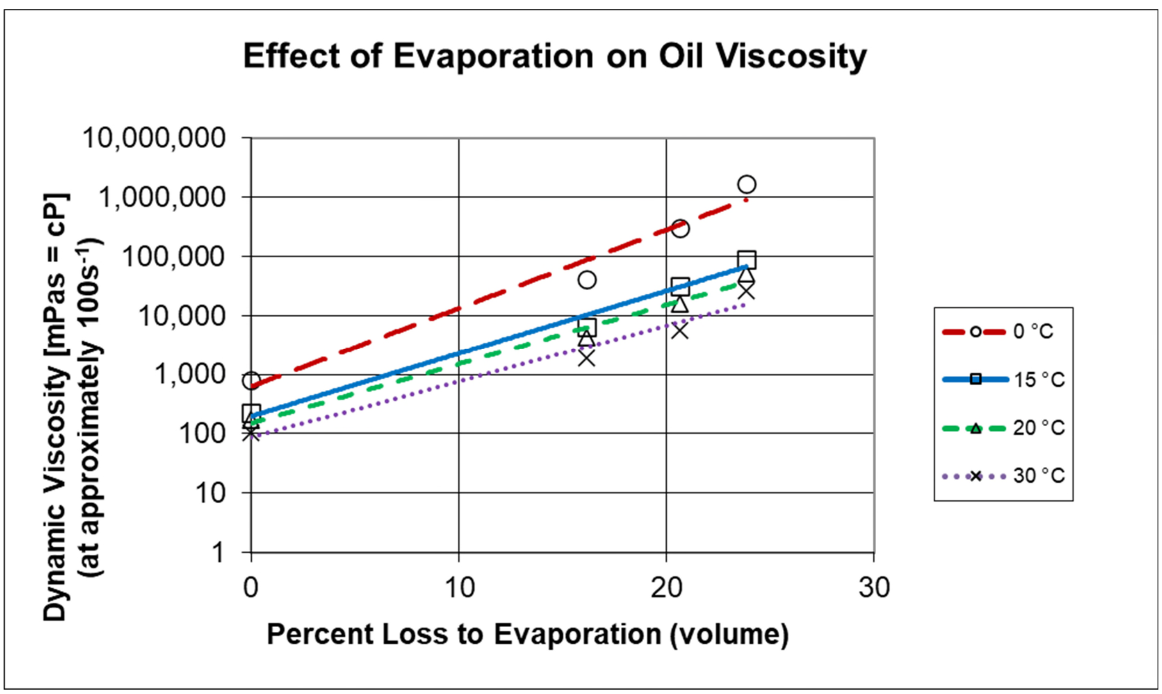


Figure 3-3 Effect of Evaporation on AHS Oil Viscosity

3.3.1.4 Pour Point
AHS has a pour point below -33°C when fresh which rises to 12°C after 24% evaporation.

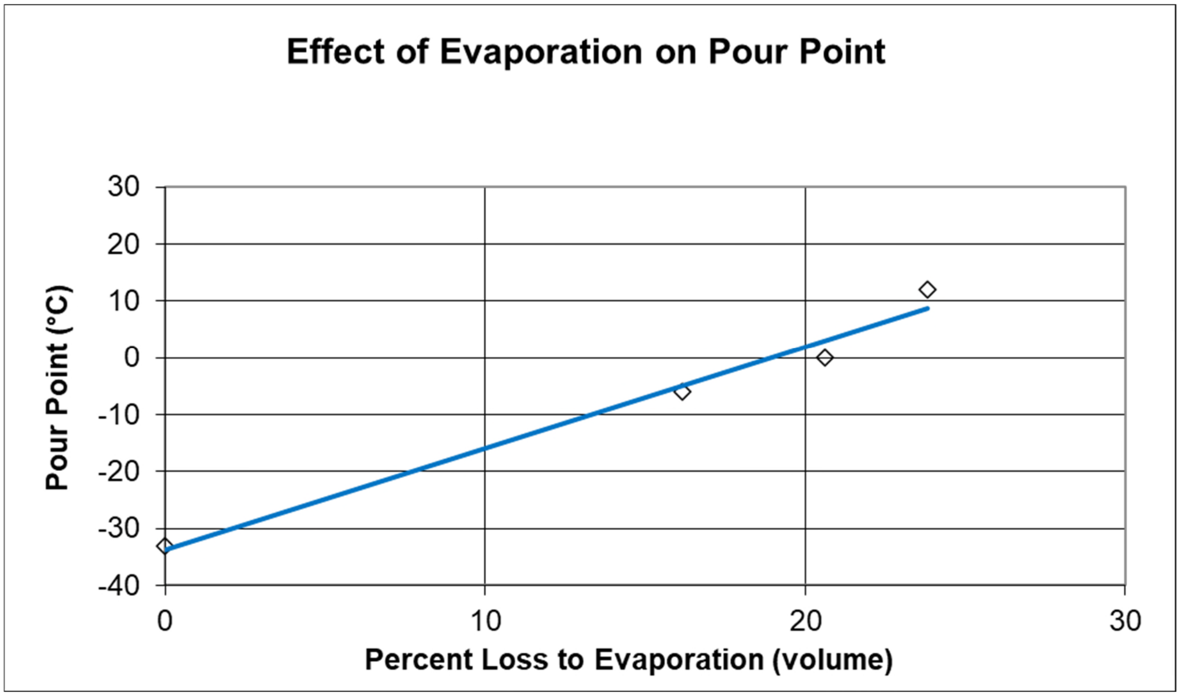


Figure 3-4 Effect of Evaporation on AHS Pour Point

3.3.1.5 Interfacial Tension
The oil/water interfacial tension of AHS was measured using standard laboratory water with 35 ppt of salt. The value measured was 24.6 dynes/cm, which is in the range of most crude oils.

3.3.1.6 Flash Point
AHS has a flash point of less than -10°C when fresh. This increases after 24% evaporation to 30°C.

3.3.1.7 Emulsification Tendency and Stability
One characteristic of AHS is that it is very likely to form meso-stable or stable water-in oil emulsions when mixed with seawater when it is fresh or slightly evaporated. Once AHS has lost 21% of its volume to evaporation it becomes too viscous to emulsify.

3.3.2 Alaskan North Slope (ANS)

A summary of ANS spill-related physical properties is listed in Table 3-3.

Table 3–3 Spill-Related Properties of ANS

Spill-related properties		Fresh	2D	14D	6W
ANS Crude	API Gravity =	32.5 °			
Evaporation (Volume %)		0	29.9	37.6	41.6
Density (g/cm^3)					
0 °C		0.874	0.932	0.944	0.952
15 °C		0.863	0.921	0.933	0.941
20 °C		0.859	0.918	0.930	0.938
30 °C		0.852	0.911	0.922	0.930
Dynamic Viscosity (mPa.s)	fresh at approx 500 s^{-1}; 2D, 14D and 6W at 100 s^{-1}				
0 °C		22	1,905	2,556	7,967
15 °C		11	241	462	913
20 °C		9	172	287	617
30 °C		7	126	145	269
Kinematic Viscosity (mm^2/s)					
0 °C		26	2,044	2,706	8,366
15 °C		12	261	495	970
20 °C		10	188	308	658
30 °C		8	138	157	289
Interfacial Tension (dyne/cm)					
Oil/ Air		25.6	29.9	29.1	29.3
Oil/ Seawater		14.2	14.0	15.6	16.9
Pour Point (°C)					
		-24	6	6	6
Flash Point (°C)					
		<-15	70	120	136
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Unlikely	Moderate	Moderate	Moderate
Stability		Unstable	Meso-stable	Entrained	Entrained
Water Content		0%	38%	31%	39%
Emulsion Formation-Tendency and Stability @ 20°C			20 °C		
Tendency		Unlikely	Unlikely	Moderate	Moderate
Stability		Unstable	Unstable	Unstable	Unstable
Water Content		0%	0%	22%	23%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	78.8		
		5	137.9		
		10	166.7		
		15	192.8		
		20	223		
		25	254		
		30	285		
		40	347		
		50	400		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta \exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 6490
C_2 = 6.00
C_3 = 3896

3.3.2.1 Evaporation

Approximately 30% of the ANS oil volume evaporated after two days in the wind tunnel; about 38% evaporated after two weeks; and, around 42 % evaporated after 6 weeks of exposure.

Figure 3-5 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-6, Figure 3-7, and Figure 3-8 show the effect of evaporation on the properties of oil viscosity, density and pour point.

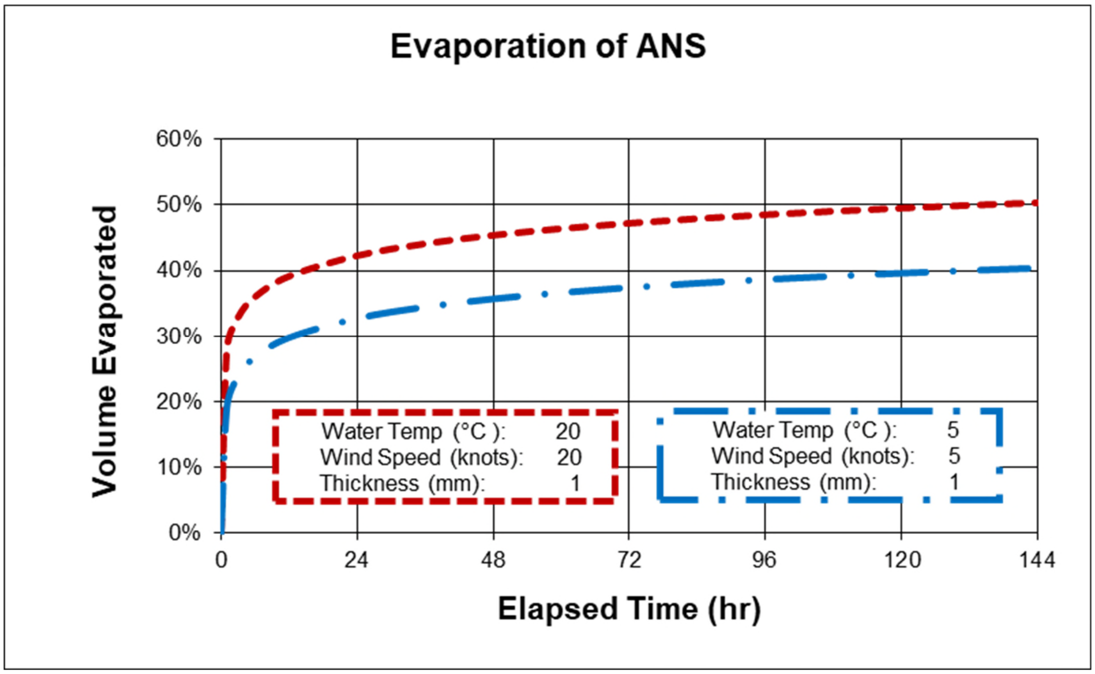


Figure 3-5: Evaporation of ANS

3.3.2.2 Density

ANS oil has a density of 0.863 g/cm³ at 15.5°C (API gravity of 32.5°C). Even after 6 weeks in the wind tunnel, the density only increases to 0.952 g/cm³ when measured at the coldest measurement temperature, 0°C.

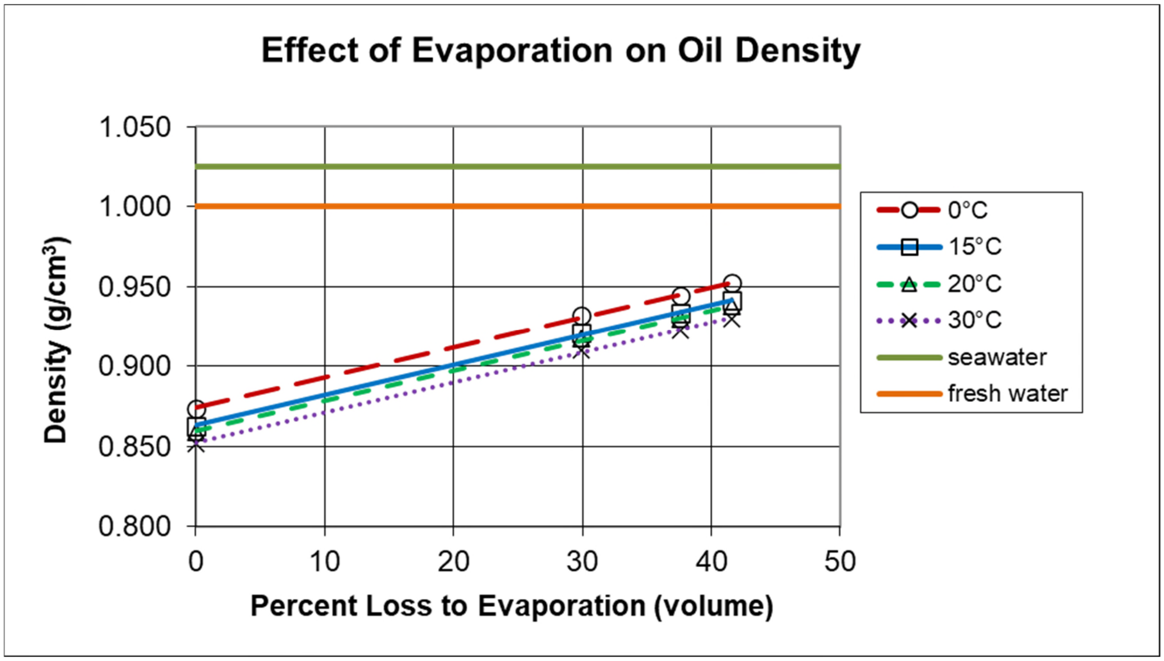


Figure 3-6: Effect of Evaporation on ANS Oil Density

3.3.2.3 Viscosity

The oil has moderate viscosity that is typical of medium gravity crudes. At 20°C the viscosity of the fresh oil is about 9 cP (mPa.s). The viscosity increases to 110 cP after 30% evaporation; to 290 cP after 38% evaporation; and, to 620 cP after 42% evaporation.

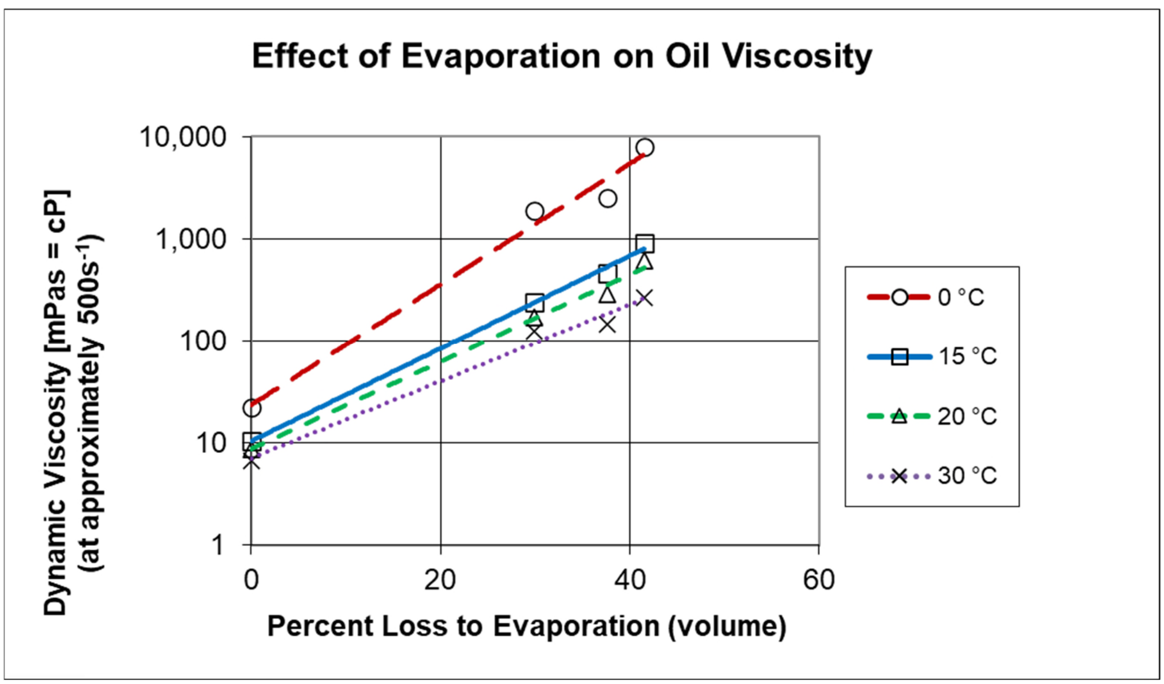


Figure 3-7: Effect of Evaporation on ANS Oil Viscosity

3.3.2.4 Pour Point

ANS has a pour point below -24°C when fresh which rises to 6°C after 42% evaporation.

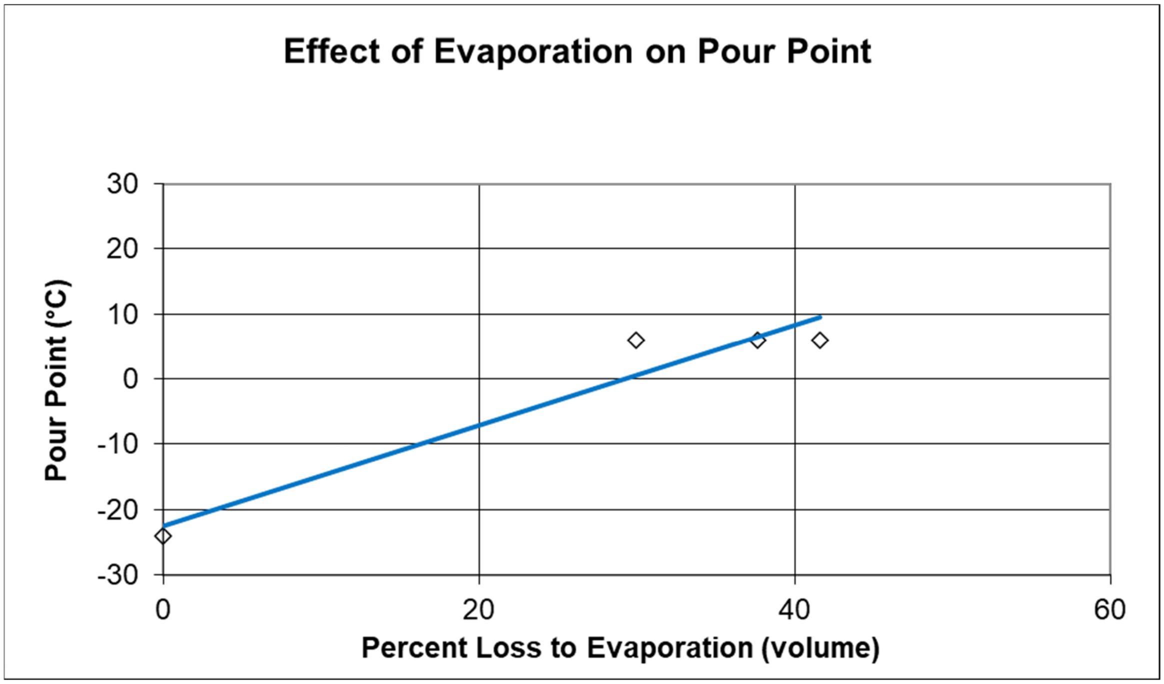


Figure 3-8: Effect of Evaporation on ANS Pour Point

3.3.2.5 Interfacial Tension

The oil/water interfacial tension of ANS was measured using standard laboratory water with 35 ppt of salt. The value measured was 14.2 dynes/cm, which is in the low end of the range of most crude oils.

3.3.2.6 Flash Point

ANS has a flash point of less than <-15°C when fresh. This increases after 42% evaporation to 136°C.

3.3.2.7 Emulsification Tendency and Stability

At 0°C the fresh crude is unlikely to form any water-in oil emulsions when mixed with seawater; once it has evaporated 30% it is moderately likely to form a meso-stable emulsion at 0°C. The 38% and 42% evaporated ANS at 0°C had a moderate tendency to form an entrained water emulsion.

At 20°C the fresh and 30% evaporated oil are unlikely to form an emulsion. Once it reaches 38% evaporated it is moderately likely to form an unstable emulsion. When the ANS crude has lost 42% of its volume to evaporation it is also only moderately likely to form an entrained emulsion at 20°C.

3.3.3 Access Western Blend (AWB)

A summary of AWB spill-related physical properties is listed below in Table 3–4.

Table 3–4: Spill-Related Properties of AWB

Spill-related properties		Fresh	2D	14D	6W
AWB	API Gravity =	22.7 °			
Evaporation (Volume %)		0	14.3	23.3	27.0
Density (g/cm^3)					
0 °C		0.929	0.966	0.994	1.009
15 °C		0.918	0.956	0.985	0.999
20 °C		0.914	0.952	0.981	0.996
30 °C		0.907	0.945	0.975	0.990
Dynamic Viscosity (mPa.s)	at approx 100 s^{-1} except at 0°				
0 °C		2,107	30,787	402,936	544,315
15 °C		450	6,852	48,900	58,780
20 °C		273	4,551	25,659	62,813
30 °C		173	2,488	8,746	35,159
Kinematic Viscosity (mm^2/s)					
0 °C		2,269	31,875	405,384	539,630
15 °C		491	7,171	49,670	58,833
20 °C		298	4,780	26,147	63,071
30 °C		191	2,632	8,970	35,530
Interfacial Tension (dyne/cm)					
Oil/ Air		29.8	31.8	34.7	NM
Oil/ Seawater		9.2	10.6	13.4	NM
Pour Point (°C)					
		-36	-12	3	12
Flash Point (°C)					
		<-10	-7	3	33
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Very Likely	Unlikely	Too Viscous	0
Stability		Entrained	Unstable	Unstable	Unstable
Water Content		43%	0%	NM	NM
Emulsion Formation-Tendency and Stability @ 20°C			20 °C		
Tendency		Very Likely	Very Likely	Too Viscous	Too Viscous
Stability		Entarined	Unstable	Unstable	Unstable
Water Content		31%	18%	NM	NM

ASTM Modified Distillation

Evaporation (% volume)	Liquid Temperature (°C)
IBP	61
5	82.6
10	106.8
15	141.8
20	205
25	298
30	327
40	343
50	354

Weathering Model

$$F_v = \frac{\ln[1 + (C_1/T_k)\theta \exp(C_2 - C_3/T_k)]}{(C_1/T_k)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 7836
C_2 = 3.80
C_3 = 3904

NM - not measured due to high viscosity

3.3.3.1 Evaporation

Approximately 14% of the AWB oil volume evaporated after two days in the wind tunnel; about 23% evaporated after two weeks; and, around 27% evaporated after 6 weeks of exposure.

Figure 3-9 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-10, Figure 3-11, and Figure 3-12 show the effect of evaporation on the properties of oil density, viscosity, and pour point.

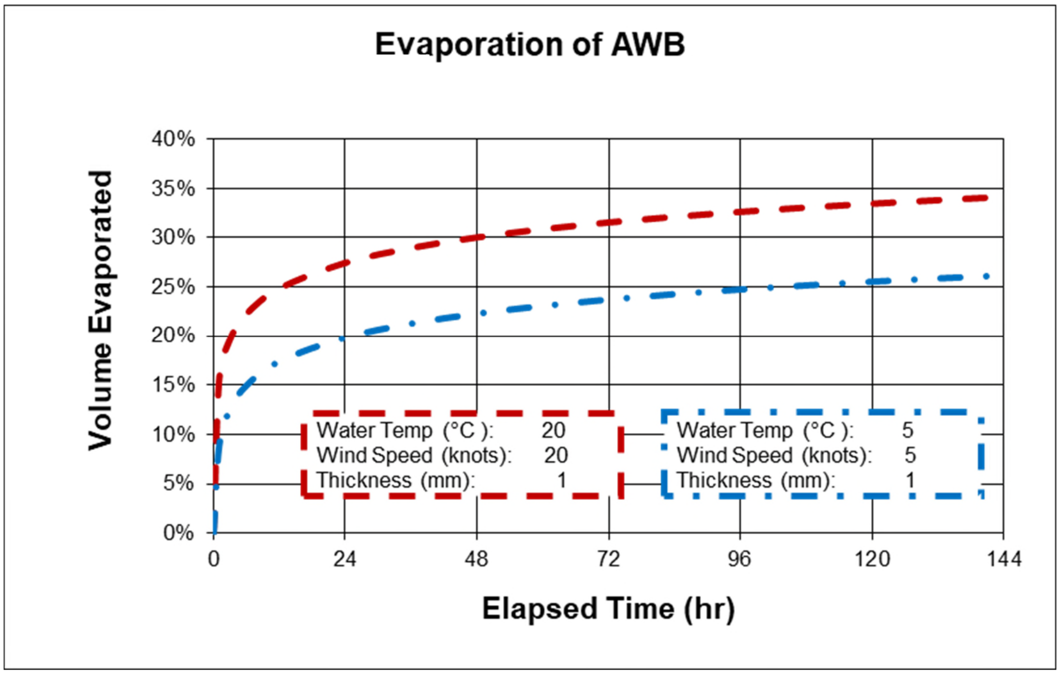


Figure 3-9: Evaporation of AWB

3.3.3.2 Density

AWB has a density of 0.918 g/cm^3 at 15.5°C (API gravity of 22.7°). After 6 weeks in the wind tunnel, the density increases to 1.009 g/cm^3 when measured at 0°C.

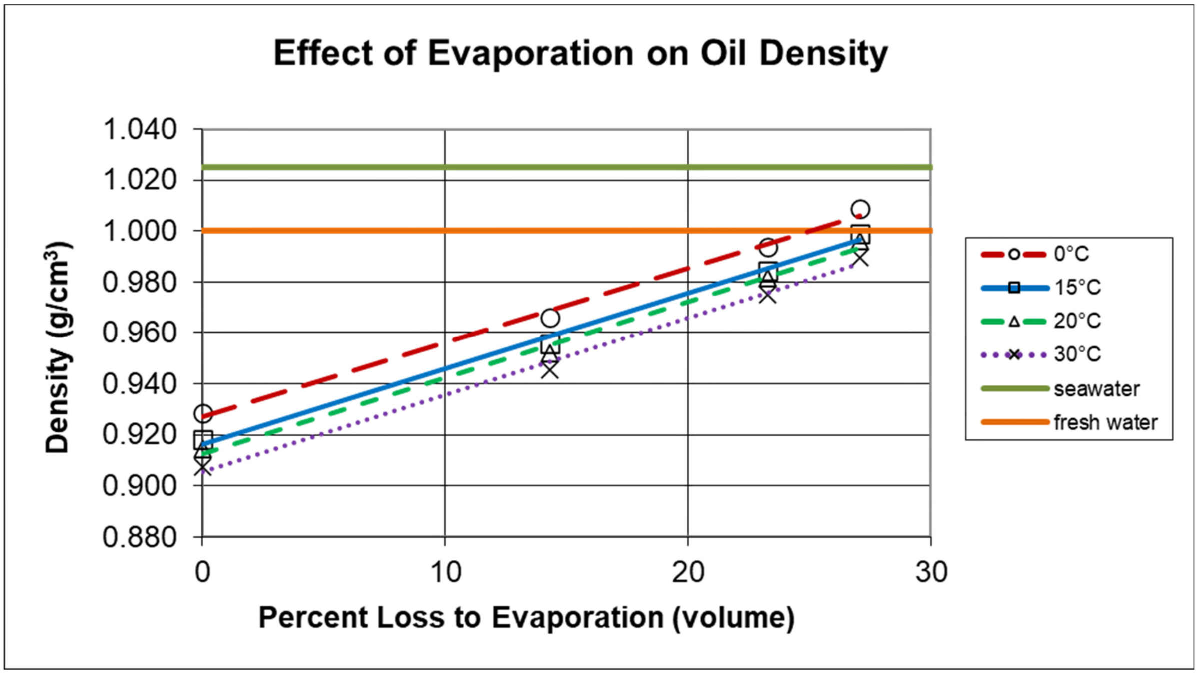


Figure 3-10: Effect of Evaporation on AWB Oil Density

3.3.3.3 Viscosity

The fresh oil has moderately high viscosity that is typical of dilbits. At 20°C the viscosity of the fresh oil is about 273 cP (mPa.s). The viscosity increases to 4,550 cP after 14% evaporation; to 25,660 cP after 23% evaporation; and, to 62,800 cP after 27% evaporation.

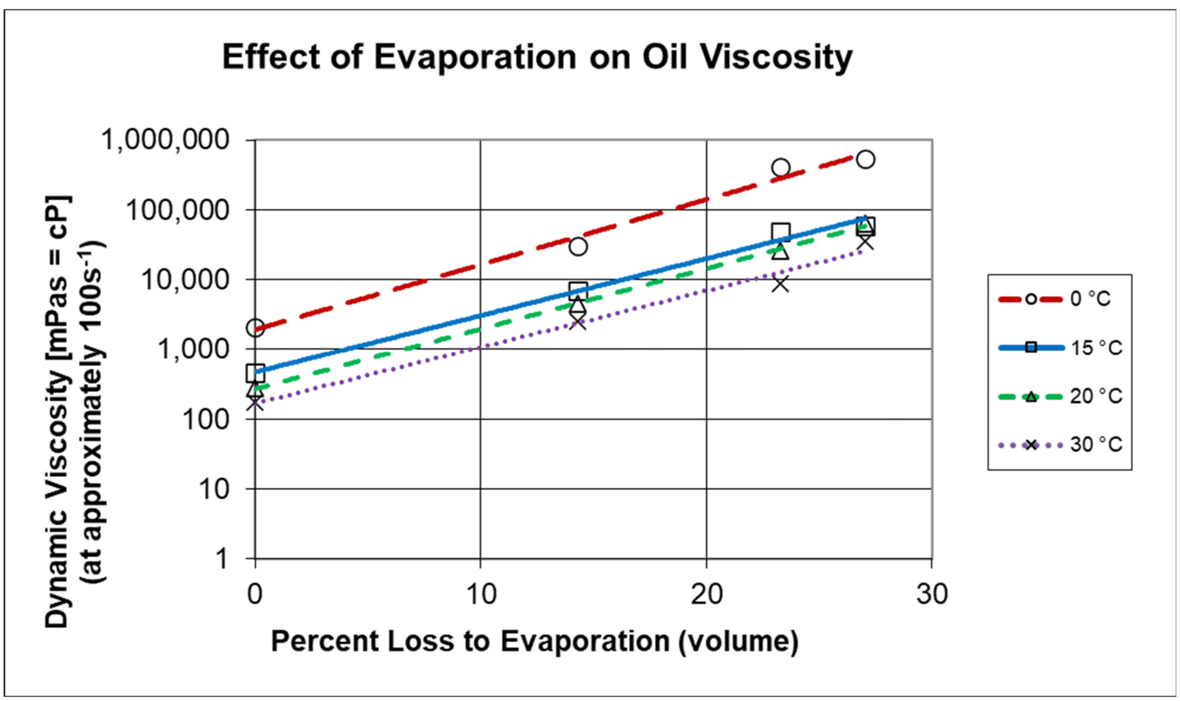


Figure 3-11: Effect of Evaporation on AWB Oil Viscosity

3.3.3.4 Pour Point
AWB has a pour point of -36°C when fresh which rises to 12°C after 27% evaporation.

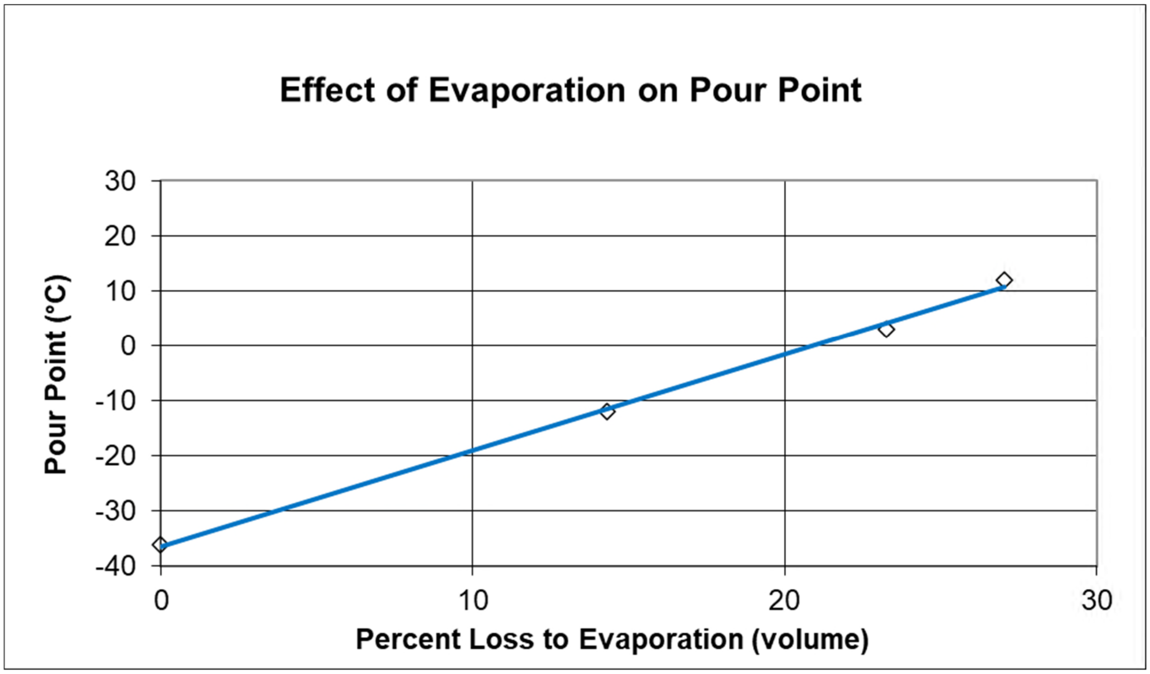


Figure 3-12: Effect of Evaporation on AWB Pour Point

3.3.3.5 Interfacial Tension
The oil/water interfacial tension of AWB was measured using standard laboratory water with 35 ppt of salt. The value measured was 9.2 dynes/cm, which is in the low end of the range of most crude oils.

3.3.3.6 Flash Point
AWB has a flash point of less than -10°C when fresh. This increases after 27% evaporation to 33°C.

3.3.3.7 Emulsification Tendency and Stability
One characteristic of AWB is that it is very likely to form entrained water emulsions when mixed with seawater when it is fresh. Once AWB crude has lost 23% of its volume to evaporation it becomes too viscous to readily emulsify.

3.3.4 Conventional Heavy Crude (CHV)

A summary of CHV spill-related physical properties is listed below in Table 3–5.

Table 3–5: Spill Related Properties of CHV Oil

Spill-related properties	Fresh	2D	14D	6W
CHV API Gravity =	21.6 °			
Evaporation (Volume %)	0	13.1	20.6	24.7
Density (g/cm^3)				
0 °C	0.936	0.970	0.988	1.000
15 °C	0.924	0.960	0.978	0.991
20 °C	0.921	0.957	0.975	0.987
30 °C	0.913	0.950	0.969	0.981
Dynamic Viscosity (mPa.s) at approx 100 s^{-1} except 2D, 14D and 6W at 0° at 10 s^{-1}				
0 °C	565	11,813	109,413	498,579
15 °C	208	2,221	14,994	49,271
20 °C	154	1,304	8,671	26,690
30 °C	90	651	3,293	8,818
Kinematic Viscosity (mm^2/s)				
0 °C	604	12,179	110,717	498,467
15 °C	225	2,314	15,325	49,740
20 °C	167	1,364	8,893	27,032
30 °C	99	685	3,400	8,990
Interfacial Tension (dyne/cm)				
Oil/ Air	29.1	31.7	34.8	NM
Oil/ Seawater	15.3	13.2	22.5	NM
Pour Point (°C)	<-42	-15	-3	0
Flash Point (°C)	<-10	1	36	79
Emulsion Formation-Tendency and Stability @ 0°C		0 °C		
Tendency	Very Likely	Very Likely	Too Viscous	Too Viscous
Stability	Entrained	Entrained	Too Viscous	Too Viscous
Water Content	53%	0%	NM	NM
Emulsion Formation-Tendency and Stability @ 20°C		20 °C		
Tendency	Very Likely	Very Likely	Too Viscous	Too Viscous
Stability	Entrained	Entrained	Too Viscous	Too Viscous
Water Content	51%	28%	0%	0%
ASTM Modified Distillation				
	Evaporation (% volume)	Liquid Temperature (°C)		
	IBP	64.8		
	5	144.7		
	10	222		
	15	299		
	20	353		
	25	390		
	30	412		
	40	434		
	50	447		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta\exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 9782
C_2 = 9.90
C_3 = 5581

NM - not measured too viscous

3.3.4.1 Evaporation

Approximately 13% of the CHV oil volume evaporated after two days in the wind tunnel; about 21% evaporated after two weeks; and, around 25 % evaporated after 6 weeks of exposure.

Figure 3-13 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-14, Figure 3-15 and Figure 3-16 show the effect of evaporation on the properties of oil viscosity, density and pour point.

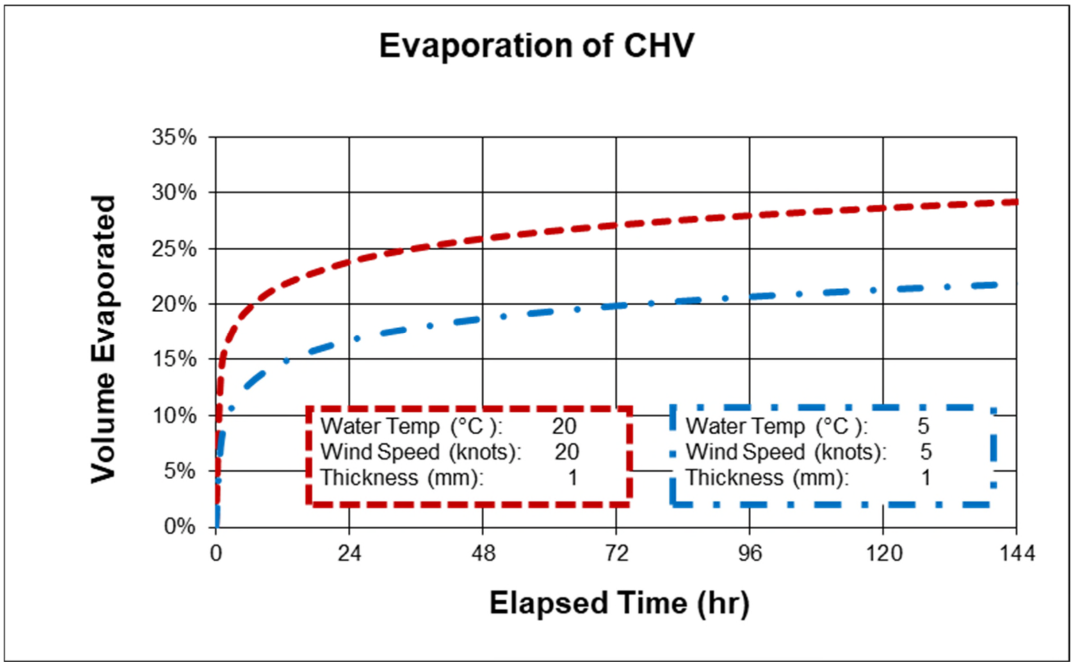


Figure 3-13: Evaporation of CHV

3.3.4.2 Density

CHV, a blend of conventional heavy crude oils, has a density of 0.924 g/cm³ at 15.5°C (API gravity of 21.6°). After 6 weeks in the wind tunnel, the density increases to 1.000 g/cm³ when measured at 0°C.

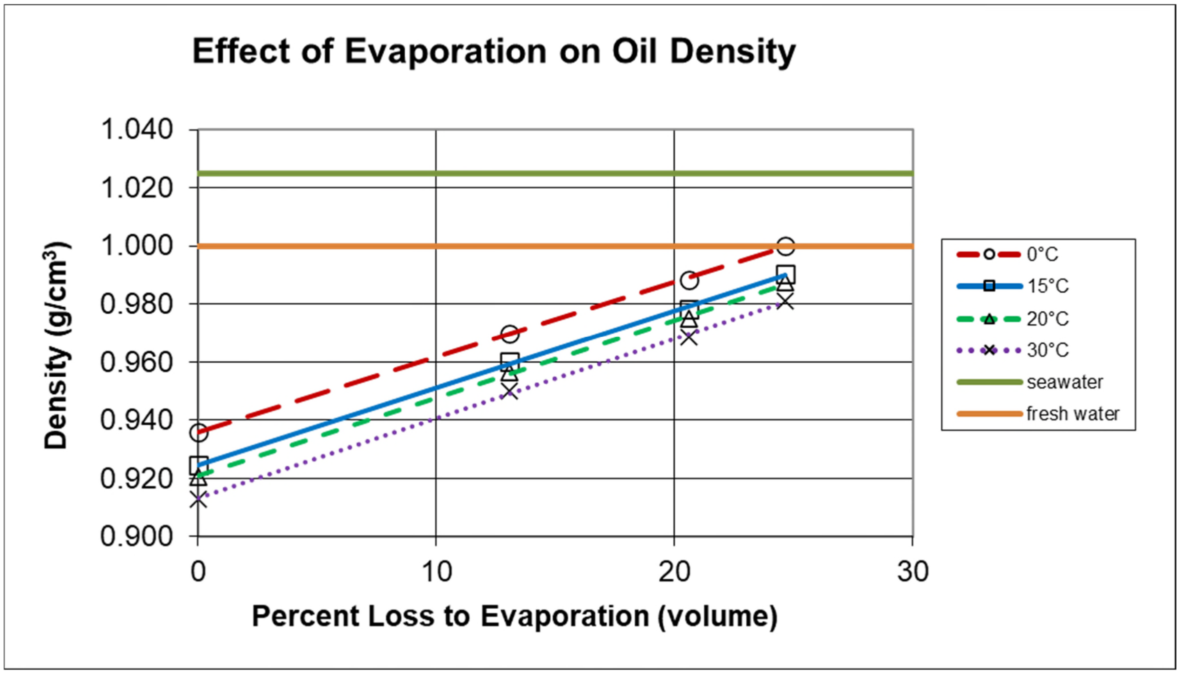


Figure 3-14: Effect of Evaporation on CHV Oil Density

3.3.4.3 Viscosity

The fresh oil has a medium high viscosity that is typical of heavy crude. At 20°C the viscosity of the fresh oil is about 154 cP (mPa.s). The viscosity increases to 1,300 cP after 13% evaporation; to 8670 cP after 21% evaporation; and, to 26,700 cP after 25% evaporation.

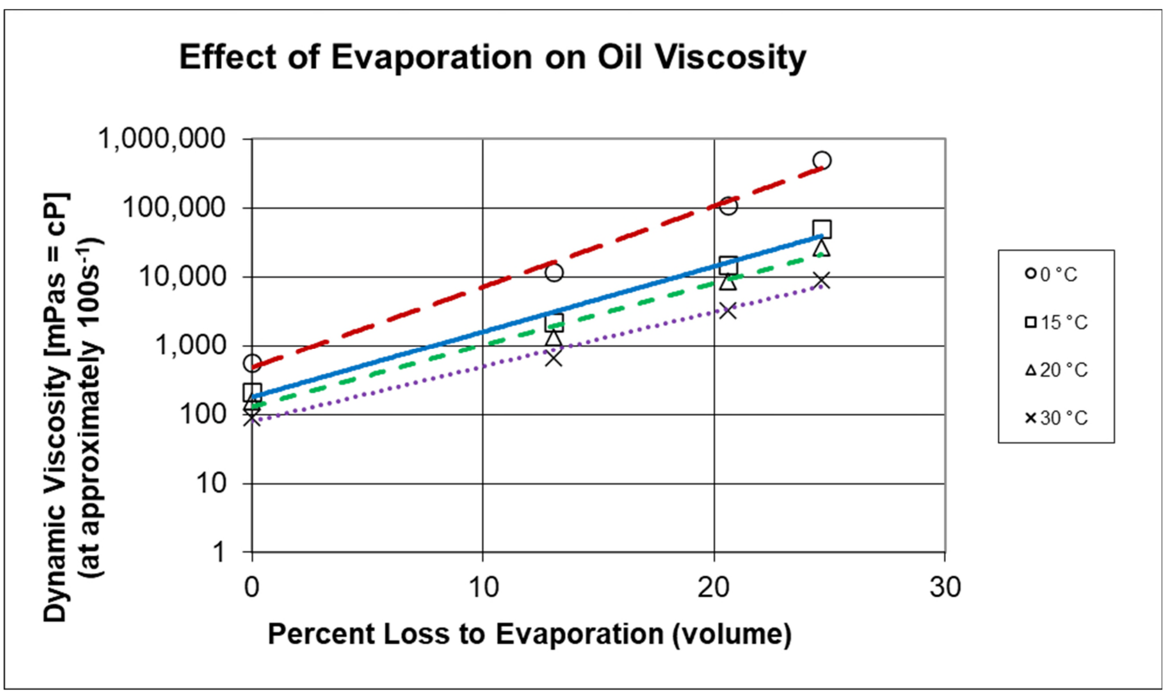


Figure 3-15: Effect of Evaporation on CHV Oil Viscosity

3.3.4.4 *Pour Point*

CHV has a pour point below -42°C when fresh which rises to 0°C after 25% evaporation.

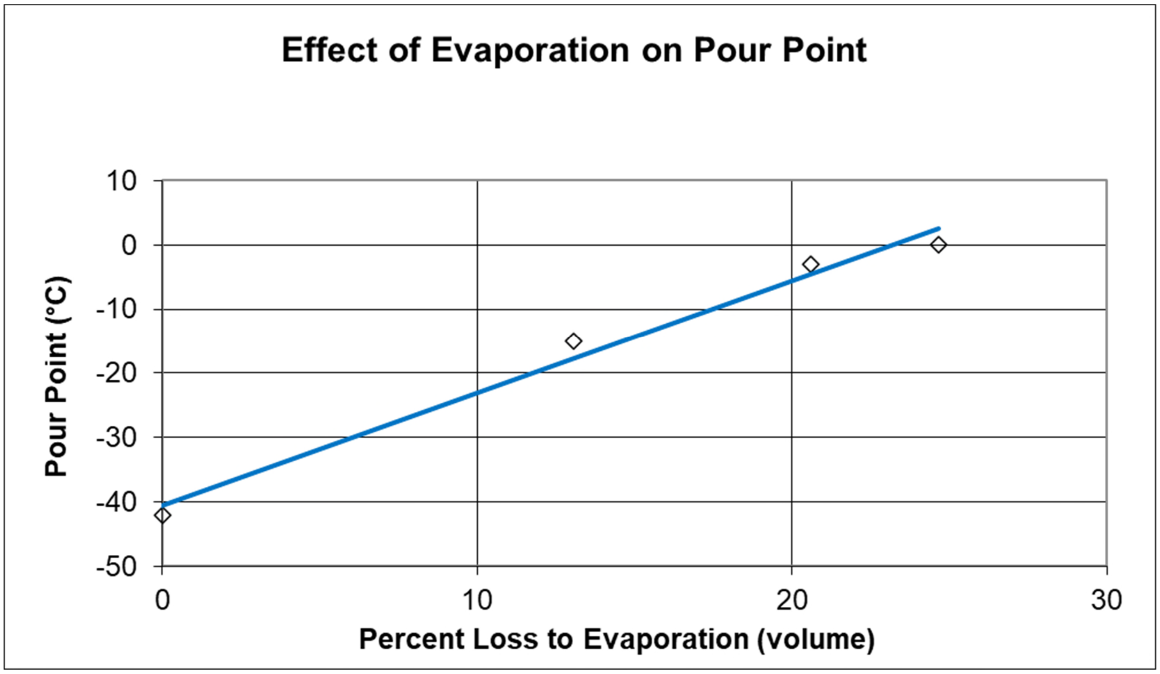


Figure 3-16: Effect of Evaporation on CHV Pour Point

3.3.4.5 *Interfacial Tension*

The oil/water interfacial tension of CHV was measured using standard laboratory water with 35 ppt of salt. The value measured was 15.3 dynes/cm, which is in the range of most crude oils.

3.3.4.6 *Flash Point*

CHV has a flash point of less than -10°C when fresh. This increases after 25% evaporation to 79°C.

3.3.4.7 *Emulsification Tendency and Stability*

One characteristic of CHV is that it is only likely to form entrained water emulsions when mixed with seawater.

3.3.5 Cold Lake Blend (CLB)

A summary of CLB spill-related physical properties is listed below in Table 3–6.

Table 3–6: Spill-Related Properties of CLB

Spill-related properties		Fresh	2D	14D	6W
CLB	API Gravity =	22.4 °			
Evaporation (Volume %)		0	14.2	22.4	26.1
Density (g/cm^3)					
0 °C		0.930	0.965	0.993	1.004
15 °C		0.920	0.955	0.983	0.995
20 °C		0.916	0.952	0.980	0.991
30 °C		0.909	0.946	0.973	0.985
Dynamic Viscosity (mPa.s)	at approx 100 s^{-1} except 2D at 15°, 20° and 30° at 500 s^{-1}				
0 °C		663	11,050	101,256	630,060
15 °C		258	3,580	27,467	72,503
20 °C		156	1,651	15,560	54,750
30 °C		100	856	7,241	21,490
Kinematic Viscosity (mm^2/s)					
0 °C		712	11,455	101,971	627,446
15 °C		280	3,748	27,936	72,897
20 °C		170	1,734	15,878	55,226
30 °C		110	905	7,438	21,817
Interfacial Tension (dyne/cm)					
Oil/ Air		30.2	31.3	29.7	NM
Oil/ Seawater		20.7	13.5	21.0	NM
Pour Point (°C)					
		<-39	-15	3	6
Flash Point (°C)					
		<-10	-5	23	50
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Very Likely	Too Viscous	Too Viscous	Too Viscous
Stability		Entrained Water	Too Viscous	Too Viscous	Too Viscous
Water Content		38%	0%	NM	NM
Emulsion Formation-Tendency and Stability @ 20°C			20 °C		
Tendency		Very Likely	Very Likely	Too Viscous	Too Viscous
Stability		Entrained	Entrained	Too viscous	Too viscous
Water Content		60%	45%	0%	0%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	42.3		
		5	61.5		
		10	88		
		15	124.8		
		20	183.1		
		25	220.5		
		30	244.6		
		40	257.5		
		50	264.4		
Weathering Model					
	$Fv = \frac{\ln[1 + (C_1/Tk)\theta\exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$				
where:	Fv is volume fraction of oil evaporated				
	θ is evaporative exposure				
	Tk is environmental temperature (K)				
	C_1 =	8098			
	C_2 =	8.80			
	C_3 =	5392			

NM - not measured too viscous

3.3.5.1 Evaporation

Approximately 14% of the CLB oil volume evaporated after two days in the wind tunnel; about 22% evaporated after two weeks; and, around 26 % evaporated after 6 weeks of exposure.

Figure 3-17 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-18, Figure 3-19 and Figure 3-20 show the effect of evaporation on the properties of oil viscosity, density and pour point.

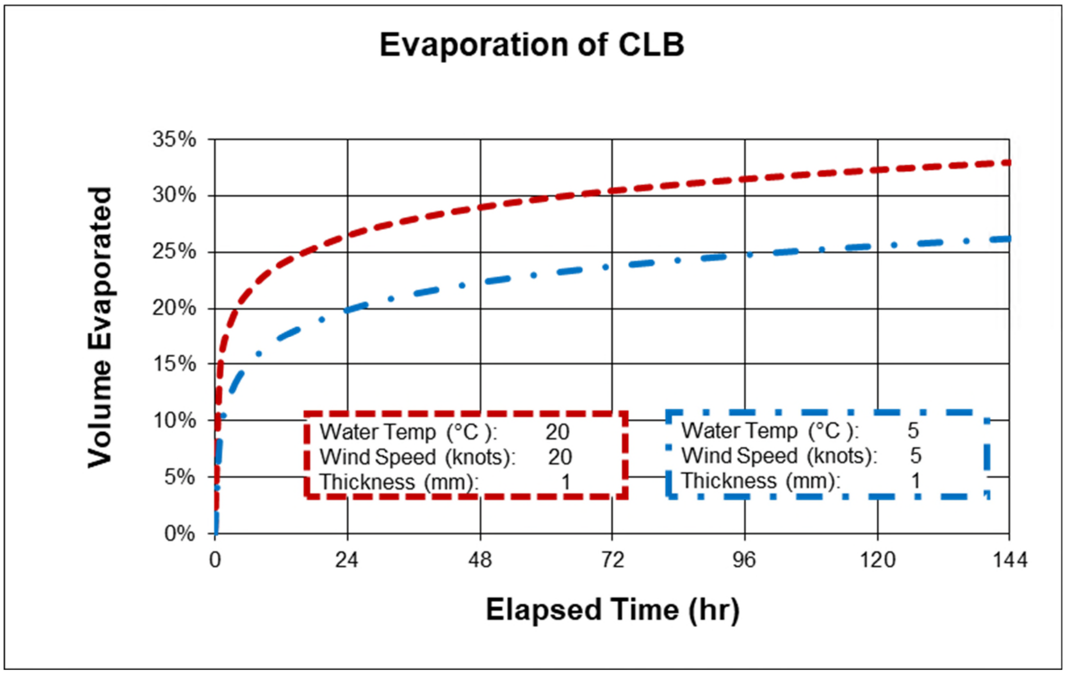


Figure 3-17: Evaporation of CLB

3.3.5.2 Density

CLB has a density of 0.920 g/cm³ at 15.5°C (API gravity of 22.4°). After 6 weeks in the wind tunnel, the density increases to 1.004 g/cm³ when measured at 0°C.

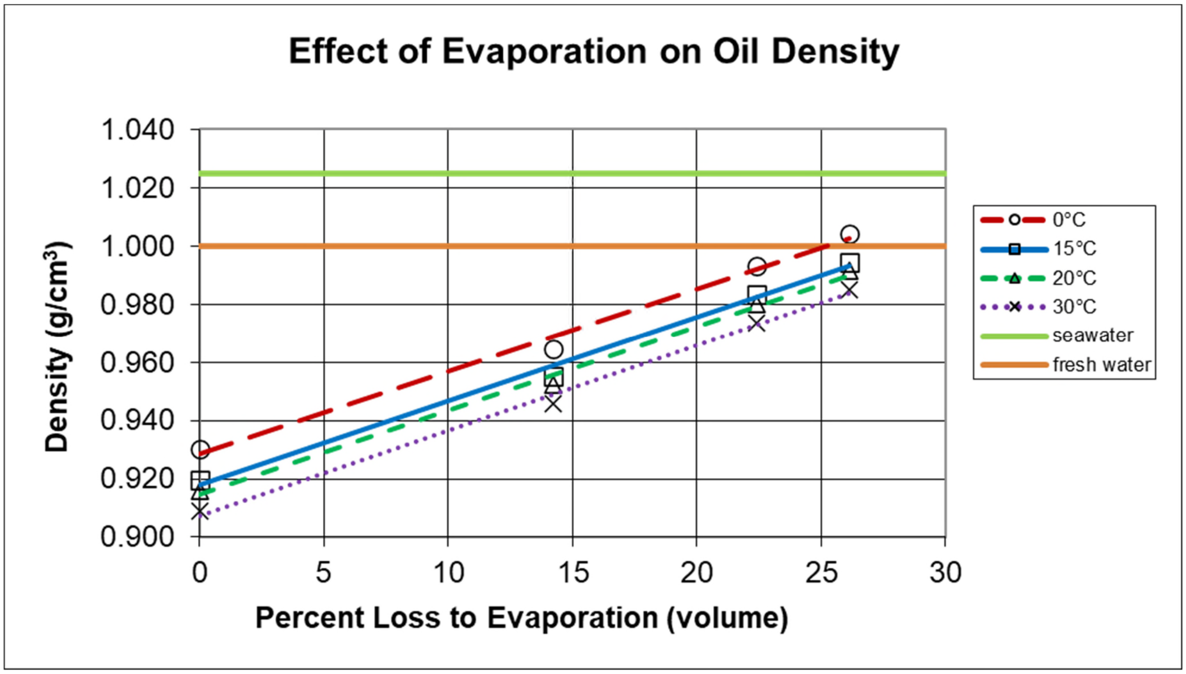


Figure 3-18: Effect of Evaporation on CLB Oil Density

3.3.5.3 Viscosity

The fresh oil has a medium high viscosity that is typical of dilbit. At 20°C the viscosity of the fresh oil is about 156 cP (mPa.s). The viscosity increases to 2,500 cP after 14% evaporation; to 27,500 cP after 22% evaporation; and, to 54,750 cP after 26% evaporation.

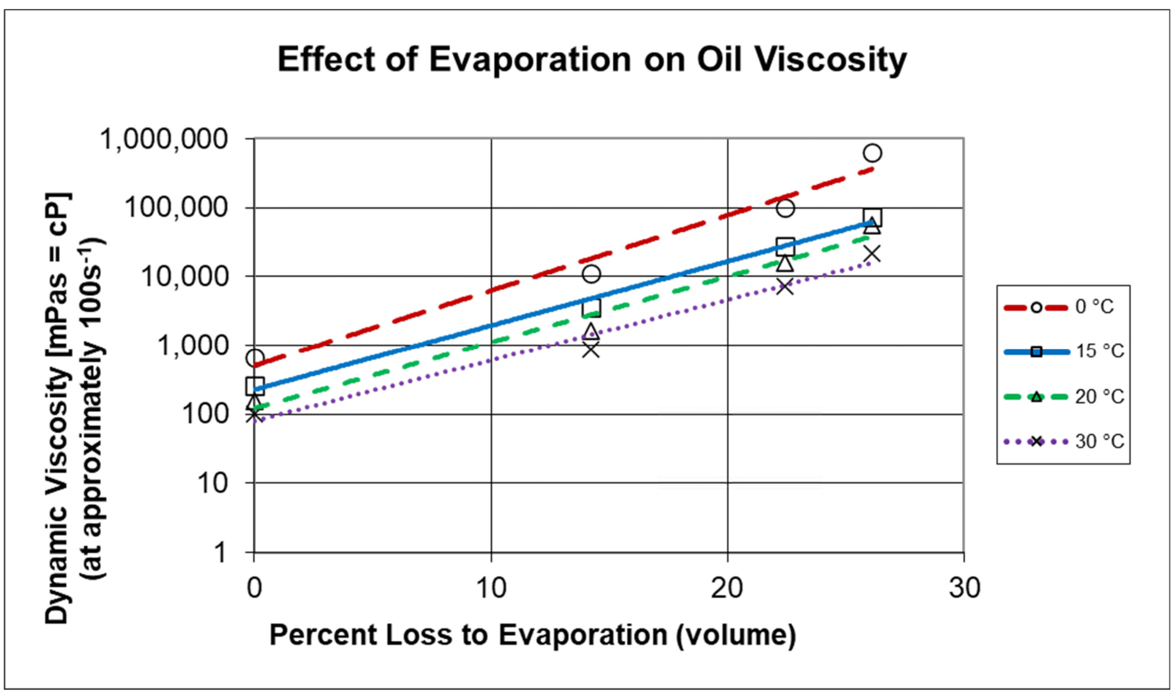


Figure 3-19: Effect of Evaporation on CLB Oil Viscosity

3.3.5.4 Pour Point

CLB has a pour point below -39°C when fresh which rises to 6°C after 26% evaporation.

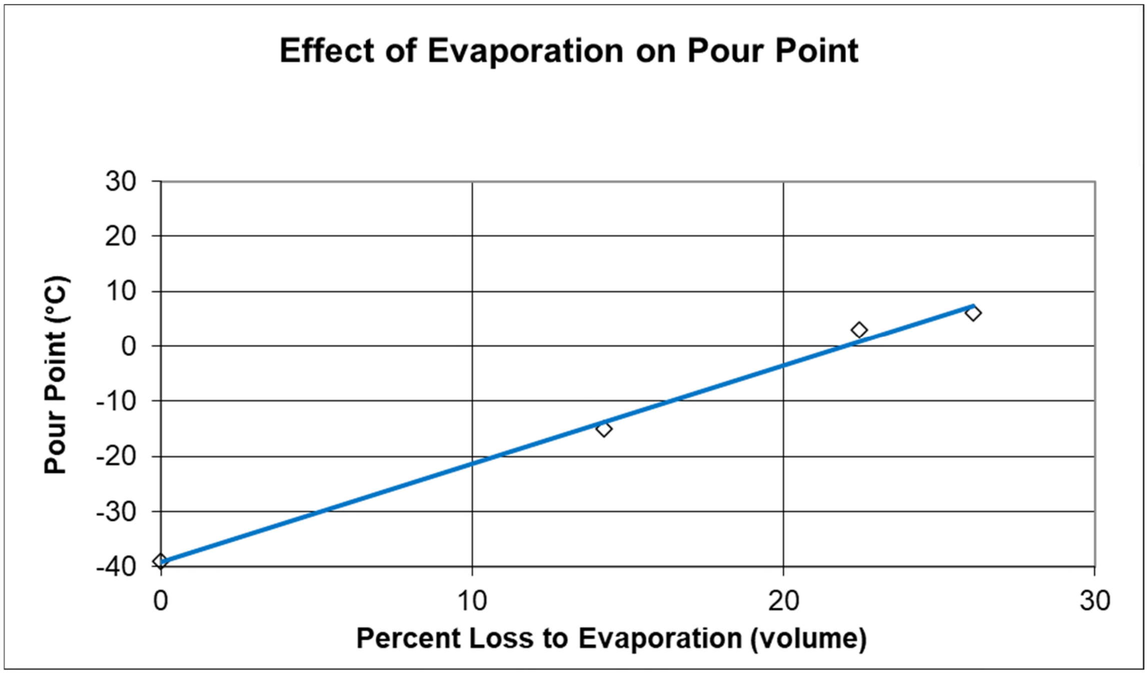


Figure 3-20: Effect of Evaporation on CLB Pour Point

3.3.5.5 Interfacial Tension

The oil/water interfacial tension of CLB was measured using standard laboratory water with 35 ppt of salt. The value measured was 20.7 dynes/cm, which is in the range of most crude oils.

3.3.5.6 Flash Point

CLB has a flash point of less than -10°C when fresh. This increases after 26% evaporation to 50°C.

3.3.5.7 Emulsification Tendency and Stability

One characteristic of CLB is that it is only likely to form entrained water emulsions when mixed with seawater.

3.3.6 Condensate Blend (CRW)

A summary of CRW spill-related physical properties is listed below in Table 3–7.

Table 3–7: Spill-Related Properties of CRW

Spill-related properties		Fresh	2D	14D	6W
CRW	API gravity =	57.7 °			
Evaporation (Volume %)		0	71.07	77.19	80.06
Density (g/cm^3)					
0	°C	0.760	0.854	0.867	0.874
15	°C	0.748	0.842	0.854	0.861
20	°C	0.744	0.838	0.850	0.856
30	°C	0.736	0.830	0.842	0.847
Dynamic Viscosity (mPa.s)	at approx 1000 s^{-1} except 2D at 0°C, 14D at 0° and 15° and 6W at approx 100 s^{-1}				
0	°C	1.2	379	2,992	17,582
15	°C	1.1	16	126	183
20	°C	0.8	12	29	76
30	°C	0.6	8	15	24
Kinematic Viscosity (mm^2/s)					
0	°C	1.6	444	3,450	20,118
15	°C	1.5	19	147	213
20	°C	1.1	14	34	89
30	°C	0.9	9	18	28
Interfacial Tension (dyne/cm)					
Oil/	Air	22.1	28.7	29.4	30.7
Oil/	Seawater	2.9	5.7	4.4	7.0
Pour Point (°C)					
		<-57	3	12	15
Flash Point (°C)					
		<-12	94	133	148
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Unlikely	Unlikely	Likely	Too Viscous
Stability		Unstable	Unstable	Unstable	Too Viscous
Water Content		0%	0%	0%	NM
Emulsion Formation-Tendency and Stability @ 15°C			20 °C		
Tendency		Unlikely	Unlikely	Unlikely	Unlikely
Stability		Unstable	Unstable	Unstable	Unstable
Water Content		0%	0%	0%	0%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	57.1		
		5	73.1		
		10	83		
		15	93.6		
		20	104.6		
		25	115.9		
		30	126.9		
		40	137.8		
		50	150.4		

Weathering Model

$$F_v = \frac{\ln[1 + (C_1/T_k)\theta \exp(C_2 - C_3/T_k)]}{(C_1/T_k)}$$

where: F_v is volume fraction of oil evaporated
θ is evaporative exposure
T_k is environmental temperature (K)

C_1 = 5896
C_2 = 26.70
C_3 = 8172

NM - not measured too viscous

3.3.6.1 Evaporation

Approximately 71% of the CRW oil volume evaporated after two days in the wind tunnel; about 77% evaporated after two weeks; and, around 80 % evaporated after 6 weeks of exposure.

Figure 3-21 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-22, Figure 3-23 and Figure 3-24 show the effect of evaporation on the properties of oil viscosity, density and pour point.

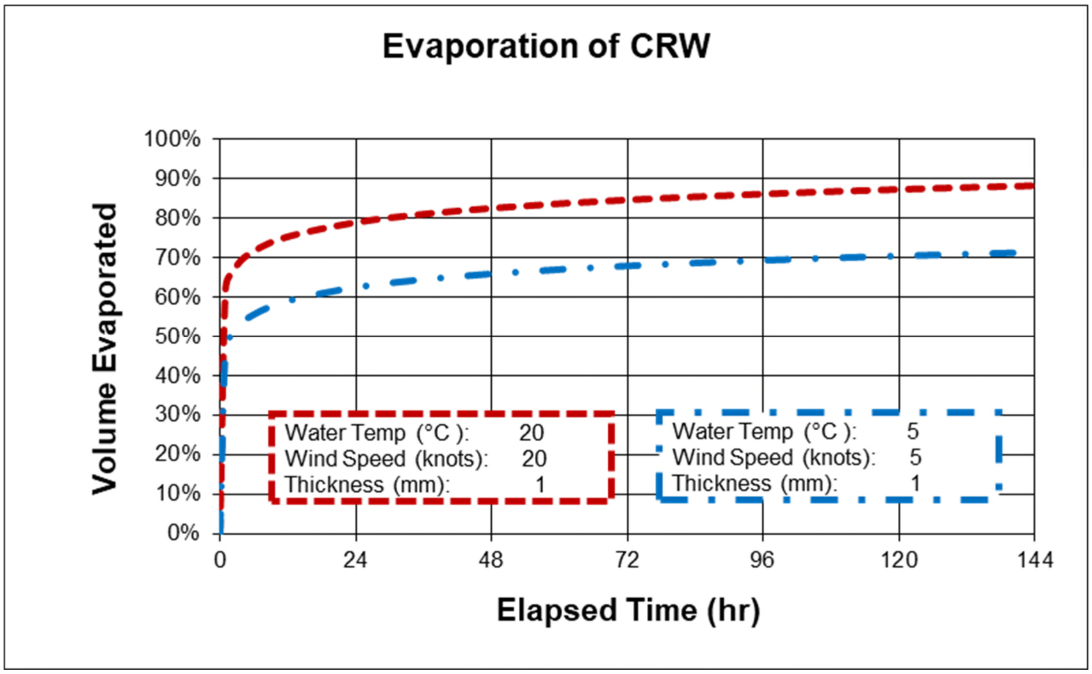


Figure 3-21: Evaporation of CRW

3.3.6.2 Density

CRW has a density of 0.748 g/cm³ at 15.5°C (API gravity of 57.7°). After 6 weeks in the wind tunnel, the density increases to 0.874 g/cm³ when measured at 0°C.

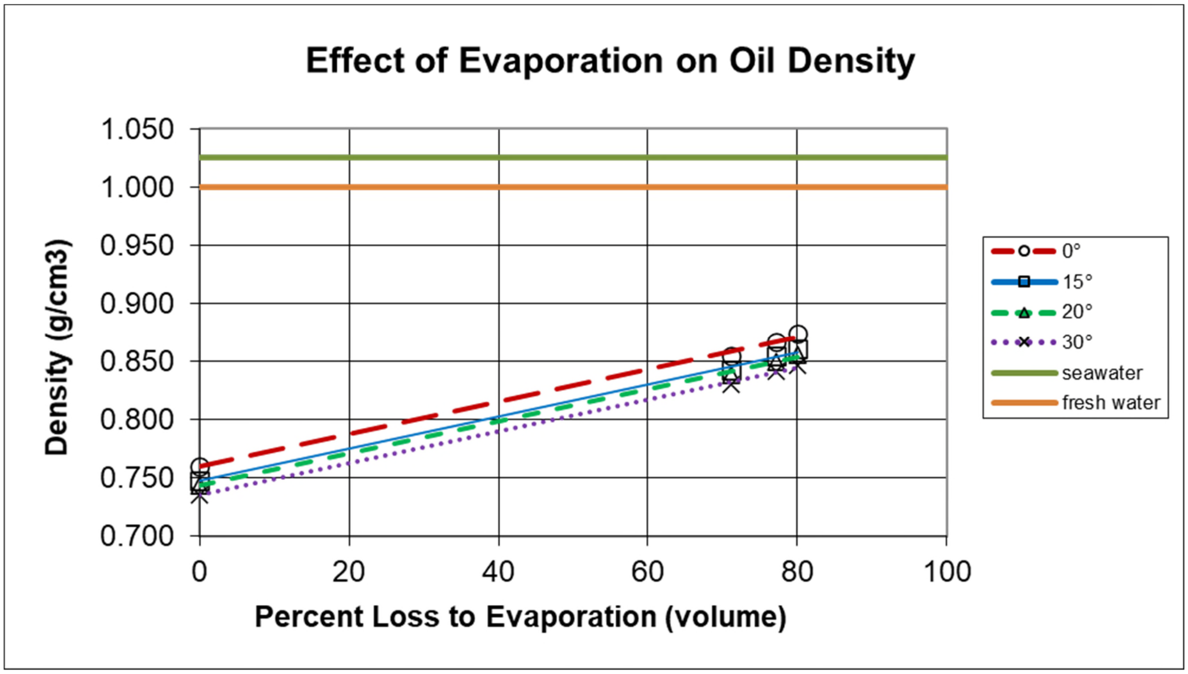


Figure 3-22: Effect of Evaporation on CRW Oil Density

3.3.6.3 Viscosity

The fresh oil has a low viscosity that is typical of condensate. At 20°C the viscosity of the fresh oil is about 0.8 cP (mPa.s). The viscosity increases to 12 cP after 71% evaporation; to 29 cP after 77% evaporation; and, to 76 cP after 80% evaporation.

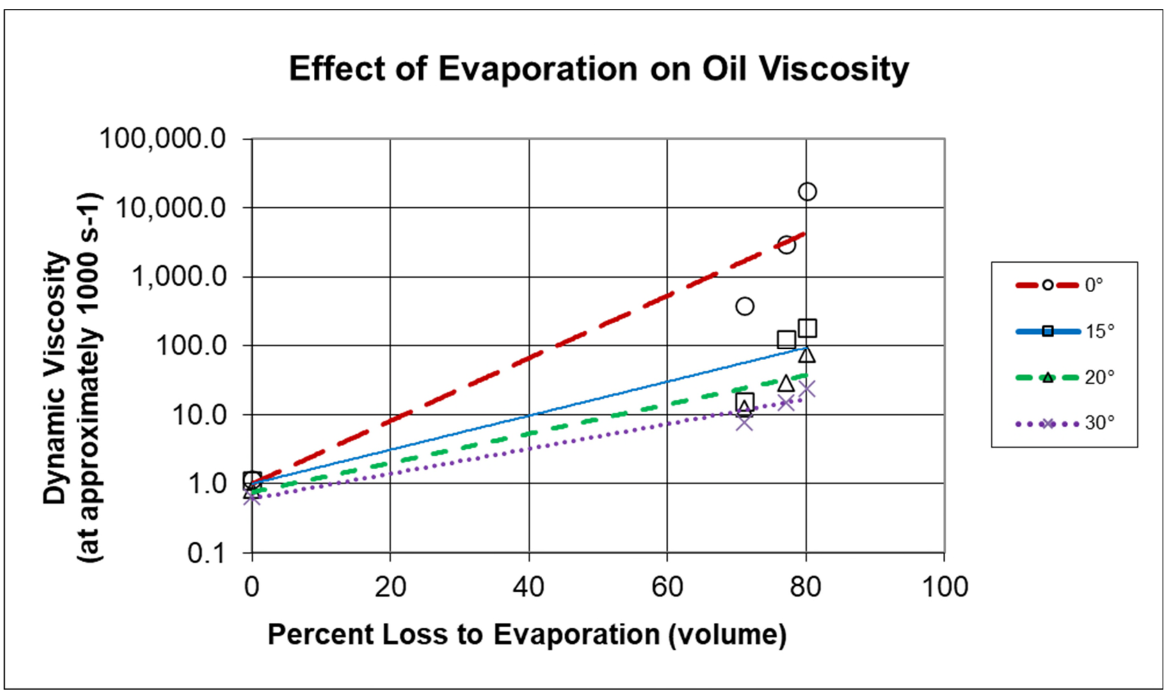


Figure 3-23: Effect of Evaporation on CRW Oil Viscosity

3.3.6.4 Pour Point

CRW has a pour point below -57°C when fresh which rises to 15°C after 80% evaporation.

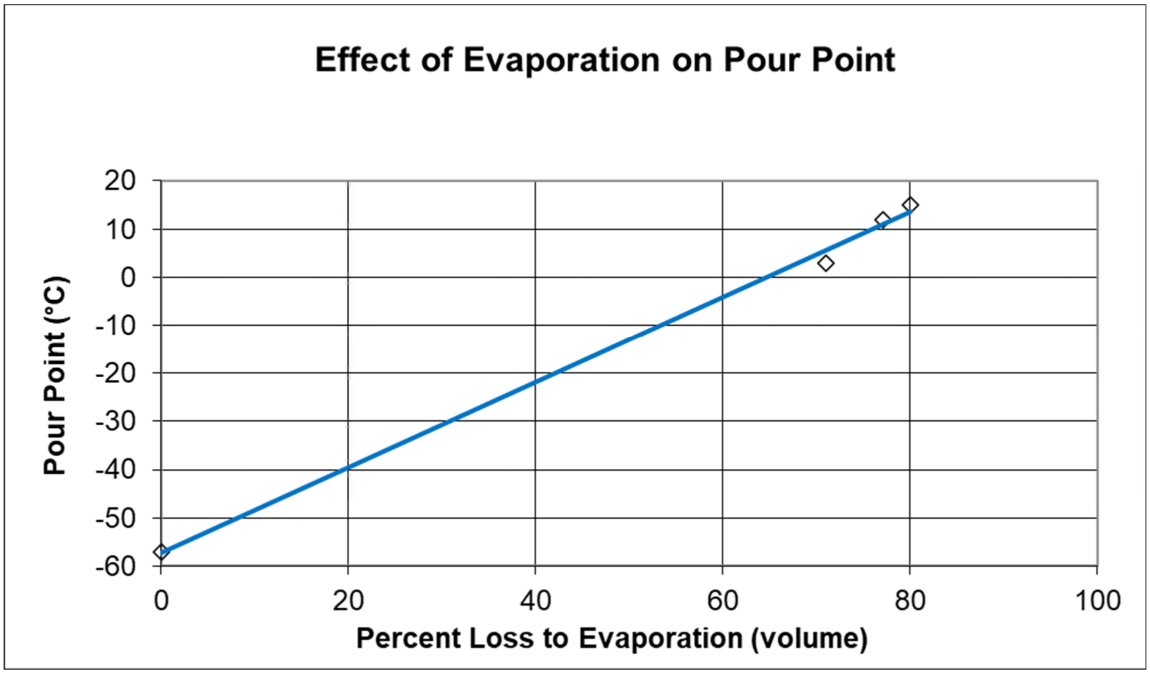


Figure 3-24: Effect of Evaporation on CRW Pour Point

3.3.6.5 Interfacial Tension

The oil/water interfacial tension of CRW condensate was measured using standard laboratory water with 35 ppt of salt. The value measured was 2.9 dynes/cm, which is in the very lowest range for most oils.

3.3.6.6 Flash Point

CRW condensate has a flash point of less than -12°C when fresh. This increases after 80% evaporation to 148°C.

3.3.6.7 Emulsification Tendency and Stability

One characteristic of CRW condensate is that it is unlikely to form water-in-oil emulsions when mixed with seawater.

3.3.7 Heavy Fuel Oil – Bunker C (HFO)

A summary of HFO spill-related physical properties is listed below in Table 3–8.

Table 3–8: Spill-Related Properties of HFO

Spill-related properties		Fresh	2D	14D	6W
HFO	API Gravity =	11.6 °			
Evaporation (Volume %)		0	0.4	1.7	4.2
Density (g/cm^3)					
0 °C		1.001	1.001	1.002	1.007
15 °C		0.990	0.990	0.990	0.995
20 °C		0.986	0.986	0.986	0.992
30 °C		0.978	0.979	0.978	0.984
Dynamic Viscosity (mPa.s)	at approx 100 s^{-1} except 2D, 14D and 6W at 0° at 10 s^{-1}				
0 °C		115,749	162,130	302,908	738,156
15 °C		10,340	10,872	17,437	36,314
20 °C		5,009	6,327	9,812	17,693
30 °C		1,779	2,062	2,913	4,860
Kinematic Viscosity (mm^2/s)					
0 °C		115,645	161,949	302,397	733,319
15 °C		10,449	10,984	17,614	36,486
20 °C		5,082	6,416	9,951	17,844
30 °C		1,818	2,107	2,978	4,940
Interfacial Tension (dyne/cm)					
Oil/ Air		31.9	31.2	31.5	NM
Oil/ Seawater		22.6	20.5	17.2	NM
Pour Point (°C)					
		3	6	12	12
Flash Point (°C)					
		67	93	107	133
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Too Viscous	Too Viscous	Too Viscous	Too Viscous
Stability		Too Viscous	Too Viscous	Too Viscous	Too Viscous
Water Content		NM	NM	NM	NM
Emulsion Formation-Tendency and Stability @ 20°C			20 °C		
Tendency		Very Likely	Likely	Too Viscous	Too Viscous
Stability		Unstable	Unstable	Too Viscous	Too Viscous
Water Content		17%	9%	0%	NM
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	323		
		5	365		
		10	393		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta \exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 10430
C_2 = 14.20
C_3 = 8918

NM - not measured too viscous

3.3.7.1 Evaporation

HFO, also known as Bunker C, is used to power large marine engines. Approximately 0.4% of the oil volume evaporated after two days in the wind tunnel; about 2% evaporated after two weeks; and, only around 4% evaporated after 6 weeks of exposure in the wind tunnel.

Figure 3-25 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-26, Figure 3-27 and Figure 3-28 show the effect of evaporation on the properties of oil viscosity, density and pour point.

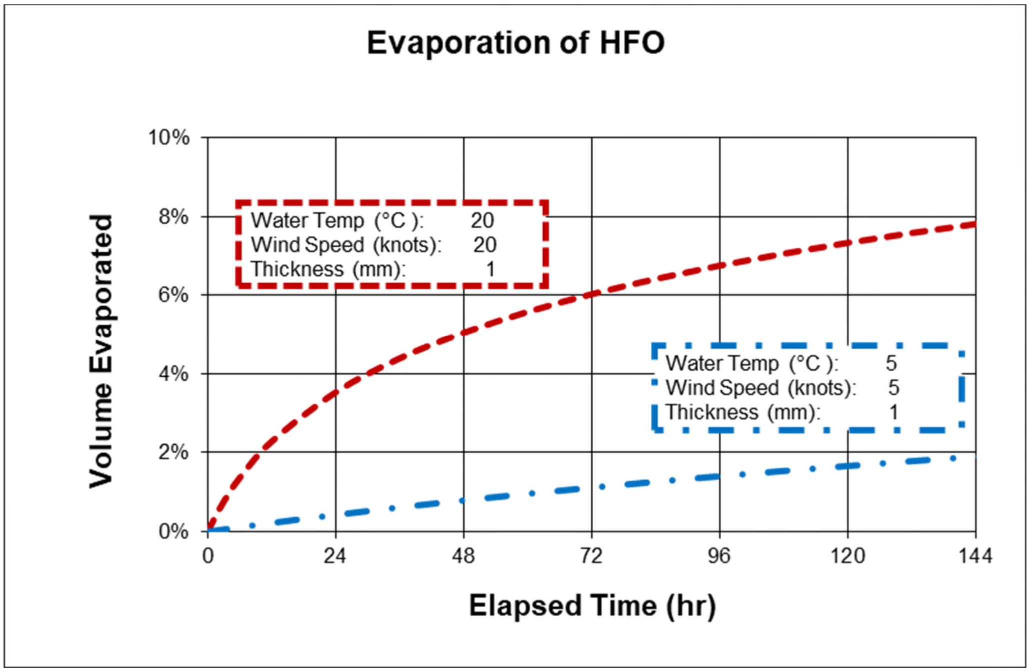


Figure 3-25: Evaporation of HFO

3.3.7.2 Density

HFO has a density of 0.986 g/cm³ at 15.5°C (API gravity of 11.6°). After 6 weeks in the wind tunnel, the density increases to 1.007 g/cm³ at 0°C. The density of seawater at 0°C is approximately 1.025 g/cm³ measured at 0°C.

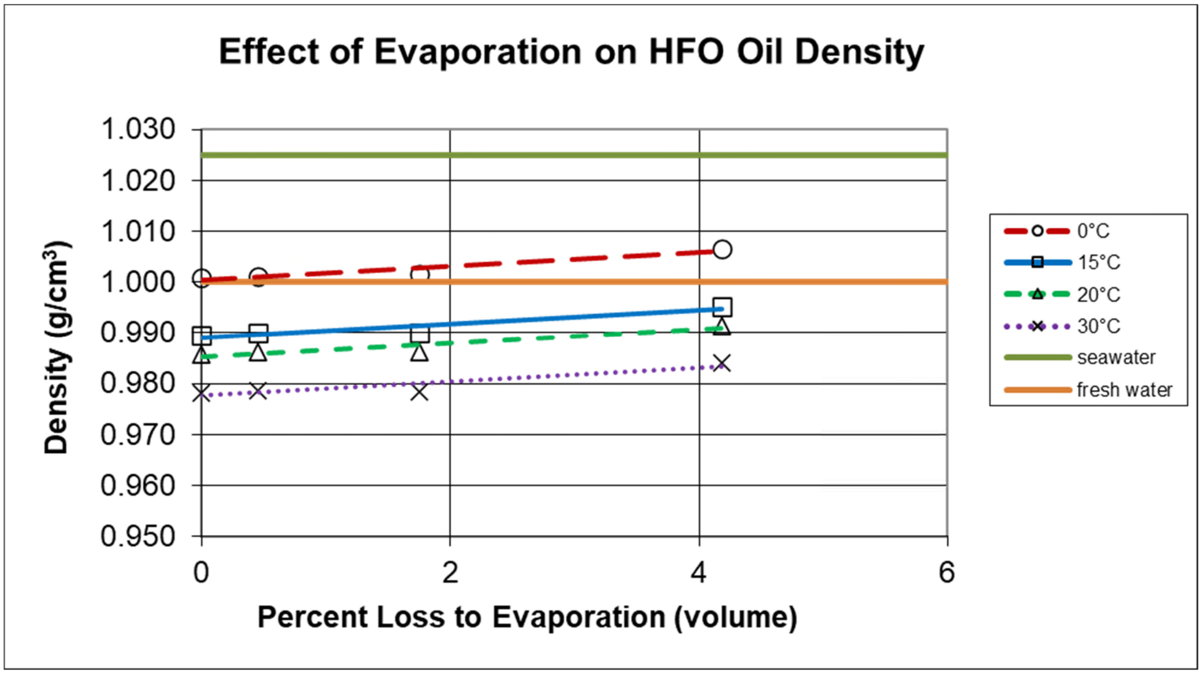


Figure 3-26: Effect of Evaporation on HFO Oil Density

3.3.7.3 Viscosity

The fresh oil has a very high viscosity that is typical of residual fuel oils. At 20°C the viscosity of the fresh oil is about 5000 cP (mPa.s). The viscosity increases to 6,300 cP after 0.4% evaporation; to 9,800 cP after 77% evaporation; and, to 17,700 cP after 4% evaporation.

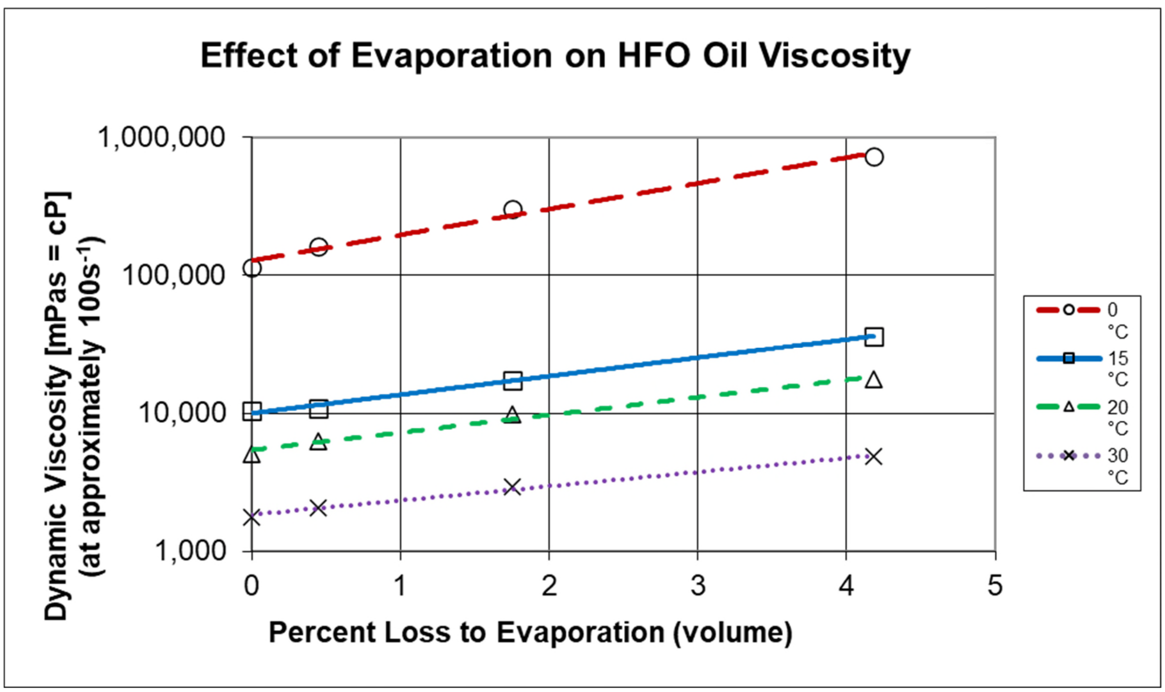


Figure 3-27: Effect of Evaporation on HFO Oil Viscosity

3.3.7.4 Pour Point

HFO has a pour point of 3°C when fresh which rises to 12°C after 4% evaporation.

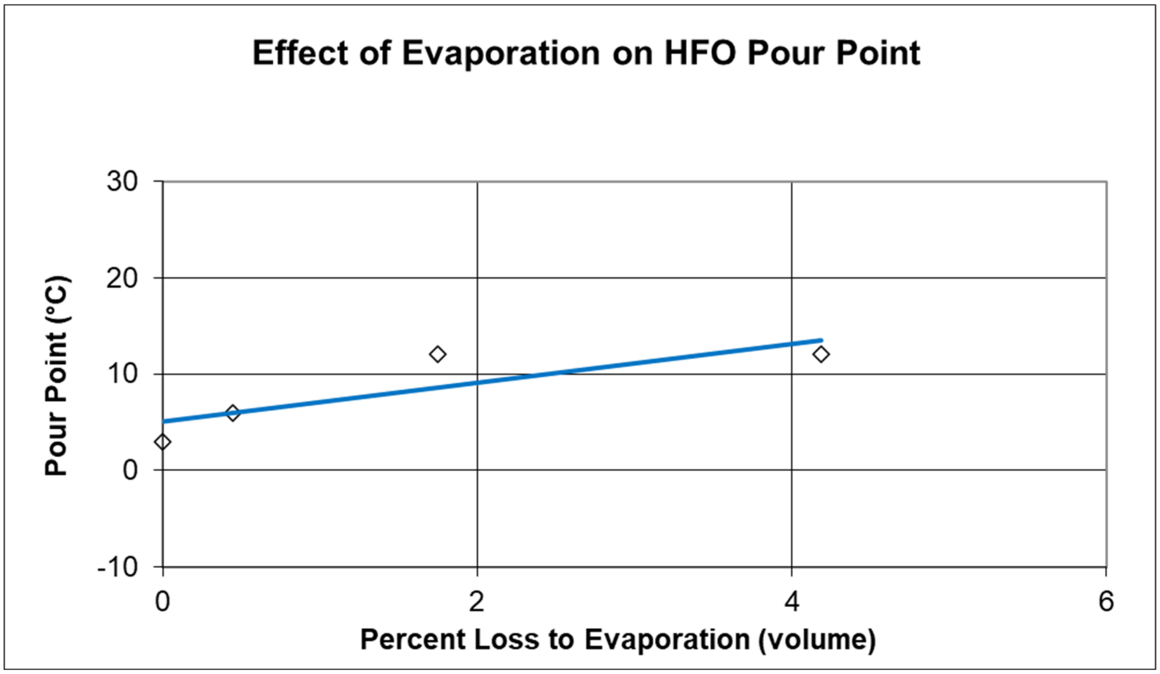


Figure 3-28: Effect of Evaporation on HFO Pour Point

3.3.7.5 Interfacial Tension

The oil/water interfacial tension of HFO was measured using standard laboratory water with 35 ppt of salt. The value measured was 22.6 dynes/cm, which is in the range of most crude oils.

3.3.7.6 Flash Point

HFO has a flash point of 67°C when fresh. This increases after 4% evaporation to 133°C.

3.3.7.7 Emulsification Tendency and Stability

One characteristic of HFO is that it is too viscous at 0°C to readily form water-in-oil emulsions when mixed with seawater. At 20°C it is likely to form unstable emulsions.

3.3.8 Light Sour Blend (LSB)

A summary of spill-related physical properties for LSB are listed below in Table 3–9.

Table 3–9: Spill-Related Properties of LSB

LSB	API Gravity = 37.2 °				
Evaporation (Volume %)		0	37.9	45.2	49.0
Density (g/cm^3)					
0	°C	0.850	0.923	0.936	0.945
15	°C	0.839	0.912	0.925	0.934
20	°C	0.835	0.908	0.921	0.930
30	°C	0.828	0.900	0.913	0.922
Dynamic Viscosity (mPa.s)	at approx 100 s^{-1} except Fresh at 1000 s^{-1}				
0	°C	9.8	346	1,658	3,545
15	°C	6.1	82	300	529
20	°C	5.6	59	158	285
30	°C	4.6	25	83	110
Kinematic Viscosity (mm^2/s)					
0	°C	11.5	375	1,772	3,750
15	°C	7.3	90	325	566
20	°C	6.7	65	172	307
30	°C	5.6	28	91	119
Interfacial Tension (dyne/cm)					
Oil/	Air	24.6	29.8	29.7	30.1
Oil/	Seawater	16.7	20.1	14.8	15.6
Pour Point (°C)					
		<-51	3	12	15
Flash Point (°C)					
		<-10	85	111	143
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Very Likely	Very Likely	Very Likely	Too Viscous
Stability		Meso-stable	Meso-stable	Meso-stable	NM
Water Content		89%	82%	69%	NM
Emulsion Formation-Tendency and Stability @ 20°C			20 °C		
Tendency		Unlikely	Very Likely	Very Likely	Very Likely
Stability		Unstable	Meso-stable	Meso-stable	Meso-stable
Water Content		0%	27%	82%	66%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	62.7		
		5	116.6		
		10	142.9		
		15	168		
		20	193.3		
		25	219		
		30	249		
		40	309		
		50	376		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta \exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 6335
C_2 = 6.60
C_3 = 3733

NM - not measured too viscous

3.3.8.1 Evaporation

Approximately 38% of the LSB oil volume evaporated after two days in the wind tunnel; about 45% evaporated after two weeks; and, around 49 % evaporated after 6 weeks of exposure.

Figure 3-29 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-30, Figure 3-31 and Figure 3-32 show the effect of evaporation on the properties of oil viscosity, density and pour point.

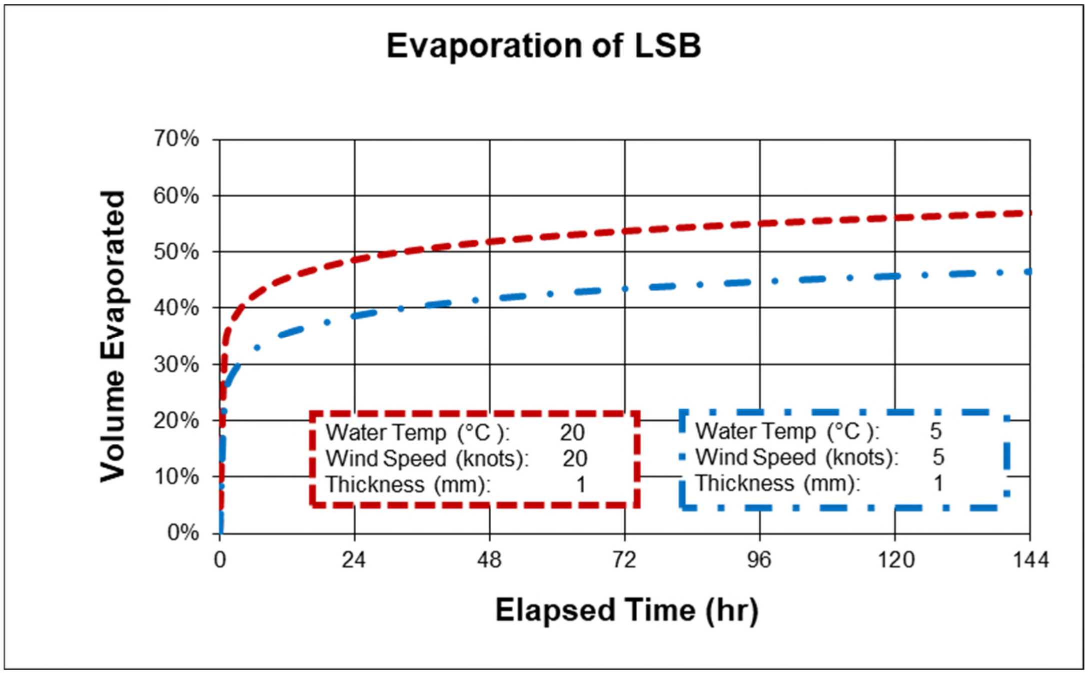


Figure 3-29: Evaporation of LSB

3.3.8.2 Density

LSB has a density of 0.839 g/cm³ at 15.5°C (API gravity of 37.2°). After 6 weeks in the wind tunnel, the density increases to 0.945 g/cm³ when measured at 0°C.

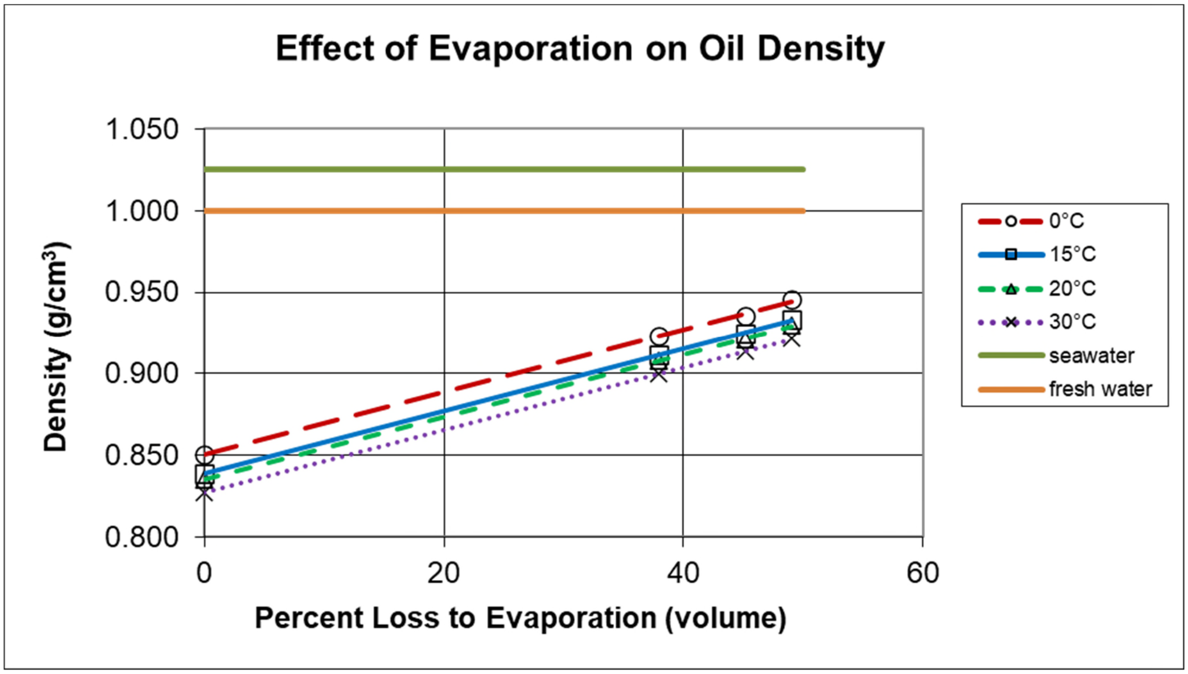


Figure 3-30: Effect of Evaporation on LSB Oil Density

3.3.8.3 Viscosity

The fresh oil has moderately low viscosity that is typical of light crude. At 20°C the viscosity of the fresh oil is about 5.6 cP (mPa.s). The viscosity increases to 59 cP after 38% evaporation; to 158 cP after 45% evaporation; and, to 285 cP after 49% evaporation.

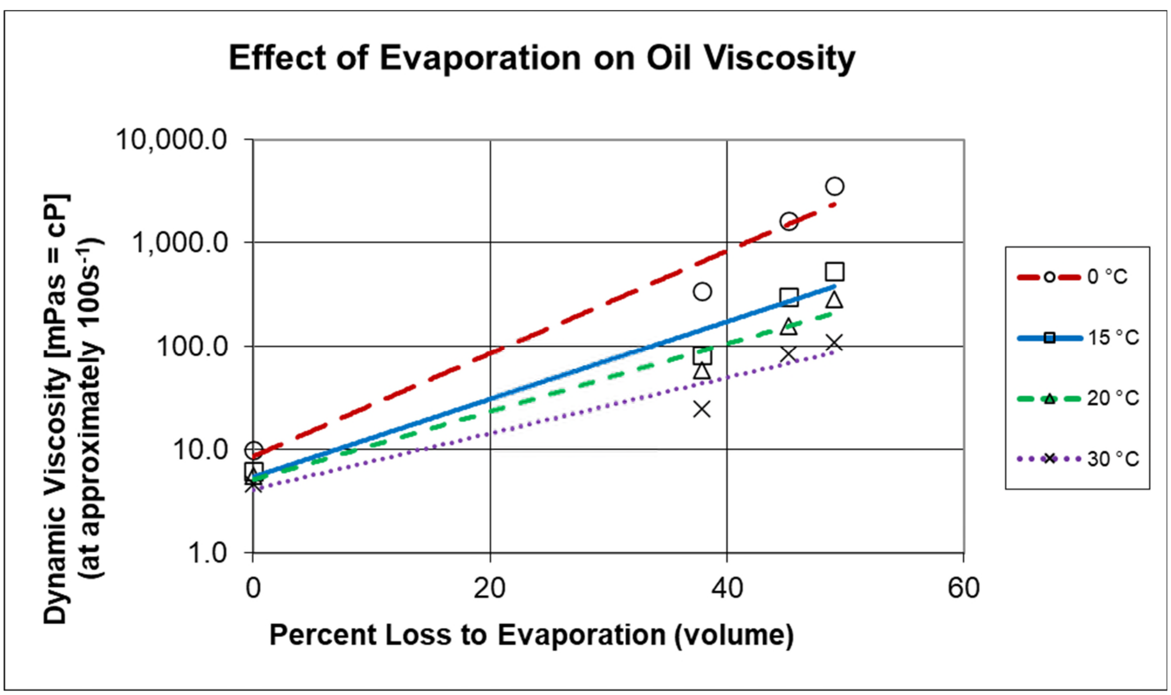


Figure 3-31: Effect of Evaporation on LSB Oil Viscosity

3.3.8.4 Pour Point

LSB has a pour point below -51°C when fresh which rises to 15°C after 49% evaporation.

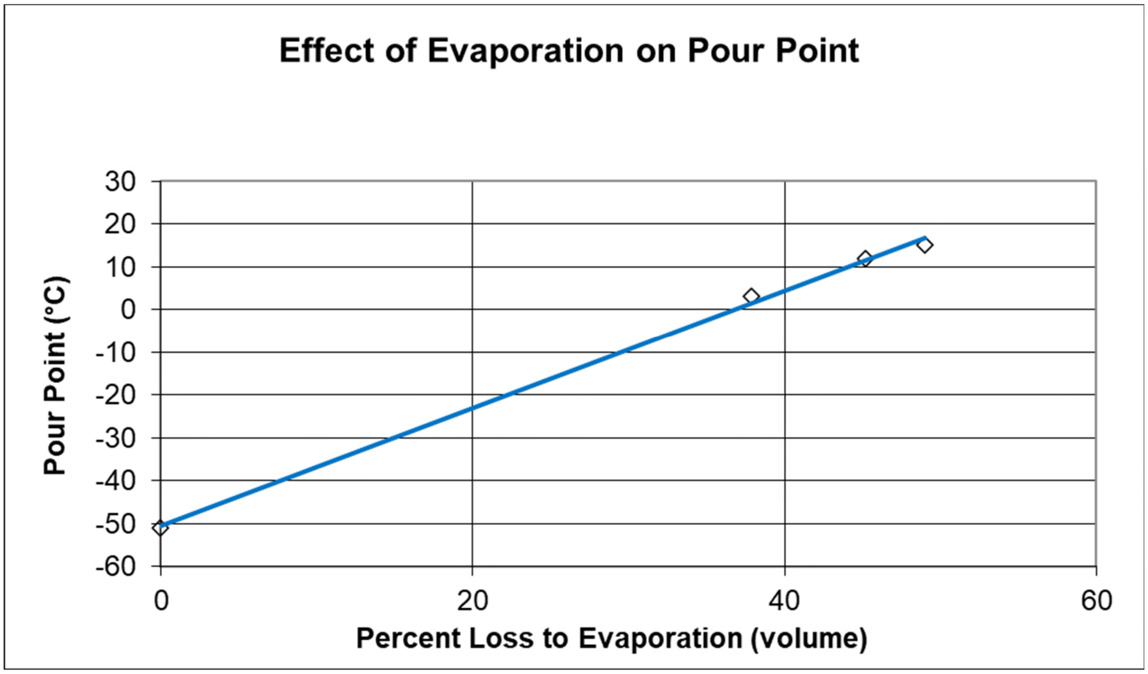


Figure 3-32: Effect of Evaporation on LSB Pour Point

3.3.8.5 Interfacial Tension

The oil/water interfacial tension of LSB was measured using standard laboratory water with 35 ppt of salt. The value measured was 16.7 dynes/cm, which is in the range of most crude oils.

3.3.8.6 Flash Point

LSB has a flash point of less than -10°C when fresh. This increases after 49% evaporation to 143°C.

3.3.8.7 Emulsification Tendency and Stability

Fresh LSB is only likely to form meso-stable water-in oil emulsions when mixed with seawater when it is at 0° C. At 20°C it needs to evaporate to 38% volume loss before it will likely form meso-stable emulsions.

3.3.9 Medium Sour Blend (MSB)

A summary of MSB spill-related physical properties is listed in Table 3–10.

Table 3–10: Spill-Related Properties of MSB

Spill-related properties		Fresh	2D	14D	6W
MSB	API Gravity =	35.5 °			
Evaporation (Volume %)		0	33.9	40.7	44.1
Density (g/cm^3)					
0	°C	0.859	0.924	0.936	0.942
15	°C	0.848	0.913	0.925	0.931
20	°C	0.844	0.909	0.921	0.927
30	°C	0.836	0.901	0.913	0.919
Dynamic Viscosity (mPa.s)	at approx 100 s^{-1} except fresh oil at 960 s^{-1}				
0	°C	15	463	2,045	3,022
15	°C	7	89	274	475
20	°C	7	65	163	274
30	°C	5	25	90	123
Kinematic Viscosity (mm^2/s)					
0	°C	18	502	2,185	3,208
15	°C	9	97	297	510
20	°C	8	71	177	296
30	°C	6	28	98	134
Interfacial Tension (dyne/cm)					
Oil/	Air	24.5	29.2	29.9	32.0
Oil/	Seawater	7.1	8.7	11.4	12.3
Pour Point (°C)					
		<-46.5	-3	6	9
Flash Point (°C)					
		<-12	70	105	144
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Unlikely	Very Likely	Very Likely	0
Stability		Unstable	Stable	Meso-stable	Meso-stable
Water Content		0%	64%	60%	57%
Emulsion Formation-Tendency and Stability @ 20°C			20 °C		
Tendency		Unlikely	Unlikely	Very Likely	Very Likely
Stability		Unstable	Unstable	Entrained	Entrained
Water Content		0%	0%	36%	42%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	70.8		
		5	131.9		
		10	161.1		
		15	186.8		
		20	212		
		25	242		
		30	276		
		40	345		
		50	398		
Weathering Model					
	$F_v = \dfrac{\ln[1 + (C_1/T_k)\theta\exp(C_2 - C_3/T_k)]}{(C_1/T_k)}$				
	where: Fv is volume fraction of oil evaporated				
	θ is evaporative exposure				
	Tk is environmental temperature (K)				
	C_1 =	7328			
	C_2 =	8.60			
	C_3 =	4195			

3.3.9.1 Evaporation

Approximately 34% of the MSB oil volume evaporated after two days in the wind tunnel; about 41% evaporated after two weeks; and, around 44 % evaporated after 6 weeks of exposure.

Figure 3-33 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-34, Figure 3-35 and Figure 3-36 show the effect of evaporation on the properties of oil viscosity, density and pour point.

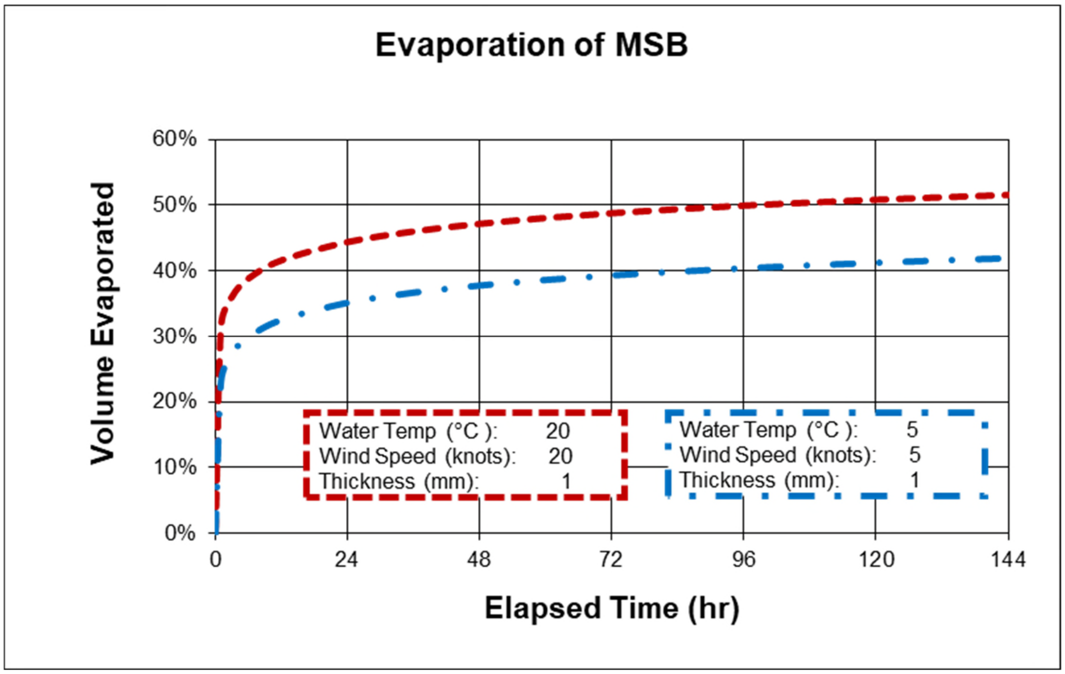


Figure 3-33: Evaporation of MSB

3.3.9.2 Density

MSB has a density of 0.847 g/cm³ at 15.5°C (API gravity of 36.5°). After 6 weeks in the wind tunnel, the density increases to 0.936 g/cm³ when measured at 0°C.

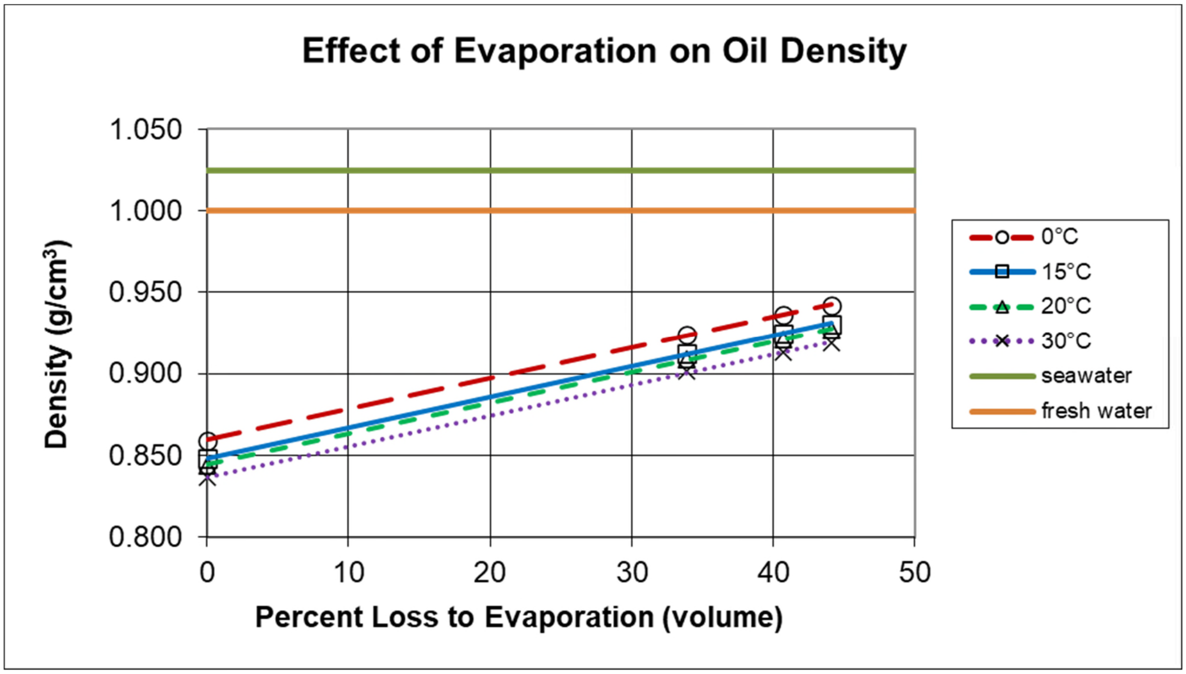


Figure 3-34: Effect of Evaporation on MSB Oil Density

3.3.9.3 Viscosity

The fresh oil has moderately low viscosity that is typical of light crude. At 20°C the viscosity of the fresh oil is about 7 cP (mPa.s). The viscosity increases to 65 cP after 34% evaporation; to 163 cP after 41% evaporation; and, to 296 cP after 44% evaporation.

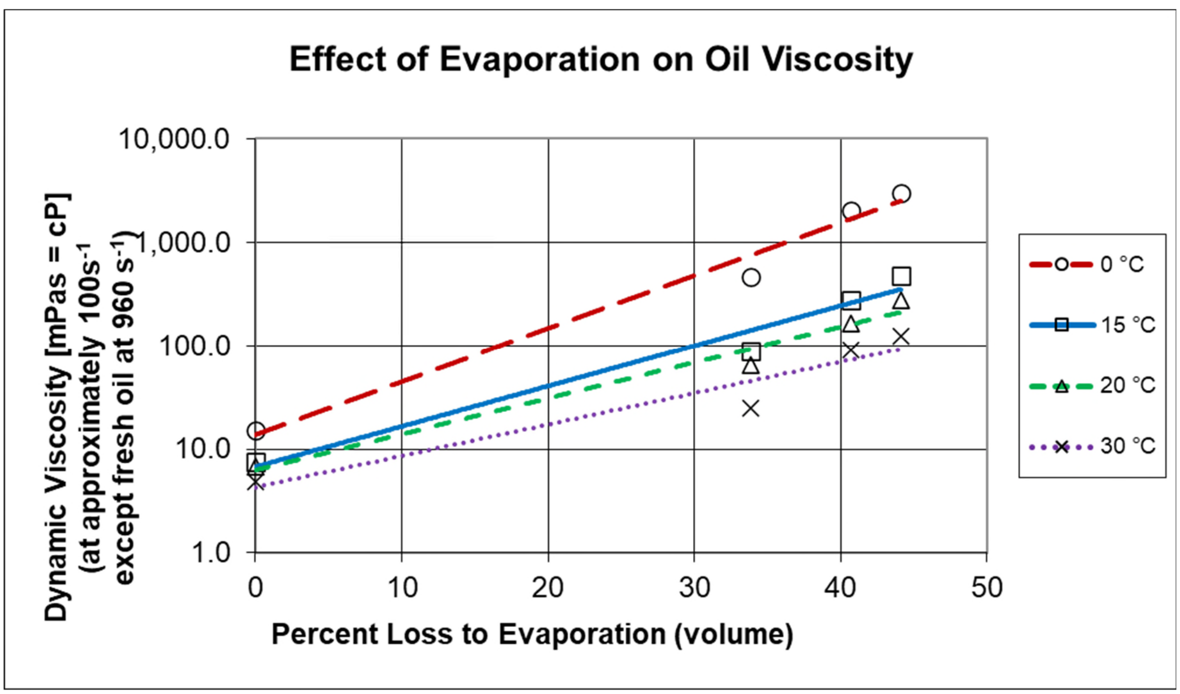


Figure 3-35: Effect of Evaporation on MSB Oil Viscosity

3.3.9.4 Pour Point

MSB has a pour point below -46°C when fresh which rises to 9°C after 44% evaporation.

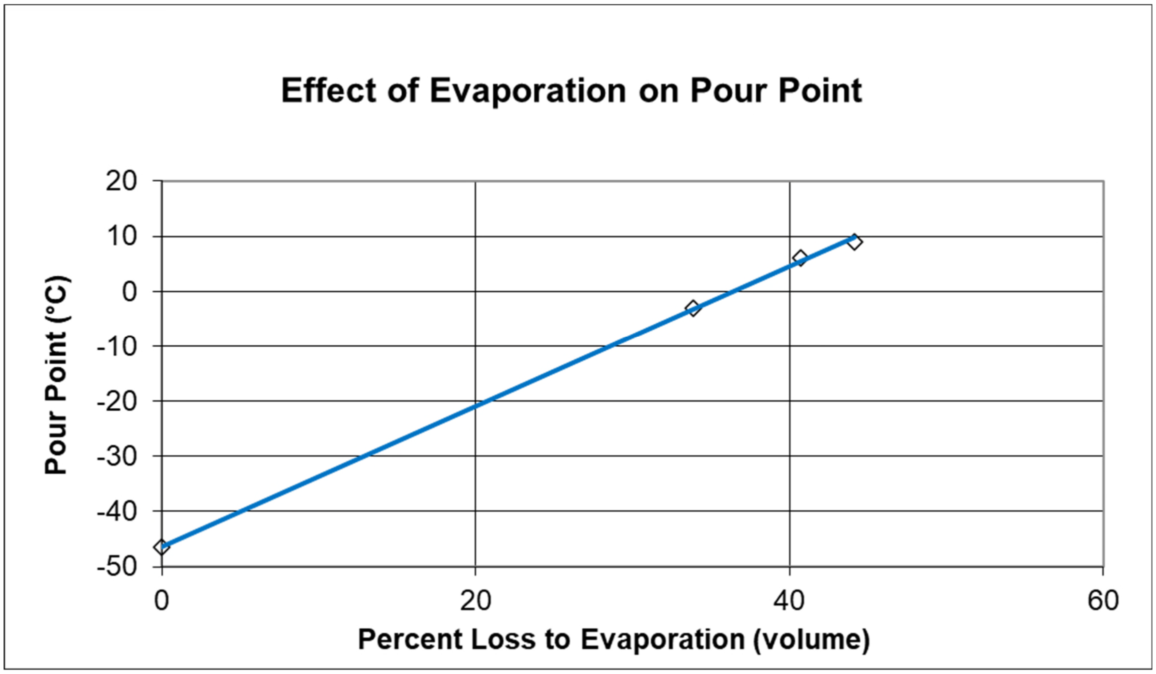


Figure 3-36: Effect of Evaporation on MSB Pour Point

3.3.9.5 Interfacial Tension

The oil/water interfacial tension of MSB was measured using standard laboratory water with 35 ppt of salt. The value measured was 7.1 dynes/cm, which is in the low end of the range of most crude oils.

3.3.9.6 Flash Point

MSB has a flash point of less than -12°C when fresh. This increases after 44% evaporation to 144°C.

3.3.9.7 Emulsification Tendency and Stability

MSB is only likely to form meso-stable or stable water-in oil emulsions when mixed with seawater when it is at 0° C and 34% evaporated. It is not likely to form stable emulsions at 20° C even when 44% evaporated.

3.3.10 Mixed Sweet Blend (MSW)

A summary of MSW spill-related physical properties is listed in Table 3–11.

Table 3–11: Spill-Related Properties of MSW

Spill-related properties		Fresh	2D	14D	6W
MSW	API Gravity =	41.2 °			
Evaporation (Volume %)		0	34.5	44.2	49.1
Density (g/cm^3)					
0 °C		0.832	0.892	0.904	0.915
15 °C		0.820	0.880	0.892	0.903
20 °C		0.816	0.876	0.888	0.898
30 °C		0.808	0.868	0.879	0.890
Dynamic Viscosity (mPa.s)	at approx 100 s^{-1} except fresh and 2D at 30° at 1000 s^{-1}				
0 °C		10	630	891	5,430
15 °C		5	48	241	440
20 °C		5	35	139	230
30 °C		4	18	18	69
Kinematic Viscosity (mm^2/s)					
0 °C		12	707	986	5,933
15 °C		7	55	270	487
20 °C		6	40	157	256
30 °C		5	21	20	78
Interfacial Tension (dyne/cm)					
Oil/ Air		25.4	28.5	29.2	27.4
Oil/ Seawater		15.9	9.1	9.5	6.5
Pour Point (°C)		-24	12	18	15
Flash Point (°C)		<-12	45	98	88
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Very Likely	Very Likely	Too Viscous	Too Viscous
Stability		Unstable	Stable	NM	NM
Water Content		0%	86%	NM	NM
Emulsion Formation-Tendency and Stability @ 20°C			18.5 °C		
Tendency		Unlikely	Very Likely	Very Likely	Very Likely
Stability		Unstable	Meso-stable	Meso-stable	Meso-stable
Water Content		0%	54%	89%	85%
ASTM Modified Distillation		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	57.4		
		5	117.3		
		10	147.3		
		15	169.8		
		20	193.3		
		25	221		
		30	253		
		40	325		
		50	388		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta \exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 5136
C_2 = 2.20
C_3 = 2832

NM - not measured too viscous

3.3.10.1 Evaporation

Approximately 34% of the MSW oil volume evaporated after two days in the wind tunnel; about 44% evaporated after two weeks; and, around 49 % evaporated after 6 weeks of exposure.

Figure 3-37 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-38, Figure 3-39 and Figure 3-40 show the effect of evaporation on the properties of oil viscosity, density and pour point.

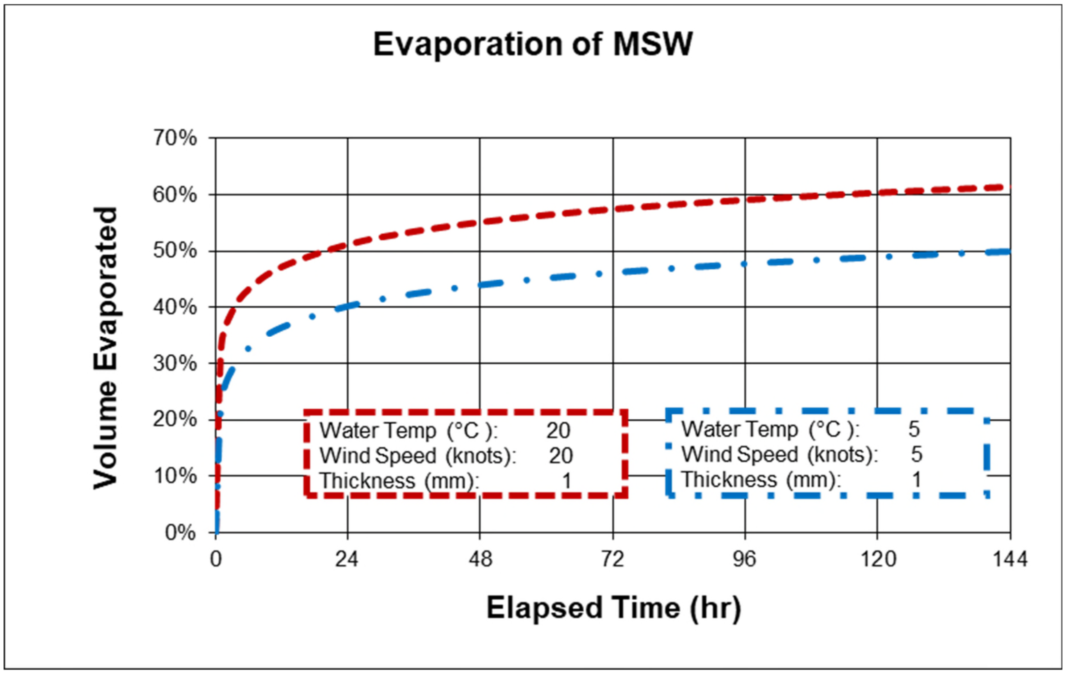


Figure 3-37: Evaporation of MSW

3.3.10.2 Density

Fresh MSW has a density of 0.820 g/cm^3 at 15.5°C (API gravity of 41.2°). After 6 weeks in the wind tunnel, the density increases to 0.915 g/cm^3 when measured at 0°C.

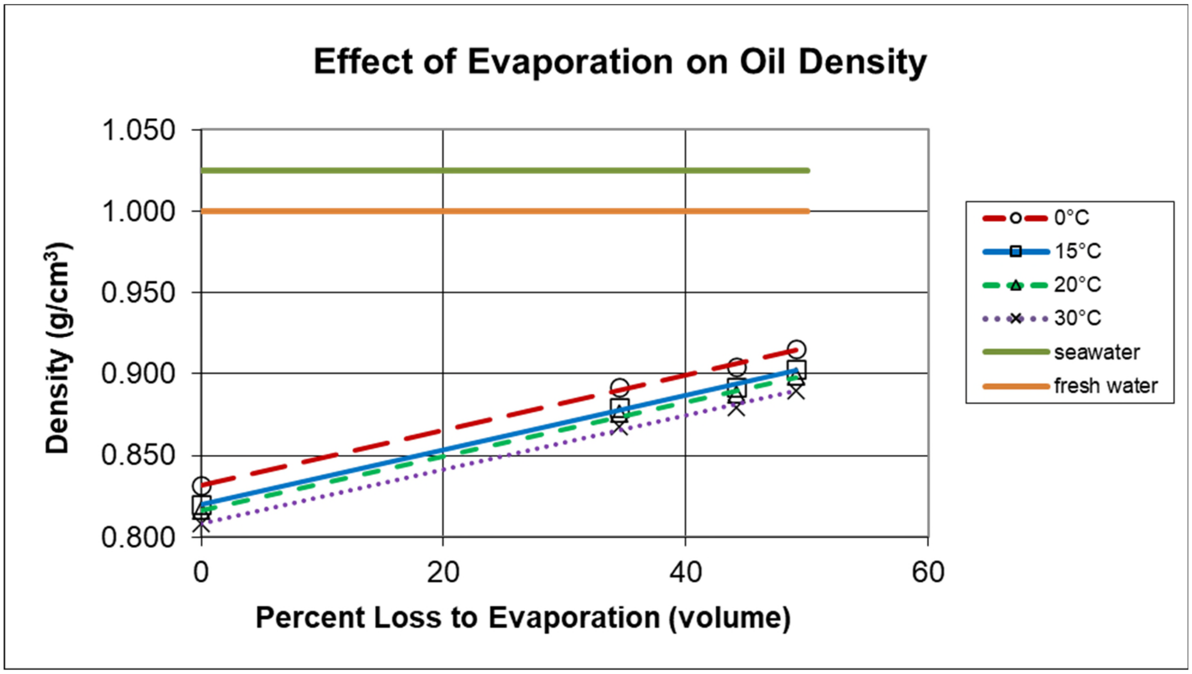


Figure 3-38: Effect of Evaporation on MSW Oil Density

3.3.10.3 Viscosity

The fresh oil has low viscosity that is typical of light crude. At 20°C the viscosity of the fresh oil is about 4.9 cP (mPa.s). The viscosity increases to 35 cP after 34% evaporation; to 139 cP after 44% evaporation; and, to 230 cP after 49% evaporation.

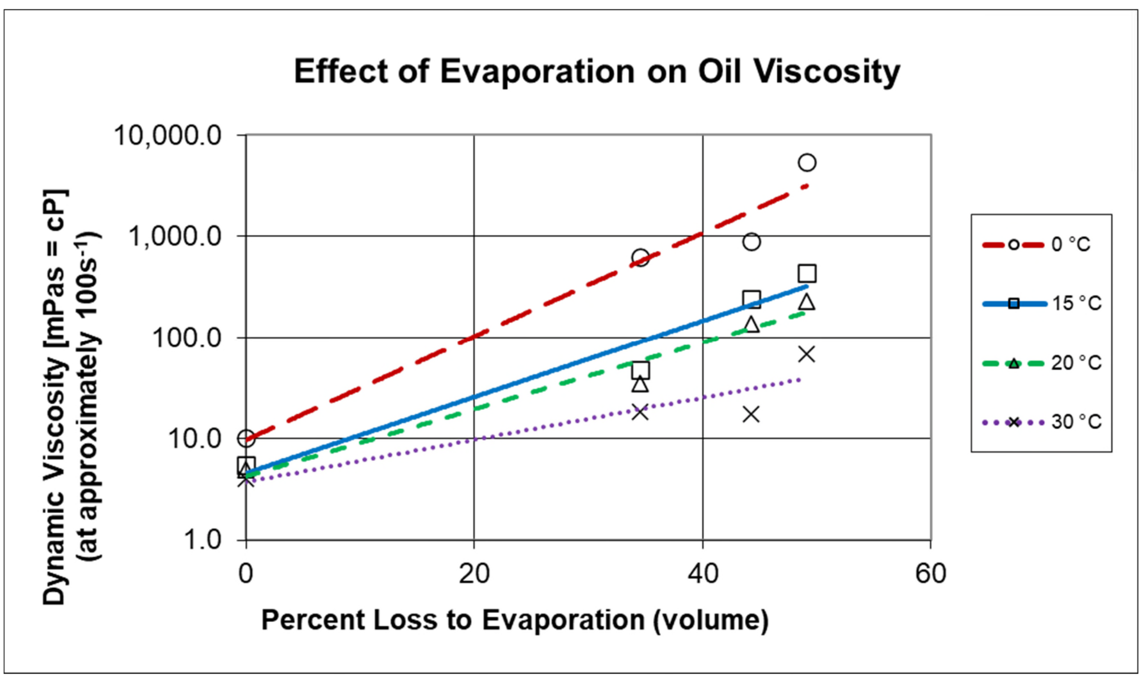


Figure 3-39: Effect of Evaporation on MSW Oil Viscosity

3.3.10.4 Pour Point

MSW has a pour point below -24°C when fresh which rises to 15°C after 49% evaporation.

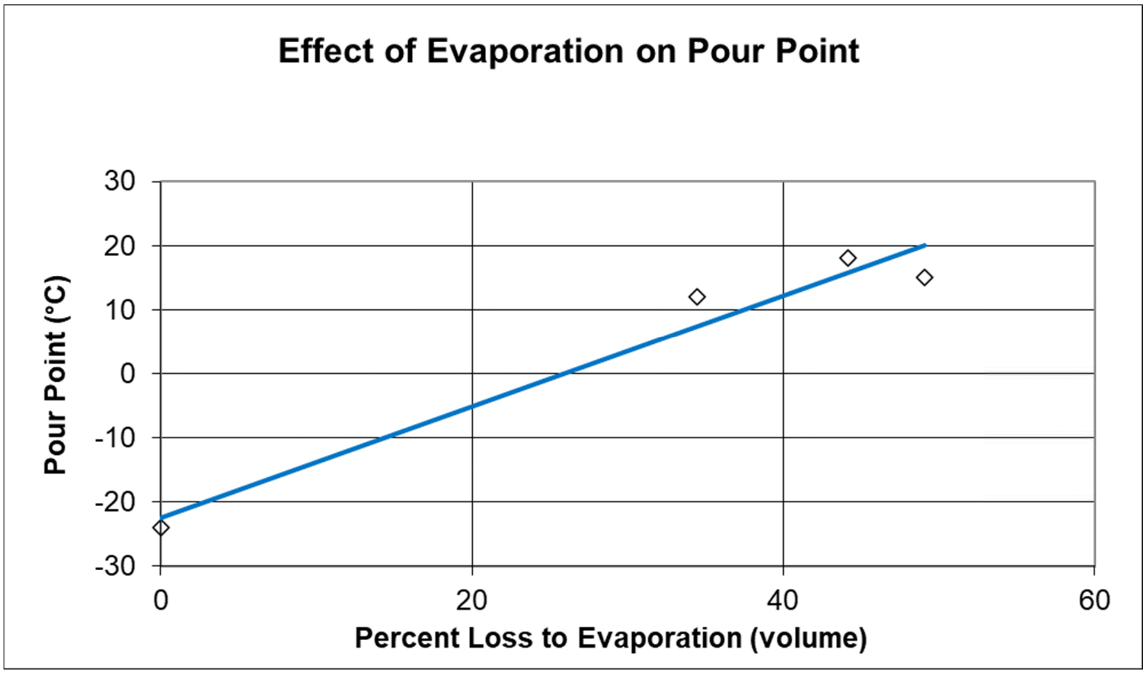


Figure 3-40: Effect of Evaporation on MSW Pour Point

3.3.10.5 Interfacial Tension

The oil/water interfacial tension of MSW was measured using standard laboratory water with 35 ppt of salt. The value measured was 15.9 dynes/cm, which is in normal range of most crude oils.

3.3.10.6 Flash Point

MSW has a flash point of less than -12°C when fresh. This increases after 49% evaporation to 88°C.

3.3.10.7 Emulsification Tendency and Stability

One characteristic of MSW is that it is only likely to form meso-stable or stable water-in oil emulsions when mixed with seawater when it is 34% evaporated.

3.3.11 North Dakota Bakken (NDB)

A summary of NDB spill-related physical properties is listed below in Table 3–12.

Table 3–12: Spill-Related Properties of NDB

Spill-related properties		Fresh	2D	14D	6W
NDB	API gravity = 42.6 °				
Evaporation (Volume %)		0	40.8	50.8	55.7
Density (g/cm^3)					
0	°C	0.824	0.885	0.896	0.902
15	°C	0.813	0.874	0.885	0.892
20	°C	0.809	0.871	0.882	0.888
30	°C	0.802	0.864	0.875	0.881
Dynamic Viscosity (mPa.s)	at various shear rates				
0	°C	4.3	60	256	414
15	°C	3.3	24	52	86
20	°C	2.7	19	39	63
30	°C	2.8	14	24	35
Kinematic Viscosity (mm^2/s)					
0	°C	5.2	68	286	459
15	°C	4.1	28	59	96
20	°C	3.3	22	44	70
30	°C	3.4	16	28	40
Interfacial Tension (dyne/cm)					
Oil/	Air	25.3	28.8	29.8	30.2
Oil/	Seawater	19.0	21.4	23.0	20.4
Pour Point (°C)		-54	-33	-18	-18
Flash Point (°C)		<-10	56	94	141
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Unlikely	Unlikely	Very Likely	Very Likely
Stability		Unstable	Unstable	Meso-stable	Meso-stable
Water Content		0%	0%	47%	54%
Emulsion Formation-Tendency and Stability @ 15°C			20 °C		
Tendency		Unlikely	Unlikely	Unlikely	Unlikely
Stability		Unstable	Unstable	Unstable	Unstable
Water Content		0%	0%	0%	0%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	53.4		
		5	88.2		
		10	100.8		
		15	112		
		20	121.3		
		25	133.9		
		30	146.5		
		40	160.8		
		50	175.6		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta \exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 5278
C_2 = 15.80
C_3 = 6559

3.3.11.1 Evaporation

NDB is produced in North Dakota, U.S. Approximately 41% of the oil volume evaporated after two days in the wind tunnel; about 51% evaporated after two weeks; and, around 56 % evaporated after 6 weeks of exposure.

Figure 3-41 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-42, Figure 3-43 and Figure 3-44 show the effect of evaporation on the properties of oil viscosity, density and pour point.

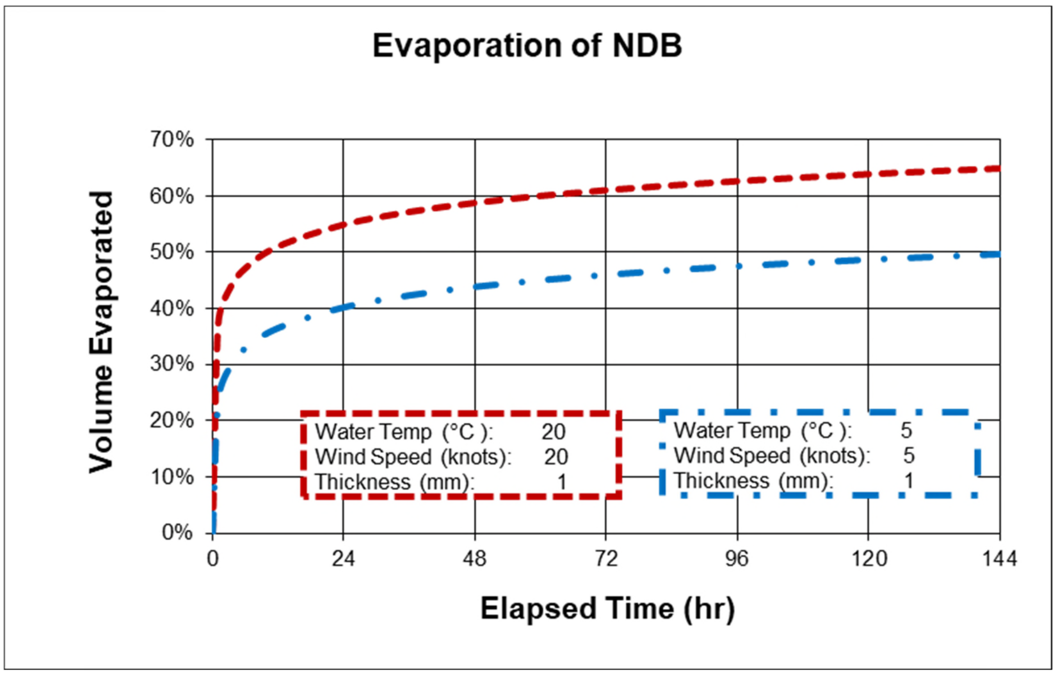


Figure 3-41: Evaporation of NDB

3.3.11.2 Density

NDB has a density of 0.813 g/cm^3 at 15.5°C (API gravity of 42.6°). After 6 weeks in the wind tunnel, the density increases to 0.902 g/cm^3 when measured at 0°C.

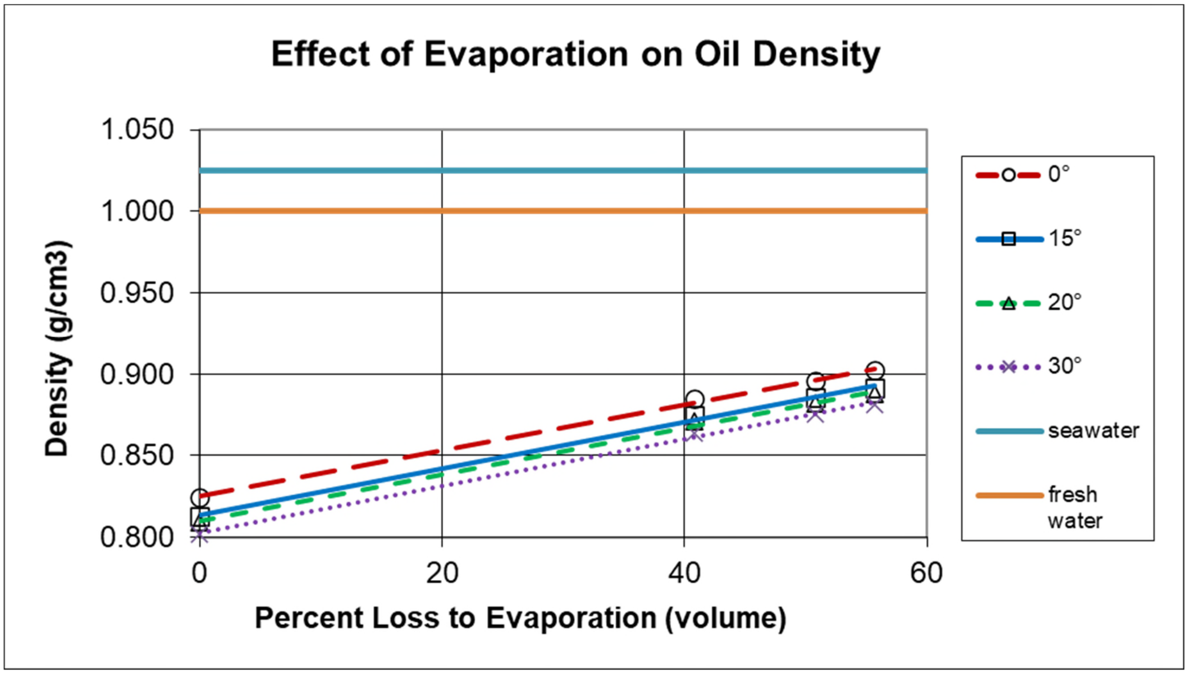


Figure 3-42: Effect of Evaporation on NDB Oil Density

3.3.11.3 Viscosity

The fresh oil has a low viscosity that is typical of light crude. At 20°C the viscosity of the fresh oil is about 2.7 cP (mPa.s). The viscosity increases to 19 cP after 41% evaporation; to 39 cP after 51% evaporation; and, to 63 cP after 56% evaporation.

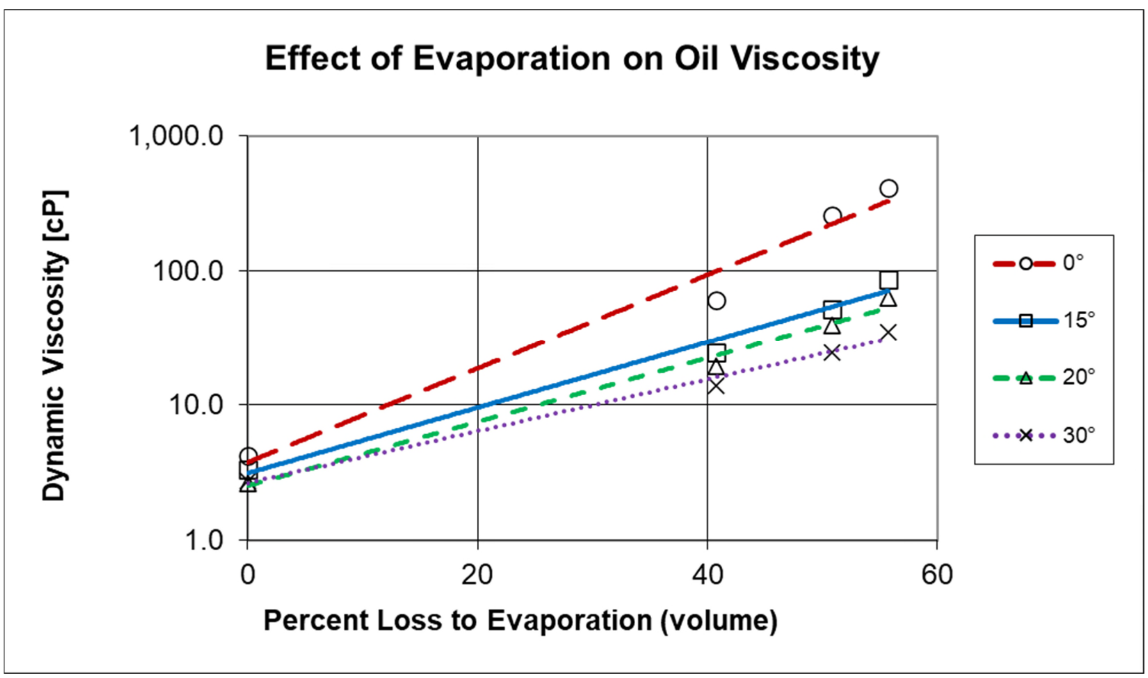


Figure 3-43: Effect of Evaporation on NDB Oil Viscosity

3.3.11.4 Pour Point

NDB has a pour point below -54°C when fresh which rises to -18°C after 56% evaporation.

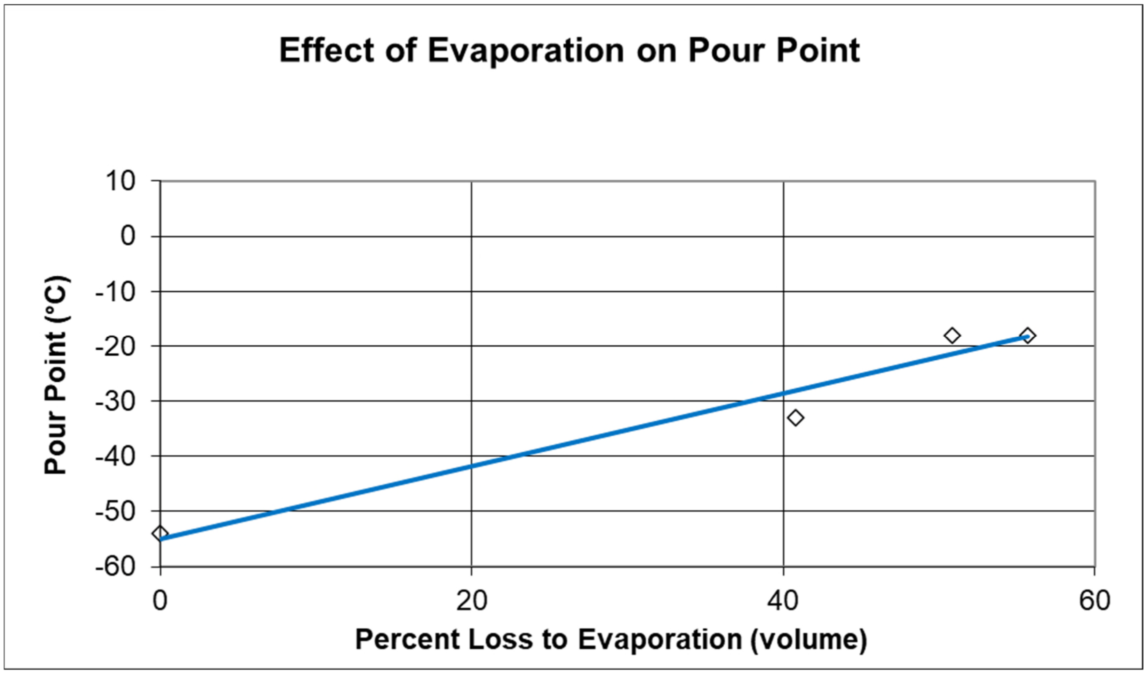


Figure 3-44: Effect of Evaporation on NDB Pour Point

3.3.11.5 Interfacial Tension

The oil/water interfacial tension of NDB was measured using standard laboratory water with 35 ppt of salt. The value measured was 19 dynes/cm, which is in the normal range for most oils.

3.3.11.6 Flash Point

NDB has a flash point of less than -10°C when fresh. This increases after 51% evaporation to 141°C.

3.3.11.7 Emulsification Tendency and Stability

NDB is unlikely to form water-in-oil emulsions when mixed with seawater at 20°C. At 0°C it will form a meso-stable emulsion after it has lost 51% of its volume to evaporation.

3.3.12 Synbit Blend (SYB)

A summary of SYB spill-related physical properties is listed below in Table 3–13.

Table 3–13: Spill-Related Properties of SYB Crude Oil

Spill-related properties		Fresh	2D	14D	6W
SYB	API Gravity =	20.5 °			
Evaporation (Volume %)		0	9.9	16.6	20.3
Density (g/cm^3)					
0 °C		0.941	0.964	0.977	0.984
15 °C		0.931	0.954	0.968	0.974
20 °C		0.928	0.951	0.964	0.971
30 °C		0.921	0.944	0.958	0.964
Dynamic Viscosity (mPa.s)	at various shear rates				
0 °C		587	4,177	20,517	55,813
15 °C		194	1,520	3,727	8,332
20 °C		144	678	2,308	4,910
30 °C		83	341	993	1,905
Kinematic Viscosity (mm^2/s)					
0 °C		623	4,334	20,996	56,730
15 °C		208	1,593	3,852	8,554
20 °C		155	714	2,394	5,058
30 °C		90	361	1,037	1,975
Interfacial Tension (dyne/cm)					
Oil/ Air		28.5	30.1	30.5	34.3
Oil/ Seawater		15.2	11.5	11.0	13.4
Pour Point (°C)		<-42	-18	-12	0
Flash Point (°C)		-10	25	66	133
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Very Likely	Very Likely	Very Likely	Too Viscous
Stability		Meso-stable	Entrained	Entrained	Too Viscous
Water Content		67%	33%	25%	NM
Emulsion Formation-Tendency and Stability @ 20°C			19 °C		
Tendency		Very Likely	Very Likely	Very Likely	Very Likely
Stability		Meso-stable	Meso-stable	Entrained	Entrained
Water Content		59%	51%	27%	28%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	104.7		
		5	217		
		10	275		
		15	314		
		20	341		
		25	365		
		30	383		
		40	413		
		50	429		

Weathering Model

$$F_v = \frac{\ln[1 + (C_1/T_k)\theta\exp(C_2 - C_3/T_k)]}{(C_1/T_k)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 11218
C_2 = 22.40
C_3 = 9381

NM - not measured too viscous

3.3.12.1 Evaporation

Approximately 10% of the SYB volume evaporated after two days in the wind tunnel; about 17% evaporated after two weeks; and, around 20 % evaporated after 6 weeks of exposure.

Figure 3-45 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figures 2-2, 2-3 and 2-4 show the effect of evaporation on the properties of oil viscosity, density and pour point.

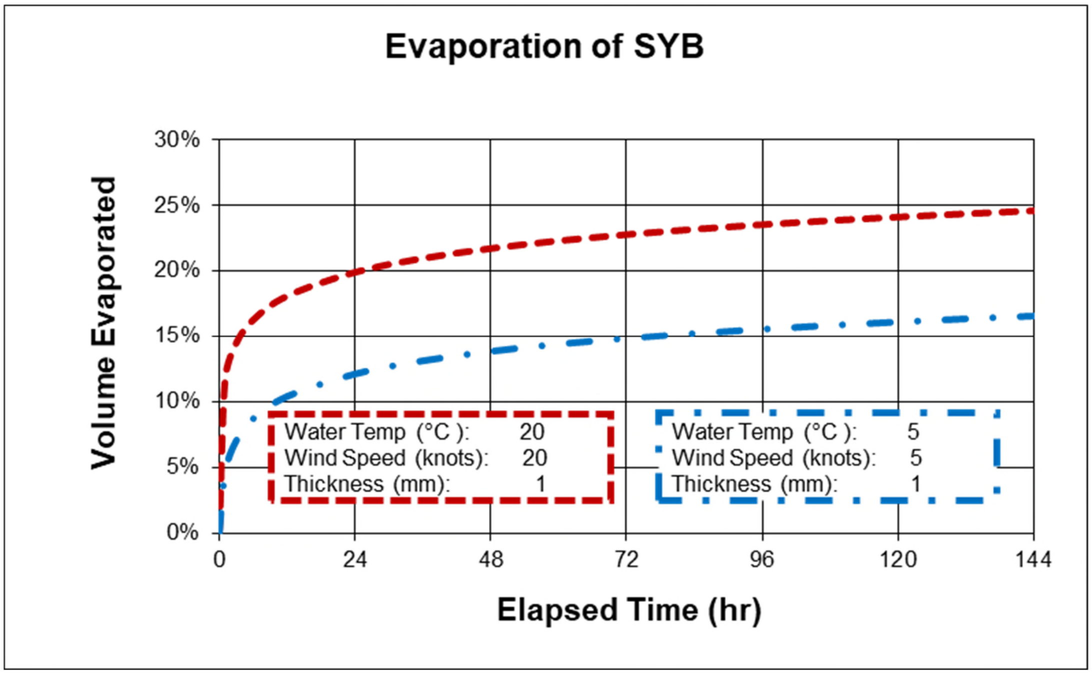


Figure 3-45: Evaporation of SYB

3.3.12.2 Density

SYB oil has a density of 0.931 g/cm³ at 15.5°C (API gravity of 20.5). After 6 weeks in the wind tunnel, the density increases to 0.984 g/cm³ at 0°C.

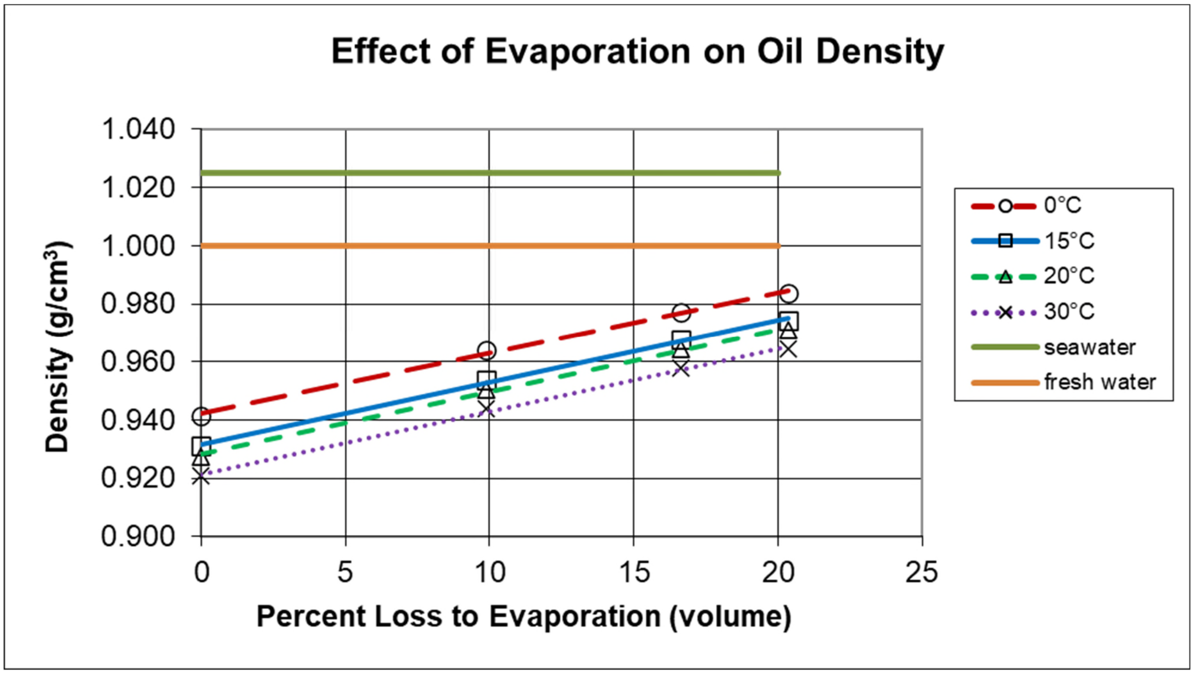


Figure 3-46: Effect of Evaporation on SYB Oil Density

3.3.12.3 Viscosity

The oil has moderately high viscosity that is typical of medium heavy crudes. At 20°C the viscosity of the fresh oil is about 144 cP (mPa.s). The viscosity increases to 680 cP after 10% evaporation; to 2,310 cP after 17% evaporation; and, increases to 4,910 cP after 20% evaporation.

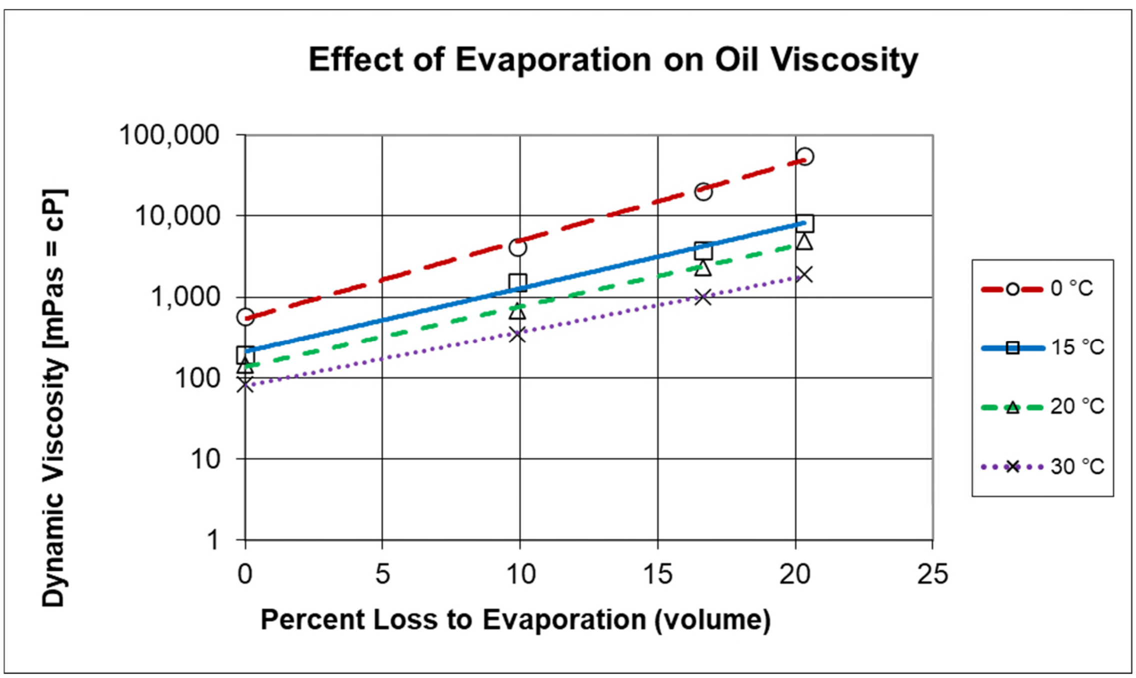


Figure 3-47: Effect of Evaporation on SYB Oil Viscosity

3.3.12.4 Pour Point

SYB has a pour point below -42°C when fresh which rises to 0°C after 20% evaporation.

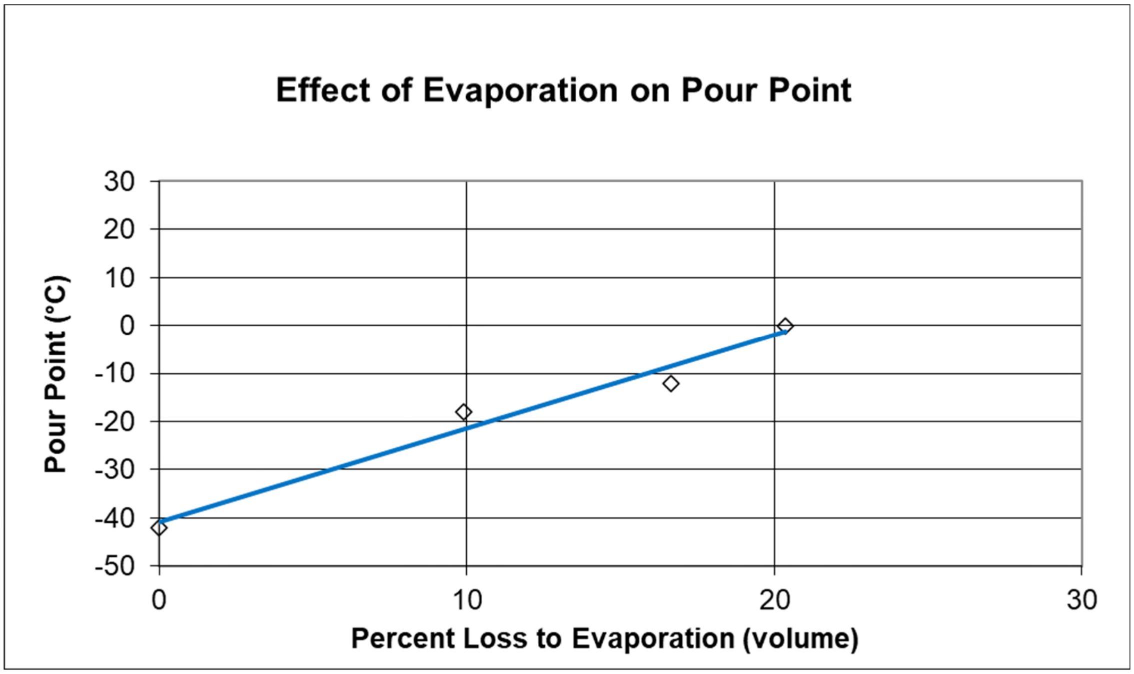


Figure 3-48: Effect of Evaporation on Pour Point

3.3.12.5 Interfacial Tension

The oil/water interfacial tension of SYB was measured using standard laboratory water with 35 ppt of salt. The value measured was 15.2 dynes/cm, which is in the normal range of most crude oils.

3.3.12.6 Flash Point

SYB has a flash point of less than <-10°C when fresh. This increases after 20% evaporation to 133°C.

3.3.12.7 Emulsification Tendency and Stability

SYB is likely to form meso-stable water-in-oil emulsions when mixed with seawater.

3.3.13 Synthetic Sweet Blend (SYN)

A summary of SYN spill-related physical properties is listed below in Table 3–14.

Table 3–14: Spill-Related Properties of SYN

Spill-related properties		Fresh	2D	14D	6W
SYN	API Gravity =	33.3 °			
Evaporation (Volume %)		0	20.4	28.6	34.0
Density (g/cm^3)					
0 °C		0.870	0.904	0.911	0.915
15 °C		0.859	0.894	0.901	0.905
20 °C		0.855	0.891	0.898	0.902
30 °C		0.848	0.884	0.891	0.895
Dynamic Viscosity (mPa.s)	at approx 1000 s^{-1} except 0° and 6W at 15° and 20° at 100 s^{-1}				
0 °C		11.7	58	111	142
15 °C		6.6	22	36	38
20 °C		6.3	17	28	30
30 °C		4.5	11	17	22
Kinematic Viscosity (mm^2/s)					
0 °C		13.4	64	122	155
15 °C		7.6	24	39	42
20 °C		7.3	19	31	33
30 °C		5.3	12	19	24
Interfacial Tension (dyne/cm)					
Oil/ Air		26.3	29.5	29.9	30.9
Oil/ Seawater		21.6	14.1	15.8	15.2
Pour Point (°C)		<-51	-27	-21	-18
Flash Point (°C)		<-12	94	124	139
Emulsion Formation-Tendency and Stability @ 0°C			0 °C		
Tendency		Unlikely	Unlikely	Unlikely	0
Stability		Unstable	Unstable	Unstable	Unstable
Water Content		0%	0%	0%	0%
Emulsion Formation-Tendency and Stability @ 20°C			20 °C		
Tendency		Unlikely	Unlikely	Unlikely	Unlikely
Stability		Unstable	Unstable	Unstable	Unstable
Water Content		0%	0%	0%	0%
ASTM Modified Distillation					
		Evaporation (% volume)	Liquid Temperature (°C)		
		IBP	106.5		
		5	171.3		
		10	213		
		15	247		
		20	271		
		25	291		
		30	308		
		40	334		
		50	359		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta\exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 7970

C_2 = 17.30

C_3 = 7460

3.3.13.1 Evaporation

Approximately 20% of the SYN oil volume evaporated after two days in the wind tunnel; about 29% evaporated after two weeks; and, around 34 % evaporated after 6 weeks of exposure.

Figure 3-49 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-50, Figure 3-51 and Figure 3-52 show the effect of evaporation on the properties of oil viscosity, density and pour point.

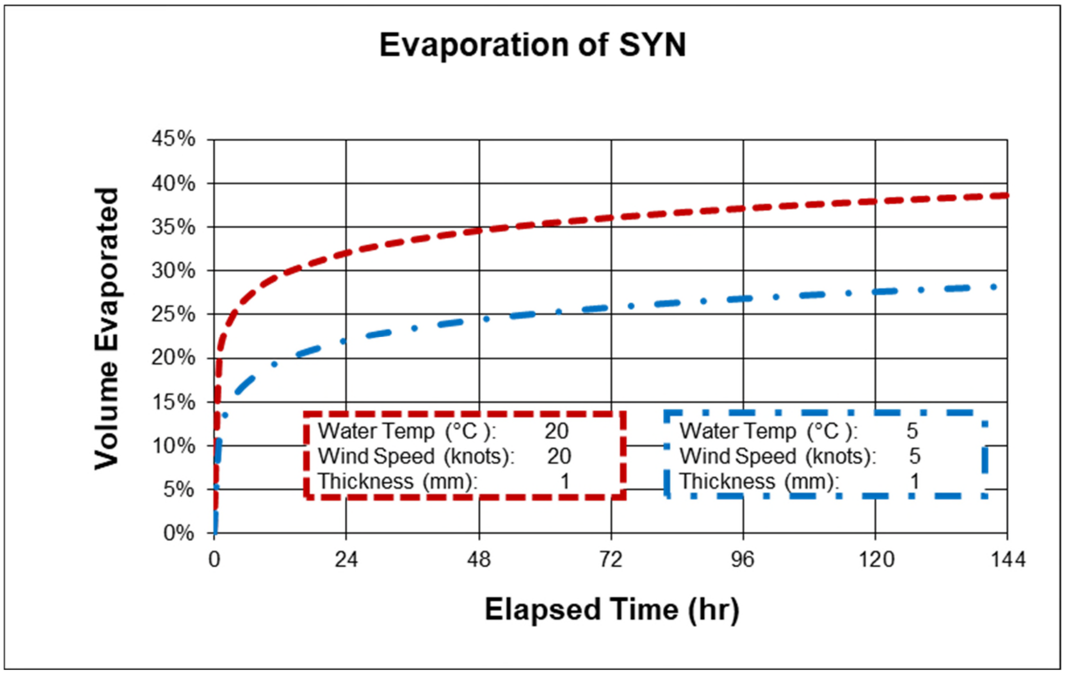


Figure 3-49: Evaporation of SYN

3.3.13.2 Density

SYN has a density of 0.855 g/cm^3 at 15.5°C (API gravity of 33.3°). After 6 weeks in the wind tunnel, the density increases to 0.915 g/cm^3 when measured at 0°C.

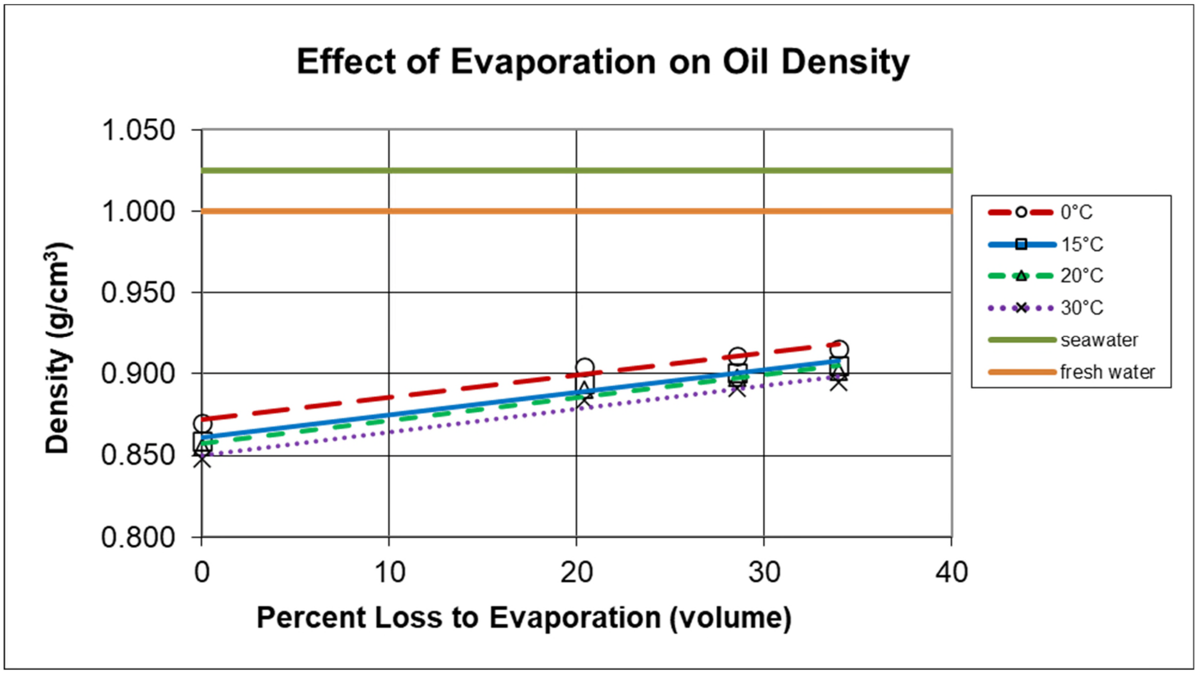


Figure 3-50: Effect of Evaporation on SYN Oil Density

3.3.13.3 Viscosity

The oil has moderate viscosity that is typical of medium gravity crudes. At 20°C the viscosity of the fresh oil is about 6.3 cP (mPa.s). The viscosity increases to 17 cP after 20% evaporation; to 28 cP after 29% evaporation; and, increases to 30 cP after 34% evaporation.

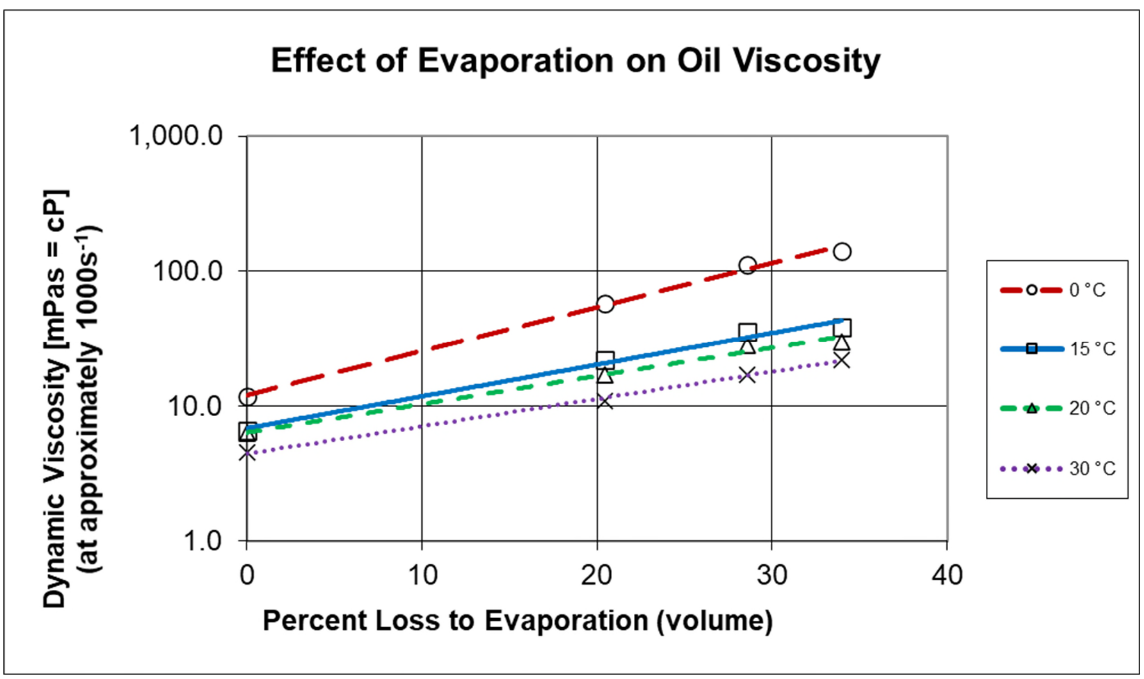


Figure 3-51: Effect of Evaporation on SYN Oil Viscosity

3.3.13.4 Pour Point
SYN has a pour point below -51°C when fresh which rises to -18°C after 34% evaporation.

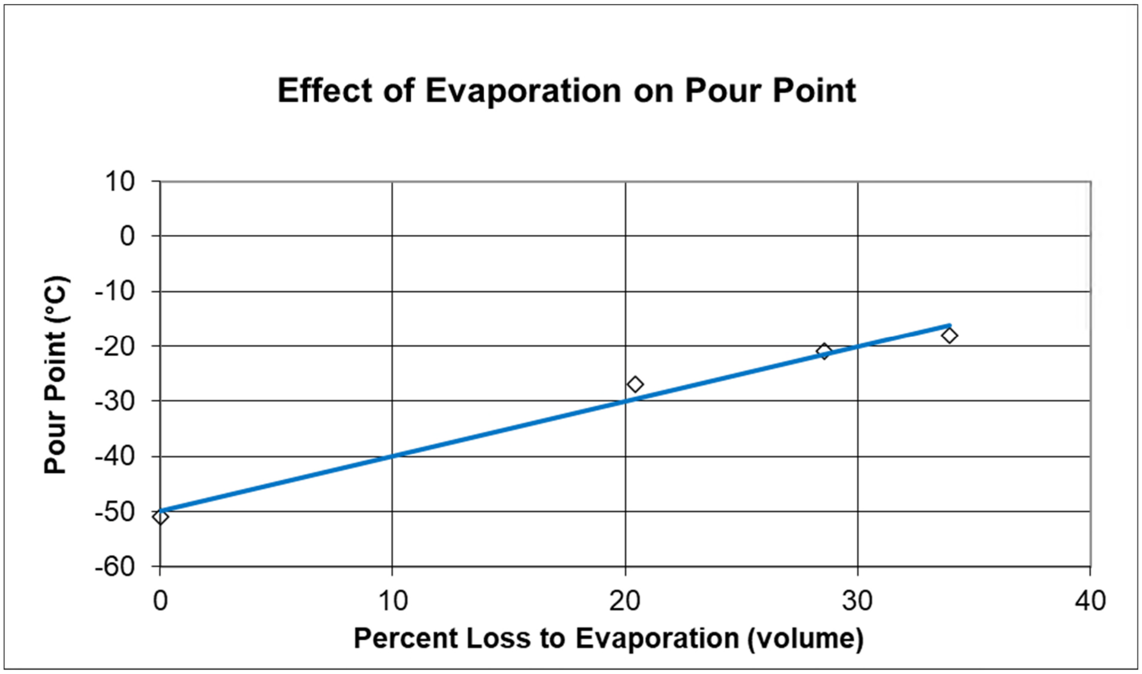


Figure 3-52: Effect of Evaporation on SYN Pour Point

3.3.13.5 Interfacial Tension
The oil/water interfacial tension of SYN was measured using standard laboratory water with 35 ppt of salt. The value measured was 21.6 dynes/cm, which is in the normal range of most crude oils.

3.3.13.6 Flash Point
SYN has a flash point of less than <-12°C when fresh. This increases after 34% evaporation to 139°C.

3.3.13.7 Emulsification Tendency and Stability
SYN has no tendency to form stable water-in oil emulsions at any degree of evaporation tested when mixed with seawater.

3.3.14 Western Canadian Select (WCS)

A summary of WCS spill-related physical properties is listed below in Table 3–15: Spill-Related Properties of WCS.

Table 3–15: Spill-Related Properties of WCS

Spill-related properties	Fresh	2D	14D	6W
WCS API Gravity =	21.6 °			
Evaporation (Volume %)	0	12.6	20.6	24.5
Density (g/cm^3)				
0 °C	0.935	0.968	0.990	1.000
15 °C	0.924	0.958	0.981	0.991
20 °C	0.921	0.955	0.978	0.987
30 °C	0.914	0.948	0.971	0.981
Dynamic Viscosity (mPa.s) at approx 100 s^{-1} except 6W at 0° at 10 s^{-1}				
0 °C	1,574	9,191	79,552	352,567
15 °C	407	2,161	18,479	61,959
20 °C	203	1,320	10,343	33,891
30 °C	164	641	4,219	11,616
Kinematic Viscosity (mm^2/s)				
0 °C	1,683	9,493	80,317	352,472
15 °C	440	2,255	18,842	62,544
20 °C	220	1,382	10,581	34,322
30 °C	180	676	4,344	11,841
Interfacial Tension (dyne/cm)				
Oil/ Air	28.5	32.4	31.4	NM
Oil/ Seawater	13.4	13.7	14.5	NM
Pour Point (°C)	-42	-12	18	18
Flash Point (°C)	<-15	4	36	58
Emulsion Formation-Tendency and Stability @ 0°C		0 °C		
Tendency	Very Likely	Very Likely	Too Viscous	Too Viscous
Stability	Meso-stable	Unstable	Too Viscous	Too Viscous
Water Content	53%	0%	NM	NM
Emulsion Formation-Tendency and Stability @ 20°C		20 °C		
Tendency	Very Likely	Very Likely	Very Likely	Too Viscous
Stability	Meso-stable	Entrained	Entrained	Too Viscous
Water Content	60%	27%	0%	NM
ASTM Modified Distillation	Evaporation (% volume)	Liquid Temperature (°C)		
	IBP	77.1		
	5	159.6		
	10	236		
	15	323		
	20	370		
	25	398		
	30	413		
	40	432		
	50	430		

Weathering Model

$$Fv = \frac{\ln[1 + (C_1/Tk)\theta\exp(C_2 - C_3/Tk)]}{(C_1/Tk)}$$

where: Fv is volume fraction of oil evaporated
θ is evaporative exposure
Tk is environmental temperature (K)

C_1 = 9644
C_2 = 12.50
C_3 = 6305

NM - not measured too viscous

3.3.14.1 Evaporation

Approximately 13% of the WCS oil volume evaporated after two days in the wind tunnel; about 21% evaporated after two weeks; and, around 24 % evaporated after 6 weeks of exposure.

Figure 3-53 is a predicted evaporation curve for a spill involving a 1-mm thick slick in two conditions. Please note that the curves apply at the indicated water temperatures and wind speeds. If other temperatures (or slick thicknesses and wind speeds) are of interest, additional curves can be calculated. Computerized oil spill models automatically do these calculations.

Figure 3-54, Figure 3-55 and Figure 3-56 show the effect of evaporation on the properties of oil viscosity, density and pour point.

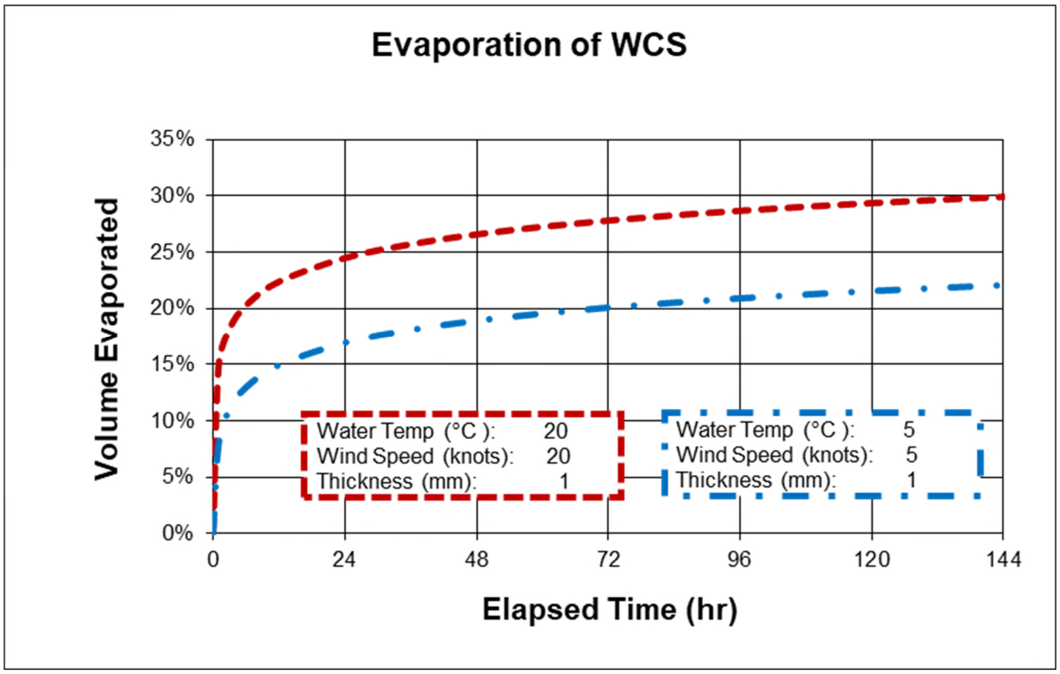


Figure 3-53: Evaporation of WCS

3.3.14.2 Density

WCS oil has a density of 0.924 g/cm³ at 15.5°C (API gravity of 21.6). After 6 weeks in the wind tunnel, the density increases to 1.000 g/cm³ when measured at 0°C.

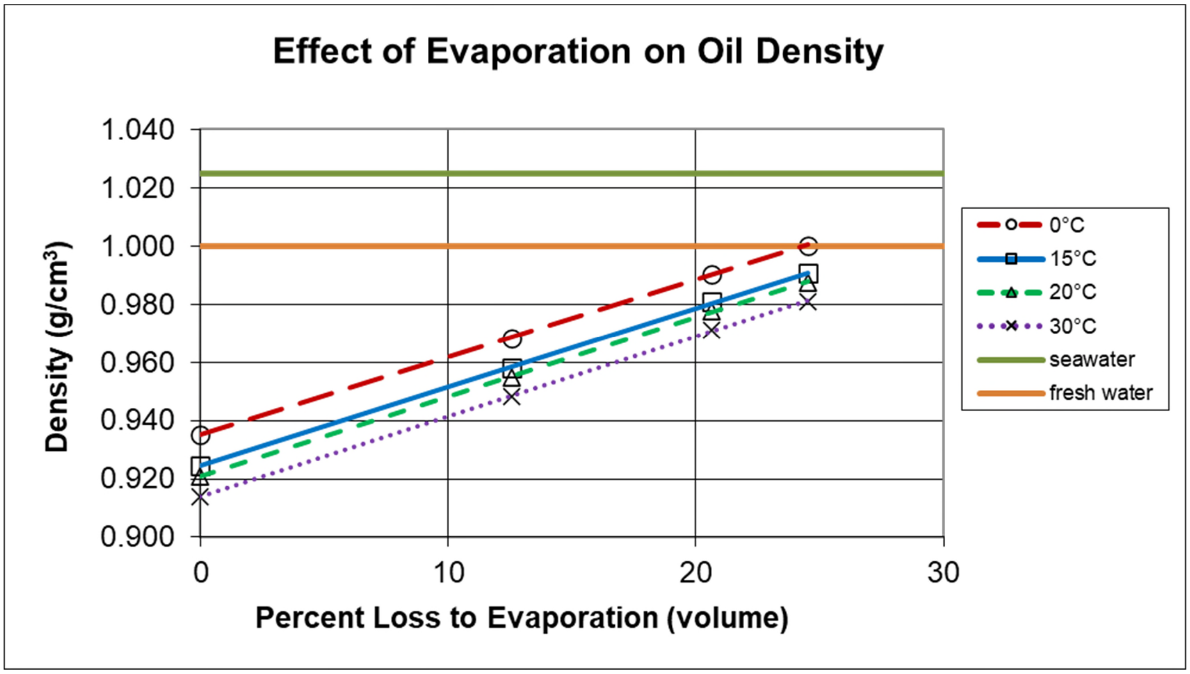


Figure 3-54: Effect of Evaporation on WCS Oil Density

3.3.14.3 Viscosity

The oil has moderately high viscosity that is typical of medium heavy crudes. At 20°C the viscosity of the fresh oil is about 200 cP (mPa.s). The viscosity increases to 1.320 cP after 13% evaporation; to 10,300 cP after 21% evaporation; and, increases to 33,900 cP after 24% evaporation.

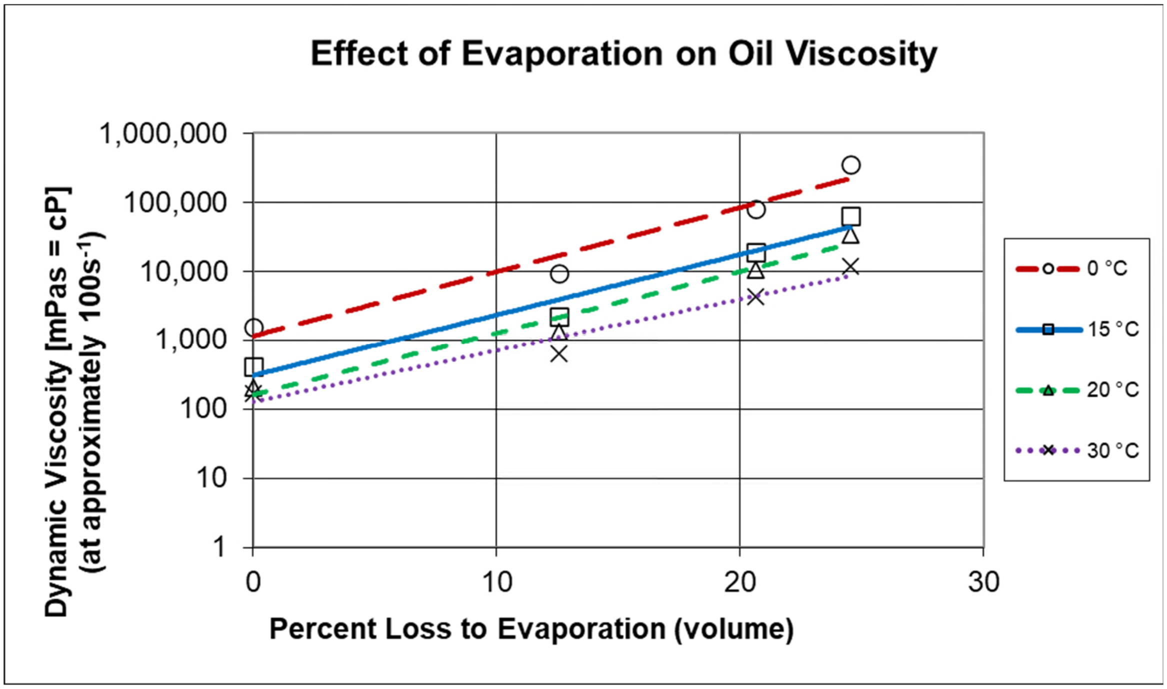


Figure 3-55: Effect of Evaporation on WCS Oil Viscosity

3.3.14.4 Pour Point

WCS has a pour point below -42°C when fresh which rises to 18°C after 24% evaporation.

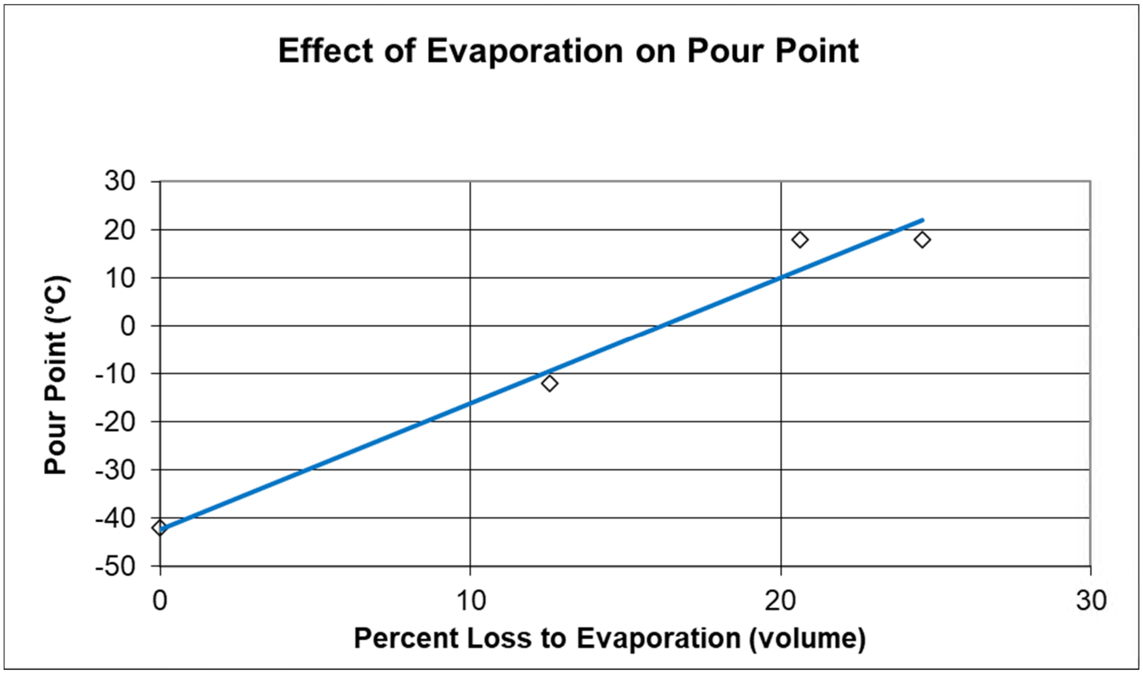


Figure 3-56: Effect of Evaporation on WCS Pour Point

3.3.14.5 Interfacial Tension

The oil/water interfacial tension of WCS was measured using standard laboratory water with 35 ppt of salt. The value measured was 13.4 dynes/cm, which is in the low range of most crude oils.

3.3.14.6 Flash Point

WCS has a flash point of less than <-15°C when fresh. This increases after 24% evaporation to 58°C.

3.3.14.7 Emulsification Tendency and Stability

One characteristic of WCS is that is very likely to form meso-stable water-in-oil emulsions when mixed with seawater.

3.4 DISCUSSION

The 14 oils were successfully subjected to the Standard Oil Analysis using fresh, Short Term Weathering, Mid-Term Weathering, plus Long Term Weathering samples. Input parameters for oil spill models were generated over the course of this task which allows for the modeling of the weathering of these oils under a variety of conditions, providing planners and spill responders with key physical parameters of interest. These parameters, in particular density and viscosity, play a major role in how an oil spill will behave and can have implications on the performance of oil spill response techniques and equipment. As an example, once an oil reaches a density range where overwash or temporary submergence is possible or likely, then specialized containment techniques and equipment may need to be employed. In addition, equipment such as certain types of skimmers will perform better within a specific viscosity range. Knowing the likelihood of an oil transitioning into specific viscosity ranges can help with the selection of appropriate equipment designed to operate best in those ranges.

3.5 REFERENCES

Fingas, M., B. Fieldhouse and J. Mullin. 1998. Studies of Water-in-Oil Emulsions: Stability and Oil Properties. *Proceedings of the 21st Arctic and Marine Oilspill Technical Seminar.* Environment Canada, Ottawa. pp 1-26

Hokstad, J. and P. Daling. 1993. Methodology for Testing Water-in-Oil Emulsions and Demulsifiers. Description of Laboratory Procedures. In *Formation and Breaking of Water-in-Oil Emulsions: Workshop Proceedings* Marine Spill Response Corporation, Washington DC, MSRC Technical Report Series 93-108, pp 239-254

Zagorski, W. and D. Mackay. 1982. Water in oil emulsions: a stability hypothesis, in Proceedings of the 5th Arctic and Marine Oilspill Program Technical Seminar, Environment Canada, Ottawa, ON, pp 61-74.

4 Artificial Weathering Methods Comparison

4.1 Introduction

Weathering oil samples in a laboratory setting is performed to generate samples of an oil so that the resultant properties can be analysed and a better understanding of the behaviour of an oil during an actual spill can be developed. When evaporation techniques are employed to generate "weathered" samples, it is not necessary to match the end conditions of an artificially weathered state to a "real life" weathered state for valuable information to be generated. Fate and behaviour models for oil spills will rely on inputs of physical weathered oil properties at a measured mass or volume loss state. For example, if an oil is subjected to evaporative weathering and losses 20% of its mass, physical parameters can be measured on the weathered sample and that data – along with the fact that those parameters were taken from a sample subjected to a 20% mass loss – can be used to generate inputs for models. Mass loss can easily be converted to volumetric loss as density is one of the parameters that would typically be measured and used to convert the remaining oil between a mass loss and volumetric loss weathered state. The actual weathered loss is completely secondary as the physical properties being measured are tied to that state. Typically, properties from fresh oil samples plus multiple artificially weathered states are used to generate equations (or variables and constants) for physical properties within models. Once the oil properties information is encoded within an oil spill model, along with environmental conditions that simulate weather and sea state, the model can project expected oil fate and behaviour over time. In summary, the weathered states generated from evaporation techniques are not necessarily attempting to mimic the behaviour of an oil at a specific targeted endpoint, rather the information is used as inputs into models that can more accurately predict expected fate and behaviour under specific environmental conditions.

4.2 Background

There are several laboratory methods that can be used to artificially weather an oil sample, typically through an evaporation process. For example, distillation (topping) is popular with SINTEF (Norway) and CEDRE (France), while Environment and Climate Change Canada (ECCC) uses a rotary evaporator, and SL Ross uses a calibrated wind tunnel. This is done as a surrogate to evaporative processes that happen during actual spills, so that the changes in properties, fate and behaviour of a specific oil can be studied and better understood. It also allows for the generation of oil samples that can be used in additional experiments to determine the best method to contain, collect, and remediate oil from a spill.

Some concern had been expressed about compatibility of the different methods used to artificially weather (evaporation processes) an oil sample. Does evaporation at an elevated temperature result in a sample with different physical properties than a sample subjected to evaporative weathering at room temperature? Obviously, the rate at which evaporation occurs at different temperatures will change, as will the rate of evaporation between two oil samples of differing layer thicknesses. Because of the rate difference, the time to reach a certain mass loss fraction will also differ between methodologies. But if a specific mass loss was identified as a targeted endpoint for different methodologies, would the physical properties of the weathered samples be similar? This is important because, as stated earlier, the properties of a weathered sample are linked to the weathered state of a sample. To answer this question, three techniques were selected for further study and comparison:

1. The SL Ross technique uses a tray with a "thick" (2 cm) layer of oil placed in a calibrated wind tunnel for a defined period of time. Typically two time periods are used, with an option to include a third long-term time period. Each tray is frequently weighed to document the evaporation rate. Samples of toluene are weathered simultaneously to determine the air-side mass transfer coefficient which is used in models and provide a linkage to the rate of evaporative losses over time of an actual oil slick on water. The thick layer is needed to provide an adequate volume of a weathered oil sample for subsequent physical and chemical analysis. The weathering typically produces a sample after two days in the wind tunnel (Weathered State 1), another sample after two weeks (Weathered State 2), and for this series of tests a third sample was generated after six weeks (Weathered State 3).

2. ECCC uses a rotary evaporator procedure, which is described as follows (Fieldhouse et al., 2016):

   - 4-L of oil are weathered in a Buchi Rotavapor® R220 at 80°C and a rotation speed of 135 rpm. Vapours are removed from the flask with a Millipore vacuum pump operating at 13 L/min.
   - Extent of evaporation is measured by periodically weighing the flask and contents.
   - The weathering proceeds for 48 hours for the first sample. Intermediate samples are then produced by repeating the procedure, but stopping after 1/3 and 2/3 of the mass loss of the 48-hour sample to obtain samples at different weathered states.
   - During interruptions (e.g., overnight), the flask of oil is sealed and stored in a cold room at 5°C.

3. A third technique used is a variation of the SL Ross technique using a "thin" (1.5 mm) layer of oil as a starting point. This technique was selected to determine if the layer thickness would influence the resultant properties of the sample.

To make a proper comparison, a targeted endpoint (mass loss) was selected. Each of the three techniques were used to generate weathered samples at that selected mass loss. For these tests, the mass loss obtained for each oil after the SL Ross 6 week wind tunnel evaporative weathering was selected as an end point (Fm loss). Once the samples were generated using the three techniques, physical properties of the weathered samples such as density and viscosity at 4 temperatures were determined, compared, and evaluated.

Figure 4-1: Buchi Rotavapor® R-220 Pro

4.3 Results

4.3.1 AHS Weathering Comparison Results

Table 4–1: AHS Weathered Oil Properties

	Fm lost	**Density (g/mL)**				**Viscosity (cP)**			
		0C	**15C**	**20C**	**30C**	**0C**	**15C**	**20C**	**30C**
1.5mm Tunnel	**0.176**	1.0256	1.0153	1.0117	1.0054	too high	112675	51849	24595
20mm Tunnel	**0.178**	1.0219	1.0114	1.0080	1.0016	1660148	90889	50844	26814
Rotary evap.	**0.178**	1.0239	1.0138	1.0106	1.0043	too high	160990	81369	27854
						LEGEND - Shear Rate 100s^{-1}, except:			
						@6 s^{-1}	*@50 s^{-1}*		

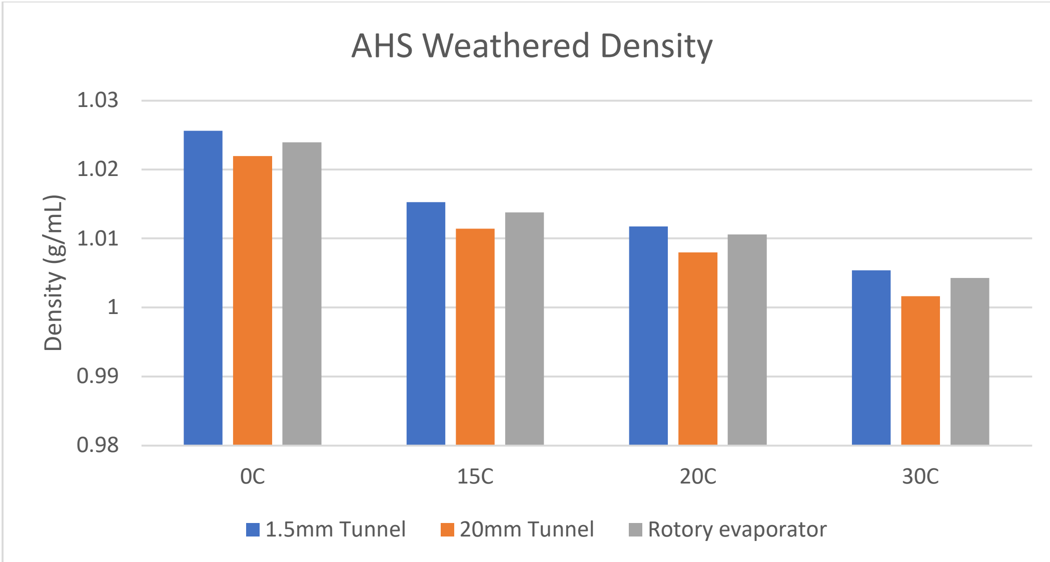


Figure 4-2: AHS Weathered Density

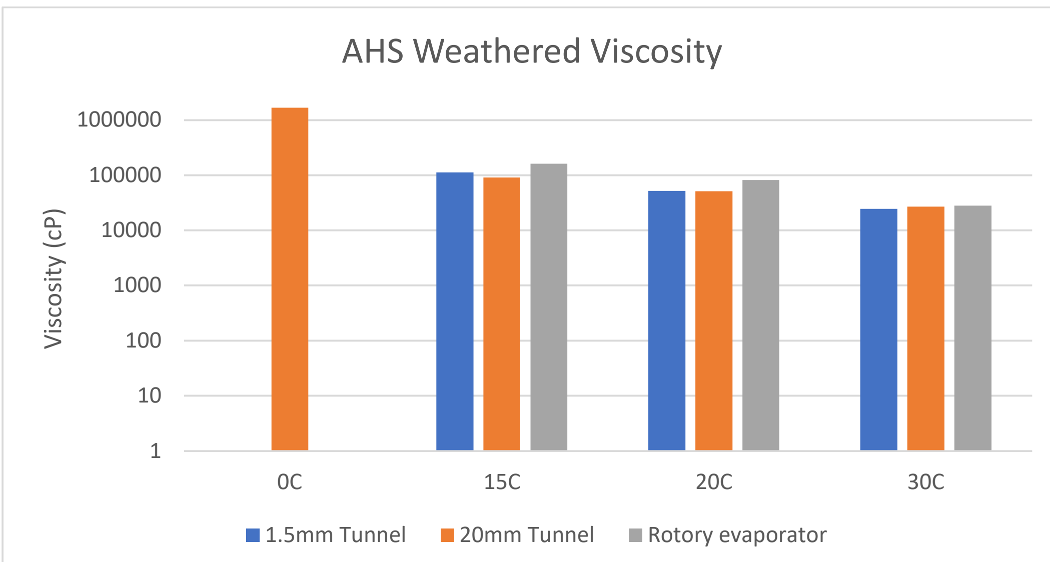


Figure 4-3: AHS Weathered Viscosity

4.3.1.1 Observations

Evaporation took place at ambient temperature in the lab, approximately 20°C. The oil samples were measured for density at this temperature and the results for the 20mm slick are slightly less dense than the results of the other two methods, but are reasonably close. When viscosity is measured, the results match well at 30°C and at 20°C but are starting to diverge a bit with the viscosity for the rotary evaporator sample becoming more viscous than the other two samples as the measurement temperature drops. Overall there is a *slight* increase in the viscosity measured for the rotary evaporator sample.

4.3.2 ANS Weathering Comparison Results

Table 4–2: ANS Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.360**	0.9539	0.9422	0.9385	0.9317	5405	903	546	253
20mm Tunnel	**0.362**	0.9526	0.9409	0.9372	0.9306	4080	889	558	248
Rotary evap.	**0.362**	0.9548	0.9431	0.9397	0.9328	6937	1016	704	306
						LEGEND - Shear Rate 100s⁻¹, except:			

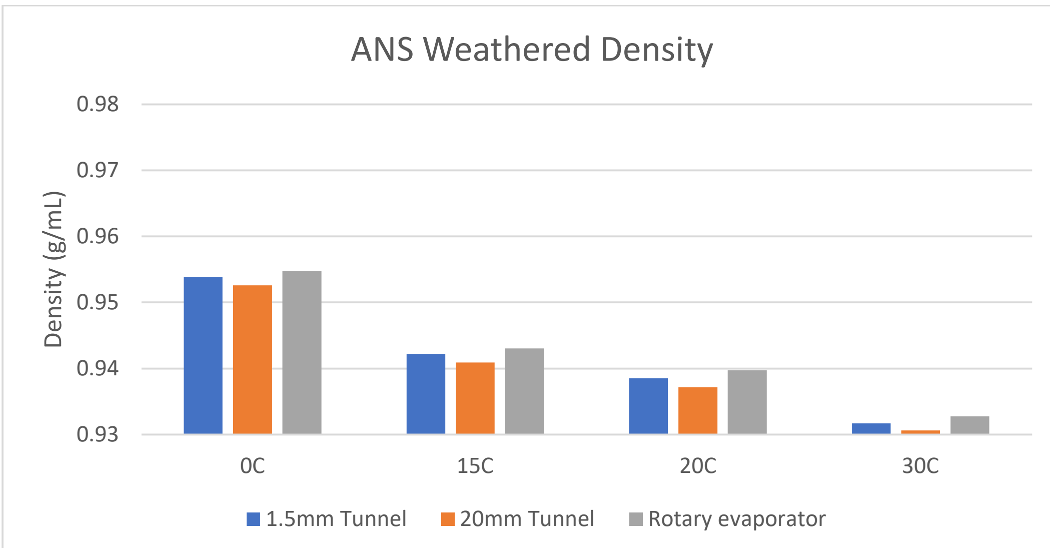


Figure 4-4: ANS Weathered Density

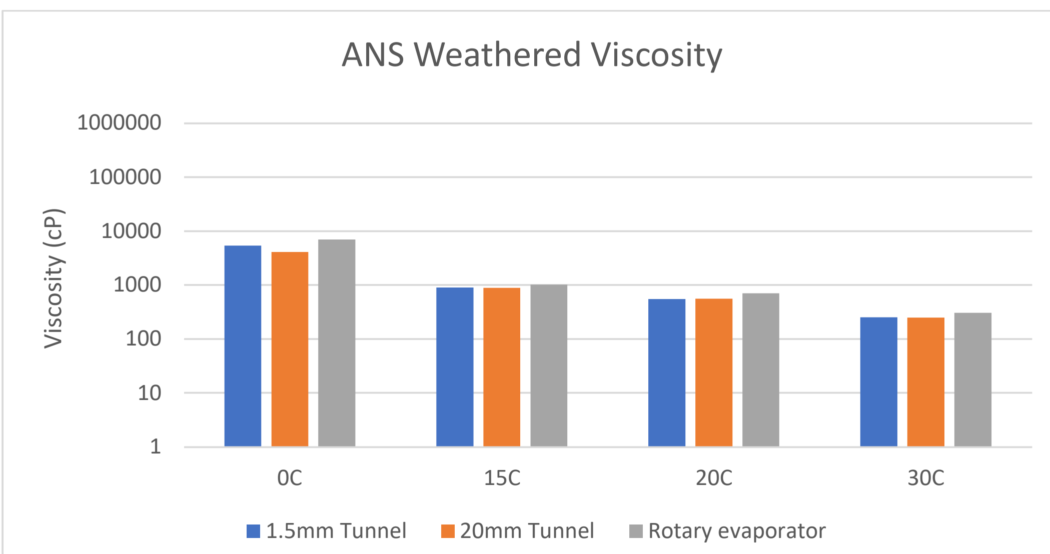


Figure 4-5: ANS Weathered Viscosity

4.3.2.1 *Observations*

Density measurements for the three techniques at the four temperatures matched nicely. Similar results were also obtained with the viscosity measurements for the three techniques across the four temperatures. Actual differences between the measured samples are minor.

4.3.3 AWB Weathering Comparison Results

Table 4–3: AWB Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.205**	1.0101	1.0005	0.9973	0.9911	too high	76062	57760	38545
20mm Tunnel	**0.205**	1.0087	0.9991	0.9959	0.9895	544315	77579	51607	28227
Rotary evap.	**0.205**	1.0109	1.0014	0.9982	0.9918	too high	74894	80664	39975
						LEGEND - Shear Rate 100s^{-1}, except:			
						@10 s^{-1}			

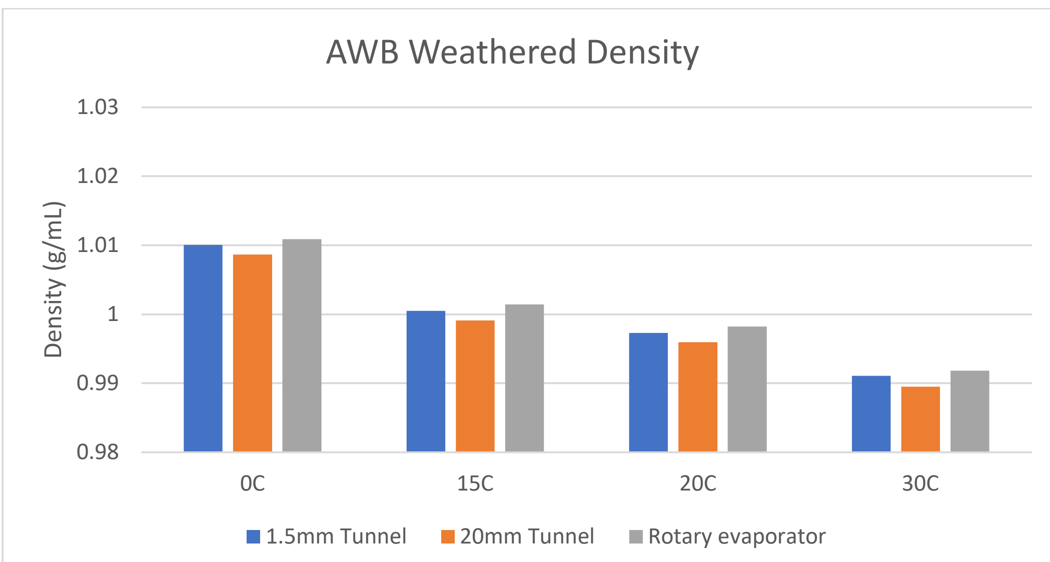


Figure 4-6: AWB Weathered Density

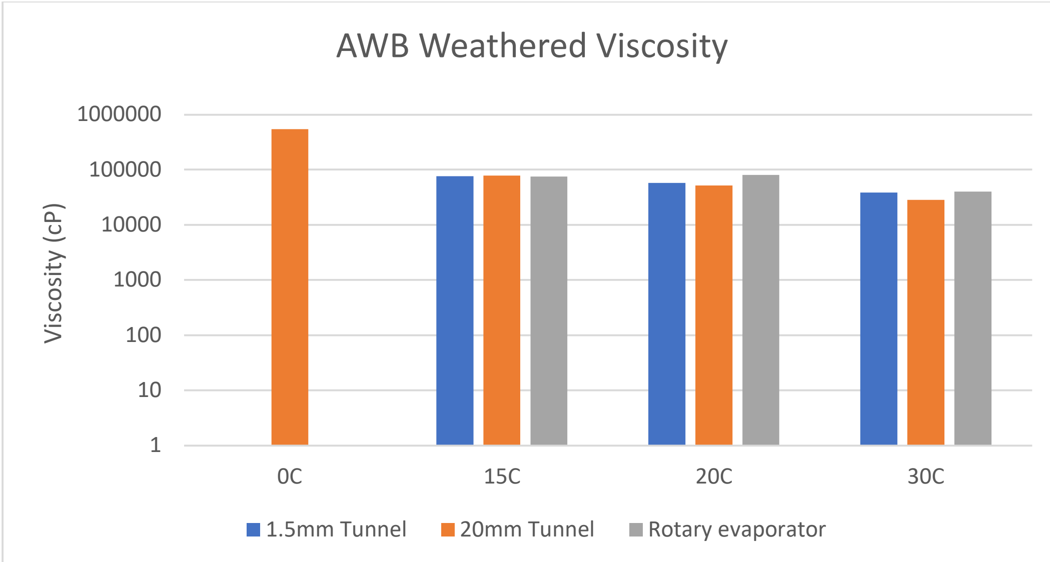


Figure 4-7: AWB Weathered Viscosity

4.3.3.1 Observations

The densities of the three AWB samples align nicely, with minor differences appearing in the third decimal place. Viscosities are close, with the rotary evaporator values being slightly higher than the other two for the 20°C measurement but matching the results at other temperatures.

4.3.4 CHV Weathering Comparison Results

Table 4–4: CHV Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.194**	1.0041	0.9943	0.9911	0.9847	too high	79590	51894	16706
20mm Tunnel	**0.192**	1.0003	0.9905	0.9873	0.9809	498579	49271	26690	8818
Rotary evap.	**0.193**	1.0030	0.9934	0.9902	0.9837	417064	45742	37518	12224
						LEGEND - Shear Rate 100s^{-1}, except:			
						@10 s^{-1}			

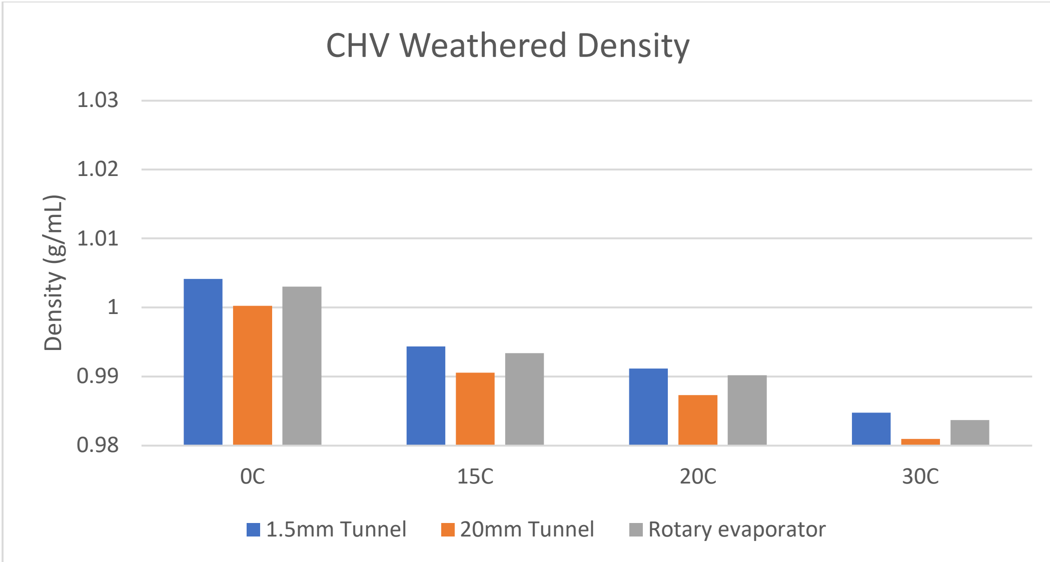


Figure 4-8: CHV Weathered Density

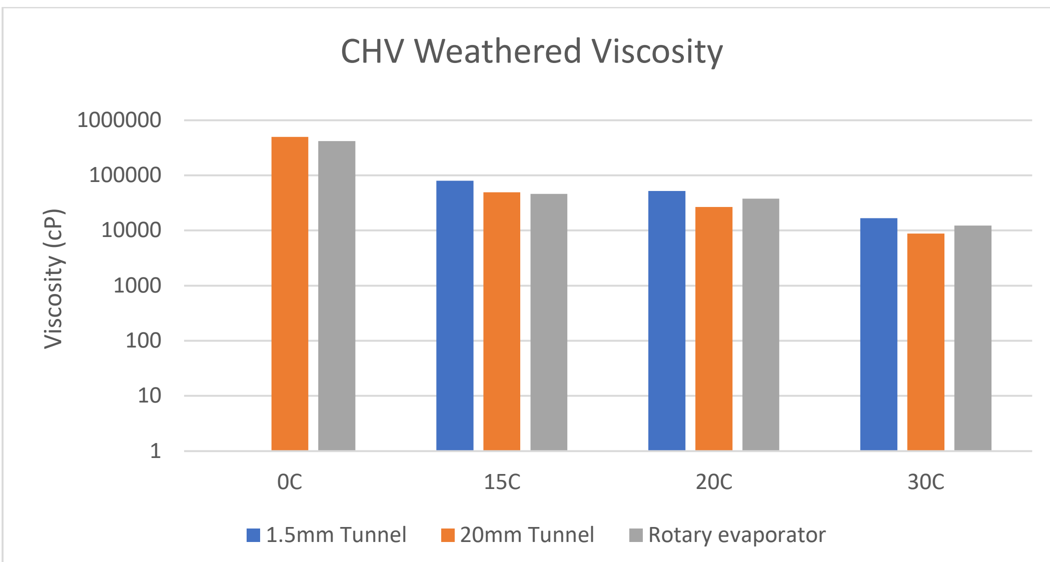


Figure 4-9: CHV Weathered Viscosity

4.3.4.1 Observations

Density measurements for the CHV evaporated samples were slightly lower (lighter) for the 20mm thick test, approximately 4 points at the third decimal, but are generally in agreement. The viscosities for the 1.5 mm thin layer were higher than the thick film and the rotary evaporator tests.

4.3.5 CLB Weathering Comparison Results

Table 4–5: CLB Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.198**	1.0087	0.9990	0.9958	0.9894	too high	68478	76731	36597
20mm Tunnel	**0.200**	1.0042	0.9946	0.9914	0.9850	630060	72503	54750	21490
Rotary evap.	**0.200**	1.0055	0.9960	0.9927	0.9860	too high	75462	61048	23421
						LEGEND - Shear Rate 100s^{-1}, except:			

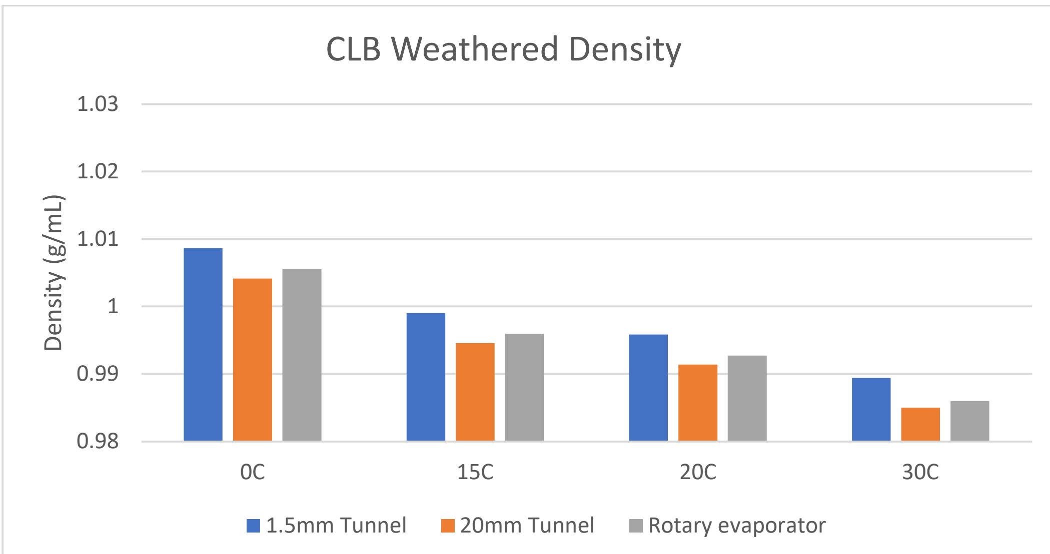


Figure 4-10: CLB Weathered Density

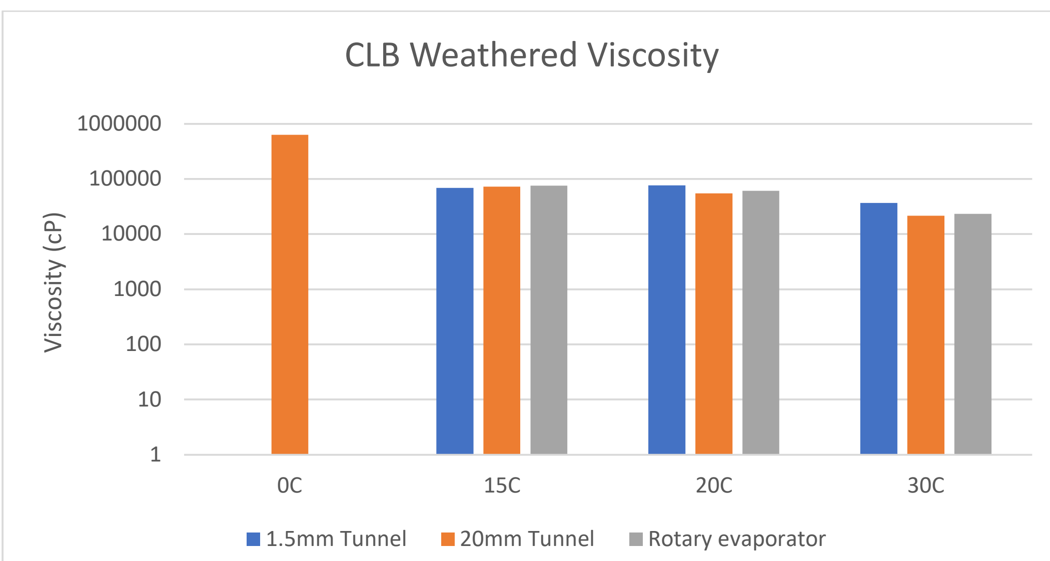


Figure 4-11: CLB Weathered Viscosity

4.3.5.1 Observations

The density measurements for the CLB oil runs were close, with the 1.5 mm thick run being slightly denser than the other two. Viscosities for all three runs are reasonably close. Viscosity measurements for two of the 0°C samples were too high for the rheometer to measure.

4.3.6 CRW Weathering Comparison Results

Table 4–6: CRW Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.771**	0.8729	0.8589	0.8547	0.8466	1201	138	71	28
20mm Tunnel	**0.771**	0.8743	0.8601	0.8555	0.8476	1391	183	76	20
Rotary evap.	**0.771**	0.8749	0.8607	0.8563	0.8483	1028	82	51	27
						LEGEND - Shear Rate 100s^{-1}, except:			
									@250 s^{-1}

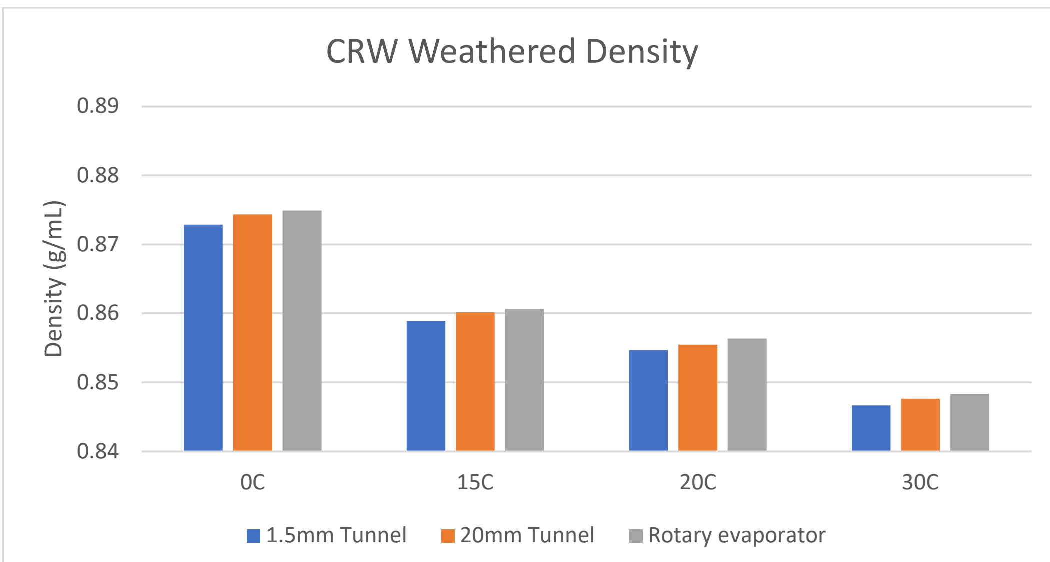


Figure 4-12: CRW Weathered Density

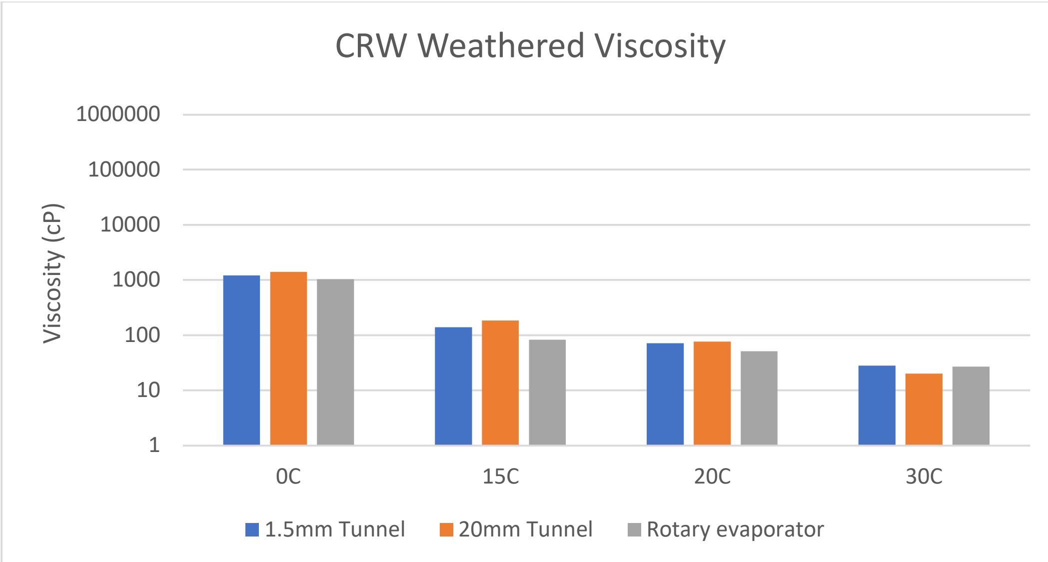


Figure 4-13: CRW Weathered Viscosity

4.3.6.1 Observations

The measured densities for the oil samples derived from the three methods are close. In this instance, the density of the CRW is lowest with the 1.5mm thin test, followed by the 20mm thick test and slightly higher with the rotary evaporator test. The viscosities are close too, with the most viscous being the 20mm thick test. The viscosity readings at 30°C were at the low end of the instrument range, and thus the shear rate was increased to 200s^{-1} for the 20mm reading. The resultant value is reasonable.

4.3.7 HFO Weathering Comparison Results

Table 4–7: HFO Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.037**	1.0079	0.9963	0.9922	0.9848	468011	25828	11690	3486
20mm Tunnel	**0.036**	1.0067	0.9951	0.9915	0.9841	738156	36314	17693	4860
Rotary evap.	**0.036**	1.0093	0.9976	0.9940	0.9866	too high	57347	25093	7240
						LEGEND - Shear Rate 100s^{-1}, except:			
						@10s^{-1}			

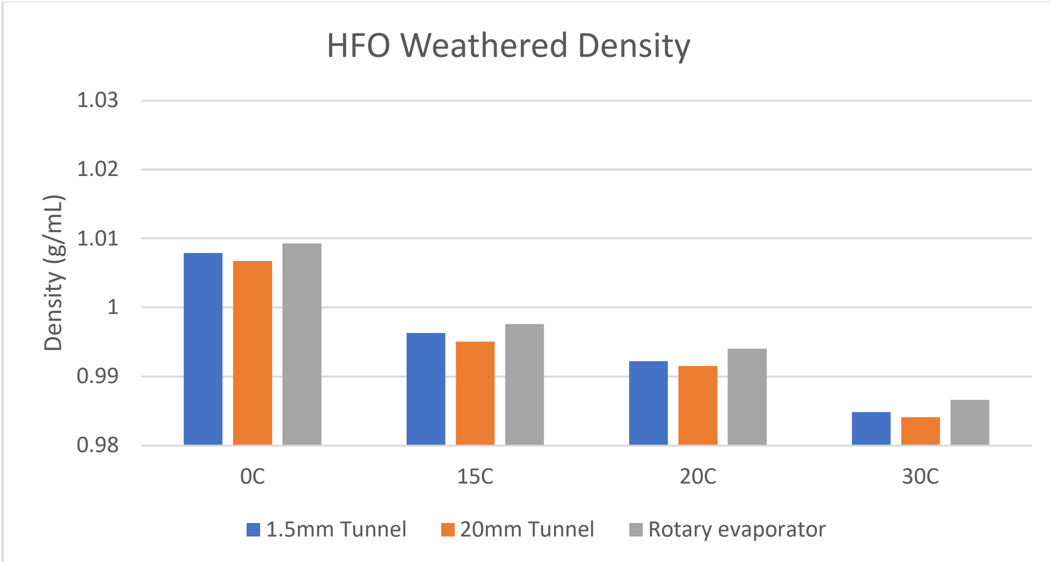


Figure 4-14: HFO Weathered Density

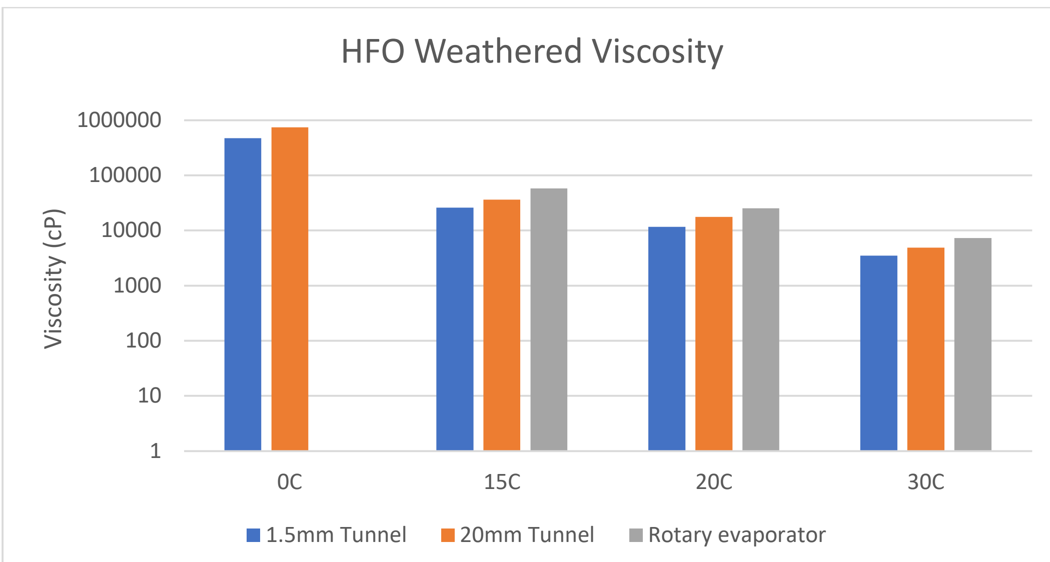


Figure 4-15: HFO Weathered Viscosity

4.3.7.1 Observations

The densities for the HFO runs are reasonably close, with the 20mm thick test being the lightest followed by the 1.5mm thin test, and finally the rotary evaporator test. Things change for the viscosity results with the 1.5mm thin test result being the least viscous, followed by the 20mm thick test and finally the rotary evaporator test result.

4.3.8 LSB Weathering Comparison Results

Table 4–8: LSB Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.433**	0.9459	0.9335	0.9298	0.9221	3182	440	300	130
20mm Tunnel	**0.432**	0.9456	0.9334	0.9292	0.9220	3545	529	285	110
Rotary evap.	**0.432**	0.9464	0.9341	0.9304	0.9228	2756	390	249	126
						LEGEND - Shear Rate 100s^{-1}, except:			

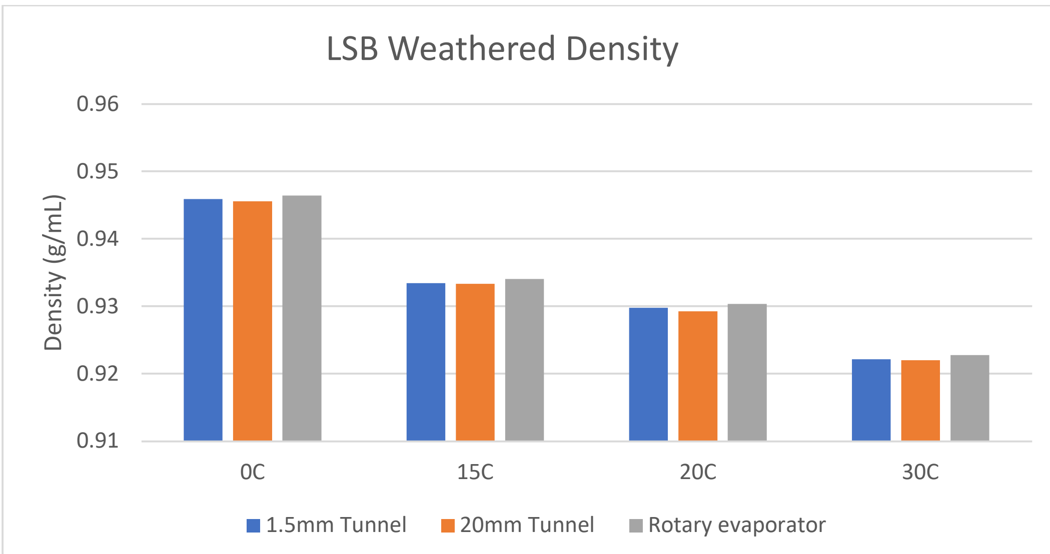


Figure 4-16: LSB Weathered Density

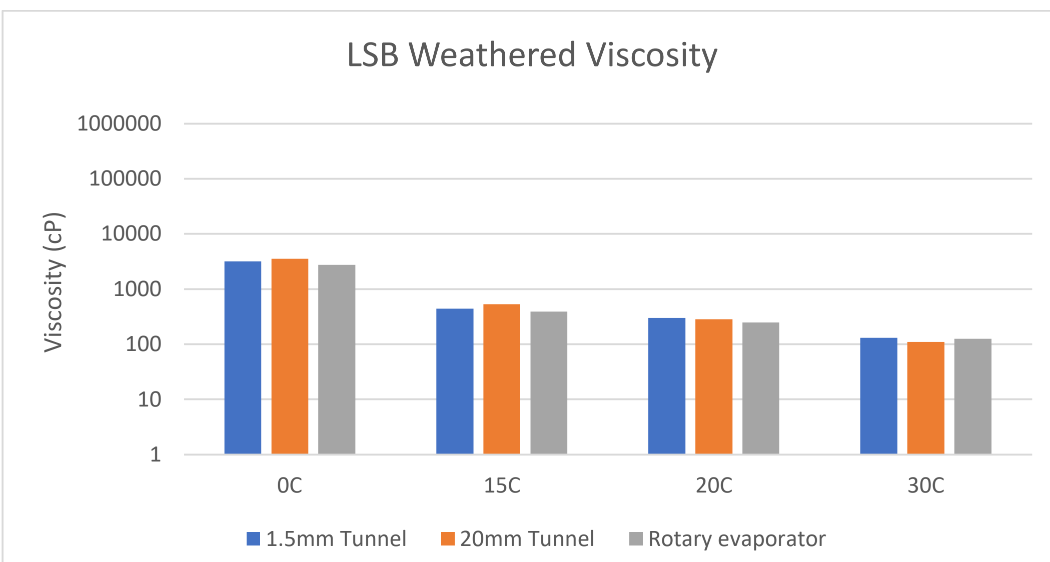


Figure 4-17: LSB Weathered Viscosity

4.3.8.1 Observations

The density results for the LSB tests match nicely across the three weathering methodologies, as do the viscosity results.

4.3.9 MSB Weathering Comparison Results

Table 4–9: MSB Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.385**	0.9447	0.9326	0.9290	0.9217	3952	630	389	182
20mm Tunnel	**0.386**	0.9422	0.9303	0.9264	0.9196	3022	475	274	123
Rotary evap.	**0.386**	0.9446	0.9325	0.9288	0.9216	4561	616	423	190
						LEGEND - Shear Rate 100s^{-1}, except:			

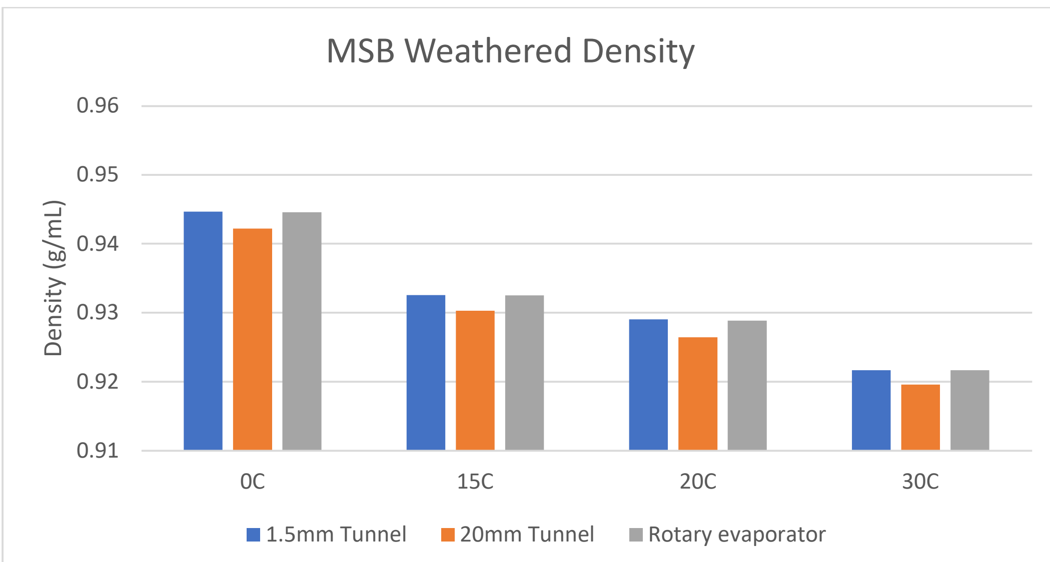


Figure 4-18: MSB Weathered Density

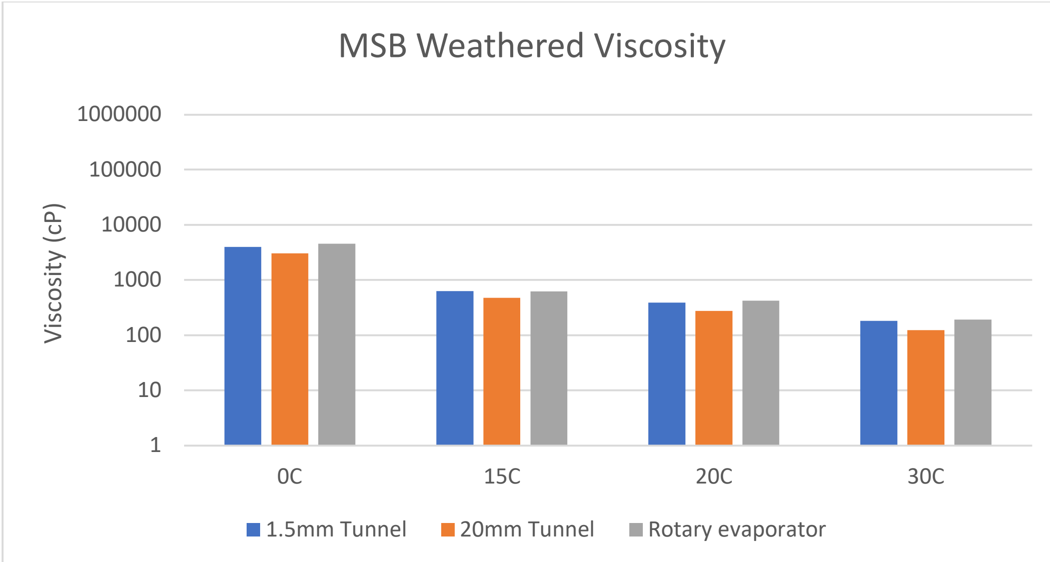


Figure 4-19: MSB Weathered Viscosity

4.3.9.1 Observations

The density results are reasonably close, with the 20mm layer results being the lightest, followed by the rotary evaporator results, and finally the 1.5mm layer results. The viscosity results are also close, with the 20mm layer again being slightly less viscous than the result of the other two methodologies.

4.3.10 MSW Weathering Comparison Results

Table 4–10: MSW Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.439**	0.9139	0.9010	0.8968	0.8890	2145	385	198	50
20mm Tunnel	**0.440**	0.9156	0.9023	0.8982	0.8903	3674	464	208	61
Rotary evap.	**0.440**	0.9166	0.9032	0.8990	0.8911	2528	298	174	77
						LEGEND - Shear Rate 100s^{-1}, except:			
						@25 s^{-1}			

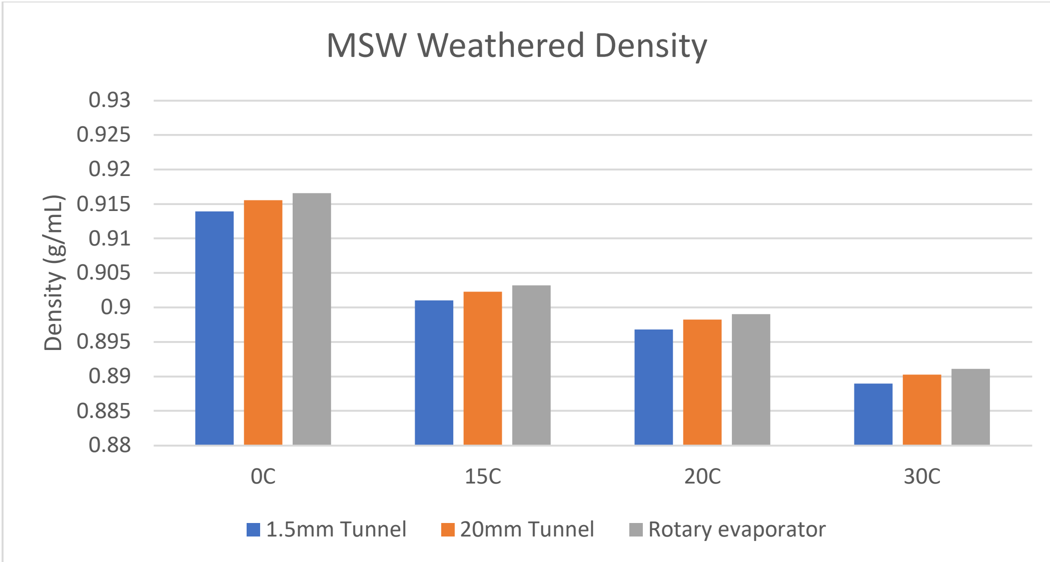


Figure 4-20: MSW Weathered Density

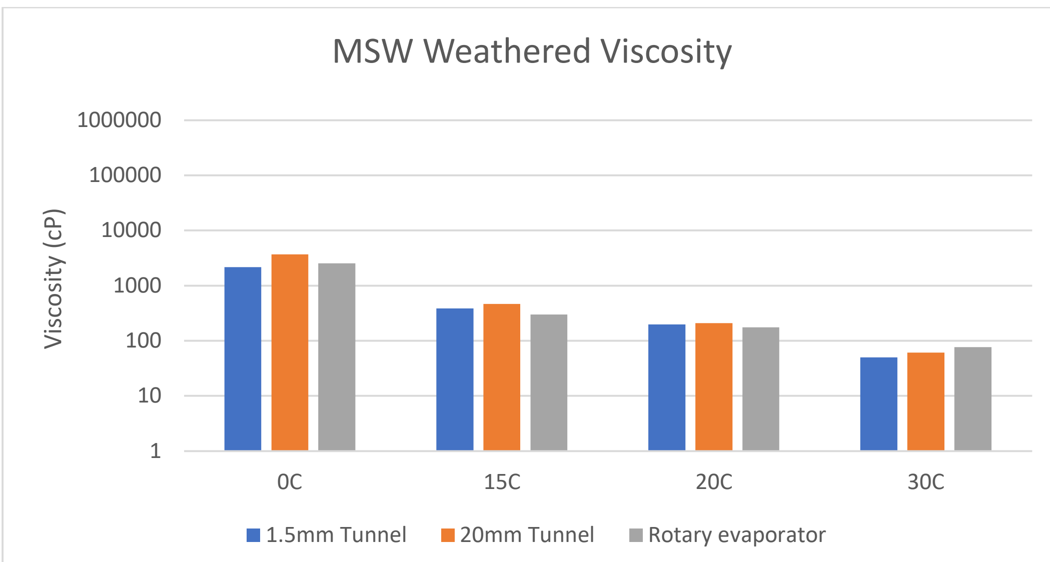


Figure 4-21: MSW Weathered Viscosity

4.3.10.1 Observations

The density results for the MSW evaporated samples are also close. For this series of tests the lightest results came from the 1.5mm layer test, followed by the 20mm layer test, and finally the rotary evaporator test. The viscosity results were comparable between the three methodologies. For this oil, the results of the 20mm layer test were the most viscous for all temperatures with the exception of the 30°C reading.

4.3.11 NDB Weathering Comparison Results

Table 4–11: NDB Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.513**	0.9026	0.8919	0.8884	0.8818	345	89	66	36
20mm Tunnel	**0.513**	0.9022	0.8913	0.8879	0.8814	414	86	63	37
Rotary evap.	**0.513**	0.9030	0.8921	0.8888	0.8820	412	89	65	39
						LEGEND - Shear Rate 100s^{-1}, except:			
									@250 s^{-1}

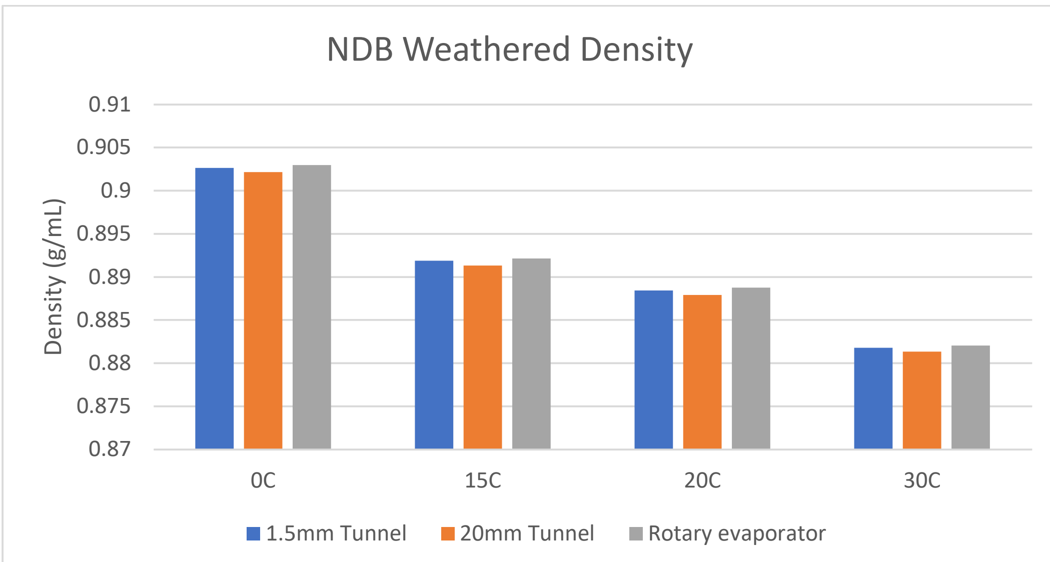


Figure 4-22: NDB Weathered Density

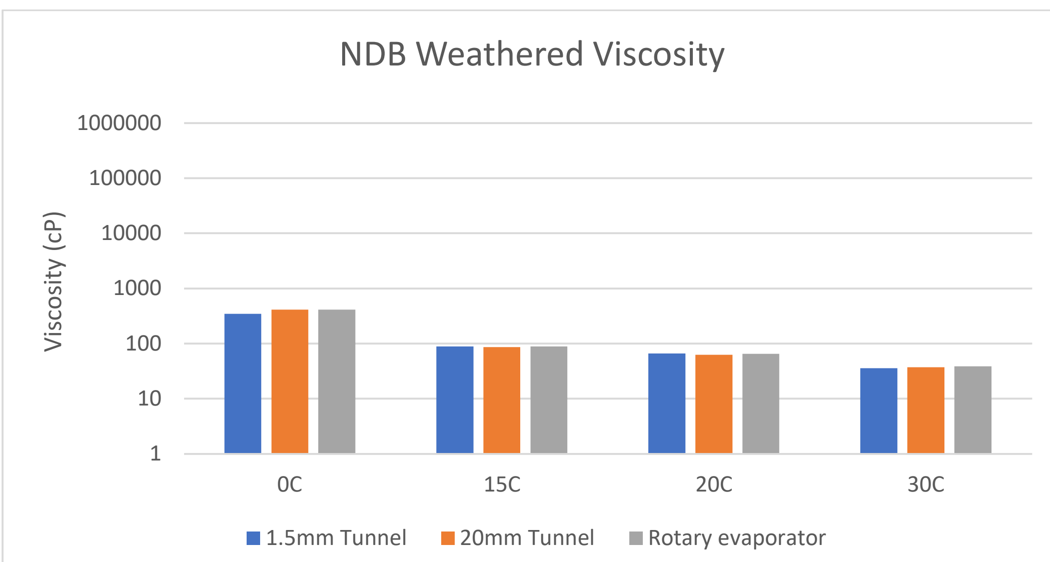


Figure 4-23: NDB Weathered Viscosity

4.3.11.1 Observations

The density results for the NDB tests match nicely between the 1.5mm layer, the 20mm layer, and the rotary evaporator methodology, as do the viscosity results.

4.3.12 SYB Weathering Comparison Results

Table 4–12: SYB Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.165**	0.9845	0.9748	0.9716	0.9651	39524	6758	4171	1759
20mm Tunnel	**0.166**	0.9838	0.9742	0.9709	0.9644	53352	8053	4774	1848
Rotary evap.	**0.166**	0.9859	0.9762	0.9730	0.9665	75859	11493	6620	2418
						LEGEND - Shear Rate 100s^{-1}, except:			
						@25 s^{-1}			

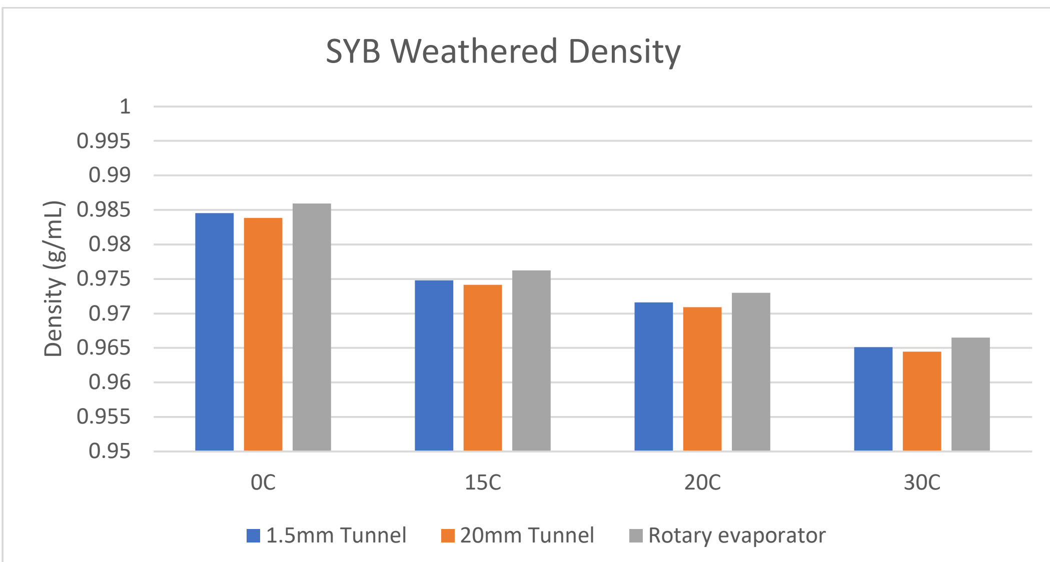


Figure 4-24: SYB Weathered Density

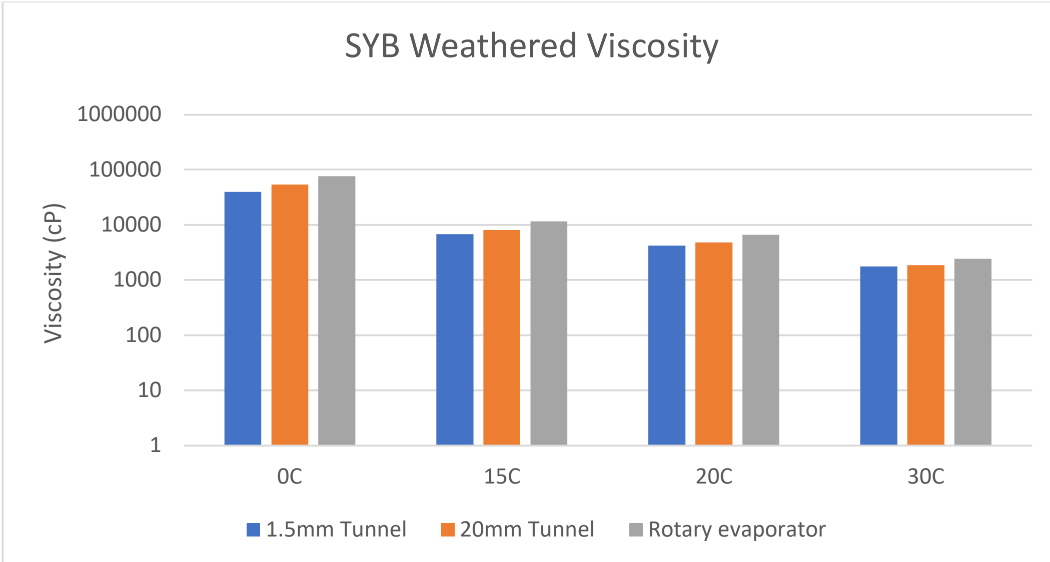


Figure 4-25: SYB Weathered Viscosity

4.3.12.1 Observations

The density results for the SYB tests are close, with differences of only 1 point at the third decimal place. The 20mm layer results are slightly lighter than the 1.5mm layer result, while the rotary evaporator results are slightly heavier than the 1.5mm layer results. The viscosities are also close, with the 1.5 mm layer being slightly less viscous than the 20mm layer results, while the rotary evaporator results are slightly more viscous.

4.3.13 SYN Weathering Comparison Results

Table 4–13: SYN Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.305**	0.9175	0.9071	0.9037	0.8971	172	47	33	19
20mm Tunnel	**0.303**	0.9152	0.9049	0.9016	0.8949	142	38	26	15
Rotary evap.	**0.303**	0.9155	0.9051	0.9017	0.8951	158	52	38	23
						LEGEND - Shear Rate 100s^{-1}, except:			
									@200 s^{-1}

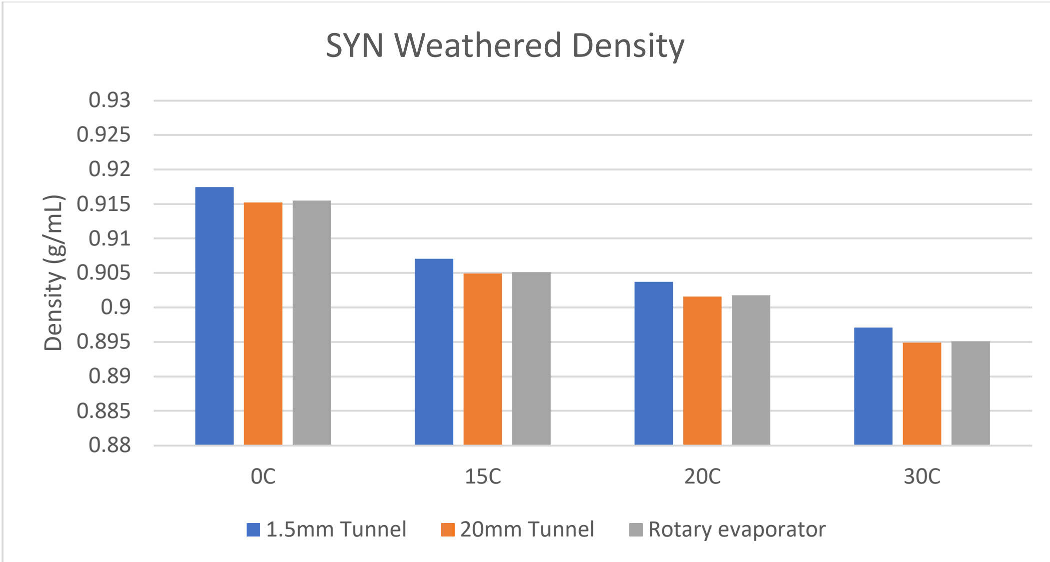


Figure 4-26: SYN Weathered Density

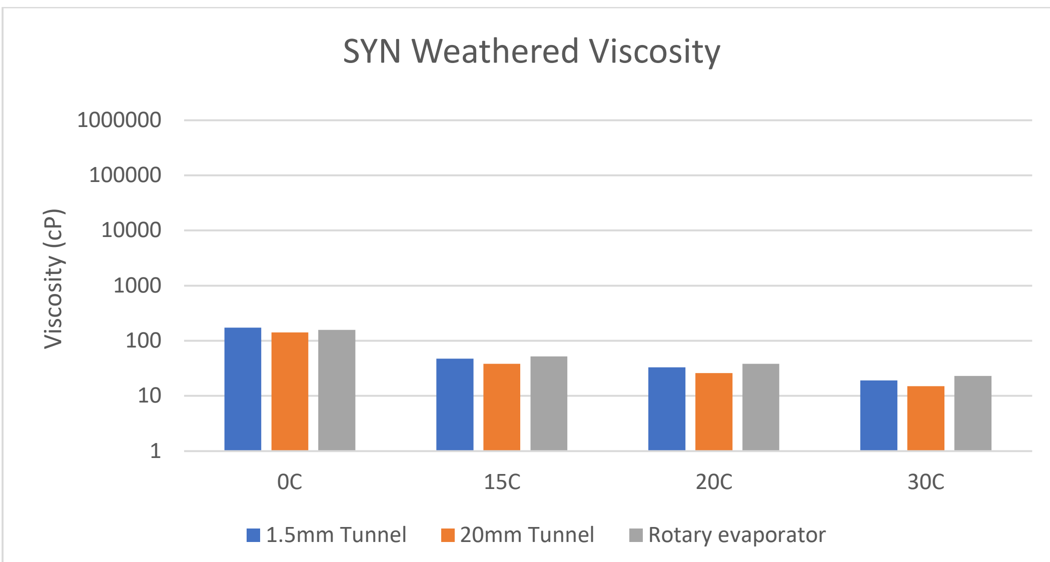


Figure 4-27: SYN Weathered Viscosity

4.3.13.1 Observations

The densities of the SYN runs match for the 20mm layer and the rotary evaporator results, with the 1.5mm layer results being slightly denser. Overall the densities are all close for the different methodologies. The viscosities for the three methodologies are reasonably close too for all the four temperature measurements.

4.3.14 WCS Weathering Comparison Results

Table 4–14: WCS Weathered Oil Properties

	Fm lost	Density (g/mL)				Viscosity (cP)			
		0C	15C	20C	30C	0C	15C	20C	30C
1.5mm Tunnel	**0.188**	1.0012	0.9916	0.9884	0.9818	440704	54272	29524	10026
20mm Tunnel	**0.190**	1.0003	0.9906	0.9874	0.9810	352567	61959	33891	11616
Rotary evap.	**0.190**	1.0026	0.9929	0.9897	0.9836	too high	67978	48606	16330
						LEGEND - Shear Rate 100s⁻¹, except:			
						@10 s⁻¹			

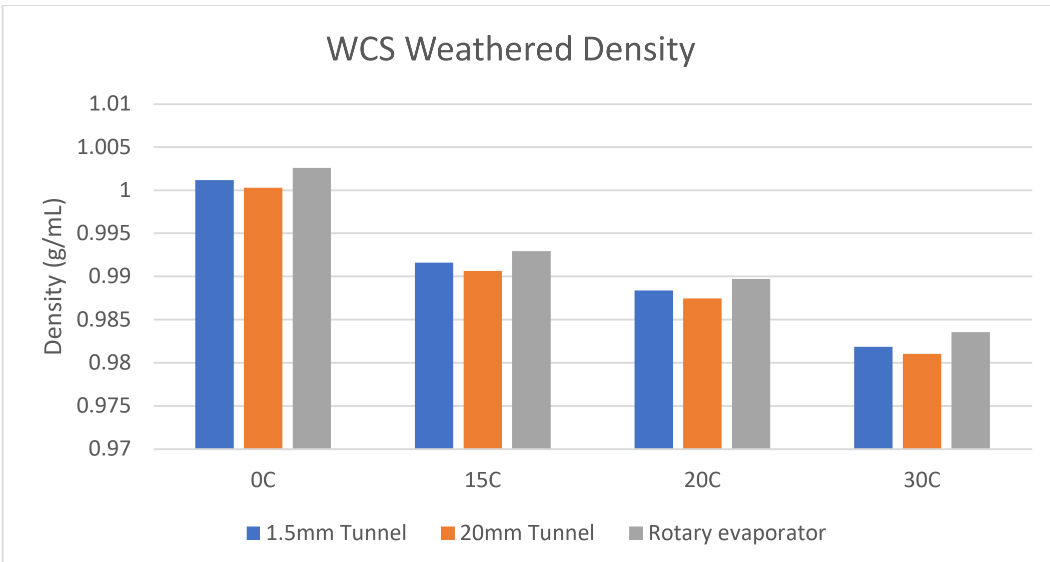


Figure 4-28: WCS Weathered Density

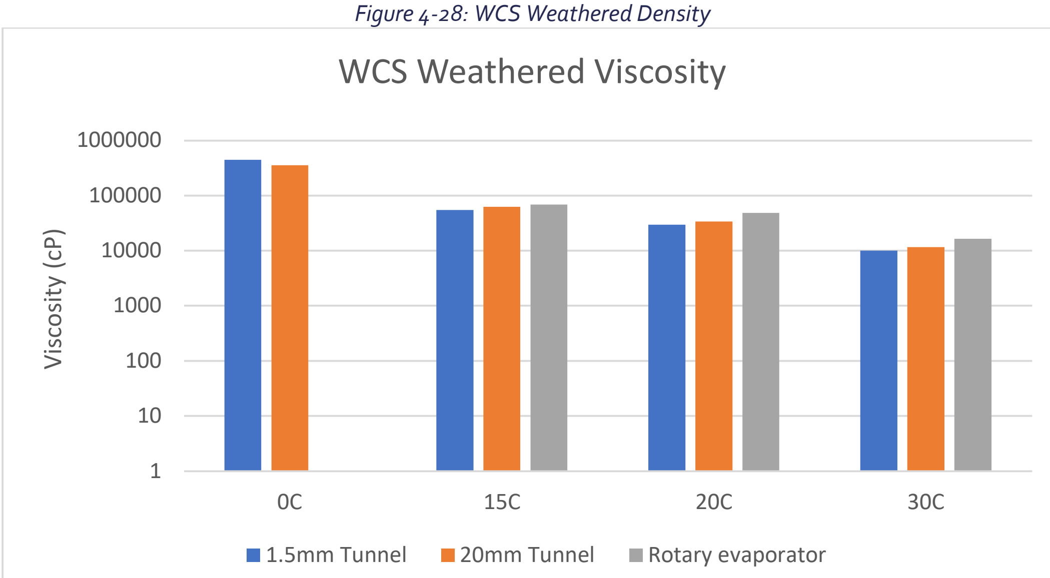


Figure 4-29: WCS Weathered Viscosity

4.3.14.1 Observations

The densities for the WCS runs were close, varying slightly at the third decimal place by a couple of points. The viscosity measurements across the three methodologies at 30°C, 20°C and 15°C are close. The one outlier is the non-reading at 0°C, but the other readings had to be performed at a lower shear rate to avoid over-torqueing the rheometer. Subtle differences between samples under these conditions can have a magnified impact on viscosity measurements. The readings generally match.

4.4 Weathering Comparison Discussion

All 14 oil samples were subject to the three methodologies for laboratory evaporation, specifically:

1. Thin film 1.5 mm layer in wind tunnel
2. Thick film 20 mm layer in wind tunnel
3. Rotary evaporator weathering method

There were some runs where the densest samples were from the rotary evaporator technique, while other runs had the densest measurements from the 1.5 mm layer tests. In spite of this, density measurements were found to be in general agreement across all three methodologies. Additionally, a review of the viscosity measurements shows that the sample with the highest density measurement did not necessarily have the highest viscosity measurement. Again, the viscosity measurements were found to be in general agreement across the three methodologies. When viewed as a collective, these findings show that the physical properties of an oil sample, when targeting a specific mass loss, are independent of the methodology used to reach that point. This is important because it reinforces the concept that the physical properties are linked to the sample mass fraction.

The weathering rates do differ between the methodologies in that the thin 1.5mm layer tests resulted in mass losses faster than the thick 20mm layer tests. The Rotary evaporator method also resulted in weathering rates faster than the thick 20mm layer wind tunnel methodology but the differences for some oils were comparatively small. This is due to the fact that weathering rates change over time and slow as weathering progresses. Mass loss from a sample slows over time, and oils will weather at different rates based upon their component make-up.

The three methods provided similar results for the physical parameters for each of the oils. This supports the view that it doesn't matter which method is used to develop a weathered sample. Nor is the extent of weathering of a sample critical to the determination of physical attributes of that sample because the results are tied back to the weathered state of the sample.

As an example, Method 1 generates two weathered samples with mass losses of 10% and 15%, and Method 2 generates two samples with mass loss of 19% and 25%. The samples from Method 1 are sent for analysis and a range of properties such as viscosity, density, flashpoint, etc. are established. Then the samples from Method 2 are sent for analysis and a range of similar properties are determined. Will the properties match? No. Are they supposed to match? No – because each of the properties is tied to the weathered state of the oil sample. Can an oil fate and behaviour model use the information? Yes – because you tell it that the Viscosity_{10}, Density_{10}, Flashpoint_{10}, etc. are measured for the sample with the mass loss of 10%, and Viscosity_{15}, Density_{15}, Flashpoint_{15}, etc. are measured for the sample with the mass loss of 15% (in the case of samples from Method 1) or that similar parameters are measured for the samples generated from Method 2. The results for Method 1 are used as inputs into equations in a particular model. Once the equations within a model are populated, you can ask it to output those parameters over time while a spill is being simulated. The parameters will be linked to the weathered state (or mass loss fraction) of the oil. If the results for Method 2 are used as inputs, the results should be the same as long as the two methods are capable of weathering an oil sample to a specific mass loss fraction, and the physical properties at that mass loss fraction match. You are simply identifying different points along a curve.

Table 4–15 Sample Model Parameters

Method 1		Method 2	
Fm 10%	**Fm 15%**	**Fm 19%**	**Fm 25%**
$\text{Viscosity}_{Fm10\%}$	$\text{Viscosity}_{Fm15\%}$	$\text{Viscosity}_{Fm19\%}$	$\text{Viscosity}_{Fm25\%}$
$\text{Density}_{Fm10\%}$	$\text{Density}_{Fm15\%}$	$\text{Density}_{Fm19\%}$	$\text{Density}_{Fm25\%}$
$\text{Flashpoint}_{Fm10\%}$	$\text{Flashpoint}_{Fm15\%}$	$\text{Flashpoint}_{Fm19\%}$	$\text{Flashpoint}_{Fm25\%}$
…	…	…	…

Artificial weathering techniques are typically used for three main purposes. The first is to weather an oil sample to an "arbitrary" point (mass loss), generate data on the physical properties, and use that information (physical properties at that specific mass loss) as inputs into an oil fate and behaviour model. Models can use this information in algorithms that take into account the weathered state of the oil that produces the oil property at that weathered condition, along with environmental conditions as inputs, to predict oil behaviour and properties over time. The second purpose is to generate a sample weathered to an "arbitrary" point (mass loss) so that the weathered sample may be used to evaluate response techniques using an expanded oil data set (i.e., with fresh and weathered samples of an oil). The third main purpose is to try to weather a sample to a specific mass loss which represents a particular state an oil attains during an actual spill (matching a grab sample from a spill, as an example). One would have to know the target mass loss endpoint, or a linked parameter such as density from the grab sample to use as a target in this instance. The general problem with weathering samples is that they are, by their very nature, an approximation and using techniques like the three described above focus only on one main process – evaporation – to weather the sample while additional processes would be occurring with an actual oil sample spilled in the environment. In addition, samples in the environment are not necessarily constrained within a container and are allowed to freely move and spread. Generally speaking, a sample weathering in the environment would be expected to weather at a faster rate. Evaporative weathering techniques however are beneficial and are used in research because of their simplicity and ability to create large samples within reasonably short periods of time.

5 OIL-PARTICLE INTERACTIONS

5.1 BACKGROUND

One of the knowledge gaps identified by the RSC report is how unconventional oils will behave when exposed to suspended particles in the water (fresh or marine). Laboratory-scale tests with the project oils were performed to determine the impacts of oil-particle interactions during a spill. Experiments focused on oil with a viscosity of less than 10,000 cP because, while lighter and less viscous oils may be amenable to being scavenged with particles and carried into the water column, more viscous oils are much more resistant to this behaviour at the short-to-medium term focus of these experiments.

Referred to as oil-mineral aggregates (OMAs) or more generally oil-particle aggregates (OPAs), the formation of oil/solid agglomerations is generally accepted as a beneficial occurrence in a marine environment, as these are more readily biodegraded (Lee et al., 1997). For example, surf-washing (oiled sediment relocation), to encourage the formation of oil-particle aggregates is an accepted technique for accelerating the natural cleaning of oiled shorelines. However, there have been instances of spills into rivers where the interaction between the oil and suspended particles caused significant amounts of the oil to sink (Waterman and Garcia, 2015) or be unaccounted for (Lee et al., 2001). Sinking could cause the oil to be less accessible to normal recovery methods and might even prevent its recovery from the environment.

Several researchers have conducted laboratory-scale investigations on oil-particle interactions; most based their apparatus on existing dispersant effectiveness tests, including the Swirling Flask Test (e.g., Lee et al., 1998), Baffled Flask Test (e.g., Waterman and Garcia, 2015), and various reciprocating shakers (e.g., Lee and Egli, 2001). The current understanding is that factors affecting oil-particle interaction include: nature of mineral fines (e.g., size and concentration, ion exchange capacity, roughness, density), oil properties (e.g., density and viscosity, chemical composition), and nature of the aquatic environment (e.g., magnitude and variability of the turbulent energy in the system, and salinity).

5.2 PROTOCOL VARIABLES

A number of variables can impact oil-particle interaction. By limiting experimental conditions to those that might normally be encountered in Canadian environments, or to what has been experimentally shown to affect OMA formation, we were able to tailor the test matrix accordingly.

- **Salinity**, even at low levels, has been shown to affect OMA formation, in particular the aggregation process between OMA constructs to form flocs (Khelifa et al, 2003). Therefore, we conducted experiments in fresh and saline water.
- **Sediment concentration** will vary from river to river, and the time of year, being highest during the spring melt (freshet). Laboratory experiments by Khelifa (2003, 2005) indicated that concentrations of 200 to 250 mg/L of sediments may be required to support OMA formation, although a subsequent summary by Fitzpatrick et al., (2015) found that concentrations as low as 100 mg/L could support OMA formation.

- A brief review of available data from the Environment and Climate Change Canada Water Service for several rivers of interest (e.g., Fraser R., North Thompson R., North Saskatchewan R., Rideau R., St. Lawrence R., Ottawa R.) determined that concentrations during freshet for some Western and Central rivers could be as high as 750 to 1,000 mg/L (e.g., N Saskatchewan R.), but for others may rarely exceed 100 mg/L (e.g., N Thompson R.). Concentration of suspended solids will depend on the river, the location in the river, and the season, and will also vary from year to year. In general, rivers in Eastern Canada typically have very low concentrations of suspended sediment year-round, and OMA formation would be insignificant. OMA formation would be an issue with rivers in Central and Western Canada. We conducted experiments with sediment concentrations of 500 and 1,500 mg/L in fresh water, in order to encompass conditions that could be expected to be encountered in these areas. The intent of the experiments was not to replicate specific river conditions, but to investigate the interactions between oil and suspended solids. If the concentration of oil or solids in the system are too low, it is difficult to detect the oil or effects.
- **Temperature** does not play a significant role in the formation of OMA, except as a secondary role in affecting oil viscosity. Testing was conducted at room temperature
- **Viscosity** of the oil controls (in part) the formation and size of oil droplets at a given turbulence level. Experiments by Wood et al. (1998) found that OMA formation was reduced significantly for oil with viscosity higher than 10,000 cP. Therefore, we focussed our tests on oil samples with viscosities lower than this cut-off, and we tested up to three samples for each oil.
- Venosa et al. (2005) compared the **turbulent energy** in the Swirling Flask and Baffled Flask tests, and determined that the latter produced a more complete mixing environment. Recent investigations into the energy dissipation rate in various laboratory apparatus (Kaku et al., 2005; Mukherjee, 2008) determined that the Baffled Flask apparatus operating between 150 and 200 rpm produced turbulence levels in the range of moderate to very turbulent flowing streams. Therefore, we conducted test using the baffled flask apparatus at two energy levels, representative of moderate and very turbulent environments.
- **Mineral Type** has been shown to affect OMA formation; however, most solids will form OPAs (Fitzpatrick et al., 2015). Therefore, we conducted experiments with two commonly occurring minerals, with one being a clay – kaolinite, and the second being quartz.

Laboratory-scale tests of oil-particle interaction were conducted based on the protocol reported in Lee et al., 1998. The tests were conducted in 250-mL trypsonizing flasks modified with a bottom spigot (for use in the US-EPA Baffled-Flask dispersant effectiveness test). The test conditions were as follows:

- Mineral: Quartz (median particle size 10 micron, range: 0.7-37 micron)
- Mineral: Kaolinite (median particle size 1-2 micron, range 0.2-44 micron)
- Mineral Concentration: 500 and 1,500 mg/L
- Water: fresh and brackish (20 ppt salt)
- Oil Type and Degree of Weathering: 12 oils, fresh and weathered
- Temperature: 20°C

An orbital shaker with a 2-cm orbital diameter was used to provide mixing energy during the tests. The shaker was operated at 160 rpm for the tests with 500 mg/L minerals, and 200 rpm for the test with

1,500 mg/L, on the assumption that higher suspended solids concentrations would typically be found in rivers with higher levels of turbulence.

5.3 Test Protocol

The test protocol is summarized as follows:

1. The required mass of mineral (0.06 g for 500 mg/L or 0.18 g for 1,500 mg/L) was weighed out and transferred to the flask
2. 120 mL of water (fresh or 20 ppt Instant Ocean salt water aquarium preparation) at 20°C was added to the flask
3. The flask was agitated for 10 minutes to hydrate and suspend the minerals
4. 400 µL of oil was added to the flask using a micropipette
5. The flask was agitated for 1 hour, then allowed to settle for 30 minutes
6. The lower water phase is then slowly drained from the bottom of the flask, through the spigot. After discarding the first few mL representing hold-up in the in the spigot, a 70 mL sample of the water phase was collected
7. Any free oil on the surface of the 70 mL was removed with a small square of sorbent (2 cm x 2 cm)
8. The 70 mL of water was transferred to a 125-mL separatory funnel and extracted with dichloromethane to remove oil associated with the solids
9. The concentration of oil in the extracts was measured with a spectrophotometer
10. The mass of oil associated with the solids was calculated from the concentration of the extract

All oils were tested at two degrees of weathering (typically fresh and 2-days of wind tunnel weathering) in fresh water. Conventional heavy oil was also tested in a second weathered state. Each condition was tested with three replicates. The fresh water test results are presented in Table 5–1, below.

Table 5–1: Average oil partitioning to solid (mass oil/mass solid) in fresh water

Oil	Weathering	Viscosity	Density	Oil Partitioning			
		cP 20°C, 100 s^{-1}	g/cm^3 20°C	[g/g] Quartz 1500 mg/L, 200 rpm	[g/g] Quartz 500 mg/L, 160 rpm	[g/g] Kaolinite 1500 mg/L, 200 rpm	[g/g] Kaolinite 500 mg/L, 160 rpm
AHS	**Fresh**	***172***	***0.933***	0.008	0.004	0.017	0.005
	2-Day	***4301***	***0.970***	0.009	0.004	0.015	0.002
ANS	**Fresh**	***9***	***0.859***	0.018	0.011	0.061	0.012
	2-Day	***109***	***0.907***	1.812	0.162	1.147	0.140
AWB	**Fresh**	***273***	***0.915***	0.026	0.020	0.165	0.047
	2-Day	***4551***	***0.946***	0.036	0.039	0.189	0.117
CHV	**Fresh**	***154***	***0.921***	0.023	0.033	0.144	0.064
	2-Day	***1304***	***0.947***	0.038	0.017	0.461	0.040
	6-Week	***26689***	***0.972***	0.029	0.032	0.052	0.037

CLB	**Fresh**	***156***	***0.916***	0.048	0.015	0.186	0.039
	2-Day	***2500***	***0.947***	0.040	0.021	0.213	0.098
CRW	**Fresh**	***0.5***	***0.742***	0.062	0.231	0.043	0.323
	2-Day	***12***	***0.836***	0.443	0.279	0.267	0.098
HFO	**2-Day**	***6668***	***0.986***	0.020	0.014	0.051	0.027
LSB	**Fresh**	***5.6***	***0.835***	0.04	0.02	0.29	0.03
	2-Day	***59***	***0.908***	0.04	0.02	0.08	0.05
MSB	**Fresh**	***7***	***0.844***	0.053	0.116	0.073	0.056
	2-Day	***65***	***0.899***	0.033	0.025	1.136	0.021
MSW	**Fresh**	***3***	***0.816***	0.029	0.016	0.031	0.027
	2-Day	***35***	***0.866***	0.054	0.014	0.165	0.010
NDB	**Fresh**	***2***	***0.810***	0.240	0.291	0.031	0.056
	2-Day	***19***	***0.860***	0.049	0.019	0.139	0.048
SYB	**Fresh**	***144***	***0.928***	0.038	0.005	0.132	0.071
	2-Day	***678***	***0.945***	0.059	0.003	1.382	0.069
SYN	**Fresh**	***6.3***	***0.855***	0.20	0.15	0.12	0.27
	2-Day	***17***	***0.891***	0.22	0.10	0.92	0.10
WCS	**Fresh**	***203***	***0.921***	0.035	0.013	0.723	0.043
	2-Day	***1320***	***0.947***	0.027	0.018	0.428	0.135
Average				**0.133**	**0.060**	**0.309**	**0.073**

5.4 Observations and Discussion

5.4.1 General

- All test conditions resulted in the formation of neutral or negatively-buoyant oil-particle aggregates, with the average partitioning of oil to solid for all tests were 0.14 mg oil/mg solid. This equates to an average oil removal from the surface of the flask of 6% by weight.
- Most of the test conditions resulted in oil partitioning in the range of 0.01 to 0.10 mg oil/mg solid, with a median of 0.041. Most of the test conditions resulted in an oil removal rate of 1 to 5%, with a median of 2%.
- Some of the test conditions resulted in oil removal rates between 20 and 90%
- Some of the test conditions resulted in dramatically higher oil loading, up to 1.8 mg oil/mg solid.

5.4.2 Mineral Type

- Kaolinite typically had higher oil loading (oil removal rate) than quartz, particularly at 1500 mg/L suspended solid concentrations. The average oil loading (oil removal rate) with Kaolinite for the two Kaolinite loadings was (8% by wt) 0.18 mg oil/mg solid, compared to 0.10 mg oil/mg solid (4% by wt.) averaged between the two Quartz loadings.
- With the exception of the 2-day weathered ANS, the very high oil loadings (oil removal rates) (> 0.5 mg oil/mg solid) (> 25%) occurred with Kaolinite.

5.4.3 Mineral Concentration

- Higher suspended solids concentration had higher oil loading. The average oil loading was 0.22 for the tests at 1500 mg/L and 0.06 for the tests at 500 mg/L.
- The higher oil loading is likely due in part to the higher turbulent energy that were used in the higher suspended solids concentration tests, but may also indicate solids concentration is a limiting factor, at least over the range of concentrations tested.

5.4.4 Brackish Water

The results of tests conducted in brackish water (20 ppt Instant Ocean) are presented in Table 5–2 and Table 5–3 below. Only the AWB and ANS oils were subjected to the test in brackish water.

Table 5–2: Average oil partitioning to solid (mass oil/mass solid) in brackish water (20 ppt)

Oil	Weathering	Viscosity	Density	Oil Partitioning			
		cP 20°C, 100 s^{-1}	g/cm3 20°C	[g/g] Quartz 1500 mg/L, 200 rpm	[g/g] Quartz 500 mg/L, 160 rpm	[g/g] Kaolinite 1500 mg/L, 200 rpm	[g/g] Kaolinite 500 mg/L, 160 rpm
ANS	**Fresh**	**9**	**0.859**	1.300	0.142	0.580	0.312
	2-Day	**109**	**0.907**	0.894	0.086	0.455	0.339
AWB	**Fresh**	**273**	**0.915**	1.655	0.090	1.888	0.019
	2-Day	**4551**	**0.946**	0.103	0.078	0.318	0.324
Average				0.988	0.099	0.810	0.248

Table 5–3: Average oil removed from surface (wt%) in brackish water (20 ppt)

Oil	Weathering	Viscosity	Density	Oil Removal from Surface			
		cP 20°C, 100 s^{-1}	g/cm3 20°C	% Quartz 1500 mg/L, 200 rpm	% Quartz 500 mg/L, 160 rpm	% Kaolinite 1500 mg/L, 200 rpm	% Kaolinite 500 mg/L, 160 rpm
ANS	**Fresh**	**9**	**0.859**	68%	2%	30%	5%
	2-Day	**109**	**0.907**	44%	1%	23%	6%
AWB	**Fresh**	**273**	**0.915**	1%	1%	93%	27%
	2-Day	**4551**	**0.946**	5%	1%	15%	5%
Average				30%	2%	40%	11%

- Oil partitioning was significantly higher in the tests with brackish water. The average oil loading over all tests was 0.54 in brackish water compared with 0.25 in fresh water, for the AWB and ANS oils.
- Oil removal rates were higher in the tests with brackish water. The average oil removal rate for AWB and ANS oils was 11% across all tests in fresh water, and 21% across all tests in brackish water.
- Quartz had a slightly higher average oil loading than Kaolinite at 1500 mg/L in brackish water.

5.4.5 Oil Type

- AHS and HFO had the lowest oil loading of all the oils tested, averaging 0.01 and 0.03 mg oil/mg solids, respectively. It is expected that HFO, being a refined product with an overall lower concentration of polar compounds, would have less affinity for suspended solids.
- The 2-day weathered ANS had the highest consistent oil loadings, averaging 0.82 mg oil/mg solid.
- Several other test conditions had very high oil loading (0.5 to almost 2.0 mg oil/mg solid), but a pattern based on oil type or properties is not currently evident.

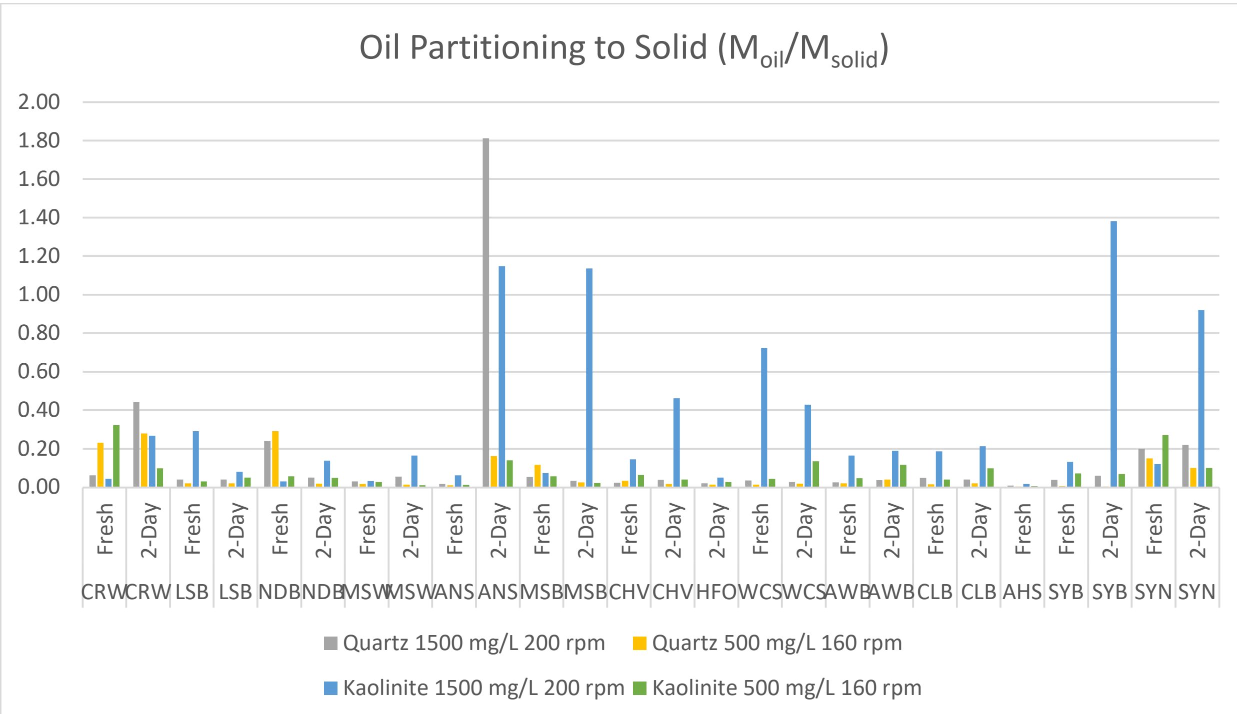


Figure 5-1: Partitioning by Oil and Mineral

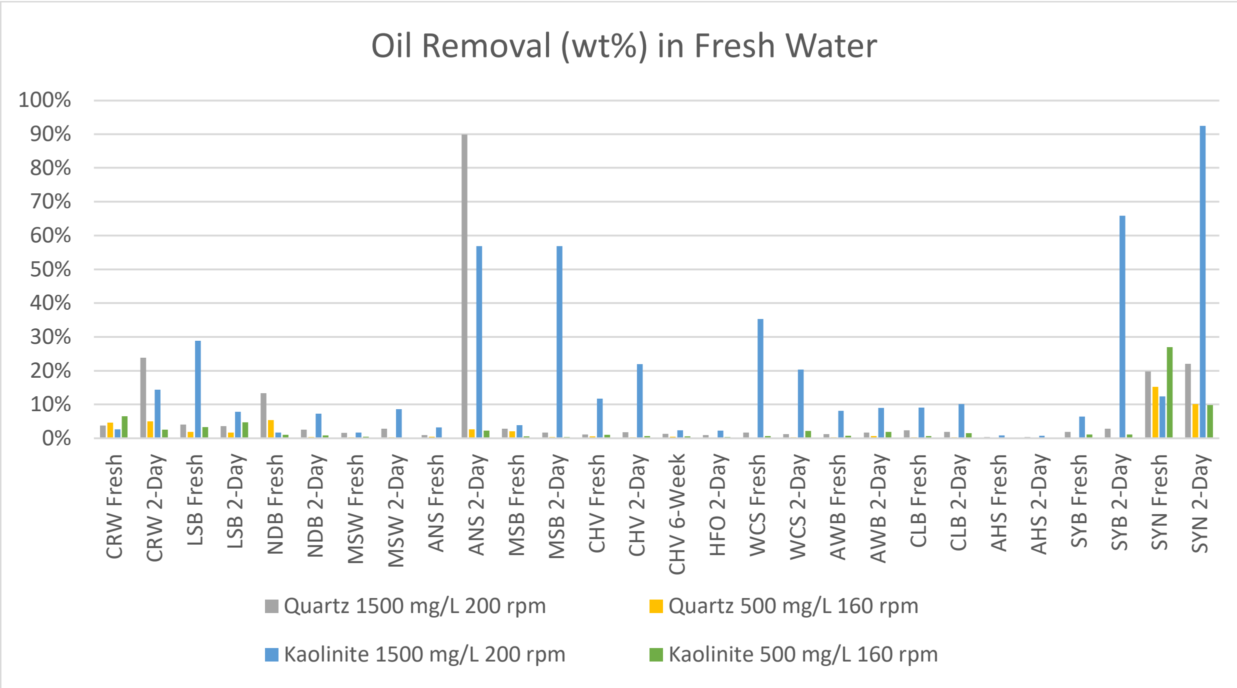


Figure 5-2: Removal by Oil and Mineral

Table 5–4 Average oil removed from surface (wt%) in fresh water

Oil	Weathering	Viscosity cP 20°C, 100 s^{-1}	Density g/cm^3 20°C	Oil Removal from Surface % Quartz 1500 mg/L, 200 rpm	% Quartz 500 mg/L, 160 rpm	% Kaolinite 1500 mg/L, 200 rpm	% Kaolinite 500 mg/L, 160 rpm
AHS	**Fresh**	**172**	**0.933**	0%	0%	1%	0%
	2-Day	**4301**	**0.970**	0%	0%	1%	0%
ANS	**Fresh**	**9**	**0.859**	1%	1%	3%	0%
	2-Day	**109**	**0.907**	90%	3%	57%	2%
AWB	**Fresh**	**273**	**0.915**	1%	0%	8%	1%
	2-Day	**4551**	**0.946**	2%	1%	9%	2%
CHV	**Fresh**	**154**	**0.921**	1%	1%	12%	1%
	2-Day	**1304**	**0.947**	2%	0%	22%	1%
	6-Week	**26689**	**0.972**	1%	0%	2%	1%
CLB	**Fresh**	**156**	**0.916**	2%	0%	9%	1%
	2-Day	**2500**	**0.947**	2%	0%	10%	2%
CRW	**Fresh**	**0.5**	**0.742**	4%	5%	3%	7%
	2-Day	**12**	**0.836**	24%	5%	14%	3%
HFO	**2-Day**	**6668**	**0.986**	1%	0%	2%	0%
LSB	**Fresh**	**5.6**	**0.835**	4%	2%	29%	3%
	2-Day	**59**	**0.908**	4%	2%	8%	5%

MSB	**Fresh**	**7**	**0.844**	3%	2%	4%	1%
	2-Day	**65**	**0.899**	2%	0%	57%	0%
MSW	**Fresh**	**3**	**0.816**	2%	0%	2%	0%
	2-Day	**35**	**0.866**	3%	0%	9%	0%
NDB	**Fresh**	**2**	**0.810**	13%	5%	2%	1%
	2-Day	**19**	**0.860**	3%	0%	7%	1%
SYB	**Fresh**	**144**	**0.928**	2%	0%	6%	1%
	2-Day	**678**	**0.945**	3%	0%	66%	1%
SYN	**Fresh**	**6**	**0.855**	20%	15%	23%	27%
	2-Day	**17**	**0.891**	22%	10%	92%	10%
WCS	**Fresh**	**203**	**0.921**	2%	0%	35%	1%
	2-Day	**1320**	**0.947**	1%	0%	20%	2%
Average				8%	2%	18%	3%

5.4.6 Overall Summary

Oil-particle aggregates were observed with all test conditions:

- All oils (at least when fresh)
- Both mineral types, at both concentrations and energy levels
- Fresh or brackish water

Therefore, we conclude that oil-particle interactions will occur to some degree at all spills where suspended solids are present in the water.

The amount of oil associated with the solids was proportional to the concentration of suspended solids, with a median oil loading of 0.10 mg oil/mg solid. Therefore (and unsurprisingly), the results indicate that oil-particle interaction will have a more significant effect on spills water bodies with high sediment concentrations.

Heavier oils will not break up into small droplets, and so will not significantly interact with suspended solids in the same way as lighter oils. Therefore, we expect oil particle interactions to be significant only in the earliest phases of a spill (e.g., hours to days).

More oil was measured associated with particulates for tests in brackish water. Therefore, we expect that oil loadings on solids will be proportionally higher in estuaries; however, these areas would tend to have lower suspended solids concentrations compared to some inland rivers, so the overall effect of the OPA formation on a spill may be lessened.

Some of the test conditions resulted in dramatically higher oil loadings on particulates, up to 1.8 mg oil/mg solid. It is not clear from the results why these conditions resulted in so much oil being scavenged by the particulates. We conclude that certain conditions could result in higher than expected amounts of oil associating with suspended solids, but further research is required.

6 FLUME WEATHERING TESTS

While small scale bench testing can be conducted to provide rough performance expectations for equipment used in spill clean-up, there is inevitably a scaling impact that cannot easily be overcome without testing to a larger scale. Similar issues exist for determining the fate and behaviour of oil spills. Small scale testing continues to be used to determine properties of weathered segments of oil that can be used as inputs for modeling purposes. Once these inputs are in a model, a range of environmental conditions and situations can be simulated with reasonable accuracy for a period of time. However, beyond that time, confidence in the accuracy of the model diminishes. For this reason, many leading oil spill models are deemed to be accurate for about the first five days after a spill. Flume weathering tests are larger scale tests that take into account factors such as wind, current, UV degradation, temperature, and surface energy (waves or other similar features). These tests are more reflective of the fate and behaviour of an oil spilled in the environment over longer periods of time. Flume tank weathering tests were performed on all 14 oils in this study.

The flume weathering tests incorporate the use of a re-circulating flume tank shown in Figure 6-1. The tank consists of a working channel that is 0.50 m wide, and 1.5 m deep with a total centre-line length of 8.7 m. A water depth of 1.00 m was used in this test series. The inner and outer radii of the tank ends are 0.5 and 1.0 m, and the tank straight sections are 2.0 m on each side. The overall tank footprint is 2.0 m wide by 4.8 m long, which includes a wave generating section that was not used in these tests. The tank enclosure is covered by polycarbonate sheets to create an air chase above the water surface. Wind is circulated above the water using two fans mounted at the beginning of each turn in the tank. A flex hose attached to a ventilation fan is used to extract vapours from the air space above the water surface (see Figure 6-1). Currents are generated using a thruster mounted on one side (see Figure 6-2).

Ultraviolet wavelength light is directed to the tank surface at one end, illuminating approximately ¼ of the tank surface (see Figure 6-1). To accommodate the limited coverage, it was run at 12 hours per day as opposed to 8 hours per day which is the solar simulator standard. The high intensity UV system emits an average of about 15 mW/cm^2. To put this UV light intensity in context, on a bright sunny June day in Ottawa (outdoor temperature reading of 30°C), approximately 5 mW/cm^2 of UV light was measured at noon.

The circulating oil was subjected to a cascade of water using the arrangement shown in Figure 6-4. Water was pumped from an isolated location separate from the main flume portion of the tank. The water cascade was implemented to impart surface energy to the system to accelerate weathering and test the emulsification formation tendencies of the oils. The water temperature is controlled using the chiller and heat transfer coil shown in Figure 6-3, and the exterior of the tank is insulated to help maintain steady temperatures. Tests were conducted for each of the fourteen oils with 20°C and 1°C water temperatures.

6.1 TEST METHOD

After filling the flume tank to the 1.00 m mark, the water was stabilized at the prescribed test temperature. The wind speed was set low at 2.0 m/s (4.0 knots). Water velocity was also set low, approximately 0.25 m/s (0.5 knots), to generate consistent movement of oil around the tank surface, while minimizing the possibility of entrainment of the oil. A single thruster was used as the primary drive during testing. The water cascade was then initiated, and the UV light system timer was activated. At the beginning of a test, approximately 5L of oil was placed in the tank and circulated around the flume via surface wind shear and water currents. Either fresh or 35 ppt salt water was used for baseline testing at two temperatures: 20 °C ± 1 °C (Warm test) and 1°C ± 1 °C (Cool test). A concentration of sediment (1000 ppm of kaolinite) was also incorporated into some runs.

Oil was sampled periodically by manually retrieving portions of oil floating near the thruster location in the North portion of tank. Oil would be sub-sampled at the surface, typically from 5-8 spots, to provide a representative composite sample of the weathering oil. The sample would be collected for physical property determinations (viscosity, density, gross water content).

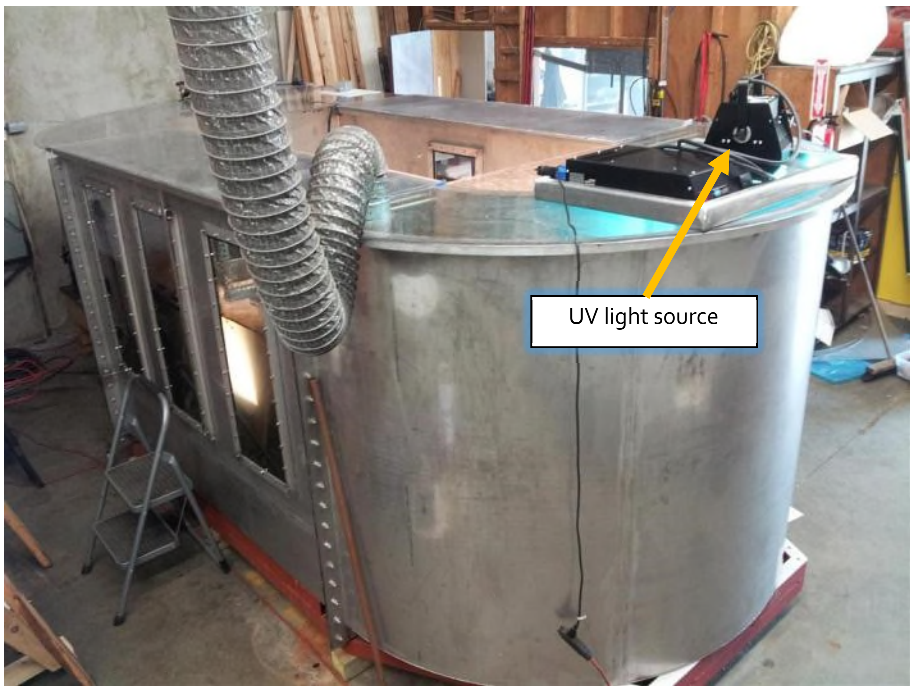


Figure 6-1: Meso-Scale Oil Weathering Tank

Figure 6-2: Water Current Thrusters

Figure 6-3: Heat Transfer Coils and Water Cascade Pump Location

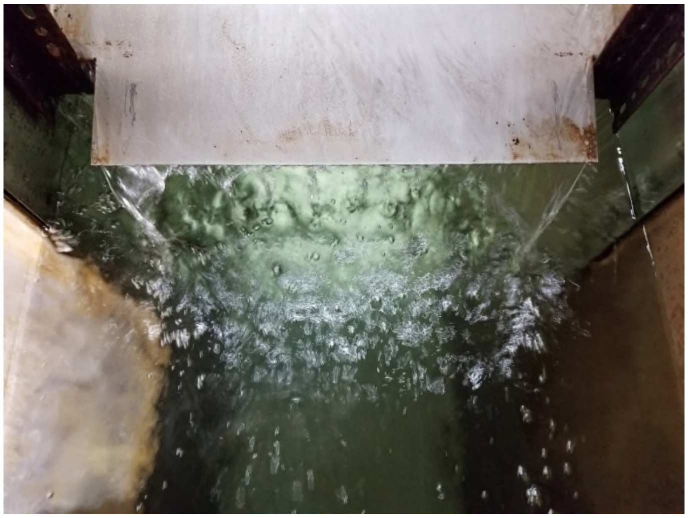


Figure 6-4: Water Cascade Waterfall

The behaviour of each oil was observed and recorded, including partitioning to the water column (droplets of oil observed in the water), wall adherence, over-wash tendency, and temporary submergence or sinking of the oil. A test typically runs continuously until the rate of change of the measured oil properties becomes small. Previous research indicates that this usually occurs within 2 to 4 days from the beginning of the test. In order to address long term weathering behaviour concerns identified in the Expert Panel report, the run time was extended for up to 2 weeks for selected runs. The intent was to document the weathering rates of the oils to the point where their change in persistence and behaviour becomes minimal.

6.2 SAMPLING PROTOCOL

Oil was introduced to the flume tank as a fresh and unweathered condition. Sampling times were established based upon results of historical testing. Changes in properties happen at a fairly rapid pace initially, then gradually slow down as weathering progresses. Because of this, sampling starting at 1 hour (Sample 1 – S1), then at 3 hours (Sample 2 – S2), then again at 6 hours (Sample 3 – S3), and at 24 hours (Sample 4 – S4). From that point on, sampling was usually performed once every 24 hours until the changes between measured properties slowed. Some runs ran over weekends and/or holidays and the sampling frequency was reduced during these periods, but these events were planned to occur in the later portion of a run when the rate of change was reduced. For some of the extended runs (longer than one week) the sampling frequency was also reduced due to a reduction in the rate of property change. Oil was collected into two small sample vials for either water content determination, or viscosity and density measurements at each sample period. The actual oil samples were retrieved as floating oil from the surface of the flume, from multiple positions to produce a composite sample. A minimum of five sampling positions were normally used during a sampling event. This is done because portions of the oil may adhere to the walls as it weathers, only to detach as additional oil pushes past from the wind and current during a run. This macro behaviour will lead to some element of non-homogeneity in the weathering process for the entire slick. Sampling from multiple positions into consolidated samples helps to minimize differences in weathering that a slick may be subjected to over time.

Density measurements were made with a Rudolph Research Analytical DDM 2911 density meter operated within an environmental chamber. Samples were injected into the instrument, which was then adjusted to multiple temperatures and measurements in triplicate were taken at each temperature. Viscosity measurements were made using either a Brookfield DV-III+ viscometer using a cone and plate system with a computer-controlled temperature bath for very light oils, or a Brookfield R/S-CPS+ Rheometer with Peltier temperature control operated at multiple temperatures and multiple shear rates.

Gross water contents of the samples pulled from the flume tank were determined by adding an emulsion breaker to the flume sample vial, which was then placed in a hot water bath maintained at 50°C overnight to break the emulsion. Heights of the water in the vial versus the overall height of free liquid was used to determine water content. Micro-photographs of samples were also taken to provide a qualitative assessment of the emulsified state of the circulating oil over time. Digital video and photographs were taken during the runs and the behaviour of the oil was observed and recorded. Free-floating surface oil, oil adhering to the walls, and any oil that sank to the bottom were collected and weighed to determine the distribution of oil at the end of the tests.

Not all of the oils were evaluated under all test conditions. A testing matrix was defined at the beginning of the flume tests which underwent some adjustment as testing progressed. The final matrix is indicated below.

Table 6–1 Flume Tank Testing Run Matrix

Temperature	Salinity	Sediment	AHS	ANS	AWB	CHV	CLB	CRW	HFO	LSB	MSB	MSW	NDB	SYB	SYN	WCS
20°C	0 salt	0 ppm	2	1	1	2	1	1	2	2	1	1	1	1	2	1
0°C	0 salt	0 ppm	1	1	1	1	1	1	1	2	1	2	1	1	1	1
20°C	0 salt	1000 ppm							1							2
0°C	0 salt	1000 ppm	1	1	1	1	1		1	1		1		1		1
20°C	35 salt	1000 ppm	1		1		1		2			1		1		1
0°C	35 salt	1000 ppm							1							
Total			5	3	4	4	4	2	8	5	2	5	2	4	3	6

6.3 Flume Results and Discussion

Summary observations from the baseline flume tank runs (0°C and 20°C, no salt, no sediment) with a focus on the first 48 hours are presented below in Table 6–2. Full details for each of the runs can be found in Appendix C.

Table 6–2: Flume Tank Runs Summary Observations

Oil		Observations
Condensate (CRW)	(0°C Run)	At 1 hour – oil flowed easily around flume, shearing in fine droplets At 48 hour – oil continued to flow, possible dispersion into column
	(20°C Run)	At 1 hour – fine droplets sheared by waterfall seen to rise quickly At 48 hour – edges of slick have slight foamy appearance, dispersion?
Light Sour Blend (LSB)	(0°C Run)	At 1 hour – oil circulating, with waterfall shearing 1-3 mm dia. oil balls At 48 hour – circ. is slowing, still shearing small droplets - resurface
	(20°C Run)	At 1 hour – oil circulating, waterfall shearing 1-3 mm dia. oil droplets At 48 hour – circulation continues, small bubbles in slick- waterfall
U.S. Bakken (NDB)	(0°C Run)	At 1 hour – slick sheared into tiny droplets in water column, flows well At 48 hour – some evidence of emulsification in slick
	(20°C Run)	At 1 hour – oil flows freely, waterfall shears small droplets (mist) At 48 hour – water column getting cloudy, dispersion into column
Mixed Sweet Blend (MSW)	(0°C Run)	At 1 hour – oil flows freely, many large 4-7 mm dia. balls in column At 48 hour – oil has emulsified appearance (although dark in color)
	(20°C Run)	At 1 hour – oil spreads easily, sheds into range of 1-2, 3-5mm dia balls At 48 hour – few droplets circ. in water column (<1mm, some 4-5mm)
Alaska North Slope (ANS)	(0°C Run)	At 1 hour – waterfall sheared 1-3 mm dia. oil balls resurfaced quick At 48 hour – water column remains clear, oil floating freely
	(20°C Run)	At 1 hour – waterfall sheared 1-5 mm dia. oil balls resurfaced quick At 48 hour – oil circulating, some 5-7 mm dia.oil balls in column

Medium Sour Blend (MSB)	(0°C Run)	At 1 hour – few waterfall sheared 1-3mm dia. oil balls resurface quick At 48 hour – water column clearing, oil circulating
	(20°C Run)	At 1 hour – oil sheared 1-3 mm dia. balls by waterfall, resurface quick At 48 hour – oil still being sheared, few small oil balls in water column
Conventional Heavy (CHV)	(0°C Run)	At 1 hour – oblong shaped blobs sheared by waterfall, resurfacing At 48 hour – waterfall had minimal impact on slick
	(20°C Run)	At 1 hour – non-spherical blobs sheared by waterfall resurface At 48 hour – some tiny oil droplets in water column – slowly resurfacing
Bunker C – Heavy Fuel Oil (HFO)	(0°C Run)	At 1 hour – viscous oil minimally impacted by waterfall At 48 hour – ring of oil submerged/overwashed along tank perimeter adhering to inner wall near surface
	(20°C Run)	At 1 hour – shredding from waterfall, spherical oil resurfacing. By 6 hours large (5-7mm) and small(1-3) oil balls apparent in water column At 48 hour – previous large (5-7mm) and small (1-3mm) balls circulating in water column diminished in concentration, resurfacing
Western Canadian Select (WCS)	(0°C Run)	At 1 hour – oil slick generates blobs/stringers from waterfall At 48 hour – increased viscosity apparent in slick. Sticking to side
	(20°C Run)	At 1 hour – slick is shedding blobby streamers at waterfall - resurface At 48 hour – impacts from waterfall diminish as viscosity increases
Access Western Blend (AWB)	(0°C Run)	At 1 hour – flowed well, some shearing into 1-7mm blobs - resurfaces At 48 hour – impact of waterfall diminishing, shedded oil resurfacing
	(20°C Run)	At 1 hour – slick shearing into 1-7mm blobs at waterfall - resurface At 48 hour – oil slick shrinking, oil floating in water column
Cold Lake Blend (CLB)	(0°C Run)	At 1 hour – slick shedding into streamers in water column - resurface At 48 hour – slick still shedding, oil streamers slower to rise
	(20°C Run)	At 1 hour – viscosity increase apparent as blobs become stringers At 48 hour – oil impacted less by waterfall as viscosity increases
Albian Heavy Synthetic (AHS)	(0°C Run)	At 1 hour – Oil sheared into stringers/blobs from waterfall At 48 hour – Some droplets (1-2mm dia.) of oil in water column
	(20°C Run)	At 1 hour – Oil sheared into stringers from waterfall At 48 hour – Larger blobs submerged and stuck to walls/floor. End.
Synbit Blend (SYB)	(0°C Run)	At 1 hour – oil shredding under waterfall (streamers) At 48 hour – oil becoming more viscous, no droplets under waterfall
	(20°C Run)	At 1 hour – oil covering flume channel, circulating well (1-4mm dia) At 48 hour – viscosity climbs, non-spherical stringers from waterfall
Synthetic Sweet Blend (SYN)	(0°C Run)	At 1 hour – oil circulating under waterfall shearing <1 mm droplets At 48 hour – larger droplets in 1mm dia. range resurface quickly
	(20°C Run)	At 1 hour – oil sheds into tiny droplets under waterfall At 48 hour – oil behaves the same, water becoming cloudy

Table 6–3 and Table 6–4 present a high level overview of the flume tests with a focus on density and viscosity at 0°C and 20°C after 1 hour and 48 hours into each test. Oils are arranged light to heavy with conventional oils being grouped first, then oil sands-derived products. When considering the cold temperature runs, HFO was the only oil to reach or surpass a density of 0.98 g/mL during the first two

days of the run. This is a threshold which denotes an increased risk in submergence. It did demonstrate submergence with some blobs of oil being detected along the walls of the flume as early as 6 hours into the run. The limit indicates potential or increased risk to become temporarily submerged/overwashed or possibly sink in a weathered state. In fact, all of the heavy oils (CHV, HFO, WCS, AWB, CLB, AHS) reached the target threshold by 48 hours for the cold temperature (0°C) run. Some of the oil samples had density measurements slightly in excess of 1.0 g/mL yet remained floating on the surface. A review of the actual slicks showed that some of the floating oil mats were embedded with small bubbles that were trapped within the oil – helping to reduce the bulk density of the slick so that it remained floating.

Oil sands-derived products showed higher densities after one hour of weathering at the 20°C run. This behaviour is consistent with the rapid initial evaporation of diluent at 20°C compared with 0°C. After 48 hours, the density differences between the two temperature runs were not significant (confined to the third decimal place). Most heavy oils (HFO, AWB, CLB, AHS) reached the density threshold of 0.98 g/mL within the first hour of the warm run, while two of the oils (CHV and WCS) remained below the limit during the first two days.

Unsurprisingly all of the oils were initially more viscous at 0°C than at 20°C. Once they started to weather, however, two of the dilbits (WCS and AWB) increased in viscosity more rapidly in the warm runs, effectively matching the viscosity reading in the cold run just beyond 48 hours. The third dilbit, CLB, stayed more viscous during the cold run (when compared with the warm 20°C run). The partially upgraded bitumen product (AHS) became more viscous in the warm run, while the two conventional heavy products (CHV and HFO) stayed more viscous in the cold run. Oil sands-derived products demonstrated accelerated weathering at warmer temperatures for the first couple of days but then their weathering tapered off rapidly.

One oil, AHS, did show signs of submergence around the 24 hour mark and gross submergence by 48 hours of the 20°C "baseline" run (no salt, no sediment added) with blobs of oil submerged and stuck to the walls and floor of the test flume. The run was halted at that point.

Table 6–3 Summary of Flume Tank Test Data at 0°C, fresh water, zero sediment

	Oil	Flume Test Summary					
		Density at 0°C g/ml	Water Content %	Viscosity @ 0°C cP	Density at 0°C g/ml	Water Content %	Viscosity @ 0°C cP
		1 hour	1 hour	1 hour	48 hours	48 hours	48 hours
1	Condensate (CRW)	0.820	0	14	0.854	2	352
2	Light Sour Blend (LSB)	0.899	0	40	0.95	16	2,015
3	U.S. Bakken (NDB)	0.859	0	15	0.887	24	87
4	Mixed Sweet Blend (MSW)	0.876	0	111	0.914[1]	21[1]	3,000[1]
5	Alaska North Slope (ANS)	0.914	4	145	0.935	0	1,175
6	Medium Sour Blend (MSB)	0.891	2	56	0.929	6	952
7	Conventional Heavy (CHV)	0.967	26	11,500	0.996	38	171,400
8	Bunker C – Heavy Fuel Oil (HFO)	0.996	2	108,500	1.002	22	201,700
9	Western Canadian Select (WCS)	0.967	7	9,000	0.997	8	45,100
10	Access Western Blend (AWB)	0.973	15	29,400	1.004	15	326,980
11	Cold Lake Blend (CLB)	0.973	18	24,900	0.998[1]	22[1]	273,750[1]
12	Albian Heavy Synthetic (AHS)	0.955	1	2,800	0.997	10	58,500
13	Synbit Blend (SYB)	0.961	8	2,927	0.975	20	12,020
14	Synthetic Sweet Blend (SYN)	0.889	0	26	0.936	39	70

Notes:

1. CLB and MSW data is for samples taken at 96 hours.

Table 6–4 Summary of Flume Tank Data at 20°C, fresh water, zero sediment

=	Oil	Flume Test Summary					
		Density at 20°C g/ml	Water Content %	Viscosity @ 20°C cP	Density at 20°C g/ml	Water Content %	Viscosity @ 20°C cP
		1 hour	1 hour	1 hour	48 hours	48 hours	48 hours
1	Condensate (CRW)	0.821	0	3	0.863	69	42
2	Light Sour Blend (LSB)	0.897	0	44	0.927	14	265
3	U.S. Bakken (NDB)	0.856	0	7	0.883	25	40
4	Mixed Sweet Blend (MSW)	0.871	0	23	0.942[1]	4[1]	520[1]
5	Alaska North Slope (ANS)	0.906	2	31	0.935	10	370
6	Medium Sour Blend (MSB)	0.896	1	31	0.922	7	200
7	Conventional Heavy (CHV)	0.969	23	3,230	0.991	27	28,800
8	Bunker C – Heavy Fuel Oil (HFO)	0.987	20	7,300	0.995	15	20,800
9	Western Canadian Select (WCS)	0.970	8	4,700	0.991	14	38,450
10	Access Western Blend (AWB)	0.985	13	27,300	0.998	9	275,000
11	Cold Lake Blend (CLB)	0.985	26	20,100	0.997	21	50,200
12	Albian Heavy Synthetic (AHS)	0.986	23	5,670	1.017	12	Too Vis
13	Synbit Blend (SYB)	0.956	19	1,100	0.975	34	6,650
14	Synthetic Sweet Blend (SYN)	0.885	0	12	0.900	4	32

Notes:

1. MSW data is for samples taken at 75 hours.

Figure 6-5 and Figure 6-6 show densities of the baseline runs (no salt, no sediment) at both 0°C and 20°C. The heavy oils generally behave in a similar fashion – approaching the density of water relatively early in the run and staying close to that limit (which puts them all at an elevated risk of submergence).

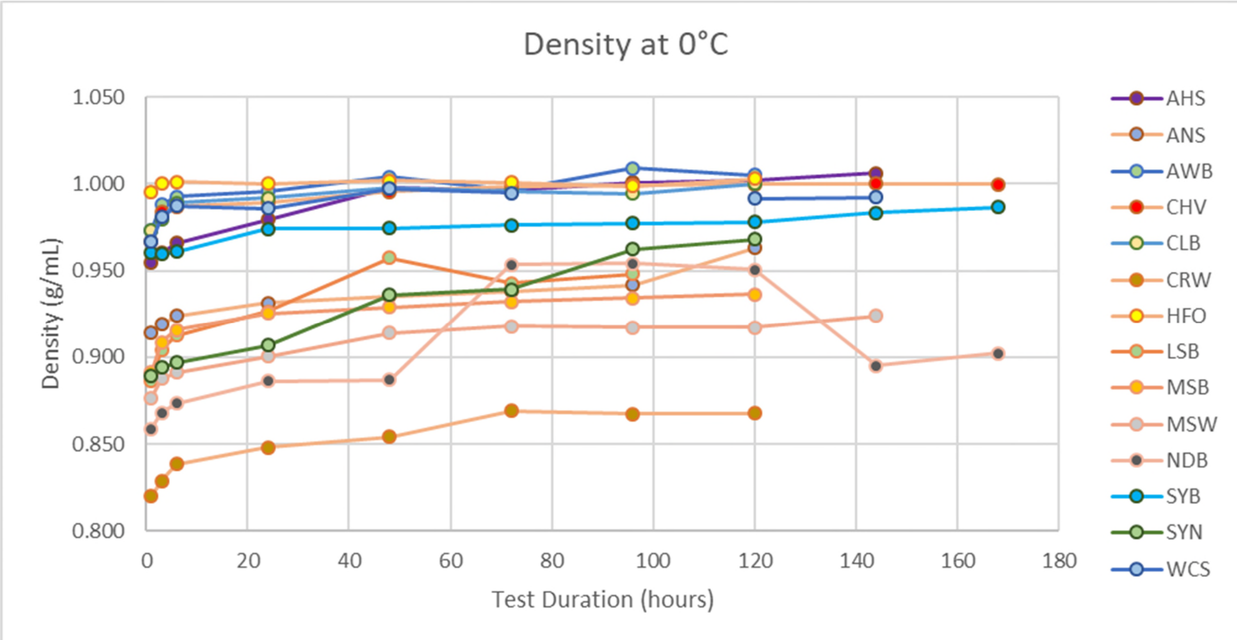


Figure 6-5 Oil Densities for Flume Tests at 0°C

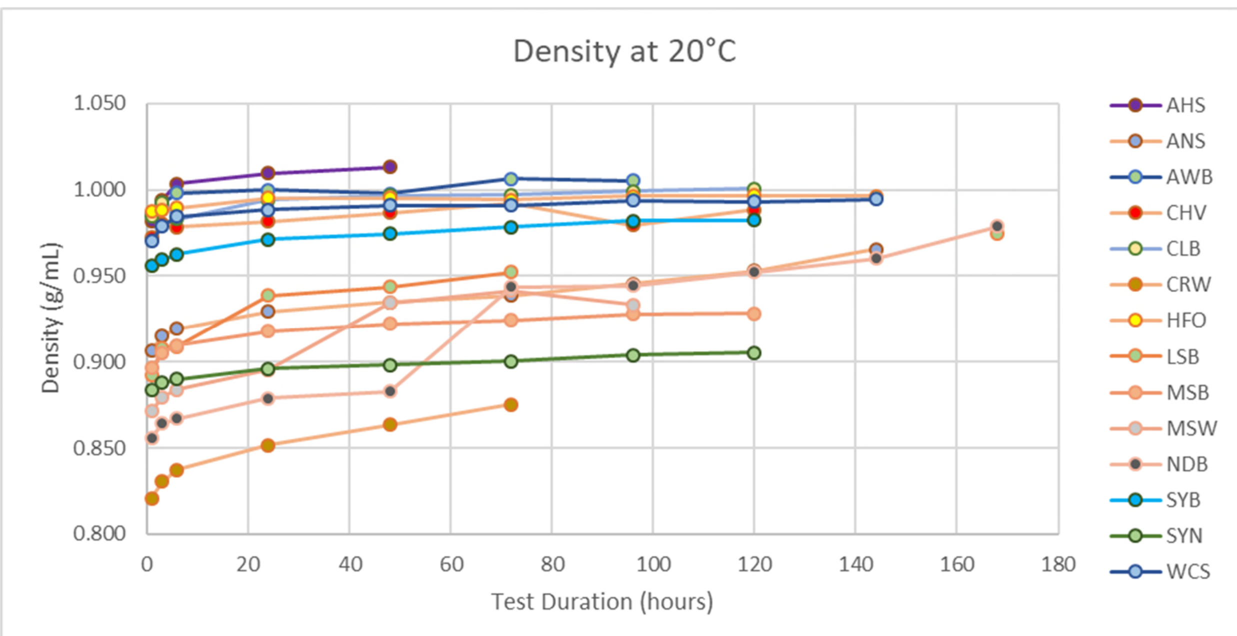


Figure 6-6 Oil Densities for Flume Tests at 20°C

Results from the flume test runs led to the following conclusions:

- All light and medium oils floated in freshwater
- All of the oils tested are expected to remain floating in marine (saltwater) environments

- CHV, HFO and the oil sands-derived crudes reached densities very close to or even slightly above 1.00 g/mL within 48 hours. This indicates a potential for temporary submergence or overwashing, but not necessarily sinking, in freshwater. Flume test observations showed that small bubbles or air entrapment reduce the bulk density of the slick, allowing it to remain floating for extended periods of time even when the measured density of the core oil sample slightly exceeds 1.0 g/mL.
- The partially upgraded oil sands-derived crude (AHS) did show evidence of submergence with some large blobs of oil settling to the bottom of the tank and sinking around the 24 hour mark of the flume test at 20°C. The test run continued through to 48 hours when gross loss of oil was detected. It remained floating in tests with fresh water at lower temperature and tests with seawater at both tested temperatures.
- Higher temperatures generally expedited the initial weathering process of oil sands-derived products, leading to higher densities for these oils in the first few hours. When comparing the results of the 0°C runs with the 20°C runs for each of these oils, there were no dramatic differences in density between them or the two heavy conventional oils by the 48 hours mark.
- All of the oils showed large increases in viscosity over the initial 48 hours, generally attributed to weathering and emulsification processes.
- The addition of sediment in the flume tests did not cause apparent gross submergence or sinking for any oil sands-derived products. There was one run, however, with HFO at 0°C with sediments which did demonstrate gross submergence very early (at 1 hour) in the run.
- There was evidence of temporary submergence in some runs. The waterfall sheared off blobs of oil which then rose to the surface. As the oil weathered, the waterfall impact generally reduced as the slicks became more viscous, eventually causing the floating oil to only submerge slightly before refloating, without breaking into droplets.
- Flume tank observations confirmed the rule of thumb that, there a viscosity window of opportunity for the uptake of sediments for floating oil. Once an oil weathers past that time window, there is minimal driving force to uptake sediment into the body of a viscous oil slick.

Descriptions of each of the runs can be found in Appendix C.

7 Porous Media Tests

7.1 Background

Spills on land can have a deleterious impact on the environment. While they may not spread as far as spills on water, they can end up contaminating soils to varying depths, depending upon the local conditions and the weathered state of the oil. Spills on water that have reached shorelines can have similar impacts if the oils end up stranded on beach sediments and shorelines, and require decontamination. All 14 selected oils were subjected to soil penetration tests to establish any differences in behaviour between conventional oils and dilbit products. Test methods were developed based on the work of Harper and others (Harper et al 2002, 1997, 1995, 1986). The behaviour of crude oils and Orimulsion products were investigated primarily in marine shore sediments with tidal influences. The test methods developed by these researchers were adapted to study spills of bitumen products and conventional oils on land using various soil types.

Fresh and slightly weathered oils on soils were studied. Cylindrical columns of well-defined sediments were established for test beds. The permeable soil types of sand, gravel, and loamy soils were used in the testing. Penetration distances and volumes of oil penetration were determined for each oil type. Movement of water soluble components of the oil were also determined by the addition of water to the top of the oiled sediments, to simulate a rainfall event, and the measurement of BTEX concentrations of the resulting effluent. Tests were completed in triplicate.

7.2 Protocol Review

A small bench scale test was developed to help compare plume geometries when oil is spilled on land. Results from the small bench scale test were fed into a larger scale test that was used to determine comparative plume geometries and determine comparative concentrations of soluble BTEX following a simulated rain event. The procedures used in testing are detailed below:

7.2.1 Small Bench Scale Materials:

The 14 oils used in these tests are listed below. The small bench scale tests used selected "2 day fumehood weathering" equivalents are listed below:

- Albian Heavy Synthetic (AHS)
- Alaskan North Slope (ANS)
- Access Western Blend (AWB)
- Conventional Heavy (CHV)
- Cold Lake Blend (CLB)
- Condensate Blend (CRW)
- Heavy Fuel Oil (HFO)
- Light Sour Blend (LSB)
- Medium Sour Blend (MSB)
- Mixed Sweet Blend (MSW)
- U.S. Bakken (NDB)
- Synbit (SYB)
- Synthetic Sweet Blend (SYN)
- Western Canadian Select (WCS)

Table 7–1: Oil Properties at Weathered State 1

Oil - Weathered State 1 (2 days in wind tunnel)	Density at 20°C (g/mL)	Viscosity at 20°C (cP)
Condensate (CRW)	0.838	12
Light Sour Blend (LSB)	0.906	59
U.S. Bakken (NDB)	0.871	19
Mixed Sweet Blend (MSW)	0.876	35
Alaska North Slope (ANS)	0.918	109
Medium Sour Blend (MSB)	0.909	65
Conventional Heavy (CHV)	0.957	1304
Bunker C – Heavy Fuel Oil (HFO)	0.986	6327
Western Canadian Select (WCS)	0.955	1320
Access Western Blend (AWB)	0.952	4551
Cold Lake Blend (CLB)	0.951	1651
Albian Heavy Synthetic (AHS)	0.977	4301
Synbit Blend (SYB)	0.951	678
Synthetic Sweet Blend (SYN)	0.891	17

Two soil types are used: sand; artificial soil. The artificial soil was made according to OECD guidelines as per the procedure below.

7.2.2 Procedure for Producing Artificial Soil

The artificial soil was created using a standard method (OECD, 1984). The soil was made by mixing air dried sand (silica sand (Grade 70), clay (kaolin clay) and peat (sphagnum peat moss dry sieved to 2mm) in a 7:2:1 ratio. The components were mixed in an industrial mixer for 5 minutes. Water was added to 15% by mass and then mixed for another 10 minutes.

1. Dry the peat moss and sand for at least 48 hours.
2. Sieve the dry peat moss through a 2mm sieve.
3. Combine the correct ratios of dry peat, dry clay and dry sand in the mixing bowl starting with the peat. (Maximum 5kg per batch)
4. Set mixer on low and mix for 5 minutes.
5. Slowly add the correct amount of water to attain the desired moisture content and mix for an additional 15 minutes.
6. Transfer mixed soil to a pail and seal with a lid to maintain the moisture content.

OECD (1984), *Test No. 207: Earthworm, Acute Toxicity Tests*, OECD Guidelines for the Testing of Chemicals, Section 2, OECD Publishing, Paris, https://doi.org/10.1787/9789264070042-en.

Item	Description
Sand	Grade 70: #505 Silica Sand, Bell and Mackenzie, Hamilton, Ontario
Peat	Sphagnum peat moss: Pro-Moss, Premier Horticulture, Riviere de Loup, Quebec
Clay	Kaolin: Pulverised kaolin: Edgar Minerals, Edgar, Florida
Mixer	Model M-12, Axis Equipment: Axis Equipment, Montreal, Quebec

7.3 Small Bench Scale Test Procedures

Two procedures are given below, one for sand and the other for artificial soil (AS). The main differences between the two methods relate to the masses and moisture contents.

7.3.1 The small bench scale test procedure for sand

1. Determine the moisture content of the substrate.
2. Weigh out 650g of sand with a moisture content of 4% in a graduated 750 mL straight walled mason jar.
3. Pack the soil to the predetermined mark (10 cm from the bottom). This will give a consistent packing of the substrate.
4. Place a containment ring (36.7 mm id) in the centre of the container.
5. Transfer 30mL of oil into the containment ring. Measure the actual mass of oil by taking the difference of the mass of the full beaker of oil and the empty beaker after the oil has been applied.
6. Record the time.
7. After 24hrs, record the results as follows:
    a. Measure the size and note the shape of the oil stain. Take a photo using the technique that gives the best contrast for the oil / substrate (either UV fluorescence or visible light spectrum).
    b. Remove soil to the next mark down (1 cm depth) and repeat step a.
    c. Repeat step b. until the oil stain is no longer visible or 1cm from the bottom of the container. Record the depth of contamination.

7.3.2 The small bench scale test procedure for artificial soil

1. Weigh out 475 g of the artificial soil with a moisture content of 15% in a graduated 750 mL straight walled mason jar.
2. Pack the soil to the predetermined mark (10 cm from the bottom). This will give a consistent packing of the substrate.
3. Place a containment ring in the centre of the container (36.7 mm id).
4. Transfer 30mL of oil into the containment ring. Measure the actual mass of oil by taking the difference of the mass of the full beaker of oil and the empty beaker after the oil has been applied.
5. Record the time.
6. After 24hrs, record the results as follows:
    a. Measure the size and note the shape of the oil stain. Take a photo using the technique that gives the best contrast for the oil (either UV fluorescence or visible light spectrum).
    b. Remove soil to the next mark down (1 cm depth) and repeat step a.
    c. Repeat step b. until the oil stain is no longer visible or 1cm from the bottom of the container. Record the depth of contamination.

The results are presented in two ways. A summary of the maximum depth of penetration with comments as to the shape of the plume is given as well as photographs of each cut.

7.4 Small Bench Scale Shakedown Test Results

A summary of the maximum depth of penetration with comments as to the shape/coverage is provided in tabular format (photographs are found in an Appendix D). When the oil has pooled at the bottom of the test vessel, transects were not performed, and that test result was declared to have "breakthrough".

Table 7–2: Penetration of weathered oil (2D equivalent) through playground sand (Results in brackets are replicates with silica sand)

OIL	Media	Depth of maximum penetration (cm)	Comments
AHS 2D	Sand	4 cm	15% coverage at 3cm.
ANS 2D	Sand	6cm	50% coverage at 5cm.
AWB 2D	Sand	4cm (4cm)	80% coverage at 3cm. (90% at 3cm)
CHV 2D	Sand	4cm	80% coverage at 3cm.
CLB 2D	Sand	5 cm	25% coverage at 4cm.
CRW 2D	Sand	9cm	The plume almost reached the bottom, there was 5% and <5% coverage at 8 and 9cm depths.
HFO 2D	Sand	4 cm	10% coverage at 3 cm.
LSB 2D	Sand	5 cm	70% coverage at 4cm.
MSB 2D	Sand	4cm	50%coverage at 3cm
MSW 2D	Sand	6cm (6cm)	50% coverage at 5cm. (5% at 5cm.)
NDB 2D	Sand	10+ (10cm)	The oil pooled at the bottom of the test vessel. (<5% at 9cm)
SYB 2D	Sand	5 cm	30% coverage at 4cm.
SYN 2D	Sand	10+cm	80% coverage at 9cm.
WCS 2D	Sand	5 cm	50% coverage at 4 cm.

Table 7–3: Penetration of weathered oil (2D equivalent) through artificial soil

OIL	Media	Depth of maximum penetration (cm)	Comments
AHS 2D	Artificial Soil (AS)	3cm	10% coverage at 2 cm. The ring still contained oil.
ANS 2D	AS	6cm	5% coverage at 5cm.
AWB 2D	AS	5cm	30% coverage at 4cm.
CHV 2D	AS	4cm	90% coverage at 3cm.
CLB 2D	AS	5cm	20% coverage at 4cm.
CRW 2D	AS	8cm	90% coverage at 7cm.
HFO 2D	AS	5cm	5% coverage at 4cm.
LSB 2D	AS	7cm	<5% coverage at 6cm. The ring still contained oil.
MSB 2D	AS	6cm	45% coverage at 5cm.
MSW 2D	AS	6cm	<5% coverage at 5cm. Oil still in the ring.
NDB 2D	AS	10+cm	2% coverage at 9cm.
SYB 2D	AS	5cm	80% coverage at 4cm.

SYN 2D	AS	7cm	90% coverage at 6cm.
WCS 2D	AS	5cm	30% coverage at 4 cm.

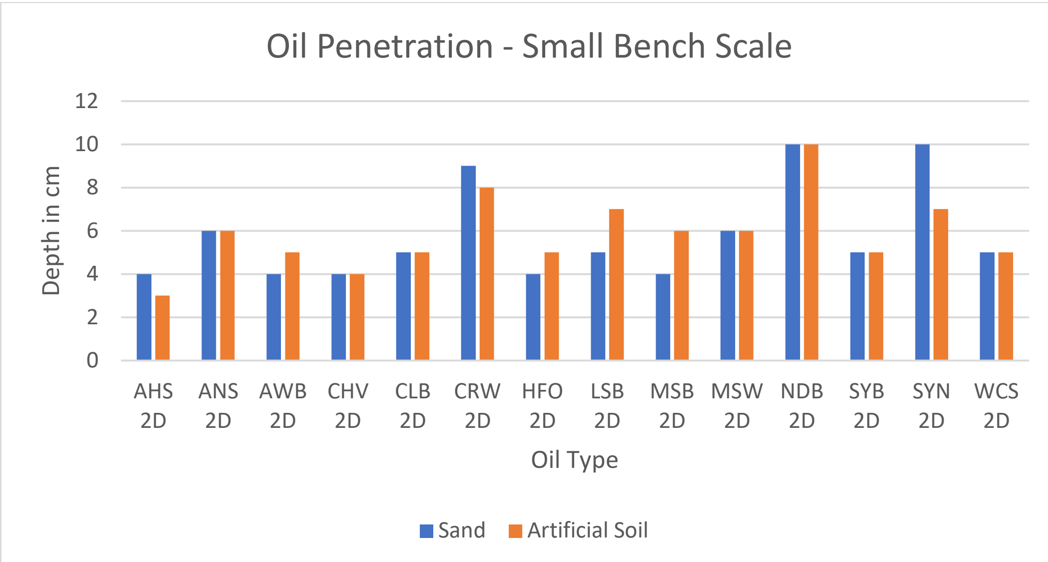


Figure 7-1: Small Bench Scale Oil Penetration Results

7.5 Large Bench Scale Materials

The 14 oils used in these tests are listed below. The large bench scale tests used fresh oil.

- Albian Heavy Synthetic (AHS)
- Alaskan North Slope (ANS)
- Access Western Blend (AWB)
- Conventional Heavy (CHV)
- Cold Lake Blend (CLB)
- Condensate Blend (CRW)
- Heavy Fuel Oil (HFO)
- Light Sour Blend (LSB)
- Medium Sour Blend (MSB)
- Mixed Sweet Blend (MSW)
- U.S. Bakken (NDB)
- Synbit (SYB)
- Synthetic Sweet Blend (SYN)
- Western Canadian Select (WCS)

Three soil types were used: small pebbles (pea gravel); sand; and artificial soil. The initial selection of a specific playground sand was replaced with grade 70 silica sand. The silica sand was chosen due to its consistency, and higher optical contrast with the tested oils. The artificial soil was made according to OECD guidelines as per the section above entitled: "Procedure for Producing Artificial Soil".

7.6 Large Bench Scale Test Procedure

Three procedures are given below, one for sand, one for artificial soil (AS), and one for small pebbles (pea gravel). The main differences between the three methods relate to the masses and moisture contents.

7.6.1 The procedure for sand

1. Determine the moisture content of the substrate and adjust it to 4% by weight (+/- 0.5%).
2. Weigh out sand (25.00 kg) with a moisture content of 4% in test buckets with integrated valves installed near bottom front.
3. Tamp/pack/settle the sand to the predetermined mark at 15L (lower lip, 8 cm from the top) in the bucket. This will give a consistent packing of the substrate.
4. Place a containment ring (13 cm id) in the centre of the container.
5. Transfer 200mL of oil into the containment ring. Measure and record the actual mass of oil by taking the difference of the mass of the full beaker of oil and the empty beaker after the oil has been applied.
6. Record the time.
7. After 24hrs, record the results as follows:
    a. Measure the size and note the shape of the oil stain at the surface. Take a photo using the technique that gives the best contrast for the oil / substrate (either UV fluorescence or visible light spectrum).
    b. Ensure valve at bottom of bucket is closed. Introduce a quantity of water (approx. 4.5L) @ 20°C, representing a rain event. Pour water using watering can into the test bucket. After a hold time of 1 hour, open drain valve allowing any excess water to flow out the open valve at the bottom front of bucket, collecting a sample of water for subsequent BTEX analysis (reject first ~100mL, then collect sample in appropriate amber 40mL sample vial).
    c. Allow remaining water to drain from bucket for 24 hours.
    d. Excavate/Remove soil to the next mark down (2.5 cm depth) and measure the size and note the shape of the oil stain at the surface. Take a photo using the technique that gives the best contrast for the oil / substrate (either UV fluorescence or visible light spectrum).
    e. Repeat step d. until the oil stain is no longer visible or to 2.5 cm from the bottom of the container. Record the penetration depth of contamination.

7.6.2 The procedure for small pebble (3/8" pea gravel)

1. Determine the moisture content of the substrate (use as-is).
2. Weigh out small pebbles (26.50 kg) in test buckets with integrated valves installed near bottom front.
3. Tamp/pack/settle the small pebbles to the predetermined mark at 15L (lower lip, 8 cm from the top) in the bucket. This will give a consistent packing of the substrate.
4. Place a containment ring (13 cm id) in the centre of the container.
5. Transfer 200mL of oil into the containment ring. Measure and record the actual mass of oil by taking the difference of the mass of the full beaker of oil and the empty beaker after the oil has been applied.
6. Record the time.
7. After 24hrs, record the results as follows:
    a. Measure the size and note the shape of the oil stain at the surface. Take a photo using the technique that gives the best contrast for the oil / substrate (either UV fluorescence or visible light spectrum).

b. Ensure valve at bottom of bucket is closed. Introduce a quantity of water (5.5L) @ 20°C, representing a rain event. Pour water using watering can into the test bucket. After a hold time of 1 hour, open drain valve allowing any excess water to flow out the open valve at the bottom front of bucket, collecting a sample of water for subsequent BTEX analysis (reject first ~100mL, then collect sample in appropriate amber 40mL sample vial).
c. Allow remaining water to drain from bucket for 24 hours.
d. Excavate/Remove soil to the next mark down (2.5 cm depth) and measure the size and note the shape of the oil stain at the surface. Take a photo using the technique that gives the best contrast for the oil / substrate (either UV fluorescence or visible light spectrum).
e. Repeat step d. until the oil stain is no longer visible or 2.5 cm from the bottom of the container. Record the penetration depth of contamination.

7.6.3 The procedure for artificial soil

1. Determine the moisture content of the substrate.
2. Weigh out artificial soil (16.40 kg) with a moisture content of 15% in test buckets with integrated valves installed near bottom front.
3. Tamp/pack/settle the sand to the predetermined mark at 15L (lower lip, 8 cm from the top) in the bucket. This will give a consistent packing of the substrate.
4. Place a containment ring (13 cm id) in the centre of the container.
5. Transfer 200mL of oil into the containment ring. Measure and record the actual mass of oil by taking the difference of the mass of the full beaker of oil and the empty beaker after the oil has been applied.
6. Record the time.
7. After 24hrs, record the results as follows:
    a. Measure the size and note the shape of the oil stain at the surface. Take a photo using the technique that gives the best contrast for the oil / substrate (either UV fluorescence or visible light spectrum).
    b. Ensure valve at bottom of bucket is closed. Introduce a quantity of water (6L) @ 20°C, representing a rain event. Pour water using watering can into the test bucket. After a hold time of 1 hour, open drain valve allowing any excess water to flow out the open valve at the bottom front of bucket, collecting a sample of water for subsequent BTEX analysis (reject first ~100mL, then collect sample in appropriate amber 40mL sample vial).
    c. Allow remaining water to drain from bucket for 24 hours.
    d. Excavate/Remove soil to the next mark down (2.5 cm depth) and measure the size and note the shape of the oil stain at the surface. Take a photo using the technique that gives the best contrast for the oil / substrate (either UV fluorescence or visible light spectrum).
    e. Repeat step d. until the oil stain is no longer visible or 2.5 cm from the bottom of the container. Record the penetration depth of contamination.

7.7 Large Bench Scale Results

7.7.1 Penetration results in different media

The results of the large scale tests are presented in Table 7–4 through Table 7–6:

Table 7–4: Penetration of weathered oil (2D equivalent) through Pebbles

OIL	Media	Depth of maximum penetration (cm)	Comments (last observation before non-detect)
AHS 2D	Pebbles	25	8 cm ovoid
ANS 2D	Pebbles	25	10 X 12 ovoid
AWB 2D	Pebbles	25	6 X 10 blob
CHV 2D	Pebbles	25	6 cm disk
CLB 2D	Pebbles	25	11 cm blob
CRW 2D	Pebbles	25	14 cm stain not very visible
HFO 2D	Pebbles	22.5	scattered stain
LSB 2D	Pebbles	25	7 cm stain
MSB 2D	Pebbles	25	9 cm blob
MSW 2D	Pebbles	25	Irregular Stain
NDB 2D	Pebbles	25	No stain, but oil is visible under UV light
SYB 2D	Pebbles	25	8 cm blob
SYN 2D	Pebbles	25	No clearly visible oil yet the surface is oily
WCS 2D	Pebbles	25	8 X 10 cm blob

Table 7–5: Penetration of weathered oil (2D equivalent) through Sand

OIL	Media	Depth of maximum penetration (cm)	Comments (last observation before non-detect)
AHS 2D	Sand	10	8 cm irregular disk
ANS 2D	Sand	22.5	5 cm disk
AWB 2D	Sand	10	3 cm stain
CHV 2D	Sand	12.5	6 X4cm ellipse
CLB 2D	Sand	10	10 cm disk
CRW 2D	Sand	25	9 cm disk
HFO 2D	Sand	7.5	3 X 1 cm stain along edge.
LSB 2D	Sand	17.5	7 cm disk
MSB 2D	Sand	17.5	9 cm X 8 cm ovoid
MSW 2D	Sand	10	4 cm stain
NDB 2D	Sand	20	13 cm disk
SYB 2D	Sand	17.5	7 cm disk
SYN 2D	Sand	25	3 cm disk
WCS 2D	Sand	15	dot

Table 7–6: Penetration of weathered oil (2D equivalent) through Artificial Soil

OIL	Media	Depth of maximum penetration (cm)	Comments (last observation before non-detect)
AHS 2D	Artificial Soil	7.5	3 X 9 cm stain
ANS 2D	Artificial Soil	10	5 cm blob
AWB 2D	Artificial Soil	5	15 cm disk with a 5 cm target
CHV 2D	Artificial Soil	10	6 X 14 cm faint stain
CLB 2D	Artificial Soil	5	11 cm disk
CRW 2D	Artificial Soil	10	11 cm blob
HFO 2D	Artificial Soil	2.5	13 cm disk. Single blob
LSB 2D	Artificial Soil	7.5	5 x 10 cm stain
MSB 2D	Artificial Soil	12.5	3 cm spot
MSW 2D	Artificial Soil	12.5	6 x 10 cm blob
NDB 2D	Artificial Soil	12.5	6 cm blob
SYB 2D	Artificial Soil	7.5	9 cm blob
SYN 2D	Artificial Soil	10	12 x 14 cm blob
WCS 2D	Artificial Soil	10	4 x 8 cm blob

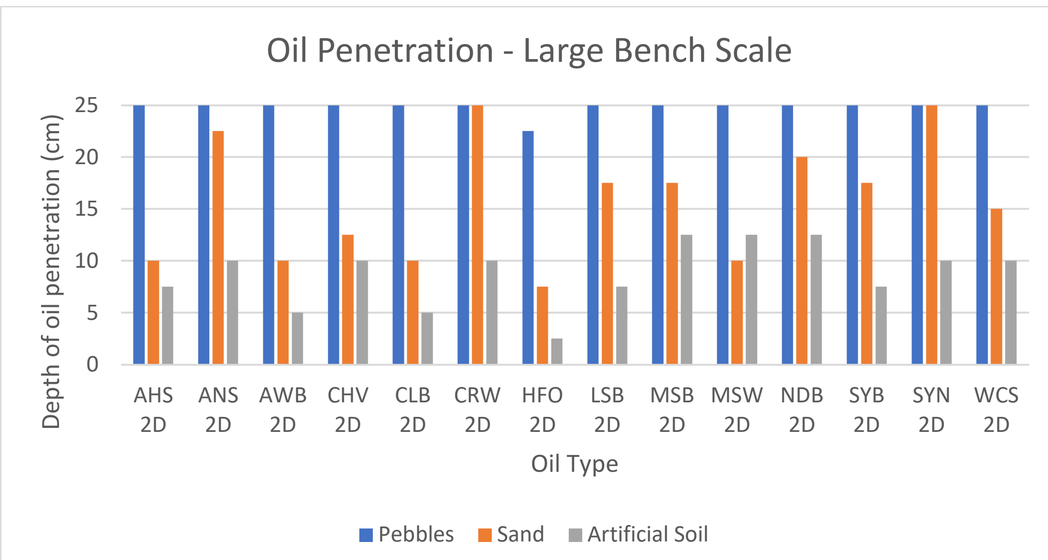


Figure 7-2: Large Bench Scale Oil Penetration Results

7.7.2 Analysis of water effluent

After the introduction of the simulated oil spill to the test cells, and a 24 hour wait, a water flooding event was simulated followed by a 1 hour hold. After this time, water samples were drawn off from the bottoms of the test cells and sent for chemical analysis (BTEX). The results are indicated below:

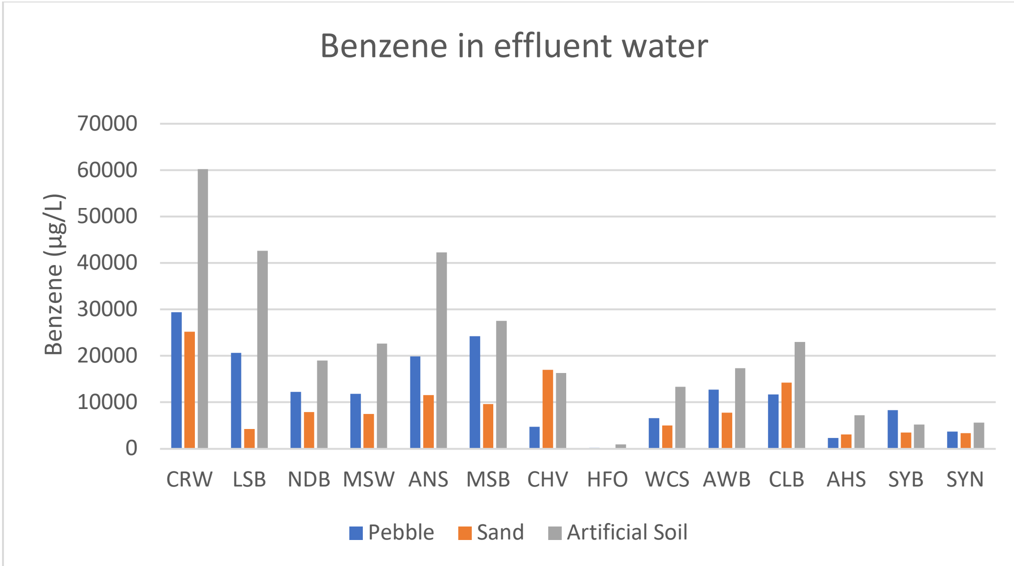


Figure 7-3: Benzene concentration in effluent water

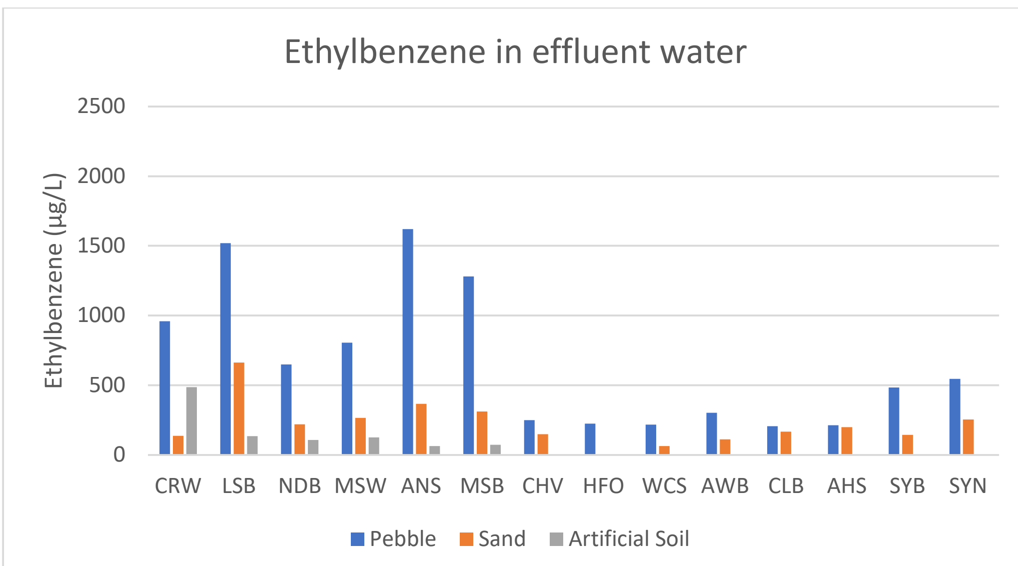


Figure 7-4: Ethylbenzene concentration in effluent water

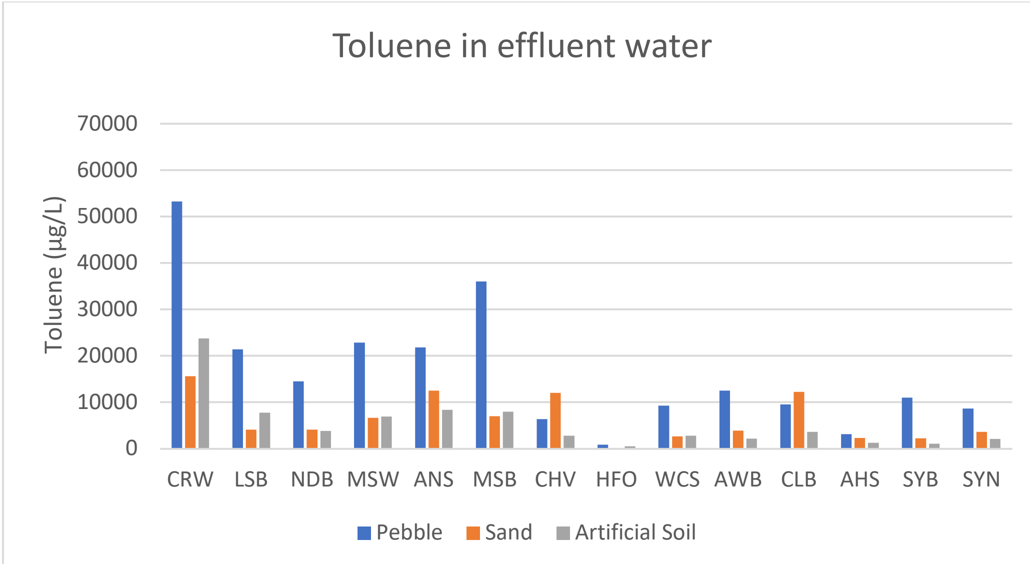


Figure 7-5: Toluene concentration in effluent water

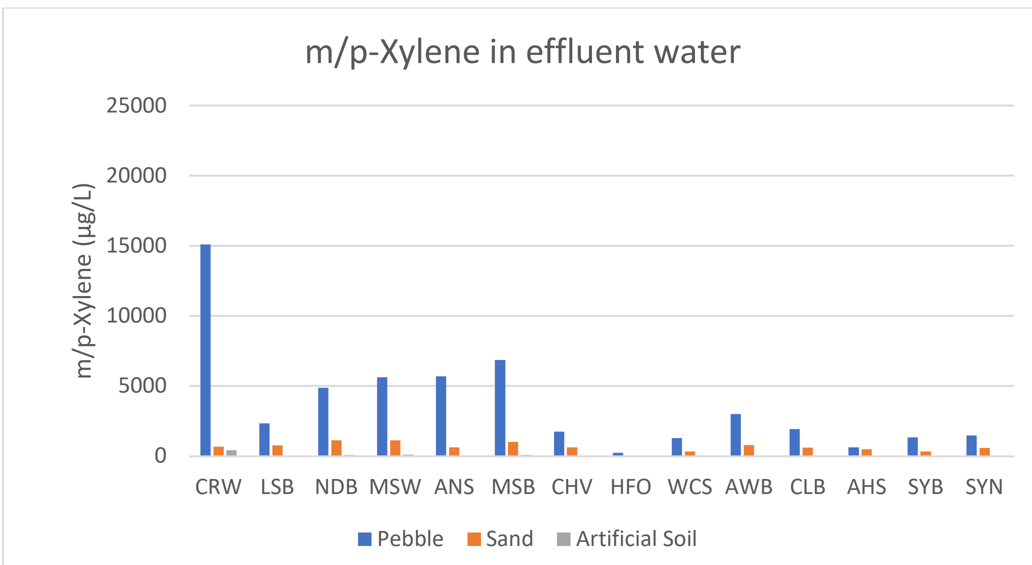


Figure 7-6: meta/para-Xylene concentration in effluent water

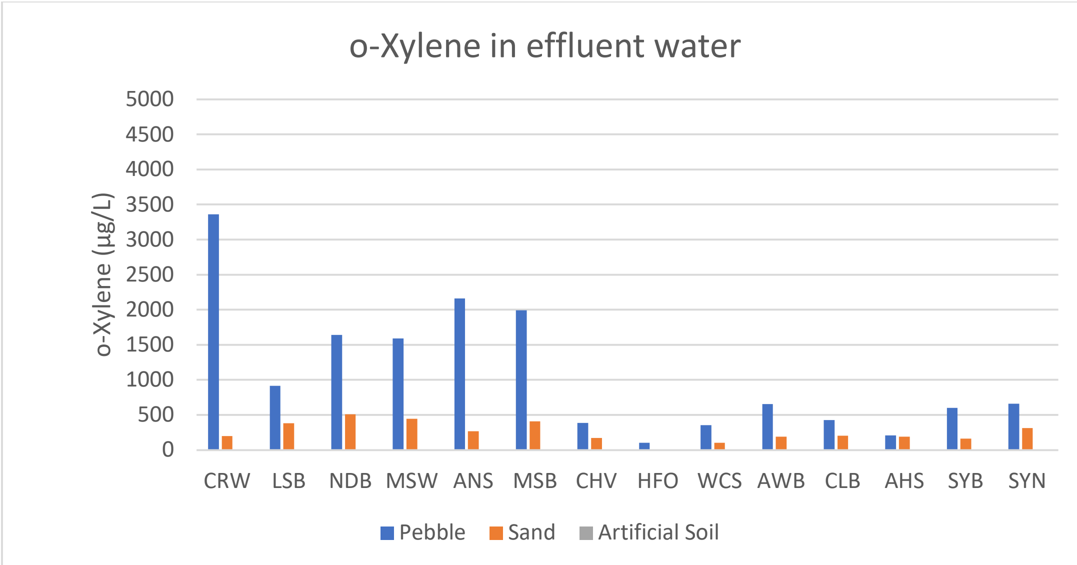


Figure 7-7 ortho-Xylene concentration in effluent water

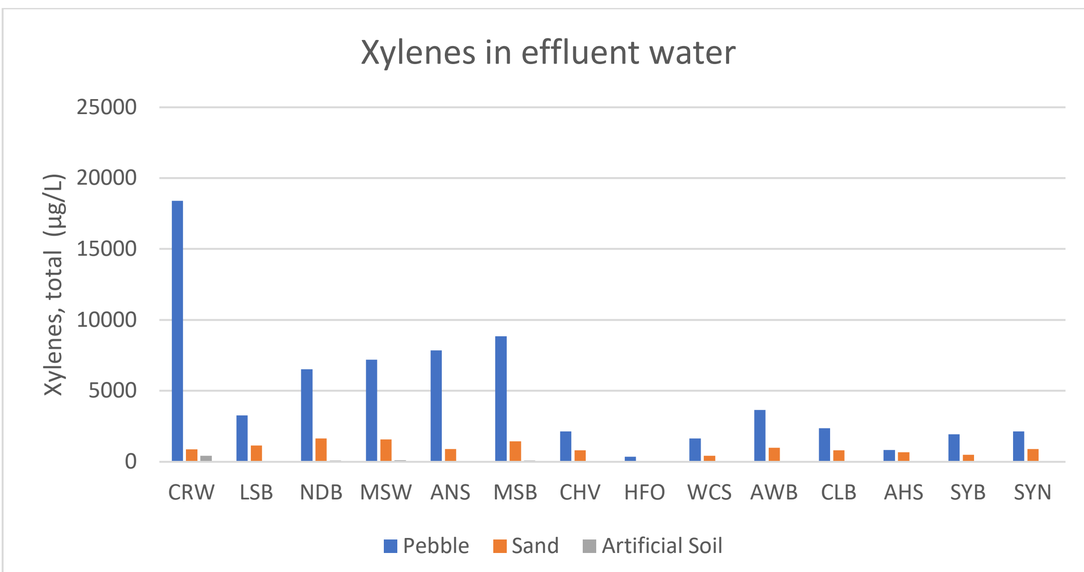


Figure 7-8: Total Xylenes concentration in effluent water

7.8 Discussion

7.8.1 Small Bench Scale Tests

The small scale test were run to determine the operating parameters for the large scale tests. The moisture contents were optimised in this phase of testing. The tests also investigated the feasibility of using silica sand in lieu of playground sand, as well as a standard artificial soil. The advantage of using silica sand are two fold: the first is it provides a better contrast with the target oils and the second, and this applies to the use of the artificial soil also, is to standardize the substrates. Standardized substrates will aid in future comparisons by eliminating biases due to substrate variability. Because of the geometry of the small scale test, gravel could not be evaluated at this scale.

It was determined that the silica sand and the artificial soil were both acceptable substrates for use in the large scale tests. The depth of penetration between the original playground sand and the silica sand were similar. The optimum moisture content for the sand was found to be 4%, while the best moisture content for the artificial soil was determined to be 15%.

7.8.1.1 Sand

The more viscous oils tended to have a lower penetration. Most of the oils (11 of the 14) penetrated to between 4 cm and 6 cm depths. This indicates that the resolution of the small scale testing is not sufficient to differentiate between the oils. What did stand out were the three oils that penetrated the furthest, these were also the least viscous oils; CRW, NDB and SYN.

7.8.1.2 Artificial Soil

The penetration of the oils in artificial soil was greater than in the sand. Most of the oils (10 of the 14) penetrated between 5cm and 7 cm. The oils with the least penetration were AHS and CHV. The oils that penetrated the furthest through the artificial soil were CRW and NDB.

7.8.1.3 Large Bench Scale Tests

The large scale test provided a better resolution with respect to oil penetration compared to the small scale test. The large scale tests also allowed for the testing of the transport of aromatics through the substrate by water.

7.8.1.4 Pea Gravel

The transport of oils through the pea gravel indicated the pea gravel did not have any retention capacity. Thirteen of the fourteen oils saturated the column, with the 14^{th} (HFO) stopping 2.5 cm from the bottom. This would indicate a spill on gravel would penetrate quickly through the soil column.

The concentration of BTEX in the effluent would be expected to be the highest in the pea gravel compared to the other substrates with a greater oil retention. This effect was seen in the total xylenes, with two notable exceptions, AHS in sand and AWB in sand. These two samples in sand were outliers for all the BTEXs indicating a possible contamination in the sample. This effect was not seen with the Benzene or Toluene, where the concentration of these compounds was higher in the sand effluent. This could be explained by the much longer retention time of the water in the sand columns allowing for more time for these compounds to dissolve into the water.

8 Shoreline Adhesion Tests

The currently accepted shoreline and inland oil recovery or treatment techniques for stranded heavy oils (i.e. manual/mechanical removal or washing) have limited effectiveness. Improvements to shoreline and inland treatment can be made if there is an improved understanding of the fate and behaviour of the oil residues stranded on shorelines, river banks, and terrestrial substrates. Despite 30+ years of research, there is no field data and very little bench-scale data on *rates of natural removal* that can be used in the decision process on when to clean or treat; how to recovery stranded oi; and, how much stranded oil to recover.

The behaviour of unconventional oils when interacting with shorelines has been identified in the RSC report as a knowledge gap. To address this, a series of experiments that evaluated the interaction of conventional and unconventional oils with two shoreline compositions was performed.

The experiments were conducted in the SL Ross wind/wave tank, which measures 11 m long, 1.2 m wide by 1.2 m deep with a nominal operating depth of 85 cm (see Figure 8-1 for scale). It is equipped with a computer-controlled, hydraulically driven wave paddle capable of producing sinusoidal, breaking, or random waves in a variety of spectra (including Pierson-Moskowitz, JONSWAP, Bretschneider, and others) mounted at one end of the tank. Wave-absorbing panels are installed at both ends of the tank to dissipate the wave energy (see Figure 8-2).

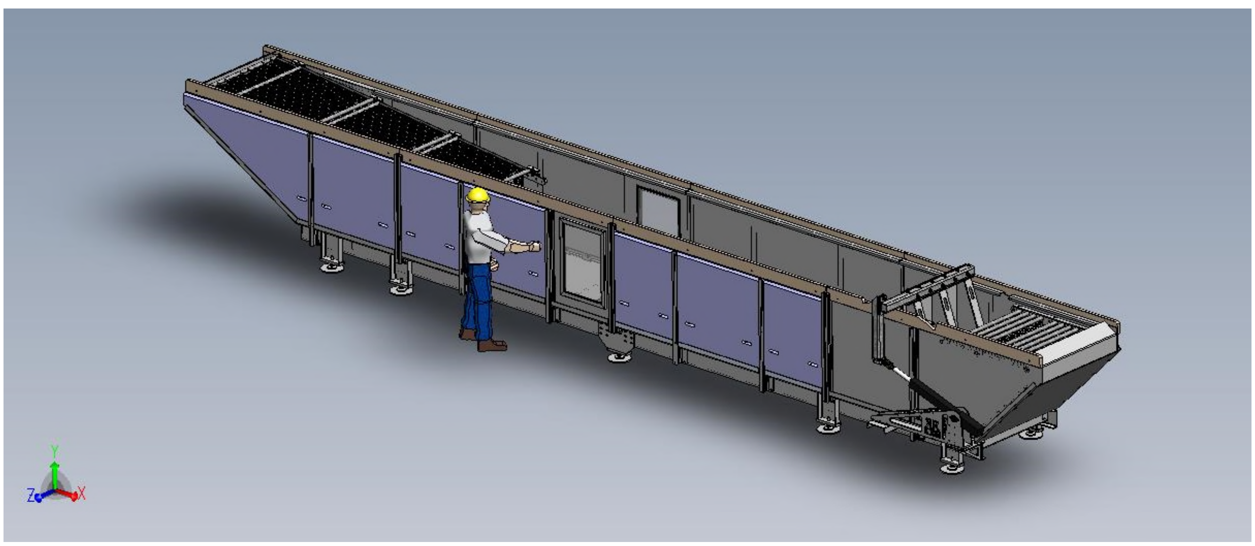


Figure 8-1: Wind-Wave Tank Scale Drawing

Figure 8-2: Wind-Wave Tank

A stabilized beach support structure was installed in the channel and the wave paddle was programmed for two series of wave patterns, a series of sinusoidal waves and a series of breaking waves. Once in place, the pre-oiled shorelines were exposed to controlled environmental conditions with repeatable and precise wave energy.

8.1 Test Matrix

The table below summarises the test matrix.

Parameter	Description
Oil	Each of the 14 project oils.
Substrate	**Small:** 10 mm (3/8") natural round stone (sold as "Pea Gravel"), King brand from Home Depot (rinsed in-house) **Large:** 3cm to 7 cm rosa beach pebbles, Vigoro brand from Home Depot
Waves	**Small substrate**: Low: 12cm height every 3 seconds, non-breaking for a set lasting 36 min. High*: 2 x 15cm height every 30 seconds, breaking for a set lasting 120 min. **Large substrate**: 20cm high every 30 seconds, breaking for a set lasting 150 minutes, 2 sets per run.
Water	Fresh or 35 ‰ NaCl
Temperature	Ambient (20°C +/-3°C)

*The number of waves includes intentionally propagated plus two secondary waves every 30 seconds, resulting in one breaking, one rolling, and one flooding wave.

Figure 8-3: Shoreline adhesion test cell mounted in wave tank

8.2 Testing and Analytical Procedure for Beach Plots Using *Small* Substrate

8.2.1 Preparation

Use slightly weathered oils as required. The density should be used to verify the exact amount of weathering.

The substrate should be rinsed and dried 24 hours prior to use.

Verify the salt content of the water and record the value if applicable.

The 'beach tray' is the perforated 56cm x 56cm tray that holds the substrate (pebbles). The 'tray holder' is the support for the beach tray that has been anchored in the test tank.

8.2.2 Test Procedure for Small Substrate

1. Record the weight of the beach tray.
2. Weigh out 15 kg of substrate and place in beach tray.
3. Record weight of tray and substrate to determine initial weight of substrate.

4. Record mass of sorbent and place in the tray holder (between beach tray and tray holder).
5. Record mass of oil + container.
6. Place oil on substrate within a 10 cm wide swath with the bottom of the swath at the ½ way point in the tray.
7. Weigh empty oil container to determine weight of oil applied.
8. Run wave profile as per test matrix and record data as in the data collection form.
    a. Run for 720 waves.
9. Once the wave profile has been run, remove the tray from the tray holder.
10. Remove the sorbent, dry overnight and weigh.
11. Continue to the analytical protocol for small substrates.

8.2.3 Sampling Plots for Small Substrate

The tray will be divided into three parts. The first area is from the front of the tray (towards the wave paddle) to 20 cm up. This is the halfway point on the tray). The second area is a 10cm long swath from 20cm from the front to 30 cm from the front edge of the tray. The third area is the 10cm wide swath remaining in the tray.

8.2.4 Analytical Procedure for Small Substrate

This procedure uses solvent extraction to determine the mass distribution of oil over the substrate. A sub plot will be weighed, extracted with toluene, filtered, evaporated overnight, and then weighed to determine the residual oil.

1. Remove all material in subplot into a tared container. Determine the mass of oil and substrate in that subplot.
2. Weigh out a 500g sample.
3. Place sample in screen and rinse 3X with 100 mL toluene.
4. Filter the toluene through #4 whatman filter paper (or equivalent) and collect in a tared pan. (The pan should be appropriate for placement into the tunnel and *not* made with folded corners.)
5. Rinse filter paper with 3x toluene.
6. Let pan evaporate overnight in the tunnel.
7. Weigh pan to determine amount of residual oil.
8. Calculate oil on substrate in grams.
9. Repeat for the remaining subplots.

8.3 SAMPLING AND ANALYTICAL PROCEDURE FOR BEACH PLOTS USING *LARGE* SUBSTRATE

8.3.1 Preparation

Use weathered oils as required. The density should be used to verify the exact amount of weathering if weathered oils are to be used.

Verify the salt content of the water and record the value.

8.3.2 Test Procedure for Large Substrate

1. Weigh beach tray.
2. Weigh out 23 kg of substrate and place in beach tray.
3. Record weight of tray and substrate to determine initial weight of substrate.
4. Record mass of sorbent and place in the tray holder (between beach tray and tray holder).
5. Weigh oil + container.
6. Place oil on substrate in a 5 cm wide swath with the bottom of the swath at the ½ way point in the tray.
7. Weigh empty oil container to determine weight of oil applied.
8. Run wave profile as per test matrix and record data as in the data collection form.
    a. Run for 600 waves.
9. Once the wave profile has been run, remove the tray from the tray holder and let dry overnight.
10. The next day, run step 8 again.
11. After the second set of waves (day2) is complete remove the tray from the holder.
12. Remove the sorbent, dry overnight and weigh.
13. Continue with the analytical protocol for large substrate.

8.3.3 Sampling Plots for Small Substrate

The tray will be divided into three parts. The first area is from the front of the tray (towards the wave paddle) to 20 cm up. This is the halfway point on the tray). The second area is a 10cm long swath from 20cm from the front to 30 cm from the front edge of the tray. The third area is the 10cm wide swath remaining in the tray.

8.3.4 Analytical Procedure for Large Substrate

This procedure uses solvent extraction to determine the mass distribution of oil over the substrate. A sub plot will be weighed, extracted with toluene, filtered, evaporated overnight, and then weighed to determine the residual oil.

1. Record the weight of clean sorbent pads.
2. Remove all material from the selected subplot and place into a tared container. Determine the mass of the total mass of the substrate remove.
3. Wipe the oil off each pebble in the selected subplot.
4. Weigh all the oiled sorbents for the selected subplot and determine the mass of oil collected.
5. Repeat for the remaining subplots.

8.4 TEST RESULTS

Table 8–1: AHS Shoreline Adhesion Testing Results

Run#	17	18	43.1, 43.2
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking

Oil:	AHS 2D	AHS 2D	AHS 2D
Pre-wave Data			
Weight of Substrate (g)	15370	15290	23430
Weight of Oil (g)	268.06	286.08	272.4
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	1.08	3.05	14.8
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	43.07	3.04	22.1
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	2.88	4.33	1.5
Calculations			
Total amount of oil applied (g)	268.06	286.08	272.4
Total amount of oil recovered from beach (g)	47.03	10.42	38.40
% of total recovered oil in band A	2%	29%	39%
% of total recovered oil in band B	92%	29%	58%
% of total recovered oil in band C	6%	42%	4%
Concentration of oil in band A (mg/kg)	145	810	1268
Concentration of oil in band B (mg/kg)	12896	810	3824
Concentration of oil in band C (mg/kg)	580	555	253

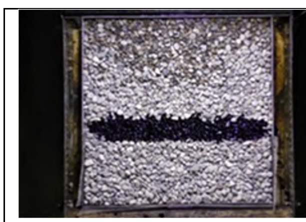


Figure 8-4: AHS (Low - Run 17) Start


Figure 8-5: AHS (High - Run 18) Start


Figure 8-6: AHS (Run 43.1) Start


Figure 8-7: AHS (Run 43.2) Start


Figure 8-8: AHS (Low - Run 17) End

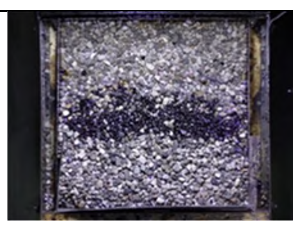


Figure 8-9: AHS (High - Run 18) End


Figure 8-10: AHS (Run 43.1) End


Figure 8-11: AHS (Run 43.2) End

Table 8–2: ANS Shoreline Adhesion Testing Results

Run#	**16**	**15**	**39.1, 39.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**ANS 2D**	**ANS 2D**	**ANS 2D**
Pre-wave Data			
Weight of Substrate (g)	15170	15300	19680
Weight of Oil (g)	215.07	228.13	253.88
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2760	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.00	0.32	1.9
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	3.36	2.09	0.5
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	0.56	1.27	1.2
Calculations			
Total amount of oil applied (g)	215.07	228.13	253.88
Total amount of oil recovered from beach (g)	3.92	3.68	3.60
% of total recovered oil in band A	0%	9%	53%
% of total recovered oil in band B	86%	57%	14%
% of total recovered oil in band C	14%	35%	33%
Concentration of oil in band A (mg/kg)	0	75	232
Concentration of oil in band B (mg/kg)	1087	655	104
Concentration of oil in band C (mg/kg)	129	156	244

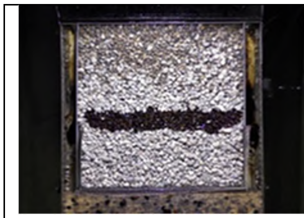


Figure 8-12: ANS (Low - Run 16) Start

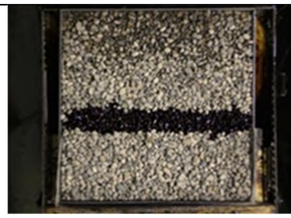


Figure 8-13: ANS (High -Run 15) Start


Figure 8-14: ANS (Run 39.1) Start


Figure 8-15: ANS (Run 39.2) Start

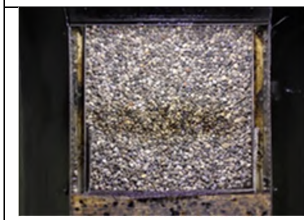


Figure 8-16: ANS (Low - Run 16) End


Figure 8-17: ANS (High - Run 15) End


Figure 8-18: ANS (Run 39.1) End


Figure 8-19: ANS (Run 39.2) End

Table 8–3: AWB Shoreline Adhesion Testing Results

Run#	**5**	**6**	**41.1, 41.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**AWB 2D**	**AWB 2D**	**AWB 2D**
Pre-wave Data			
Weight of Substrate (g)	15490	15190	23390
Weight of Oil (g)	267.77	210.31	267.93
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	1.99	9.60	9.2
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	23.69	27.95	14.9
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	4.82	6.46	1.9
Calculations			
Total amount of oil applied (g)	267.77	210.31	267.93
Total amount of oil recovered from beach (g)	30.49	44.01	26.00
% of total recovered oil in band A	7%	22%	35%
% of total recovered oil in band B	78%	64%	57%
% of total recovered oil in band C	16%	15%	7%

Concentration of oil in band A (mg/kg)	268	2124	793
Concentration of oil in band B (mg/kg)	6967	8469	2258
Concentration of oil in band C (mg/kg)	951	838	373

Figure 8-20: AWB (Low - Run 5) Start

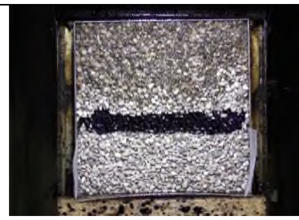


Figure 8-21: AWB (High - Run 6) Start

Figure 8-22: AWB (Run 41.1) Start

Figure 8-23: AWB (Run 41.2) Start

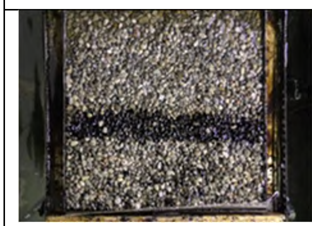


Figure 8-24: AWB (Low - Run 5) End

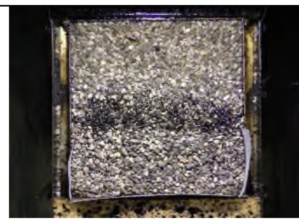


Figure 8-25: AWB (High - Run 6) End

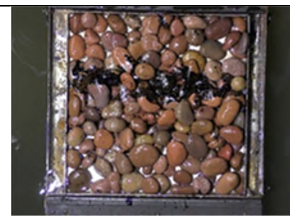


Figure 8-26: AWB (Run 41.1) End

Figure 8-27: AWB (Run 41.2) End

Table 8–4: CHV Shoreline Adhesion Testing Results

Run#	**8**	**7**	**34.1, 34.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**CHV 2D**	**CHV 2D**	**CHV 2D**
Pre-wave Data			
Weight of Substrate (g)	15210	15180	22920
Weight of Oil (g)	237.61	234.74	267.54
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.99	0.18	3.09
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	25.50	3.64	3.4
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	2.96	6.37	1.69
Calculations			

Total amount of oil applied (g)	237.61	234.74	267.54
Total amount of oil recovered from beach (g)	29.44	10.18	8.18
% of total recovered oil in band A	3%	2%	38%
% of total recovered oil in band B	87%	36%	42%
% of total recovered oil in band C	10%	63%	21%
Concentration of oil in band A (mg/kg)	135	39	299
Concentration of oil in band B (mg/kg)	7103	1263	616
Concentration of oil in band C (mg/kg)	626	786	260

Figure 8-28: CHV (Low - Run 8) Start

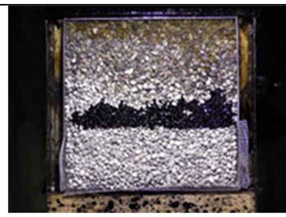


Figure 8-29 CHV (High - Run 7) Start

Figure 8-30: CHV (Run 34.1) Start

Figure 8-31: CHV (Run 34.2) Start

Figure 8-32: CHV (Low - Run 8) End

Figure 8-33: CHV (High - Run 7) End

Figure 8-34: CHV (Run 34.1) End

Figure 8-35 CHV (Run 34.2) End

Table 8–5: CLB Shoreline Adhesion Testing Results

Run#	**12**	**11**	**42.1, 42.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**CLB 2D**	**CLB 2D**	**CLB 2D**
Pre-wave Data			
Weight of Substrate (g)	15030	15210	21440
Weight of Oil (g)	276.45	266.24	289.62
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2760	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	1.93	0.00	0.9

Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	21.40	12.88	5.6
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	4.90	6.63	0.1
Calculations			
Total amount of oil applied (g)	276.45	266.24	289.62
Total amount of oil recovered from beach (g)	28.23	19.50	6.60
% of total recovered oil in band A	7%	0%	14%
% of total recovered oil in band B	76%	66%	85%
% of total recovered oil in band C	17%	34%	2%
Concentration of oil in band A (mg/kg)	245	0	94
Concentration of oil in band B (mg/kg)	6625	4036	957
Concentration of oil in band C (mg/kg)	1135	811	17


Figure 8-36: CLB (Low - Run 12) Start


Figure 8-37: CLB (High - Run 11) Start

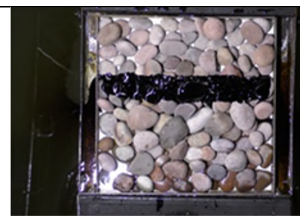


Figure 8-38: CLB (Run 42.1) Start


Figure 8-39: CLB (Run 42.2) End

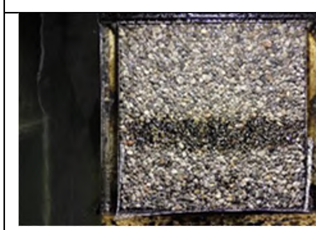


Figure 8-40: CLB (Low - Run 12) End

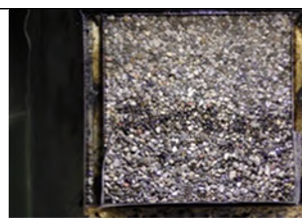


Figure 8-41: CLB (High - Run 11) End

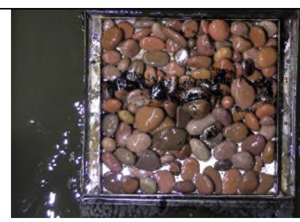


Figure 8-42: CLB (Run 42.1) End

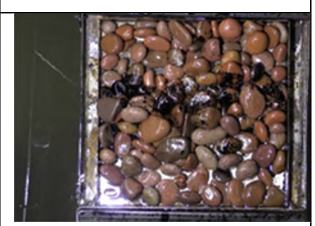


Figure 8-43: CLB (Run 42.2) End

Table 8–6: CRW Shoreline Adhesion Testing Results

Run#	**24**	**23**	**40.1, 40.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**CRW 2D**	**CRW 2D**	**CRW 2D**
Pre-wave Data			
Weight of Substrate (g)	15730	15270	19690
Weight of Oil (g)	123.43	151.64	181.98
Test			

Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.00	0.00	0.4
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	2.74	0.39	0
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	0.09	0.45	0.2
Calculations			
Total amount of oil applied (g)	123.43	151.64	181.98
Total amount of oil recovered from beach (g)	2.84	0.84	0.60
% of total recovered oil in band A	0%	0%	67%
% of total recovered oil in band B	97%	46%	0%
% of total recovered oil in band C	3%	54%	33%
Concentration of oil in band A (mg/kg)	0	0	48
Concentration of oil in band B (mg/kg)	859	118	0
Concentration of oil in band C (mg/kg)	18	56	38

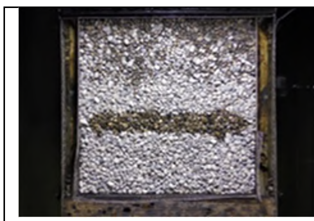


Figure 8-44: CRW (Low - Run 24) Start


Figure 8-45: CRW (High - Run 23) Start


Figure 8-46: CRW (Run 40.1) Start


Figure 8-47: CRW (Run 40.2) Start


Figure 8-48: CRW (Low - Run 24) End


Figure 8-49: CRW (High - Run 23) End


Figure 8-50: CRW (Run 40.1) End


Figure 8-51: CRW (Run 40.2) End

Table 8–7: HFO Shoreline Adhesion Testing Results

Run#	**31**	**32**	**33.1, 33.2**
Wave Condition:	**Low**	**High**	**High**

Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**HFO 2D**	**HFO 2D**	**HFO 2D**
Pre-wave Data			
Weight of Substrate (g)	15030	15140	22490
Weight of Oil (g)	242.46	205.68	267.3
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2760	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.26	1.39	1
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	30.67	5.56	1.5
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	4.93	0.00	1.4
Calculations			
Total amount of oil applied (g)	242.46	205.68	267.3
Total amount of oil recovered from beach (g)	35.86	6.95	3.90
% of total recovered oil in band A	1%	20%	26%
% of total recovered oil in band B	86%	80%	38%
% of total recovered oil in band C	14%	0%	36%
Concentration of oil in band A (mg/kg)	36	316	95
Concentration of oil in band B (mg/kg)	8640	1745	296
Concentration of oil in band C (mg/kg)	1095	0	202

Figure 8-52: HFO (Low - Run 31) Start

Figure 8-53: HFO (High - Run 32) Start

Figure 8-54 HFO (Run 33.1) Start

Figure 8-55: HFO (Run 33.2) Start

Figure 8-56: HFO (Low - Run 31) End

Figure 8-57: HFO (High - Run 32) End

Figure 8-58: HFO (Run 33.1) End

Figure 8-59: HFO (Run 33.2) End

Table 8–8: LSB Shoreline Adhesion Testing Results

Run#	**25**	**26**	**36.1, 36.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**LSB 2D**	**LSB 2D**	**LSB 2D**
Pre-wave Data			
Weight of Substrate (g)	15320	15190	19830
Weight of Oil (g)	188.83	135.95	261.5
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.00	0.00	0
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	9.78	1.06	0.2
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	0.75	0.00	1.3
Calculations			
Total amount of oil applied (g)	188.83	135.95	261.5
Total amount of oil recovered from beach (g)	10.53	1.06	1.50
% of total recovered oil in band A	0%	0%	0%

% of total recovered oil in band B	93%	100%	13%
% of total recovered oil in band C	7%	0%	87%
Concentration of oil in band A (mg/kg)	0	0	0
Concentration of oil in band B (mg/kg)	2946	273	38
Concentration of oil in band C (mg/kg)	148	0	198

Figure 8-60: LSB (Low - Run 25) Start

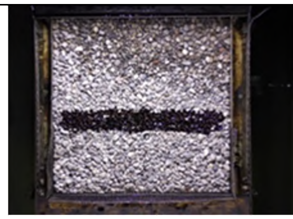


Figure 8-61: LSB (High - Run 26) Start

Figure 8-62: LSB (Run 36.1) Start

Figure 8-63: LSB (Run 36.2) Start

Figure 8-64: LSB (Low - Run 25) End

Figure 8-65: LSB (High - Run 26) End

Figure 8-66: LSB (Run 36.1) End

Figure 8-67: LSB (Run 36.2) End

Table 8–9: MSB Shoreline Adhesion Testing Results

Run#	**21**	**22**	**37.1, 37.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**MSB 2D**	**MSB 2D**	**MSB 2D**
Pre-wave Data			
Weight of Substrate (g)	15270	15190	20370
Weight of Oil (g)	175.38	192.72	257.34
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.00	0.37	1.4
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	7.36	2.04	0
Sub-Plot C (high beach)			

Total weight of oil in sub-plot C	0.25	0.28	1.3
Calculations			
Total amount of oil applied (g)	175.38	192.72	257.34
Total amount of oil recovered from beach (g)	7.60	2.68	2.70
% of total recovered oil in band A	0%	14%	52%
% of total recovered oil in band B	97%	76%	0%
% of total recovered oil in band C	3%	10%	48%
Concentration of oil in band A (mg/kg)	0	94	168
Concentration of oil in band B (mg/kg)	2404	494	0
Concentration of oil in band C (mg/kg)	58	37	203


Figure 8-68: MSB (Low - Run 21) Start

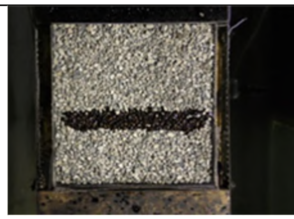


Figure 8-69: MSB (High - Run 22) Start


Figure 8-70: MSB (Run 37.1) Start


Figure 8-71: MSB (Run 37.2) Start


Figure 8-72: MSB (Low - Run 21) End

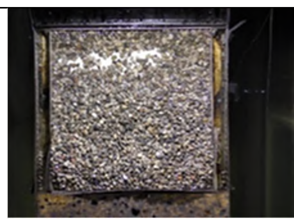


Figure 8-73: MSB (High - Run 22) End


Figure 8-74: MSB (Run 37.1) End


Figure 8-75: MSB (Run 37.2) End

Table 8–10: MSW Shoreline Adhesion Testing Results

Run#	**27**	**28**	**44.1, 44.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**MSW 2D**	**MSW 2D**	**MSW 2D**
Pre-wave Data			
Weight of Substrate (g)	15090	15190	23380
Weight of Oil (g)	205.16	127.3	219.03
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2760	7200	18000
Number of Waves per Run	720	720	1200

Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	1.93	0.21	2.2
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	8.68	1.68	1
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	1.23	0.89	0.5
Calculations			
Total amount of oil applied (g)	205.16	127.3	219.03
Total amount of oil recovered from beach (g)	11.85	2.77	3.70
% of total recovered oil in band A	16%	8%	59%
% of total recovered oil in band B	73%	60%	27%
% of total recovered oil in band C	10%	32%	14%
Concentration of oil in band A (mg/kg)	239	58	176
Concentration of oil in band B (mg/kg)	3158	431	186
Concentration of oil in band C (mg/kg)	267	110	91


Figure 8-76: MSW (Low - Run 27) Start


Figure 8-77: MSW (High - Run 28) Start


Figure 8-78: MSW (Run 44.1) Start


Figure 8-79: MSW (Run 44.2) Start


Figure 8-80: MSW (Low - Run 27) End


Figure 8-81: MSW (High - Run 28) End


Figure 8-82: MSW (Run 44.1) End


Figure 8-83: MSW (Run 44.2) End

Table 8–11: NDB Shoreline Adhesion Testing Results

Run#	**30**	**29**	**46.1, 46.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**NDB 2D**	**NDB 2D**	**NDB 2D**
Pre-wave Data			
Weight of Substrate (g)	15140	15190	23250

Weight of Oil (g)	187.04	184.08	240.04
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2760	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.00	0.32	1.1
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	2.29	1.46	0
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	1.10	1.10	0.4
Calculations			
Total amount of oil applied (g)	187.04	184.08	240.04
Total amount of oil recovered from beach (g)	3.38	2.88	1.50
% of total recovered oil in band A	0%	11%	73%
% of total recovered oil in band B	68%	51%	0%
% of total recovered oil in band C	32%	38%	27%
Concentration of oil in band A (mg/kg)	0	95	98
Concentration of oil in band B (mg/kg)	817	352	0
Concentration of oil in band C (mg/kg)	229	137	72

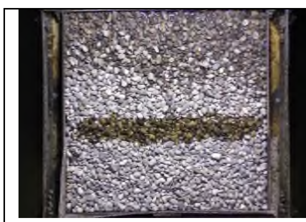


Figure 8-84: NDB (Low - Run 30) Start

Figure 8-85: NDB (High - Run 29) Start

Figure 8-86: NDB (Run 46.1) Start

Figure 8-87: NDB (Run 46.2) Start

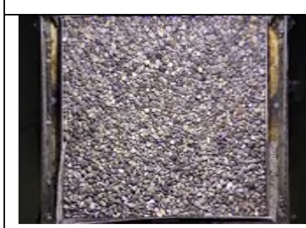


Figure 8-88: NDB (Low - Run 30) End

Figure 8-89: NDB (High - Run 29) End

Figure 8-90: NDB (Run 46.1) End

Figure 8-91: NDB (Run 46.2) End

Table 8–12: SYB Shoreline Adhesion Testing Results

Run#	**9**	**10**	**38.1, 38.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**SYB 2D**	**SYB 2D**	**SYB 2D**
Pre-wave Data			
Weight of Substrate (g)	15140	15290	1081
Weight of Oil (g)	246.65	267.52	253.9
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.79	0.09	0
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	7.00	1.72	0
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	0.78	1.23	0.9
Calculations			
Total amount of oil applied (g)	246.65	267.52	253.9
Total amount of oil recovered from beach (g)	8.57	3.05	0.90
% of total recovered oil in band A	9%	3%	0%
% of total recovered oil in band B	82%	56%	0%
% of total recovered oil in band C	9%	41%	100%
Concentration of oil in band A (mg/kg)	98	20	0
Concentration of oil in band B (mg/kg)	2396	478	0
Concentration of oil in band C (mg/kg)	175	169	134


Figure 8-92: SYB (Low - Run 9) Start


Figure 8-93: SYB (High - Run 10) Start


Figure 8-94: SYB (Run 38.1) Start


Figure 8-95: SYB (Run 38.2) Start

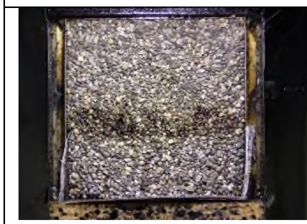


Figure 8-96: SYB (Low - Run 9) End


Figure 8-97: SYB (High - Run 10) End


Figure 8-98: SYB (Run 38.1) End


Figure 8-99: SYB (Run 38.2) End

Table 8–13: SYN Shoreline Adhesion Testing Results

Run#	**13**	**14**	**45.1, 45.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**SYN 2D**	**SYN 2D**	**SYN 2D**
Pre-wave Data			
Weight of Substrate (g)	15320	15150	23360
Weight of Oil (g)	232.58	212.14	255.94
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2760	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	0.60	0.22	0.2
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	3.72	1.43	0.5
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	0.98	1.59	0.7
Calculations			
Total amount of oil applied (g)	232.58	212.14	255.94
Total amount of oil recovered from beach (g)	5.29	3.24	1.40
% of total recovered oil in band A	11%	7%	14%
% of total recovered oil in band B	70%	44%	36%

% of total recovered oil in band C	19%	49%	50%
Concentration of oil in band A (mg/kg)	77	56	17
Concentration of oil in band B (mg/kg)	1561	452	87
Concentration of oil in band C (mg/kg)	272	191	116

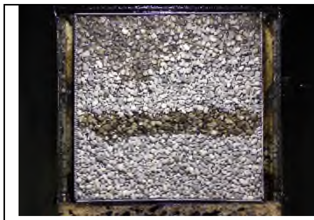


Figure 8-100: SYN (Low - Run 13) Start

Figure 8-101: SYN (High - Run 14) Start

Figure 8-102: SYN (Run 45.1) Start

Figure 8-103: SYN (Run 45.2) Start

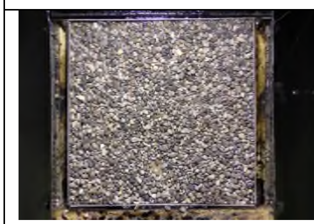


Figure 8-104: SYN (Low - Run 13) End

Figure 8-105: SYN (High - Run 14) End

Figure 8-106: SYN (Run 45.1) End

Figure 8-107: SYN (Run 45.2) End

Table 8–14: WCS Shoreline Adhesion Testing Results

Run#	**19**	**20**	**35.1, 35.2**
Wave Condition:	**Low**	**High**	**High**
Wave Amplitude (cm):	12	15	20
Wave Period (s):	3	30	30
Wave Description:	rolling	breaking	breaking
Oil:	**WCS 2D**	**WCS 2D**	**WCS 2D**
Pre-wave Data			
Weight of Substrate (g)	15320	15380	26000
Weight of Oil (g)	269.99	232.96	278.39
Test			
Test Sets per Run	1	1	2
Duration of Run (sec)	2160	7200	18000
Number of Waves per Run	720	720	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	1.95	2.71	3.9
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	22.60	11.65	4.6
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	4.32	4.85	2.4

Calculations			
Total amount of oil applied (g)	269.99	232.96	278.39
Total amount of oil recovered from beach (g)	28.87	19.20	10.90
% of total recovered oil in band A	7%	14%	36%
% of total recovered oil in band B	78%	61%	42%
% of total recovered oil in band C	15%	25%	22%
Concentration of oil in band A (mg/kg)	234	690	426
Concentration of oil in band B (mg/kg)	7337	3073	740
Concentration of oil in band C (mg/kg)	1013	601	423


Figure 8-108: WCS (Low - Run 19) Start


Figure 8-109: WCS (High - Run 20) Start


Figure 8-110: WCS (Run 35.1) Start


Figure 8-111: WCS (Run 35.2) Start


Figure 8-112: WCS (Low - Run 19) End


Figure 8-113: WCS (High - Run 20) End


Figure 8-114: WCS (Run 35.1) End

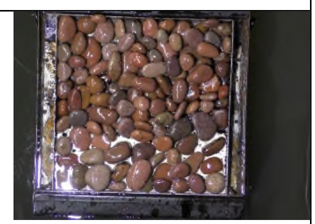


Figure 8-115: WCS (Run 35.2) End

Table 8–15: Fresh Water Small Substrate Test Results

Run#	**F3**	**F4**	**F50**	**F51**	**F52**
Wave Condition:	**Low**	**High**	**Low**	**Low**	**Low**
Wave Amplitude (cm):	12	15	12	12	12
Wave Period (s):	3	30	3	3	3
Wave Description:	rolling	breaking	rolling	rolling	rolling
Oil:	**HFO 2D**	**HFO 2D**	**AWB 2D**	**LSB 2D**	**NDB 2D**
Pre-wave Data					
Weight of Substrate (g)	15070	15150	14020	14180	14280
Weight of Oil (g)	247.5	230.26	233.81	255.31	204.04
Test					
Test Sets per Run	1	1	1	1	1
Duration of Run (sec)	2160	7200	2760	2760	2760
Number of Waves per Run	720	720	720	720	720
Sub-Plot A (low beach)					

Total weight of oil in sub-plot A	0.85	2.97	1.63	0.87	0.00
Sub-Plot B (oiled band)					
Total weight of oil in sub-plot B	48.49	18.08	22.41	2.78	0.00
Sub-Plot C (high beach)					
Total weight of oil in sub-plot C	2.14	8.59	19.49	0.78	0.50
Calculations					
Total amount of oil applied (g)	247.5	230.26	233.81	255.31	204.04
Total amount of oil recovered from beach (g)	51.48	29.64	43.52	4.43	0.50
% of total recovered oil in band A	2%	10%	4%	20%	0%
% of total recovered oil in band B	94%	61%	51%	63%	0%
% of total recovered oil in band C	4%	29%	45%	18%	100%
Concentration of oil in band A (mg/kg)	117	686	264	126	0
Concentration of oil in band B (mg/kg)	13106	5703	8268	1108	0
Concentration of oil in band C (mg/kg)	488	1070	3741	160	96


Figure 8-116: Run F3 HFO Start


Figure 8-117: Run F4 HFO Start


Figure 8-118: Run F50 AWB Start

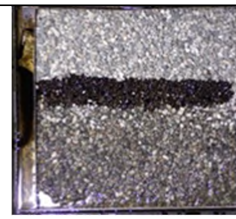


Figure 8-119: Run F51 LSB Start

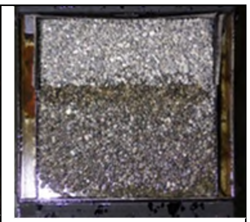


Figure 8-120: Run F52 NDB Start


Figure 8-121: Run F3 HFO End

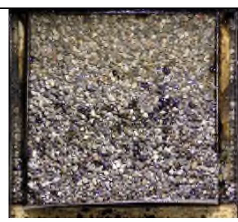


Figure 8-122: Run F4 HFO End


Figure 8-123: Run F50 AWB End

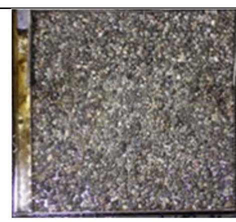


Figure 8-124: Run F51 LSB End

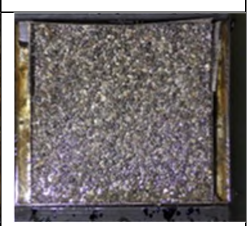


Figure 8-125: Run F52 NDB End

Table 8–16: Fresh Water Large Substrate Test Results

Run#	**F47.1, F47.2**	**F48.1, F48.2**	**F49.1, F49.2**
Wave Condition:	**High**	**High**	**High**
Wave Amplitude (cm):	20	20	20
Wave Period (s):	30	30	30
Wave Description:	breaking	breaking	breaking
Oil:	**AWB 2D**	**LSB 2D**	**NDB 2D**
Pre-wave Data			

Weight of Substrate (g)	23040	23230	23830
Weight of Oil (g)	258.23	155.05	188.67
Test			
Test Sets per Run	2	2	2
Duration of Run (sec)	18000	18000	18000
Number of Waves per Run	1200	1200	1200
Sub-Plot A (low beach)			
Total weight of oil in sub-plot A	6.3	0	0.5
Sub-Plot B (oiled band)			
Total weight of oil in sub-plot B	8.9	0	0
Sub-Plot C (high beach)			
Total weight of oil in sub-plot C	0.7	0.5	0
Calculations			
Total amount of oil applied (g)	258.23	155.05	188.67
Total amount of oil recovered from beach (g)	15.90	0.50	0.50
% of total recovered oil in band A	40%	0%	100%
% of total recovered oil in band B	56%	0%	0%
% of total recovered oil in band C	4%	100%	0%
Concentration of oil in band A (mg/kg)	532	0	41
Concentration of oil in band B (mg/kg)	1745	0	0
Concentration of oil in band C (mg/kg)	127	89	0

Figure 8-126: AWB (Run F47.1) Start

Figure 8-127: AWB (Run F47.2) Start

Figure 8-128: AWB (Run F47.1) End

Figure 8-129: AWB (Run F47.2) End

 *Figure 8-130: LSB (Run F48.1) Start*	 *Figure 8-131: LSB (Run F48.2) Start*
 *Figure 8-132: LSB (Run F48.1) End*	 *Figure 8-133: LSB (Run F48.2) End*

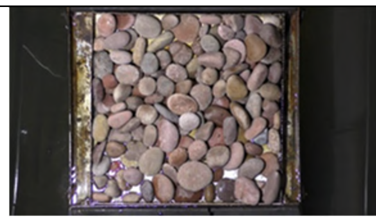
 *Figure 8-134: NDB (Run F49.1) Start*	 *Figure 8-135: NDB (Run F49.2) Start*
 *Figure 8-136: NDB (Run F49.1) End*	 *Figure 8-137: NDB (Run F49.2) End*

Table 8–17 summarizes the percentage of oil retained in the small and large substrate with different wave energies. Results show that on average, the beach materials retained three times as much of the heavy conventional crude and oil sands-derived products compared to the light to medium crudes. Not surprisingly, the very light condensate and shale oil (NDB) showed the least retention. Bunker C, while showing the highest retention in the small stones with low waves, behaved more like a light to medium crude at higher wave energies.

Table 8–17: Percent Oil Retention in the Shoreline Adhesion Tests

	Oil	Shoreline Retention Percentage - taken as weight of oil recovered from the beach/weight spilled		
		Small 10mm Stone (Pea Gravel)		Large Substrate 3-7 cm - Pebbles
		Low Rolling Waves	Breaking 15 cm waves	Breaking 20 cm waves
1	Condensate (CRW)	2.2%	0.5%	0.3%
2	Light Sour Blend (LSB)	5.6%	0.8%	0.6%
3	U.S. Bakken (NDB)	1.8%	1.6%	0.6%
4	Mixed Sweet Blend (MSW)	5.8%	2.2%	1.7%
5	Alaska North Slope (ANS)	1.8%	1.6%	1.4%
6	Medium Sour Blend (MSB)	4.3%	1.4%	1%
	Average for light to medium oils	**3.6%**	**1.4%**	**0.9%**
7	Conventional Heavy (CHV)	12.2%	4.2%	3%
8	Bunker C – Heavy Fuel Oil (HFO)	14.9%	3.4%	1.5%
9	Western Canadian Select (WCS)	10.7%	8.2%	3.9%
10	Access Western Blend (AWB)	11.2%	21%	9.7%
11	Cold Lake Blend (CLB)	10%	7.3%	2.2%
	Average for conventional heavy crude and dilbits	**11.8%**	**8.8%**	**4.1%**
12	Albian Heavy Synthetic (AHS)	17.5%	3.6%	14%
13	Synbit Blend (SYB)	3.5%	1.1%	0.3%
14	Synthetic Sweet Blend (SYN)	2.2%	1.5%	0.5%

8.5 Discussion

The shoreline adhesion tests performed were designed to give an insight into the effect of waves on the mobility of oils on the surface of a beach. In these tests, two types of substrates were evaluated, a small 10 mm pea gravel and a larger 3 to 7 cm river pebble. These were chosen to represent a wider range of beaches. The waves were selected to provide different energies. The limitation to the selection of the waves was that the energy was to be high enough to have an effect, yet not so high that the substrate would be removed by the end of a test cycle.

It was noted that the more viscous oils (i.e. HFO) tended to have a stabilizing effect on the small substrate (acted as a kind of glue). In other words, the oil tended to hold the substrate together which lessened the effect of the waves.

The lighter oils tended to disperse quicker in the water column. This would result in a larger loss of oil to the water column. In all cases, there was an initial limited loss of oil (at least a sheen) to the water surface before the onset of the waves. Due to this effect, it was not possible to perform a comprehensive mass balance of the oil. Instead the distribution of oil was used to determine the translocation of the oil.

All of the oils migrated to the bottom of the tray. Even though the beach is relatively shallow, the soil penetration data from the previous section indicates that even a 25cm deep gravel beach would show the same effect.

For the more viscous (sticky) oils, the distribution seemed to follow the movement of the substrate. For the lighter oils, the oil distribution was dependent on the water flow around the substrate. A beach with more organic matter should be able to retain more of the lighter oils.

The wave energy had a noticeable effect on the oil distribution. The low waves on the small substrate did not observably redistribute the oil. Most of the remaining oil stayed in the area of application. The higher energy waves on the small substrate tended to move the oil up towards the shore. The higher energy waves on the large substrate was more variable, but showed evidence of the oil being moved down the test cell (towards the direction of the wave) in a few instances.

A few key points from the tests can be summarized as follows:

- Light and medium oils are more susceptible to relocation within the beach sediments and dispersion into the water column, potentially leading to shoreline oiling over a larger area.
- Heavy oils (high viscosity) are less susceptible to relocation, indicating the possibility of a heavier more concentrated shoreline oiling over a smaller area.
- The smaller fine stone substrate was affected by wave action to a much greater degree than the larger pebble substrate even at lower wave energies. There was some movement of the substrate during the tests as shown by the formation of a trough in the stones in front of the wave break and the formation of a berm higher on the beach. This slight movement imparts an abrasion action between the substrate pieces and can impact oil retention.
- The simulated beach materials retained over three times as much of the heavy conventional crude and oil sands-derived products as the light to medium crudes. Bunker C showed the highest retention in the small stones with low waves but behaved more like a light to medium crude at higher wave energies.

Caution is advised in interpreting laboratory tests for such a complex process as oil interaction with an actual shoreline. For example, the test results show the distribution of the oil remaining on the beach but not the oil removed and redistributed back into the water. In a natural environment, oil is free to lift off and move laterally to potentially strand on a different section of shoreline or carry it back out to sea. Another factor is the likely presence of organic material (e.g. kelp, seaweed, driftwood) on the beach that in an actual spill could increase the retention of all oils including lighter crudes and fuel oils.

From a spill remediation point of view, this test would indicate that the heavier oils would tend to stabilize a small pebble beach, resulting in a longer clean up window. However, the results only show the distribution of the oil remaining on the beach and not the oil which has been removed from the beach. In an actual spill situation, this loss of oil back to the water would have to be addressed and/or monitored.

9 OVERALL CONCLUSIONS AND RECOMMENDATIONS

The large amounts of test data from this study show the differences in a range of oil properties and behaviours for fourteen oils tested in a variety of simulated scenarios including oil spilled on water, land and shorelines.

The series of small and meso-scale tests conducted in this project generated valuable input data needed to validate fate and behaviour computer models under controlled environmental conditions, with the overall goal being to improve the ability of models to predict oil property changes over time in a real-world situation.

Laboratory testing can never fully replicate a natural environment, but it can readily identify trends, and highlight relative differences in oil properties and behaviour. In interpreting the test results from this study, it is important to focus on the relative differences in behaviour (or similarities) between oils rather than concentrating solely on specific data values.

The likelihood or potential for oil to sink following a spill is an ongoing concern. Spills where oil is more likely to temporarily submerge, be over washed by wave action, become entrained in the water column or possibly sink may require emergency response strategies and equipment developed to deal with oil in the water column and/or on the bottom. In such cases, it is anticipated there would be the need for more extensive environmental remediation and restoration efforts. Results from the standardized physical properties and flume tests in this study can help determine which oils present a possible risk of sinking or submergence under different conditions.

The six research areas and their main conclusions are summarized below:

9.1 STANDARDIZED ANALYSIS OF PHYSICAL PROPERTIES

All 14 oils included in this study were subjected to a suite of physical and chemical property analysis of the fresh oil, along with repeat analysis conducted on multiple weathered samples.

- **Evaporative loss**
    - Some oil sands-derived products tend to evaporate somewhat more rapidly than Conventional Heavy Crude (CHV) in the initial few hours following a spill, especially at warmer temperatures. Over time (days to weeks), the oil sands-derived crude oils weather to reach densities and viscosities similar to conventional heavy crude oils. It is important to realize that as dilbits and related oil sands-derived crudes evaporate, there is no distinct separation into the parent oil stock (bitumen or heavy residue) and diluent components; both are infinitely soluble in each other.
    - With condensates, nearly all of the oil will naturally evaporate (and disperse/dissolve) from the water surface quickly after the spill. Light to medium crude oils can lose close to 50 percent of their volume within a week. Heavy conventional crudes and dilbits experience lower but still significant evaporative losses over the same time frame in the order of 25 percent. In contrast, heavy fuel oils (HFO) experience evaporative losses less than 5 percent.

- **Density**
    - Oil sands-derived crudes have physical properties closely aligned with a range of intermediate fuel oils and other heavy conventional crude oils. Their behaviour is consistent with what are known as Group 3 oils under an international oil classification scheme based on density. These oils tend to float on fresh water until densities increase enough through weathering and/or sediment uptake to increase the likelihood of temporary submergence.
    - In the extended evaporation weathering WS-3 (6-week small-scale lab weathering results, representing time scales in the order of one week in flume tank testing), CHV and the oil sands-derived products reached specific gravities between 0.98 and 1.01 at 15°C. This indicates a risk of these oils in a weathered state becoming temporarily submerged or over-washed with wave action in fresh water, a conclusion subsequently confirmed in the recirculating flume tests.
- **Viscosity**
    - The small-scale test results showed that any heavy oil, conventional or bitumen-derived, can become very viscous over a short period of time, emphasizing the importance of rapid response and selection of an appropriate recovery system (e.g. skimmers, pumps) designed to deal with viscous oils.
- **Pour Point**
    - In many cases the pour point was measured to exceed 10°C by WS-3. It may take 5-7 days of environmental exposure to reach this level in the event of a spill on water (or even longer time as weathering slows with lower temperatures). Once the pour point threshold is reached the behaviour of the oil will change and a modification of equipment (supplemental heat) or other techniques may be warranted for dealing with oil that is highly resistant to flow.
- **Emulsification**
    - Data showed that the two lightest products, condensate and synthetic sweet blend, were the only oils unlikely to emulsify in either a fresh or weathered state.
    - Light to medium crudes are unlikely to emulsify until they reach a highly weathered state after a few days.
    - Heavy oils and oil sands-derived crudes are very likely to form emulsions with water contents over 50 percent in a fresh state, and to form emulsions with lower water contents as they rapidly weather. As weathering continues, these oils (including CHV and HFO) quickly become too viscous to emulsify any further.

9.2 COMPARISON OF DIFFERENT LABORATORY EVAPORATION METHODS

- The different methods may arrive at a target endpoint at different times, but once a common target mass loss is reached, physical properties of the remaining oil sample were found to be remarkably consistent, irrespective of the technique used to generate the desired mass loss.
- Testing showed that the method used to get to a particular weathered state is not critically important because the physical parameters of an oil sample are tied to the evaporative state of the oil.
- Artificial weathering of oils are primarily used for three purposes:
    - Physical parameters at the oil's weathered state are determined and used as inputs for spill modeling;

- To generate a large quantity of weathered oil so that the sample may be used to evaluate a response technique using an expanded oil data set (fresh plus weathered); and,
- A sample is weathered to a specific mass loss state to match another sample and used for further analysis.

9.3 OIL-PARTICLE INTERACTIONS

A study of oil-particle interactions used a small-scale shaking flask apparatus to determine the propensity of each oil to bind with sediment, forming what are known as oil-mineral aggregates (OMAs). These are oil droplets stabilized by fine mineral particles in the water column, thereby potentially removing oil from the surface.

- Heavier oils will not break up into small droplets, and so will not significantly interact with suspended solids in the same way as lighter oils. Therefore, we expect oil particle interactions to be significant only in the earliest phases of a spill (e.g., hours to days).
- At moderate turbulence levels and particle concentrations expected in marine and freshwater environments, on average, less than 6 percent of the oil on the surface was agglomerated and transferred into the water column as part of OMA (so called "removal rate"). This rule of thumb applied across all of the oil types from light or heavy conventional crudes to a wide range of oil sands-derived crudes.
- A small number of the tests resulted in oil removal rates between 20 percent and 60 percent, and one run with ANS crude saw 90 percent. However, these elevated results occurred with particle concentrations at the extreme end of conditions expected in a natural environment with high turbulence and sediment loads such as might be found for short periods of time in a fast-flowing river during the spring flood.

9.4 FLUME WEATHERING TESTS

Long-term Flume Weathering Tests used on-water weathering in a recirculating flume, representing a methodology that more closely mimics behaviour in the environment when compared to evaporative weathering such as the techniques used in the wind tunnel, or rotary evaporator employed in small-scale tests. Results support conclusions drawn from the small-scale physical properties data, specifically:

- All of the test oils are expected to remain floating in marine (saltwater) environments in any weathering state tested in the flume tank. However, scenarios involving highly turbulent water with suspended sediments or stranded oil being refloated after picking up beach material could increase that risk for any oil.
- Light and medium oils continued to float in fresh water as their specific gravity remained less than 1.0 g/mL even after the long duration test runs (minimum 5 days).
- Heavy oils (conventional and non-conventional) weathered to have specific gravities very close to or equal to neutral buoyancy in freshwater (e.g. >0.98 – 1.01) within a few hours to days. This characteristic makes them more susceptible to temporary submergence/over washing and entrainment in the natural environment. It is important to note that a density slightly greater than 1.0 does not mean that large portions of a weathered oil slick will immediately sink. Blobs of oil may separate and submerge from under the main slick but slightly negatively buoyant oil

mats with entrained air bubbles were observed to remain floating in the recirculating flume for extended periods of time (many days).

- Bitumen derived non-conventional oils typically weathered much faster than conventional oils, then slowed dramatically after the first few hours (up to a day). Ultimate densities (after the test week) were similar between the non-conventional and conventional heavy oils.
- During one cold temperature run, the Heavy Fuel Oil (HFO) showed signs of submergence by the 6-hour mark with some blobs of oil being stuck to the walls of the flume. At 24 hours a noticeable portion of the oil was in the water.
- During the warm temperature runs, two oils showed submergence tendencies during testing. The first, AHS, had a few blobs of oil stuck to the wall of the tank at the 6 hour mark. By 24 hours large blobs of oil could be seen at the bottom of the flume. The second oil, AWB, had numerous blobs of oil floating within the water column and the water seemed to darken in colour by 72 hours. At this time, the volume remaining floating at the surface was diminished.
- The potential for entrainment in the water column through an uptake of suspended sediments is not unique to oil sands-derived crudes and can occur for heavy crudes and fuel oils. The only oil substantially affected by the addition of sediments to the flume tank in these tests was the Heavy Fuel Oil (HFO) during a cold temperature run. In that case, noticeable submergence occurred almost immediately, with most of the oil submerging below the surface by the 1-hour mark.
- Oils that start out with similar physical properties may weather at different rates and stop weathering (get to a point where change over short periods of time is not noticed) at different points.
- Chemical properties as a sole predictor of fate and behaviour is not yet a feasible means of accurate modeling. In fact, a process as well known as emulsification may yet still confound models with respect to the point at which an oil will start to emulsify – and the impact that the emulsification will have on apparent density and viscosity.
- Weathering at a smaller scale is sufficient for generating data for models, or for simple comparative testing that is “disconnected” from how it would behave in the environment due to limited weathering pathways and scaling impacts.
- The flume tank is perhaps a more “realistic” weathering method as it employs many of the weathering attributes that an oil would experience in the event of a spill in the environment.

9.5 Porous Media Tests

Porous Media Tests determined the depths of penetration of each of the oils when spilled onto three soil types: small pebbles, sand, and loamy soil. Results showed that:

- The most viscous oils (e.g. Bunker C) displayed the lowest penetration and the least viscous oils (notably condensate, U.S. Bakken and Synthetic Sweet Blend) penetrated the furthest. The six heaviest oils including conventional crude and oil sands-derived crudes showed no significant pattern in terms of penetration depths vs. oil type.
- The pea gravel had no significant retention capacity for any of the oils in the test column, indicating that a spill on fine-grained gravel would penetrate quickly as confirmed in the shoreline adhesion tests.

9.6 Shoreline Adhesion Tests

Shoreline Adhesion Tests used a wave tank and artificial "beach" to determine the propensity of the oil to adhere to two different beach substrates after being subjected to low rolling waves and higher breaking waves.

- Light and medium oils were more susceptible to lifting off and relocating laterally. In a natural environment, this behaviour could theoretically result in the oil dispersing into the water column as well as causing lighter shoreline oiling over a larger area. In an actual spill, organic matter on the beach (kelp, seaweed etc.) could increase the retention of even light oils.
- Heavy oils (higher viscosity) were less susceptible to relocation resulting in a heavier more concentrated shoreline oiling over a smaller area.
- The more viscous oils (e.g. Bunker C) tended to have a stabilizing effect on the small substrate (acting as a kind of glue). In other words, the oil tended to hold the substrate together which lessened the effect of the waves.

In summary, fresh oil sands-derived crudes are similar to heavy conventional crude and fuel oils in their physical characteristics. Proven response equipment developed over several decades is readily available to deal with the high viscosities of weathered heavy oils such as Bunker C, CHV, and oil sands- derived crudes, even as viscosity exceeds 100,000 cP (centipoise).

In some scenarios, oil sands-derived crudes may temporarily submerge or sink in fresh water, but there are also conventional crudes and residual fuel oils that behave in a similar fashion as their densities approach or exceed a specific gravity of one.

Data generated in this project covers the full spectrum of expected behaviours for a wide range of oils. In particular, results show that oil sands-derived crudes (including dilbits) do not exhibit unusual characteristics that would substantially affect decisions to use oil spill response strategies already developed to deal with a wide range of spill-related scenarios and oil types.

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APPENDIX A – OIL PROPERTY TEST METHODOLOGY AND RELATIONSHIP TO SPILL BEHAVIOR

A.1 Evaporation

The oil was divided into four aliquots. Three aliquots were weathered in a wind tunnel: one for two days; one for two weeks; and, one for six weeks. Depending on the conditions at a spill site, this is typically equivalent to a few hours; a few days; and a week or so at sea. In addition, the fresh oil was subjected to a modified ASTM distillation (ASTM D86-90, modified in that both liquid and vapor temperature are measured) in order to obtain two oil-specific constants for evaporation prediction purposes. Evaporation is correlated using Evaporative Exposure (θ), a dimensionless time unit calculated by:

$$\theta = kt/x$$

where: k = a mass transfer coefficient [m/s] *(determined experimentally in the laboratory wind tunnel or by an equation related to wind speed for spills at sea)*

t = elapsed time [s]

x = oil thickness [m]

The modified distillation information is used in conjunction with the wind tunnel data to predict evaporation rates for oil spills at sea.

A Gas Chromatographic Simulated Distillation (GC SIMDIS) was also conducted on the fresh AHS by an outside laboratory using ASTM D7169/D7900 procedures, as required.

A.2 Physical properties

The oils were subjected to the analyses outlined in Table A.1. Test temperatures are chosen to represent typical values for the region for those tests that are temperature-sensitive, such as density and viscosity.

Table A.1: Test procedures for oil analysis

Property	Test Temperature(s)	Equipment	Procedure
Evaporation	Ambient	Wind Tunnel ASTM Distillation Apparatus	ASTM D86 (modified)
Density	0°, 15°, 20° and 30°C	Rudolph Research Analytical DDM 2911	ASTM D5002
Viscosity	0°, 15°, 20° and 30°C	Brookfield DV III+ Digital Rheometer c/w Cone and Plate and/or Brookfield R/S-CPS+ Rheometer	Brookfield M/98-211 and/or M/01-213-A0706

Interfacial Tension	Room Temperature	CSC DuNouy Ring Tensiometer	ASTM D971
Pour Point	N/A	ASTM Test Jars and Thermometers/Thermocouples	ASTM D5853
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93
Emulsification Tendency/Stability	1° and 20 °C	Rotating Flask Apparatus	(Hokstad and Daling 1993, Zagorski and Mackay 1982)

A.2.1 Density

Density, the mass per unit volume of the oil (or emulsion), determines how buoyant the oil is in water. The common unit of density is grams per millilitre or cubic centimetre (g/mL or g/cm^3); the SI unit is kg/m^3, which is numerically 1000 times the value in g/mL. The density of spilled crude oil increases with weathering and decreases with increasing temperature. Density affects the following spill processes:

- Sinking - if the density of the oil exceeds that of the water it will sink;
- Spreading - in the early stages of a spill, more dense oils spread faster;
- Natural dispersion - more dense oils stay dispersed more easily; and,
- Emulsification stability - dense oils form more stable emulsions.

A.2.2 Viscosity

Viscosity is a measure of the resistance of oil to flowing, once it is in motion. The common unit of dynamic viscosity is the centi-Poise (cP); the SI unit is the milli-Pascal second (mPas), which is numerically equivalent to the centi-Poise. The common unit of kinematic viscosity (calculated by multiplying the dynamic viscosity by the density) is the centi-Stoke (cSt) the SI unit is the square millimetre/second (mm^2/s), which is numerically equivalent to the centi-Stoke. The viscosity of spilled crude oil increases as weathering progresses and decreases with increasing temperature. Viscosity is one of the most important properties from the perspective of spill behavior and affects the following processes:

- Spreading - viscous oils spread more slowly;
- Natural and chemical dispersion - highly viscous oils are difficult to disperse;
- Emulsification tendency and stability - viscous oils form more stable emulsions; and,
- Recovery and transfer operations - more viscous oils are generally harder to skim and more difficult to pump.

A.2.3 Interfacial Tension

Interfacial tension is a measure of the surface forces that exist between the interfaces of the oil and water, and the oil and air. The common unit of interfacial tension is the dyne/cm; the SI unit is the milli-Newton/metre (mN/m), which is numerically equivalent to the dyne/cm. Chemical dispersants work by reducing the oil/water interfacial tension to allow a given mixing energy (i.e., sea state) to produce smaller oil droplets. Emulsion breakers work by lowering the oil/water interfacial tension; this weakens the continuous layer of oil surrounding the suspended water droplets and allows them to coalesce and drop out of the emulsion. Herding agents work by reducing the water/air interfacial tension (surface tension) around a slick causing some oils to contract and thicken. Interfacial tensions (oil/air and oil/water) are fairly insensitive to temperature, but are affected by evaporation. Interfacial tension affects the following processes:

- Spreading - interfacial tensions determine how fast an oil will spread and whether the oil will form a sheen;
- Natural and chemical dispersion - oils with high interfacial tensions are more difficult to disperse naturally, chemical dispersant work by temporarily reducing the oil/water interfacial tension;
- Emulsification rates and stability; and,
- Mechanical recovery - oleophilic skimmers (e.g., rope-mop and belt skimmers) work best on oils with moderate to high interfacial tensions.

A.2.4 Pour Point

The pour point is the lowest temperature (to the nearest multiple of 3 °C) at which crude oil will still flow in a small test jar tipped on its side. Near, and below this temperature, the oil develops a yield stress and, in essence, gels. The pour point of an oil increases with weathering. Pour point affects the following processes:

- Spreading - oils at temperatures below their pour points will not spread on water;
- Viscosity - an oil's viscosity at low shear rates increases dramatically at temperatures below its pour point;
- Dispersion - an oil at a temperature below its pour point may be difficult to disperse; and,
- Recovery - crude oil below its pour point may not flow towards skimmers or down inclined surfaces in skimmers

A.2.5 Flash Point

The flash point of crude oil is the temperature at which the oil produces sufficient vapors to ignite when exposed to an open flame or other ignition source. Flash point increases with increasing evaporation. It is an important safety-related spill property.

A.2.6 Emulsification Tendency and Stability

The tendency of crude oil to form water-in-oil emulsions (or "mousse") and the stability of the emulsion formed are measured by two numbers: the Emulsification Tendency Index (Zagorski and Mackay 1982, Hokstad and Daling 1993) and the Emulsion Stability (adapted from Fingas *et al.* 1998). The Emulsification Tendency Index is a measure of the oil's propensity to form an emulsion, quantified by extrapolating back to time = 0 the fraction of the parent oil that remains (i.e., does not cream out) in the emulsion formed in a rotating flask apparatus over several hours. If a crude oil has an Emulsification Tendency Index between 0 and 0.25 it is unlikely to form an emulsion; if it has a Tendency Index between 0.25 and 0.75 it has a moderate tendency to form emulsions. A value of 0.75 to 1.0 indicates a high tendency to form emulsions. Recently the Emulsion Stability assessment has been changed to reflect the four categories suggested by Fingas *et al.* 1998. Emulsion types are selected based on water content, emulsion rheology and the visual appearance of the emulsion after 24 hours settling. The four categories, and their defining characteristics, are:

5. Unstable – looks like original oil; water contents after 24 hours of 1% to 23% averaging 5%; viscosity same as oil on average

6. Entrained Water – looks black, with large water droplets; water contents after 24 hours of 26% to 62% averaging 42%; emulsion viscosity 13 times greater than oil on average
7. Meso-stable – brown viscous liquid; water contents after 24 hours of 35% to 83% averaging 62%; emulsion viscosity 45 times greater than oil on average
8. Stable – the classic "mousse", a brown gel/solid; water contents after 24 hours of 65% to 93% averaging 80%; emulsion viscosity 1100 times greater than oil on average

Both the Tendency Index and Stability generally increase with increased degree of evaporation. Colder temperatures generally increase both the Tendency Index and Stability (i.e., promote emulsification) unless the oil gels as the temperature drops below its pour point and it becomes too viscous to form an emulsion. Emulsion formation results in large increases in the spill's volume, enormous viscosity increases (which can reduce dispersant effectiveness), and increased water content (which can prevent ignition of the slicks and *in situ* burning).

APPENDIX B – OIL MODEL INPUTS AND CHEMICAL ANALYSIS

B.1 AHS OIL

SL Ross Model	AHS	
Modeling Constants		
Standard Density	936.515	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	308.042	kg/m3
Density Constant 2	0.70397	kg/K.m3
Standard Viscosity	757.10443	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	24.9485	
Viscosity Constant 2	9281.53	K-1
Oil/Water Interfacial Tension	23.9805	dyne/cm
Air/Oil Interfacial Tension	29.9402	dyne/cm
Oil/Water Interfacial Tension Constant	0.54064	
Air/Oil Interfacial Tension Constant	0.56570	
Initial Pour Point	239.411	K
Pour Point Constant	0.74389	
ASTM Distillation Constant A (slope)	932.109	K
ASTM Distillation Constant B (intercept)	347.533	K
Emulsification Delay	0	
Initial Flash Point	212.983	K
Flash Point Constant	1.76991	
Fv vs. Theta A	9.60000	
Fv vs. Theta B	13.70000	
B.Tg	12769.89	
B.To	4761.20	

AHS SIMDIS Results, Chemical Analysis

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3884-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	AHS FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	5.6	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	47.7	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	85	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	33.1	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	33.7	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	34.8	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	35.4	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	37.2	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	40.2	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	47.4	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	59.9	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	70.0	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	80.1	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	90.2	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	103.8	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	115.6	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	130.7	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	143.4	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	157.7	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	172.0	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	192.5	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	222.3	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	251.8	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	276.7	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	297.4	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	314.9	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	331.1	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	345.4	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	357.5	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	368.2	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	377.8	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	386.4	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	394.3	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	401.4	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	408.0	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	414.1	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	419.7	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

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B8A8666:UY3884-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID
SL ROSS ENVIRONMENTAL RESEARCH | N/A | SL ROSS ENVIRONMENTAL RESEARC
Well/Plant/Facility | Initials of Sampler | Sampling Company
AHS FRESH | VIAL
Field or Area | Pool or Zone | Sample Point | Container Identity | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas
Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode
Production Rates (Water m³/d | Oil m³/d | Gas 1000m³/d) | Gauge Pressures kPa (Source | As Received) | Temperature °C (Source | As Received: 23.0) | Well Status Type | Well Type
Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/04/24		2018/12/13	2018/12/31		DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	425.1	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	430.3	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	435.6	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	440.9	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	446.1	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	451.1	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	455.5	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	460.0	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	464.4	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	468.7	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	473.0	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	477.3	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	481.6	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	486.1	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	490.6	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	495.1	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	499.3	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	503.4	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	507.5	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	511.7	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	516.1	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	520.5	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	525.0	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	529.7	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	534.4	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	539.0	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	543.7	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	548.6	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	553.7	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	558.7	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	563.7	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	568.7	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	573.7	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	579.0	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	584.5	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	590.0	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	595.7	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	601.6	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	608.0	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	614.3	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	621.2	°C	ASTM D7169	N/A

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3884-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	AHS FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval	From: To:
Elevations (m)	KB: GRD:
Sample Gathering Point	
Solution Gas	
Test Type	
No.	
Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates	Water m³/d: Oil m³/d: Gas 1000m³/d:
Gauge Pressures kPa	Source: As Received:
Temperature °C	Source: As Received: 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	628.2	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	635.1	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	642.7	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	650.7	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	658.4	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	668.5	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	678.7	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	689.4	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	699.7	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	709.9	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	15.11	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	54	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	23	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	17	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	5.4	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	74	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	31	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	43	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	23	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	15	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	12	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	17	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	15	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	27	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	13	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	31	mg/kg	EPA 3540C/8270E m	5.0
Perylene	24	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	93	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	510	mg/kg	CCME CWS/EPA 8260d m	1.5
Toluene	1600	mg/kg	CCME CWS/EPA 8260d m	6.0

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Results relate only to items tested

Remarks:

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3884-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	AHS FRESH
Container Identity	VIAL
Percent Full	
Temperature °C (As Received)	23.0
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

Test Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas; Test Type; No.; Multiple Recovery; Well Fluid Status; Well Status Mode; Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d; Gauge Pressures kPa: Source, As Received; Temperature °C: Source, As Received; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Ethylbenzene	500	mg/kg	CCME CWS/EPA 8260d m	3.0
m & p-Xylene	1300	mg/kg	CCME CWS/EPA 8260d m	12
o-Xylene	480	mg/kg	CCME CWS/EPA 8260d m	6.0
Xylenes (Total)	1800	mg/kg	Auto Calc	13
F1 (C6-C10) - BTEX	64000	mg/kg	Auto Calc	3000
F1 (C6-C10)	68000	mg/kg	CCME CWS/EPA 8260d m	3000

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B926180:VM7398-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

SL ROSS ENVIRONMENTAL RESEARCH | N/A | SL ROSS ENVIRONMENTAL RESEARC
Well/Plant/Facility | Initials of Sampler | Sampling Company

AHS | VIAL
Field or Area | Pool or Zone | Sample Point | Container Identity | Percent Full

Test Recovery | Interval (From: To:) | Elevations (m) (KB, GRD) | Sample Gathering Point | Solution Gas
Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode
Production Rates: Water m³/d | Oil m³/d | Gas 1000m³/d
Gauge Pressures kPa: Source | As Received
Temperature °C: Source | As Received 23.0
Well Status Type | Well Type | Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2019/04/01		2019/04/03	2019/04/16	2019/05/29	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	1.2	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	3	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	42.6	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	2	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	76.0	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3885-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL RESEARC
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	AHS 2 DAY
Sampling Company	VIAL
Field or Area	
Pool or Zone	
Sample Point	
Container Identity	
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d)	
Gauge Pressures kPa (Source, As Received)	
Temperature °C (Source / As Received)	23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/28
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	18	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	6.9	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	6.9	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	7.6	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	13	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	6.2	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	100	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	1100	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1600	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	760	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	250	mg/kg	EPA 3540C/8270E m	5.0
Perylene	5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	20	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	20	mg/kg	CCME CWS/EPA 8260d m	0.15
Toluene	170	mg/kg	CCME CWS/EPA 8260d m	0.61
Ethylbenzene	100	mg/kg	CCME CWS/EPA 8260d m	0.31
m & p-Xylene	420	mg/kg	CCME CWS/EPA 8260d m	1.2
o-Xylene	220	mg/kg	CCME CWS/EPA 8260d m	0.61
Xylenes (Total)	640	mg/kg	Auto Calc	1.4
F1 (C6-C10) - BTEX	24000	mg/kg	Auto Calc	310
F1 (C6-C10)	25000	mg/kg	CCME CWS/EPA 8260d m	310

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25

Page 1 of 1

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8666:UY3886-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL RESEARC
Sample Point	AHS 14 DAY
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/05/10
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	DUO,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	65	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	28	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	20	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	5.2	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	92	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	38	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	52	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	26	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	19	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	14	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	5.2	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	21	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	17	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	30	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	9.8	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	37	mg/kg	EPA 3540C/8270E m	5.0
Perylene	29	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	110	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	93	mg/kg	CCME CWS/EPA 8260d m	0.19
Toluene	440	mg/kg	CCME CWS/EPA 8260d m	0.78
Ethylbenzene	180	mg/kg	CCME CWS/EPA 8260d m	0.39
m & p-Xylene	500	mg/kg	CCME CWS/EPA 8260d m	1.6
o-Xylene	240	mg/kg	CCME CWS/EPA 8260d m	0.78
Xylenes (Total)	740	mg/kg	Auto Calc	1.7
F1 (C6-C10) - BTEX	43000	mg/kg	Auto Calc	390
F1 (C6-C10)	44000	mg/kg	CCME CWS/EPA 8260d m	390

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Remarks:

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2018/12/31 16:25   Page 1 of 1

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B.2 ANS OIL

SL Ross Model	ANS	
Modeling Constants		
Standard Density	862.639	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	188.168	kg/m3
Density Constant 2	0.73160	kg/K.m3
Standard Viscosity	21.38200	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	10.6586	
Viscosity Constant 2	7165.55	K-1
Oil/Water Interfacial Tension	13.8544	dyne/cm
Air/Oil Interfacial Tension	25.8526	dyne/cm
Oil/Water Interfacial Tension Constant	0.35248	
Air/Oil Interfacial Tension Constant	0.36866	
Initial Pour Point	250.637	K
Pour Point Constant	0.30729	
ASTM Distillation Constant A (slope)	618.127	K
ASTM Distillation Constant B (intercept)	371.010	K
Emulsification Delay	9999999999	
Initial Flash Point	171.661	K
Flash Point Constant	3.36540	
Fv vs. Theta A	6.00000	
Fv vs. Theta B	10.50000	
B.Tg	6490.34	
B.To	3895.61	

ANS SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8666:UY3887-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	ANS FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From / To	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/27
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	0.6	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	10.5	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	24	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	33.0	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	33.2	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	34.9	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	38.3	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	50.2	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	65.3	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	71.6	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	77.2	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	82.9	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	88.8	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	93.7	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	99.7	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	104.2	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	108.1	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	115.4	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	121.2	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	128.3	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	133.2	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	139.0	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	144.6	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	152.1	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	158.1	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	165.2	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	170.3	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	177.7	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	184.6	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	190.3	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	197.4	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	204.3	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	209.9	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	215.8	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	222.0	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	227.9	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	234.5	°C	ASTM D7169	N/A

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Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 1 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3887-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	ANS FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/04/27
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	240.2	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	245.7	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	251.9	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	257.7	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	263.0	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	269.4	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	276.2	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	282.0	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	288.2	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	293.9	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	299.0	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	305.1	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	310.0	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	315.9	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	321.7	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	327.7	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	334.0	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	340.0	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	346.3	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	352.1	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	358.5	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	364.5	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	371.0	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	377.4	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	383.9	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	390.6	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	397.1	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	403.5	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	410.0	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	416.1	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	422.5	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	428.8	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	435.8	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	443.2	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	450.9	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	458.1	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	465.6	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	473.3	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	481.2	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	489.9	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	498.7	°C	ASTM D7169	N/A

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Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 2 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3887-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL RESEARC
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	
Sampling Company	
Field or Area	
Pool or Zone	
Sample Point	ANS FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/04/27
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	507.2	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	516.4	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	526.2	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	536.5	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	547.1	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	558.3	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	569.3	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	580.6	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	592.5	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	604.9	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	618.1	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	631.9	°C	ASTM D7169	N/A
D7169 Distillation 87 mass % off	646.7	°C	ASTM D7169	N/A
D7169 Distillation 88 mass % off	662.1	°C	ASTM D7169	N/A
D7169 Distillation 89 mass % off	681.2	°C	ASTM D7169	N/A
D7169 Distillation 90 mass % off	699.4	°C	ASTM D7169	N/A
D7169 Distillation 91 mass % off	716.7	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	8.82	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	13	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	11	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	5.1	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	6.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	8.9	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	9.5	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	75	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	900	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1300	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	690	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	200	mg/kg	EPA 3540C/8270E m	5.0

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Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

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2018/12/31 16:25   Page 3 of 4

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CERTIFICATE OF ANALYSIS

B8A8666:UY3887-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name

LSD: N/A
Well ID: SL ROSS ENVIRONMENTAL RESEARC

SL ROSS ENVIRONMENTAL RESEARCH
Well/Plant/Facility

Initials of Sampler | Sampling Company

Field or Area | Pool or Zone | Sample Point: ANS FRESH | Container Identity: VIAL | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d) | Gauge Pressures kPa (Source, As Received) | Temperature °C (Source, As Received: 23.0) | Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/04/27		2018/12/13	2018/12/31		DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	14	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	2300	mg/kg	CCME CWS/EPA 8260d m	1.6
Toluene	5400	mg/kg	CCME CWS/EPA 8260d m	6.3
Ethylbenzene	1200	mg/kg	CCME CWS/EPA 8260d m	3.1
m & p-Xylene	4000	mg/kg	CCME CWS/EPA 8260d m	13
o-Xylene	1400	mg/kg	CCME CWS/EPA 8260d m	6.3
Xylenes (Total)	5400	mg/kg	Auto Calc	14
F1 (C6-C10) - BTEX	130000	mg/kg	Auto Calc	3100
F1 (C6-C10)	140000	mg/kg	CCME CWS/EPA 8260d m	3100

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 4 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B926180:VM7399-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	ANS
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	<1	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	10.8	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	1.7	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	25.5	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

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2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3888-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	ANS 2 DAY
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/04/20
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	24	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	14	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	6.9	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	7.9	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	12	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	14	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	6.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	100	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	1200	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1700	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	700	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	260	mg/kg	EPA 3540C/8270E m	5.0
Perylene	5.3	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	19	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	210	mg/kg	CCME CWS/EPA 8260d m	1.5
Toluene	1200	mg/kg	CCME CWS/EPA 8260d m	6.0
Ethylbenzene	330	mg/kg	CCME CWS/EPA 8260d m	3.0
m & p-Xylene	900	mg/kg	CCME CWS/EPA 8260d m	12
o-Xylene	400	mg/kg	CCME CWS/EPA 8260d m	6.0
Xylenes (Total)	1300	mg/kg	Auto Calc	13
F1 (C6-C10) - BTEX	50000	mg/kg	Auto Calc	3000
F1 (C6-C10)	53000	mg/kg	CCME CWS/EPA 8260d m	3000

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 1 of 1

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CERTIFICATE OF ANALYSIS

B8A8666:UY3889-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

SL ROSS ENVIRONMENTAL RESEARCH — Well/Plant/Facility
N/A — Initials of Sampler
SL ROSS ENVIRONMENTAL RESEARC — Sampling Company

Field or Area | Pool or Zone | Sample Point: ANS 14 DAY | Container Identity: VIAL | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas
Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode
Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d) | Gauge Pressures kPa (Source / As Received) | Temperature °C (Source / As Received: 23.0) | Well Status Type | Well Type
Gas or Condensate Project | Licence No.

Date Sampled Start: 2017/05/02 | Date Sampled End | Date Received: 2018/12/13 | Date Reported: 2018/12/31 | Date Reissued | Analyst: HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	17	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	16	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	7.1	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	8.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	12	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	13	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	5.9	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	100	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	830	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1100	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	220	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	260	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	19	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	<0.16	mg/kg	CCME CWS/EPA 8260d m	0.16
Toluene	7.7	mg/kg	CCME CWS/EPA 8260d m	0.65
Ethylbenzene	0.64	mg/kg	CCME CWS/EPA 8260d m	0.32
m & p-Xylene	2.7	mg/kg	CCME CWS/EPA 8260d m	1.3
o-Xylene	1.6	mg/kg	CCME CWS/EPA 8260d m	0.65
Xylenes (Total)	4.3	mg/kg	Auto Calc	1.4
F1 (C6-C10) - BTEX	<320	mg/kg	Auto Calc	320
F1 (C6-C10)	<320	mg/kg	CCME CWS/EPA 8260d m	320

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 1 of 1

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B.3 AWB Oil

SL Ross Model	AWB	
Modeling Constants		
Standard Density	917.554	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	297.327	kg/m3
Density Constant 2	0.66878	kg/K.m3
Standard Viscosity	1907.42478	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	19.6816	
Viscosity Constant 2	8102.83	K-1
Oil/Water Interfacial Tension	8.8956	dyne/cm
Air/Oil Interfacial Tension	29.4944	dyne/cm
Oil/Water Interfacial Tension Constant	1.94852	
Air/Oil Interfacial Tension Constant	0.70392	
Initial Pour Point	236.751	K
Pour Point Constant	0.73610	
ASTM Distillation Constant A (slope)	681.382	K
ASTM Distillation Constant B (intercept)	339.469	K
Emulsification Delay	9999999999	
Initial Flash Point	223.204	K
Flash Point Constant	1.24014	
Fv vs. Theta A	3.80000	
Fv vs. Theta B	11.50000	
B.Tg	7835.89	
B.To	3903.89	

AWB SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3890-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	AWB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/10
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	1.6	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	65.7	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	170	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	33.7	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	34.2	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	34.8	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	35.3	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	36.3	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	37.9	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	40.2	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	44.6	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	53.4	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	63.8	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	69.6	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	76.5	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	85.5	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	97.7	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	112.3	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	132.9	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	152.2	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	173.2	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	200.0	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	220.4	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	238.0	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	252.4	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	265.1	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	277.4	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	288.1	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	297.3	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	306.2	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	314.5	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	323.0	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	331.5	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	339.8	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	347.7	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	355.5	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	363.1	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 1 of 3

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Maxxam
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CERTIFICATE OF ANALYSIS

B8A8666:UY3890-01
Laboratory Number

MaxxID *Client ID* *Meter Number*

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name *LSD* *Well ID*

SL ROSS ENVIRONMENTAL RESEARCH — N/A — SL ROSS ENVIRONMENTAL RESEARC
Well/Plant/Facility *Initials of Sampler* *Sampling Company*

AWB FRESH — VIAL
Field or Area *Pool or Zone* *Sample Point* *Container Identity* *Percent Full*

Test Recovery *Interval* (*From:* *To:*) *Elevations (m)* (*KB* *GRD*) *Sample Gathering Point* *Solution Gas*

Test Type *No.* *Multiple Recovery* *Well Fluid Status* *Well Status Mode*

Production Rates (*Water m³/d* *Oil m³/d* *Gas 1000m³/d*) *Gauge Pressures kPa* (*Source* *As Received*) *Temperature °C* (*Source* *As Received* 23.0) *Well Status Type* *Well Type*

Gas or Condensate Project *Licence No.*

2017/05/10 — 2018/12/13 — 2018/12/31 — DUO,DR3,YT2,BC5,MN2
Date Sampled Start *Date Sampled End* *Date Received* *Date Reported* *Date Reissued* *Analyst*

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	370.8	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	378.5	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	386.2	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	393.8	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	401.2	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	408.4	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	415.1	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	421.6	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	428.1	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	434.9	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	442.3	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	449.9	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	456.9	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	464.2	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	471.5	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	479.0	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	486.9	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	495.2	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	502.8	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	510.5	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	518.7	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	527.3	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	536.0	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	544.8	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	554.1	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	563.1	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	571.8	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	580.6	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	589.6	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	598.4	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	607.6	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	616.7	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	625.9	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	634.6	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	643.4	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	651.9	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	660.0	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	669.6	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	678.4	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	687.2	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	694.4	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information — Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 2 of 3

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8666:UY3890-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
LSD	N/A
Initials of Sampler	
Well ID	
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	AWB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From / To	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/10
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	701.8	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	708.1	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	714.7	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	22.13	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	5.2	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	31	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	60	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	25	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	13	mg/kg	EPA 3540C/8270E m	5.0
Perylene	12	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	9.5	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	1300	mg/kg	CCME CWS/EPA 8260d m	1.9
Toluene	2300	mg/kg	CCME CWS/EPA 8260d m	7.6
Ethylbenzene	210	mg/kg	CCME CWS/EPA 8260d m	3.8
m & p-Xylene	1600	mg/kg	CCME CWS/EPA 8260d m	15
o-Xylene	380	mg/kg	CCME CWS/EPA 8260d m	7.6
Xylenes (Total)	2000	mg/kg	Auto Calc	17
F1 (C6-C10) - BTEX	67000	mg/kg	Auto Calc	3800
F1 (C6-C10)	73000	mg/kg	CCME CWS/EPA 8260d m	3800

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 3 of 3

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CERTIFICATE OF ANALYSIS

B926180:VM7400-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

SL ROSS ENVIRONMENTAL RESEARCH | N/A | SL ROSS ENVIRONMENTAL RESEARC
Well/Plant/Facility | Initials of Sampler | Sampling Company

AWB | VIAL
Field or Area | Pool or Zone | Sample Point | Container Identity | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas
Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode
Production Rates: Water m³/d | Oil m³/d | Gas 1000m³/d
Gauge Pressures kPa: Source | As Received
Temperature °C: Source | As Received: 23.0
Well Status Type | Well Type | Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2019/04/01		2019/04/03	2019/04/16	2019/05/29	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	2	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	1.3	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	9	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	66.0	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	1.4	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	173	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

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2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

Laboratory Number: B8A8666:UY3892-01

MaxxID:
Client ID:
Meter Number:

Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD: N/A
Well ID: SL ROSS ENVIRONMENTAL RESEARC

Well/Plant/Facility: SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler:
Sampling Company:

Field or Area:
Pool or Zone:
Sample Point: AWB 2 DAY
Container Identity: VIAL
Percent Full:

Test Recovery:
Interval — From: To:
Elevations (m) — KB: GRD:
Sample Gathering Point:
Solution Gas:

Test Type:
No.:
Multiple Recovery:
Well Fluid Status:
Well Status Mode:

Production Rates — Water m³/d: Oil m³/d: Gas 1000m³/d:
Gauge Pressures kPa — Source: As Received:
Temperature °C — Source: As Received: 23.0
Well Status Type:
Well Type:
Gas or Condensate Project:
Licence No.:

Date Sampled Start: 2017/05/12
Date Sampled End:
Date Received: 2018/12/13
Date Reported: 2018/12/31
Date Reissued:
Analyst: DUO,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.1	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	5.5	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	6.7	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	5.5	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	5.4	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	34	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	67	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	24	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	16	mg/kg	EPA 3540C/8270E m	5.0
Perylene	13	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	650	mg/kg	CCME CWS/EPA 8260d m	1.4
Toluene	1400	mg/kg	CCME CWS/EPA 8260d m	5.4
Ethylbenzene	130	mg/kg	CCME CWS/EPA 8260d m	2.7
m & p-Xylene	1000	mg/kg	CCME CWS/EPA 8260d m	11
o-Xylene	270	mg/kg	CCME CWS/EPA 8260d m	5.4
Xylenes (Total)	1300	mg/kg	Auto Calc	12
F1 (C6-C10) - BTEX	29000	mg/kg	Auto Calc	2700
F1 (C6-C10)	32000	mg/kg	CCME CWS/EPA 8260d m	2700

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25

Page 1 of 1

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CERTIFICATE OF ANALYSIS

B8A8666:UY3891-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name

LSD: N/A

Well ID: SL ROSS ENVIRONMENTAL RESEARC

SL ROSS ENVIRONMENTAL RESEARCH
Well/Plant/Facility

Initials of Sampler | Sampling Company

Field or Area | Pool or Zone

Sample Point: AWB 14 DAY

Container Identity: VIAL

Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates (Water m³/d | Oil m³/d | Gas 1000m³/d) | Gauge Pressures kPa (Source | As Received) | Temperature °C (Source | As Received: 23.0) | Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/05/24		2018/12/13	2018/12/31		DUO,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	5.8	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	6.8	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	5.3	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	5.2	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	30	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	53	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	16	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	16	mg/kg	EPA 3540C/8270E m	5.0
Perylene	13	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	190	mg/kg	CCME CWS/EPA 8260d m	0.21
Toluene	470	mg/kg	CCME CWS/EPA 8260d m	0.83
Ethylbenzene	52	mg/kg	CCME CWS/EPA 8260d m	0.42
m & p-Xylene	410	mg/kg	CCME CWS/EPA 8260d m	1.7
o-Xylene	130	mg/kg	CCME CWS/EPA 8260d m	0.83
Xylenes (Total)	540	mg/kg	Auto Calc	1.9
F1 (C6-C10) - BTEX	36000	mg/kg	Auto Calc	420
F1 (C6-C10)	38000	mg/kg	CCME CWS/EPA 8260d m	420

** Information not supplied by Client -- data derived from LSD information Results relate only to items tested

Remarks:

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PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 1 of 1

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B.4 CHV OIL

SL Ross Model	CHV	
Modeling Constants		
Standard Density	923.961	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	266.520	kg/m3
Density Constant 2	0.68349	kg/K.m3
Standard Viscosity	557.65876	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	22.0069	
Viscosity Constant 2	8539.89	K-1
Oil/Water Interfacial Tension	13.7136	dyne/cm
Air/Oil Interfacial Tension	28.8308	dyne/cm
Oil/Water Interfacial Tension Constant	2.14041	
Air/Oil Interfacial Tension Constant	0.93241	
Initial Pour Point	232.637	K
Pour Point Constant	0.75204	
ASTM Distillation Constant A (slope)	735.491	K
ASTM Distillation Constant B (intercept)	419.605	K
Emulsification Delay	9999999999	
Initial Flash Point	186.180	K
Flash Point Constant	3.47065	
Fv vs. Theta A	9.90000	
Fv vs. Theta B	13.30000	
B.Tg	9782.03	
B.To	5580.75	

CHV SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3990-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Sample Point	CHV FRESH
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/04/24
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	1.4	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	44.9	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	104	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	34.5	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	34.7	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	35.9	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	37.6	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	41.4	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	51.5	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	67.4	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	76.3	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	84.9	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	93.0	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	100.1	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	112.8	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	128.7	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	143.5	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	161.4	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	177.1	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	192.6	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	206.6	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	218.5	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	229.6	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	240.6	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	250.5	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	260.1	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	268.8	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	278.0	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	287.1	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	294.8	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	302.3	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	309.7	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	316.8	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	324.3	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	331.5	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	338.9	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	346.0	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information. Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26 Page 1 of 4

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Maxxam
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CERTIFICATE OF ANALYSIS

B8A8693:UY3990-01

MaxxID	Client ID	Meter Number	Laboratory Number
			B8A8693:UY3990-01

Operator Name	LSD	Well ID
SL ROSS ENVIRONMENTAL RESEARCH LIMITED		

Well/Plant/Facility	Initials of Sampler	Sampling Company
	NA	SL ROSS ENVIRONMENTAL

Field or Area	Pool or Zone	Sample Point	Container Identity	Percent Full
		CHV FRESH	VIAL	

Test Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas
Test Type; No.; Multiple Recovery; Well Fluid Status; Well Status Mode
Production Rates: Water m³/d; Oil m³/d; Gas 1000m³/d
Gauge Pressures kPa: Source; As Received
Temperature °C: Source; As Received 23.0
Well Status Type; Well Type; Gas or Condensate Project; Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/04/24		2018/12/13	2018/12/31		HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	353.0	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	359.8	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	366.7	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	373.6	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	380.6	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	387.6	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	394.6	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	401.4	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	408.0	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	414.3	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	420.1	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	425.9	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	431.7	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	437.8	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	444.0	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	450.4	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	456.6	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	462.9	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	469.3	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	475.6	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	482.0	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	488.8	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	495.7	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	502.1	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	508.5	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	515.3	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	522.3	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	529.7	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	537.2	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	544.6	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	552.4	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	560.3	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	568.2	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	575.8	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	583.9	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	591.9	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	600.1	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	608.6	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	617.2	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	626.2	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	635.0	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 2 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3990-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CHV FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	644.1	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	653.2	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	662.3	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	672.5	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	682.8	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	692.1	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	700.9	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	709.1	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	717.5	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	16.70	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	10	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	12	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	5.3	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	7.7	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	14	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	7.6	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	12	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	8.1	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	7.3	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	26	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	110	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	170	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	48	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	71	mg/kg	EPA 3540C/8270E m	5.0
Perylene	8.2	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	28	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	750	mg/kg	CCME CWS/EPA 8260d m	0.11
Toluene	1700	mg/kg	CCME CWS/EPA 8260d m	0.45
Ethylbenzene	270	mg/kg	CCME CWS/EPA 8260d m	0.23

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Remarks:

PAH: Detection limits raised due to matrix interference.

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 3 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3990-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CHV FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
m & p-Xylene	1400	mg/kg	CCME CWS/EPA 8260d m	0.90
o-Xylene	410	mg/kg	CCME CWS/EPA 8260d m	0.45
Xylenes (Total)	1800	mg/kg	Auto Calc	1.0
F1 (C6-C10) - BTEX	47000	mg/kg	Auto Calc	230
F1 (C6-C10)	51000	mg/kg	CCME CWS/EPA 8260d m	230

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26

Page 4 of 4

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CERTIFICATE OF ANALYSIS

B926180:VM7401-01
MaxxID | Client ID | Meter Number | Laboratory Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

SL ROSS ENVIRONMENTAL RESEARCH | N/A | SL ROSS ENVIRONMENTAL RESEARC
Well/Plant/Facility | Initials of Sampler | Sampling Company

CHV | VIAL
Field or Area | Pool or Zone | Sample Point | Container Identity | Percent Full

Test Recovery | Interval From: To: | Elevations (m) KB GRD | Sample Gathering Point | Solution Gas
Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode
Production Rates: Water m³/d | Oil m³/d | Gas 1000m³/d
Gauge Pressures kPa: Source | As Received
Temperature °C: Source | As Received 23.0
Well Status Type | Well Type | Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2019/04/01		2019/04/03	2019/04/16	2019/05/29	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	2	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	1.5	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	4	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	44.8	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	1.0	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	2	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	104	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2019/05/29 14:33 Page 1 of 1

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8693:UY3991-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CHV 2 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From / To	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/26
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	12	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	13	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.3	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	6.2	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	7.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	17	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	8.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	14	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	9.5	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	8.2	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	28	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	120	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	170	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	49	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	73	mg/kg	EPA 3540C/8270E m	5.0
Perylene	8.5	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	29	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	330	mg/kg	CCME CWS/EPA 8260d m	1.6
Toluene	1000	mg/kg	CCME CWS/EPA 8260d m	6.5
Ethylbenzene	150	mg/kg	CCME CWS/EPA 8260d m	3.2
m & p-Xylene	830	mg/kg	CCME CWS/EPA 8260d m	13
o-Xylene	240	mg/kg	CCME CWS/EPA 8260d m	6.5
Xylenes (Total)	1100	mg/kg	Auto Calc	14
F1 (C6-C10) - BTEX	28000	mg/kg	Auto Calc	3200
F1 (C6-C10)	31000	mg/kg	CCME CWS/EPA 8260d m	3200

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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CERTIFICATE OF ANALYSIS

B8A8693:UY3992-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

Well/Plant/Facility | Initials of Sampler: NA | Sampling Company: SL ROSS ENVIRONMENTAL

Field or Area | Pool or Zone | Sample Point: CHV 14 DAY | Container Identity: VIAL | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates: Water m³/d | Oil m³/d | Gas 1000m³/d

Gauge Pressures kPa: Source | As Received

Temperature °C: Source | As Received: 23.0

Well Status Type | Well Type | Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/08/05		2018/12/13	2018/12/31		HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	14	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	14	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	6.8	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	8.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	18	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	9.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	16	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	11	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	9.6	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	32	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	5.4	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	100	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	150	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	30	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	85	mg/kg	EPA 3540C/8270E m	5.0
Perylene	9.3	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	33	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	69	mg/kg	CCME CWS/EPA 8260d m	2.4
Toluene	200	mg/kg	CCME CWS/EPA 8260d m	9.6
Ethylbenzene	42	mg/kg	CCME CWS/EPA 8260d m	4.8
m & p-Xylene	250	mg/kg	CCME CWS/EPA 8260d m	19
o-Xylene	89	mg/kg	CCME CWS/EPA 8260d m	9.6
Xylenes (Total)	340	mg/kg	Auto Calc	21
F1 (C6-C10) - BTEX	14000	mg/kg	Auto Calc	4800
F1 (C6-C10)	15000	mg/kg	CCME CWS/EPA 8260d m	4800

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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B.5 CLB OIL

SL Ross Model	CLB	
Modeling Constants		
Standard Density	919.222	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	288.093	kg/m3
Density Constant 2	0.65719	kg/K.m3
Standard Viscosity	660.59498	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	22.2392	
Viscosity Constant 2	7298.21	K-1
Oil/Water Interfacial Tension	18.9170	dyne/cm
Air/Oil Interfacial Tension	30.5593	dyne/cm
Oil/Water Interfacial Tension Constant	-0.22482	
Air/Oil Interfacial Tension Constant	-0.04492	
Initial Pour Point	233.949	K
Pour Point Constant	0.76153	
ASTM Distillation Constant A (slope)	496.818	K
ASTM Distillation Constant B (intercept)	330.792	K
Emulsification Delay	9999999999	
Initial Flash Point	203.225	K
Flash Point Constant	2.17803	
Fv vs. Theta A	8.80000	
Fv vs. Theta B	16.30000	
B.Tg	8098.14	
B.To	5391.91	

CLB SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8693:UY3993-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CLB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From / To	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2018/11/12
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	21.2	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	60.3	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	156	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	33.0	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	33.2	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	33.8	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	34.5	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	36.1	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	41.9	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	53.2	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	65.3	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	70.3	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	75.9	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	80.9	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	86.3	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	91.3	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	95.3	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	102.6	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	106.4	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	109.9	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	116.8	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	125.4	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	130.4	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	135.0	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	142.0	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	149.9	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	156.3	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	163.5	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	168.7	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	176.1	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	183.7	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	189.6	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	197.6	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	205.1	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	209.9	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	216.6	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	223.0	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26 Page 1 of 4

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CERTIFICATE OF ANALYSIS

MaxxID | Client ID | Meter Number | Laboratory Number: B8A8693:UY3993-01

Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED | LSD | Well ID

Well/Plant/Facility | Initials of Sampler: NA | Sampling Company: SL ROSS ENVIRONMENTAL

Field or Area | Pool or Zone | Sample Point: CLB FRESH | Container Identity: VIAL | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d) | Gauge Pressures kPa (Source, As Received) | Temperature °C (Source, As Received: 23.0) | Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start: 2018/11/12 | Date Sampled End | Date Received: 2018/12/13 | Date Reported: 2018/12/31 | Date Reissued | Analyst: HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	228.7	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	235.8	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	241.5	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	246.9	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	253.8	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	259.4	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	264.5	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	271.0	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	277.2	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	283.2	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	288.8	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	293.5	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	298.7	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	304.3	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	308.5	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	313.8	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	319.2	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	324.1	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	329.8	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	334.7	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	340.2	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	345.6	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	350.6	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	356.0	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	361.0	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	366.3	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	371.5	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	377.1	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	382.4	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	388.1	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	393.5	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	399.1	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	404.6	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	410.2	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	415.6	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	421.2	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	426.9	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	432.9	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	439.7	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	446.7	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	453.6	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to matrix interference.

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26 Page 2 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8693:UY3993-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CLB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2018/11/12
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	460.6	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	467.9	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	475.6	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	483.7	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	492.7	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	501.8	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	511.3	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	522.0	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	533.8	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	546.3	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	560.0	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	573.6	°C	ASTM D7169	N/A
D7169 Distillation 87 mass % off	588.5	°C	ASTM D7169	N/A
D7169 Distillation 88 mass % off	604.3	°C	ASTM D7169	N/A
D7169 Distillation 89 mass % off	621.8	°C	ASTM D7169	N/A
D7169 Distillation 90 mass % off	640.2	°C	ASTM D7169	N/A
D7169 Distillation 91 mass % off	660.1	°C	ASTM D7169	N/A
D7169 Distillation 92 mass % off	684.8	°C	ASTM D7169	N/A
D7169 Distillation 93 mass % off	707.6	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	6.48	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	7.6	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	5.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	5.3	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	17	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	48	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	86	mg/kg	EPA 3540C/8270E m	5.0

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26 Page 3 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8693:UY3993-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CLB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2018/11/12
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Naphthalene	28	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	45	mg/kg	EPA 3540C/8270E m	5.0
Perylene	8.2	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	1400	mg/kg	CCME CWS/EPA 8260d m	0.16
Toluene	2300	mg/kg	CCME CWS/EPA 8260d m	0.64
Ethylbenzene	240	mg/kg	CCME CWS/EPA 8260d m	0.32
m & p-Xylene	1600	mg/kg	CCME CWS/EPA 8260d m	1.3
o-Xylene	410	mg/kg	CCME CWS/EPA 8260d m	0.64
Xylenes (Total)	2000	mg/kg	Auto Calc	1.4
F1 (C6-C10) - BTEX	45000	mg/kg	Auto Calc	320
F1 (C6-C10)	51000	mg/kg	CCME CWS/EPA 8260d m	320

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 4 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B926180:VM7402-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	CLB
Container Identity	VIAL
Percent Full	
Temperature °C (As Received)	23.0
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

Test Recovery; Test Type; No.; Multiple Recovery; Interval From: To:; Elevations (m) KB GRD; Production Rates Water m³/d Oil m³/d Gas 1000m³/d; Gauge Pressures kPa Source As Received; Temperature °C Source As Received; Sample Gathering Point; Solution Gas; Well Fluid Status; Well Status Mode; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	2	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	1.8	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	7	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	57.3	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	152	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

B8A8693:UY3994-01
Laboratory Number

MaxxID | Client ID | Meter Number

Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED

LSD | Well ID

Well/Plant/Facility | Initials of Sampler: NA | Sampling Company: SL ROSS ENVIRONMENTAL

Field or Area | Pool or Zone | Sample Point: CLB 2 DAY | Container Identity: VIAL | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates (Water m³/d / Oil m³/d / Gas 1000m³/d) | Gauge Pressures kPa (Source / As Received) | Temperature °C (Source / As Received: 23.0) | Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/04/20		2018/12/13	2018/12/31		HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	11	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	6.2	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	6.1	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	6.1	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	20	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	56	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	96	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	29	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	55	mg/kg	EPA 3540C/8270E m	5.0
Perylene	9.4	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	14	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	1100	mg/kg	CCME CWS/EPA 8260d m	2.5
Toluene	2200	mg/kg	CCME CWS/EPA 8260d m	9.8
Ethylbenzene	230	mg/kg	CCME CWS/EPA 8260d m	4.9
m & p-Xylene	1700	mg/kg	CCME CWS/EPA 8260d m	20
o-Xylene	470	mg/kg	CCME CWS/EPA 8260d m	9.8
Xylenes (Total)	2200	mg/kg	Auto Calc	22
F1 (C6-C10) - BTEX	56000	mg/kg	Auto Calc	4900
F1 (C6-C10)	62000	mg/kg	CCME CWS/EPA 8260d m	4900

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

Maxxam Analytics International Corporation o/a Maxxam Analytics Edmonton: 6744 - 50th Street T6B 3M9 Telephone(780) 378-8500 FAX(780) 378-8699

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3995-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CLB 14 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From / To	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/02/05
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	11	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	5.4	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	5.9	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	19	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	44	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	70	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	18	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	51	mg/kg	EPA 3540C/8270E m	5.0
Perylene	9.2	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	13	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	170	mg/kg	CCME CWS/EPA 8260d m	2.3
Toluene	530	mg/kg	CCME CWS/EPA 8260d m	9.1
Ethylbenzene	43	mg/kg	CCME CWS/EPA 8260d m	4.6
m & p-Xylene	330	mg/kg	CCME CWS/EPA 8260d m	18
o-Xylene	110	mg/kg	CCME CWS/EPA 8260d m	9.1
Xylenes (Total)	440	mg/kg	Auto Calc	20
F1 (C6-C10) - BTEX	16000	mg/kg	Auto Calc	4500
F1 (C6-C10)	17000	mg/kg	CCME CWS/EPA 8260d m	4500

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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B.6 CRW OIL

SL Ross Model	CRW	
Modeling Constants		
Standard Density	747.806	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	138.633	kg/m3
Density Constant 2	1.23988	kg/K.m3
Standard Viscosity	1.28311	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	6.2837	
Viscosity Constant 2	11695.54	K-1
Oil/Water Interfacial Tension	2.8721	dyne/cm
Air/Oil Interfacial Tension	22.0300	dyne/cm
Oil/Water Interfacial Tension Constant	1.29359	
Air/Oil Interfacial Tension Constant	0.45154	
Initial Pour Point	215.889	K
Pour Point Constant	0.40995	
ASTM Distillation Constant A (slope)	238.691	K
ASTM Distillation Constant B (intercept)	330.860	K
Emulsification Delay	9999999999	
Initial Flash Point	-63.345	K
Flash Point Constant	-9.57381	
Fv vs. Theta A	26.70000	
Fv vs. Theta B	24.70000	
B.Tg	5895.67	
B.To	8172.24	

CRW SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3996-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CRW FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/05/16
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	1.6	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	0.4	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	<1	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	34.4	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	34.6	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	35.4	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	35.8	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	36.2	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	36.6	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	37.5	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	38.6	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	40.0	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	41.7	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	43.7	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	46.7	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	50.0	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	53.5	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	57.1	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	60.6	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	64.2	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	67.1	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	68.5	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	71.6	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	74.7	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	77.3	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	81.9	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	85.2	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	88.7	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	92.9	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	96.5	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	98.7	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	99.5	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	100.4	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	101.5	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	102.7	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	104.6	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	107.3	°C	ASTM D7169	N/A
D7169 Distillation 34 mass % off	109.7	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 4

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CERTIFICATE OF ANALYSIS

B8A8693:UY3996-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

NA | SL ROSS ENVIRONMENTAL
Well/Plant/Facility | Initials of Sampler | Sampling Company

CRW FRESH | VIAL
Field or Area | Pool or Zone | Sample Point | Container Identity | Percent Full

Test Recovery | Interval (From: To:) | Elevations (m) (KB, GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d | Gauge Pressures kPa: Source, As Received | Temperature °C: Source, As Received 23.0 | Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/05/16		2018/12/13	2018/12/31		HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 35 mass % off	112.1	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	114.1	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	115.8	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	117.8	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	121.2	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	126.0	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	127.4	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	129.2	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	131.7	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	134.2	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	136.0	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	137.9	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	140.7	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	142.7	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	146.6	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	150.8	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	152.7	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	156.7	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	159.4	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	163.5	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	165.8	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	170.2	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	174.0	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	177.8	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	181.9	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	188.5	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	195.3	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	199.1	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	206.7	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	214.3	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	218.2	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	224.6	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	231.1	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	236.6	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	245.2	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	252.2	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	258.1	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	266.0	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	272.7	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	283.3	°C	ASTM D7169	N/A
D7169 Distillation 75 mass % off	291.3	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	300.1	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 2 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3996-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Sample Point	CRW FRESH
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/05/16
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	HP5,JGI,YD0,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 77 mass % off	306.5	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	315.8	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	324.8	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	334.4	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	345.1	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	356.1	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	367.5	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	379.3	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	391.8	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	405.2	°C	ASTM D7169	N/A
D7169 Distillation 87 mass % off	418.9	°C	ASTM D7169	N/A
D7169 Distillation 88 mass % off	433.5	°C	ASTM D7169	N/A
D7169 Distillation 89 mass % off	450.9	°C	ASTM D7169	N/A
D7169 Distillation 90 mass % off	469.4	°C	ASTM D7169	N/A
D7169 Distillation 91 mass % off	489.9	°C	ASTM D7169	N/A
D7169 Distillation 92 mass % off	513.1	°C	ASTM D7169	N/A
D7169 Distillation 93 mass % off	542.9	°C	ASTM D7169	N/A
D7169 Distillation 94 mass % off	582.2	°C	ASTM D7169	N/A
D7169 Distillation 95 mass % off	640.6	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	4.35	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	10	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	0.76	mg/kg	Auto Calc	0.71
Acenaphthylene	2.0	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	<0.40	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	1.7	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	1.5	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	1.4	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	25	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	230	mg/kg	EPA 3540C/8270E m	0.50
2-Methylnaphthalene	440	mg/kg	EPA 3540C/8270E m	0.50
Naphthalene	110	mg/kg	EPA 3540C/8270E m	0.50

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 3 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8693:UY3996-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	CRW FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/05/16
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,YD0,MN2

Test Recovery; Test Type; No.; Multiple Recovery; Interval From: To:; Elevations (m) KB GRD; Production Rates Water m³/d Oil m³/d Gas 1000m³/d; Gauge Pressures kPa Source As Received; Temperature °C Source As Received; Sample Gathering Point; Solution Gas; Well Fluid Status; Well Status Mode; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Phenanthrene	33	mg/kg	EPA 3540C/8270E m	0.50
Perylene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	2.7	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	3700	mg/kg	CCME CWS/EPA 8260d m	1.5
Toluene	12000	mg/kg	CCME CWS/EPA 8260d m	6.2
Ethylbenzene	1200	mg/kg	CCME CWS/EPA 8260d m	3.1
m & p-Xylene	11000	mg/kg	CCME CWS/EPA 8260d m	12
o-Xylene	2700	mg/kg	CCME CWS/EPA 8260d m	6.2
Xylenes (Total)	14000	mg/kg	Auto Calc	14
F1 (C6-C10) - BTEX	180000	mg/kg	Auto Calc	3100
F1 (C6-C10)	210000	mg/kg	CCME CWS/EPA 8260d m	3100

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Remarks:

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2018/12/31 16:26   Page 4 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B926180:VM7403-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	CRW
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	0.9	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	<1	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	2	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	0.6	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3997-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Sample Point	CRW 2 DAY
Container Identity	VIAL
Temperature °C (As Received)	23.0
Date Sampled Start	2017/05/18
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	HP5,DR3,JGI,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	25	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	1.9	mg/kg	Auto Calc	0.71
Acenaphthylene	8.1	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	4.6	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	0.86	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	4.2	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	0.67	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	1.0	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	4.9	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	4.3	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	1.0	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	72	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	540	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1000	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	190	mg/kg	EPA 3540C/8270E m	0.50
Phenanthrene	99	mg/kg	EPA 3540C/8270E m	0.50
Perylene	0.75	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	8.0	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	0.19	mg/kg	CCME CWS/EPA 8260d m	0.13
Toluene	3.2	mg/kg	CCME CWS/EPA 8260d m	0.50
Ethylbenzene	3.1	mg/kg	CCME CWS/EPA 8260d m	0.25
m & p-Xylene	4.4	mg/kg	CCME CWS/EPA 8260d m	1.0
o-Xylene	2.5	mg/kg	CCME CWS/EPA 8260d m	0.50
Xylenes (Total)	6.9	mg/kg	Auto Calc	1.1
F1 (C6-C10) - BTEX	2500	mg/kg	Auto Calc	250
F1 (C6-C10)	2500	mg/kg	CCME CWS/EPA 8260d m	250

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749 Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26 Page 1 of 1

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8693:UY3998-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Sample Point	CRW 14 DAY
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/05/30
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	26	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	2.5	mg/kg	Auto Calc	0.71
Acenaphthylene	5.4	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	3.6	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	1.1	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	6.9	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	0.86	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	1.4	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	6.0	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	5.9	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	1.1	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	76	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	130	mg/kg	EPA 3540C/8270E m	0.50
2-Methylnaphthalene	190	mg/kg	EPA 3540C/8270E m	0.50
Naphthalene	1.0	mg/kg	EPA 3540C/8270E m	0.50
Phenanthrene	120	mg/kg	EPA 3540C/8270E m	0.50
Perylene	2.4	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	10	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	0.033	mg/kg	CCME CWS/EPA 8260d m	0.018
Toluene	4.9	mg/kg	CCME CWS/EPA 8260d m	0.070
Ethylbenzene	0.79	mg/kg	CCME CWS/EPA 8260d m	0.035
m & p-Xylene	4.0	mg/kg	CCME CWS/EPA 8260d m	0.14
o-Xylene	0.93	mg/kg	CCME CWS/EPA 8260d m	0.070
Xylenes (Total)	4.9	mg/kg	Auto Calc	0.16
F1 (C6-C10) - BTEX	<35	mg/kg	Auto Calc	35
F1 (C6-C10)	<35	mg/kg	CCME CWS/EPA 8260d m	35

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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B.7 HFO OIL

SL Ross Model	**HFO**	
Modeling Constants		
Standard Density	989.127	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	137.502	kg/m3
Density Constant 2	0.75997	kg/K.m3
Standard Viscosity	105713.46913	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	31.7377	
Viscosity Constant 2	12689.49	K-1
Oil/Water Interfacial Tension	22.2480	dyne/cm
Air/Oil Interfacial Tension	31.6382	dyne/cm
Oil/Water Interfacial Tension Constant	-13.30036	
Air/Oil Interfacial Tension Constant	-0.48946	
Initial Pour Point	278.201	K
Pour Point Constant	0.72092	
ASTM Distillation Constant A (slope)	700.000	K
ASTM Distillation Constant B (intercept)	598.493	K
Emulsification Delay	9999999999	
Initial Flash Point	350.983	K
Flash Point Constant	3.95959	
Fv vs. Theta A	14.20000	
Fv vs. Theta B	14.90000	
B.Tg	10430.00	
B.To	8917.55	

HFO SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3874-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	HFO FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/09/01
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	36.3	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	30.4	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	68	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	160.1	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	177.2	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	198.7	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	214.7	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	228.5	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	238.6	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	249.7	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	258.6	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	266.8	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	275.8	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	283.4	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	290.9	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	297.8	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	304.4	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	310.4	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	317.3	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	322.9	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	329.2	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	335.8	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	342.0	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	347.8	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	354.4	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	360.1	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	365.8	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	371.7	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	377.1	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	382.3	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	387.6	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	392.7	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	397.4	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	402.2	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	406.9	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	411.5	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	415.7	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information — Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 1 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3874-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	HFO FRESH
Container Identity	VIAL
Percent Full	
Temperature °C (As Received)	23.0
Date Sampled Start	2017/09/01
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	420.2	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	424.4	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	428.8	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	433.2	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	438.0	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	442.7	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	447.6	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	452.2	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	456.7	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	461.3	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	466.1	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	471.0	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	476.0	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	481.2	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	486.9	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	492.9	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	498.9	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	504.6	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	510.6	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	516.9	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	523.3	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	529.8	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	536.2	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	542.4	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	548.7	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	554.9	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	560.7	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	566.3	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	571.5	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	576.6	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	581.9	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	586.9	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	591.9	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	596.8	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	601.8	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	606.9	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	611.9	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	616.9	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	622.2	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	627.5	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	632.6	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 2 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8664:UY3874-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Sample Point	HFO FRESH
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/09/01
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	DUO,JGI,YD0,BC5,MN2

Other form fields (blank): MaxxID, Client ID, Meter Number, LSD, Well ID, Field or Area, Pool or Zone, Percent Full, Test Recovery, Interval From: To:, Elevations (m) KB GRD, Sample Gathering Point, Solution Gas, Test Type, No., Multiple Recovery, Well Fluid Status, Well Status Mode, Production Rates Water m³/d Oil m³/d Gas 1000m³/d, Gauge Pressures kPa Source As Received, Temperature °C Source, Well Status Type, Well Type, Gas or Condensate Project, Licence No., Date Sampled End, Date Reissued

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	638.0	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	643.7	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	649.6	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	655.2	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	661.7	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	669.2	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	676.3	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	684.5	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	691.9	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	699.3	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	706.2	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	714.0	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	13.21	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	110	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	260	mg/kg	Auto Calc	7.1
Acenaphthylene	26	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	99	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	180	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	83	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	14	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	140	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	190	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	170	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	200	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	42	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	59	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	150	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	21	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	800	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1400	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	300	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	700	mg/kg	EPA 3540C/8270E m	5.0
Perylene	67	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	370	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25

Page 3 of 4

Maxxam Analytics International Corporation o/a Maxxam Analytics Edmonton: 6744 - 50th Street T6B 3M9 Telephone(780) 378-8500 FAX(780) 378-8699

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CERTIFICATE OF ANALYSIS

B8A8664:UY3874-01
MaxxID | Client ID | Meter Number | Laboratory Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

SL ROSS ENVIRONMENTAL | N/A | SL ROSS ENVIRONMENTAL
Well/Plant/Facility | Initials of Sampler | Sampling Company

HFO FRESH | VIAL
Field or Area | Pool or Zone | Sample Point | Container Identity | Percent Full

Test Recovery | Interval From: To: | Elevations (m) KB GRD | Sample Gathering Point | Solution Gas
Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode
Production Rates: Water m³/d | Oil m³/d | Gas 1000m³/d
Gauge Pressures kPa: Source | As Received
Temperature °C: Source | As Received 23.0
Well Status Type | Well Type
Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/09/01		2018/12/13	2018/12/31		DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Volatiles				
Benzene	13	mg/kg	CCME CWS/EPA 8260d m	0.016
Toluene	130	mg/kg	CCME CWS/EPA 8260d m	0.066
Ethylbenzene	74	mg/kg	CCME CWS/EPA 8260d m	0.033
m & p-Xylene	240	mg/kg	CCME CWS/EPA 8260d m	0.13
o-Xylene	110	mg/kg	CCME CWS/EPA 8260d m	0.066
Xylenes (Total)	350	mg/kg	Auto Calc	0.15
F1 (C6-C10) - BTEX	2700	mg/kg	Auto Calc	33
F1 (C6-C10)	3300	mg/kg	CCME CWS/EPA 8260d m	33

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 4 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B926180:VM7404-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	HFO
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	6	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	6	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	28.5	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	3	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	31.1	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	0.9	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	7.0	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	10	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	65.2	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	4	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3875-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	HFO 2 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/09/01
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	100	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	240	mg/kg	Auto Calc	7.1
Acenaphthylene	25	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	92	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	180	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	78	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	10	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	140	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	6.5	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	170	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	170	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	190	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	39	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	57	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	150	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	20	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	780	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1400	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	280	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	660	mg/kg	EPA 3540C/8270E m	5.0
Perylene	67	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	370	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	11	mg/kg	CCME CWS/EPA 8260d m	2.1
Toluene	160	mg/kg	CCME CWS/EPA 8260d m	8.3
Ethylbenzene	86	mg/kg	CCME CWS/EPA 8260d m	4.1
m & p-Xylene	300	mg/kg	CCME CWS/EPA 8260d m	17
o-Xylene	140	mg/kg	CCME CWS/EPA 8260d m	8.3
Xylenes (Total)	440	mg/kg	Auto Calc	18
F1 (C6-C10) - BTEX	<4100	mg/kg	Auto Calc	4100
F1 (C6-C10)	<4100	mg/kg	CCME CWS/EPA 8260d m	4100

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

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2018/12/31 16:25   Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3876-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	HFO 14 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval	From: / To:
Elevations (m)	KB / GRD
Sample Gathering Point	
Solution Gas	
Test Type	
No.	
Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates	Water m³/d / Oil m³/d / Gas 1000m³/d
Gauge Pressures kPa	Source / As Received
Temperature °C	Source / As Received: 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/09/13
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	97	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	250	mg/kg	Auto Calc	7.1
Acenaphthylene	24	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	100	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	180	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	82	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	11	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	140	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	180	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	170	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	210	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	42	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	59	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	150	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	21	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	680	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1100	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	210	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	670	mg/kg	EPA 3540C/8270E m	5.0
Perylene	70	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	370	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	5.8	mg/kg	CCME CWS/EPA 8260d m	1.6
Toluene	96	mg/kg	CCME CWS/EPA 8260d m	6.6
Ethylbenzene	36	mg/kg	CCME CWS/EPA 8260d m	3.3
m & p-Xylene	130	mg/kg	CCME CWS/EPA 8260d m	13
o-Xylene	65	mg/kg	CCME CWS/EPA 8260d m	6.6
Xylenes (Total)	190	mg/kg	Auto Calc	15
F1 (C6-C10) - BTEX	<3300	mg/kg	Auto Calc	3300
F1 (C6-C10)	<3300	mg/kg	CCME CWS/EPA 8260d m	3300

** Information not supplied by Client -- data derived from LSD information Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 1 of 1

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B.8 LSB OIL

SL Ross Model	LSB	
Modeling Constants		
Standard Density	838.572	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	191.555	kg/m3
Density Constant 2	0.76664	kg/K.m3
Standard Viscosity	9.55165	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	8.4741	
Viscosity Constant 2	6860.42	K-1
Oil/Water Interfacial Tension	17.3567	dyne/cm
Air/Oil Interfacial Tension	24.7130	dyne/cm
Oil/Water Interfacial Tension Constant	-0.09508	
Air/Oil Interfacial Tension Constant	0.47112	
Initial Pour Point	222.540	K
Pour Point Constant	0.61728	
ASTM Distillation Constant A (slope)	592.018	K
ASTM Distillation Constant B (intercept)	348.837	K
Emulsification Delay	50000	
Initial Flash Point	165.536	K
Flash Point Constant	3.02706	
Fv vs. Theta A	6.60000	
Fv vs. Theta B	10.70000	
B.Tg	6334.59	
B.To	3732.56	

LSB SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8664:UY3877-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Sample Point	LSB FRESH
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/04/24
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	DUO,JGI,YD0,BC5,MN2

MaxxID, Client ID, Meter Number, LSD, Well ID, Field or Area, Pool or Zone, Percent Full, Test Recovery, Interval From: To:, Elevations (m) KB GRD, Sample Gathering Point, Solution Gas, Test Type, No., Multiple Recovery, Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d), Gauge Pressures kPa (Source, As Received), Temperature °C Source, Well Fluid Status, Well Status Mode, Well Status Type, Well Type, Gas or Condensate Project, Licence No., Date Sampled End, Date Reissued

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	8.4	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	10.2	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	19	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	33.1	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	33.7	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	35.1	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	37.8	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	43.4	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	53.6	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	64.1	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	69.5	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	74.0	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	78.9	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	82.9	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	86.3	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	91.6	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	95.6	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	102.1	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	106.1	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	108.7	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	115.3	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	120.7	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	127.1	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	132.4	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	136.4	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	142.4	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	149.2	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	154.1	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	158.9	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	165.2	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	170.3	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	176.3	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	182.3	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	188.0	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	193.4	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	200.2	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	206.3	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 1 of 4

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Maxxam
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CERTIFICATE OF ANALYSIS

MaxxID	Client ID	Meter Number	Laboratory Number
			B8A8664:UY3877-01

Operator Name	LSD	Well ID
SL ROSS ENVIRONMENTAL RESEARCH LIMITED		

Well/Plant/Facility	Initials of Sampler	Sampling Company
SL ROSS ENVIRONMENTAL	N/A	SL ROSS ENVIRONMENTAL

Field or Area	Pool or Zone	Sample Point	Container Identity	Percent Full
		LSB FRESH	VIAL	

Test Recovery; Test Type; No.; Multiple Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas; Well Fluid Status; Well Status Mode

Production Rates: Water m³/d; Oil m³/d; Gas 1000m³/d. Gauge Pressures kPa: Source; As Received. Temperature °C: Source; As Received 23.0. Well Status Type; Well Type; Gas or Condensate Project; Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/04/24		2018/12/13	2018/12/31		DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	210.3	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	215.8	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	221.5	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	226.9	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	232.6	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	238.3	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	243.6	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	248.6	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	254.7	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	259.9	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	264.6	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	270.9	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	277.1	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	282.7	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	288.3	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	293.5	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	298.9	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	304.8	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	309.3	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	315.1	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	320.8	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	326.7	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	333.1	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	338.9	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	345.3	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	351.0	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	357.4	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	363.3	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	369.7	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	375.8	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	382.2	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	388.8	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	395.2	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	401.8	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	408.3	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	414.8	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	421.4	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	428.1	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	435.4	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	443.2	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	451.2	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 2 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3877-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	
Sampling Company	
Field or Area	
Pool or Zone	
Sample Point	LSB FRESH
Container Identity	VIAL
Percent Full	
Temperature °C (As Received)	23.0
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,BC5,MN2

Test Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas; Test Type; No.; Multiple Recovery; Well Fluid Status; Well Status Mode; Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d; Gauge Pressures kPa: Source, As Received; Temperature °C: Source, As Received; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	458.8	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	466.8	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	474.9	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	483.6	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	493.1	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	502.5	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	512.5	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	523.5	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	535.6	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	548.3	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	562.1	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	576.1	°C	ASTM D7169	N/A
D7169 Distillation 87 mass % off	591.5	°C	ASTM D7169	N/A
D7169 Distillation 88 mass % off	608.4	°C	ASTM D7169	N/A
D7169 Distillation 89 mass % off	627.4	°C	ASTM D7169	N/A
D7169 Distillation 90 mass % off	648.5	°C	ASTM D7169	N/A
D7169 Distillation 91 mass % off	673.8	°C	ASTM D7169	N/A
D7169 Distillation 92 mass % off	702.7	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	7.39	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	11	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	12	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	5.7	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	5.4	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	6.0	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	6.2	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	73	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	630	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	790	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	320	mg/kg	EPA 3540C/8270E m	5.0

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Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

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2018/12/31 16:25   Page 3 of 4

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3877-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	LSB FRESH
Container Identity	VIAL
Percent Full	
Temperature °C (As Received)	23.0
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Phenanthrene	97	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	14	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	2400	mg/kg	CCME CWS/EPA 8260d m	0.16
Toluene	4900	mg/kg	CCME CWS/EPA 8260d m	6.3
Ethylbenzene	1800	mg/kg	CCME CWS/EPA 8260d m	0.31
m & p-Xylene	2500	mg/kg	CCME CWS/EPA 8260d m	1.3
o-Xylene	1100	mg/kg	CCME CWS/EPA 8260d m	0.63
Xylenes (Total)	3600	mg/kg	Auto Calc	1.4
F1 (C6-C10) - BTEX	110000	mg/kg	Auto Calc	310
F1 (C6-C10)	130000	mg/kg	CCME CWS/EPA 8260d m	310

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Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

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2018/12/31 16:25   Page 4 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B926180:VM7405-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	LSB
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

Test Recovery; Test Type; No.; Multiple Recovery; Interval From: To:; Elevations (m) KB GRD; Production Rates Water m³/d Oil m³/d Gas 1000m³/d; Gauge Pressures kPa Source As Received; Temperature °C Source As Received; Sample Gathering Point; Solution Gas; Well Fluid Status; Well Status Mode; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	1.3	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	<1	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	9.0	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	17.0	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

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2019/05/29 14:33 Page 1 of 1

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3878-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	LSB 2 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/26
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	12	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	16	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	6.7	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	8.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	5.7	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	8.4	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	7.6	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	100	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	830	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1000	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	300	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	130	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	22	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	2.1	mg/kg	CCME CWS/EPA 8260d m	1.1
Toluene	49	mg/kg	CCME CWS/EPA 8260d m	4.4
Ethylbenzene	54	mg/kg	CCME CWS/EPA 8260d m	2.2
m & p-Xylene	110	mg/kg	CCME CWS/EPA 8260d m	8.8
o-Xylene	73	mg/kg	CCME CWS/EPA 8260d m	4.4
Xylenes (Total)	180	mg/kg	Auto Calc	9.8
F1 (C6-C10) - BTEX	5900	mg/kg	Auto Calc	2200
F1 (C6-C10)	6200	mg/kg	CCME CWS/EPA 8260d m	2200

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 1 of 1

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8664:UY3879-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	
Sampling Company	
Sample Point	LSB 14 DAY
Container Identity	VIAL
Field or Area	
Pool or Zone	
Percent Full	
Temperature °C (As Received)	23.0
Date Sampled Start	2017/05/08
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	13	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	21	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	6.1	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	8.2	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	6.4	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	9.4	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	10	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	120	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	650	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	740	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	80	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	150	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	24	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	0.18	mg/kg	CCME CWS/EPA 8260d m	0.16
Toluene	2.5	mg/kg	CCME CWS/EPA 8260d m	0.65
Ethylbenzene	0.59	mg/kg	CCME CWS/EPA 8260d m	0.33
m & p-Xylene	2.0	mg/kg	CCME CWS/EPA 8260d m	1.3
o-Xylene	0.94	mg/kg	CCME CWS/EPA 8260d m	0.65
Xylenes (Total)	3.0	mg/kg	Auto Calc	1.5
F1 (C6-C10) - BTEX	<330	mg/kg	Auto Calc	330
F1 (C6-C10)	<330	mg/kg	CCME CWS/EPA 8260d m	330

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

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B.9 MSB OIL

SL Ross Model	MSB	
Modeling Constants		
Standard Density	847.351	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	188.497	kg/m3
Density Constant 2	0.75541	kg/K.m3
Standard Viscosity	14.71040	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	8.9254	
Viscosity Constant 2	7242.26	K-1
Oil/Water Interfacial Tension	6.7852	dyne/cm
Air/Oil Interfacial Tension	24.4090	dyne/cm
Oil/Water Interfacial Tension Constant	1.54108	
Air/Oil Interfacial Tension Constant	0.62000	
Initial Pour Point	228.211	K
Pour Point Constant	0.54192	
ASTM Distillation Constant A (slope)	631.727	K
ASTM Distillation Constant B (intercept)	361.646	K
Emulsification Delay	9999999999	
Initial Flash Point	105.524	K
Flash Point Constant	6.56355	
Fv vs. Theta A	8.60000	
Fv vs. Theta B	11.60000	
B.Tg	7328.04	
B.To	4195.10	

MSB SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

B8A8664:UY3880-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

SL ROSS ENVIRONMENTAL
Well/Plant/Facility

N/A
Initials of Sampler

SL ROSS ENVIRONMENTAL
Sampling Company

MSB FRESH
Sample Point

VIAL
Container Identity

Field or Area | Pool or Zone | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates: Water m³/d | Oil m³/d | Gas 1000m³/d

Gauge Pressures kPa: Source | As Received

Temperature °C: Source | As Received: 23.0

Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/04/24		2018/12/13	2018/12/31		DUO,JGI,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	3.1	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	11.7	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	30	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	32.9	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	33.1	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	34.4	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	36.5	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	42.6	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	54.5	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	66.0	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	70.4	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	76.5	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	81.5	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	87.0	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	91.6	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	100.0	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	104.9	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	108.4	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	115.6	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	123.6	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	129.6	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	134.4	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	141.2	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	147.4	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	153.1	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	158.2	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	164.6	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	169.8	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	176.8	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	184.1	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	190.0	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	197.6	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	205.0	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	210.0	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	216.5	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	222.9	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	228.8	°C	ASTM D7169	N/A

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Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference; Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 1 of 4

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CERTIFICATE OF ANALYSIS

B8A8664:UY3880-01
Laboratory Number

MaxxID | Client ID | Meter Number

Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED

Well/Plant/Facility: SL ROSS ENVIRONMENTAL | LSD: N/A | Well ID: SL ROSS ENVIRONMENTAL

Initials of Sampler | Sampling Company

Field or Area | Pool or Zone | Sample Point: MSB FRESH | Container Identity: VIAL | Percent Full

Test Recovery | Interval From: To: | Elevations (m) KB GRD | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d | Gauge Pressures kPa: Source, As Received | Temperature °C: Source, As Received 23.0 | Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start: 2017/04/24 | Date Sampled End | Date Received: 2018/12/13 | Date Reported: 2018/12/31 | Date Reissued | Analyst: DUO,JGI,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 34 mass % off	235.7	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	241.5	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	246.9	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	253.6	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	259.1	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	264.2	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	270.7	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	277.1	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	282.7	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	288.4	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	293.4	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	298.3	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	303.8	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	308.3	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	313.3	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	318.8	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	323.5	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	329.1	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	334.3	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	339.5	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	345.0	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	349.9	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	355.1	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	360.1	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	365.4	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	370.6	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	376.0	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	381.4	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	386.8	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	392.3	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	397.8	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	403.2	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	408.7	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	414.1	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	419.6	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	425.2	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	431.0	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	437.4	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	444.2	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	451.2	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	457.9	°C	ASTM D7169	N/A

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Remarks:

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Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25 Page 2 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8664:UY3880-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSB FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YT2,BC5,MN2

Test Recovery; Interval (From: / To:); Elevations (m) (KB / GRD); Sample Gathering Point; Solution Gas; Test Type; No.; Multiple Recovery; Well Fluid Status; Well Status Mode; Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d); Gauge Pressures kPa (Source / As Received); Temperature °C (Source / As Received); Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 75 mass % off	465.0	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	472.3	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	480.0	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	488.5	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	497.6	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	506.5	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	516.5	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	527.5	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	539.4	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	552.4	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	566.0	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	579.8	°C	ASTM D7169	N/A
D7169 Distillation 87 mass % off	594.9	°C	ASTM D7169	N/A
D7169 Distillation 88 mass % off	611.3	°C	ASTM D7169	N/A
D7169 Distillation 89 mass % off	629.2	°C	ASTM D7169	N/A
D7169 Distillation 90 mass % off	648.4	°C	ASTM D7169	N/A
D7169 Distillation 91 mass % off	670.8	°C	ASTM D7169	N/A
D7169 Distillation 92 mass % off	696.5	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	7.07	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	16	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	11	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.8	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	5.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	5.6	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	7.2	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	10	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	51	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	470	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	650	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	280	mg/kg	EPA 3540C/8270E m	5.0

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2018/12/31 16:25   Page 3 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3880-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval	From: To:
Elevations (m)	KB GRD
Sample Gathering Point	
Solution Gas	
Test Type	
No.	
Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates	Water m³/d, Oil m³/d, Gas 1000m³/d
Gauge Pressures kPa	Source, As Received
Temperature °C	Source: ; As Received: 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YT2,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Phenanthrene	91	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	19	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	2300	mg/kg	CCME CWS/EPA 8260d m	0.16
Toluene	5800	mg/kg	CCME CWS/EPA 8260d m	6.3
Ethylbenzene	1300	mg/kg	CCME CWS/EPA 8260d m	0.31
m & p-Xylene	3800	mg/kg	CCME CWS/EPA 8260d m	1.3
o-Xylene	1400	mg/kg	CCME CWS/EPA 8260d m	0.63
Xylenes (Total)	5200	mg/kg	Auto Calc	1.4
F1 (C6-C10) - BTEX	90000	mg/kg	Auto Calc	310
F1 (C6-C10)	100000	mg/kg	CCME CWS/EPA 8260d m	310

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2018/12/31 16:25   Page 4 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B926180:VM7406-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	MSB
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	2.7	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	1	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	13.5	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	0.9	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	34.8	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

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2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3881-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSB 2 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/26
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	12	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	14	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	7.9	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	8.3	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	8.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	9.1	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	78	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	680	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	920	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	260	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	130	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	30	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	6.0	mg/kg	CCME CWS/EPA 8260d m	1.5
Toluene	99	mg/kg	CCME CWS/EPA 8260d m	5.9
Ethylbenzene	50	mg/kg	CCME CWS/EPA 8260d m	2.9
m & p-Xylene	220	mg/kg	CCME CWS/EPA 8260d m	12
o-Xylene	120	mg/kg	CCME CWS/EPA 8260d m	5.9
Xylenes (Total)	330	mg/kg	Auto Calc	13
F1 (C6-C10) - BTEX	7100	mg/kg	Auto Calc	2900
F1 (C6-C10)	7500	mg/kg	CCME CWS/EPA 8260d m	2900

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:25   Page 1 of 1

Maxxam Analytics International Corporation o/a Maxxam Analytics Edmonton: 6744 - 50th Street T6B 3M9 Telephone(780) 378-8500 FAX(780) 378-8699

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8664:UY3882-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSB 14 DAY
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/05/08
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

Test Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas; Test Type; No.; Multiple Recovery; Well Fluid Status; Well Status Mode; Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d; Gauge Pressures kPa: Source, As Received; Temperature °C: Source, As Received; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	9.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	11	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	8.2	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	7.7	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	8.5	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	11	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	76	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	420	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	530	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	47	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	130	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	31	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	0.035	mg/kg	CCME CWS/EPA 8260d m	0.017
Toluene	2.4	mg/kg	CCME CWS/EPA 8260d m	0.067
Ethylbenzene	0.39	mg/kg	CCME CWS/EPA 8260d m	0.034
m & p-Xylene	1.7	mg/kg	CCME CWS/EPA 8260d m	0.13
o-Xylene	0.73	mg/kg	CCME CWS/EPA 8260d m	0.067
Xylenes (Total)	2.4	mg/kg	Auto Calc	0.15
F1 (C6-C10) - BTEX	35	mg/kg	Auto Calc	34
F1 (C6-C10)	40	mg/kg	CCME CWS/EPA 8260d m	34

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

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2018/12/31 16:25   Page 1 of 1

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B.10 MSW OIL

SL Ross Model	MSW	
Modeling Constants		
Standard Density	819.500	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	166.350	kg/m3
Density Constant 2	0.81585	kg/K.m3
Standard Viscosity	9.62252	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	8.2094	
Viscosity Constant 2	8760.13	K-1
Oil/Water Interfacial Tension	15.8167	dyne/cm
Air/Oil Interfacial Tension	25.7137	dyne/cm
Oil/Water Interfacial Tension Constant	-1.10593	
Air/Oil Interfacial Tension Constant	0.23220	
Initial Pour Point	250.717	K
Pour Point Constant	0.34576	
ASTM Distillation Constant A (slope)	626.364	K
ASTM Distillation Constant B (intercept)	345.396	K
Emulsification Delay	50000	
Initial Flash Point	209.685	K
Flash Point Constant	1.57328	
Fv vs. Theta A	2.20000	
Fv vs. Theta B	8.20000	
B.Tg	5136.18	
B.To	2832.25	

MSW SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4548-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSW FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source	
Temperature °C: As Received	23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/10/25
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	6.3	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	3.1	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	8	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	32.9	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	33.1	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	34.1	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	35.7	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	40.9	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	51.1	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	62.2	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	69.2	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	74.9	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	80.2	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	85.3	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	89.4	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	93.3	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	98.6	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	102.5	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	106.1	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	108.8	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	114.7	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	119.5	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	126.1	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	129.9	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	134.0	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	139.6	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	143.8	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	150.1	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	154.8	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	159.0	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	165.1	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	169.7	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	175.6	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	182.2	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	188.0	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	193.3	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

Reference Method suffix “M” indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26 Page 1 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8814:UY4548-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSW FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d)	
Gauge Pressures kPa (Source, As Received)	
Temperature °C (Source / As Received)	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/10/25
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 33 mass % off	200.8	°C	ASTM D7169	N/A
D7169 Distillation 34 mass % off	207.2	°C	ASTM D7169	N/A
D7169 Distillation 35 mass % off	211.1	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	217.2	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	222.9	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	227.9	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	234.5	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	240.2	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	245.1	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	250.9	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	256.7	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	261.8	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	267.3	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	274.2	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	279.6	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	285.9	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	291.9	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	295.4	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	301.2	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	307.0	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	311.5	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	317.8	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	322.9	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	329.6	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	335.5	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	342.2	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	348.0	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	354.5	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	360.5	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	367.1	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	373.3	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	380.3	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	386.6	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	393.2	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	399.9	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	406.2	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	412.7	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	419.0	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	425.4	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	432.2	°C	ASTM D7169	N/A

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Remarks:

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PAH: Detection limits raised due to matrix interference.

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2018/12/31 16:26   Page 2 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4548-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	
Sampling Company	
Sample Point	MSW FRESH
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/10/25
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 73 mass % off	439.7	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	447.5	°C	ASTM D7169	N/A
D7169 Distillation 75 mass % off	455.0	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	462.6	°C	ASTM D7169	N/A
D7169 Distillation 77 mass % off	470.4	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	478.4	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	486.9	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	496.1	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	504.8	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	514.4	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	524.9	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	536.1	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	548.0	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	560.8	°C	ASTM D7169	N/A
D7169 Distillation 87 mass % off	573.6	°C	ASTM D7169	N/A
D7169 Distillation 88 mass % off	587.6	°C	ASTM D7169	N/A
D7169 Distillation 89 mass % off	602.7	°C	ASTM D7169	N/A
D7169 Distillation 90 mass % off	619.6	°C	ASTM D7169	N/A
D7169 Distillation 91 mass % off	638.2	°C	ASTM D7169	N/A
D7169 Distillation 92 mass % off	659.3	°C	ASTM D7169	N/A
D7169 Distillation 93 mass % off	688.1	°C	ASTM D7169	N/A
D7169 Distillation 94 mass % off	718.3	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	5.95	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	7.7	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	8.4	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	5.7	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	7.5	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	6.6	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4548-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSW FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/10/25
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Fluorene	61	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	620	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	920	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	380	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	110	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	1600	mg/kg	CCME CWS/EPA 8260d m	1.8
Toluene	4700	mg/kg	CCME CWS/EPA 8260d m	7.1
Ethylbenzene	850	mg/kg	CCME CWS/EPA 8260d m	3.6
m & p-Xylene	4100	mg/kg	CCME CWS/EPA 8260d m	14
o-Xylene	1300	mg/kg	CCME CWS/EPA 8260d m	7.1
Xylenes (Total)	5400	mg/kg	Auto Calc	16
F1 (C6-C10) - BTEX	140000	mg/kg	Auto Calc	3600
F1 (C6-C10)	150000	mg/kg	CCME CWS/EPA 8260d m	3600

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

PAH: Detection limits raised due to matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 4 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B926180:VM7407-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	MSW
Container Identity	VIAL
Percent Full	
Test Recovery	
Test Type	
No.	
Multiple Recovery	
Interval From:	
Interval To:	
Elevations (m) KB	
Elevations (m) GRD	
Sample Gathering Point	
Solution Gas	
Well Fluid Status	
Well Status Mode	
Production Rates Water m³/d	
Production Rates Oil m³/d	
Production Rates Gas 1000m³/d	
Gauge Pressures kPa Source	
Gauge Pressures kPa As Received	
Temperature °C Source	
Temperature °C As Received	23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	3.1	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	<1	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	3.9	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	0.9	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	4	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	6.8	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4549-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	MSW 2 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/12/05
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	9.7	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	11	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	7.6	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	8.7	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	9.9	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	79	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	740	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1100	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	350	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	140	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	13	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	51	mg/kg	CCME CWS/EPA 8260d m	2.3
Toluene	750	mg/kg	CCME CWS/EPA 8260d m	9.2
Ethylbenzene	230	mg/kg	CCME CWS/EPA 8260d m	4.6
m & p-Xylene	1300	mg/kg	CCME CWS/EPA 8260d m	18
o-Xylene	520	mg/kg	CCME CWS/EPA 8260d m	9.2
Xylenes (Total)	1800	mg/kg	Auto Calc	20
F1 (C6-C10) - BTEX	32000	mg/kg	Auto Calc	4600
F1 (C6-C10)	35000	mg/kg	CCME CWS/EPA 8260d m	4600

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID:
Client ID:
Meter Number:
Laboratory Number: B8A8814:UY4550-01

Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD:
Well ID:

Well/Plant/Facility: SL ROSS ENVIRONMENTAL
Initials of Sampler: N/A
Sampling Company: SL ROSS ENVIRONMENTAL

Field or Area:
Pool or Zone:
Sample Point: MSW 14 DAY
Container Identity: VIAL
Percent Full:

Test Recovery
Test Type / No. / Multiple Recovery
Interval — From: / To:
Elevations (m) — KB / GRD
Sample Gathering Point
Solution Gas
Well Fluid Status
Well Status Mode
Production Rates — Water m³/d / Oil m³/d / Gas 1000m³/d
Gauge Pressures kPa — Source / As Received
Temperature °C — Source / As Received: 23.0
Well Status Type
Well Type
Gas or Condensate Project
Licence No.

Date Sampled Start: 2017/05/24
Date Sampled End:
Date Received: 2018/12/13
Date Reported: 2018/12/31
Date Reissued:
Analyst: HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	12	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	11	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	10	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	12	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	9.6	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	95	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	590	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	810	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	140	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	180	mg/kg	EPA 3540C/8270E m	5.0
Perylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	17	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	3.2	mg/kg	CCME CWS/EPA 8260d m	2.1
Toluene	55	mg/kg	CCME CWS/EPA 8260d m	8.3
Ethylbenzene	25	mg/kg	CCME CWS/EPA 8260d m	4.2
m & p-Xylene	150	mg/kg	CCME CWS/EPA 8260d m	17
o-Xylene	83	mg/kg	CCME CWS/EPA 8260d m	8.3
Xylenes (Total)	230	mg/kg	Auto Calc	19
F1 (C6-C10) - BTEX	8000	mg/kg	Auto Calc	4200
F1 (C6-C10)	8300	mg/kg	CCME CWS/EPA 8260d m	4200

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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B.11 NDB OIL

SL Ross Model	NDB	
Modeling Constants		
Standard Density	812.657	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	142.068	kg/m3
Density Constant 2	0.70427	kg/K.m3
Standard Viscosity	4.15262	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	5.8359	
Viscosity Constant 2	4730.88	K-1
Oil/Water Interfacial Tension	19.2150	dyne/cm
Air/Oil Interfacial Tension	25.3033	dyne/cm
Oil/Water Interfacial Tension Constant	0.24775	
Air/Oil Interfacial Tension Constant	0.34861	
Initial Pour Point	218.206	K
Pour Point Constant	0.30384	
ASTM Distillation Constant A (slope)	273.491	K
ASTM Distillation Constant B (intercept)	339.860	K
Emulsification Delay	9999999999	
Initial Flash Point	256.004	K
Flash Point Constant	0.93553	
Fv vs. Theta A	15.80000	
Fv vs. Theta B	19.30000	
B.Tg	5278.37	
B.To	6559.30	

NDB SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4551-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	NDB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/10
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YT2,DR3,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	0.4	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	<0.1	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	<1	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	33.1	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	33.4	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	35.2	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	39.8	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	49.7	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	60.4	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	68.4	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	72.3	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	77.5	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	80.7	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	84.7	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	87.6	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	91.0	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	94.6	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	100.0	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	104.5	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	106.7	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	108.4	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	112.9	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	116.8	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	121.8	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	127.3	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	131.4	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	134.2	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	138.5	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	142.5	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	148.0	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	152.0	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	156.4	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	158.7	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	164.3	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	167.4	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	171.6	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	176.9	°C	ASTM D7169	N/A
D7169 Distillation 34 mass % off	181.1	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 4

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8814:UY4551-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	NDB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/10
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YT2,DR3,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 35 mass % off	186.3	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	189.9	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	194.4	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	199.7	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	204.2	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	208.5	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	212.3	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	216.9	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	221.4	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	226.3	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	230.6	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	235.6	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	239.9	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	244.6	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	249.3	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	254.5	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	258.6	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	263.0	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	268.3	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	273.6	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	278.7	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	284.1	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	289.1	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	293.8	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	298.8	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	304.0	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	308.7	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	314.0	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	319.7	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	324.9	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	330.8	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	336.5	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	342.4	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	348.1	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	354.1	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	360.1	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	366.3	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	372.6	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	379.1	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	385.6	°C	ASTM D7169	N/A
D7169 Distillation 75 mass % off	392.2	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	399.0	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26

Page 2 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	Client ID	Meter Number	Laboratory Number
			B8A8814:UY4551-01

Operator Name	LSD	Well ID
SL ROSS ENVIRONMENTAL RESEARCH LIMITED		

Well/Plant/Facility	Initials of Sampler	Sampling Company
SL ROSS ENVIRONMENTAL	N/A	SL ROSS ENVIRONMENTAL

Field or Area	Pool or Zone	Sample Point	Container Identity	Percent Full
		NDB FRESH	VIAL	

Test Recovery; Test Type; No.; Multiple Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas; Well Fluid Status; Well Status Mode
Production Rates: Water m³/d; Oil m³/d; Gas 1000m³/d; Gauge Pressures kPa: Source, As Received; Temperature °C: Source, As Received 23.0; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/05/10		2018/12/13	2018/12/31		DUO,JGI,YT2,DR3,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 77 mass % off	405.9	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	412.9	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	419.9	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	427.1	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	434.9	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	443.3	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	451.7	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	459.8	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	468.2	°C	ASTM D7169	N/A
D7169 Distillation 86 mass % off	476.9	°C	ASTM D7169	N/A
D7169 Distillation 87 mass % off	486.3	°C	ASTM D7169	N/A
D7169 Distillation 88 mass % off	496.5	°C	ASTM D7169	N/A
D7169 Distillation 89 mass % off	506.3	°C	ASTM D7169	N/A
D7169 Distillation 90 mass % off	517.2	°C	ASTM D7169	N/A
D7169 Distillation 91 mass % off	529.3	°C	ASTM D7169	N/A
D7169 Distillation 92 mass % off	542.3	°C	ASTM D7169	N/A
D7169 Distillation 93 mass % off	556.9	°C	ASTM D7169	N/A
D7169 Distillation 94 mass % off	572.2	°C	ASTM D7169	N/A
D7169 Distillation 95 mass % off	589.9	°C	ASTM D7169	N/A
D7169 Distillation 96 mass % off	611.1	°C	ASTM D7169	N/A
D7169 Distillation 97 mass % off	638.8	°C	ASTM D7169	N/A
D7169 Distillation 98 mass % off	684.6	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	1.52	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	7.9	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	2.0	mg/kg	Auto Calc	0.71
Acenaphthylene	5.4	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	1.4	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	1.7	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	1.6	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	0.92	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	3.6	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	5.9	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	0.63	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	1.5	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	39	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 3 of 4

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CERTIFICATE OF ANALYSIS

B8A8814:UY4551-01
Laboratory Number

MaxxID	*Client ID*	*Meter Number*	

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | *LSD* | *Well ID*

SL ROSS ENVIRONMENTAL | N/A | SL ROSS ENVIRONMENTAL
Well/Plant/Facility | *Initials of Sampler* | *Sampling Company*

Field or Area | *Pool or Zone* | NDB FRESH *Sample Point* | VIAL *Container Identity* | *Percent Full*

Test Recovery | *Interval* From: To: | *Elevations (m)* KB GRD | *Sample Gathering Point* | *Solution Gas*

Test Type | *No.* | *Multiple Recovery* | *Well Fluid Status* | *Well Status Mode*

Production Rates: *Water m³/d* | *Oil m³/d* | *Gas 1000m³/d*
Gauge Pressures kPa: *Source* | *As Received*
Temperature °C: *Source* | 23.0 *As Received*
Well Status Type | *Well Type*
Gas or Condensate Project | *Licence No.*

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/05/10		2018/12/13	2018/12/31		DUO,JGI,YT2,DR3,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
1-Methylnaphthalene	480	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	740	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	150	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	92	mg/kg	EPA 3540C/8270E m	0.50
Perylene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	9.9	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	1300	mg/kg	CCME CWS/EPA 8260d m	1.5
Toluene	2500	mg/kg	CCME CWS/EPA 8260d m	5.8
Ethylbenzene	610	mg/kg	CCME CWS/EPA 8260d m	2.9
m & p-Xylene	3300	mg/kg	CCME CWS/EPA 8260d m	12
o-Xylene	1200	mg/kg	CCME CWS/EPA 8260d m	5.8
Xylenes (Total)	4500	mg/kg	Auto Calc	13
F1 (C6-C10) - BTEX	140000	mg/kg	Auto Calc	2900
F1 (C6-C10)	150000	mg/kg	CCME CWS/EPA 8260d m	2900

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 4 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B926180:VM7408-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	NDB
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	<1	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

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2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8814:UY4552-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL
Sample Point	NDB 2 DAY
Container Identity	VIAL
Temperature °C As Received	23.0
Date Sampled Start	2017/05/10
Date Received	2018/12/13
Date Reported	2018/12/31
Analyst	HP5,DR3,JGI,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	23	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	3.2	mg/kg	Auto Calc	0.71
Acenaphthylene	9.4	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	4.0	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	2.8	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	2.1	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	0.72	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	1.7	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	6.0	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	10	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	0.85	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	1.8	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	62	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	770	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	1200	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	230	mg/kg	EPA 3540C/8270E m	0.50
Phenanthrene	150	mg/kg	EPA 3540C/8270E m	0.50
Perylene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	16	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	0.053	mg/kg	CCME CWS/EPA 8260d m	0.019
Toluene	7.4	mg/kg	CCME CWS/EPA 8260d m	0.078
Ethylbenzene	4.1	mg/kg	CCME CWS/EPA 8260d m	0.039
m & p-Xylene	36	mg/kg	CCME CWS/EPA 8260d m	0.16
o-Xylene	25	mg/kg	CCME CWS/EPA 8260d m	0.078
Xylenes (Total)	61	mg/kg	Auto Calc	0.17
F1 (C6-C10) - BTEX	4300	mg/kg	Auto Calc	39
F1 (C6-C10)	4400	mg/kg	CCME CWS/EPA 8260d m	39

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749 Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS. PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4553-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	NDB 14 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/30
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,JGI,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	23	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	3.6	mg/kg	Auto Calc	0.71
Acenaphthylene	7.7	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	2.8	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	3.1	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	3.1	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	0.94	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	1.8	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	6.9	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	12	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	1.1	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	2.1	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	67	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	440	mg/kg	EPA 3540C/8270E m	0.50
2-Methylnaphthalene	570	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	16	mg/kg	EPA 3540C/8270E m	0.50
Phenanthrene	170	mg/kg	EPA 3540C/8270E m	0.50
Perylene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	19	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	0.032	mg/kg	CCME CWS/EPA 8260d m	0.019
Toluene	14	mg/kg	CCME CWS/EPA 8260d m	0.078
Ethylbenzene	0.80	mg/kg	CCME CWS/EPA 8260d m	0.039
m & p-Xylene	3.9	mg/kg	CCME CWS/EPA 8260d m	0.16
o-Xylene	0.97	mg/kg	CCME CWS/EPA 8260d m	0.078
Xylenes (Total)	4.9	mg/kg	Auto Calc	0.17
F1 (C6-C10) - BTEX	<39	mg/kg	Auto Calc	39
F1 (C6-C10)	<39	mg/kg	CCME CWS/EPA 8260d m	39

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749 Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted.

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2018/12/31 16:26   Page 1 of 1

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B.12 SYB Oil

SL Ross Model	SYB	
Modeling Constants		
Standard Density	930.683	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	213.050	kg/m3
Density Constant 2	0.66109	kg/K.m3
Standard Viscosity	570.64766	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	18.2217	
Viscosity Constant 2	7563.10	K-1
Oil/Water Interfacial Tension	14.2443	dyne/cm
Air/Oil Interfacial Tension	28.0388	dyne/cm
Oil/Water Interfacial Tension Constant	-0.87045	
Air/Oil Interfacial Tension Constant	0.85076	
Initial Pour Point	232.338	K
Pour Point Constant	0.83822	
ASTM Distillation Constant A (slope)	558.091	K
ASTM Distillation Constant B (intercept)	466.701	K
Emulsification Delay	0	
Initial Flash Point	194.786	K
Flash Point Constant	5.03038	
Fv vs. Theta A	22.40000	
Fv vs. Theta B	20.10000	
B.Tg	11217.63	
B.To	9380.69	

SYB SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4554-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	SYB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2018/12/11
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,DR3,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	1.6	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	45.9	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	123	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	33.5	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	35.1	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	47.7	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	70.0	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	88.3	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	106.8	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	126.1	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	141.6	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	157.5	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	170.4	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	182.5	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	193.4	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	202.9	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	211.2	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	219.3	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	227.0	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	234.6	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	241.6	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	248.1	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	254.6	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	260.7	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	266.6	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	272.7	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	278.6	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	284.3	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	289.6	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	294.6	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	299.5	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	304.4	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	309.1	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	313.8	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	318.6	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	323.4	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	328.3	°C	ASTM D7169	N/A
D7169 Distillation 34 mass % off	333.1	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted., PAH: Detection limits raised due to dilution as a result of sample matrix interference.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	Client ID	Meter Number	Laboratory Number: B8A8814:UY4554-01
Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED		LSD	Well ID
Well/Plant/Facility: SL ROSS ENVIRONMENTAL		Initials of Sampler: N/A	Sampling Company: SL ROSS ENVIRONMENTAL
Field or Area	Pool or Zone	Sample Point: SYB FRESH	Container Identity: VIAL; Percent Full
Test Recovery	Interval (From: / To:)	Elevations (m) (KB / GRD)	Sample Gathering Point; Solution Gas
Test Type; No.; Multiple Recovery			Well Fluid Status; Well Status Mode
Production Rates (Water m³/d; Oil m³/d; Gas 1000m³/d)	Gauge Pressures kPa (Source; As Received)	Temperature °C (Source; As Received: 23.0)	Well Status Type; Well Type
			Gas or Condensate Project; Licence No.
Date Sampled Start: 2018/12/11	Date Sampled End	Date Received: 2018/12/13	Date Reported: 2018/12/31
Date Reissued	Analyst: DUO,JGI,YD0,DR3,BC5,MN2		

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 35 mass % off	338.0	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	342.8	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	347.4	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	352.0	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	356.6	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	361.2	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	365.8	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	370.5	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	375.2	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	379.9	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	384.6	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	389.4	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	394.1	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	398.8	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	403.5	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	408.1	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	412.6	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	417.0	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	421.5	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	425.9	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	430.6	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	435.6	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	441.0	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	446.5	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	452.1	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	457.5	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	463.2	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	469.2	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	475.4	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	482.0	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	489.3	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	497.0	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	504.4	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	512.5	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	521.4	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	531.3	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	541.7	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	553.1	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	564.7	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	576.2	°C	ASTM D7169	N/A
D7169 Distillation 75 mass % off	588.4	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	600.6	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted., PAH: Detection limits raised due to dilution as a result of sample matrix interference.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 2 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4554-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	SL ROSS ENVIRONMENTAL
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	
Sampling Company	
Field or Area	
Pool or Zone	
Sample Point	SYB FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval	From: To:
Elevations (m)	KB: GRD:
Sample Gathering Point	
Solution Gas	
Test Type	
No.	
Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates	Water m³/d: Oil m³/d: Gas 1000m³/d:
Gauge Pressures kPa	Source: As Received:
Temperature °C	Source: As Received: 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2018/12/11
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,YD0,DR3,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 77 mass % off	613.4	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	626.5	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	639.0	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	651.8	°C	ASTM D7169	N/A
D7169 Distillation 81 mass % off	664.5	°C	ASTM D7169	N/A
D7169 Distillation 82 mass % off	678.5	°C	ASTM D7169	N/A
D7169 Distillation 83 mass % off	691.5	°C	ASTM D7169	N/A
D7169 Distillation 84 mass % off	702.6	°C	ASTM D7169	N/A
D7169 Distillation 85 mass % off	713.1	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	14.30	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	8.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.1	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	5.8	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	8.1	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	5.1	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	15	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	82	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	110	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	53	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	29	mg/kg	EPA 3540C/8270E m	5.0
Perylene	10	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	21	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	420	mg/kg	CCME CWS/EPA 8260d m	1.3
Toluene	1100	mg/kg	CCME CWS/EPA 8260d m	5.1
Ethylbenzene	320	mg/kg	CCME CWS/EPA 8260d m	2.5
m & p-Xylene	830	mg/kg	CCME CWS/EPA 8260d m	10

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Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted., PAH: Detection limits raised due to dilution as a result of sample matrix interference.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 3 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	Client ID	Meter Number	Laboratory Number: B8A8814:UY4554-01
Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED		LSD	Well ID
Well/Plant/Facility: SL ROSS ENVIRONMENTAL		Initials of Sampler: N/A	Sampling Company: SL ROSS ENVIRONMENTAL
Field or Area	Pool or Zone	Sample Point: SYB FRESH	Container Identity: VIAL
Percent Full	Test Recovery	Sample Gathering Point	Solution Gas
Test Type	No.	Multiple Recovery	Interval From: To:
Elevations (m) KB	GRD	Well Fluid Status	Well Status Mode
Production Rates: Water m³/d	Oil m³/d	Gas 1000m³/d	Gauge Pressures kPa: Source / As Received
Temperature °C: Source	As Received: 23.0	Well Status Type	Well Type
Gas or Condensate Project	Licence No.		
Date Sampled Start: 2018/12/11	Date Sampled End	Date Received: 2018/12/13	Date Reported: 2018/12/31
Date Reissued	Analyst: DUO,JGI,YD0,DR3,BC5,MN2		

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
o-Xylene	360	mg/kg	CCME CWS/EPA 8260d m	5.1
Xylenes (Total)	1200	mg/kg	Auto Calc	11
F1 (C6-C10) - BTEX	49000	mg/kg	Auto Calc	2500
F1 (C6-C10)	52000	mg/kg	CCME CWS/EPA 8260d m	2500

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted., PAH: Detection limits raised due to dilution as a result of sample matrix interference.

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2018/12/31 16:26   Page 4 of 4

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B926180:VM7409-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	SYB
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	2	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	1.0	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	6	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	45.4	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	120	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	Client ID	Meter Number	Laboratory Number
			B8A8814:UY4555-01

Operator Name	LSD	Well ID
SL ROSS ENVIRONMENTAL RESEARCH LIMITED		

Well/Plant/Facility	Initials of Sampler	Sampling Company
SL ROSS ENVIRONMENTAL	N/A	SL ROSS ENVIRONMENTAL

Field or Area	Pool or Zone	Sample Point	Container Identity	Percent Full
		SYB 2 DAY	VIAL	

Test Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas
Test Type; No.; Multiple Recovery; Well Fluid Status; Well Status Mode
Production Rates: Water m³/d; Oil m³/d; Gas 1000m³/d
Gauge Pressures kPa: Source; As Received
Temperature °C: Source; As Received: 23.0
Well Status Type; Well Type; Gas or Condensate Project; Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/04/20		2018/12/13	2018/12/31		HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	9.4	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	9.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.4	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	7.4	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	5.2	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	9.6	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	18	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	84	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	110	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	45	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	29	mg/kg	EPA 3540C/8270E m	5.0
Perylene	12	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	23	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	130	mg/kg	CCME CWS/EPA 8260d m	2.3
Toluene	450	mg/kg	CCME CWS/EPA 8260d m	9.0
Ethylbenzene	200	mg/kg	CCME CWS/EPA 8260d m	4.5
m & p-Xylene	540	mg/kg	CCME CWS/EPA 8260d m	18
o-Xylene	260	mg/kg	CCME CWS/EPA 8260d m	9.0
Xylenes (Total)	800	mg/kg	Auto Calc	20
F1 (C6-C10) - BTEX	26000	mg/kg	Auto Calc	4500
F1 (C6-C10)	27000	mg/kg	CCME CWS/EPA 8260d m	4500

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8814:UY4556-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	N/A
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL
Initials of Sampler	
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	SYB 14 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From / To	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/02/05
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,DR3,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	11	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.9	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	6.6	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	7.3	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	11	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	5.1	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	5.8	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	20	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	77	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	98	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	26	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	34	mg/kg	EPA 3540C/8270E m	5.0
Perylene	13	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	27	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	12	mg/kg	CCME CWS/EPA 8260d m	2.4
Toluene	96	mg/kg	CCME CWS/EPA 8260d m	9.5
Ethylbenzene	23	mg/kg	CCME CWS/EPA 8260d m	4.8
m & p-Xylene	66	mg/kg	CCME CWS/EPA 8260d m	19
o-Xylene	42	mg/kg	CCME CWS/EPA 8260d m	9.5
Xylenes (Total)	110	mg/kg	Auto Calc	21
F1 (C6-C10) - BTEX	6900	mg/kg	Auto Calc	4800
F1 (C6-C10)	7200	mg/kg	CCME CWS/EPA 8260d m	4800

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Detection limits raised based on sample volume used for analysis. on Volatiles Batch: 9267749, Detection limits raised due to dilution as a result of sample matrix interference. on Semi-Volatiles Batch: 9270444, PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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B.13 SYN OIL

SL Ross Model	SYN	
Modeling Constants		
Standard Density	858.596	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	139.247	kg/m3
Density Constant 2	0.69492	kg/K.m3
Standard Viscosity	11.48362	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	5.6082	
Viscosity Constant 2	4435.68	K-1
Oil/Water Interfacial Tension	20.6587	dyne/cm
Air/Oil Interfacial Tension	26.3819	dyne/cm
Oil/Water Interfacial Tension Constant	-0.93144	
Air/Oil Interfacial Tension Constant	0.50793	
Initial Pour Point	223.242	K
Pour Point Constant	0.44622	
ASTM Distillation Constant A (slope)	458.055	K
ASTM Distillation Constant B (intercept)	428.719	K
Emulsification Delay	9999999999	
Initial Flash Point	265.145	K
Flash Point Constant	1.71413	
Fv vs. Theta A	17.30000	
Fv vs. Theta B	17.40000	
B.Tg	7970.15	
B.To	7459.71	

SYN SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

B8A8826:UY4641-01
Laboratory Number

MaxxID | Client ID | Meter Number

SL ROSS ENVIRONMENTAL RESEARCH LIMITED
Operator Name | LSD | Well ID

Well/Plant/Facility | Initials of Sampler: NA | Sampling Company: SL ROSS ENVIRONMENTAL

Field or Area | Pool or Zone | Sample Point: SYN FRESH | Container Identity: VIAL | Percent Full

Test Recovery | Interval (From: / To:) | Elevations (m) (KB / GRD) | Sample Gathering Point | Solution Gas

Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode

Production Rates (Water m³/d | Oil m³/d | Gas 1000m³/d) | Gauge Pressures kPa (Source | As Received) | Temperature °C (Source | As Received: 23.0) | Well Status Type | Well Type

Gas or Condensate Project | Licence No.

Date Sampled Start	Date Sampled End	Date Received	Date Reported	Date Reissued	Analyst
2017/05/10		2018/12/13	2018/12/31		DUO,DR3,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	0.5	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	<0.1	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	<1	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D6352				
D6352 Distillation Initial Boiling Point	35.5	°C	ASTM D6352	N/A
D6352 Distillation 1 mass % off	37.7	°C	ASTM D6352	N/A
D6352 Distillation 2 mass % off	51.5	°C	ASTM D6352	N/A
D6352 Distillation 3 mass % off	68.3	°C	ASTM D6352	N/A
D6352 Distillation 4 mass % off	85.0	°C	ASTM D6352	N/A
D6352 Distillation 5 mass % off	98.6	°C	ASTM D6352	N/A
D6352 Distillation 6 mass % off	104.3	°C	ASTM D6352	N/A
D6352 Distillation 7 mass % off	114.9	°C	ASTM D6352	N/A
D6352 Distillation 8 mass % off	126.0	°C	ASTM D6352	N/A
D6352 Distillation 9 mass % off	133.7	°C	ASTM D6352	N/A
D6352 Distillation 10 mass % off	141.9	°C	ASTM D6352	N/A
D6352 Distillation 11 mass % off	151.5	°C	ASTM D6352	N/A
D6352 Distillation 12 mass % off	159.4	°C	ASTM D6352	N/A
D6352 Distillation 13 mass % off	166.6	°C	ASTM D6352	N/A
D6352 Distillation 14 mass % off	174.3	°C	ASTM D6352	N/A
D6352 Distillation 15 mass % off	180.4	°C	ASTM D6352	N/A
D6352 Distillation 16 mass % off	187.3	°C	ASTM D6352	N/A
D6352 Distillation 17 mass % off	194.2	°C	ASTM D6352	N/A
D6352 Distillation 18 mass % off	199.1	°C	ASTM D6352	N/A
D6352 Distillation 19 mass % off	204.8	°C	ASTM D6352	N/A
D6352 Distillation 20 mass % off	210.2	°C	ASTM D6352	N/A
D6352 Distillation 21 mass % off	215.6	°C	ASTM D6352	N/A
D6352 Distillation 22 mass % off	219.6	°C	ASTM D6352	N/A
D6352 Distillation 23 mass % off	224.2	°C	ASTM D6352	N/A
D6352 Distillation 24 mass % off	228.9	°C	ASTM D6352	N/A
D6352 Distillation 25 mass % off	233.3	°C	ASTM D6352	N/A
D6352 Distillation 26 mass % off	237.3	°C	ASTM D6352	N/A
D6352 Distillation 27 mass % off	241.6	°C	ASTM D6352	N/A
D6352 Distillation 28 mass % off	246.0	°C	ASTM D6352	N/A
D6352 Distillation 29 mass % off	250.0	°C	ASTM D6352	N/A
D6352 Distillation 30 mass % off	253.7	°C	ASTM D6352	N/A
D6352 Distillation 31 mass % off	257.0	°C	ASTM D6352	N/A
D6352 Distillation 32 mass % off	260.7	°C	ASTM D6352	N/A
D6352 Distillation 33 mass % off	264.3	°C	ASTM D6352	N/A
D6352 Distillation 34 mass % off	267.7	°C	ASTM D6352	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 4

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8826:UY4641-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	SYN FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d)	
Gauge Pressures kPa (Source / As Received)	
Temperature °C (Source / As Received)	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/10
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D6352 Distillation 35 mass % off	271.1	°C	ASTM D6352	N/A
D6352 Distillation 36 mass % off	274.5	°C	ASTM D6352	N/A
D6352 Distillation 37 mass % off	278.0	°C	ASTM D6352	N/A
D6352 Distillation 38 mass % off	281.5	°C	ASTM D6352	N/A
D6352 Distillation 39 mass % off	284.9	°C	ASTM D6352	N/A
D6352 Distillation 40 mass % off	288.1	°C	ASTM D6352	N/A
D6352 Distillation 41 mass % off	291.2	°C	ASTM D6352	N/A
D6352 Distillation 42 mass % off	294.2	°C	ASTM D6352	N/A
D6352 Distillation 43 mass % off	297.2	°C	ASTM D6352	N/A
D6352 Distillation 44 mass % off	300.2	°C	ASTM D6352	N/A
D6352 Distillation 45 mass % off	302.9	°C	ASTM D6352	N/A
D6352 Distillation 46 mass % off	305.7	°C	ASTM D6352	N/A
D6352 Distillation 47 mass % off	308.5	°C	ASTM D6352	N/A
D6352 Distillation 48 mass % off	311.2	°C	ASTM D6352	N/A
D6352 Distillation 49 mass % off	314.1	°C	ASTM D6352	N/A
D6352 Distillation 50 mass % off	316.7	°C	ASTM D6352	N/A
D6352 Distillation 51 mass % off	319.4	°C	ASTM D6352	N/A
D6352 Distillation 52 mass % off	322.2	°C	ASTM D6352	N/A
D6352 Distillation 53 mass % off	325.0	°C	ASTM D6352	N/A
D6352 Distillation 54 mass % off	327.9	°C	ASTM D6352	N/A
D6352 Distillation 55 mass % off	330.6	°C	ASTM D6352	N/A
D6352 Distillation 56 mass % off	333.3	°C	ASTM D6352	N/A
D6352 Distillation 57 mass % off	336.2	°C	ASTM D6352	N/A
D6352 Distillation 58 mass % off	339.0	°C	ASTM D6352	N/A
D6352 Distillation 59 mass % off	342.0	°C	ASTM D6352	N/A
D6352 Distillation 60 mass % off	344.7	°C	ASTM D6352	N/A
D6352 Distillation 61 mass % off	347.4	°C	ASTM D6352	N/A
D6352 Distillation 62 mass % off	350.2	°C	ASTM D6352	N/A
D6352 Distillation 63 mass % off	353.0	°C	ASTM D6352	N/A
D6352 Distillation 64 mass % off	355.8	°C	ASTM D6352	N/A
D6352 Distillation 65 mass % off	358.5	°C	ASTM D6352	N/A
D6352 Distillation 66 mass % off	361.3	°C	ASTM D6352	N/A
D6352 Distillation 67 mass % off	364.2	°C	ASTM D6352	N/A
D6352 Distillation 68 mass % off	367.0	°C	ASTM D6352	N/A
D6352 Distillation 69 mass % off	369.9	°C	ASTM D6352	N/A
D6352 Distillation 70 mass % off	372.9	°C	ASTM D6352	N/A
D6352 Distillation 71 mass % off	375.9	°C	ASTM D6352	N/A
D6352 Distillation 72 mass % off	379.1	°C	ASTM D6352	N/A
D6352 Distillation 73 mass % off	382.2	°C	ASTM D6352	N/A
D6352 Distillation 74 mass % off	385.4	°C	ASTM D6352	N/A
D6352 Distillation 75 mass % off	388.8	°C	ASTM D6352	N/A
D6352 Distillation 76 mass % off	392.1	°C	ASTM D6352	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 2 of 4

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CERTIFICATE OF ANALYSIS

B8A8826:UY4641-01
Laboratory Number

MaxxID | Client ID | Meter Number

Operator Name: SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD: NA | Well ID: SL ROSS ENVIRONMENTAL
Well/Plant/Facility | Initials of Sampler | Sampling Company
Sample Point: SYN FRESH | Container Identity: VIAL
Field or Area | Pool or Zone | Percent Full

Test Recovery | Interval From: To: | Elevations (m) KB GRD | Sample Gathering Point | Solution Gas
Test Type | No. | Multiple Recovery | Well Fluid Status | Well Status Mode
Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d | Gauge Pressures kPa: Source, As Received | Temperature °C: Source, As Received 23.0 | Well Status Type | Well Type
Gas or Condensate Project | Licence No.

Date Sampled Start: 2017/05/10 | Date Sampled End | Date Received: 2018/12/13 | Date Reported: 2018/12/31 | Date Reissued | Analyst: DUO,DR3,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D6352 Distillation 77 mass % off	395.5	°C	ASTM D6352	N/A
D6352 Distillation 78 mass % off	399.1	°C	ASTM D6352	N/A
D6352 Distillation 79 mass % off	402.6	°C	ASTM D6352	N/A
D6352 Distillation 80 mass % off	406.2	°C	ASTM D6352	N/A
D6352 Distillation 81 mass % off	409.9	°C	ASTM D6352	N/A
D6352 Distillation 82 mass % off	413.5	°C	ASTM D6352	N/A
D6352 Distillation 83 mass % off	417.0	°C	ASTM D6352	N/A
D6352 Distillation 84 mass % off	420.6	°C	ASTM D6352	N/A
D6352 Distillation 85 mass % off	424.2	°C	ASTM D6352	N/A
D6352 Distillation 86 mass % off	428.0	°C	ASTM D6352	N/A
D6352 Distillation 87 mass % off	432.0	°C	ASTM D6352	N/A
D6352 Distillation 88 mass % off	436.4	°C	ASTM D6352	N/A
D6352 Distillation 89 mass % off	441.1	°C	ASTM D6352	N/A
D6352 Distillation 90 mass % off	446.1	°C	ASTM D6352	N/A
D6352 Distillation 91 mass % off	451.5	°C	ASTM D6352	N/A
D6352 Distillation 92 mass % off	457.3	°C	ASTM D6352	N/A
D6352 Distillation 93 mass % off	463.7	°C	ASTM D6352	N/A
D6352 Distillation 94 mass % off	470.6	°C	ASTM D6352	N/A
D6352 Distillation 95 mass % off	478.5	°C	ASTM D6352	N/A
D6352 Distillation 96 mass % off	488.1	°C	ASTM D6352	N/A
D6352 Distillation 97 mass % off	499.9	°C	ASTM D6352	N/A
D6352 Distillation 98 mass % off	515.7	°C	ASTM D6352	N/A
D6352 Distillation 99 mass % off	546.7	°C	ASTM D6352	N/A
D6352 Distillation Final Boiling Point	585.0	°C	ASTM D6352	N/A
Polycyclic Aromatics				
Acenaphthene	8.0	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	2.3	mg/kg	Auto Calc	0.71
Acenaphthylene	4.4	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	<0.40	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	1.2	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	2.7	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	7.2	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	1.4	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	8.8	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	2.5	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	2.4	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	45	mg/kg	EPA 3540C/8270E m	0.50

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8826:UY4641-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	SYN FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates (Water m³/d, Oil m³/d, Gas 1000m³/d)	
Gauge Pressures kPa (Source, As Received)	
Temperature °C (Source / As Received)	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/10
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Indeno(1,2,3-cd)pyrene	1.3	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	68	mg/kg	EPA 3540C/8270E m	0.50
2-Methylnaphthalene	100	mg/kg	EPA 3540C/8270E m	0.50
Naphthalene	27	mg/kg	EPA 3540C/8270E m	0.50
Phenanthrene	33	mg/kg	EPA 3540C/8270E m	0.50
Perylene	1.2	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	49	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	680	mg/kg	CCME CWS/EPA 8260d m	0.17
Toluene	2400	mg/kg	CCME CWS/EPA 8260d m	0.69
Ethylbenzene	880	mg/kg	CCME CWS/EPA 8260d m	0.35
m & p-Xylene	2200	mg/kg	CCME CWS/EPA 8260d m	1.4
o-Xylene	970	mg/kg	CCME CWS/EPA 8260d m	0.69
Xylenes (Total)	3100	mg/kg	Auto Calc	1.5
F1 (C6-C10) - BTEX	48000	mg/kg	Auto Calc	350
F1 (C6-C10)	55000	mg/kg	CCME CWS/EPA 8260d m	350

**** Information not supplied by Client -- data derived from LSD information** **Results relate only to items tested**

Remarks:

Sample was analyzed past method specified hold time for PAH in Soil by GC/MS., PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B926180:VM7410-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	SYN
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/03
Date Reported	2019/04/16
Date Reissued	2019/05/29
Analyst	YD0

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	<1	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	<1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	<1	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2019/05/29 14:33 Page 1 of 1

Maxxam Analytics International Corporation o/a Maxxam Analytics Edmonton: 6744 - 50th Street T6B 3M9 Telephone(780) 378-8500 FAX(780) 378-8699

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8826:UY4642-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	SYN 2 DAY
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2017/05/12
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,BC5

Test Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas; Test Type; No.; Multiple Recovery; Well Fluid Status; Well Status Mode; Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d; Gauge Pressures kPa: Source, As Received; Temperature °C: Source, As Received; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	13	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	3.4	mg/kg	Auto Calc	0.71
Acenaphthylene	7.0	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	12	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	2.1	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	3.8	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	8.7	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	0.95	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	2.2	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	11	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	3.0	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	2.6	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	48	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	2.0	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	76	mg/kg	EPA 3540C/8270E m	0.50
2-Methylnaphthalene	120	mg/kg	EPA 3540C/8270E m	0.50
Naphthalene	24	mg/kg	EPA 3540C/8270E m	0.50
Phenanthrene	38	mg/kg	EPA 3540C/8270E m	0.50
Perylene	1.7	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	62	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	0.61	mg/kg	CCME CWS/EPA 8260d m	0.013
Toluene	35	mg/kg	CCME CWS/EPA 8260d m	0.054
Ethylbenzene	23	mg/kg	CCME CWS/EPA 8260d m	0.027
m & p-Xylene	81	mg/kg	CCME CWS/EPA 8260d m	0.11
o-Xylene	52	mg/kg	CCME CWS/EPA 8260d m	0.054
Xylenes (Total)	130	mg/kg	Auto Calc	0.12
F1 (C6-C10) - BTEX	5800	mg/kg	Auto Calc	27
F1 (C6-C10)	6000	mg/kg	CCME CWS/EPA 8260d m	27

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8826:UY4643-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	SYN 14 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/24
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	HP5,JGI,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	9.6	mg/kg	EPA 3540C/8270E m	0.50
Benzo[a]pyrene equivalency	3.6	mg/kg	Auto Calc	0.71
Acenaphthylene	7.1	mg/kg	EPA 3540C/8270E m	0.50
Acridine	<1.0	mg/kg	EPA 3540C/8270E m	1.0
Anthracene	12	mg/kg	EPA 3540C/8270E m	0.40
Benzo(a)anthracene	2.2	mg/kg	EPA 3540C/8270E m	0.50
Benzo(b&j)fluoranthene	4.0	mg/kg	EPA 3540C/8270E m	0.50
Benzo(k)fluoranthene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(g,h,i)perylene	10	mg/kg	EPA 3540C/8270E m	0.50
Benzo(c)phenanthrene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Benzo(a)pyrene	2.4	mg/kg	EPA 3540C/8270E m	0.50
Benzo[e]pyrene	12	mg/kg	EPA 3540C/8270E m	0.50
Chrysene	3.8	mg/kg	EPA 3540C/8270E m	0.50
Dibenz(a,h)anthracene	<0.50	mg/kg	EPA 3540C/8270E m	0.50
Fluoranthene	4.9	mg/kg	EPA 3540C/8270E m	0.50
Fluorene	54	mg/kg	EPA 3540C/8270E m	0.50
Indeno(1,2,3-cd)pyrene	2.2	mg/kg	EPA 3540C/8270E m	0.50
1-Methylnaphthalene	58	mg/kg	EPA 3540C/8270E m	0.50
2-Methylnaphthalene	84	mg/kg	EPA 3540C/8270E m	0.50
Naphthalene	8.3	mg/kg	EPA 3540C/8270E m	0.50
Phenanthrene	42	mg/kg	EPA 3540C/8270E m	0.50
Perylene	1.9	mg/kg	EPA 3540C/8270E m	0.50
Pyrene	64	mg/kg	EPA 3540C/8270E m	0.50
Quinoline	NC	mg/kg	EPA 3540C/8270E m	1.0
Volatiles				
Benzene	0.039	mg/kg	CCME CWS/EPA 8260d m	0.013
Toluene	5.8	mg/kg	CCME CWS/EPA 8260d m	0.054
Ethylbenzene	0.48	mg/kg	CCME CWS/EPA 8260d m	0.027
m & p-Xylene	2.0	mg/kg	CCME CWS/EPA 8260d m	0.11
o-Xylene	0.85	mg/kg	CCME CWS/EPA 8260d m	0.054
Xylenes (Total)	2.9	mg/kg	Auto Calc	0.12
F1 (C6-C10) - BTEX	<27	mg/kg	Auto Calc	27
F1 (C6-C10)	<27	mg/kg	CCME CWS/EPA 8260d m	27

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

Maxxam Analytics International Corporation o/a Maxxam Analytics Edmonton: 6744 - 50th Street T6B 3M9 Telephone(780) 378-8500 FAX(780) 378-8699

B.14 WCS OIL

SL Ross Model	WCS	
Modeling Constants		
Standard Density	924.021	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	271.350	kg/m3
Density Constant 2	0.66790	kg/K.m3
Standard Viscosity	1425.27593	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	19.8731	
Viscosity Constant 2	7883.10	K-1
Oil/Water Interfacial Tension	13.2780	dyne/cm
Air/Oil Interfacial Tension	29.0764	dyne/cm
Oil/Water Interfacial Tension Constant	0.40026	
Air/Oil Interfacial Tension Constant	0.52751	
Initial Pour Point	230.879	K
Pour Point Constant	1.13304	
ASTM Distillation Constant A (slope)	674.382	K
ASTM Distillation Constant B (intercept)	440.901	K
Emulsification Delay	0	
Initial Flash Point	220.625	K
Flash Point Constant	2.00573	
Fv vs. Theta A	12.50000	
Fv vs. Theta B	14.30000	
B.Tg	9643.66	
B.To	6304.88	

WCS SIMDIS Results, Chemical Analysis

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8826:UY4644-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	WCS FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2018/12/11
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Total Metals by ICP				
Total Iron (Fe)	5.7	mg/kg	PTC SOP-00205	0.1
Total Nickel (Ni)	56.1	mg/kg	PTC SOP-00205	0.1
Total Vanadium (V)	136	mg/kg	PTC SOP-00205	1
Simulated Dist ASTM D7169				
D7169 Distillation Initial Boiling Point	34.4	°C	ASTM D7169	N/A
D7169 Distillation 1 mass % off	34.5	°C	ASTM D7169	N/A
D7169 Distillation 2 mass % off	35.5	°C	ASTM D7169	N/A
D7169 Distillation 3 mass % off	36.5	°C	ASTM D7169	N/A
D7169 Distillation 4 mass % off	39.0	°C	ASTM D7169	N/A
D7169 Distillation 5 mass % off	44.0	°C	ASTM D7169	N/A
D7169 Distillation 6 mass % off	56.2	°C	ASTM D7169	N/A
D7169 Distillation 7 mass % off	69.1	°C	ASTM D7169	N/A
D7169 Distillation 8 mass % off	84.1	°C	ASTM D7169	N/A
D7169 Distillation 9 mass % off	99.2	°C	ASTM D7169	N/A
D7169 Distillation 10 mass % off	110.4	°C	ASTM D7169	N/A
D7169 Distillation 11 mass % off	126.8	°C	ASTM D7169	N/A
D7169 Distillation 12 mass % off	141.7	°C	ASTM D7169	N/A
D7169 Distillation 13 mass % off	159.8	°C	ASTM D7169	N/A
D7169 Distillation 14 mass % off	176.3	°C	ASTM D7169	N/A
D7169 Distillation 15 mass % off	193.4	°C	ASTM D7169	N/A
D7169 Distillation 16 mass % off	208.4	°C	ASTM D7169	N/A
D7169 Distillation 17 mass % off	220.8	°C	ASTM D7169	N/A
D7169 Distillation 18 mass % off	232.5	°C	ASTM D7169	N/A
D7169 Distillation 19 mass % off	244.2	°C	ASTM D7169	N/A
D7169 Distillation 20 mass % off	253.9	°C	ASTM D7169	N/A
D7169 Distillation 21 mass % off	263.5	°C	ASTM D7169	N/A
D7169 Distillation 22 mass % off	272.2	°C	ASTM D7169	N/A
D7169 Distillation 23 mass % off	281.8	°C	ASTM D7169	N/A
D7169 Distillation 24 mass % off	290.5	°C	ASTM D7169	N/A
D7169 Distillation 25 mass % off	298.2	°C	ASTM D7169	N/A
D7169 Distillation 26 mass % off	305.6	°C	ASTM D7169	N/A
D7169 Distillation 27 mass % off	313.0	°C	ASTM D7169	N/A
D7169 Distillation 28 mass % off	320.2	°C	ASTM D7169	N/A
D7169 Distillation 29 mass % off	327.7	°C	ASTM D7169	N/A
D7169 Distillation 30 mass % off	334.9	°C	ASTM D7169	N/A
D7169 Distillation 31 mass % off	342.3	°C	ASTM D7169	N/A
D7169 Distillation 32 mass % off	349.3	°C	ASTM D7169	N/A
D7169 Distillation 33 mass % off	356.1	°C	ASTM D7169	N/A
D7169 Distillation 34 mass % off	363.1	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted., PAH: Detection limits raised due to dilution as a result of sample matrix interference. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 3

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8826:UY4644-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	WCS FRESH
Container Identity	VIAL
Percent Full	
Test Recovery	
Test Type / No. / Multiple Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	23.0 (As Received)
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2018/12/11
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 35 mass % off	370.0	°C	ASTM D7169	N/A
D7169 Distillation 36 mass % off	377.1	°C	ASTM D7169	N/A
D7169 Distillation 37 mass % off	384.2	°C	ASTM D7169	N/A
D7169 Distillation 38 mass % off	391.3	°C	ASTM D7169	N/A
D7169 Distillation 39 mass % off	398.4	°C	ASTM D7169	N/A
D7169 Distillation 40 mass % off	405.3	°C	ASTM D7169	N/A
D7169 Distillation 41 mass % off	412.0	°C	ASTM D7169	N/A
D7169 Distillation 42 mass % off	418.2	°C	ASTM D7169	N/A
D7169 Distillation 43 mass % off	424.2	°C	ASTM D7169	N/A
D7169 Distillation 44 mass % off	430.2	°C	ASTM D7169	N/A
D7169 Distillation 45 mass % off	436.5	°C	ASTM D7169	N/A
D7169 Distillation 46 mass % off	443.1	°C	ASTM D7169	N/A
D7169 Distillation 47 mass % off	449.9	°C	ASTM D7169	N/A
D7169 Distillation 48 mass % off	456.5	°C	ASTM D7169	N/A
D7169 Distillation 49 mass % off	463.2	°C	ASTM D7169	N/A
D7169 Distillation 50 mass % off	470.1	°C	ASTM D7169	N/A
D7169 Distillation 51 mass % off	476.9	°C	ASTM D7169	N/A
D7169 Distillation 52 mass % off	483.9	°C	ASTM D7169	N/A
D7169 Distillation 53 mass % off	491.3	°C	ASTM D7169	N/A
D7169 Distillation 54 mass % off	498.6	°C	ASTM D7169	N/A
D7169 Distillation 55 mass % off	505.5	°C	ASTM D7169	N/A
D7169 Distillation 56 mass % off	512.7	°C	ASTM D7169	N/A
D7169 Distillation 57 mass % off	520.1	°C	ASTM D7169	N/A
D7169 Distillation 58 mass % off	528.1	°C	ASTM D7169	N/A
D7169 Distillation 59 mass % off	536.2	°C	ASTM D7169	N/A
D7169 Distillation 60 mass % off	544.1	°C	ASTM D7169	N/A
D7169 Distillation 61 mass % off	552.4	°C	ASTM D7169	N/A
D7169 Distillation 62 mass % off	560.9	°C	ASTM D7169	N/A
D7169 Distillation 63 mass % off	569.2	°C	ASTM D7169	N/A
D7169 Distillation 64 mass % off	577.4	°C	ASTM D7169	N/A
D7169 Distillation 65 mass % off	585.9	°C	ASTM D7169	N/A
D7169 Distillation 66 mass % off	594.3	°C	ASTM D7169	N/A
D7169 Distillation 67 mass % off	602.9	°C	ASTM D7169	N/A
D7169 Distillation 68 mass % off	611.6	°C	ASTM D7169	N/A
D7169 Distillation 69 mass % off	620.7	°C	ASTM D7169	N/A
D7169 Distillation 70 mass % off	629.6	°C	ASTM D7169	N/A
D7169 Distillation 71 mass % off	638.5	°C	ASTM D7169	N/A
D7169 Distillation 72 mass % off	647.8	°C	ASTM D7169	N/A
D7169 Distillation 73 mass % off	656.3	°C	ASTM D7169	N/A
D7169 Distillation 74 mass % off	666.3	°C	ASTM D7169	N/A
D7169 Distillation 75 mass % off	676.0	°C	ASTM D7169	N/A
D7169 Distillation 76 mass % off	686.0	°C	ASTM D7169	N/A

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted., PAH: Detection limits raised due to dilution as a result of sample matrix interference. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26

Page 2 of 3

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8826:UY4644-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	WCS FRESH
Container Identity	VIAL
Percent Full	
Temperature °C As Received	23.0
Date Sampled Start	2018/12/11
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,DR3,YD0,BC5,MN2

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
D7169 Distillation 77 mass % off	694.4	°C	ASTM D7169	N/A
D7169 Distillation 78 mass % off	703.0	°C	ASTM D7169	N/A
D7169 Distillation 79 mass % off	711.1	°C	ASTM D7169	N/A
D7169 Distillation 80 mass % off	718.8	°C	ASTM D7169	N/A
D7169 Distillation Residue @ 720 °C	19.86	mass%	ASTM D7169	0.01
Polycyclic Aromatics				
Acenaphthene	7.3	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	<7.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	<4.0	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	5.8	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	6.2	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	6.0	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	21	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	97	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	160	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	46	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	52	mg/kg	EPA 3540C/8270E m	5.0
Perylene	6.9	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	14	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	1100	mg/kg	CCME CWS/EPA 8260d m	0.18
Toluene	2200	mg/kg	CCME CWS/EPA 8260d m	0.74
Ethylbenzene	320	mg/kg	CCME CWS/EPA 8260d m	0.37
m & p-Xylene	1900	mg/kg	CCME CWS/EPA 8260d m	1.5
o-Xylene	510	mg/kg	CCME CWS/EPA 8260d m	0.74
Xylenes (Total)	2400	mg/kg	Auto Calc	1.6
F1 (C6-C10) - BTEX	37000	mg/kg	Auto Calc	370
F1 (C6-C10)	43000	mg/kg	CCME CWS/EPA 8260d m	370

** Information not supplied by Client -- data derived from LSD information   Results relate only to items tested

Remarks:

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2018/12/31 16:26   Page 3 of 3

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CERTIFICATE OF ANALYSIS

Laboratory Number	B928395:VN7074-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	SL ROSS ENVIRONMENTAL RESEARCH
Initials of Sampler	N/A
Sampling Company	SL ROSS ENVIRONMENTAL RESEARC
Field or Area	
Pool or Zone	
Sample Point	WCS
Container Identity	VIAL
Percent Full	
Temperature °C (As Received)	23.0
Date Sampled Start	2019/04/01
Date Sampled End	
Date Received	2019/04/17
Date Reported	2019/04/18
Date Reissued	2019/05/29
Analyst	YD0

Test Recovery; Test Type; No.; Multiple Recovery; Interval From: To:; Elevations (m) KB GRD; Sample Gathering Point; Solution Gas; Well Fluid Status; Well Status Mode; Production Rates: Water m³/d, Oil m³/d, Gas 1000m³/d; Gauge Pressures kPa: Source, As Received; Temperature °C: Source; Well Status Type; Well Type; Gas or Condensate Project; Licence No.

PARAMETER DESCRIPTION	RESULT	UNIT	METHOD	RDL
Dissolved Metals by ICP				
Dissolved Aluminum (Al)	2	mg/kg	ASTM D5185	1
Dissolved Arsenic (As)	<1	mg/kg	ASTM D5185	1
Dissolved Barium (Ba)	<1	mg/kg	ASTM D5185	1
Dissolved Beryllium (Be)	<1	mg/kg	ASTM D5185	1
Dissolved Boron (B)	<1	mg/kg	ASTM D5185	1
Dissolved Cadmium (Cd)	<1	mg/kg	ASTM D5185	1
Dissolved Calcium (Ca)	<1	mg/kg	ASTM D5185	1
Dissolved Chromium (Cr)	<1	mg/kg	ASTM D5185	1
Dissolved Cobalt (Co)	<1	mg/kg	ASTM D5185	1
Dissolved Copper (Cu)	<1	mg/kg	ASTM D5185	1
Dissolved Iron (Fe)	1.4	mg/kg	ASTM D5185	0.5
Dissolved Lead (Pb)	<1	mg/kg	ASTM D5185	1
Dissolved Lithium (Li)	<1	mg/kg	ASTM D5185	1
Dissolved Magnesium (Mg)	<1	mg/kg	ASTM D5185	1
Dissolved Manganese (Mn)	<1	mg/kg	ASTM D5185	1
Dissolved Molybdenum (Mo)	6	mg/kg	ASTM D5185	1
Dissolved Nickel (Ni)	54.4	mg/kg	ASTM D5185	0.5
Dissolved Phosphorus (P)	<0.5	mg/kg	ASTM D5185	0.5
Dissolved Potassium (K)	<1	mg/kg	ASTM D5185	1
Dissolved Selenium (Se)	<1	mg/kg	ASTM D5185	1
Dissolved Silicon (Si)	0.6	mg/kg	ASTM D5185	0.5
Dissolved Silver (Ag)	1	mg/kg	ASTM D5185	1
Dissolved Sodium (Na)	<1	mg/kg	ASTM D5185	1
Dissolved Strontium (Sr)	<1	mg/kg	ASTM D5185	1
Dissolved Tin (Sn)	<1	mg/kg	ASTM D5185	1
Dissolved Titanium (Ti)	2	mg/kg	ASTM D5185	1
Dissolved Vanadium (V)	128	mg/kg	ASTM D5185	0.5
Dissolved Zinc (Zn)	<1	mg/kg	ASTM D5185	1

Results relate only to items tested

Remarks:

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2019/05/29 14:33 Page 1 of 1

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CERTIFICATE OF ANALYSIS

Laboratory Number	B8A8826:UY4645-01
MaxxID	
Client ID	
Meter Number	
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	WCS 2 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From / To	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source	
Temperature °C: As Received	23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/04/20
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	8.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	9.1	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.4	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	6.2	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	6.9	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	5.1	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	7.4	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	6.0	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	6.3	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	26	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	110	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	180	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	50	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	63	mg/kg	EPA 3540C/8270E m	5.0
Perylene	8.5	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	16	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	300	mg/kg	CCME CWS/EPA 8260d m	0.25
Toluene	970	mg/kg	CCME CWS/EPA 8260d m	0.99
Ethylbenzene	140	mg/kg	CCME CWS/EPA 8260d m	0.50
m & p-Xylene	780	mg/kg	CCME CWS/EPA 8260d m	2.0
o-Xylene	230	mg/kg	CCME CWS/EPA 8260d m	0.99
Xylenes (Total)	1000	mg/kg	Auto Calc	2.2
F1 (C6-C10) - BTEX	52000	mg/kg	Auto Calc	500
F1 (C6-C10)	54000	mg/kg	CCME CWS/EPA 8260d m	500

** Information not supplied by Client -- data derived from LSD information

Results relate only to items tested

Remarks:

PAH: Detection limits raised due to dilution as a result of sample matrix interference.

PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26 Page 1 of 1

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CERTIFICATE OF ANALYSIS

MaxxID	
Client ID	
Meter Number	
Laboratory Number	B8A8826:UY4646-01
Operator Name	SL ROSS ENVIRONMENTAL RESEARCH LIMITED
LSD	
Well ID	
Well/Plant/Facility	
Initials of Sampler	NA
Sampling Company	SL ROSS ENVIRONMENTAL
Field or Area	
Pool or Zone	
Sample Point	WCS 14 DAY
Container Identity	VIAL
Percent Full	
Test Recovery	
Interval From: / To:	
Elevations (m) KB / GRD	
Sample Gathering Point	
Solution Gas	
Test Type / No. / Multiple Recovery	
Well Fluid Status	
Well Status Mode	
Production Rates: Water m³/d / Oil m³/d / Gas 1000m³/d	
Gauge Pressures kPa: Source / As Received	
Temperature °C: Source / As Received	/ 23.0
Well Status Type	
Well Type	
Gas or Condensate Project	
Licence No.	
Date Sampled Start	2017/05/02
Date Sampled End	
Date Received	2018/12/13
Date Reported	2018/12/31
Date Reissued	
Analyst	DUO,JGI,BC5

PARAMETER DESCRIPTION	Result	Unit	Method	MDL
Polycyclic Aromatics				
Acenaphthene	12	mg/kg	EPA 3540C/8270E m	5.0
Benzo[a]pyrene equivalency	9.4	mg/kg	Auto Calc	7.1
Acenaphthylene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Acridine	<10	mg/kg	EPA 3540C/8270E m	10
Anthracene	4.4	mg/kg	EPA 3540C/8270E m	4.0
Benzo(a)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(b&j)fluoranthene	6.3	mg/kg	EPA 3540C/8270E m	5.0
Benzo(k)fluoranthene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(g,h,i)perylene	7.2	mg/kg	EPA 3540C/8270E m	5.0
Benzo(c)phenanthrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Benzo(a)pyrene	5.4	mg/kg	EPA 3540C/8270E m	5.0
Benzo[e]pyrene	8.5	mg/kg	EPA 3540C/8270E m	5.0
Chrysene	6.6	mg/kg	EPA 3540C/8270E m	5.0
Dibenz(a,h)anthracene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
Fluoranthene	7.7	mg/kg	EPA 3540C/8270E m	5.0
Fluorene	30	mg/kg	EPA 3540C/8270E m	5.0
Indeno(1,2,3-cd)pyrene	<5.0	mg/kg	EPA 3540C/8270E m	5.0
1-Methylnaphthalene	110	mg/kg	EPA 3540C/8270E m	5.0
2-Methylnaphthalene	170	mg/kg	EPA 3540C/8270E m	5.0
Naphthalene	35	mg/kg	EPA 3540C/8270E m	5.0
Phenanthrene	74	mg/kg	EPA 3540C/8270E m	5.0
Perylene	9.8	mg/kg	EPA 3540C/8270E m	5.0
Pyrene	19	mg/kg	EPA 3540C/8270E m	5.0
Quinoline	NC	mg/kg	EPA 3540C/8270E m	10
Volatiles				
Benzene	83	mg/kg	CCME CWS/EPA 8260d m	0.024
Toluene	340	mg/kg	CCME CWS/EPA 8260d m	0.095
Ethylbenzene	47	mg/kg	CCME CWS/EPA 8260d m	0.048
m & p-Xylene	270	mg/kg	CCME CWS/EPA 8260d m	0.19
o-Xylene	100	mg/kg	CCME CWS/EPA 8260d m	0.095
Xylenes (Total)	380	mg/kg	Auto Calc	0.21
F1 (C6-C10) - BTEX	17000	mg/kg	Auto Calc	48
F1 (C6-C10)	18000	mg/kg	CCME CWS/EPA 8260d m	48

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Remarks:

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PAH: Extraction surrogate not calculable. Sample was diluted, not extracted. Sample received was not in compliance with CCME sampling requirements for VOC/BTEX/F1 in soil. Sample was analyzed past method specified hold time for PAH in Soil by GC/MS.

Reference Method suffix "M" indicates test methods incorporate validated modifications from specific reference methods to improve performance.

2018/12/31 16:26   Page 1 of 1

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APPENDIX C – FLUME TANK RUN DETAILS

C.1 AHS IN FLUME TANK

C.1.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

Oil initially circulated well, with waterfall shearing oil into droplets in a diameter range of 1-5 mm. By 1 hour (S1) the viscosity increased dramatically resulting in non spherical stringers of oil from the waterfall impacts. Viscosity and density climbed by 3 hours (S2), approaching the density of the water. The water remained clear under the slick, but occasional 1-2 mm diameter spherical oil droplets are seen in the water column. This continued through 6 hours (S3). The oil began to collect on the walls around the perimeter of the flume due to its increasing viscosity and sticky nature, while the measured density reached that of the water column. Sampling continued through 24 hours (S4) and by 48 hours (S5) larger blobs from the slick were seen submerged and stuck to the walls and floor. Almost no oil remained on the surface at 48 hours. The run was halted.

Figure C-0-1: AHS R1 S1 Waterfall impact on slick (streamers)

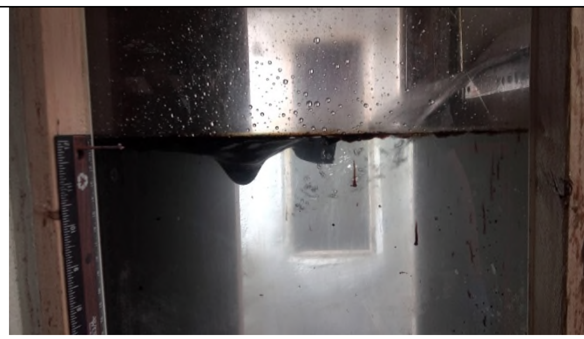


Figure C-0-2: AHS R1 S4 Waterfall impact on slick (minimal)

Figure C-0-3 AHS R1 S5 Oil collecting on sidewalls

Figure C-0-4 AHS R1 S5 Bulk oil had effectively sunken by S5

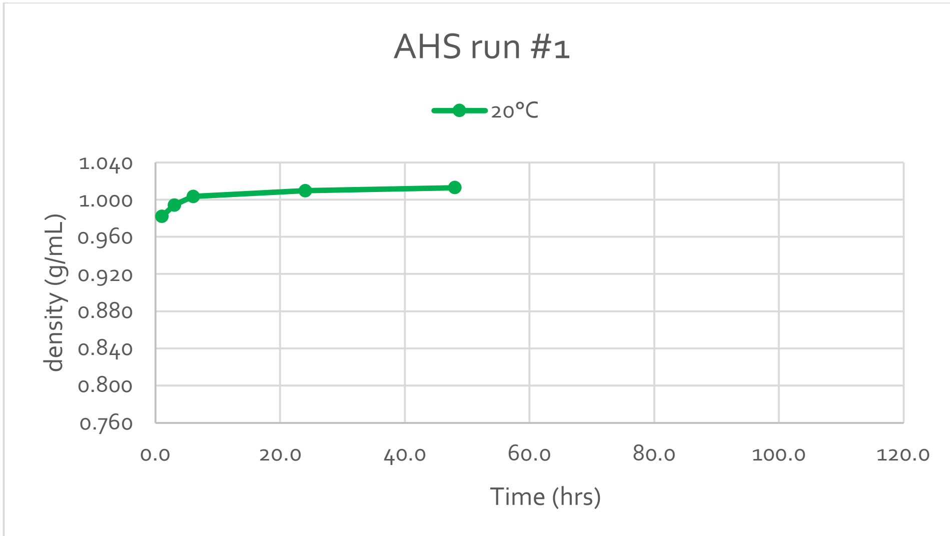


Figure C-0-5: AHS Run #1 Density vs Time

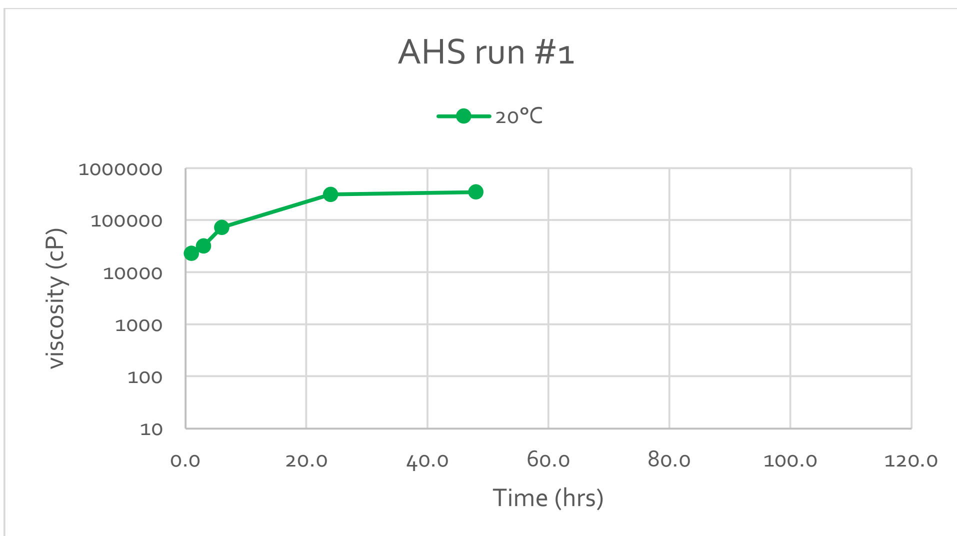


Figure C-0-6: AHS Run #1 Viscosity vs Time

C.1.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

Oil added to the flume tank initially flowed well, shearing as non spherical stringers with some droplets under the waterfall. As the viscosity increased from 1 hour through 6 hours (S1 through S3), no droplets were seen from the waterfall impacts (limited to non-spherical stringers/blobs). Some 1-2 mm diameter spherical droplets across all depths were seen in the water column. As the oil began to collect and be held up between the thruster and Fan in the north channel, an inspection around the remaining areas showed no evidence of large blobs of sunken oil during 48 hour (S5) sampling. The oil mat had a small bumpy appearance, indicating bubbles trapped in the oil. Water column remained clear at end of test.

Figure C-0-7: AHS R2 S1 Oil held up above thruster

Figure C-0-8 AHS R2 S3 Bubbles seen on surface of slick

Figure C-0-9 AHS R2 S5 Oil held up near thrusters, not passing by the viewing area, no sinking detected

Figure C-0-10 AHS R2 S8 Bulk oil still floating near thrusters

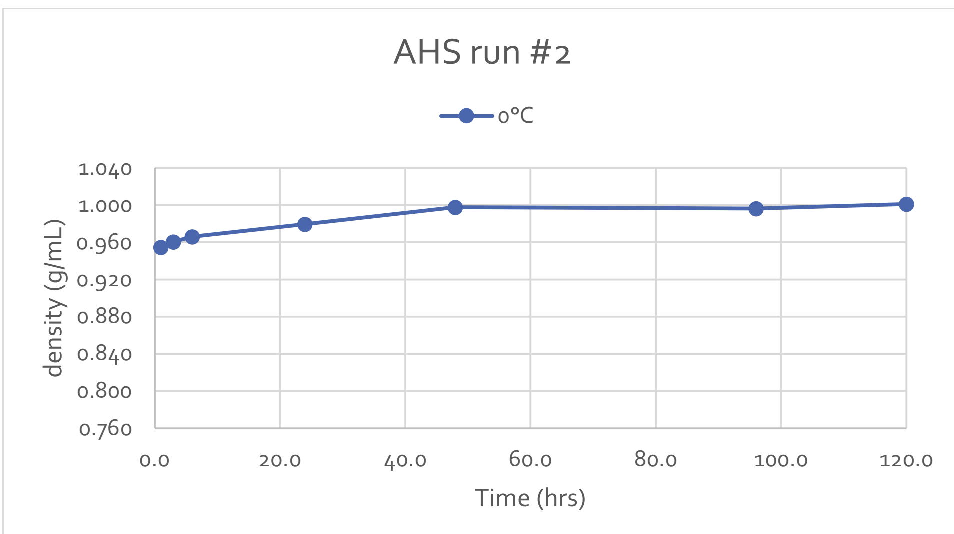


Figure C-0-11: AHS Run #2 Density vs Time

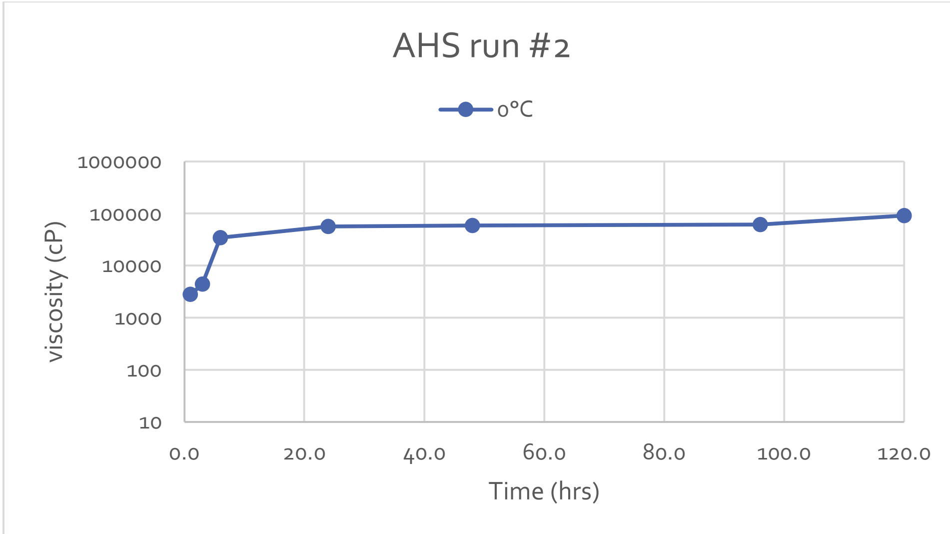


Figure C-0-12: AHS Run #2 Viscosity vs Time

C.1.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

Oil was initially flowed well, but quickly collected near the thruster which had to be cycled during the testing. Water became slightly opaque because of the sediment but some droplets of oil (approximately 10 mm diameter) could be detected circulating near the surface. Viscosity increased through 6 hours (S3), when it began to stick to the sides and small bumps on the surface of the slick indicated small air bubbles trapped within the slick. Viscosity and density increased through 24 hours (S4), then seemed to stabilize through the end of the run, 144 hours (S7).

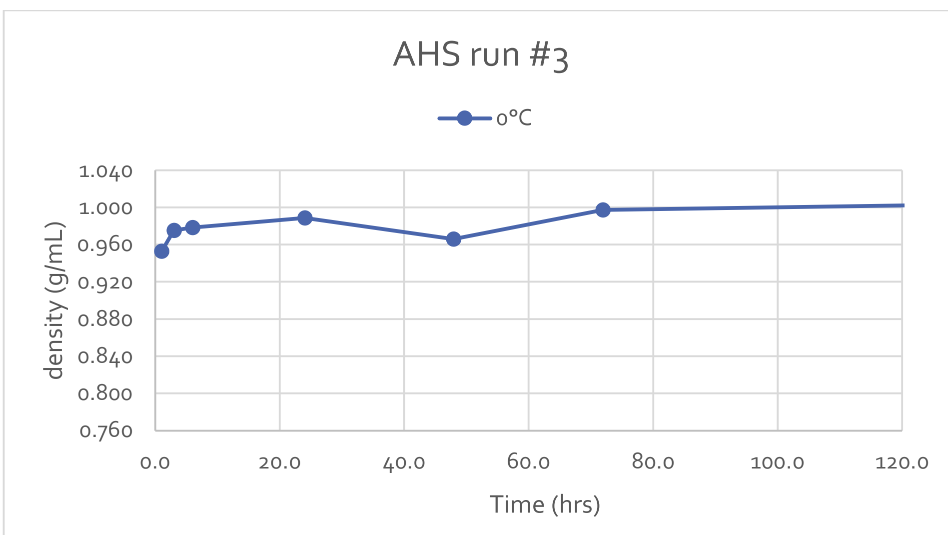


Figure C-0-13: AHS Run #3 Density vs Time

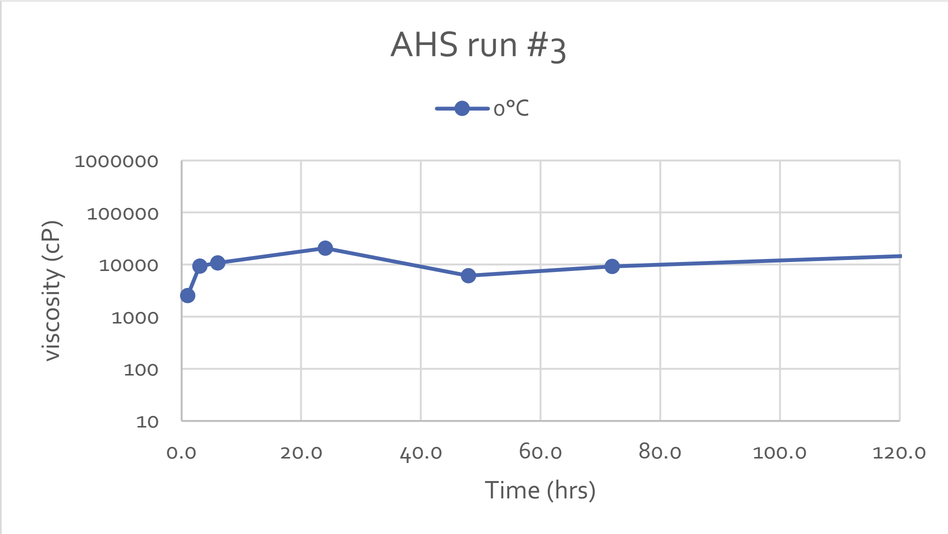


Figure C-0-14: AHS Run #3 Viscosity vs Time

C.1.4 Run #4 (20C, 35‰ salt, 1000 ppm sediment)

Oil flowed freely at the onset but increased in viscosity rather quickly. From 1 hour (S1) through 6 hours (S3), the increase in viscosity seemed apparent. It was noticed by the 24 hour mark (S4) that the volume of oil at the surface was reduced compared with the start of the run. This may be explained, at least in part, by oil that was becoming more viscous and thickening the slick. By 48 hours (S5), residue oil was sticking along the walls on the inside track of the tank. This impeded free oil circulation within the flume track. By 120 hours (S7), there was a limited amount of oil freely circulating at the surface, most seemed to be adhering to a floating slick along the inside wall track. Analysis during the run indicates the oil did increase in density, but the density of the oil did not surpass the density of the salt water and the slick remained floating.

Figure C-0-15: AHS R4 S1 Oil becoming viscous already

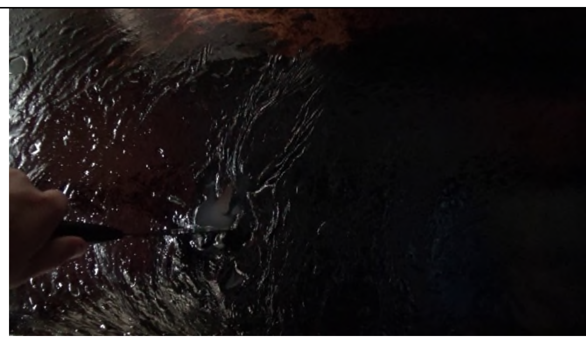


Figure C-0-16: AHS R4 S2 Oil sampling

Figure C-0-17 AHS R4 S5 Leading edge of slick

Figure C-0-18 AHS R4 S7 Oil losses from surface are apparent

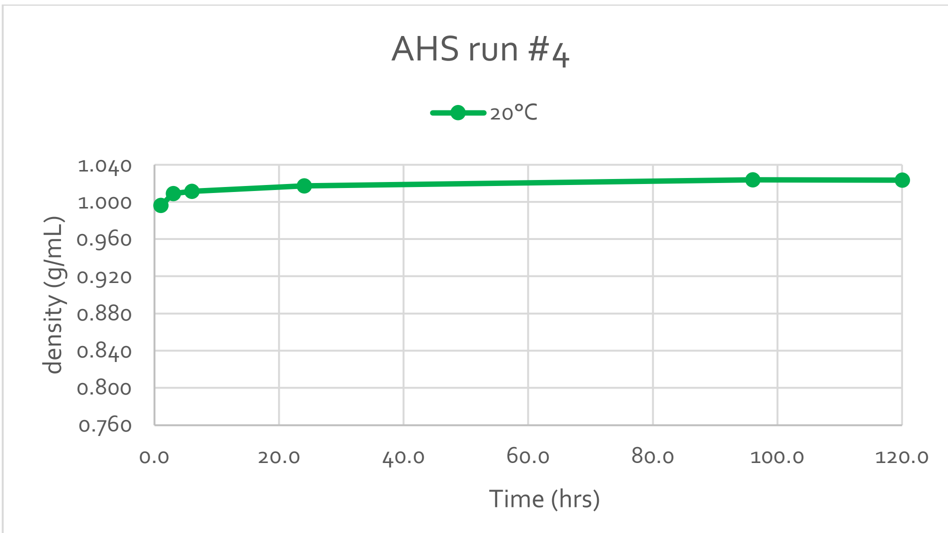


Figure C-0-19: AHS Run #4 Density vs Time

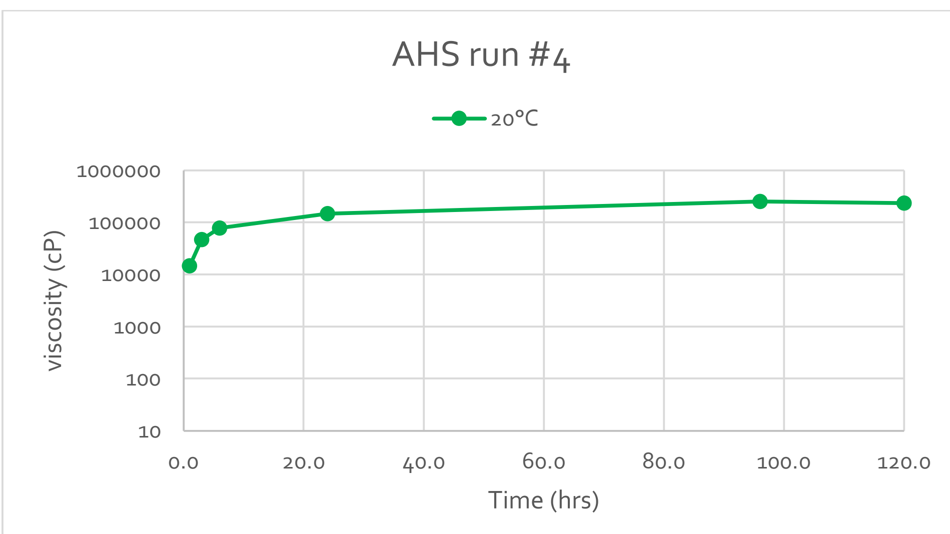


Figure C-0-20: AHS Run #4 Viscosity vs Time

C.1.5 Run #5 (20°C, 0‰ salt, 0 ppm sediment)

This run was a repeat of Run #1. The oil initially flowed freely and circulated around the flume. Oil sheared into a range of sizes (mm –cm) blobs from the waterfall and were slow to rise. By the 3 hour mark (S2), multiple blobs and stringers in the mm – cm range were observed floating at depths down to 20 cm. By 6 hours (S3) oil partially stuck to walls was seen slowly migrating down, while floating portions were moving freely. At 24 hours (S4), evidence of portions of the oil sinking with blobs was observed at the bottom. The run was halted at 72 hours (S6) due to sinking of oil, with minimal remaining at the surface.

Figure C-0-21: AHS R5 S1 Oil circulating freely

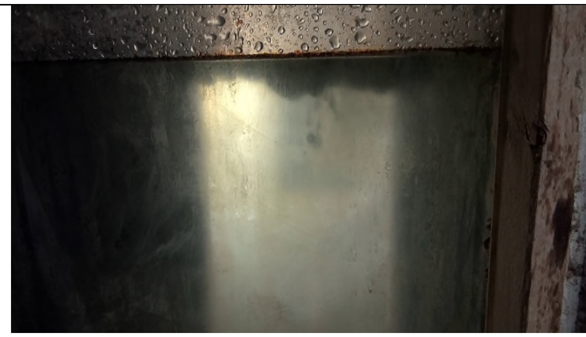


Figure C-0-22: AHS R5 S2 Waterfall has low impact on slick

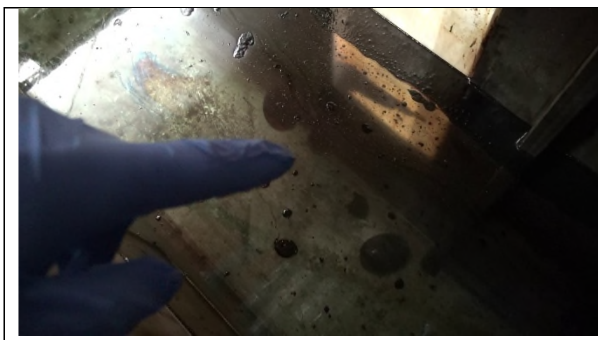


Figure C-0-23: AHS R5 S4 Oil blobs sunken to tank floor

Figure C-0-24: AHS R5 S4 Portion of oil still circulating

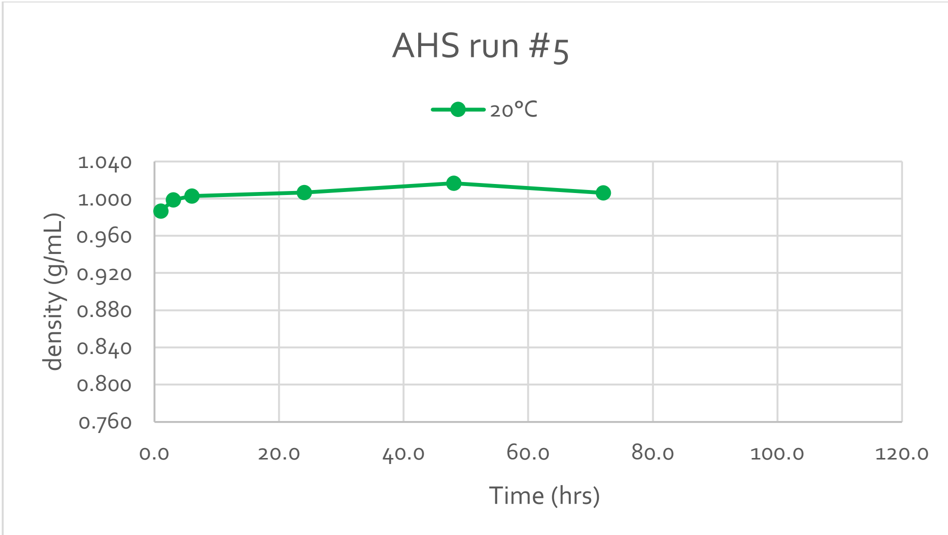


Figure C-0-25: AHS Run #5 Density vs Time

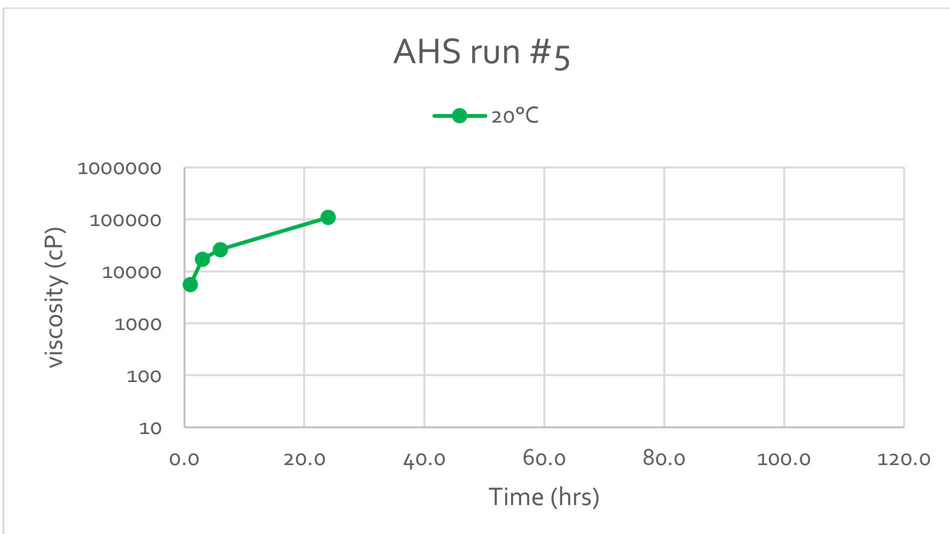


Figure C-0-26: AHS Run #5 Viscosity vs Time

C.1.6 AHS Flume Sample Water Contents

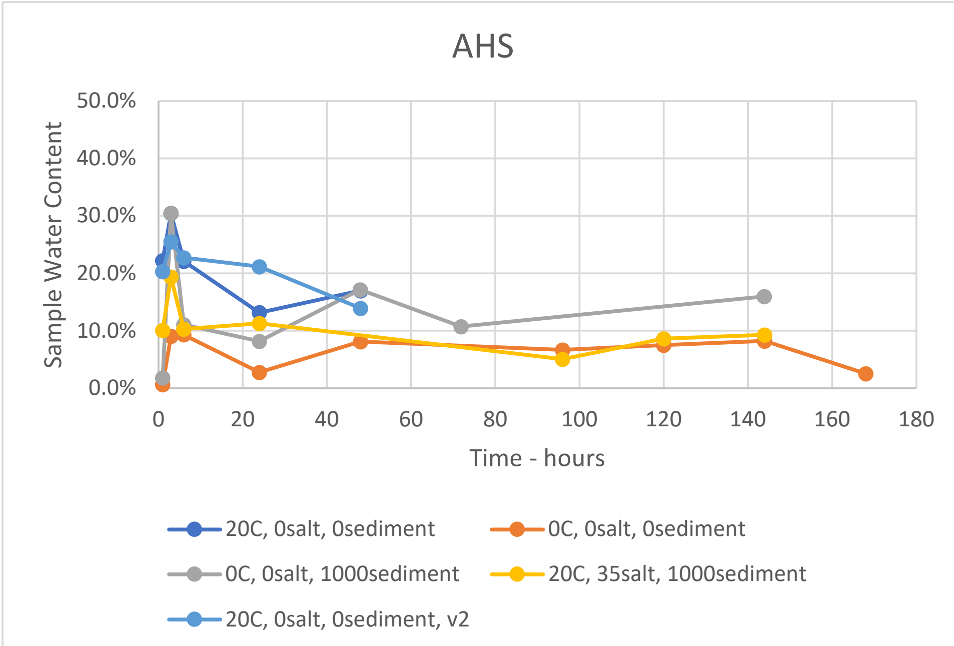


Figure C-0-27 Ultimate Water Content of AHS Flume Samples

C.1.7 AHS Flume Testing Discussion

The AHS sample weathered quickly during the "Warm" 20°C tests (Run #1, Run #4, Run #5). Analytical measurements showed that the density increased to 1.000 g/mL in the 6 hour to 24 hour measurement range, however; bulk submergence and sinking was not apparent until the 24 hour mark. Closer review of the condition of the slick showed a slightly "pebbled" surface – indicative of small air bubbles trapped within the slick. These would happen as a result of the waterfall cascade driving the slick down into the water column (the mixing energy helped to accelerate the weathering processes) along with some air bubbles. The amount of air trapped was small, but enough to temporarily stabilize the slick at the surface. As the slick continued to weather past this stage, more evidence of submergence was noted and the viscosity also increased past the 100,000 cP point when measured at 20°C. The density and submergence of the slick was not an issue for the Warm Test with salt and sediment (Run #4) as it remained below the density of the marine simulated flume water (1.027 g/mL).

The weathering of the oil samples slowed dramatically during the "Cool Test" occurring at 1°C (Run #2, Run #3). The density for these runs did not reach 1.000 g/mL until 120 hours into the run. While the cooler temperatures do have an impact on increasing the starting density of the oil, the reduction in evaporation rates slows the weathering process noticeably.

C.2 ANS IN FLUME TANK

C.2.1 Run #1, #2 (20°C, 0‰ salt, 0 ppm sediment)

An equipment issue caused Run #1 to be scrubbed at the 24 hour mark. Run #2 was a repeat of those conditions.

Starting as a light oil, the ANS covered the tank surface and circulated freely. From the first sampling, at the 1 hour mark of the run (S1), the waterfall was causing 1-5 mm diameter spherical shaped droplets to shear from the slick. These droplets quickly rose to the surface. Occasional 1mm diameter spherical droplets were seen deeper in the water column. This behaviour continued for the first three samples. By 24 hours (S4), some larger droplets (5-7mm) were also seen circulating in the water column. The large droplets in the water column trailed off by 96 hours (S7). The oil retained a low viscosity through sampling at 120 hours (S8 for this run) and it wasn't until 144 hours (S9) that the viscosity increase to the point where non-symmetrical spheroids were being sheared from the slick by the waterfall. Very little hold-up was observed during the run.

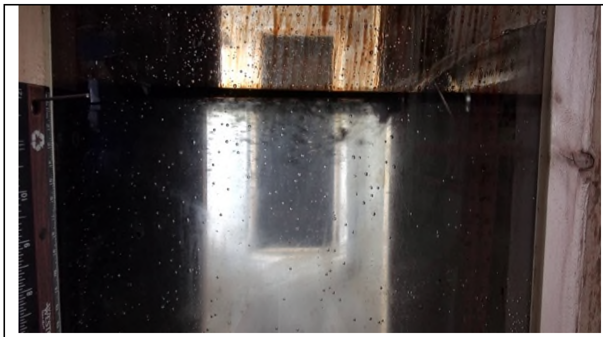


Figure C-0-28: ANS R2 S1 1-5mm droplets rising quickly

Figure C-0-29 ANS R2 S9 Small non-spherical droplets

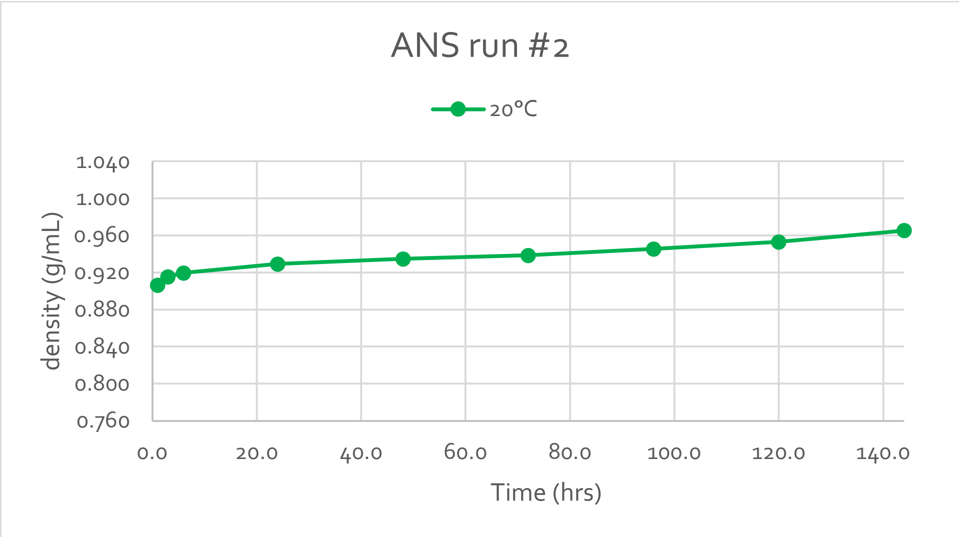


Figure C-0-30: ANS Run #2 Density vs Time

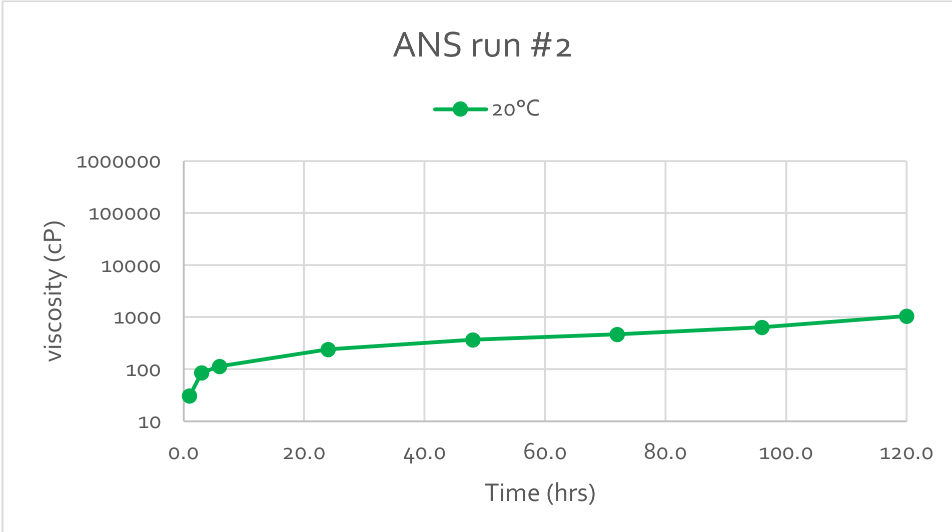


Figure C-0-31: ANS Run #2 Viscosity vs Time

C.2.2 Run #3 (0°C, 0‰ salt, 0 ppm sediment)

Oil remained low viscosity and circulated freely for the duration of the run. Small oil droplets sheared off the slick by the waterfall quickly resurfaced through final sampling at 168 hours (S8). Some hold-up between the props and the fans was observed.

Figure C-0-32: ANS R3 S2 Oil slick temporary hold-up at fan

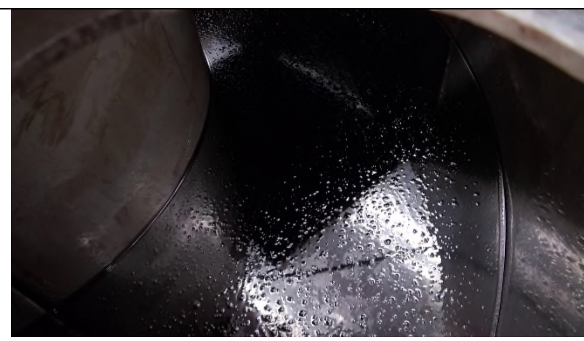


Figure C-0-33 ANS R3 S8 Oil circulating

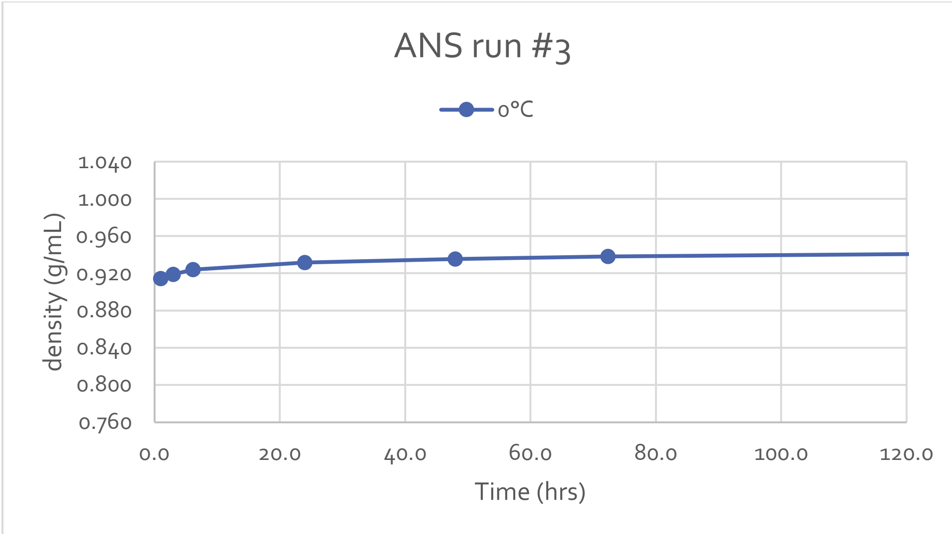


Figure C-0-34: ANS Run #3 Density vs Time

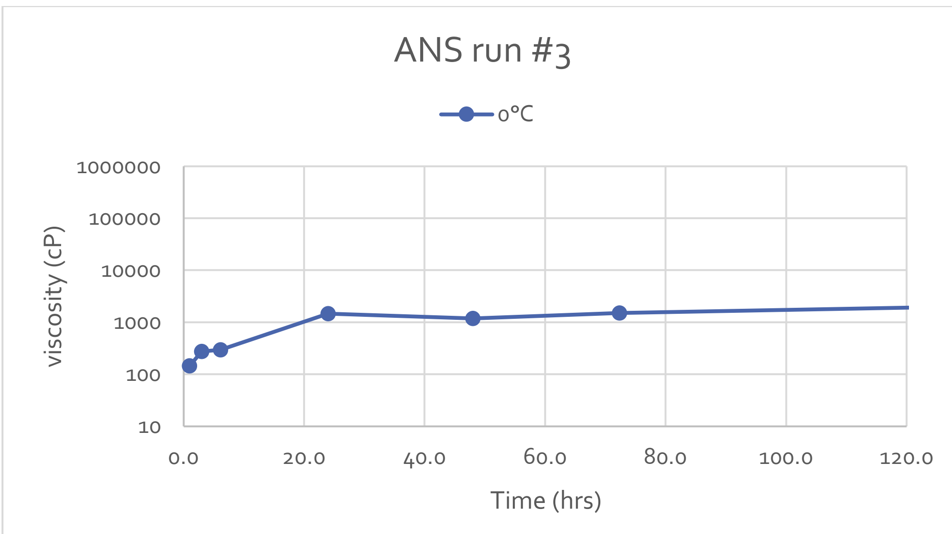


Figure C-0-35: ANS Run #3 Viscosity vs Time

C.2.3 Run #4 (0°C, 0‰ salt, 1000 ppm sediment)

Oil remained low viscosity again for this run. Free circulation during the first sampling points diminished over time until the oil became held up between the thruster and the fan (around 24 hours). After that time, the thruster would have to be cycled to allow the oil to circulate. No unexpected behaviour was observed for this run which was completed at 144 hours (S7).

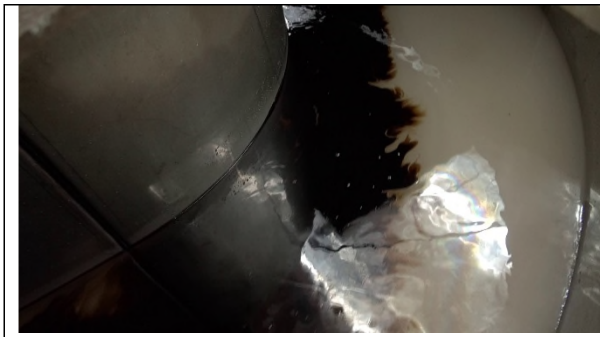


Figure C-0-36: ANS R4 S1 Oil circulating

Figure C-0-37 ANS R4 S7 Oil impacted by waterfall

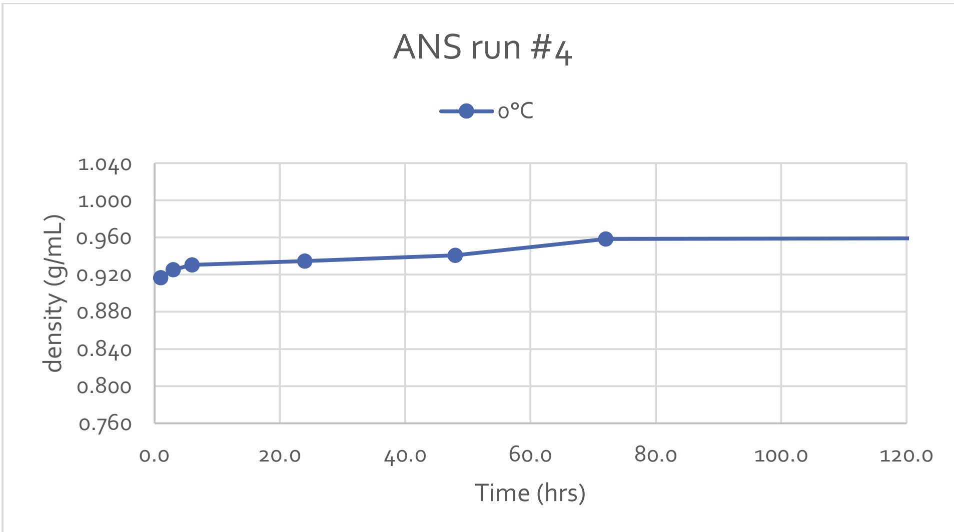


Figure C-0-38: ANS Run #4 Density vs Time

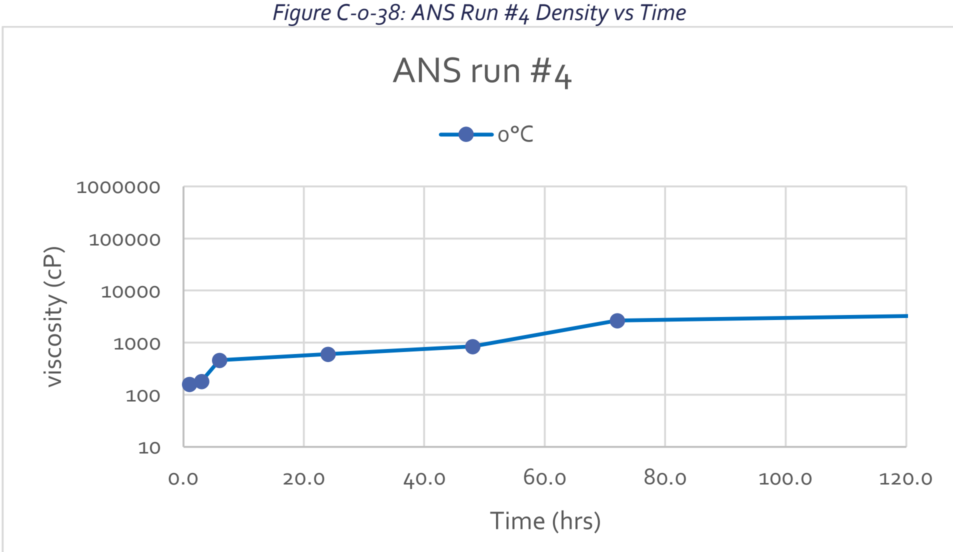


Figure C-0-39: ANS Run #4 Viscosity vs Time

C.2.4 ANS Flume Sample Water Contents

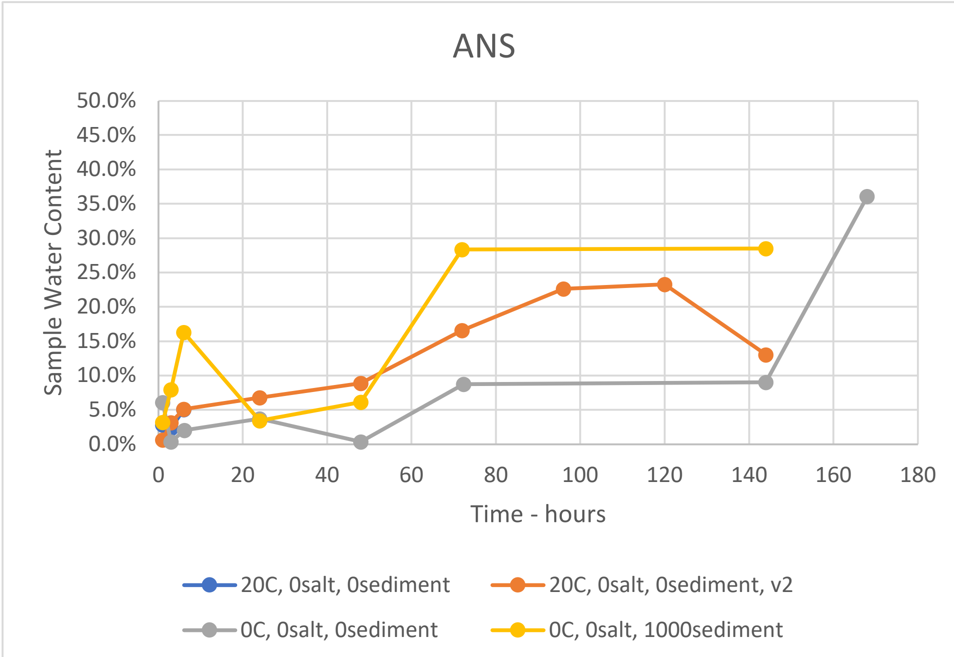


Figure C-0-40 Ultimate Water Content of ANS Flume Samples

C.2.5 ANS Flume Testing Discussion

The ANS samples started as relatively light oils and had a tendency to weather slowly. Density did not approach 1.000 g/mL for any of the runs and the viscosity peaked at 6,300 cP after an extended run (168 hours) during a 0°C (1°C) run. The oil behaved in a predictably consistent manner, with changes happening slowly over the length of the multiple runs to which it was subjected.

C.3 AWB IN FLUME TANK

C.3.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

The run began with good coverage and free flowing oil which quickly became more viscous. Shearing of the oil slick into 1-7mm non-spheroid blobs was occurring by 1 hour (S1). Hold-up became apparent around 3 hours (S2) and the thruster had to be cycled. Occasional 1mm diameter oil droplet was seen in the water column. By the 24 hour mark (S4), the oil slick was becoming noticeably viscous. The water column had darkened slightly over time and many droplets/blobs of neutrally buoyant oil (2-20 mm diameter) are seen, circulating in the water column. By 48 hours (S5), the area of slick coverage seemed reduced, and by 72 hours (S6), it was estimated that only ¼ remained on the surface. By 120 hours (S7), the run was stopped with many droplets/blobs of oil still neutrally buoyant in the water column.

Figure C-0-41: AWB R1 S1 Oil shedding under waterfall

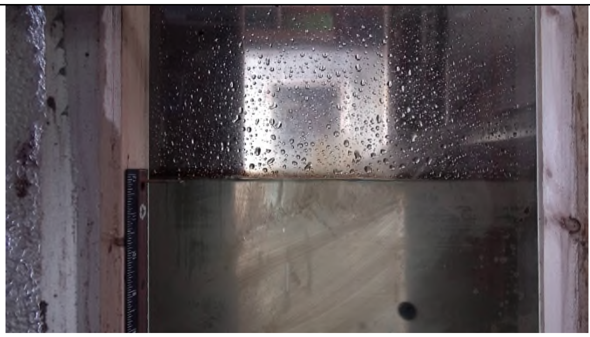


Figure C-0-42: AWB R1 S4 Oil droplet in water column

Figure C-0-43 AWB R1 S7 Oil stuck to inside curve E side

Figure C-0-44 AWB R1 S7 Usual spot for oil hold-up.

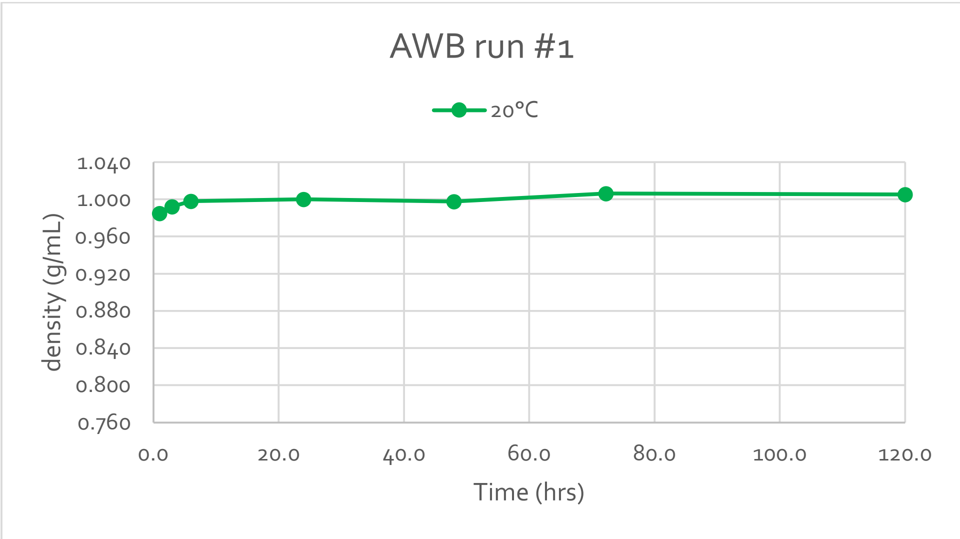


Figure C-0-45: AWB Run #1 Density vs Time

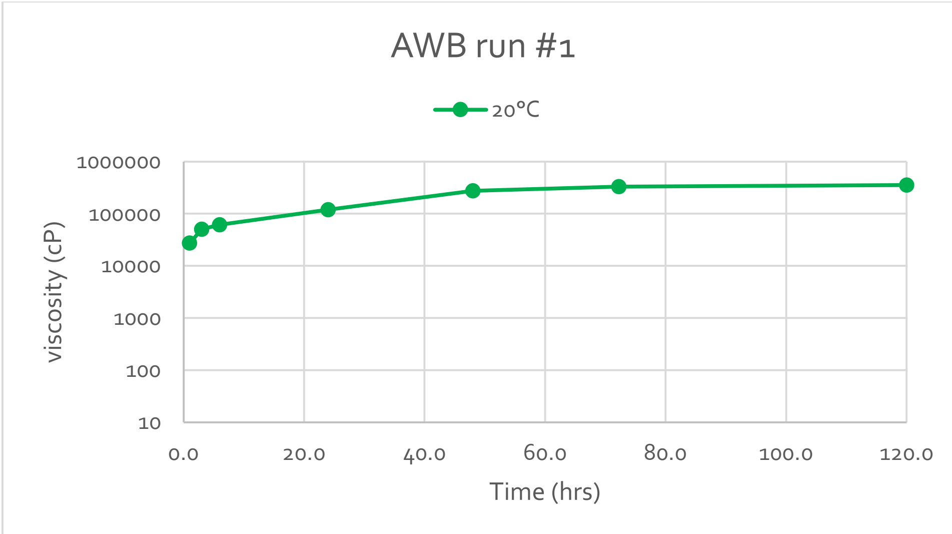


Figure C-0-46: AWB Run #1 Viscosity vs Time

C.3.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

The oil initially flowed well, providing good coverage around the surface of the flume. The oil weathered quickly and shearing by the waterfall resulted in 1-7mm non-spheroid shedding of the slick. By S2 (3 hours), the oil became noticeably more viscous, shedding in more ragged shapes with no noticeable droplets in the water column. By 6 hours (S3), the impact of the waterfall was diminishing, with blobs of oil being shedded, which then resurface. By 96 hours (S7), the oil slick had the appearance and behaviour of small-bubble infused taffy. By 168 hours (S8), the viscous oil was resisting movement within the tank, adhering to the walls at the surface of the water. Water column was clear.

Figure C-0-47 AWB R2 S1 Impact of waterfall

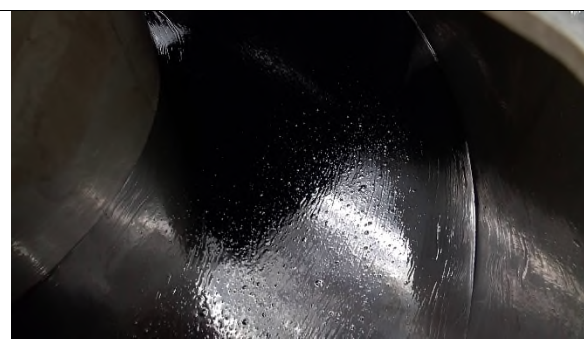


Figure C-0-48 AWB R2 S1 Free flowing slick

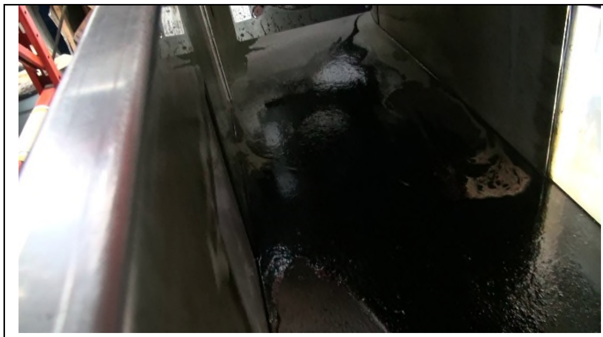


Figure C-0-49 Viscous oil resisting movement within flume

Figure C-0-50 Oil stuck to sides of tank at water surface

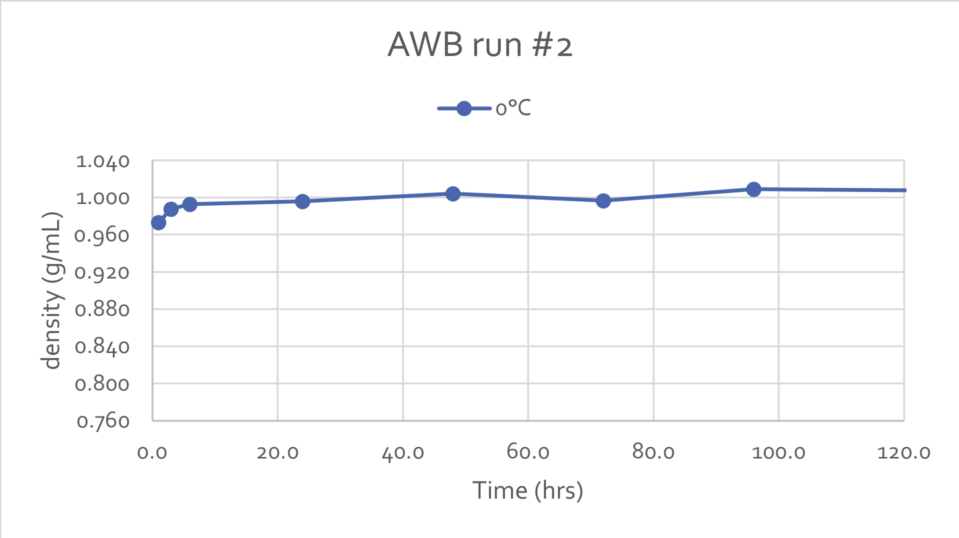


Figure C-0-51: AWB Run #2 Density vs Time

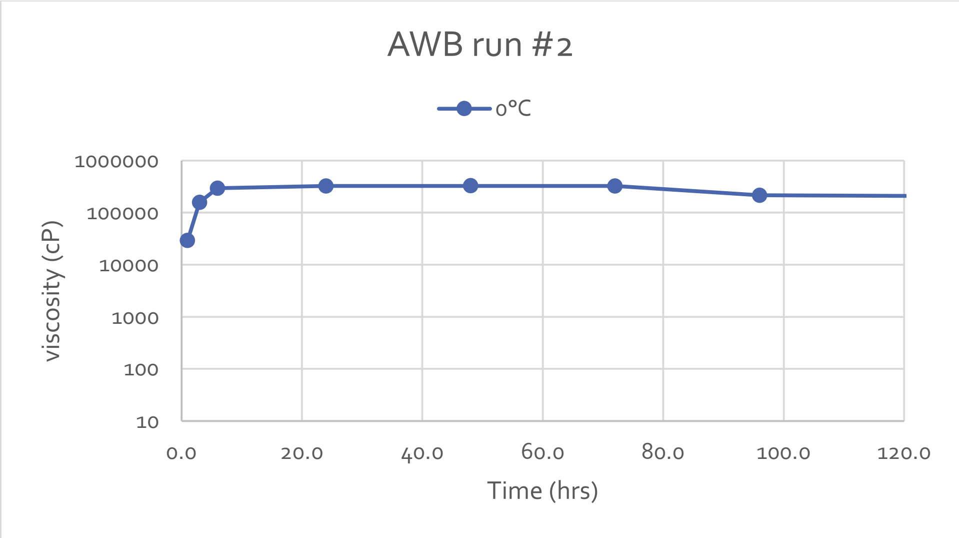


Figure C-0-52: AWB Run #2 Viscosity vs Time

C.3.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

The oil for Run #3 started dark but a lighter brown coating appeared at the surface. By 3 hours (S2), bubbles trapped in the oil layer were evident. At the 24 hour (S4) mark, the oil temporarily held position near the cooling coils at the W side of the flume. The run continued with tracking of the oil slowing to a halt round the 120 hour mark (S6), with some bubbles apparent in the oil slick. The main body of oil was dark, with a dull colour over leading edge areas. The run ended at 144 hours (S7). No bulk sinking of oil was detected.

Figure C-0-53: AWB R3 S1 Oil weathering very quickly

Figure C-0-54 AWB R3 S2 Oil circulation starting to slow down

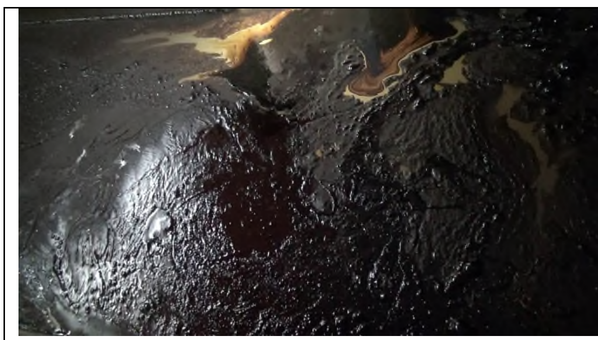


Figure C-0-55 AWB R3 S7 Very weathered slick

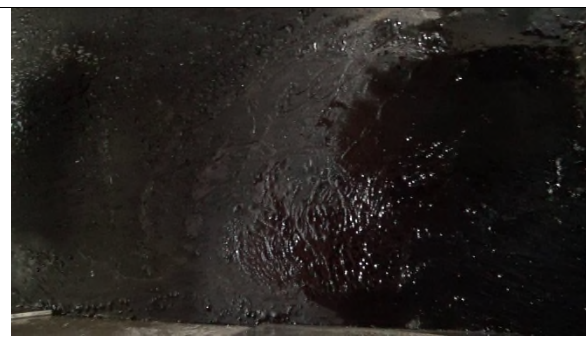


Figure C-0-56 WB R3 S7 Dull thin layer around thick portion

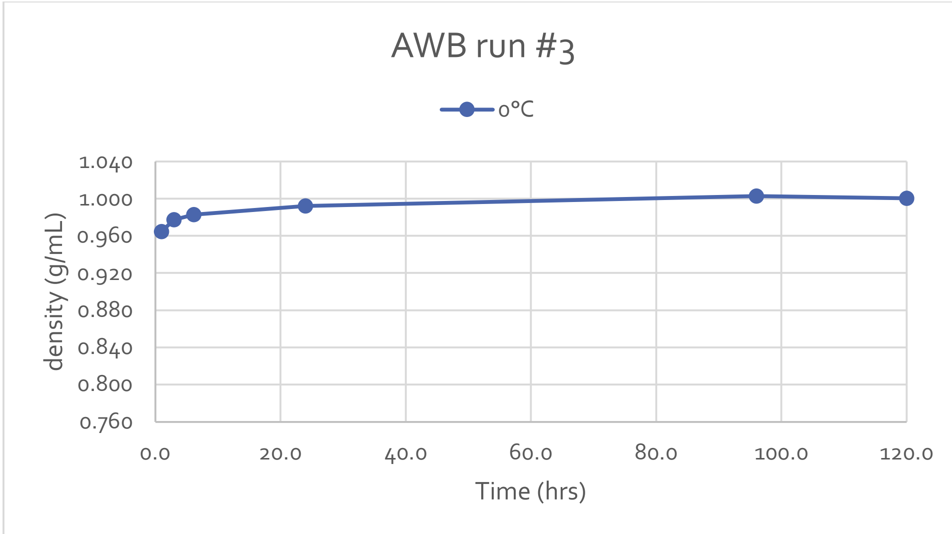


Figure C-0-57: AWB Run #3 Density vs Time

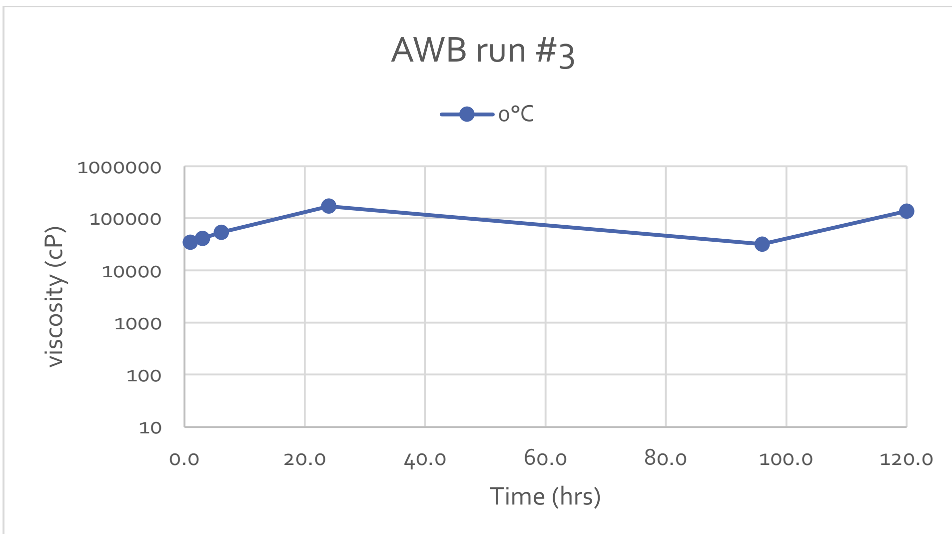


Figure C-0-58: AWB Run #3 Viscosity vs Time

C.3.4 Run #4 (20°C, 35‰ salt, 1000 ppm sediment)

Oil starts off dark and freely flowing. By 1 hour (S1), the viscosity is apparently increasing as some hold-up is observed along the North side of the flume. By 24 hours (S4), the oil gains viscosity as sampling begins to pose challenges. Oil continues to circulate as discrete portions are sheared off the leading edge of the slick under the fan. It then circulates past the waterfall, and around to the end of the slick. By 96 hours (S6), oil movement is more constrained, with portions of the slick collecting on the short curved areas of the tank. At 120 hours (S7), the viscous slick is collecting near the curved sections, with some remaining at the water surface along the inner wall of the straight sections.

Figure C-0-59: ASWB R4 S1 Free flowing oil

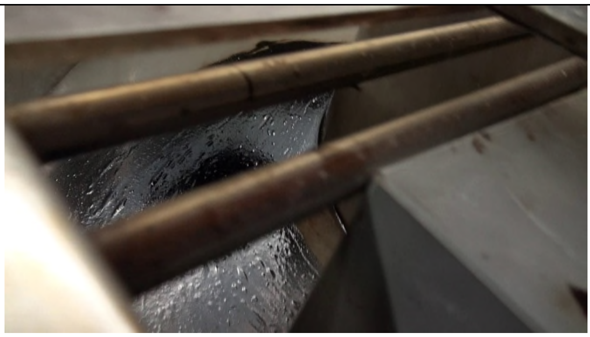


Figure C-0-60: AWB R4 S3 Oil starting to collect under fan

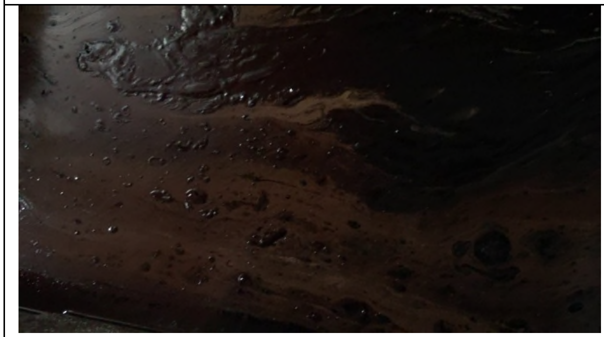


Figure C-0-61: AWB R4 S6 Sporadic coverage along N side of tank

Figure C-0-62: AWB R4 S6 Hold-up under fan

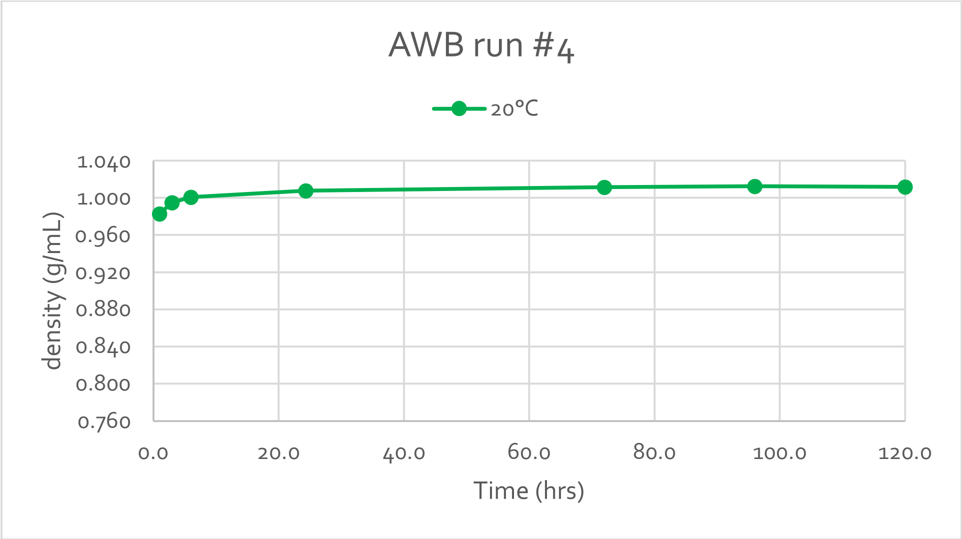


Figure C-0-63: AWB Run #4 Density vs Time

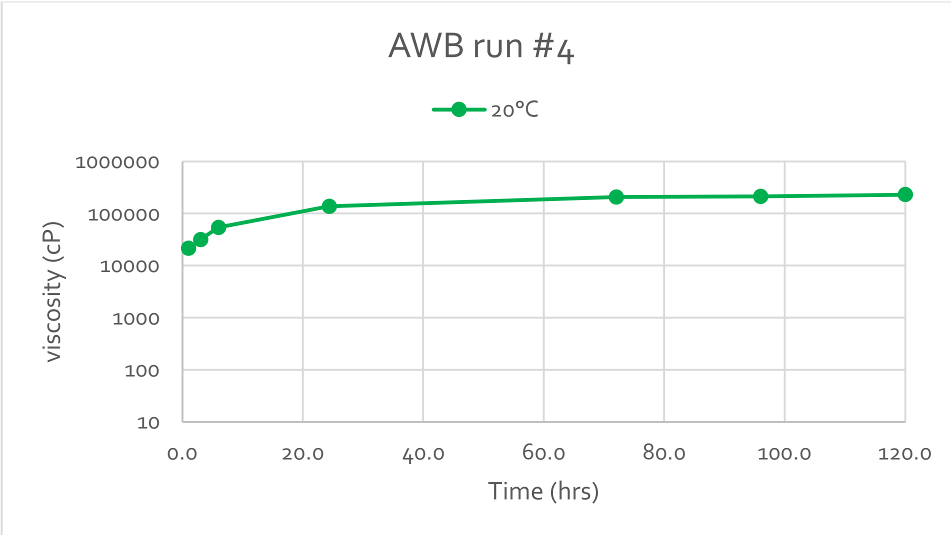


Figure C-0-64: AWB Run #4 Viscosity vs Time

C.3.5 AWB Flume Sample Water Contents

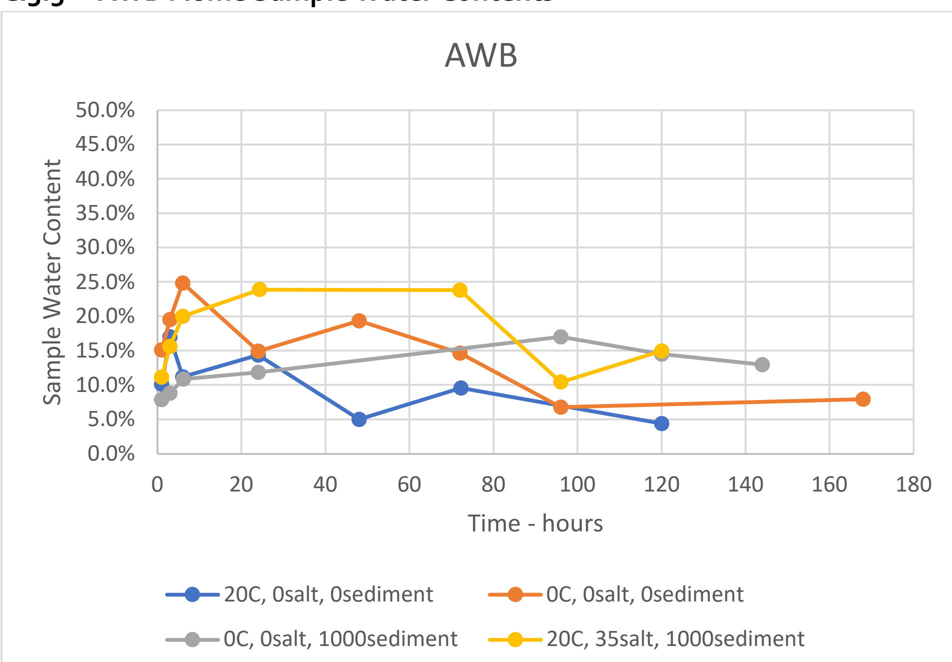


Figure C-0-65 Ultimate Water Content of AWB Flume Samples

C.3.6 AWB Flume Testing Discussion

The AWB oil weathered quickly to a density just below 1.000 g/mL in the baseline test at 20°C. The volume of oil at the surface seemed to diminish at from 48 hours through 72 hours as multiple blobs of oil (2-20 mm diameter) are seen circulating in the water column which began to darken in colour. While the oil did reach that density threshold at 48 hours for the baseline test at 0°C, there was no associated evidence of gross losses to the tank. The density of the oil did surpass 1.000 g/mL in a subsequent test but that was conducted using salt water. Salt water uptake, due to its higher density, will increase the density of an oil emulsion/mixture faster than fresh water uptake would. In this instance, the slick density stayed far below the density of the salt water.

C.4 CHV IN FLUME TANK

C.4.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

Circulation slows down through the first hour (S1), becoming viscous – non-spherical blobs of oil sheared off of the slick by waterfall which rise to the surface. Water column was clear with occasional large (5-7 mm diameter) droplets of oil, along with some smaller ones (2 mm diameter). As the run progressed past 24 hours, the occurrences of large oil droplets in the water column seemed to diminish, with only some tiny (1 mm and less diameter) droplets remaining. As the oil weathered, the waterfall had a reduced impact as the oil slick would merely submerge slightly, then refloat after passing by the point of contact and not break into droplets. By the end of the test, between 30-50% of the oil was smeared on the inside curve of the bend at the East side of the tank, approximately 3-15 cm under the surface.

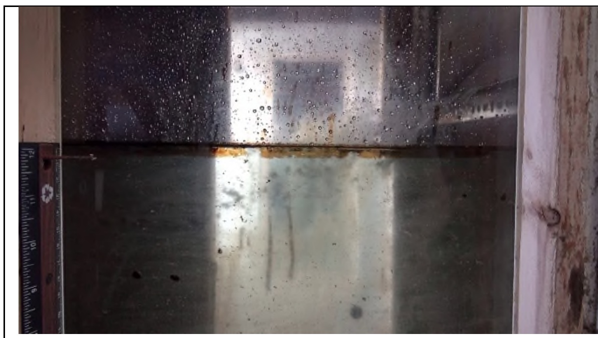


Figure C-0-66: CHV R1 S1 Non-spherical shearing, oil in column, with large neutrally buoyant droplet below.

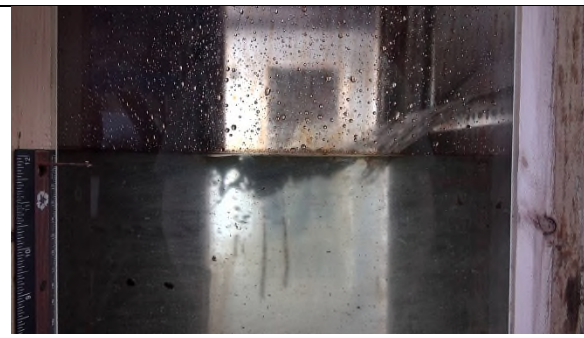


Figure C-0-67: CHV R1 S3 Waterfall's decreasing impact as oil weathers

Figure C-0-68: CHV R1 S8 Viscous oil behaviour

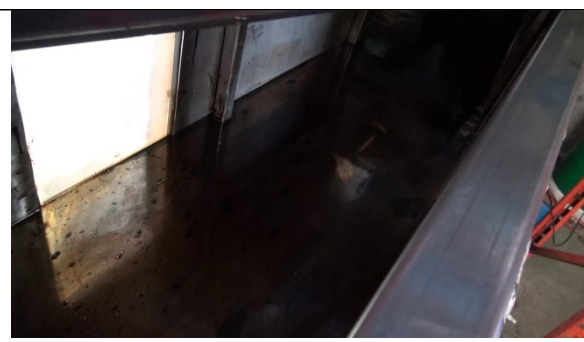


Figure C-0-69: CHV R1 S8 Very little oil remaining on straight sections

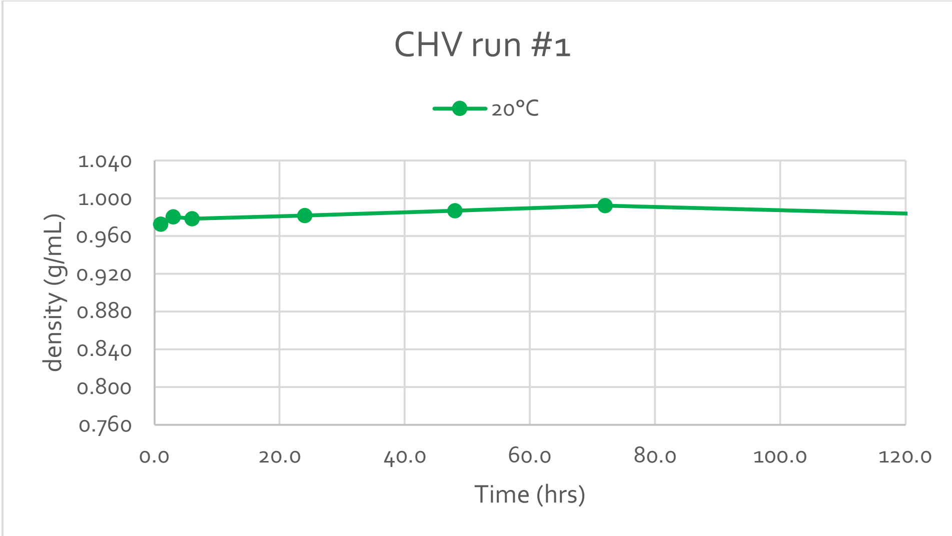


Figure C-0-70: CHV Run #1 Density vs Time

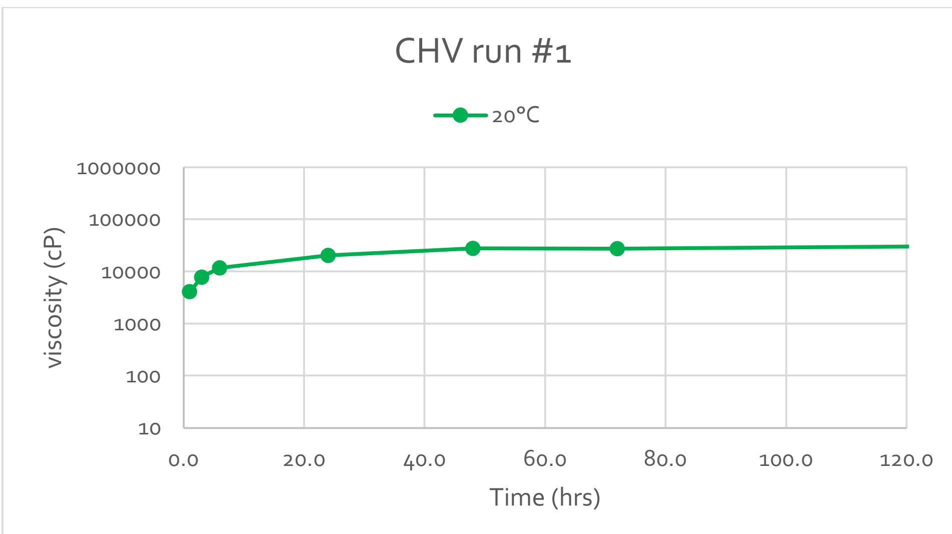


Figure C-0-71: CHV Run #1 Viscosity vs Time

C.4.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

After circulating for the first hour (S1), the waterfall causes the oil to shed into oblong shapes indicating an increase in viscosity. Oil droplets would rise to the surface afterwards, but a few small droplets (1-2mm diameter) were noticed lower in the water column. As the oil weathered the circulation slowed by 6 hours (S3). At the 24 hour mark (S4), the oil continued to circulate slowly and there were minimal droplets seen deeper in the water column. By 48 hours (S5), the waterfall had a minimal impact on the slick. Oil hold-up migrated to the West portion of the tank. The test continued until the 216 hour mark (S10), displaying similar behaviour.

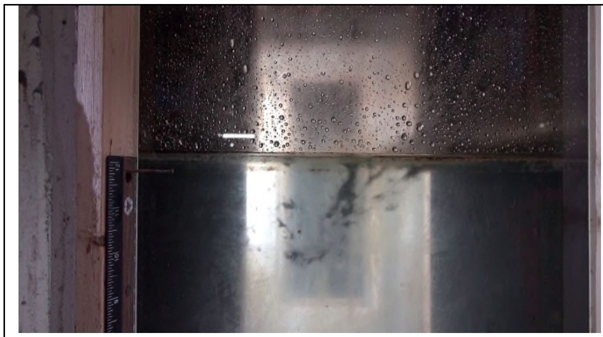


Figure C-0-72: CHV R2 S1 Impact of waterfall on slick

Figure C-0-73: CHV R2 S1 Oil circulating

Figure C-0-74: CHV R2 S10 Oil hold-up from chiller to thrusters

Figure C-0-75: CHV R2 S10 Impact of waterfall on slick

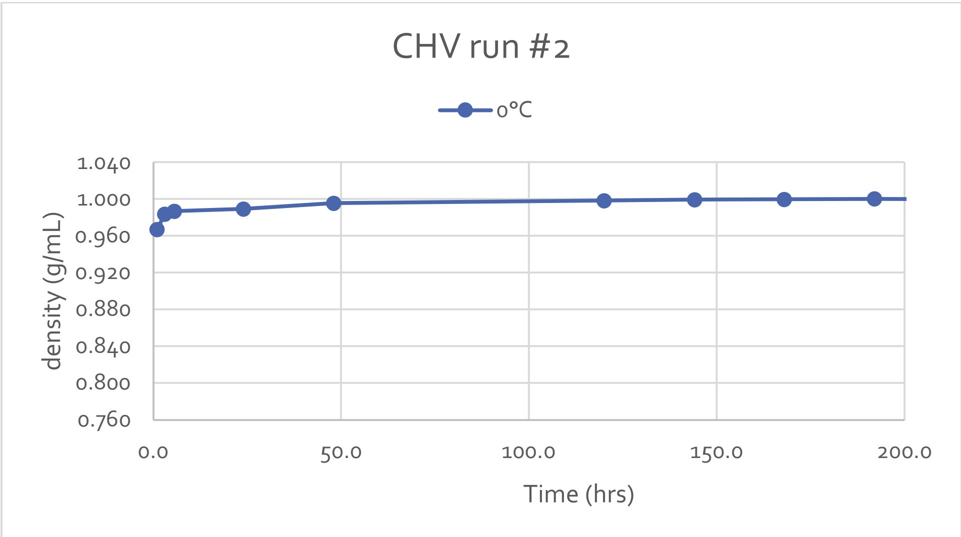


Figure C-0-76: CHV Run #2 Density vs Time

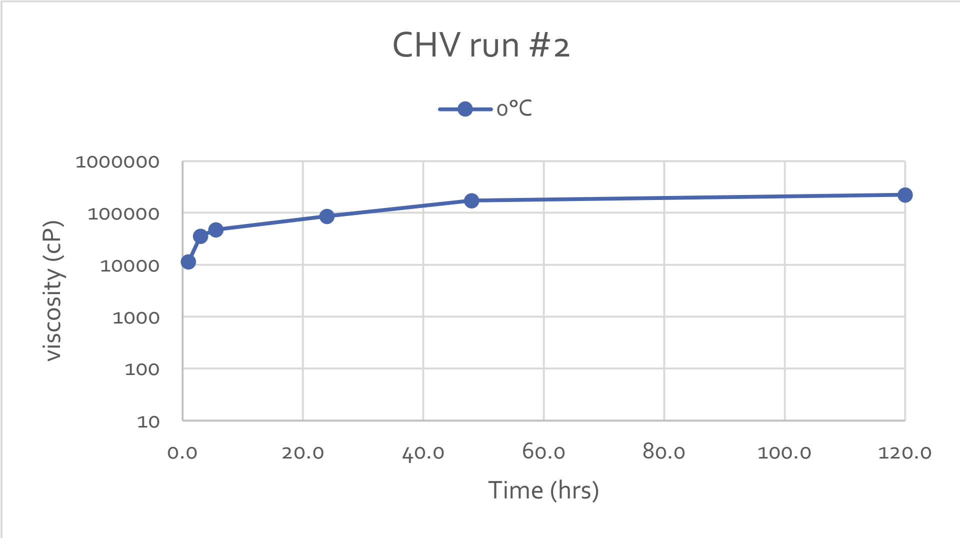


Figure C-0-77: CHV Run #2 Viscosity vs Time

C.4.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

Oil circulates well initially, slowly weathering which affects viscosity and movement. By 24 hours (S4), the oil has reached a stage where portions of the slick are starting to adhere to the walls near the thruster. By 48 hours (S5), the migration of oil around the tank has slowed to portions breaking free of the main slick to circulate under the waterfall and around the flume to reattach to the back of the slick. Final sample emulsion at 144 hours (S7) was extremely stable.

Figure C-0-78: CHV R3 S1 Oil circulating

Figure C-0-79: CHV R3 S4 Oil beginning to adhere firmly to walls


Figure C-0-80: CHV R3 S5 Oil slowly migrating past fan

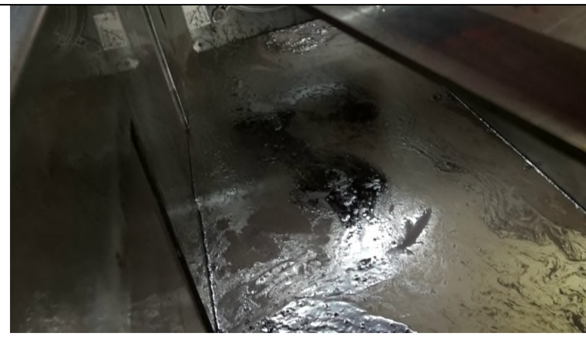


Figure C-0-81: CHV R3 S7 Hold-up between fan and thruster

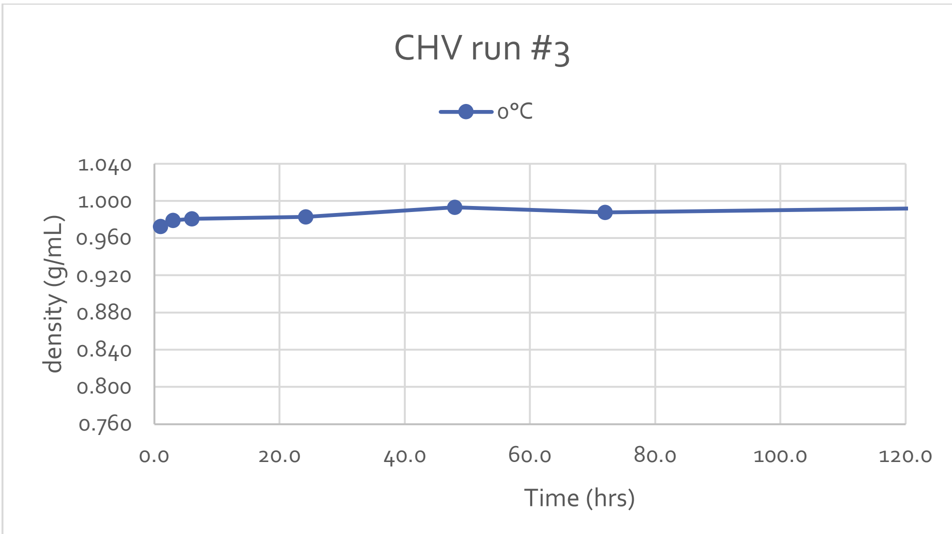


Figure C-0-82: CHV Run #3 Density vs Time

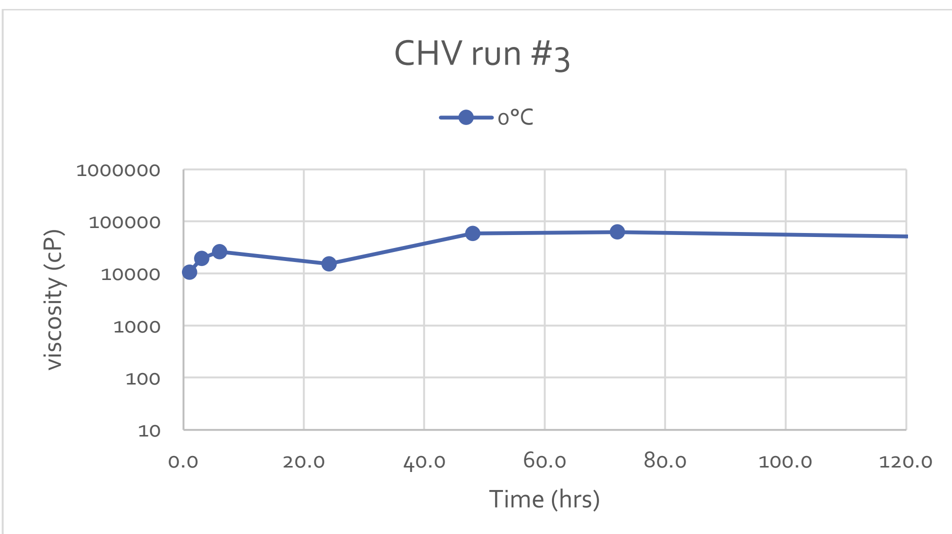


Figure C-0-83: CHV Run #3 Viscosity vs Time

C.4.4 Run #4 (20°C, 0‰ salt, 0 ppm sediment)

This run was a repeat of Run#1. Oil starts off flowing well, circulating around the flume. By 3 hours into the run (S2), the waterfall is shearing stringers and non-spherical droplets which rise to the surface. This continues as the oil viscosity increases and the circulation slows at 48 hours (S5). Circulation slows to a crawl and the surface of the slick loses some of the initial bubbling shapes. By the end of the run at 216 hours (S9), there is no apparent sinking and the oil layer is biased to the N side near the thruster.

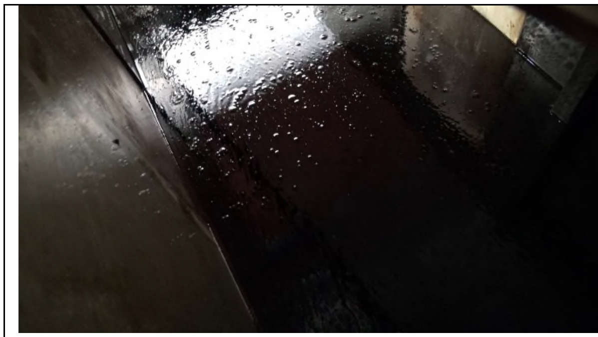


Figure C-0-84: CHV R4 S1 Oil circulation

Figure C-0-85: CHV R4 S7 Oil circulation

Figure C-0-86: CHV R4 S9 Oil hold-up

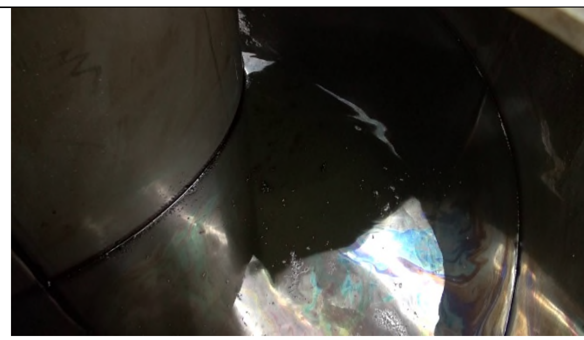


Figure C-0-87: CHV R4 S9 Oil hold-up

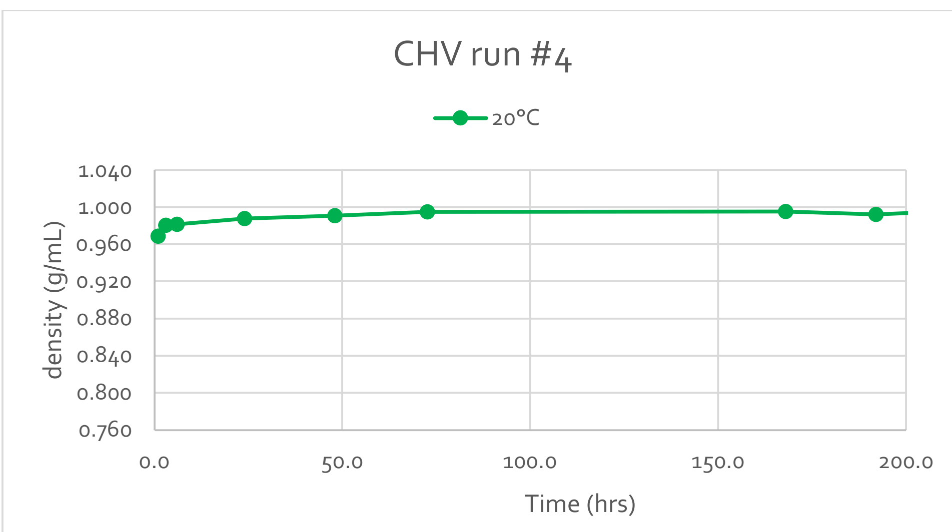


Figure C-0-88: CHV Run #4 Density vs Time

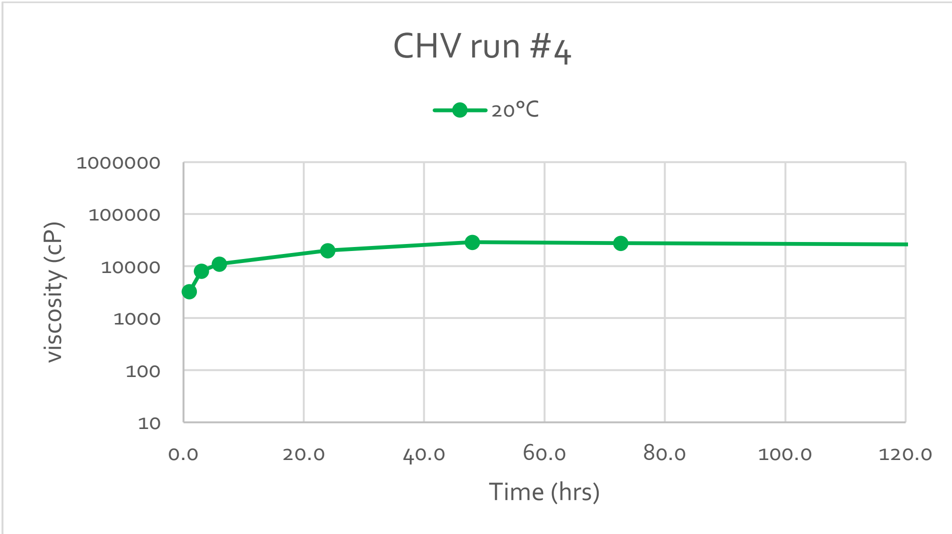


Figure C-0-89: CHV Run #4 Viscosity vs Time

C.4.5 CHV Flume Sample Water Contents

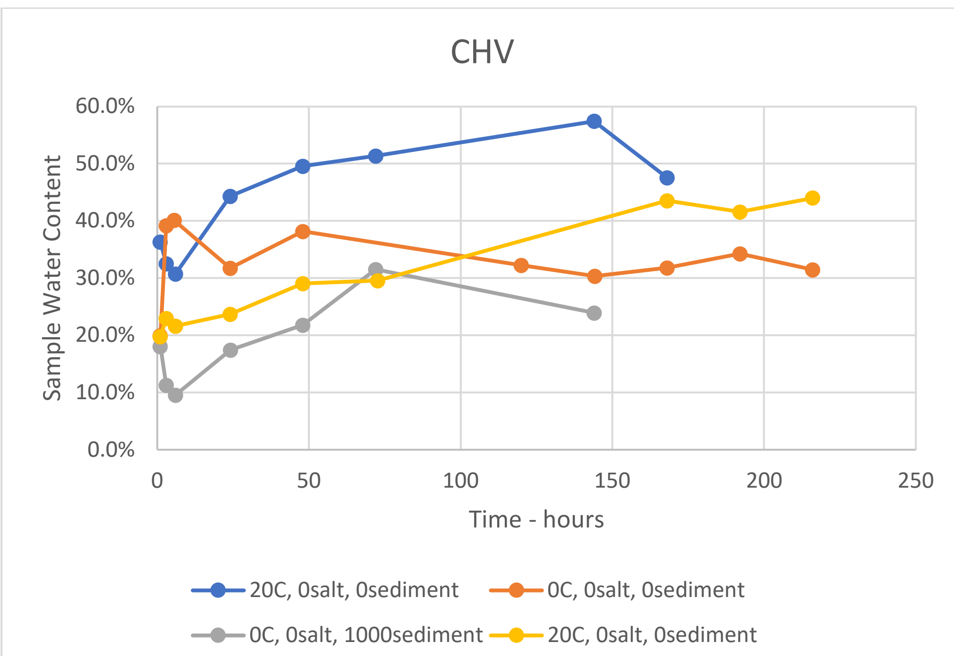


Figure C-0-90 Ultimate Water Content of CHV Flume Samples

C.4.6 CHV Flume Testing Discussion

The CHV oil was a heavy oil that weathered at a slow rate during test runs. The baseline test at 20°C showed an increase in density that did not reach 1.000 g/mL. Oil viscosity topped out at around 31,000 cP by the end of the 168 hour run. The baseline test at 0°C saw the oil just reach 1.000 g/mL density, but that happened at the 192 hour mark and the slick remained floating. Sediment addition did not seem to have a large impact on the oil – the density stayed below 1.000 g/mL during the run.

C.5 CLB IN FLUME TANK

C.5.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

Oil starts of circulating well, viscosity is already increasing by 1 hour (S1) as shown by stringers being created from the waterfall impacting the slick. Shedding into larger strands is seen at 3 hours (S2) and a large hold-up of oil is seen at 6 hours (S3). Weathering slows and by the end of the run 192 hours (S8), the bulk of the slick is held up near the thruster and stuck to the inner wall at the surface along the N and E sides.

Figure C-0-91: CLB R1 S1 Oil shedding stringers

Figure C-0-92: CLB R1 S6 Oil viscosity and density increase

Figure C-0-93: CLB R1 S8 Limited circulation

Figure C-0-94: CLB R1 S8 Oil layer at wall, none apparent on floor

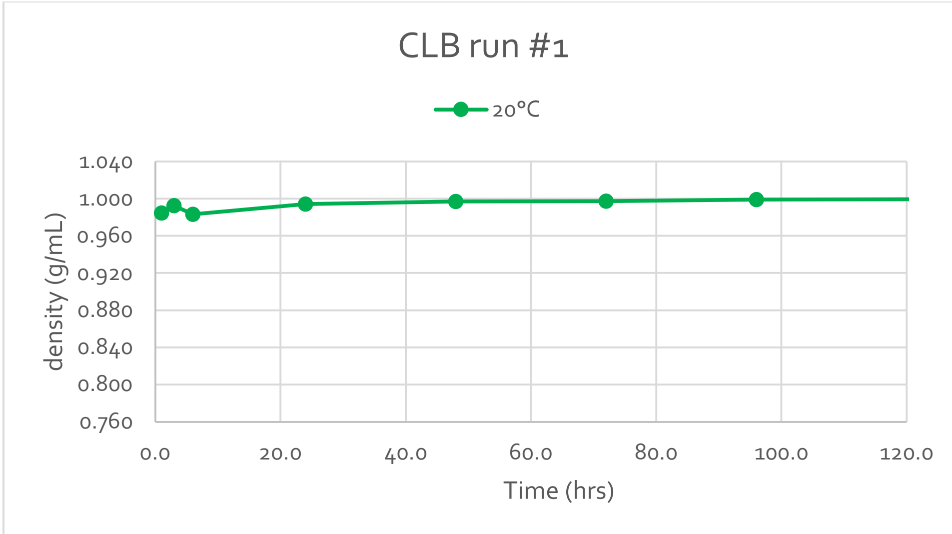


Figure C-0-95: CLB Run #1 Density vs Time

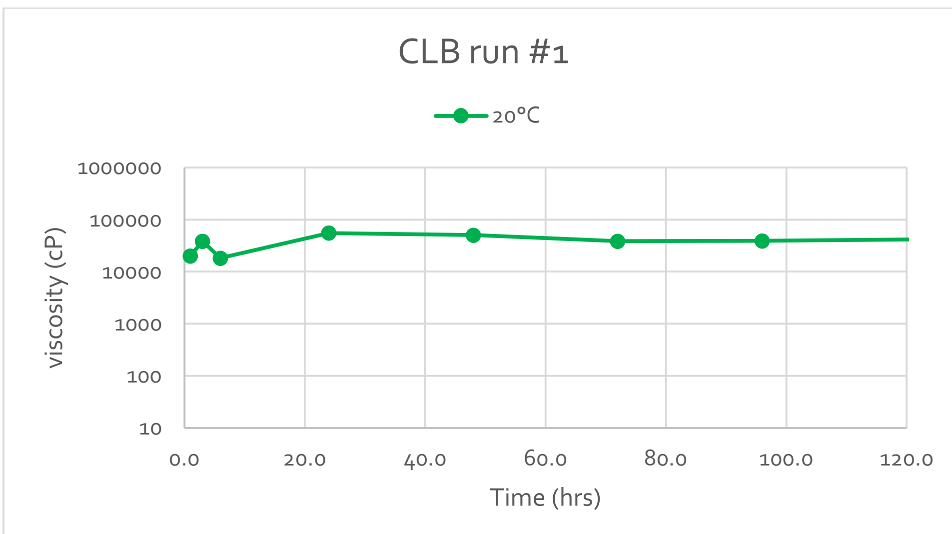


Figure C-0-96: CLB Run #1 Viscosity vs Time

C.5.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

As in the previous run the oil starts of flowing nicely then begins to weather quickly. By 1 hour (S1), the oil is shredding into streamers in the water column following the waterfall. Oil continues to flow around the tank at the 3 hour mark (S2). Weathering slows and by 144 hours (S7 for this run), oil is shredded into clumping streamers that are approaching neutral buoyancy. By the end of the run 168 hours (S8), the bulk of the remaining oil is held up near the thruster. The area encompassed by the slick was noticeably reduced from the start, by perhaps 50%. No oil blobs on the floor of the test tank were observed in the open areas of the test tank indicating the slick thickness had increased.


Figure C-0-97: CLB R2 S1 Oil shedding under waterfall

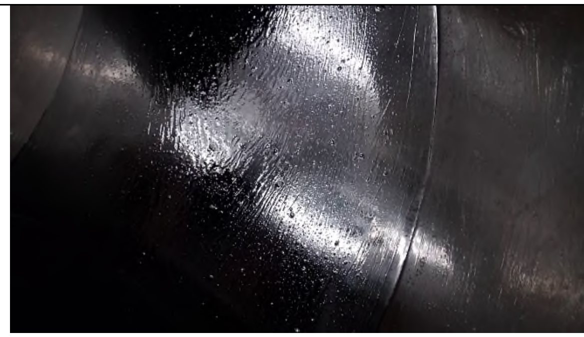


Figure C-0-98: CLB R2 S2 Good circulation of oil


Figure C-0-99 CLB R2 S7 Oil shedding from waterfall, slow to rise


Figure C-0-100 CLB R2 S8 Oil hold-up above thruster

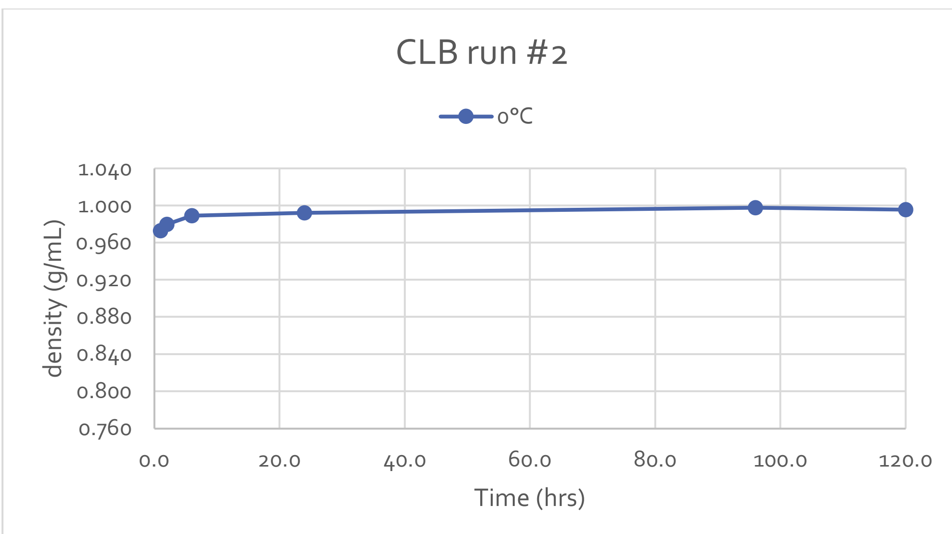


Figure C-0-101: CLB Run #2 Density vs Time

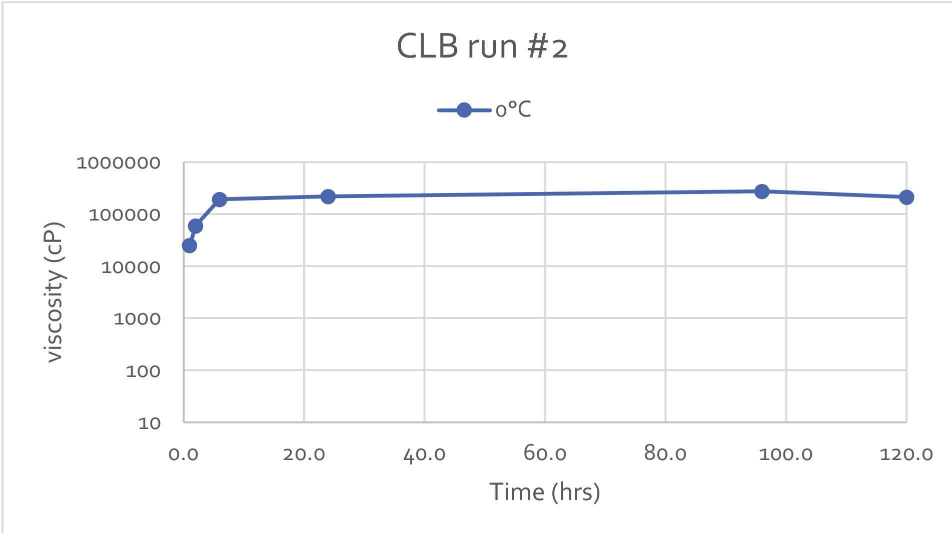


Figure C-0-102: CLB Run #2 Viscosity vs Time

C.5.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

Oil start off flowing well, but slows down as it weathers. By 6 hours (S3), oil flow begins to stall above the thrusters, encompassing a confined area from the beginning of the thruster mounting bracket to the mid-point of the viewing window. Thruster use was occasionally cycled to allow oil to circulate around the flume between sampling times. Like the previously described test, at the end of this run 168 hours (S8), the surface area encompassed by the slick was noticeably reduced from the start, by perhaps 50%.

Figure C-0-103 CLB R3 S2 Oil flowing around flume

Figure C-0-104 CLB R3 S3 Oil hold-up between window and thruster

Figure C-0-105 CLB R3 S7 Leading edge of slick

Figure C-0-106 CLB R3 S8 Oil hold-up at edge of window

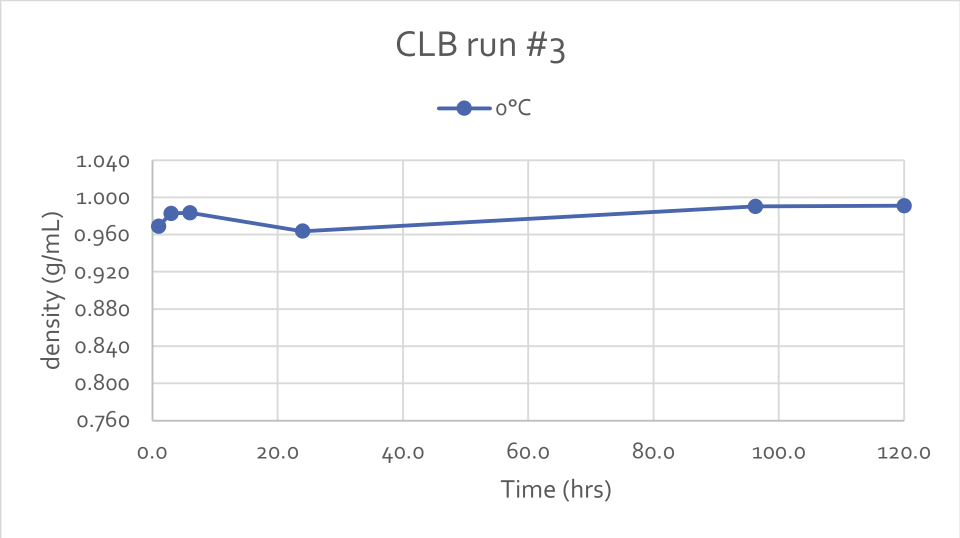


Figure C-0-107: CLB Run #3 Density vs Time

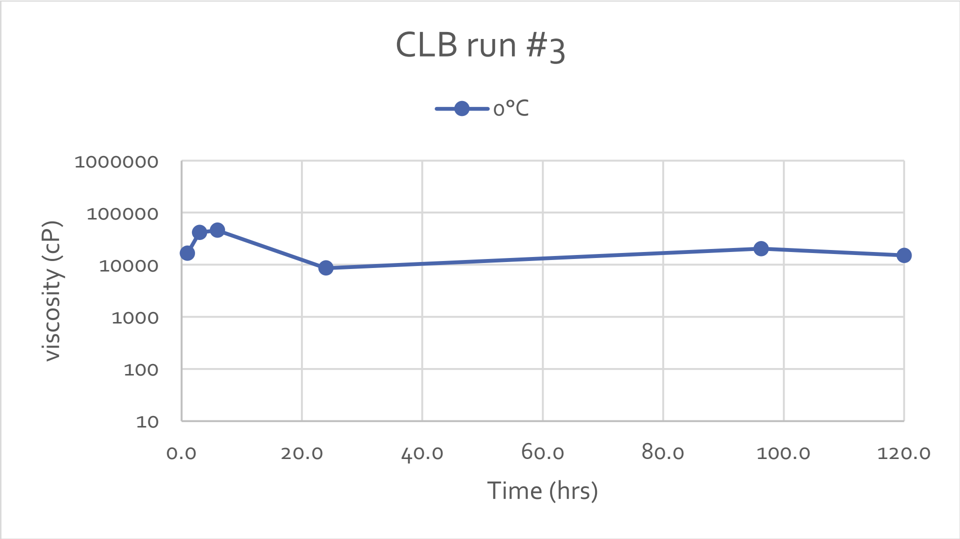


Figure C-0-108: CLB Run #3 Viscosity vs Time

C.5.4 Run #4 (20°C, 35‰ salt, 1000 ppm sediment)

Oil circulated nicely at the beginning, through 6 hours (S3) when it started to slow down. Changes to the behaviour of the oil slowed from 24 hours (S4) to the end. Clumps of oil separated from the main slick and circulated around the tank. By 120 hours (S7), some larger portions were demonstrating neutral buoyancy tendencies. By 144 hours (S8), a layer of oil was stuck to the inside track of the East wall, at and below the surface.

Figure C-0-109: CLB R4 S1 Oil migrating around tank

Figure C-0-110: CLB R4 S2 Free flowing oil

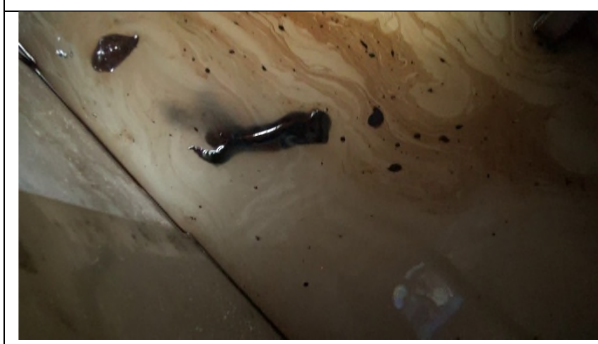


Figure C-0-111: CLB R4 S6 Neutrally buoyant slug of oil

Figure C-0-112: CLB R4 S8 Oil slick at end of test

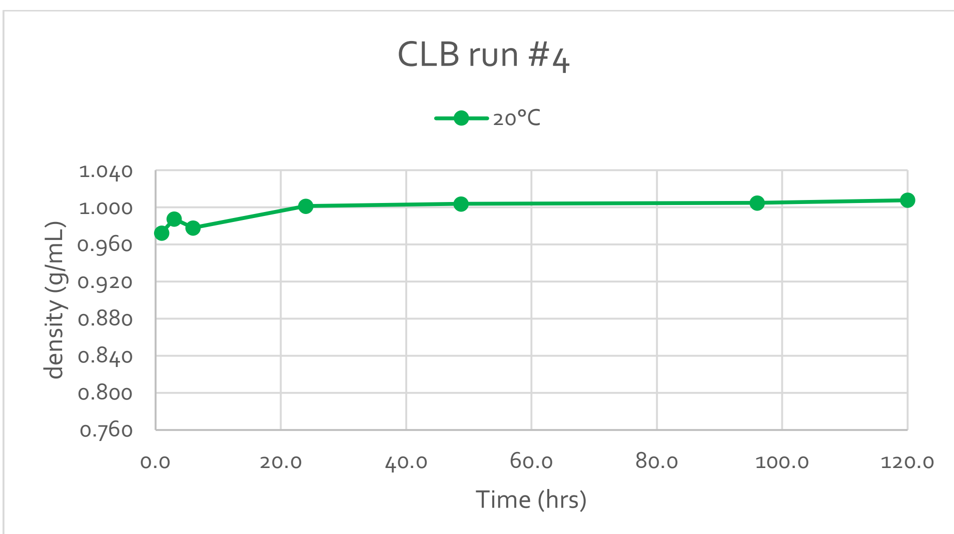


Figure C-0-113: CLB Run #4 Density vs Time

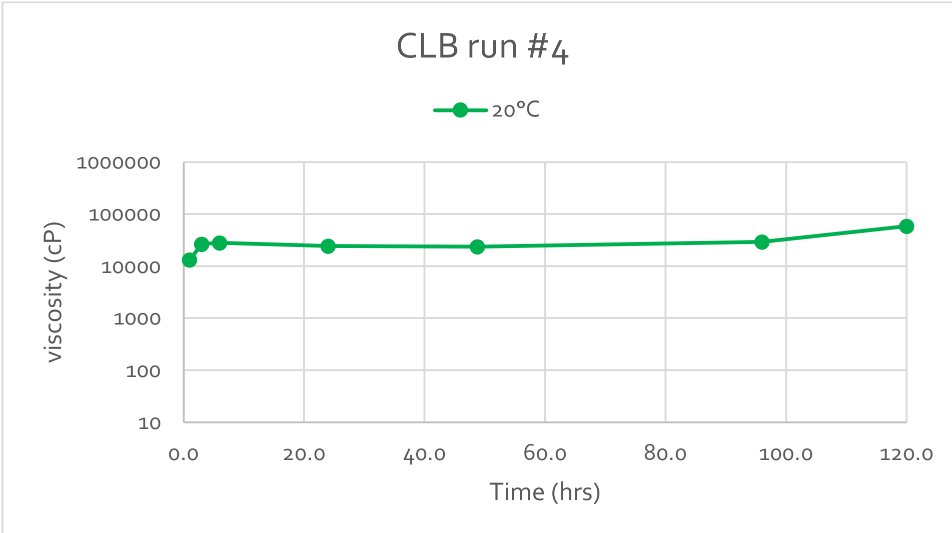


Figure C-0-114: CLB Run #4 Viscosity vs Time

C.5.5 CLB Flume Sample Water Contents

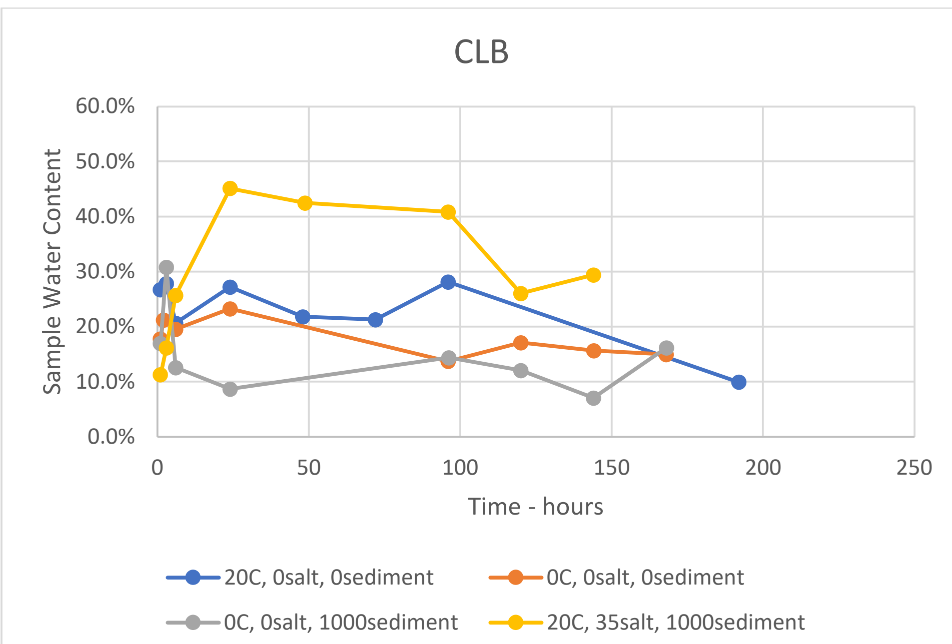


Figure 0-115 Ultimate Water Content of CLB Flume Samples

C.5.6 CLB Flume Testing Discussion

The CLB oil weathered to a density under 1.000 g/mL for the baseline run at 20°C until the end of the extended run. At the 192 hour mark, a density reading above 1.000 g/mL was obtained. There was no evidence of sinking. The viscosity of the oil was high during the baseline 0°C run, but was moderate during a related run with sediment. It is possible that some water droplets had become trapped within the oil – this would cause slippage on the rheometer which would indicate a lower reading.

C.6 CRW IN FLUME TANK

C.6.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

The condensate flows very easily around the tank. The waterfall feature causes the slick to break into tiny droplets that seem to drift into the water column, then rise up. By 6 hours (S3), circulation continues with minimal change, as it does not appear to have emulsified. The tank water seems to have taken on a very slight cloudiness. Droplets from the slick are still driven into the water column as a "mist" which then rises. By 48 hours (S5), the edges of the slick by the walls have taken on a slightly "foamy" appearance, possibly indicating some emulsification taking place. Oil still flows freely although in more discrete "blobs" rather than a homogeneous film. At 120 hours (S6), the water column has taken on a very light but cloudy appearance, indicating dispersion into the water column.

Figure C-0-116: CRW R1 S1 Oil "misting" into water column

Figure C-0-117 CRW R1 S6 Very little slick remaining on surface

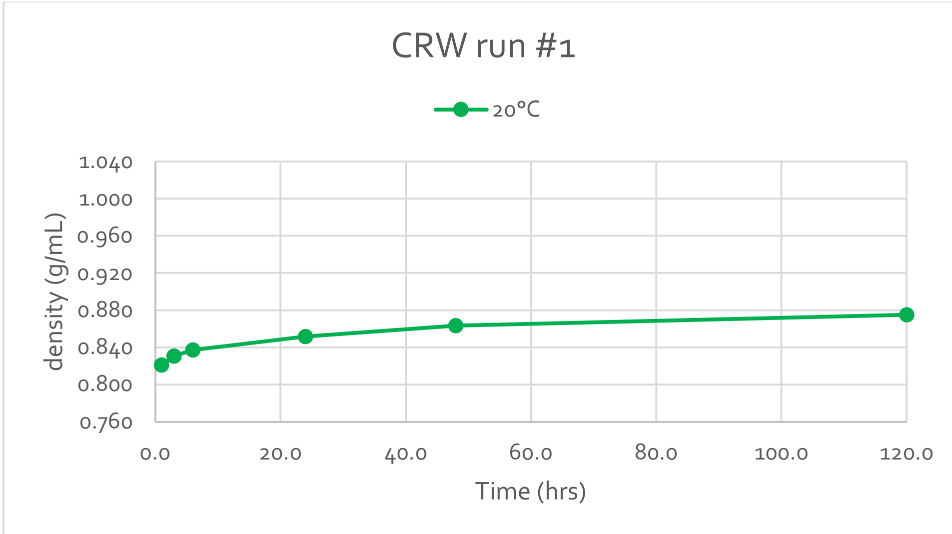


Figure C-0-118: CRW Run #1 Density vs Time

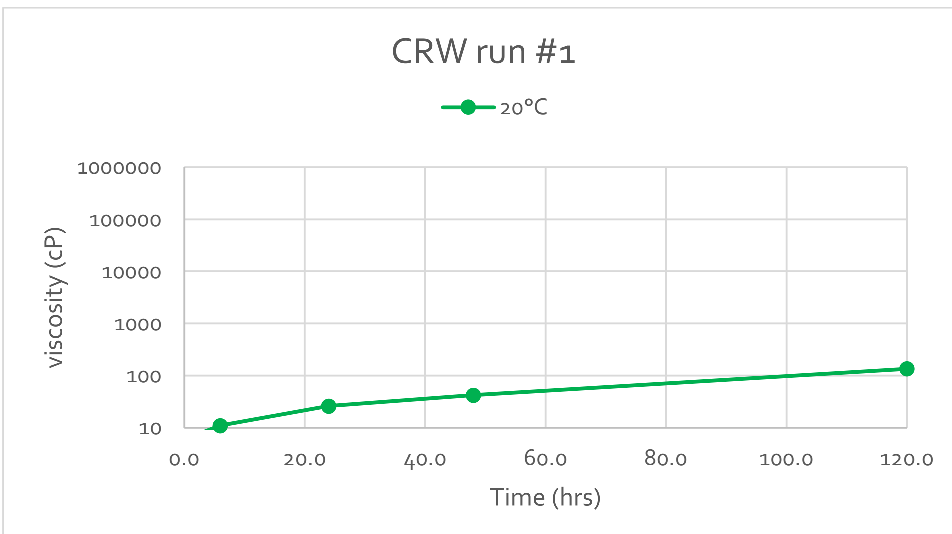


Figure C-0-119: CRW Run #1 Viscosity vs Time

C.6.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

The slick flowed easily around the flume due to its initial low viscosity. It was difficult to see the actual droplets due to their small size, but it seemed like a mist in the water column. By 24 hours (S4), there seemed to be some hold-up between the thruster and fan which prompted cycling of the thruster to get the oil to migrate around the flume. By 168 hours (S8), there still was a slick on the surface, but it was limited in area and was not thick indicating losses by evaporation and dispersion into the water column.

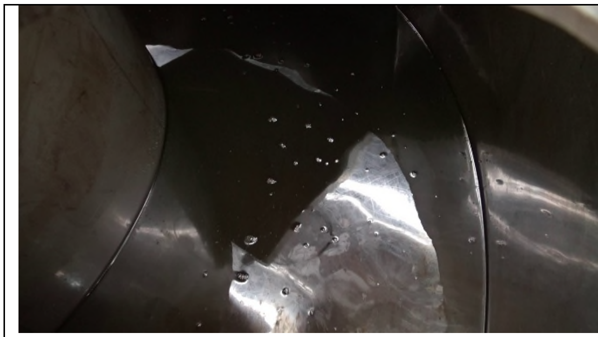


Figure C-0-120: CRW R2 S1 Oil flowing freely, clear

Figure C-0-121 CRW R2 S1 Some bubbles imparted from waterfall

Figure C-0-122 CRW R2 S6 Slick flowing around flume

Figure C-0-123 CRW R2 S8 Slick hung up between thruster and fan

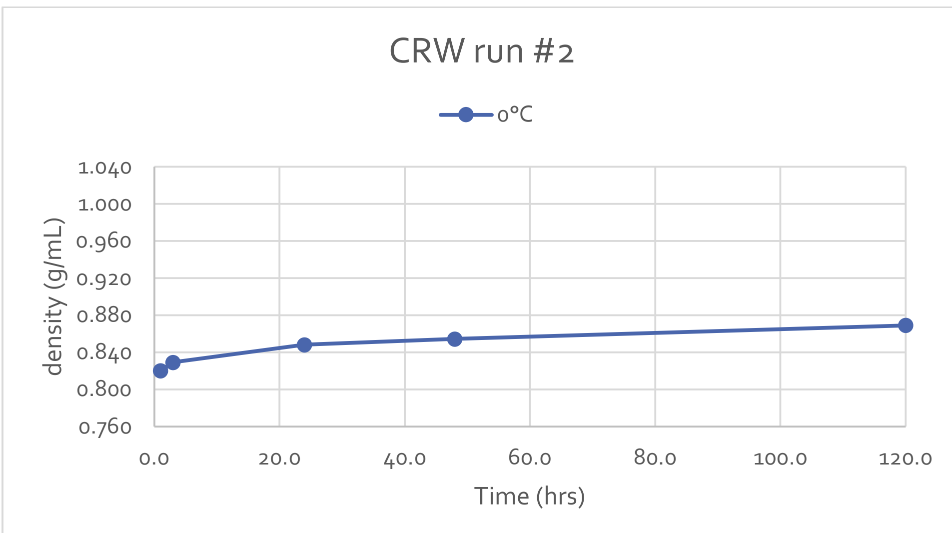


Figure C-0-124: CRW Run #2 Density vs Time

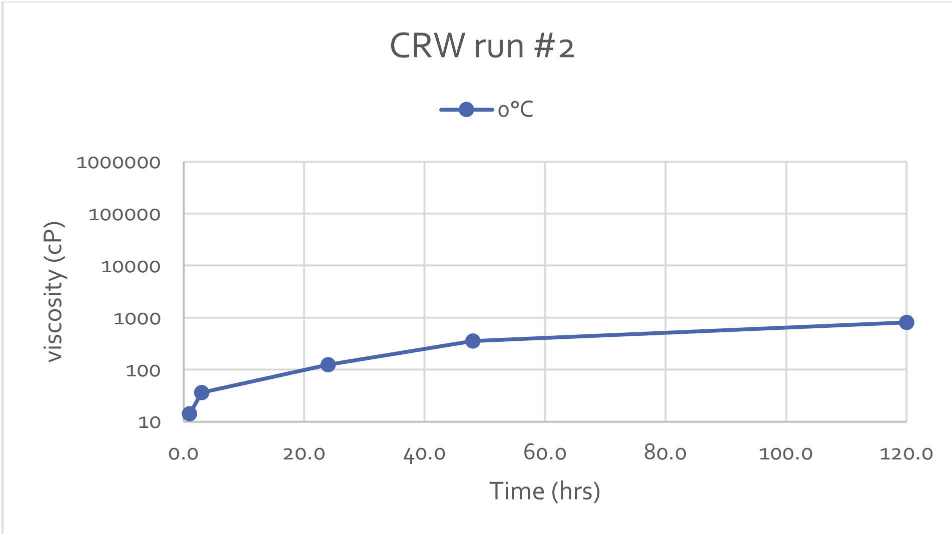


Figure C-0-125: CRW Run #2 Viscosity vs Time

C.6.3 CRW Flume Sample Water Contents

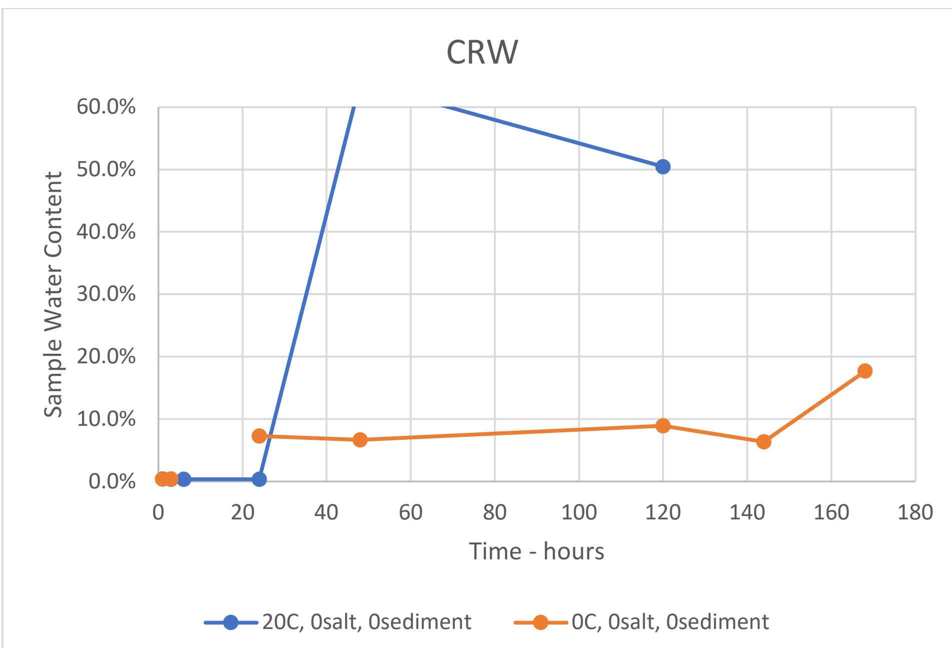


Figure C-0-126 Ultimate Water Content of CRW Flume Samples

C.6.4 CRW Flume Testing Discussion

The CRW oil was a very light product that circulated freely in the flume tank. Over the course of the test runs, the oil could be seen breaking down into small droplets when impacted by the cascading waterfall – and mechanically starting to disperse the oil into the water. The density remained light during the runs in spite of the fairly consistent weathering. The viscosity slowly increased as well but it remained very fluid.

C.7 HFO IN FLUME TANK

C.7.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

Oil flowed freely around the flume, shredding from the waterfall but quickly forming spheres which resurfaced during 1 hour (S1). Both large (5-7mm) and small (1-3mm) diameter oil droplets were noticed in the water column. By 6 hours (S3), the oil slick was not forming spheres anymore when impacted by the waterfall, rather non-symmetrical blobs of oil which also resurfaced. Droplets within the water column were starting to decrease. During sampling at 96 hours (S6), it was noticed that the viscosity had increased as the waterfall had a reduced impact on floating oil, resulting in shredding/stringers which resurfaced. Very little droplets were noticed in the water column. These properties continued through 168 hours (S9).

Figure C-0-127: HFO R1 S1 Waterfall impacts

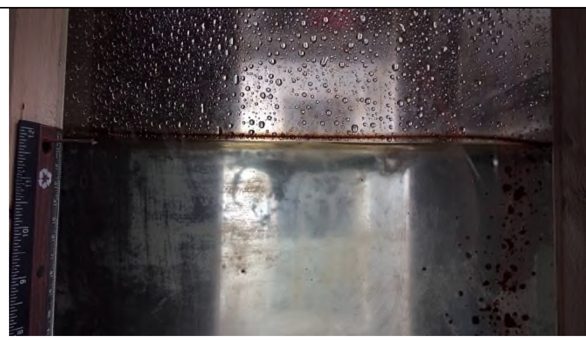


Figure C-0-128: HFO R1 S4 Waterfall impacts

Figure C-0-129: HFO R1 S6 Waterfall impacts

Figure C-0-130: HFO R1 S9 Waterfall impacts

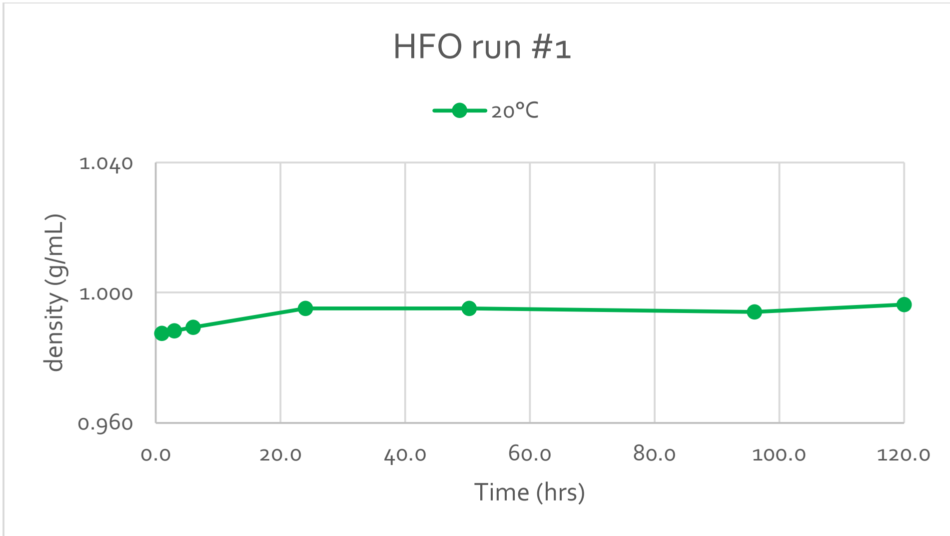


Figure C-0-131: HFO Run #1 Density vs Time

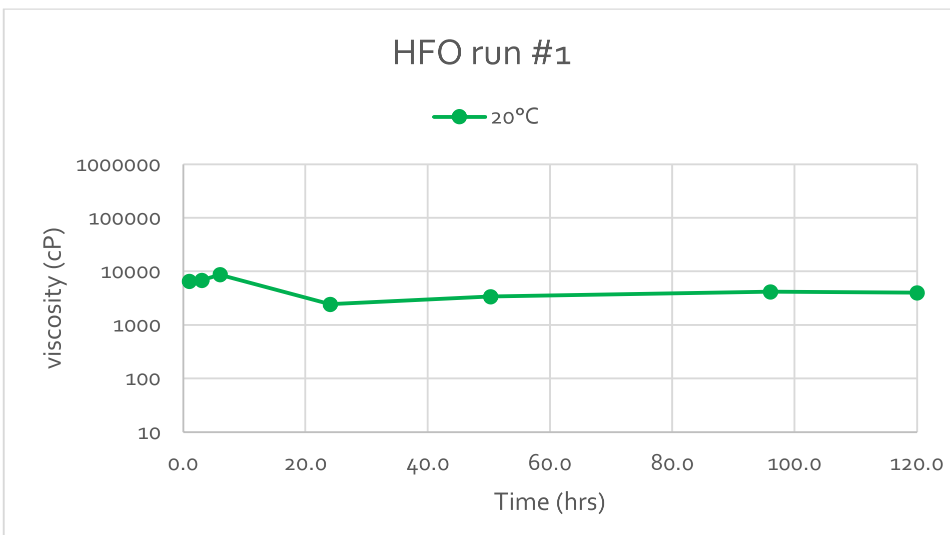


Figure C-0-132: HFO Run #1 Viscosity vs Time

C.7.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

The oil starts off viscous and close to neutrally buoyant. The waterfall has minimal impacts on submerging as the oil is too viscous to shear. By 6 hours (S3), some oil blobs are seen, submerged, affixed to the sidewall on the N portion of the flume with more oil blobs (5-20 mm diameter) submerged, floating in the water column. At 24 hours (S4), large portion of the oil is submerged. The portion of the oil that is floating remains primarily above the thruster, while an intermittent "bathtub ring" of oil stains the walls with some small blobs being located on the floor. As the run progresses through 48 hours (S5), oil is seen as a falling ring around the tank. A small quantity still floats near the thruster on the North side of the tank. The remaining oil is either attached to walls or the floor in streaks at the end of the run at 168 hours (S8).

Figure C-0-133: HFO R2 S0 Fresh oil hits waterfall for first time

Figure C-0-134 HFO R2 S4 Minimal remaining on surface

Figure C-0-135 HFO R2 S4 Oil sinking near thruster

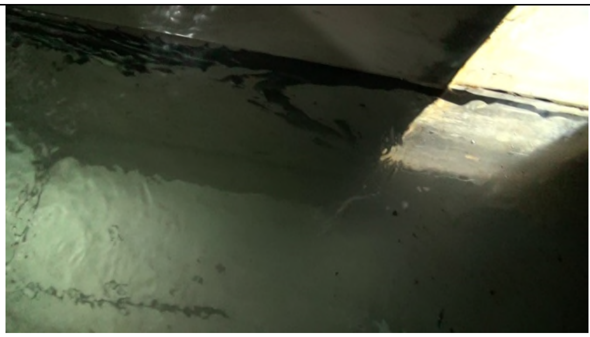


Figure C-0-136 Oil staining walls

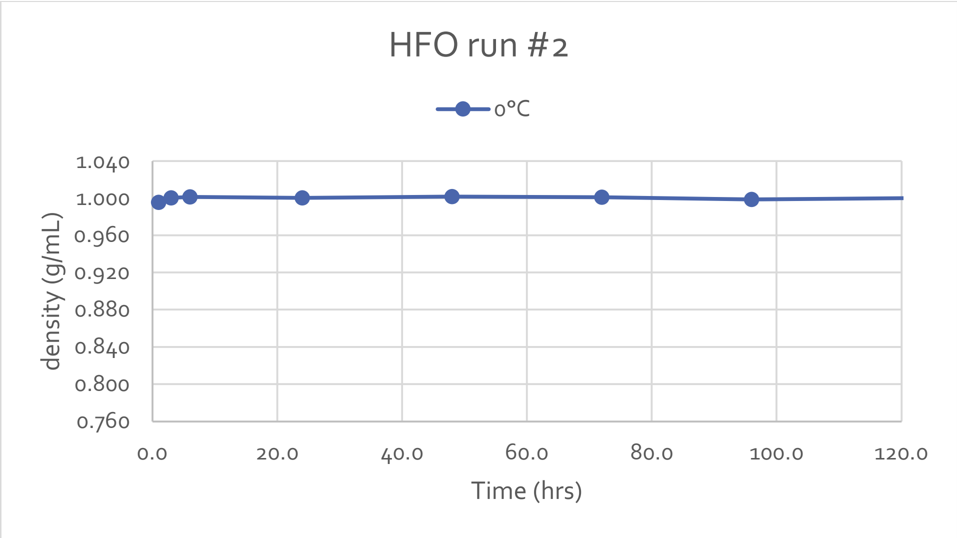


Figure C-0-137: HFO Run #2 Density vs Time

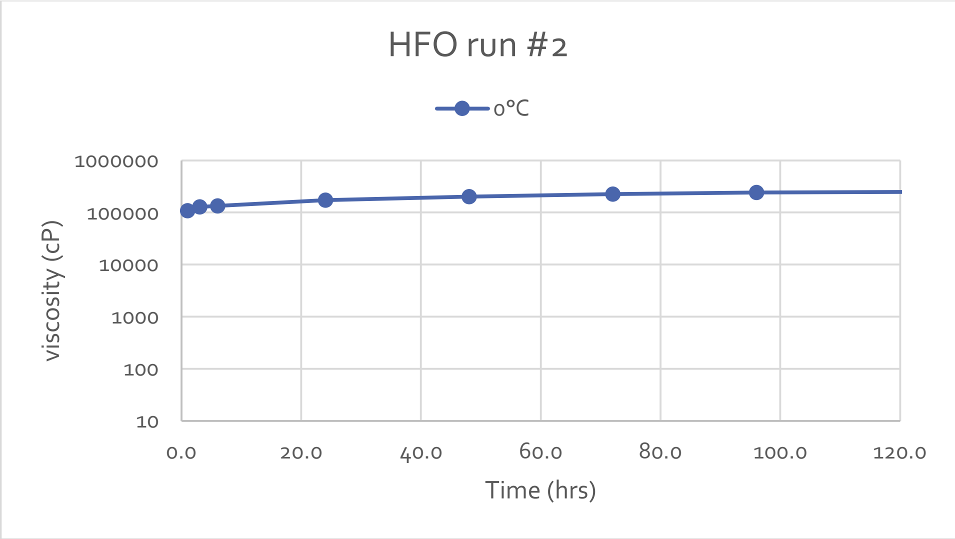


Figure C-0-138: HFO Run #3 Viscosity vs Time

C.7.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

Oil added to tank at S0 (start) stayed in staging area above thruster at the beginning of the run. By 1 hour (S1), there was a minimal amount of oil remaining at the surface. At 3 hours (S2), a small pocket of viscous oil plus a very thin fragmented slick were seen floating at the surface. This continued until 48 hours (S5) when the run was halted. During cleanup, multiple oil clumps were found along the walls.

Figure C-0-139: HFO R3 S0 Oil introduced to flume tank

Figure C-0-140: HFO R3 S1 Minimal slick remaining

Figure C-0-141: HFO R3 S2 Little oil remaining at surface

Figure C-0-142: HFO R3 S5 Cleanup

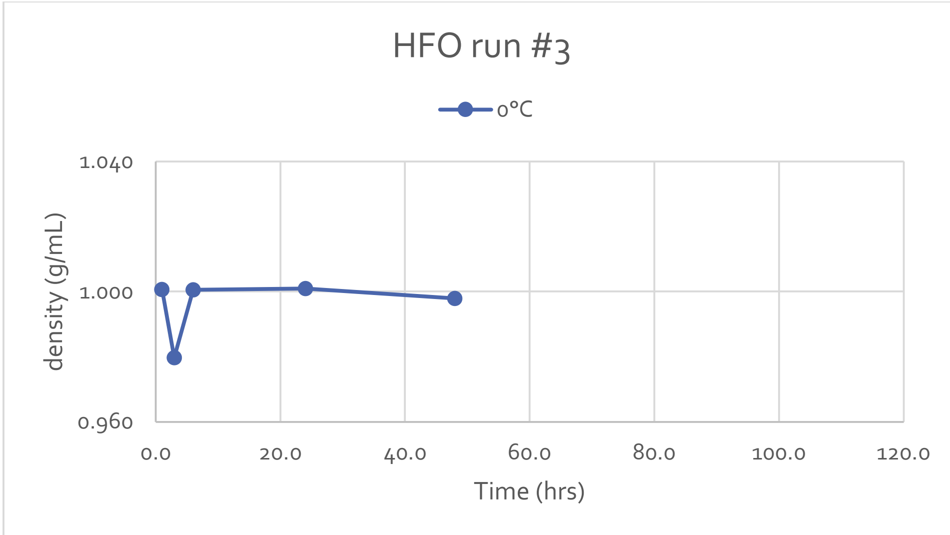


Figure C-0-143: HFO Run #3 Density vs Time

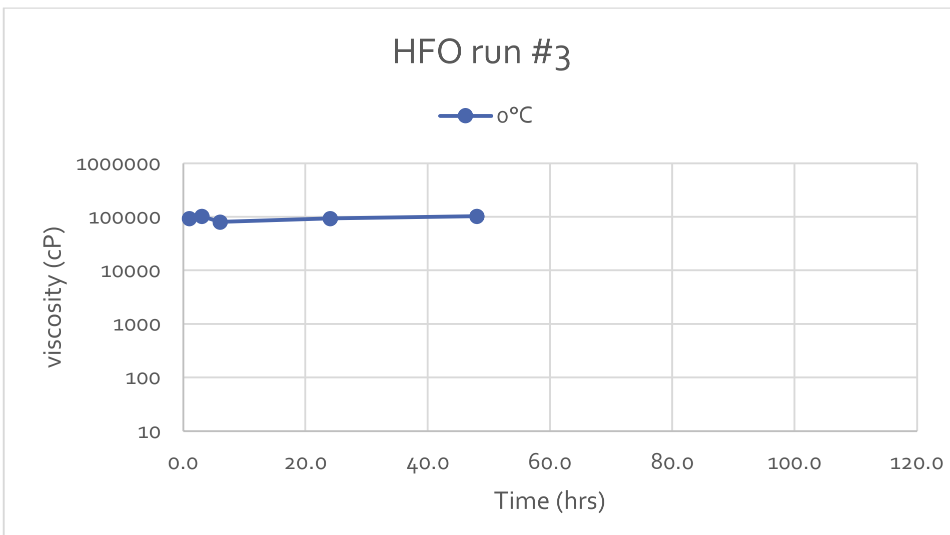


Figure C-0-144: HFO Run #3 Viscosity vs Time

C.7.4 Run #4 (0°C, 35‰ salt, 1000 ppm sediment)

Oil added to the tank at the beginning of the run initially stayed near the fan along the N side. Some portions of the slick broke free and circulated around the flume. Movement is limited, but portions do circulate. By 6 hours (S3), the large portion of the slick gathers in front of the fan near the thruster. At 24 hours (S4), the oil viscosity remains high, with the main portion of the slick being a dark thick layer, while it is surrounded by a thin layer with a dull brown colour. Small portions eventually break off from the larger slick and do circulate, a behaviour that repeats itself for the rest of the run which ends at 192 hours (S8).

Figure C-0-145: HFO R4 S0 Start of run

Figure C-0-146 HFO R4 S5 Oil slick

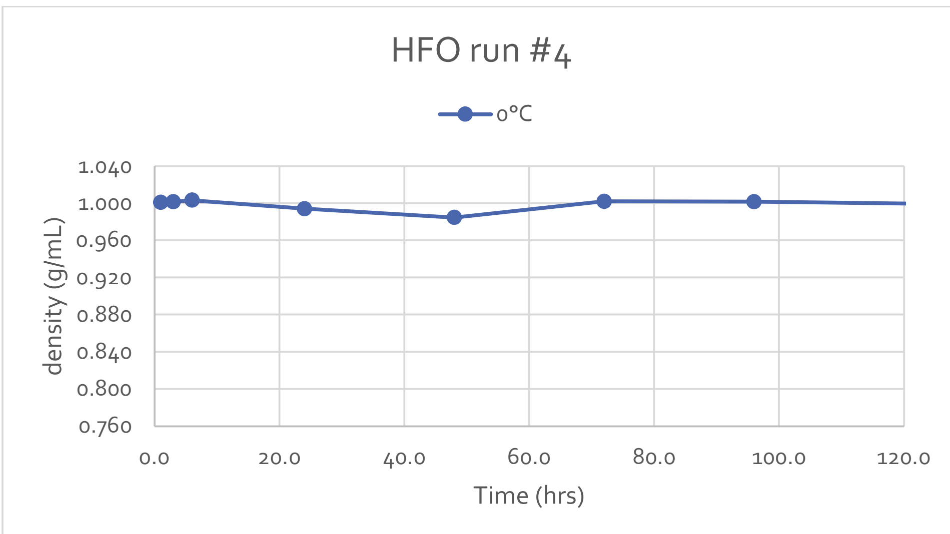


Figure C-0-147: HFO Run #4 Density vs Time

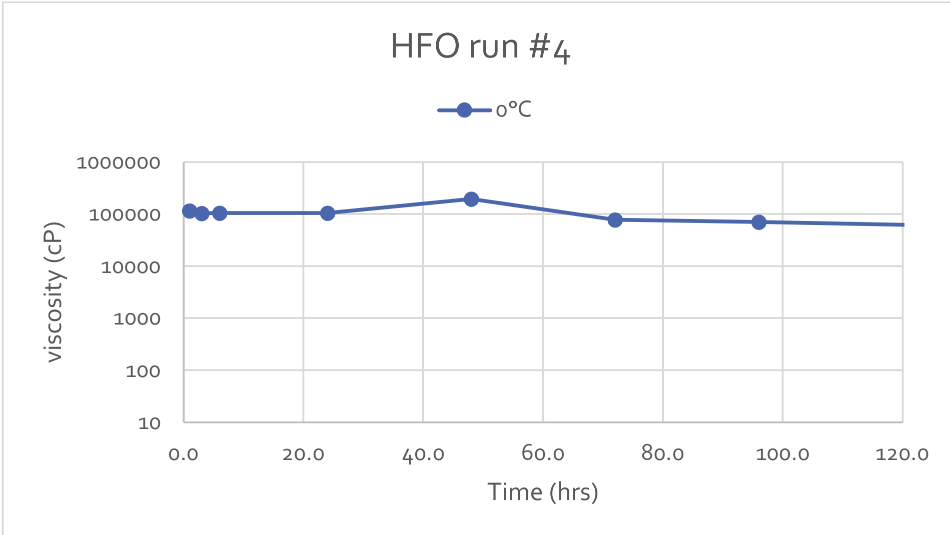


Figure C-0-148: HFO Run #4 Viscosity vs Time

C.7.5 Run #5 (20°C, 35‰ salt, 1000 ppm sediment)

The oil initially flowed nicely around the flume with some minor hold-up between thruster and fan on N side. By 24 hours (S4), the portion of the slick that has been subjected to the turbulence of the waterfall is turning slightly brown. At 48 hours (S5), the slick is still flowing around the tank. The waterfall pump failed after 48 hour (S5) and was replaced shortly thereafter. Water level also dropped 10 cm due to leaky valve. This was replaced too. At 144 hours (S7), the waterfall seemed to have minimal impact as the oil slick was not shearing at all.


Figure C-0-149: HFO R5 S1 Main slick


Figure C-0-150: HFO R5 S2 Waterfall impacts

Figure C-0-151: HFO R5 S5 Circulation slowing

Figure C-0-152: Waterfall impacts minimal near end of run

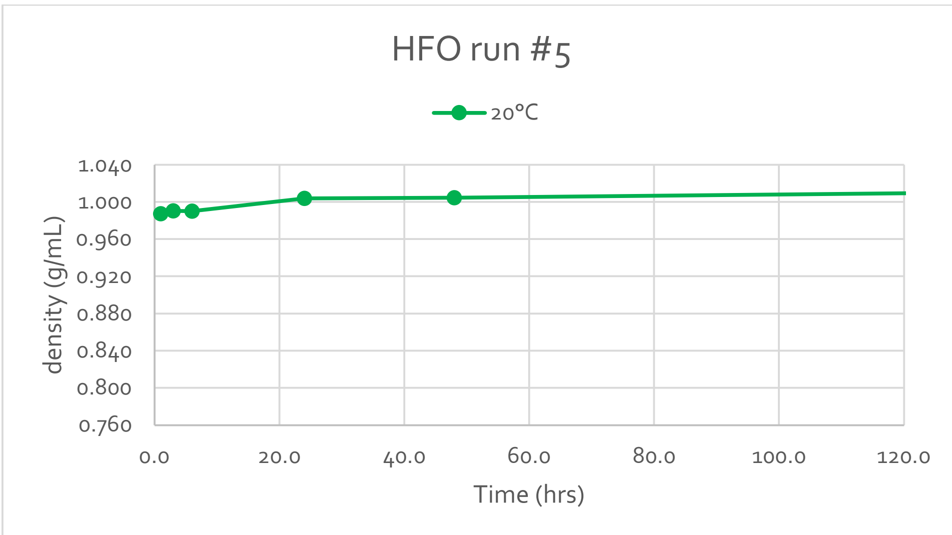


Figure C-0-153: HFO Run #5 Density vs Time

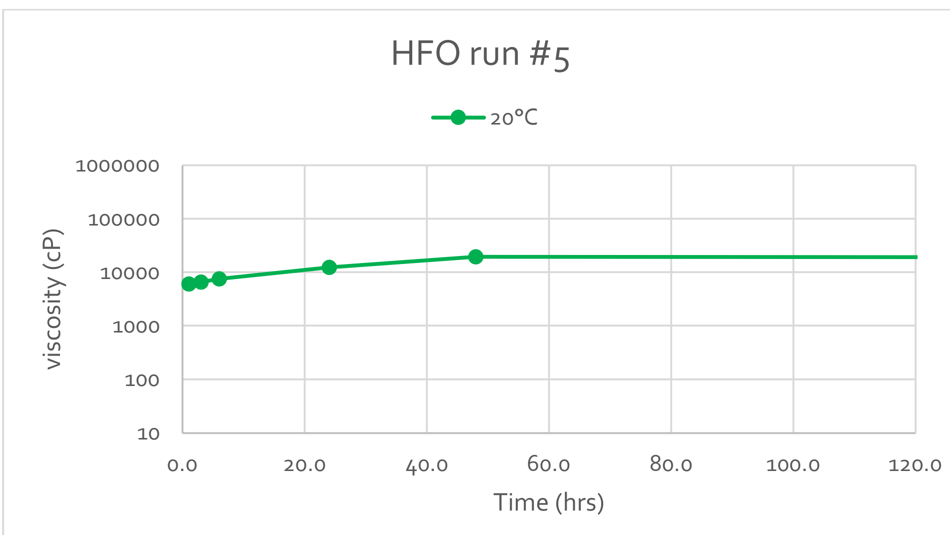


Figure C-0-154: HFO Run #5 Density vs Time

C.7.6 Run #6 (20°C, 0‰ salt, 1000 ppm sediment)

Oil flowed nicely around flume tank initially at 1 hour (S1). Some slight hold-up occurred between the thruster and fan on the N side. Oil continued to flow through 6 hours (S3). At 24 hours (S4), some oil was discovered behind a flow diverter plate which was then redirected back into the main flow area. At 48 hours (S5), the oil was starting to become more viscous but continued to circulate. Coverage area of the slick seemed to be decreasing. The run continued through 144 hours (S7). Oil volume at the surface seemed diminished and a "bathtub ring" of oil was seen along the inner curve walls.

Figure C-0-155: HFO R6 S1 Waterfall impacting slick

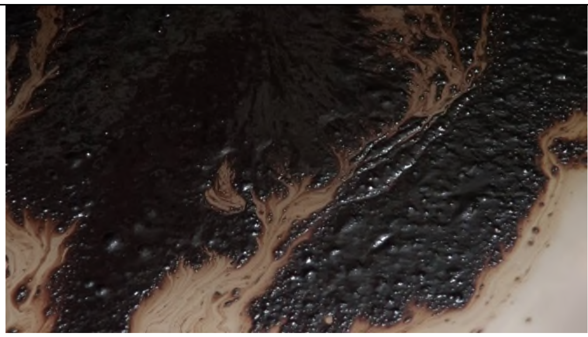


Figure C-0-156: HFO R6 S5 Oil weathering for 48 hours

Figure C-0-157: HFO R6 S6 Oil slick hold-up

Figure C-0-158: HFO R6 S8 Final sampling but oil quantity diminished at surface

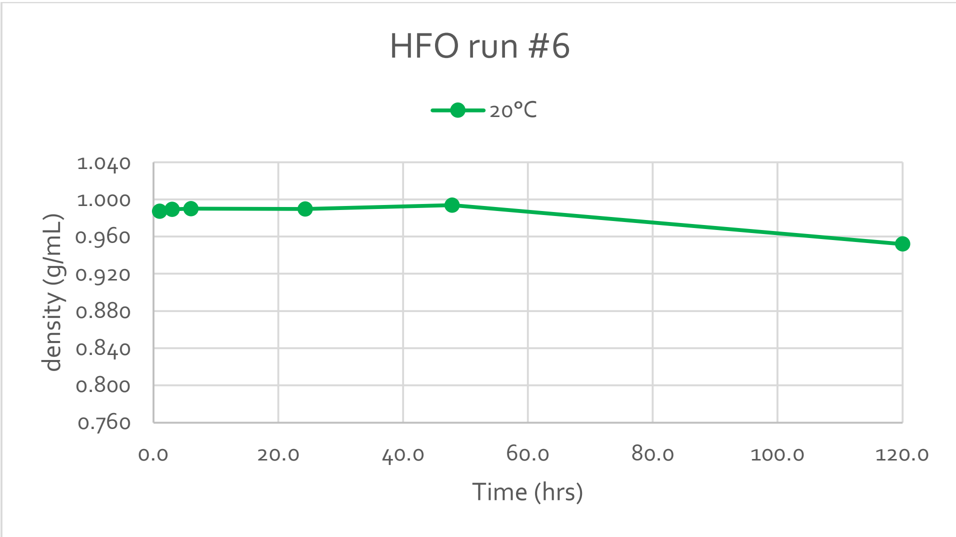


Figure C-0-159: HFO Run #6 Density vs Time

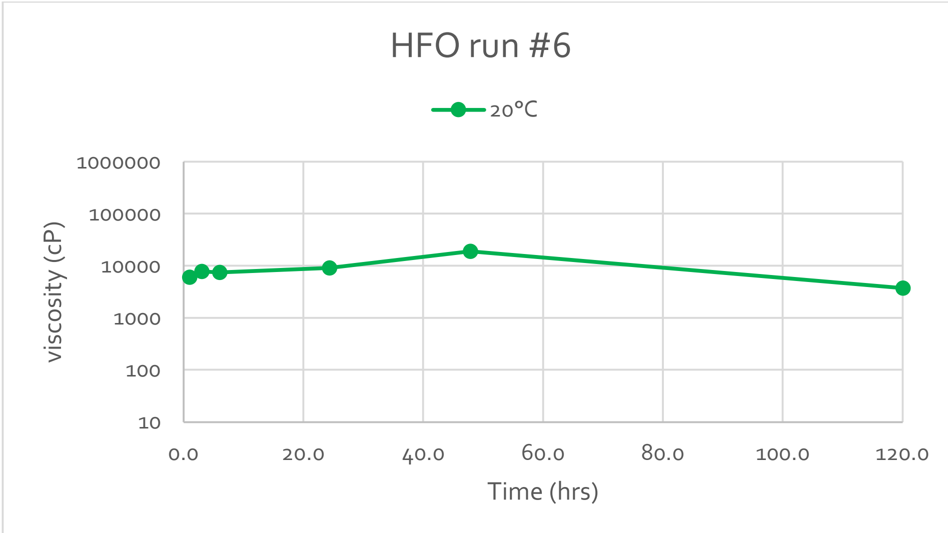


Figure C-0-160: HFO Run #6 Viscosity vs Time

C.7.7 Run #7 (20°C, 35‰ salt, 1000 ppm sediment)

This run was a repeat of Run #5. Oil starts off with a sufficiently low viscosity to flow easily around the flume. The oil started to show the effects of weathering with a circulation slow down at 24 hours (S4) and some hold-up between the thruster and the fan. At 50 hours (S5), the area of the main slick seemed to be getting smaller – possibly due to the thickening of the oil layer. At 96 hours (S6), oil was noticed to be accumulating on the inside track of the tank, near the thruster and fan. This accumulation continued at 120 hours (S7). The run was stopped at 144 hours (S8). Properties for Run #5 and Run #7, which were effectively repeats, are plotted on the same graphs below for comparison purposes.

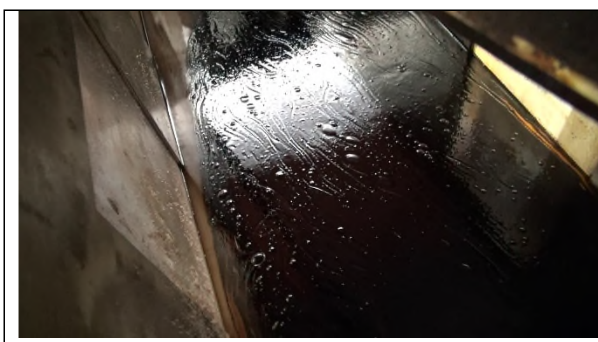


Figure C-0-161 HFO R7 S1 Oil flowing nicely

Figure C-0-162 HFO R7 S5 Main oil slick

Figure C-0-163 HFO R7 S8 End of run hold-up

Figure C-0-164 HFO R7 S8 End of run main slick

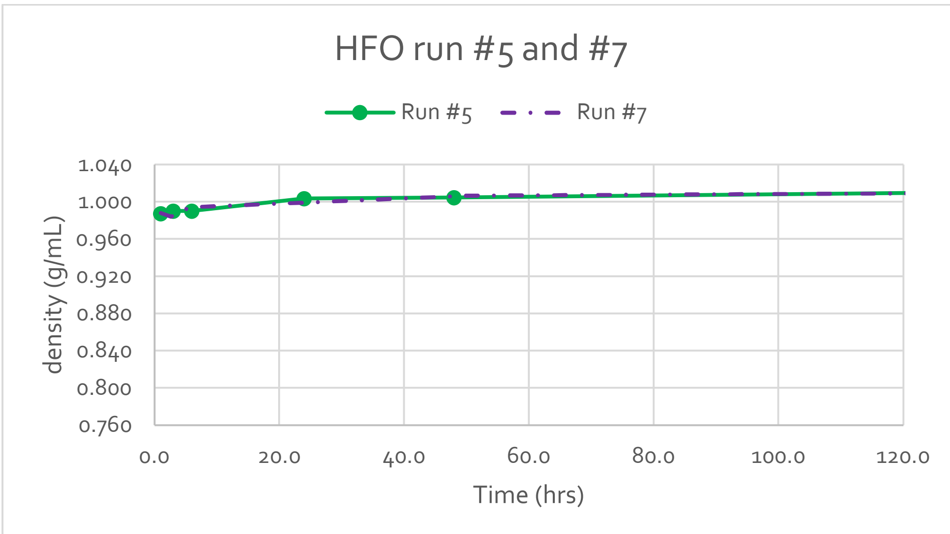


Figure C-0-165: HFO Run #5 and #7 Density vs Time

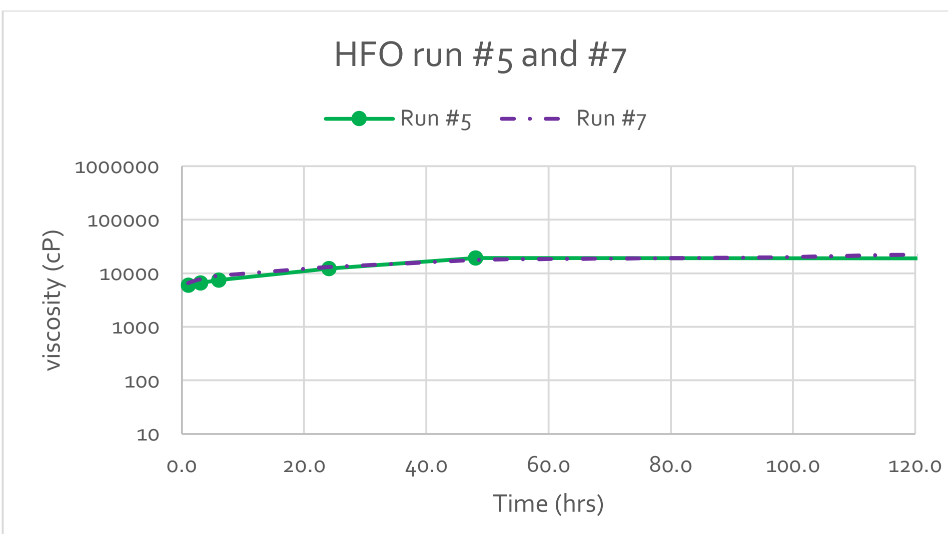


Figure C-0-166: HFO Run #5 and #7 Viscosity vs Time

C.7.8 Run #8 (20°C, 0‰ salt, 0 ppm sediment)

This run was a repeat of Run #1. The oil initially flowed freely around the flume. Oil was shredded by the waterfall, but quickly formed spheres which generally resurfaced at the first hour (S1). Some small and large diameter spheres were seen in the water column that were not resurfacing quickly. The oil started becoming more viscous by 6 hours (S3) and was no longer forming spheres following impacts by the waterfall, rather non-symmetrical blobs. Droplet concentration within the flume decreased. By 120 hours (S6), the viscosity had increased to the point where impacts from the waterfall resulted in stringers/shredding of the oil which resurfaced. Very few droplets were seen the water column. This behaviour continued through 168 hours (S8) when the run was stopped. Properties for Run #1 and Run #8, which were repeats, are plotted on the same graphs below for comparison purposes.

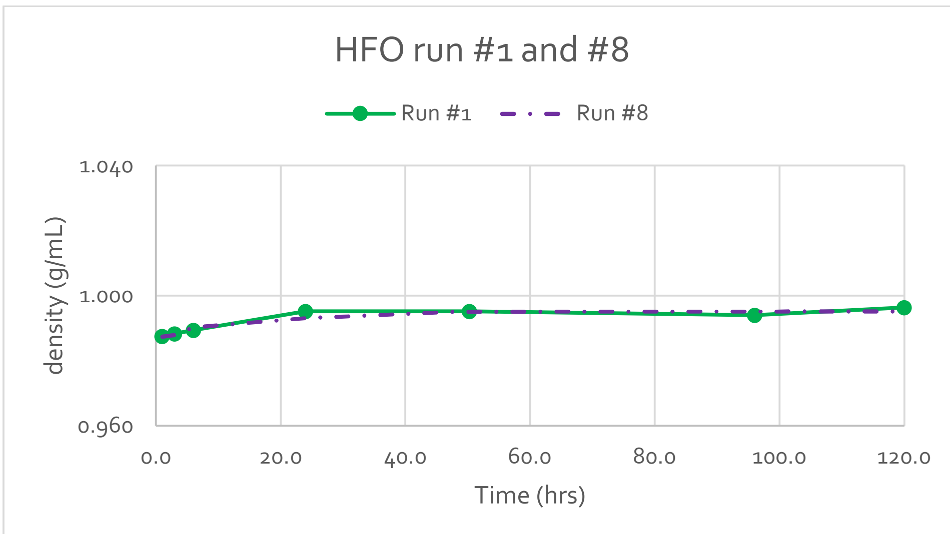


Figure C-0-167: HFO Run #1 and #8 Density vs Time

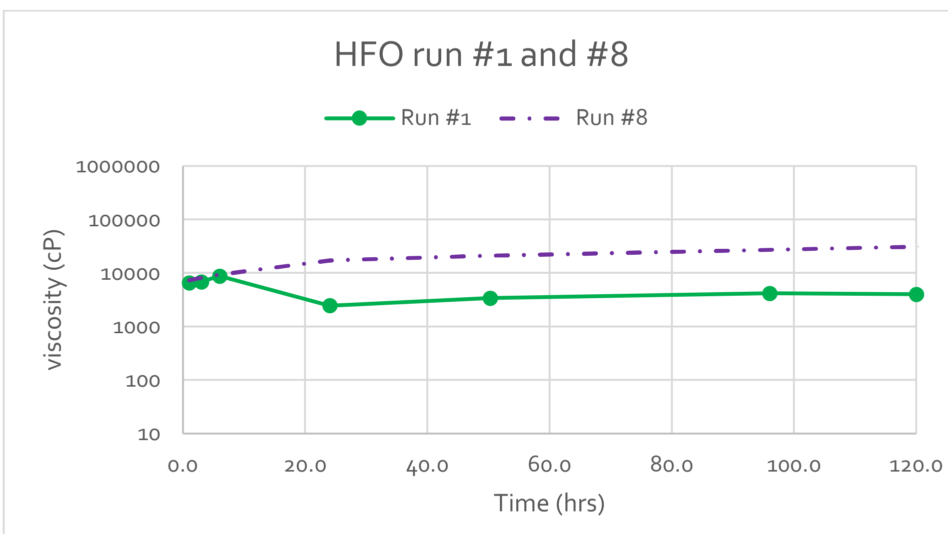


Figure C-0-168: HFO Viscosity vs Time

C.7.9 HFO Flume Sample Water Contents

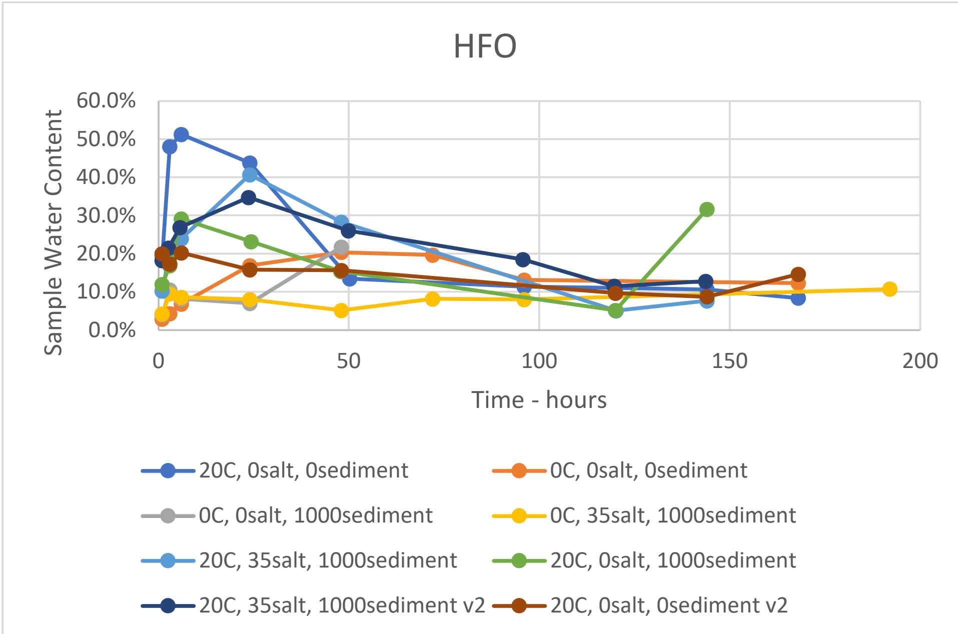


Figure C-0-169 Ultimate Water Content of HFO Flume Samples

C.7.10 HFO Flume Testing Discussion

The HFO oil started out as a heavy, dense product that weathered slightly during the baseline runs. During the 0°C baseline run the density did reach 1.000 at the 3 hour point. The density varied a bit but did not change dramatically after that. At one point (96 hours) it measured just below 1.000 g/mL but the subsequent reading was higher again. Some oil slugs were stuck to the walls of the tank. The density also surpassed 1.000 g/mL at the 1 hour mark during the 0°C run with sediment.

C.8 LSB IN FLUME TANK

C.8.1 Run #1 (0°C, 0‰ salt, 0 ppm sediment)

The oil starts off circulating well with the waterfall shearing small oil droplets off the slick in the 1-3 mm diameter range. The water column remains clear. The oil continues to flow freely around the flume through 3 hours (S2) and into 6 hours (S3) where it starts to have some hold-up between the thruster and fan. The hold-up increases in 24 hours (S4) and circulation begins to slow. This progresses through 49 hours (S5) up to 96 hours (S7) where the oil circulation has mostly stopped. At this point the thruster is cycled to get the oil to circulate. By 120 hours (S8), the oil is turning brownish and the oil has become sufficiently viscous that oil patties circulating past the waterfall are not shearing at all. This continues through 360 hours (S13) and 456 hours (S14).

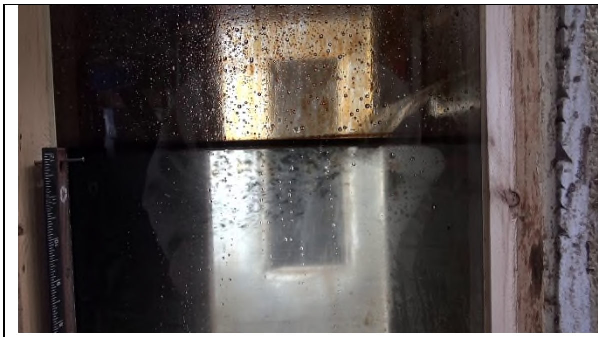


Figure C-0-170: LSB R1 S1 Small oil droplets shear off at waterfall

Figure C-0-171: LSB R1 S9 Oil hold-up between thruster and fan

Figure C-0-172 LSB R1 S9 Oil turning brown as it emulsifies

Figure C-0-173 LSB R1 S13 Oil too viscous for waterfall

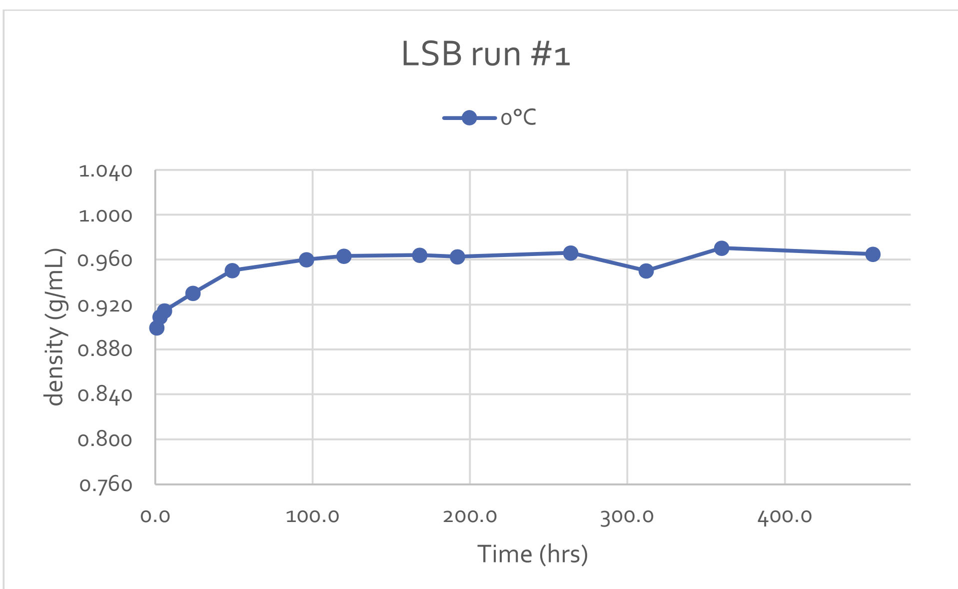


Figure C-0-174: LSB Run #1 Density vs Time

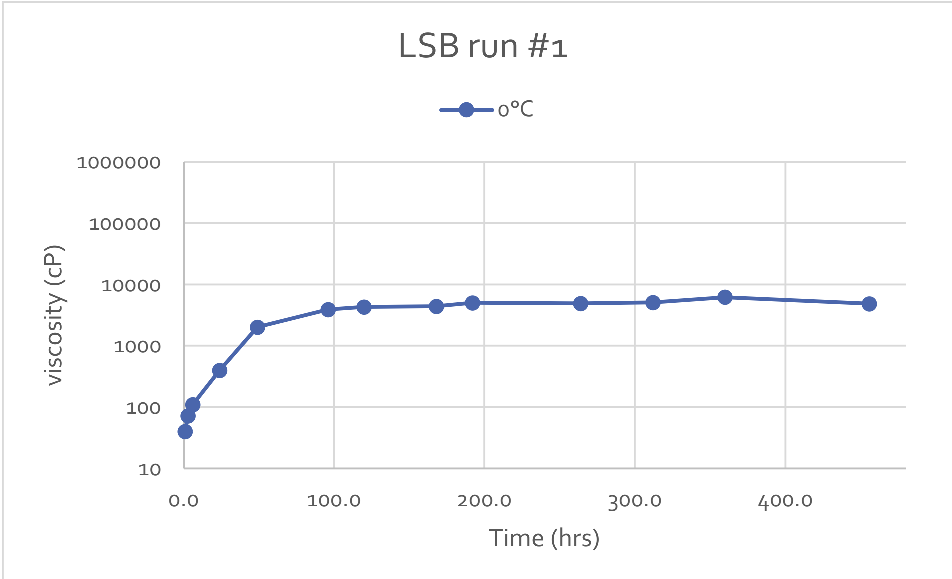


Figure C-0-175: LSB Run #1 Viscosity vs Time

C.8.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

This run was a repeat of Run#1. At 1 hour (S1), the oil flows freely, nicely circulating while the waterfall shears the oil into small droplets that quickly resurface. By 3 hours (S2), the oil is partially held-up above the thruster on the N side of the tank. A thin slick continues to circulate. By 48 hours (S5), circulation has slowed to a crawl and the thruster is cycled to encourage the oil to pass. At 144 hours (S7), the oil picks up a brown colour, and the waterfall causes streamers and blobs to form.

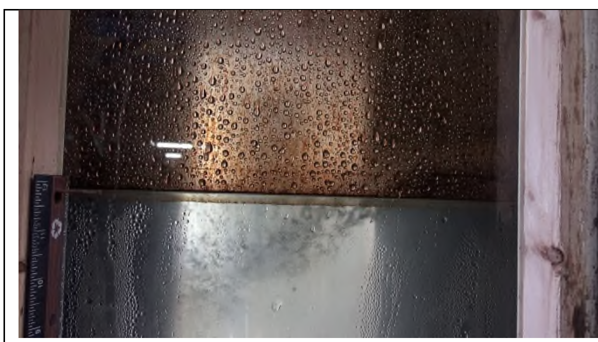


Figure C-0-176 LSB R2 S5 Oil still forms small droplets under the waterfall

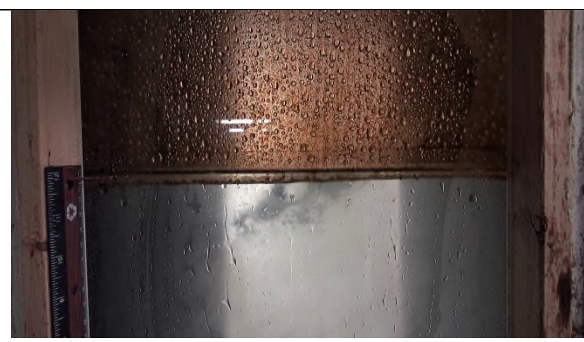


Figure C-0-177 LSB R2 S7 Larger stringers and blobs of oil are sheared from the slick as viscosity increases

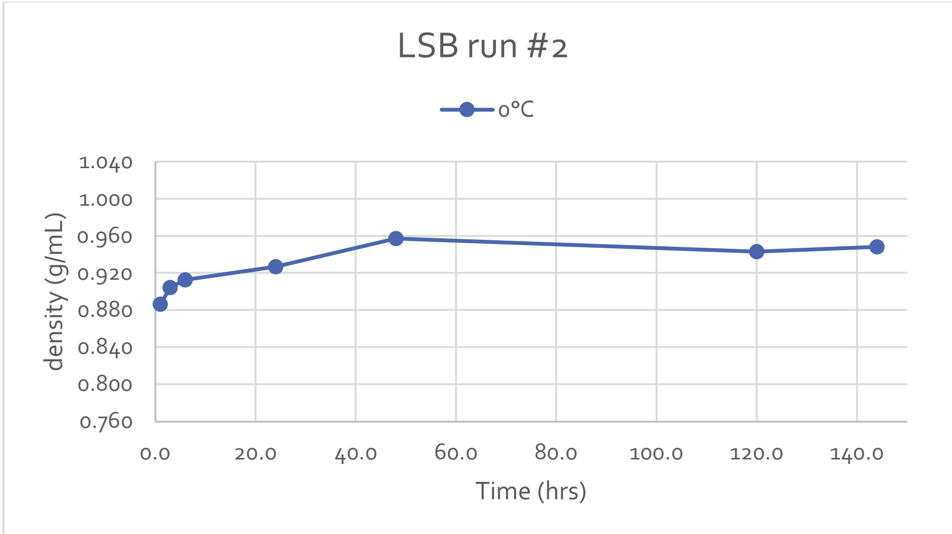


Figure C-0-178: LSB Run #2 Density vs Time

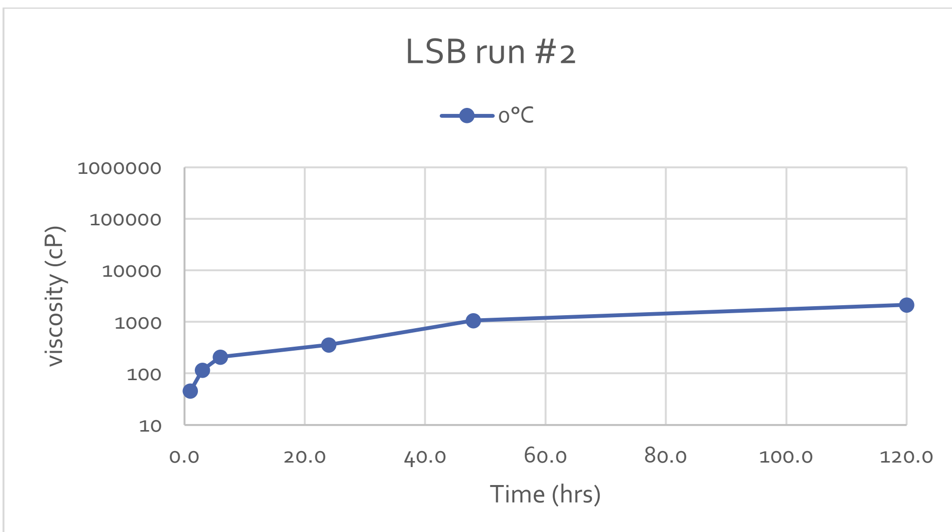
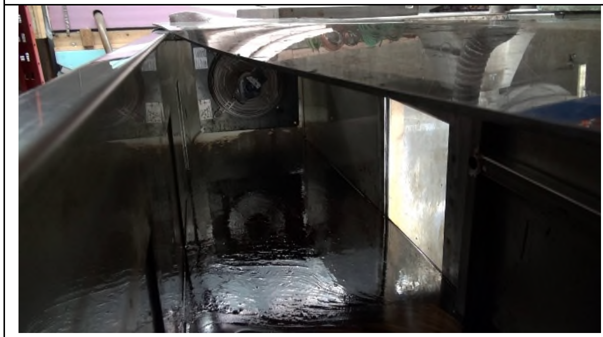


Figure C-0-179: LSB Run #2 Viscosity vs Time

C.8.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

Oil flows nicely at the beginning of the run. By 3 hours (S2), some hold-up is occurring but circulation around the flume continues. By 24 hours (S4), circulation is impeded by hold-up above the thruster, so the thruster is cycled to allow the oil slick to pass.

 *Figure C-0-180: LSB R3 S4 Oil hold-up above thruster*	 *Figure C-0-181: LSB R3 S5 Oil circulating*
 *Figure C-0-182: LSB R3 S6 Oil hold-up*	 *Figure C-0-183: LSB R3 S7 Final weathered state*

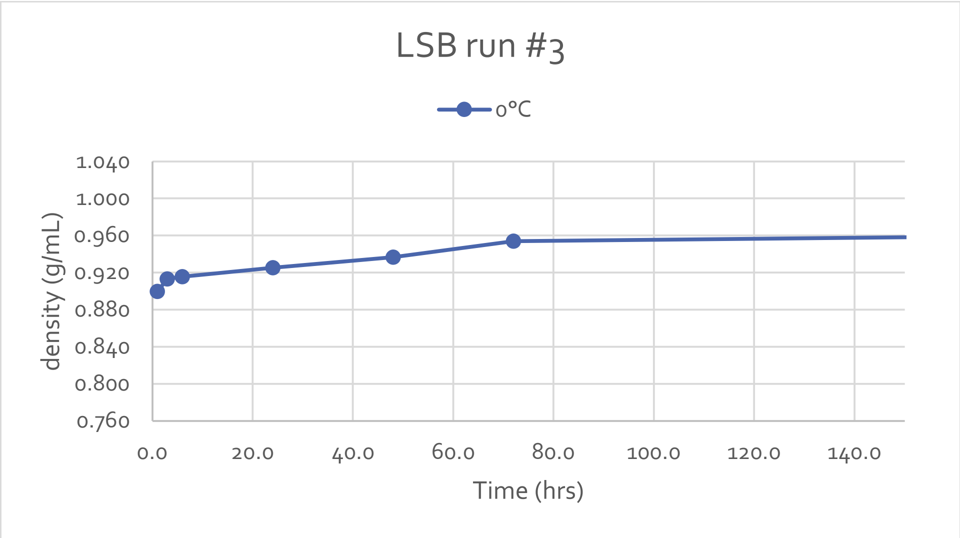


Figure C-0-184: LSB Run #3 Density vs Time

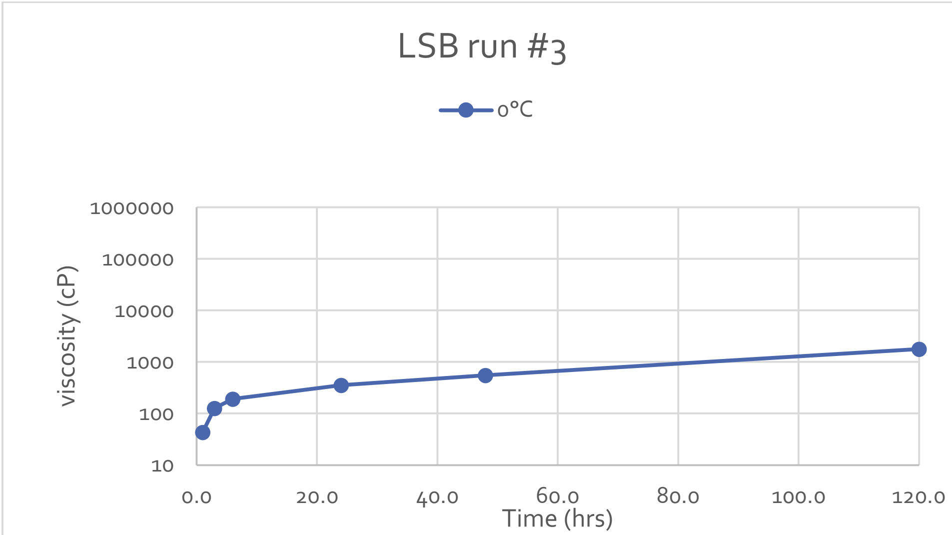


Figure C-0-185: LSB Run #3 Viscosity vs Time

C.8.4 Run #4 (20°C, 0‰ salt, 0 ppm sediment)

Oil circulates nicely at the beginning. By 24 hours (S4), there is the main portion of the oil slick building up between the thruster and the fan along the N side. Oil continues to circulate as it gradually weathers and becomes more viscous. By 167 hours (S7) ,the oil has become noticeably more viscous, although it did not seem to change colour. Along the S side a problem with the second fan in the flume was identified. This run will be repeated.

Figure C-0-186: LSB R4 S3 Oil is still very fluid

Figure C-0-187: LSB R4 S7 Main oil slick

Figure C-0-188: LSB R4 S7 Oil hold-up between thrusters and fan

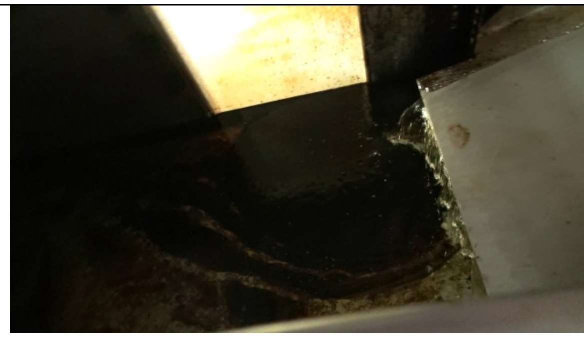


Figure C-0-189: LSB Impact of waterfall

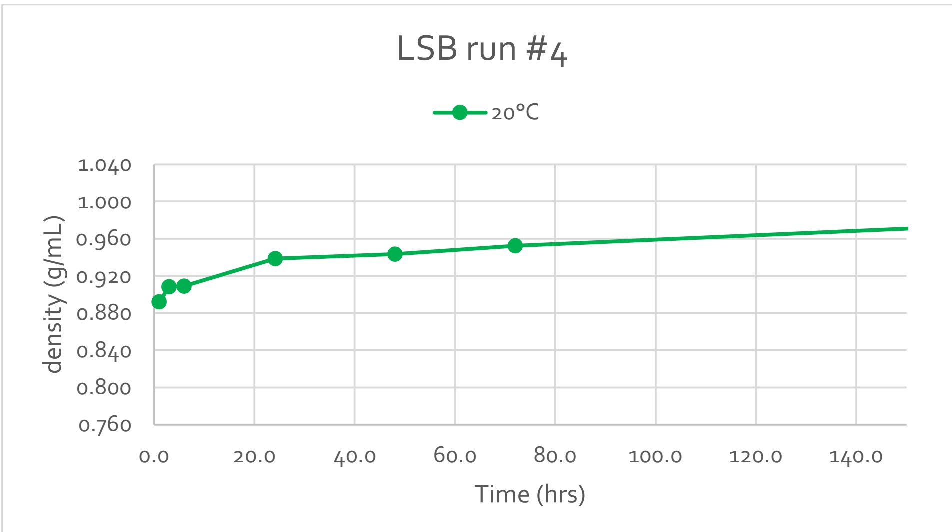


Figure C-0-190: LSB Run #4 Density vs Time

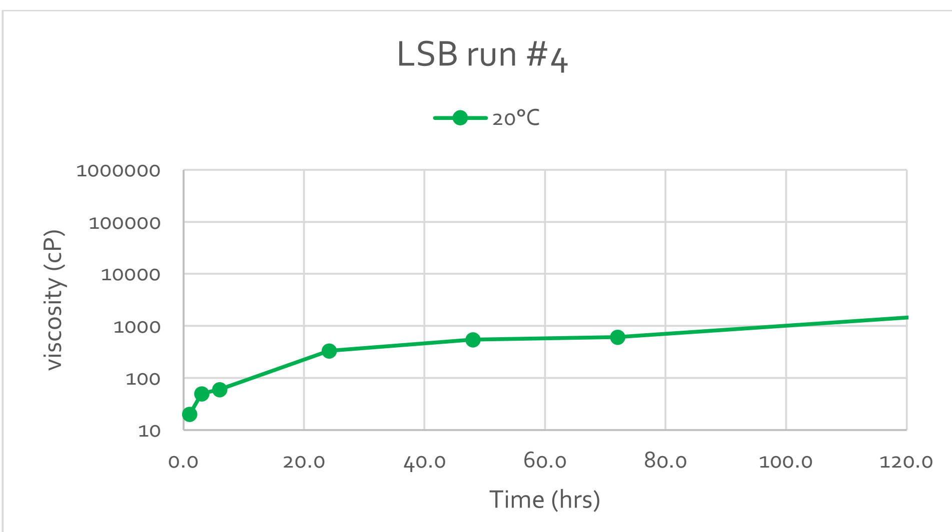


Figure C-0-191: LSB Run #4 Viscosity vs Time

C.8.5 Run #5 (20°C, 0‰ salt, 0 ppm sediment)

This run was a repeat of Run#4. This run begins with a light oil that flows particularly well. At 3 hours (S2), the oil has a few bubbles near the surface of the slick (likely imparted by the turbulence of the waterfall). It is not until 72 hours (S6) that emphatic movement patters appear in the slick, indicating an increase in viscosity. Non-spherical shedding is caused by the waterfall, as viewed from above.

Figure C-0-192: LSB R5 S1 Start of run

Figure C-0-193: LSB R5 S6 Oil continues to circulate, getting more viscous

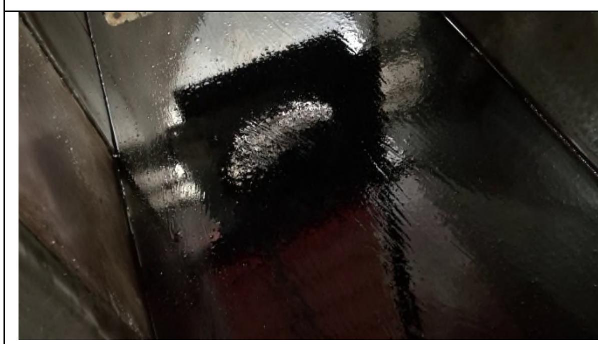


Figure C-0-194: LSB R5 S7 Run ending soon

Figure C-0-195: LSB R5 S7 Waterfall feature

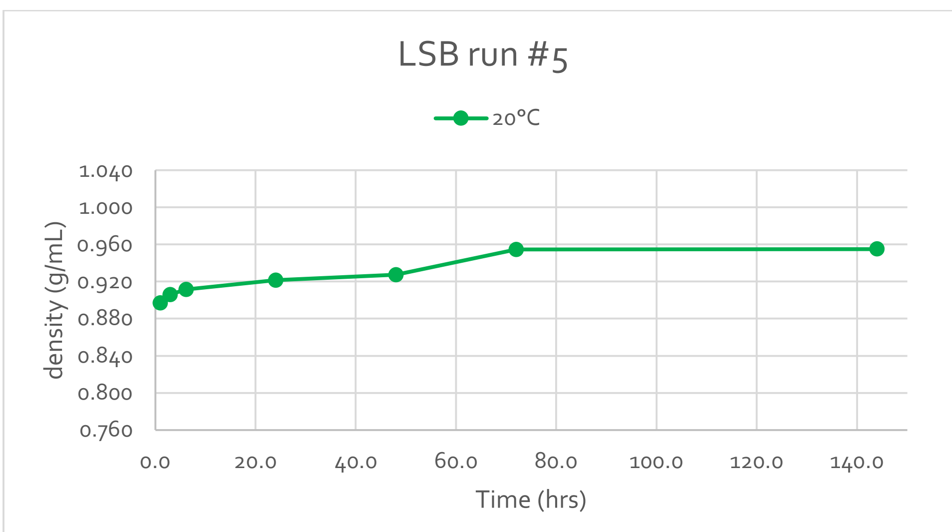


Figure C-0-196: LSB Run #5 Density vs Time

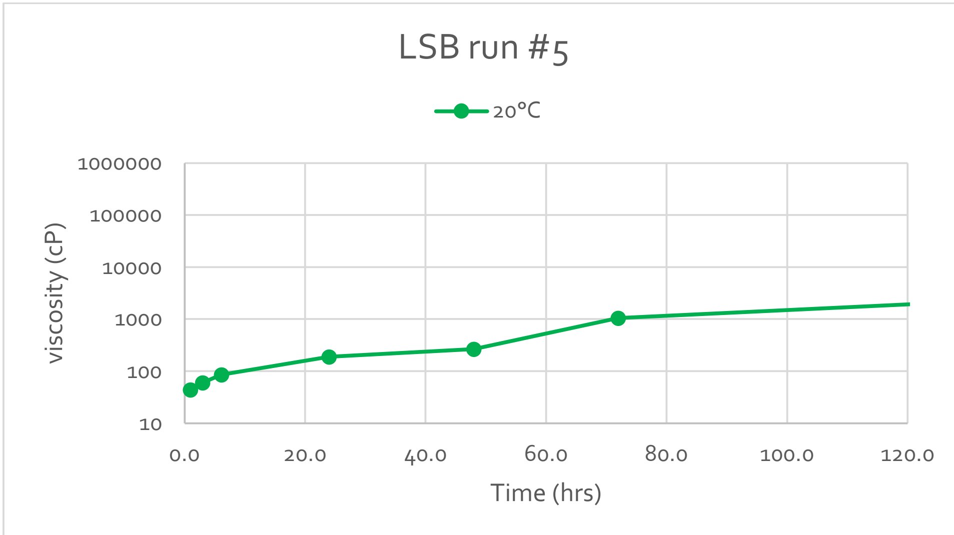


Figure C-0-197: LSB Run #5 Viscosity vs Time

C.8.6 LSB Flume Sample Water Contents

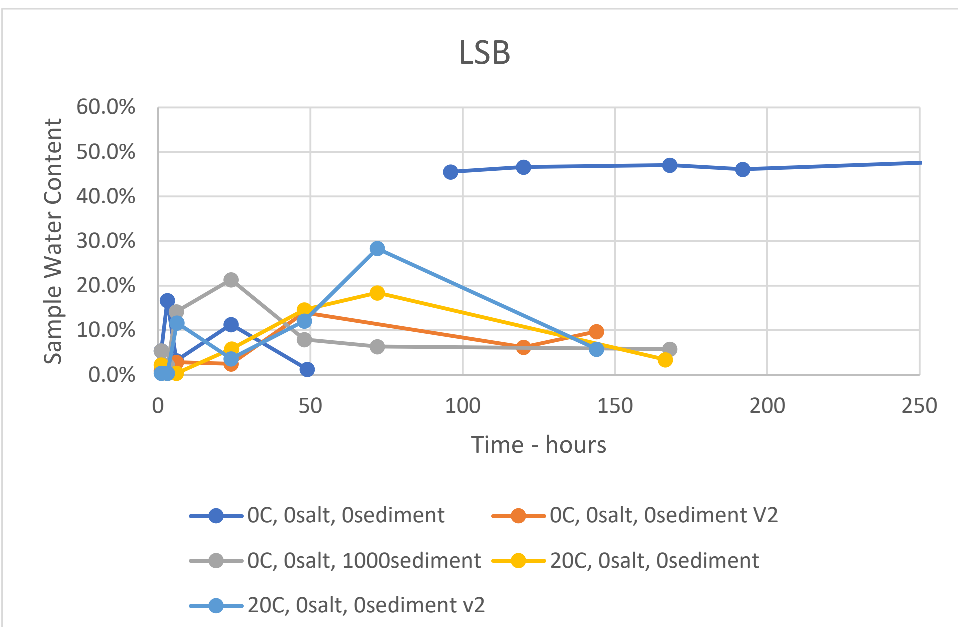


Figure C-0-198 Ultimate Water Content of LSB Flume Samples

C.8.7 LSB Flume Testing Discussion

The LSB weathered consistently through the baseline and supplemental tests but did not approach a density of 1.000 g/mL. Viscosity results were relatively light for the tests as well, never reaching 10,000 cP.

C.9 MSB IN FLUME TANK

C.9.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

At 1 hour (S1), free flowing oil is sheared into droplets of 1-3 mm diameter from the waterfall. Droplets are also appearing in the water column, mostly less than 1mm but some larger (2mm). The oil does not dramatically change its behaviour over the course of the run. By 168 hours (S8), the waterfall still shears the passing oil slick into droplets which quickly rise to the surface. Over the course of the run, large droplets in the water column reduced in frequency while smaller droplets (<1mm diameter) persisted for longer but eventually diminished as well.

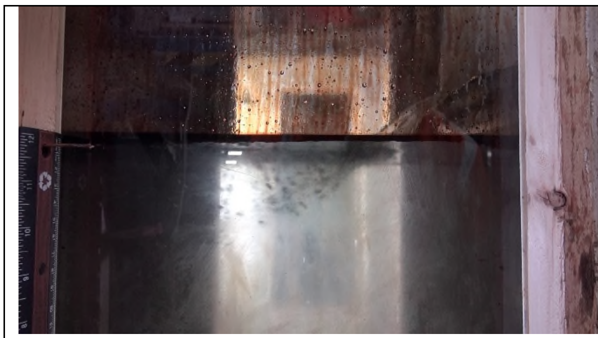


Figure C-0-199: MSB R1 S1 Waterfall shearing oil into droplets

Figure C-0-200: MSB R1 S8 Waterfall still shearing oil droplets

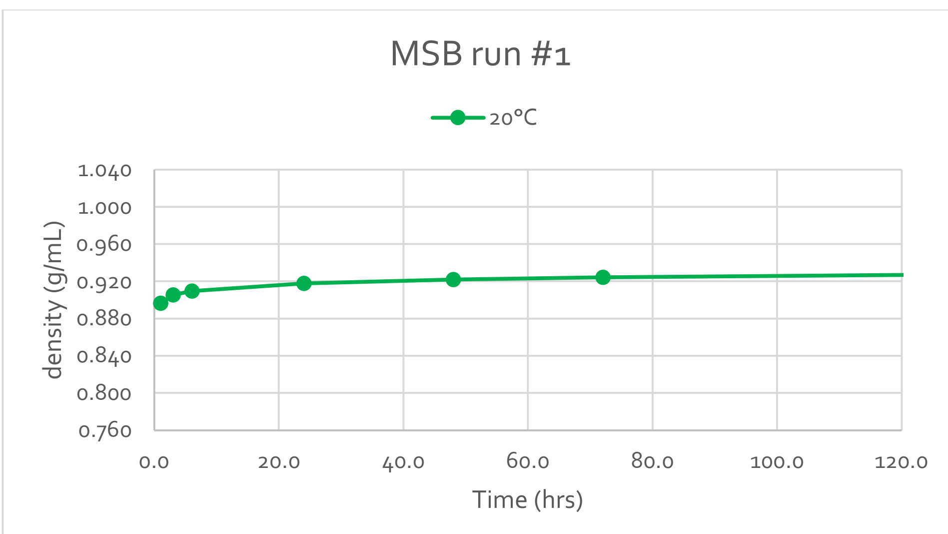


Figure C-0-201: MSB Run #1 Density vs Time

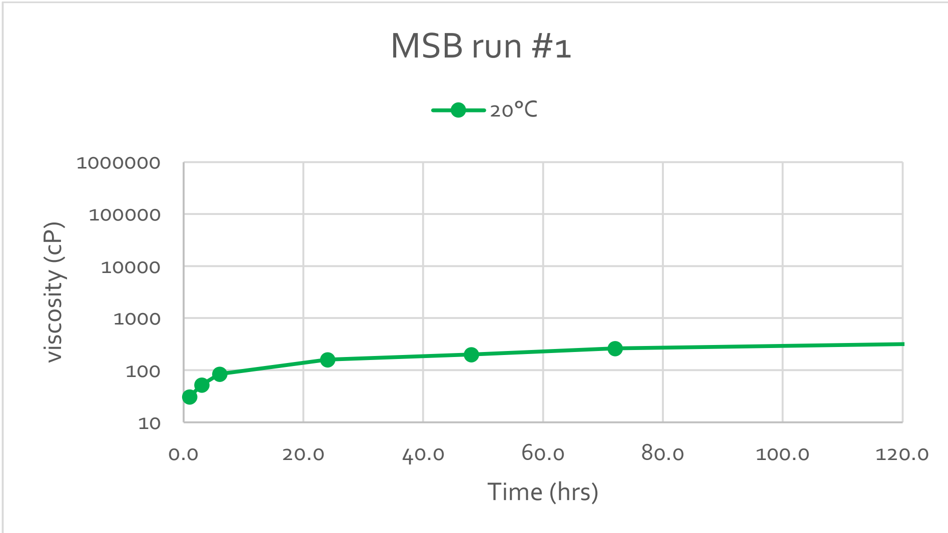


Figure C-0-202: MSB Run #1 Viscosity vs Time

C.9.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

Oil initially circulates freely and is sheared into small (1-3 mm diameter) droplets by the waterfall before quickly rising to the surface. By 1 hour (S1), there is noticeable hold-up and the concentration of small droplets circulating deeper in the water column has diminished. By 3 hours (S2), the water column is still clear, with very occasional observances of small (<1-2 mm) and large (4-5mm) diameter droplets. At 6 hours (S3), some large oil droplets seem to be stripped off the slick from underneath due to some turbulence caused by the thruster. This behaviour was not noticed again for the duration of the run. Some oil hold-up was noted, but portions of the oil slick continued to circulate. This behaviour persisted for the duration of the run which ended at 168 hours (S8).

Figure C-0-203: MSB R2 S3 Circulation of oil

Figure C-0-204: MSB R2 S3 Mini vortex under slick near thruster

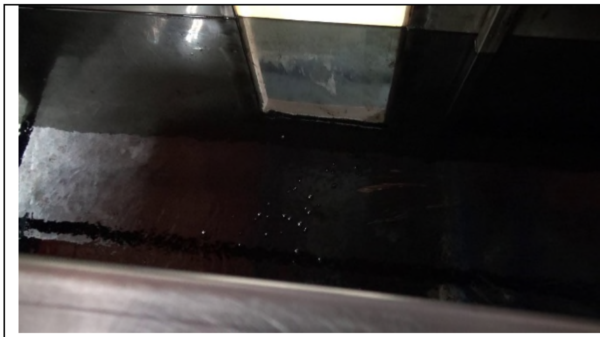


Figure C-0-205: MSB R2 S8 Oil hold-up between thruster and fan

Figure C-0-206: MSB R2 S8 Circulation of oil

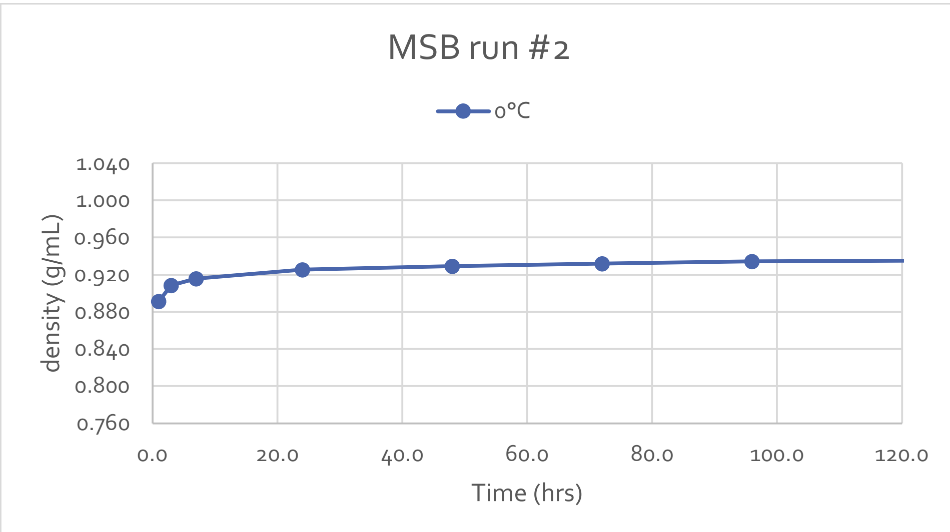


Figure C-0-207: MSB Run #2 Density vs Time

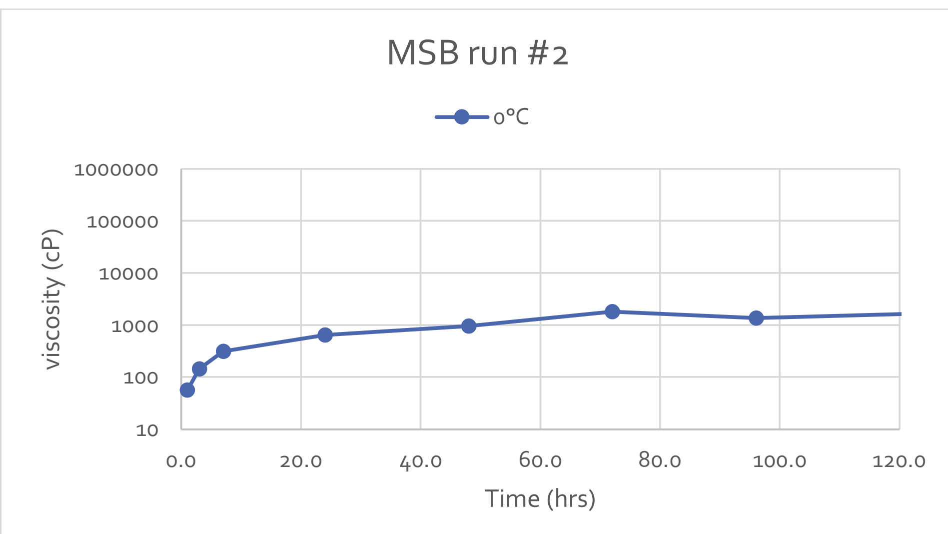


Figure C-0-208: MSB Run #2 Viscosity vs Time

C.9.3 MSB Flume Sample Water Contents

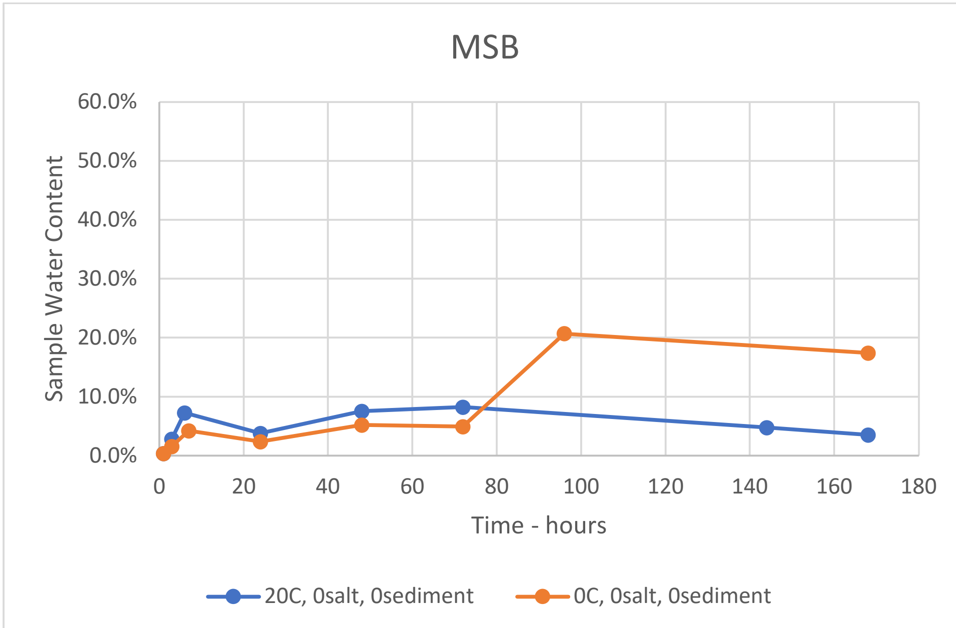


Figure 0-209 Ultimate Water Content of MSB Flume Samples

C.9.4 MSB Flume Testing Discussion

The MSB oil started light and ended the two baseline tests below 0.940 g/mL. Oil viscosity topped out at 2,300 cP at the 168 hour mark of the 0°C baseline run.

C.10 MSW IN FLUME TANK

C.10.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

Very light oil spreads easily over surface of test tank. Sheds into a range of droplet sizes from 1-2 and from 3-5 mm diameters. The sample seemed very slow to weather, as the low viscosity held for several sampling points. Tiny droplets (<1mm diameter) were seen in the water column circulating around the tank, along with an occasional larger diameter (4-5mm) droplet. By 48 hours (S5), the hold-up became more pronounced and the portion of oil circulating thinned out a bit. The slick was still being sheared into spherical droplets indicating the viscosity was still low. This continued until the end of the run at 120 hours (S7).

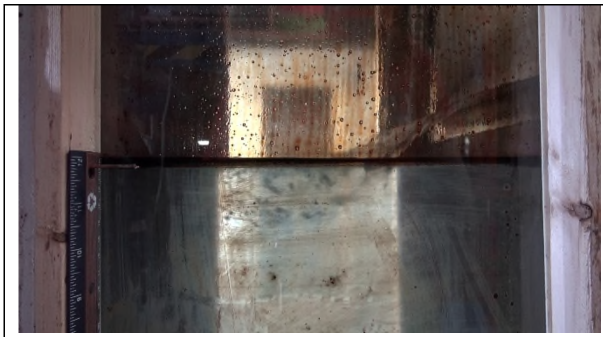


Figure C-0-210: MSW R1 S1 initial impacts from waterfall


Figure C-0-211: MSW R1 S4 Large circulating 5mm droplet under waterfall


Figure C-0-212: MSW R1 S6 Circulation of slick


Figure C-0-213: MSW R1 S6 Slick coverage near thruster

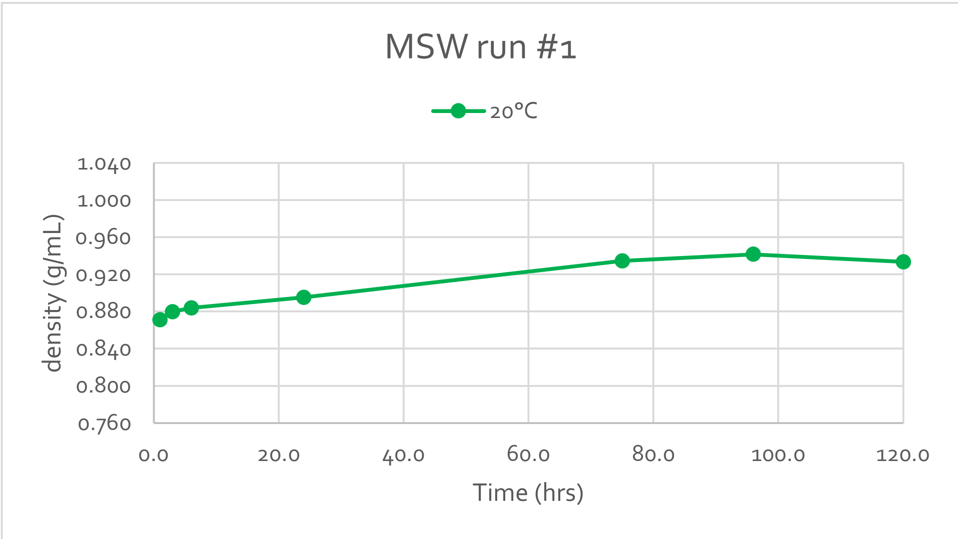


Figure C-0-214: MSW Run #1 Density vs Time

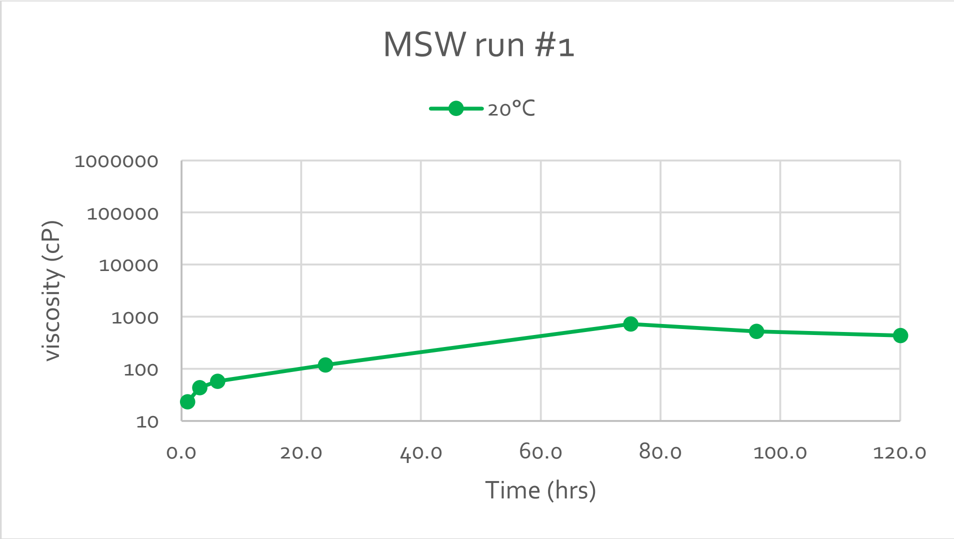


Figure C-0-215: MSW Run #1 Viscosity vs Time

C.10.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

Oil slick circulates nicely with some hold-up between the thruster and fan at 1 hour (S1). Props are cycled to determine their impact on flow. Water column is clear. By 3 hours (S2), the slick is still sheared into small droplets (1-2 mm diameter) by the waterfall. At 24 hours (S4), when oil is circulated, the slick is sheared into non-spherical blobs by the waterfall.

Figure C-0-216: MSW R2 S4 circulation has diminished

Figure C-0-217: MSW R2 S4 Oil sheared into blob by waterfall

Figure C-0-218: MSW R2 S5 Oil emulsified and turning brown

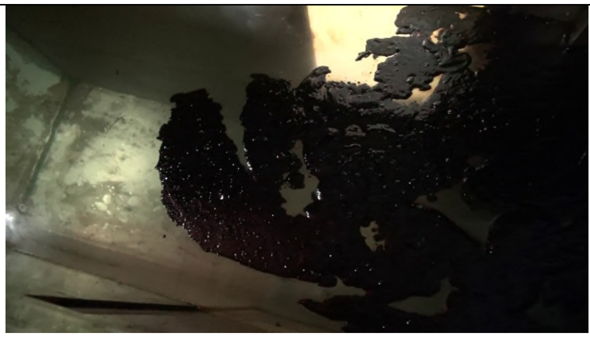


Figure C-0-219: MSW R2 S9 Oil at end of run

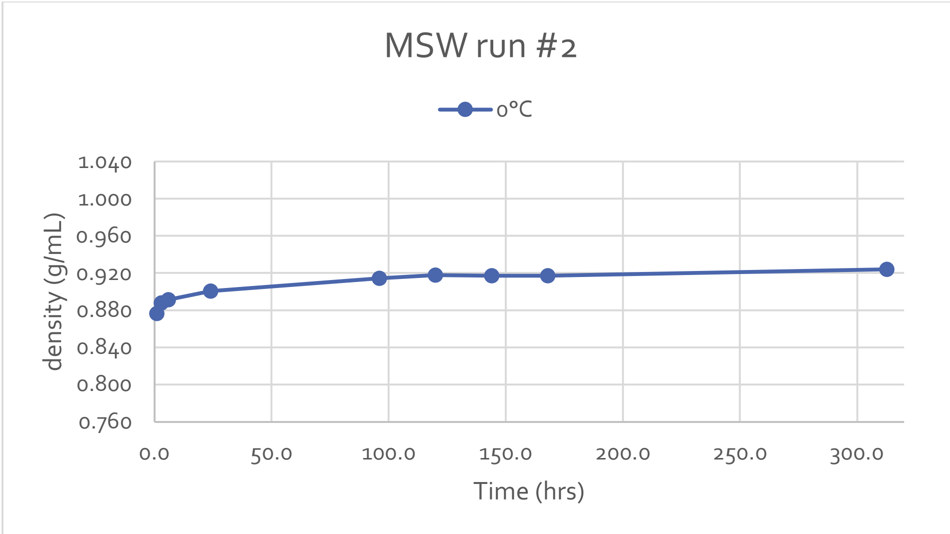


Figure C-0-220: MSW Run #2 Density vs Time

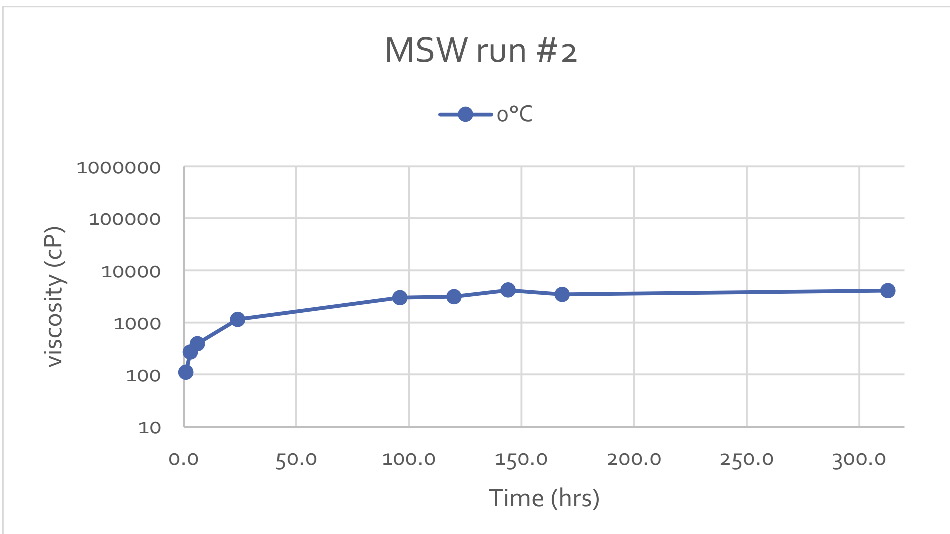


Figure C-0-221: MSW Run #2 Viscosity vs Time

C.10.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

Oil starts off light and circulates well when the thruster is cycled. Oil increases in viscosity as sampling continues through 6 hours (S3). Oil continues to weather, and the props are cycled to encourage oil circulation between sampling times. At 48 hours (S5), the oil continues to weather, slowly increasing in viscosity. This behaviour continues through 168 hours (S8).

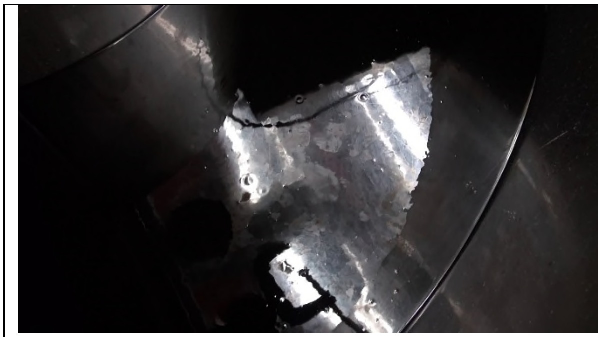


Figure C-0-222: MSW R3 S1 Oil circulating

Figure C-0-223: MSW R3 S4 Oil slick on N side

Figure C-0-224: MSW R3 S7 Oil hold-up on N side limits flow when thruster is engaged

Figure C-0-225: MSW R3 S9 Fragmented slick

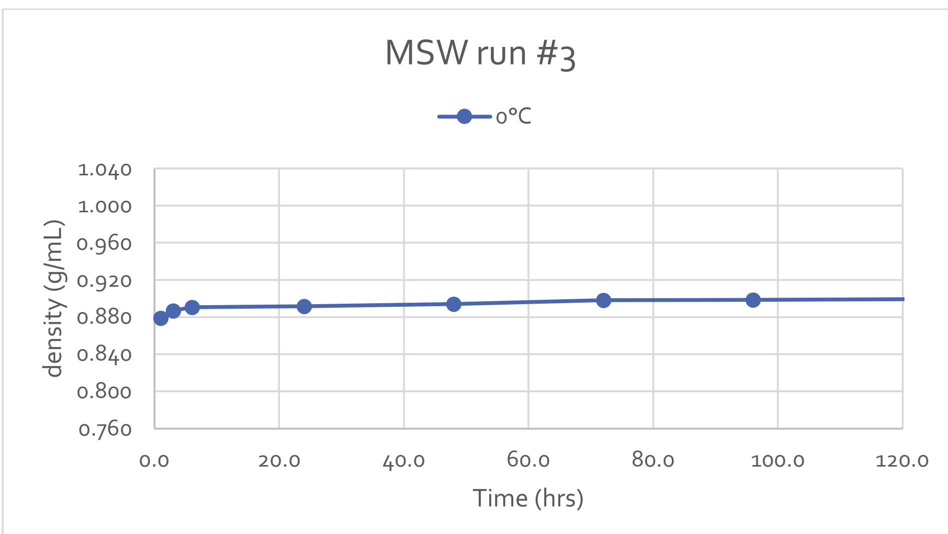


Figure C-0-226: MSW Run #3 Density vs Time

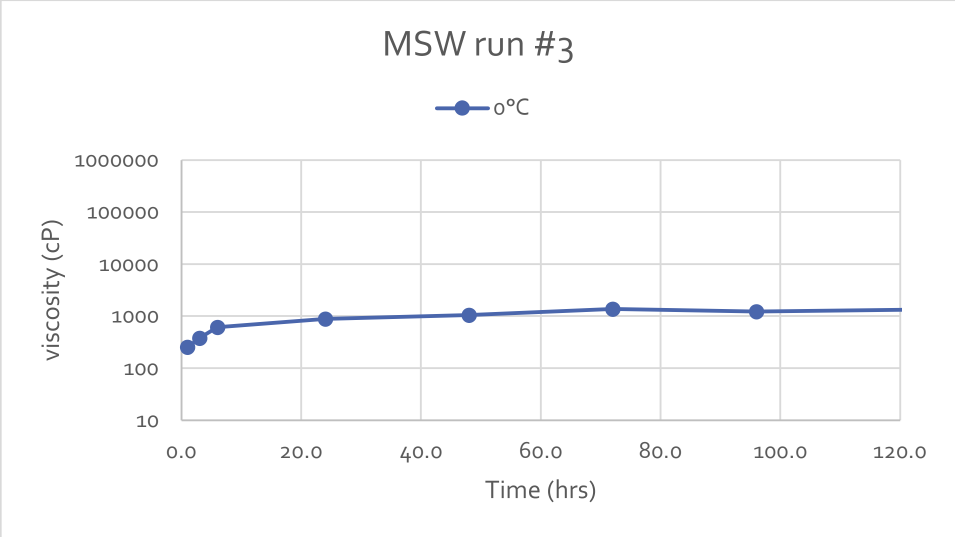


Figure C-0-227: MSW Run #3 Viscosity vs Time

C.10.4 Run #4 (20°C, 35‰ salt, 1000 ppm sediment)

Oil initially had low viscosity and covered the tank surface nicely. Weathering began at a comparatively slow pace, as the oil circulated well through 48 hours (S5). At 120 hours (S6), the viscosity did creep up, as the oil slick retained a rippled surface while it was held-up on the N side. The test run continued through 144 hours (S7).

Figure C-0-228: MSW R4 S1 View from back of waterfall

Figure C-0-229 MSW R4 S4 Circulation of oil

Figure C-0-230 MSW R4 S6 Stringers resurfacing at waterfall

Figure C-0-231 MSW R4 S7 Final oil slick condition

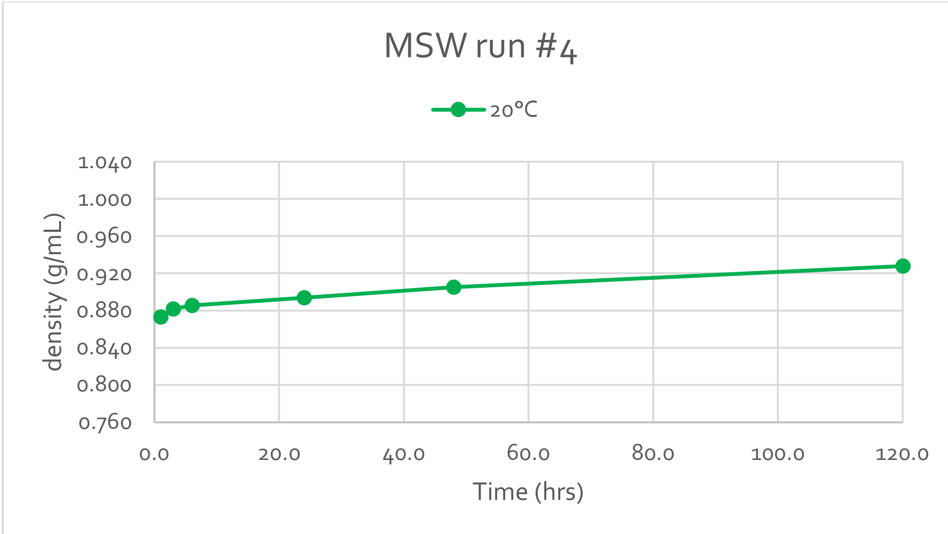


Figure C-0-232: MSW Run #4 Density vs Time

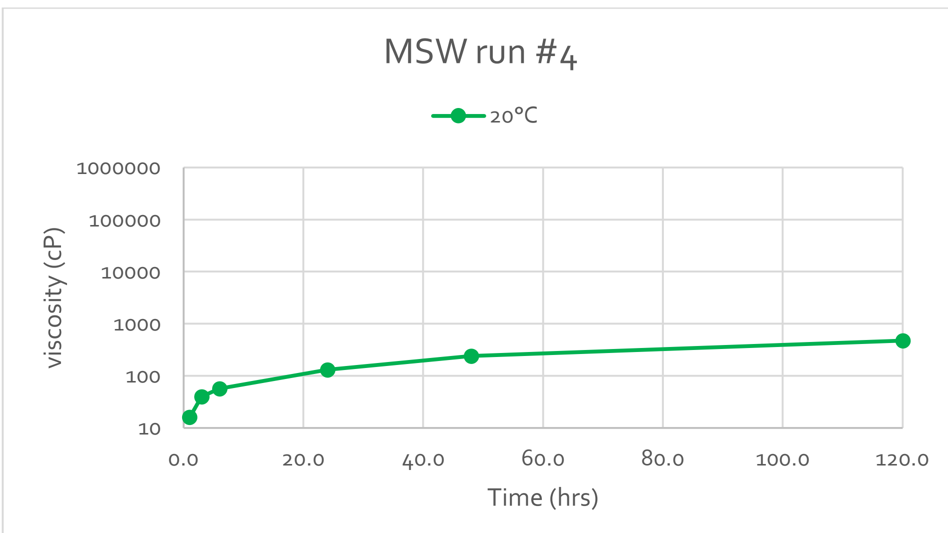


Figure C-0-233: MSW Run #4 Viscosity vs Time

C.10.5 Run #5 (0°C, 0‰ salt, 0 ppm sediment)

This run was a repeat of Run #2. Oil moves freely around tank at 1 hour (S1). Many large (4-7 mm) diameter droplets are seen swirling under the slick before the slick is impacted by the waterfall. Oil continues to weather and by 24 hours (S4) is sufficiently weathered that the slick stops circulating. The thruster is temporarily turned down to eliminate the "hump" in the water at the first turn, and the oil begins to circulate again. The oil continues to weather relatively slowly through to the end of the run at 144 hours (S7).

 *Figure C-0-234: MSW R5 S1 Oil moves freely around flume tank*	 *Figure C-0-235: MSW R5 S1 Many large (4-7 mm) diameter droplets swirling under slick*
 *Figure C-0-236: MSW R5 S4 Thruster turned down, oil now flowing again*	 *Figure C-0-237: MSW R5 S7 Oil mass moved around the tank to a spot between the waterfall and the S side fan*

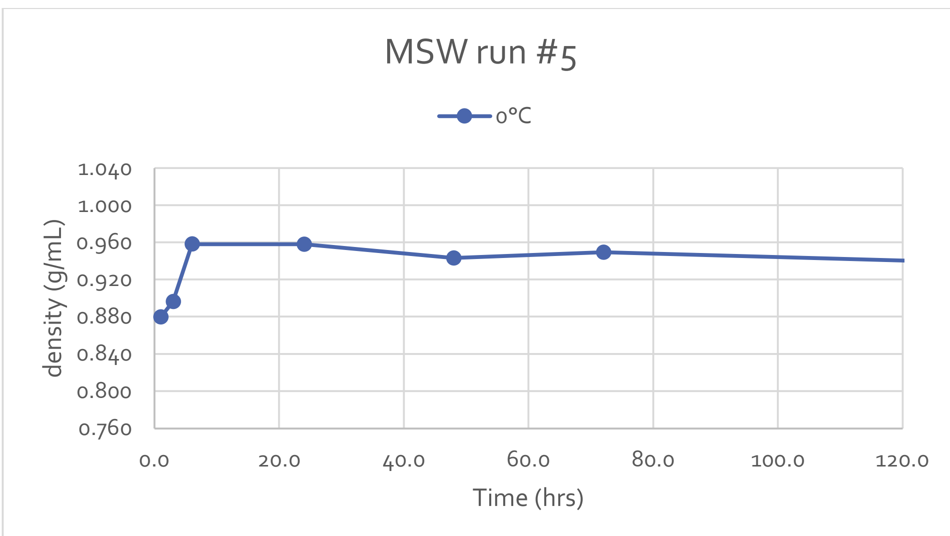


Figure C-0-238: MSW Run #5 Density vs Time

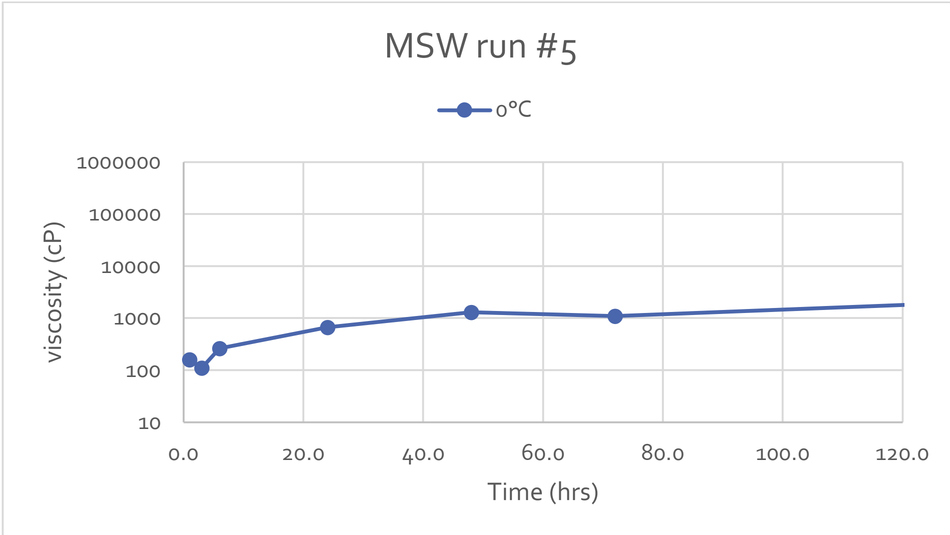


Figure C-0-239: MSW Run #5 Viscosity vs Time

C.10.6 MSW Flume Sample Water Contents

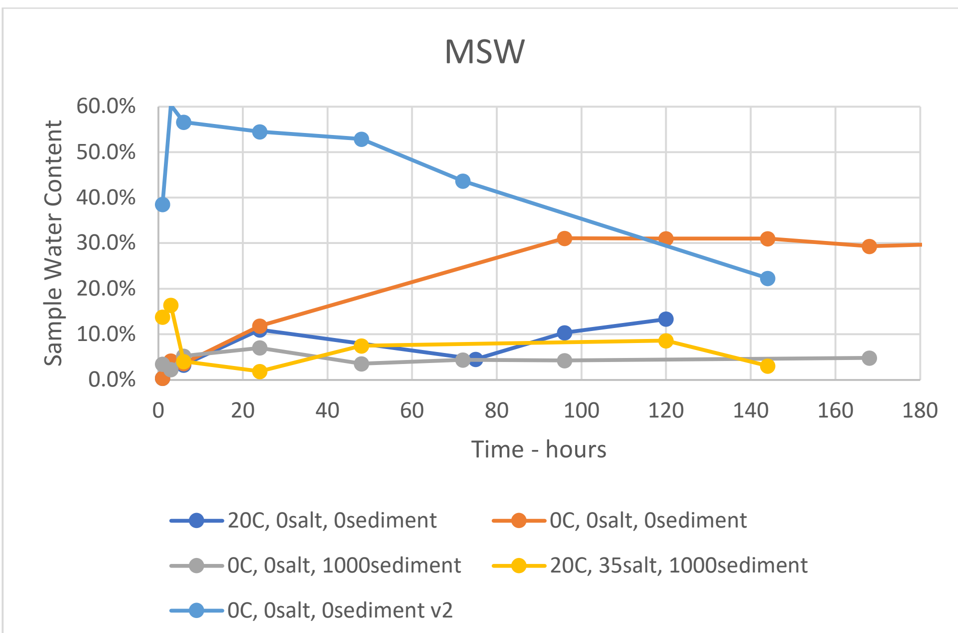


Figure C-0-240 Ultimate Water Content of MSW Flume Samples

C.10.7 MSW Flume Testing Discussion

The MSW oil behaved like a medium oil in the flume tank. It weathered slowly, with density increasing slightly over the duration of the runs, topping out at 0.94 g/mL during the baseline run at 20°C. Viscosity measurements showed similar trends – the oil started off light and weathered slightly.

C.11 NDB IN FLUME TANK

C.11.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

Very light oil circulates freely and sheds into very small droplets (like a mist) when impacted by the waterfall at 1 hour (S1). This continues through 24 hours (S4) where a partial oil hold-up on the N. side becomes apparent, although some oil still circulates. The water column is starting to get a bit cloudy. By 120 hours (S6), there is very little oil circulating and by 144 hours (S7), it is described as trace amounts (droplet coverage across surface of water). By 168 hours (S8), there is some weak emulsification which breaks readily during density and viscosity analysis. The run continued through 192 hours (S9) and 216 hours (S10) where the oil showed a slight increase in the stability of the emulsification.

Figure C-0-241: NDB R1 S1 Impact of waterfall on slick - misting

Figure C-0-242: NDB R1 S6 Some oil hold-up on N side but slick still circulates

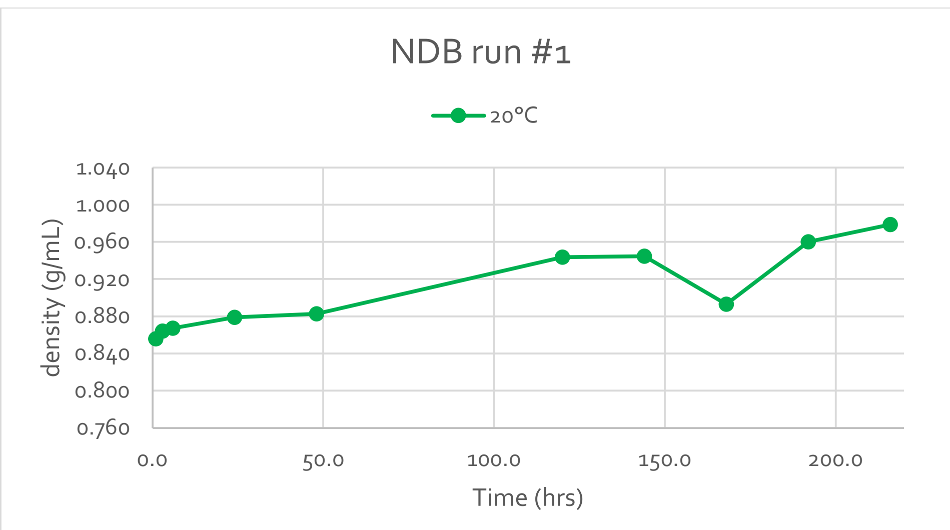


Figure C-0-243: NDB Run #1 Density vs Time

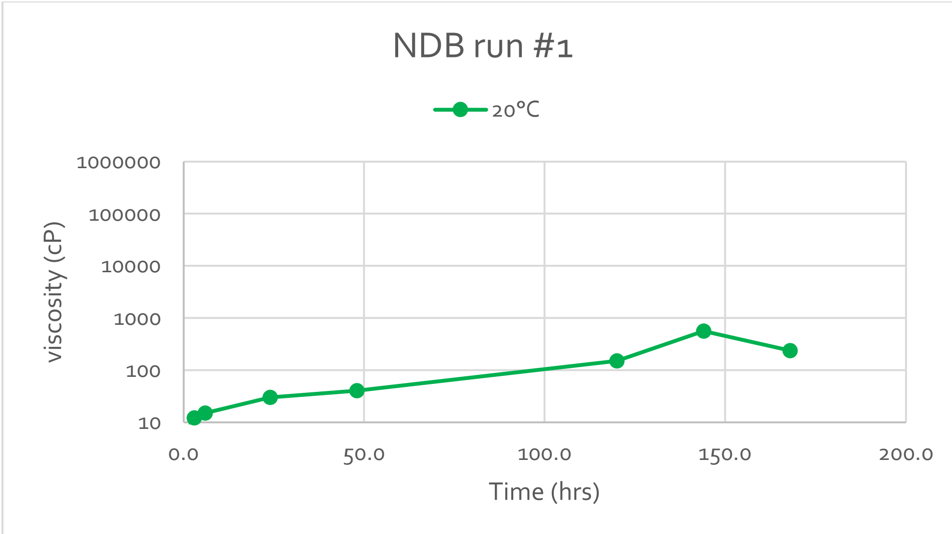


Figure C-0-244: NDB Run #1 Viscosity vs Time

C.11.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

Oil is very light and circulating nicely around the flume. The slick is being sheared into tiny droplets (mist) in the water column as of 1 hour (S1). By 24 hours (S4), it has started to hold-up on North side but oil does still circulate around the flume. At 96 hours (S6), the slick was emulsified and mostly stationed on the N side of the tank, between the thruster and fan, with occasional occurrences of oil patches- circulating. This behaviour did not change for the duration of this test which lasted until 192 hours (S10).

Figure C-0-245: NDB R2 S6 Some oil hold-up, reducing circulation

Figure C-0-246: NDB R2 S6 Emulsified oil on N side of tank

Figure C-0-247: NDB R2 S8 Oil circulation is patchy

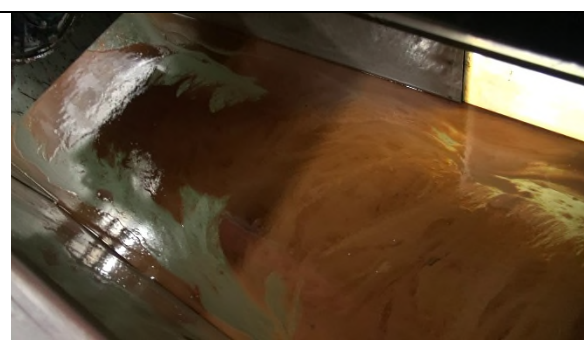


Figure C-0-248: Oil condition at end of run

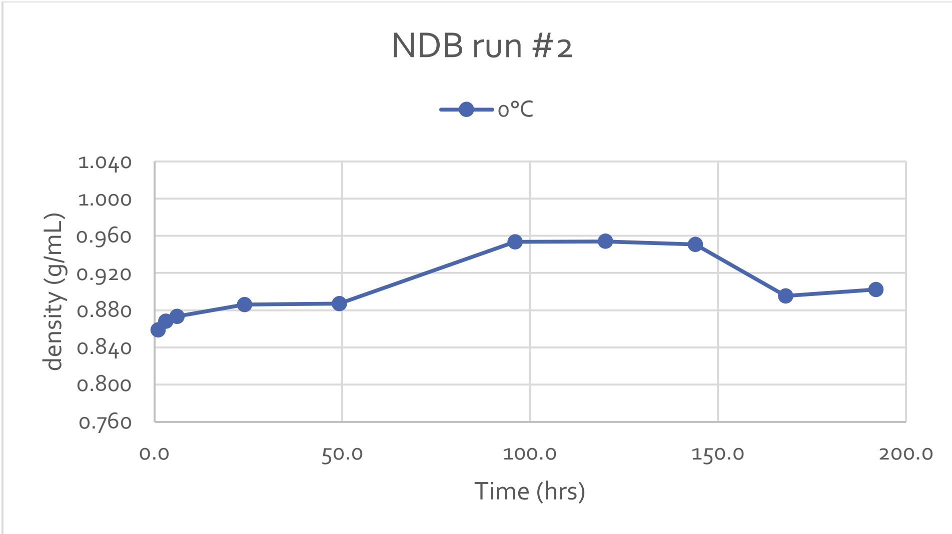


Figure C-0-249: NDB Run #2 Density vs Time

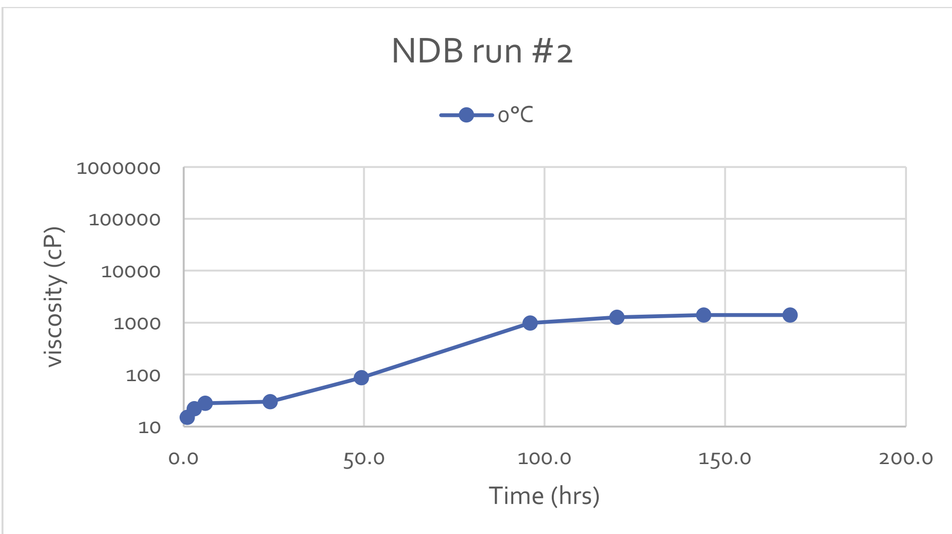


Figure C-0-250: NDB Run #2 Viscosity vs Time

C.11.3 NDB Flume Sample Water Contents

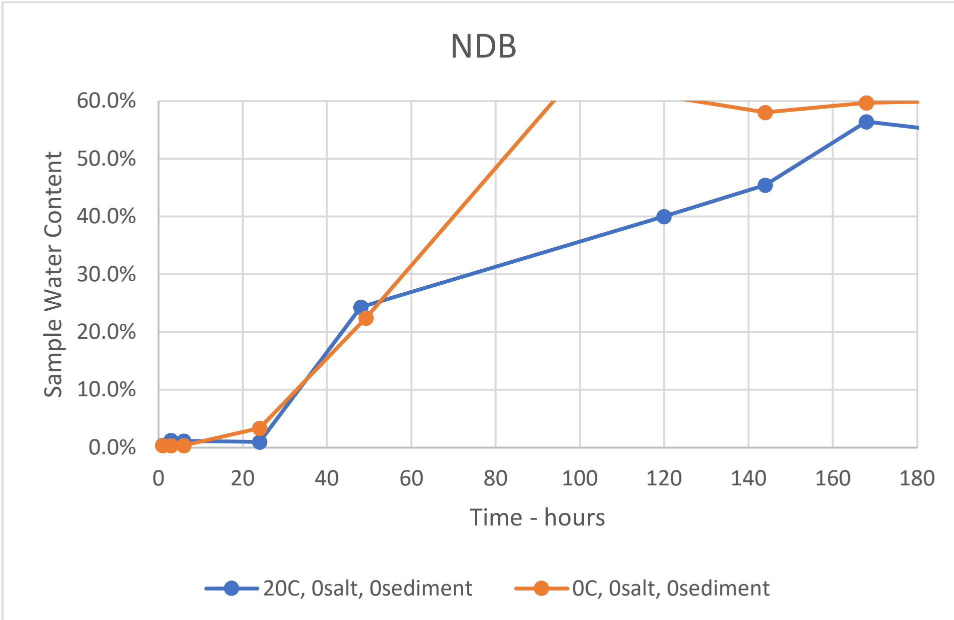


Figure C-0-251 Ultimate Water Content of NDB Flume Samples

C.11.4 NDB Flume Testing Discussion

The NDB oil was a very light oil that seemed to increase in density faster than some other oils – but did display some variability with a later reading which would indicate some possible water uptake. The viscosity remained low, never surpassing 1,500 cP for either of the two baseline runs.

C.12 SYB IN FLUME TANK

C.12.1 Run #1 (20°C, 0‰ salt, 0 ppm sediment)

At 1 hour (S1) the oil covers the tank and is circulating well. As it passes the waterfall, the slick is sheared into spherical droplets in the 1-4 mm diameter range which rise up to the surface. At 3 hours (S2), the oil is still shedding into water droplets in the 1-4 mm diameter range, and small <1 mm droplets are now being seen lower in the water column. At 6 hours (S3), the slick is sheared into non-spherical droplets and there are now many small diameter droplets lower in the water column. By 48 hours (S5), the oil has continued to weather and the oil is shearing into non-spherical droplets and stringers. Circulation continued albeit at a diminishing rate. Hold-up is apparent on the North side between the thruster and fan.

Figure C-0-252: SYB R1 S1 Spherical droplets approx 1-4 mm

Figure C-0-253: SYB R1 S1 Circulation of oil

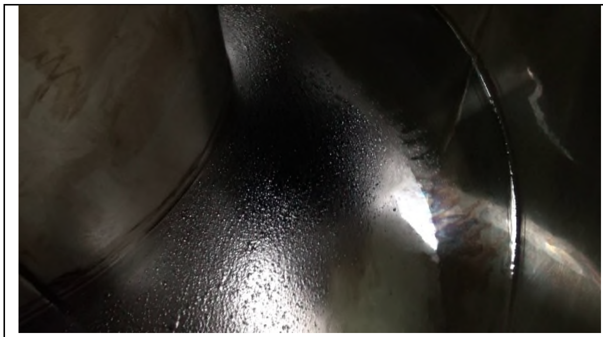


Figure C-0-254: SYB R1 S8 Diminished circulation of oil slick

Figure C-0-255: SYB R1 S8 Oil hold-up on N side of tank

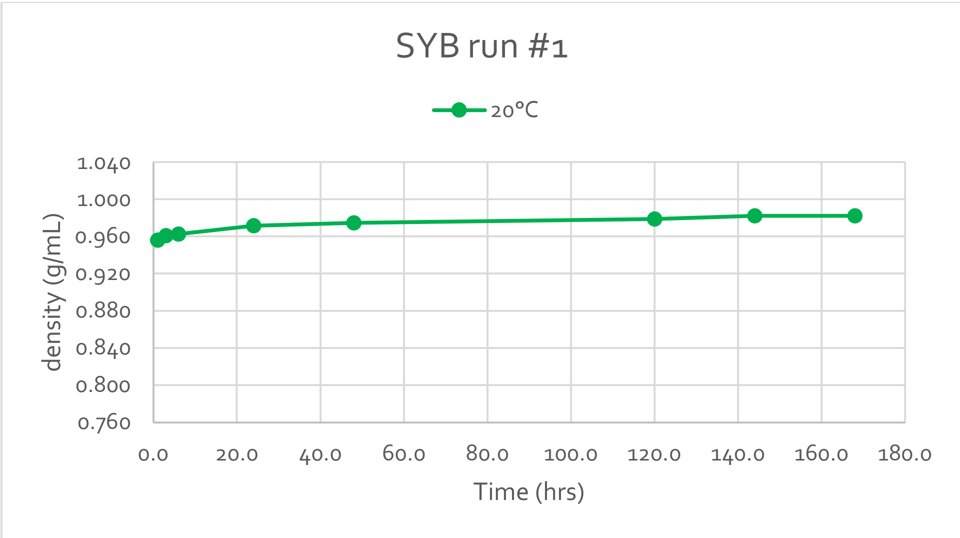


Figure C-0-256: SYB Run #1 Density vs Time

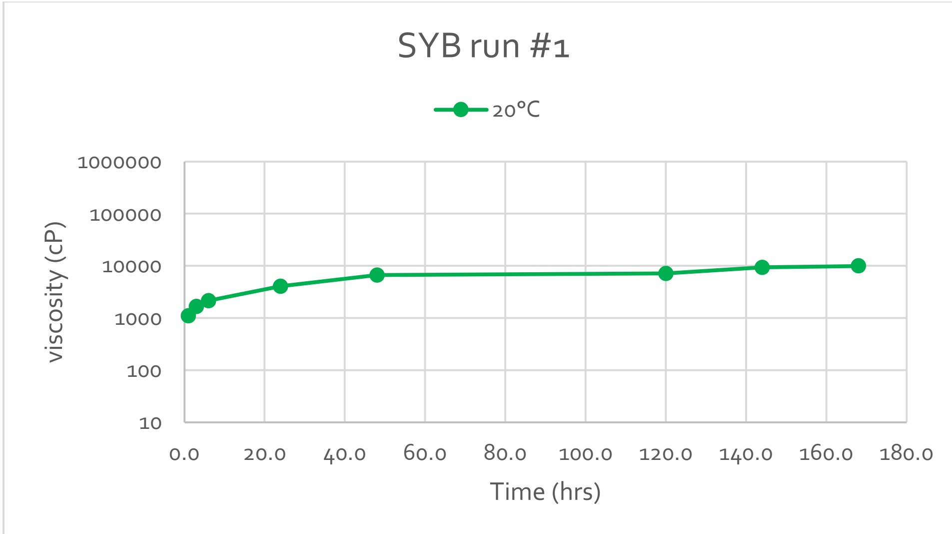


Figure C-0-257: SYB Run #1 Viscosity vs Time

C.12.2 Run #2 (0°C, 0‰ salt, 0 ppm sediment)

Oil did not circulate initially with the thruster engaged so it was cycled off temporarily. At 1 hour (S1),the oil is noticeably viscous shedding streamers under the waterfall. By 3 hours (S2), the circulation has dropped off with most of the oil being held-up on the N side. No droplets have been seen under the waterfall. At 6 hours (S3) after the thruster was cycled, large patches of oil were impacted by the waterfall shearing large stringer blobs. As the oil weathered, the impact of the waterfall diminished. From 72 hours (S6), there was a diminished circulation of the oil slick which continued through the end.

Figure C-0-258: SYB R1 S1 Streamers and droplets forming

Figure C-0-259: SYB R2 S1 Good oil coverage and circulation

Figure C-0-260: SYB R2 S3 Large stringers from waterfall impacts

Figure C-0-261: SYB R2 S10 Oil hold-up at end of run

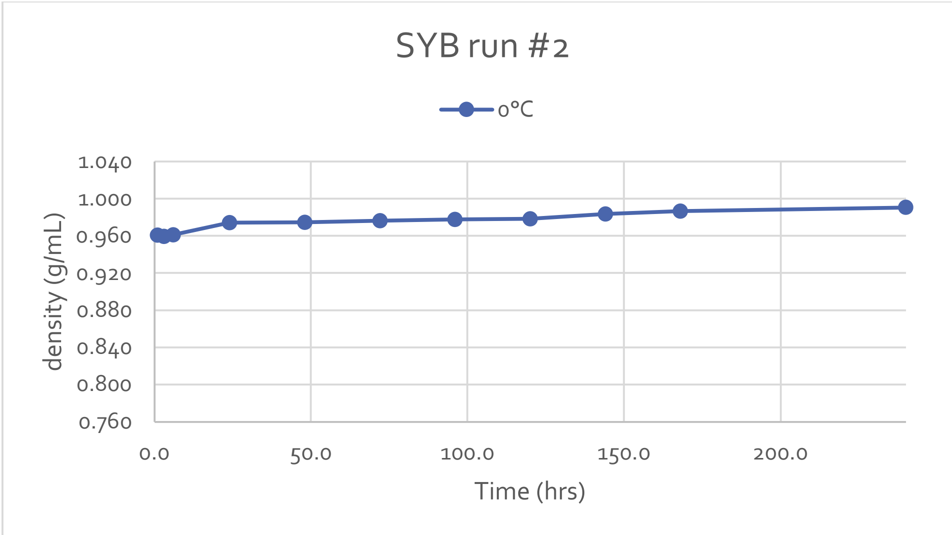


Figure C-0-262: SYB Run #2 Density vs Time

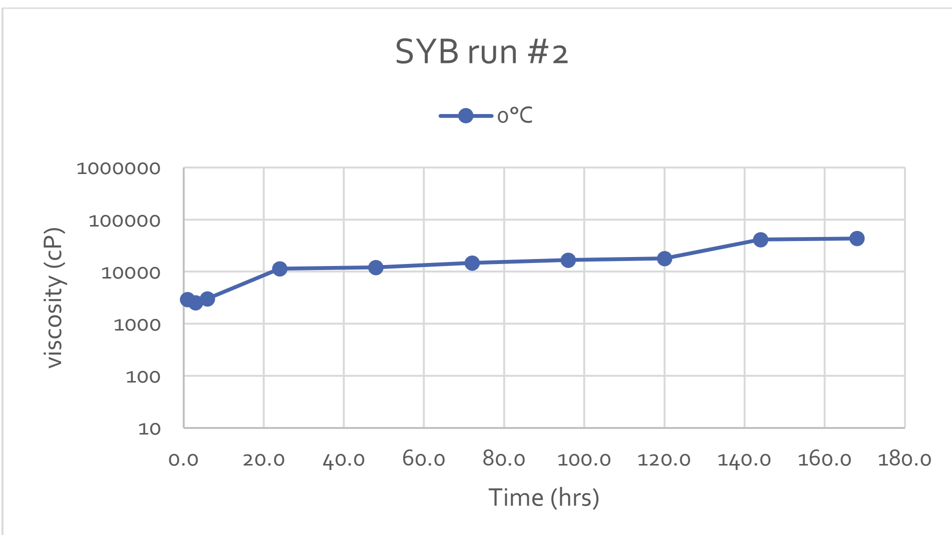


Figure C-0-263: SYB Run #2 Viscosity vs Time

C.12.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

Oil starts off viscous at 1 hour (S1) with constrained circulation. Oil circulation slows down over time. By 48 hours (S5), the oil is circulating in drips and drabs, while the bulk oil is held-up with a thin sheen turning brown. This repeat in 120 hours (S6) and again at 144 hours (S7).

Figure C-0-264: SYB R3 S1 Constrained circulation

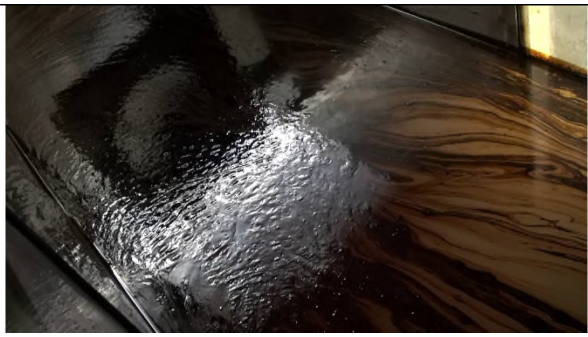


Figure C-0-265: SYB R3 S1 Oil hold-up between thruster and fan

Figure C-0-266: SYB R3 S5 Diminished circulation

Figure C-0-267: SYB R3 S7 Oil hold-up at end of run

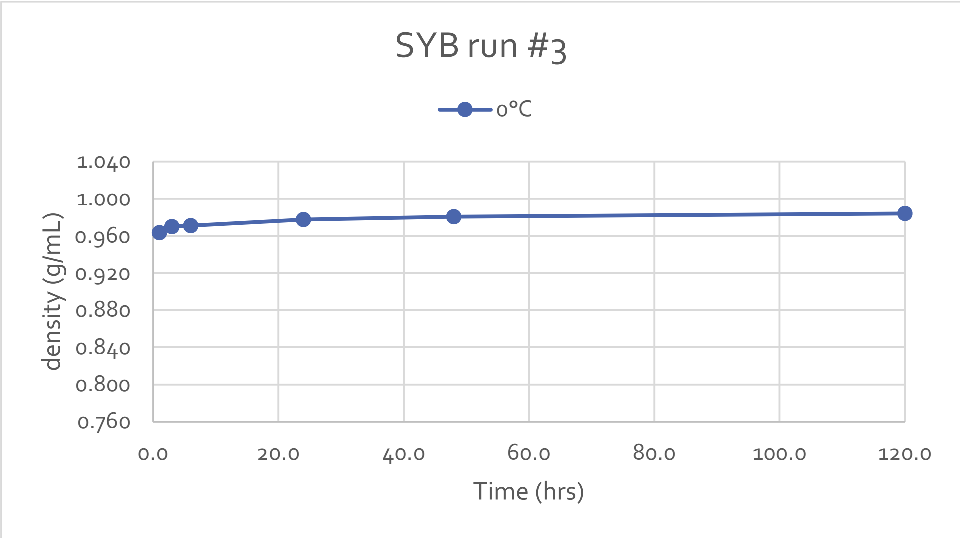


Figure C-0-268: SYB Run #3 Density vs Time

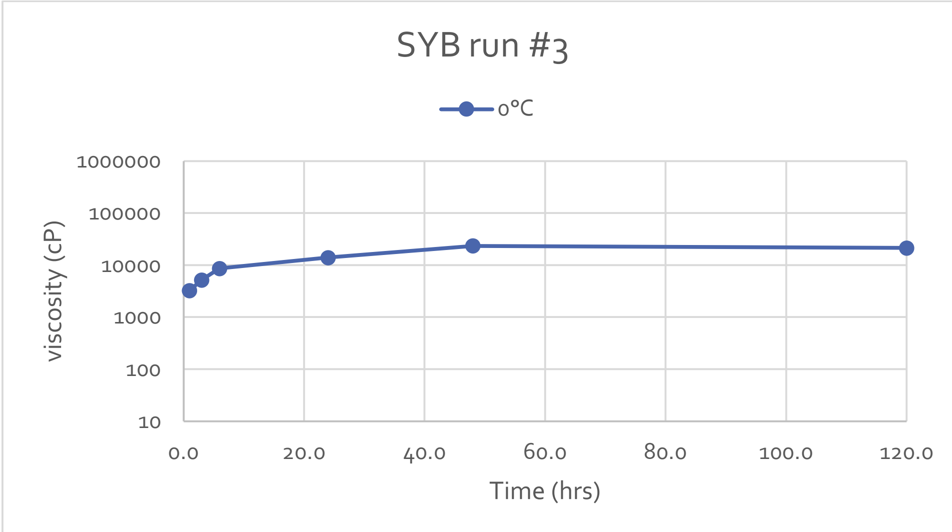


Figure C-0-269: SYB Run #3 Viscosity vs Time

C.12.4 Run #4 (20°C, 35‰ salt, 1000 ppm sediment)

Oil starts off moderately viscous at 1 hour (S1) but circulates. As the oil weathers, the hold-up keeps oil between the thruster and the fan on the N side. This changed at 24 hours (S4) when the oil was discovered to have shifted around the tank to the waterfall area. The oil stayed in this area at 48 hours (S5) as well, but migrated back to the N side during the 72 hour (S6) sampling.

Figure C-0-270: SYB R4 S1 Initial oil slick

Figure C-0-271: SYB Oil collecting around waterfall

Figure C-0-272: SYB R4 S6 Oil back along N side

Figure C-0-273: SYB R4 S8 End of run

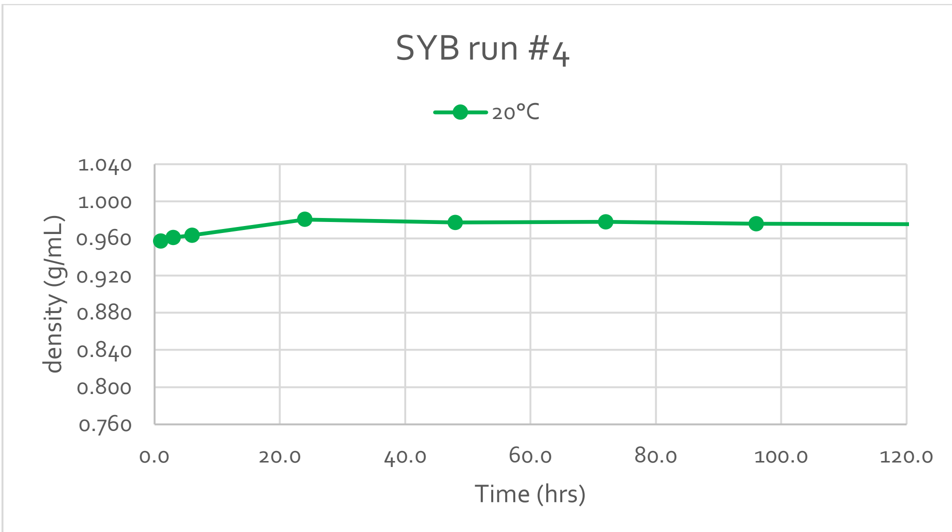


Figure C-0-274: SYB Run #4 Density vs Time

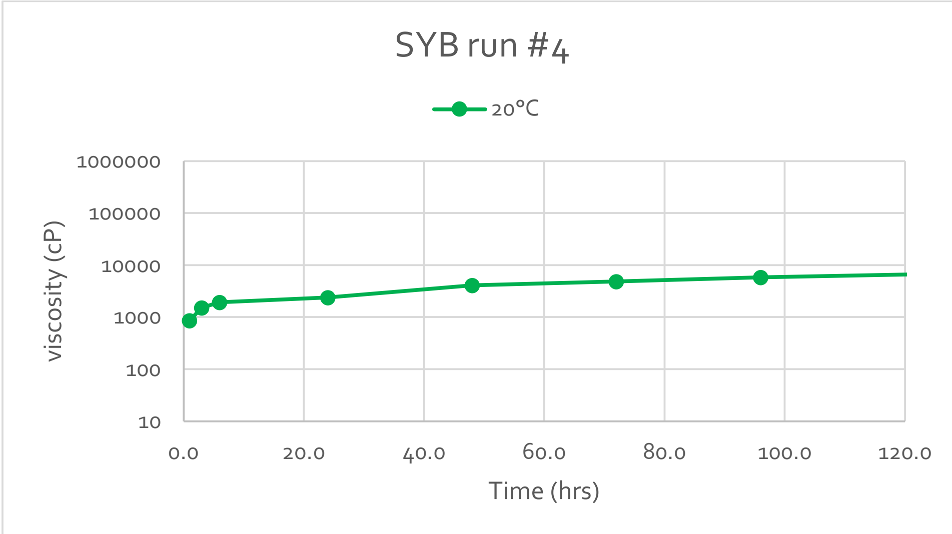


Figure C-0-275: SYB Run #4 Viscosity vs Time

C.12.5 SYB Flume Sample Water Contents

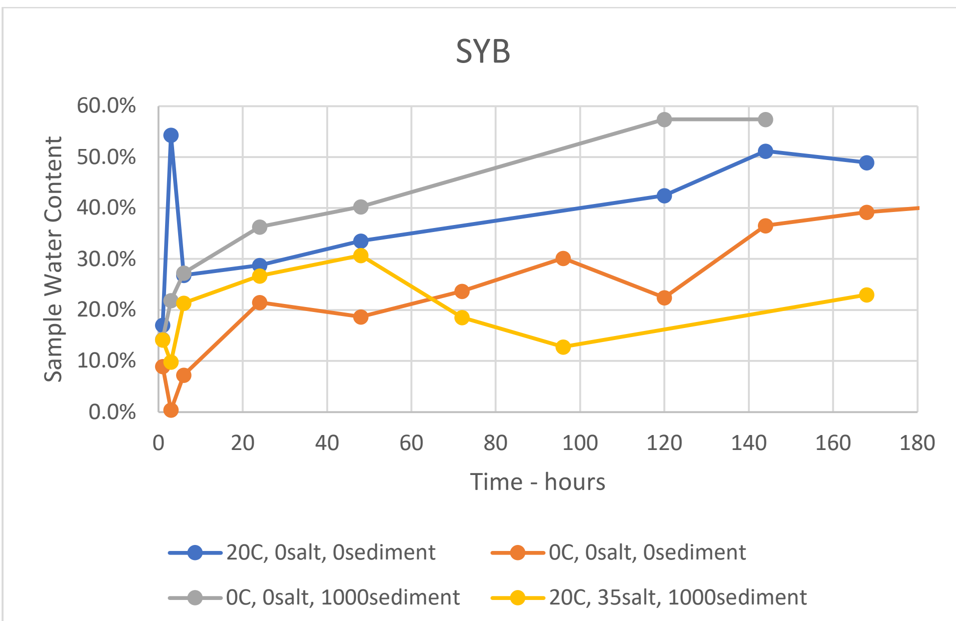


Figure C-0-276 Ultimate Water Content of SYB Flume Samples

C.12.6 SYB Flume Testing Discussion

This oil weathered slowly over the course of the two baseline runs. It did not reach a density of 1.000 g/mL during any run (even in a simulated marine environment). Long term testing (up to 240 hours in the flume tank) showed slow and stable weathering characteristics. Viscosity measurements stayed below 50,000 cP for all of the runs.

C.13 SYN IN FLUME TANK

C.13.1 Run #1 (0°C, 0‰ salt, 0 ppm sediment)

Oil starts off very light and is held up at the N. side. Thruster is cycled to allow oil to circulate after 1 hour (S1). By 6 hours (S3), the slick impacted by the waterfall forms small (<1 mm diameter) droplets that mist into the water column and move past the window in addition to slightly larger droplets (~1 mm diameter) that resurface quickly. By 72 hours (S6), the oil is actually circulating better than earlier in the test. The oil is becoming emulsified. There is some hold-up on the N. side. At 96 hours (S7), there is a thin sheen on the top of the flume circulating. Water column remains clear, with some very fine droplets (much less than 1 mm diameter).

Figure C-0-277: SYN R1 S3 Slick impacted by waterfall very fine to 1mm diameter droplets

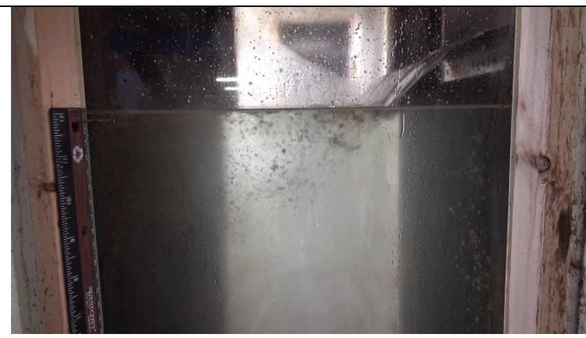


Figure C-0-278: SYN R1 S5 Oil droplets range from 1-3 mm diameter

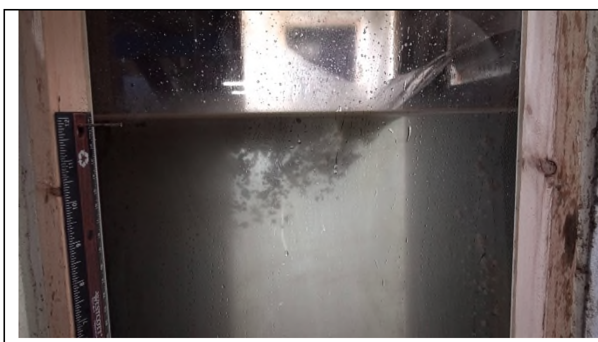


Figure C-0-279: SYN R1 S5 Large slug of oil hits waterfall results in semi-spherical droplets (oil still has low viscosity)

Figure C-0-280: SYN R1 S8 Oil hold-up limits circulation to thin sheen

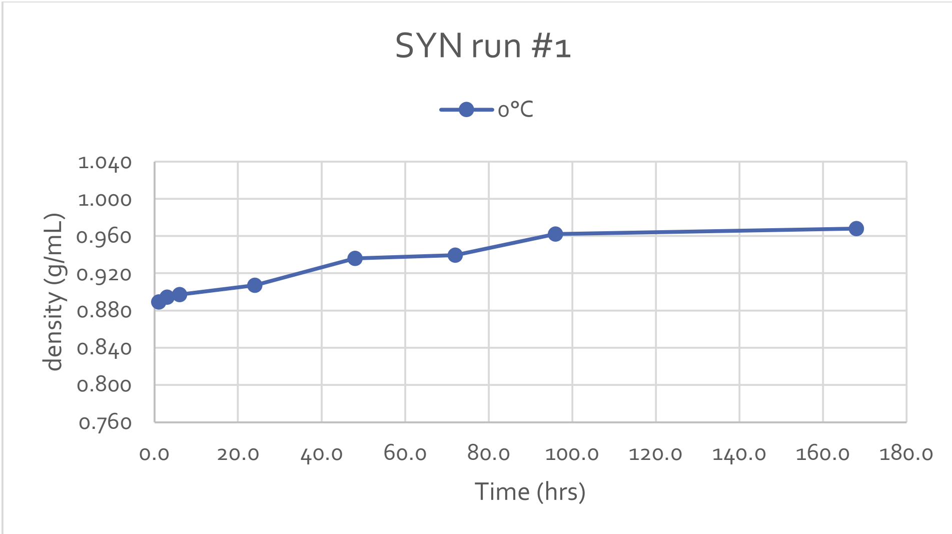


Figure C-0-281: SYN Run #1 Density vs Time

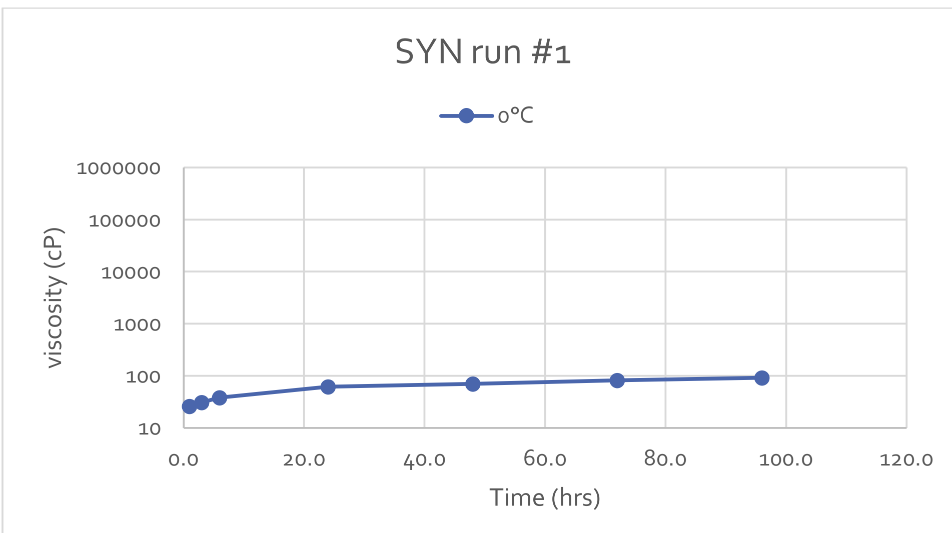


Figure C-0-282: SYN Run #1 Viscosity vs Time

C.13.2 Run #2 (20°C, 0‰ salt, 0 ppm sediment)

Oil is light and flows nicely around tank at 1 hour (S1). Some hold-up is occurring which restricts the flow rate, but modulating the thruster enables more oil to circulate. Oil sheds into very tiny droplets that mist into the water. At 6 hours (S3), the oil continues to circulate well. The oil continues to have very low viscosity and does not stick to any walls. At 48 hours (S5), the oil behaviour has not changed. Water column has become very slightly cloudy which increases through 144 hours (S7). Oil continues to circulate but maintains low viscosity. Circulation slows at the end of the run at 168 hours (S8) which leads to less oil dispersing into the water column and consequently the column clears a bit.

 *Figure C-0-283: SYN R2 S1 Beginning of test run*	 *Figure C-0-284: SYN R2 S5 Oil circulating in non-continguous patches on the water surface*
 *Figure C-0-285: SYN R2 S7 Water column beginning to get cloudy*	 *Figure C-0-286: SYN R2 S8 Higher hold-up leads to less dispersing into column which leads to clearing of column*

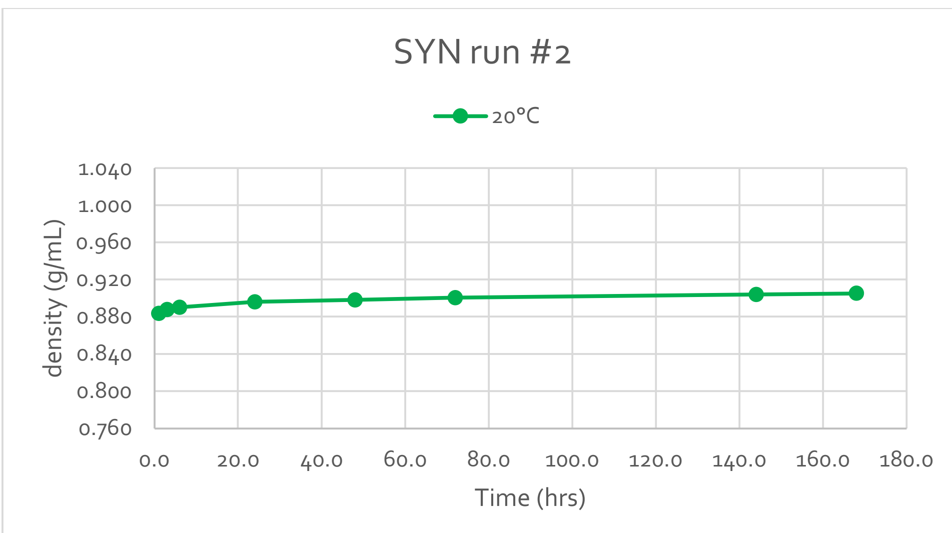


Figure C-0-287: SYN Run #2 Density vs Time

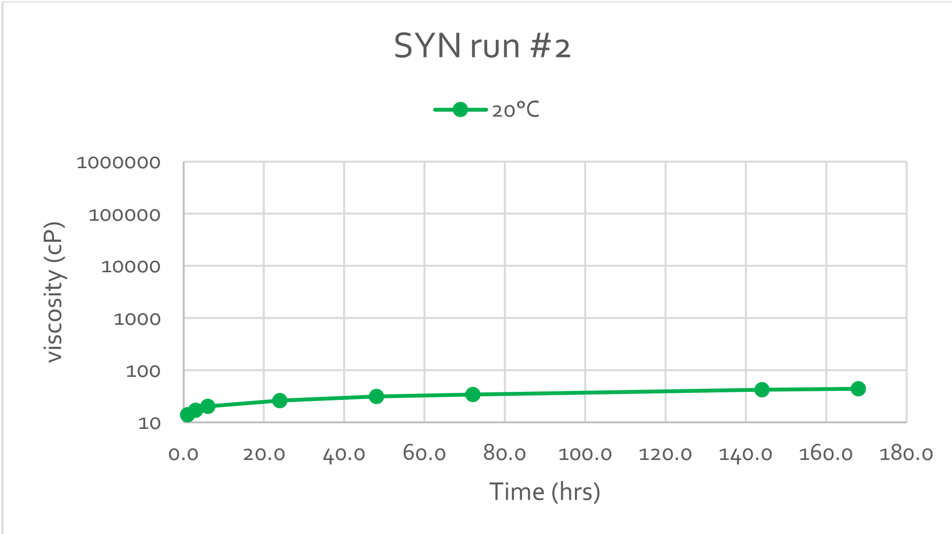


Figure C-0-288: SYN Run #2 Viscosity vs Time

C.13.3 Run #3 (20°C, 0‰ salt, 0 ppm sediment)

This run was a repeat of Run #2. Oil starts off light in colour and viscosity. At 1 hour (S1), the oil slick is sheared by the waterfall into tiny droplets that disperse into the column. Due to the low viscosity, the behaviour does not change over the first few sampling points through 24 hours (S4). There is some hold-up at 48 hours (S5) and tiny droplets are seen in the water column, but oil is still circulating. At 144 hours (S6), the water column has become slightly cloudy. There are few small droplets in the water column, and the oil, which looks like an unstable emulsion, is still circulating.

Figure C-0-289: SYN R3 S1 Column is clear, oil is very fluid

Figure C-0-290: SYN R3 S6 Oil still circulating at end of test

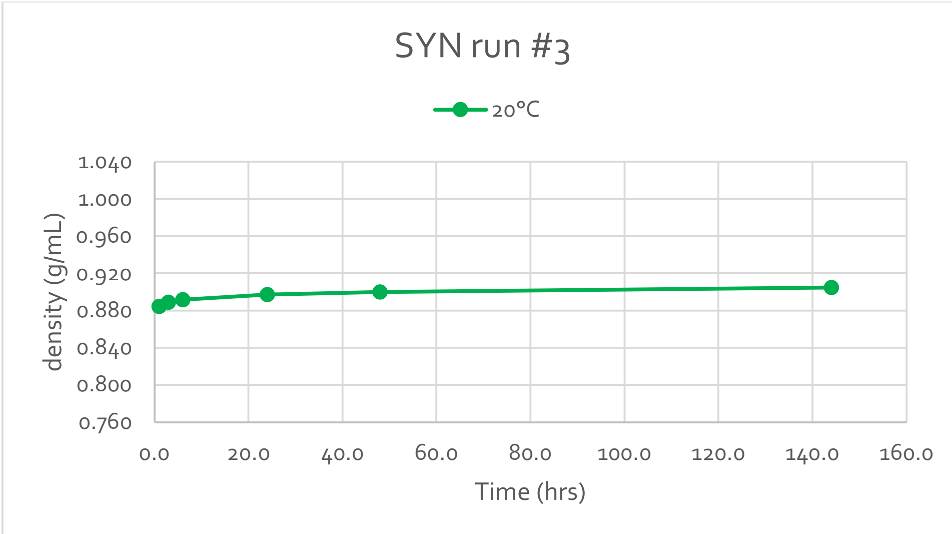


Figure C-0-291: SYN Run #3 Density vs Time

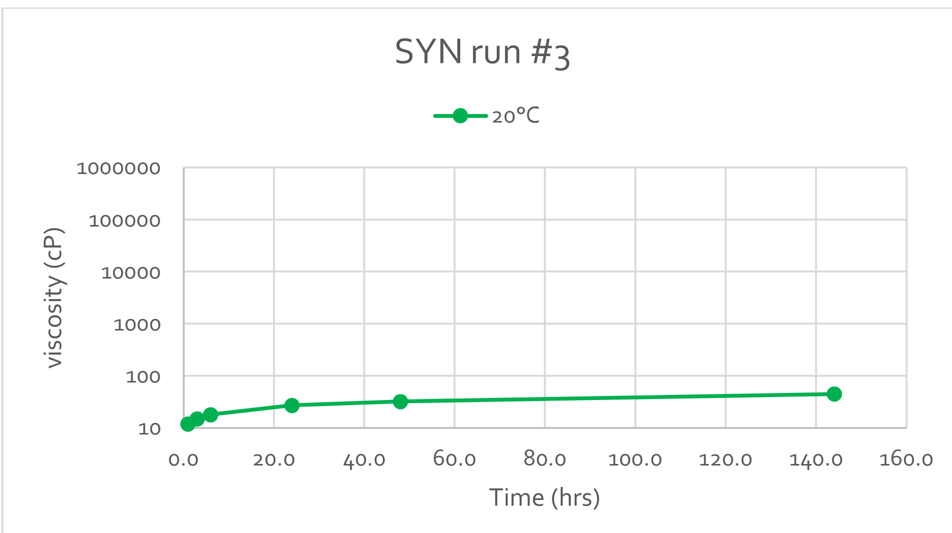


Figure C-0-292: SYN Run #3 Viscosity vs Time

C.13.4 SYN Flume Sample Water Contents

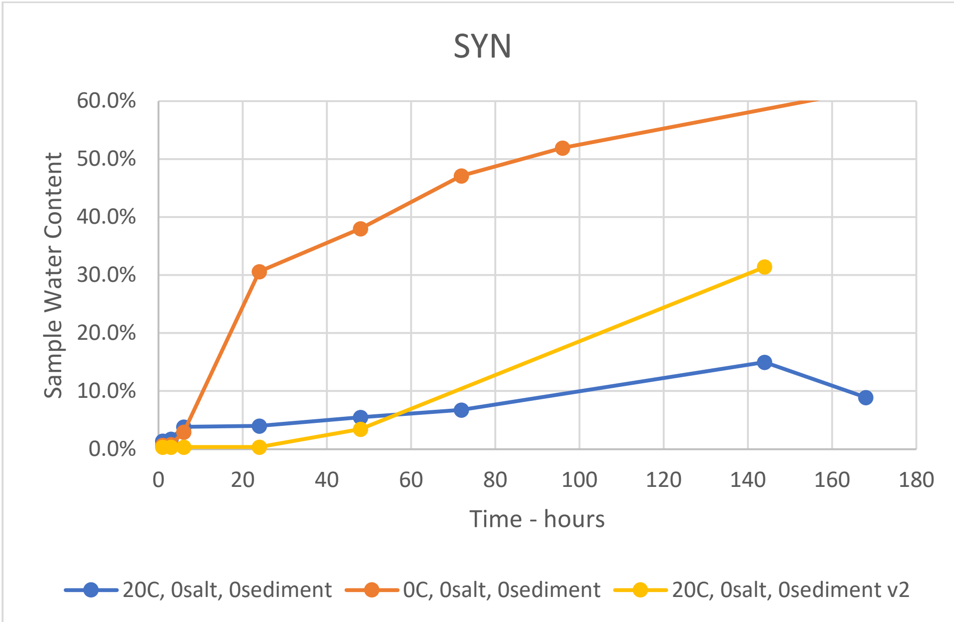


Figure C-0-293 Ultimate Water Content of SYN Flume Samples

C.13.5 SYN Flume Testing Discussion

The SYN oil started light and weathered very slowly. Density changes during the 0°C baseline run were moderate, but the density measurements barely changed for the 20°C run. Viscosities started light and stayed light for all of the runs, never surpassing 100 cP when measured at the operating temperatures of the runs.

C.14 WCS IN FLUME TANK

C.14.1 Run #1 (0°C, 0‰ salt, 0 ppm sediment)

Oil starts at a moderately high viscosity due to the low temperature. At the first sampling point 1 hour (S1), the slick is pushed into the water column as a large blob, as stringers, or a combination of the two, then resurfacing quickly. By 24 hours (S4), the oil has increased in viscosity and is held up on the N side. At 96 hours (S6), the oil is held up on the North side – oil seems viscous but breaks apart. Oil is now very viscous and resistant to movement.

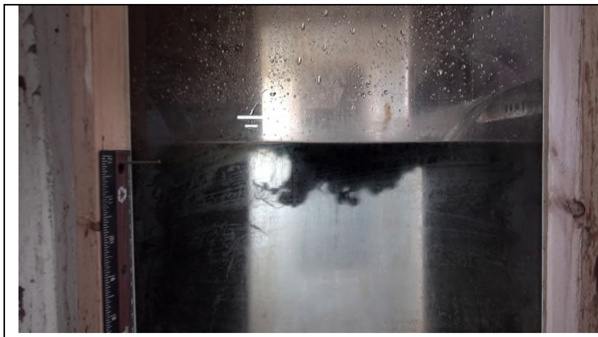


Figure C-0-294: WCS R1 S1 Viscous oil - limited shearing from waterfall

Figure C-0-295: Oil still generates some streamers

Figure C-0-296: WCS R1 S8 Hold-up on N side

Figure C-0-297: WCS R1 S9 Final condition of oil

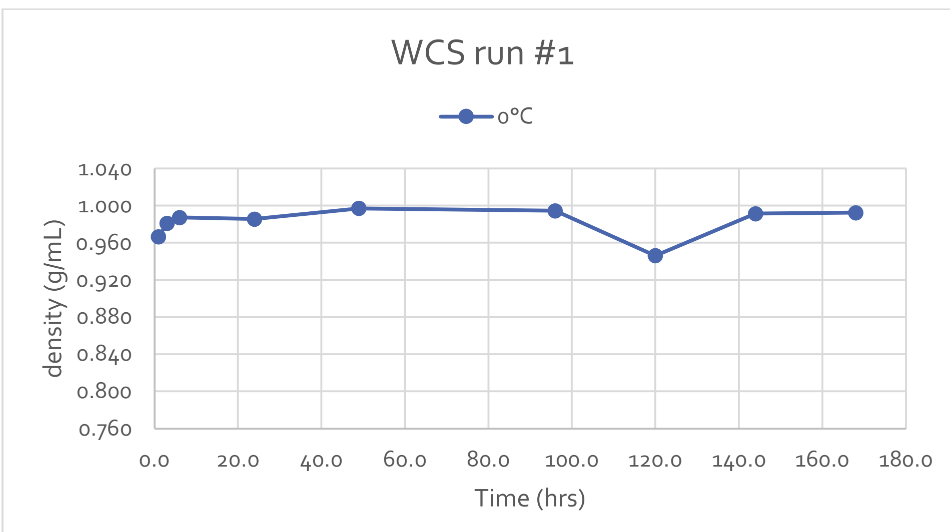


Figure C-0-298: WCS Run #1 Density vs Time

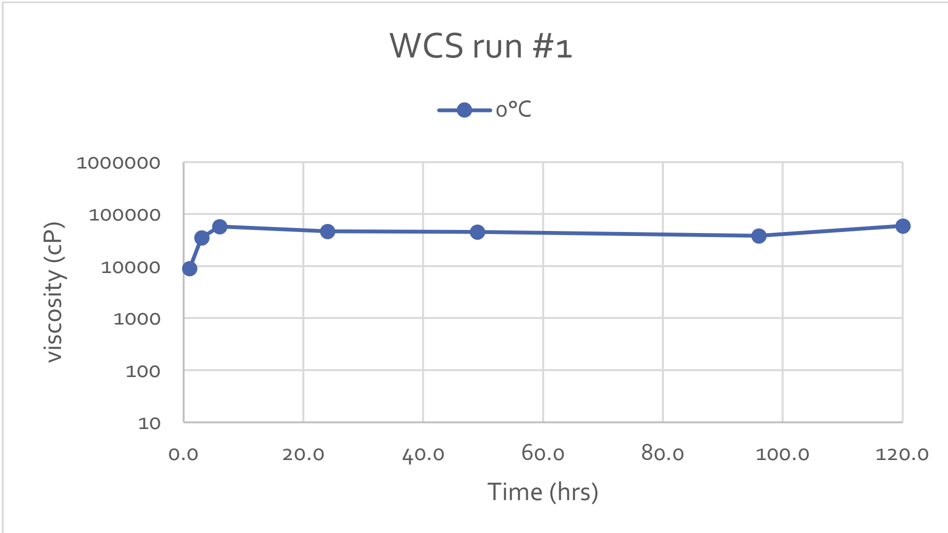


Figure C-0-299: WCS Run #1 Viscosity vs Time

C.14.2 Run #2 (20°C, 0‰ salt, 0 ppm sediment)

Oil starts fairly viscous, shedding to blobby streamers as it passes the waterfall at 1 hour (S1). At 3 hours (S2), the oil also sheds into larger 10 – 12 mm diameter spherical shapes which float back to the surface. Some spherical shapes in the 1 – 5 mm range are sparsely distributed throughout the water column. At 6 hours (S3), the oil has thickened up a bit. Shedding from the waterfall quickly rises back to the surface. At 24 hours (S4), the oil is circulating in a small stream that is still impacted by the waterfall. There is some hold-up along the N side of the tank. At 96 hours (S6), the oil is circulating in small patties which get pushed under at the waterfall but then resurface. By 120 hours (S7), the oil is stuck to the inside wall at the E side curve. Some large spherical shapes are still circulating. This continues through 144 hours (S8) and the end of the run.

Figure C-0-300: WCS R2 S1 Blobs and streamers already

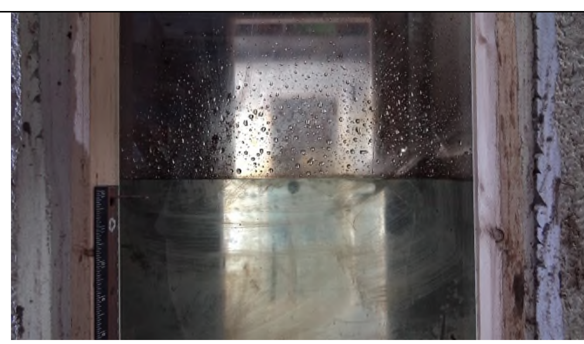


Figure C-0-301: WCS R2 S2 Large spherical shape from waterfall

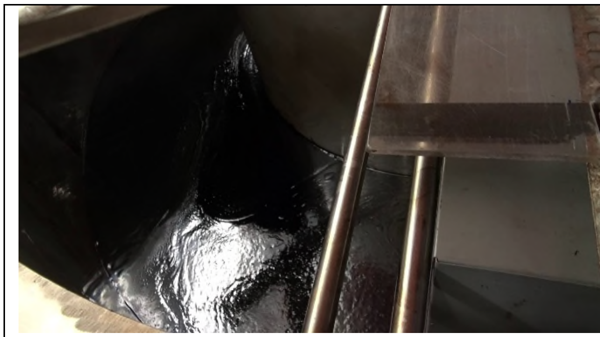


Figure C-0-302: WCS R2 S8 Oil hold up past fan

Figure C-0-303: WCS R2 S9 Final sampling

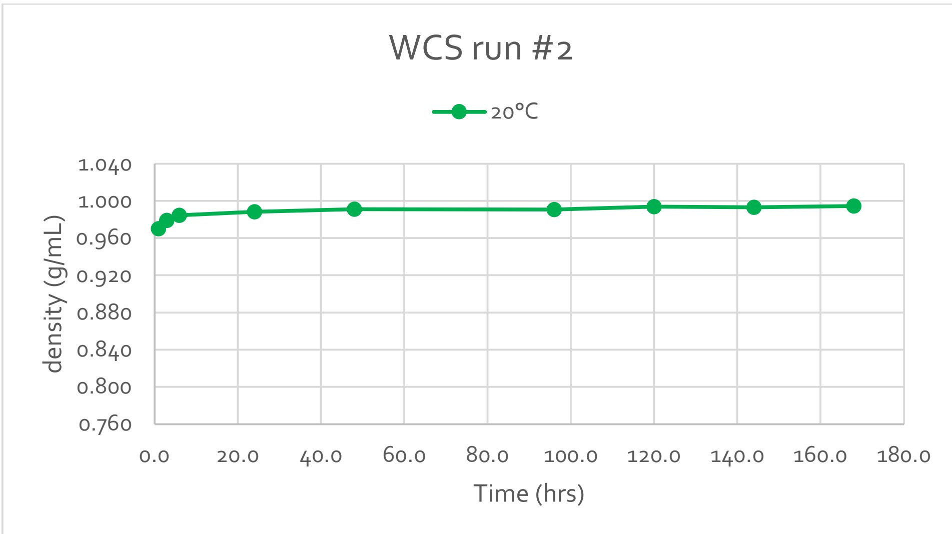


Figure C-0-304: WCS Run #2 Density vs Time

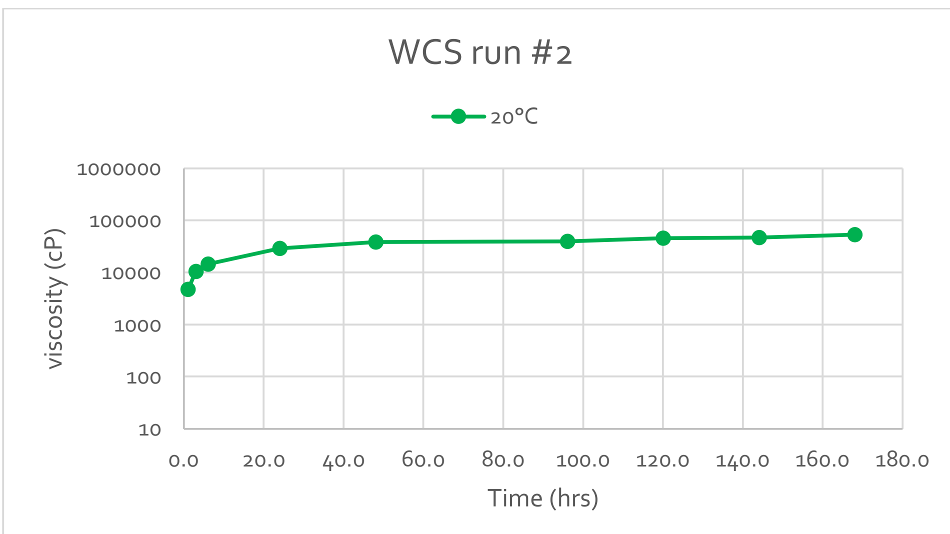


Figure C-0-305: WCS Run #2 Viscosity vs Time

C.14.3 Run #3 (0°C, 0‰ salt, 1000 ppm sediment)

The oil starts off at a moderately high viscosity but still circulates over the first few sampling points. By 24 hours (S4), the oil has become more viscous which impedes some movement within the flume tank. Oil continues to weather as measured viscosity slowly increases during the extended run time for this run. Density did not reach 1.00 g/mL during this run.

Figure C-0-306: WCS R3 S2 Oil hold up between thruster and fan

Figure C-0-307: WCS R3 S2: Oil migrating to trailing edge of slick

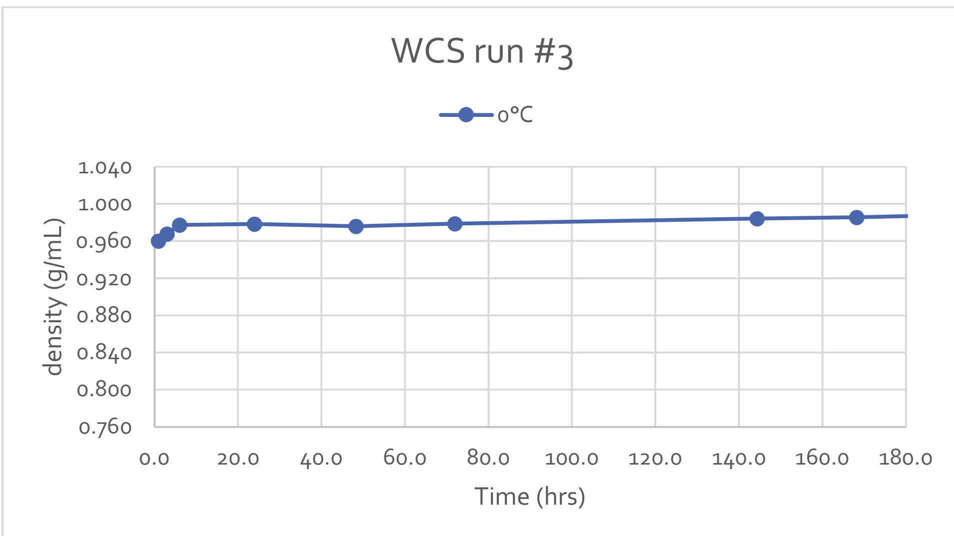


Figure C-0-308: WCS Run #3 Density vs Time

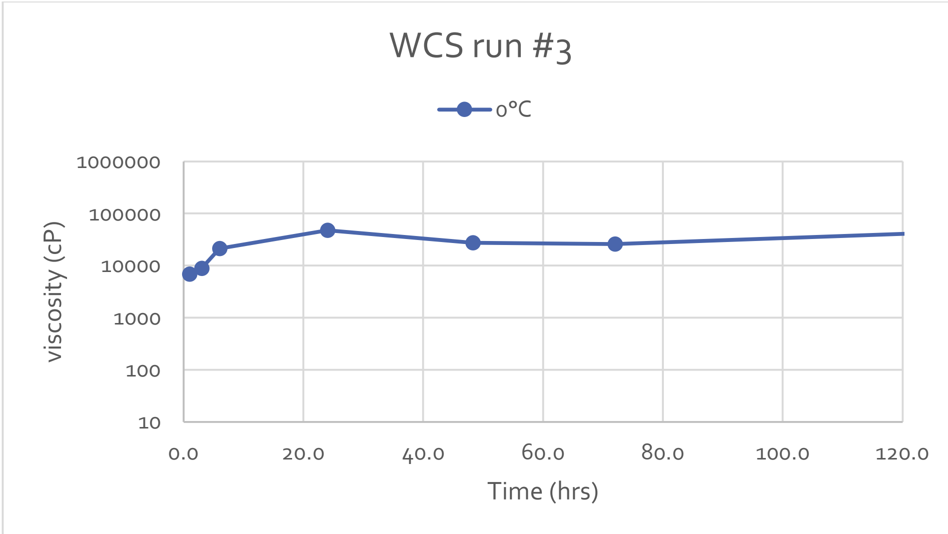


Figure C-0-309: WCS Run #3 Viscosity vs Time

C.14.4 Run #4 (20°C, 0‰ salt, 1000 ppm sediment)

Quite a bit of circulation of oil with thrusters on at the 1 hour mark (S1) although some hold-up is occurring along the N side. Oil continues to impact the inner wall at 3 hours (S2) as the circulation slows. This process continues through 48 hours (S5) when the circulation becomes sporadic. The circulation does continue through 120 hours (S6) but the amount of oil on the surface of the flume seems to be reduced. At 144 hours (S7), there are streaks forming a "bathtub ring" around the tank with a small slick and some neutrally buoyant slugs of oil circulating below the surface.

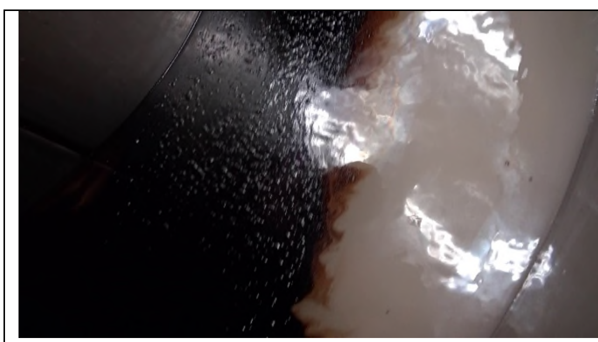


Figure C-0-310 WCS R4 S1 Fairly good circulation

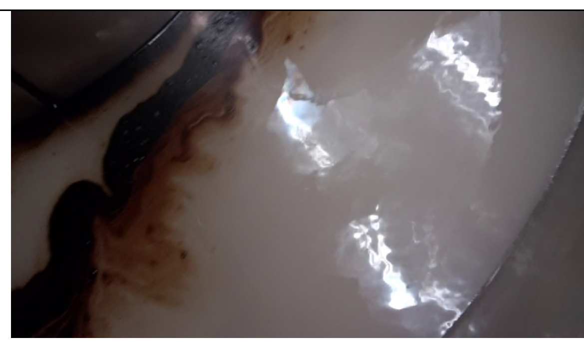


Figure C-0-311 WCS R4 S2 Circulation slowing with thruster on

Figure C-0-312 WCS R4 S6 Remaining oil circulating

Figure C-0-313 WCS R4 S7 Slugs of neutrally buoyant oil through water column

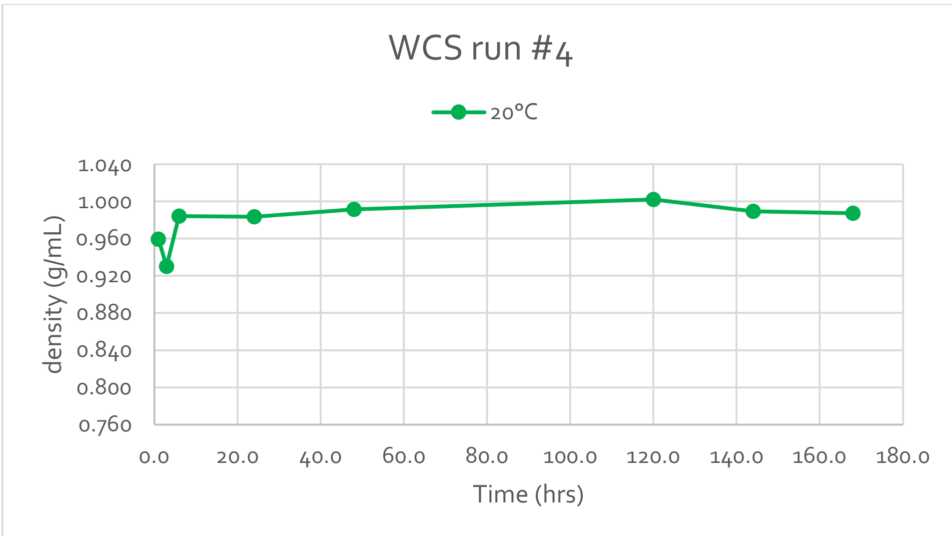


Figure C-0-314: WCS Run #4 Density vs Time

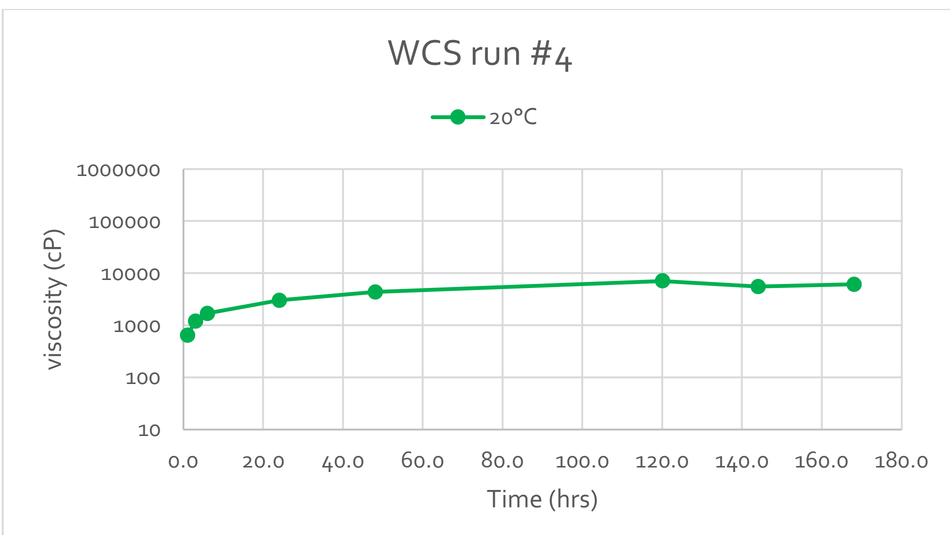


Figure C-0-315: WCS Run #4 Viscosity vs Time

C.14.5 Run #5 (20°C, 35‰ salt, 1000 ppm sediment)

Oil spreads out covering entire surface of flume tank and flows freely at 1 hour (S1). At 3 hours (S2), the oil gains some viscosity as flow patterns are more obvious on the surface and the flow is more broken up, or fragmented. By 24 hours (S4), the oil no longer completely covers the N side surface, and circulation is impacted as the oil becomes more viscous and adheres to the sidewalls, slowing movement. By 120 hours (S6), the oil is mostly stuck to the side wall of the tank at the waterline, although a portion still circulates. The run ends at 144 hours (S7) with minimal changes to oil behaviour.

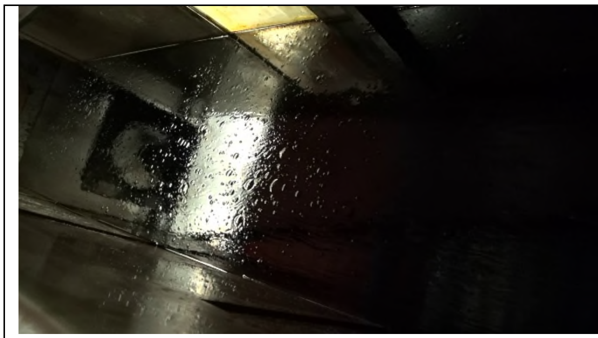


Figure C-0-316: WCS R5 S1 Oil spreads over flume surface

Figure C-0-317: WCS R5 S4 Circulation of oil into waterfall region

Figure C-0-318 WCS R5 S6 Hold-up on N side

Figure C-0-319 WCS R5 S6 Oil along E side wall

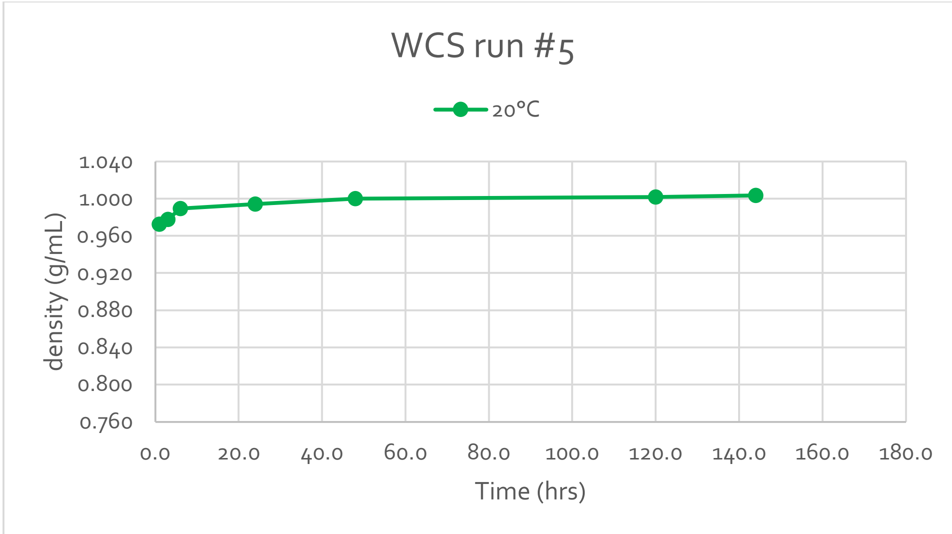


Figure C-0-320: WCS Run #5 Density vs Time

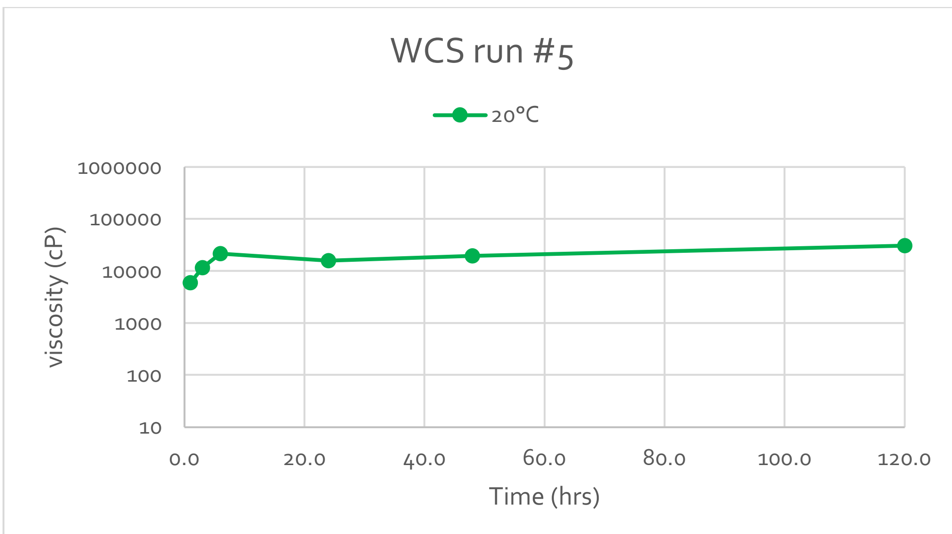


Figure C-0-321: WCS Run #5 Viscosity vs Time

C.14.6 Run #6 (20°C, 0‰ salt, 1000 ppm sediment)

Waterfall pump was replaced at the beginning of the run. At 1 hour (S1), the oil is moderately viscous as the oil moves readily around the tank. At 3 hours (S2), oil continues to circulate well. Oil crossing the waterfall is sheared into stringers which seem to resurface quickly (visibility is limited to oil near the windows or surface). The oil changes by the 24 hour mark (S4). Oil is circulating in discrete patties (versus a cohesive slick) which continues until the end of the run, at 191 hours (S10).

Figure C-0-322: WCS R6 S1 Impacts of waterfall

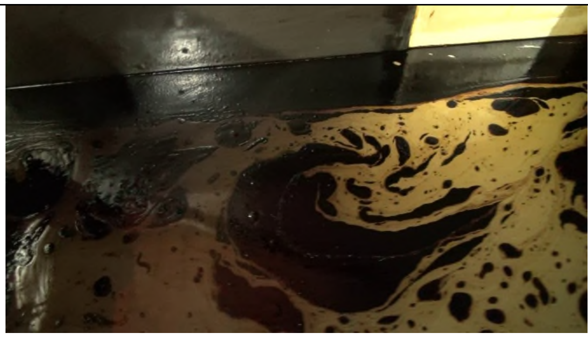


Figure C-0-323: WCS R6 S4 Oil along N. side

Figure C-0-324: WCS R6 S7 Weathered oil on N. side of tank

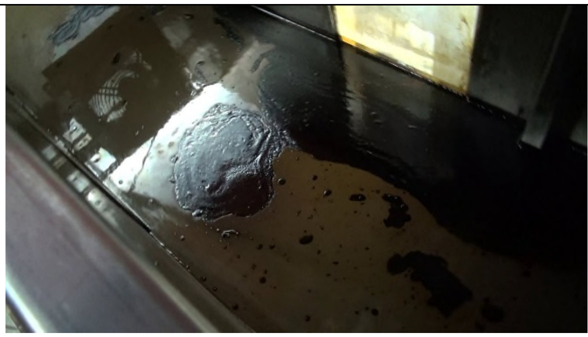


Figure C-0-325: WCS R6 S9 Oil continues to circulate

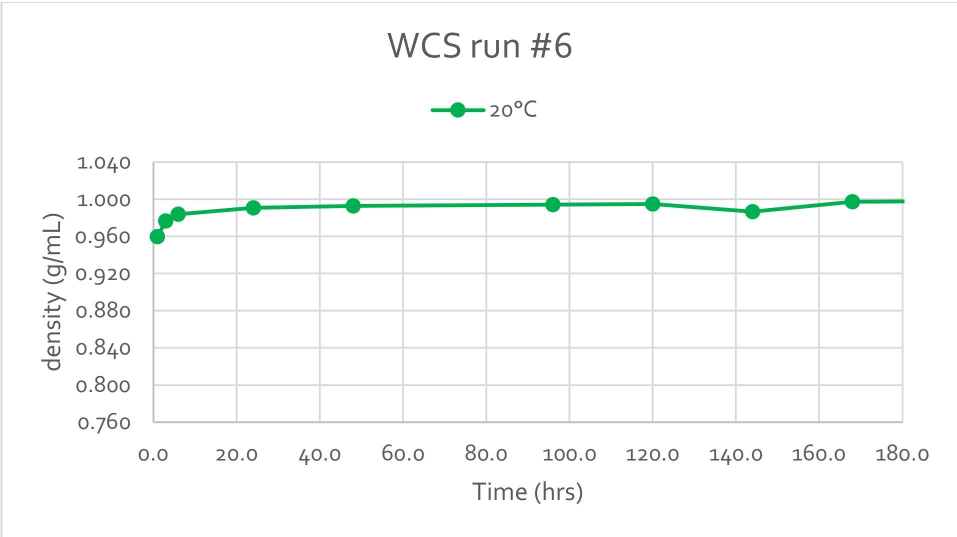


Figure C-0-326: WCS Run #6 Density vs Time

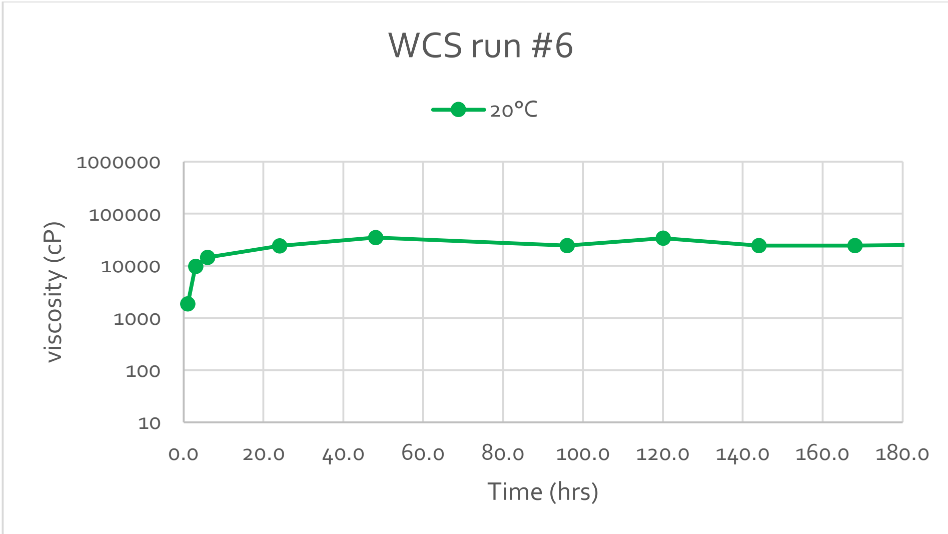


Figure C-0-327: WCS Run #6 Viscosity vs Time

C.14.7 WCS Flume Sample Water Contents

Figure C-0-328 Ultimate Water Content of WCS Flume Samples

C.14.8 WCS Flume Testing Discussion

The WCS oil density measurements approached 1.000 g/mL for the baseline runs but did not surpass it even at the extended time of 168 hours. One measurement during a run at 20°C with 1000 ppm of sediment did surpass 1.000 g/mL at the 120 hour mark, but the subsequent measurement was below that value and no submergence was observed. Viscosity stayed reasonable with values reaching near 55,000 cP during a 20°C run, and 78,100 cP during a 0°C run with sediment.

APPENDIX D – FLUME TANK DENSITY AND VISCOSITY DATA

Table D - 1: AHS Runs

AHS run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-06-21	10:00 AM	Time (hrs	g/mL	cP	SR
R1	S1	2017-06-21	11:00 AM	1.0	0.98204	23200	@100s-1
	S2	2017-06-21	1:00 PM	3.0	0.99412	32100	@100s-1
sample	S3	2017-06-21	4:00 PM	6.0	1.00342	72100	@100s-1
	S4	2017-06-22	10:00 AM	24.0	1.00961	310000	@100s-1
	S5	2017-06-23	10:00 AM	48.0	1.01300	347000	@100s-1

AHS run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-02-08	10:10 AM	Time (hrs	g/mL	cP	SR
R2	S1	2018-02-08	11:10 AM	1.0	0.95468	2450	@25s-1
	S2	2018-02-08	1:10 PM	3.0	0.96031	3900	@25s-1
sample	S3	2018-02-08	4:10 PM	6.0	0.96599	20500	@25s-1
	S4	2018-02-09	10:10 AM	24.0	0.97929	47100	@25s-1
	S5	2018-02-10	10:10 AM	48.0	0.99748	51400	@25s-1
	S6	2018-02-12	10:10 AM	96.0	0.99612	55300	@25s-1
	S7	2018-02-13	10:10 AM	120.0	1.00093	88600	@25s-1
	S8	2018-02-14	10:10 AM	144.0	1.00174	126400	@25s-1
	S9	2018-02-15	10:10 AM	168.0	1.00619	236600	@25s-1

AHS run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-04-24	9:10 AM	Time (hrs	g/mL	cP	SR
R3	S1	2018-04-24	10:10 AM	1.0	0.95292	2550	@25s-1
	S2	2018-04-24	12:10 PM	3.0	0.97505	9350	@25s-1
sample	S3	2018-04-24	3:10 PM	6.0	0.97838	10720	@25s-1
	S4	2018-04-25	9:10 AM	24.0	0.98875	20650	@25s-1
	S5	2018-04-26	9:05 AM	47.9	0.96597	6070	@25s-1
	S6	2018-04-27	9:05 AM	71.9	0.99730	9150	@25s-1
	S7	2018-04-30	9:05 AM	143.9	1.00447	18200	@25s-1

AHS run #4	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-07-26	9:35 AM	Time (hrs	g/mL	cP	SR
R4	S1	2018-07-26	10:35 AM	1.0	0.99604	14700	@100s-1
	S2	2018-07-26	12:35 PM	3.0	1.00878	46900	@25s-1
sample	S3	2018-07-26	3:35 PM	6.0	1.01134	77700	@25s-1
	S4	2018-07-27	9:35 AM	24.0	1.01714	148100	@25s-1
	S5	2018-07-30	9:35 AM	96.0	1.02375	252500	@25s-1
	S6	2018-07-31	9:35 AM	120.0	1.02331	234100	@25s-1
	S7	2018-08-01	9:35 AM	144.0	1.02060	234800	@25s-1

AHS run #5	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-10-09	10:00 AM	Time (hrs	g/mL	cP	SR
R5	S1	2018-10-09	11:00 AM	1.0	0.98641	5670	@100s-1
	S2	2018-10-09	1:00 PM	3.0	0.99865	17200	@100s-1
sample	S3	2018-10-09	4:00 PM	6.0	1.00286	26500	@100s-1
	S4	2018-10-10	10:00 AM	24.0	1.00643	110900	@20s-1
	S5	2018-10-11	10:00 AM	48.0	1.01664		

Table D - 2: ANS Runs

ANS run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-04-25	10:45 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-04-25	11:45 AM	1.0	0.90827	32	@100s-1
	S2	2017-04-25	1:45 PM	3.0	0.91569	75	@100s-1
sample	S3	2017-04-25	4:45 PM	6.0	0.92085	117	@100s-1
	S4	2017-04-26	10:45 AM	24.0	0.93026	250	@100s-1

ANS run #2	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-04-27	11:05 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2017-04-27	12:05 PM	1.0	0.90646	31	@100s-1
	S2	2017-04-27	2:05 PM	3.0	0.91534	86	@100s-1
sample	S3	2017-04-27	5:05 PM	6.0	0.91943	113	@100s-1
	S4	2017-04-28	11:05 AM	24.0	0.92923	240	@100s-1
	S5	2017-04-29	11:05 AM	48.0	0.93463	370	@100s-1
	S6	2017-04-30	11:05 AM	72.0	0.93858	465	@100s-1
	S7	2017-05-01	11:05 AM	96.0	0.94533	635	@100s-1
	S8	2017-05-02	11:05 AM	120.0	0.95305	1050	@100s-1
	S9	2017-05-03	11:05 AM	144.0	0.96535	1560	@100s-1

ANS run #3	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-01-02	11:00 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-01-02	12:00 PM	1.0	0.91438	154	@100s-1
	S2	2018-01-02	2:00 PM	3.0	0.91879	175	@100s-1
sample	S3	2018-01-02	5:10 PM	6.2	0.92383	290	@100s-1
	S4	2018-01-03	11:00 AM	24.0	0.93146	1465	@100s-1
	S5	2018-01-04	11:00 AM	48.0	0.93543	910	@100s-1
	S6	2018-01-05	11:20 AM	72.3	0.93817	1175	@100s-1
	S7	2018-01-08	11:00 AM	144.0	0.94187	1710	@100s-1
	S8	2018-01-09	11:00 AM	168.0	0.96315	7340	@100s-1

ANS run #4	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-05-01	10:00 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-05-01	11:00 AM	1.0	0.91675	160	@100s-1
	S2	2018-05-01	1:00 PM	3.0	0.92518	180	@100s-1
sample	S3	2018-05-01	4:00 PM	6.0	0.93039	460	@100s-1
	S4	2018-05-02	10:00 AM	24.0	0.93443	600	@100s-1
	S5	2018-05-03	10:00 AM	48.0	0.94051	845	@100s-1
	S6	2018-05-04	10:00 AM	72.0	0.95829	2670	@100s-1
	S7	2018-05-07	10:00 AM	144.0	0.95950	3600	@100s-1

Table D - 3: AWB Runs

AWB run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-08-09	9:30 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-08-09	10:30 AM	1.0	0.98505	27300	@100s-1
	S2	2017-08-09	12:30 PM	3.0	0.99212	50000	@100s-1
sample	S3	2017-08-09	3:30 PM	6.0	0.99813	61000	@100s-1
	S4	2017-08-10	9:30 AM	24.0	0.99998	119800	@50s-1
	S5	2017-08-11	9:30 AM	48.0	0.99780	275000	@20s-1
	S6	2017-08-12	9:45 AM	72.3	1.00638	331300	@20s-1
	S7	2017-08-14	9:30 AM	120.0	1.00513	354700	@20s-1

AWB run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-11-27	11:00 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2017-11-27	12:00 PM	1.0	0.97326	29400	@100s-1
	S2	2017-11-27	2:00 PM	3.0	0.98786	105900	@100s-1
sample	S3	2017-11-27	5:00 PM	6.0	0.99268	238500	@25s-1
	S4	2017-11-28	11:00 AM	24.0	0.99584	258200	@25s-1
	S5	2017-11-29	11:00 AM	48.0	1.00409	151000	@25s-1
	S6	2017-11-30	11:00 AM	72.0	0.99665	111200	@25s-1
	S7	2017-12-01	11:00 AM	96.0	1.00902	112800	@25s-1
	S8	2017-12-04	11:00 AM	168.0	1.00512	198100	@25s-1

AWB run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-06-14	9:40 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-06-14	10:40 AM	1.0	0.96454	34650	@100s-1
	S2	2018-06-14	12:40 PM	3.0	0.9774	41200	@100s-1
sample	S3	2018-06-14	3:50 PM	6.2	0.98275	53700	@100s-1
	S4	2018-06-15	9:40 AM	24.0	0.99191	171300	@25s-1
	S5	2018-06-18	9:40 AM	96.0	1.0028	32100	@25s-1
	S6	2018-06-19	9:40 AM	120.0	1.00038	138000	@25s-1
	S7	2018-06-20	9:40 AM	144.0	1.00145	42200	@25s-1

AWB run #4	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-07-20	9:20 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-07-20	10:20 AM	1.0	0.98285	21600	@100s-1
	S2	2018-07-20	12:20 PM	3.0	0.99483	31400	@100s-1
sample	S3	2018-07-20	3:20 PM	6.0	1.00084	54200	@100s-1
	S4	2018-07-21	9:40 AM	24.3	1.00775	137300	@25s-1
	S5	2018-07-23	9:20 AM	72.0	1.01155	208000	@25s-1
	S6	2018-07-24	9:20 AM	96.0	1.01261	211600	@25s-1
	S7	2018-07-25	9:20 AM	120.0	1.01179	231100	@25s-1

Table D - 4: CHV Runs

CHV run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-07-18	9:40 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-07-18	10:40 AM	1.0	0.97231	4080	@100s-1
	S2	2017-07-18	12:40 PM	3.0	0.98025	7800	@100s-1
sample	S3	2017-07-18	3:40 PM	6.0	0.97824	11750	@100s-1
	S4	2017-07-19	9:40 AM	24.0	0.98144	20175	@100s-1
	S5	2017-07-20	9:40 AM	48.0	0.98674	26900	@100s-1
	S6	2017-07-21	9:40 AM	72.0	0.99225	27400	@100s-1
	S7	2017-07-24	9:40 AM	144.0	0.97951	31700	@100s-1
	S8	2017-07-25	9:40 AM	168.0	0.98852	31000	@100s-1

CHV run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-11-15	10:40 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2017-11-15	11:40 AM	1.0	0.96698	11500	@100s-1
	S2	2017-11-15	1:40 PM	3.0	0.98383	35800	@100s-1
sample	S3	2017-11-15	4:15 PM	5.6	0.98673	47300	@100s-1
	S4	2017-11-16	10:40 AM	24.0	0.98922	86100	@100s-1
	S5	2017-11-17	10:40 AM	48.0	0.99551	171400	@25s-1
	S6	2017-11-20	10:40 AM	120.0	0.99835	222300	@25s-1
	S7	2017-11-21	10:50 AM	144.2	0.99927	203200	@25s-1
	S8	2017-11-22	10:40 AM	168.0	0.99983	162500	@25s-1
	S9	2017-11-23	10:40 AM	192.0	1.00019	163900	@25s-1
	S10	2017-11-24	10:40 AM	216.0	0.99958	140200	@25s-1

CHV run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-05-08	9:40 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-05-08	10:40 AM	1.0	0.97245	10600	@25s-1
	S2	2018-05-08	12:40 PM	3.0	0.97883	19500	@25s-1
sample	S3	2018-05-08	3:40 PM	6.0	0.98054	26200	@25s-1
	S4	2018-05-09	9:50 AM	24.2	0.98269	15300	@25s-1
	S5	2018-05-10	9:40 AM	48.0	0.99299	59000	@100s-1
	S6	2018-05-11	9:40 AM	72.0	0.98755	62600	@100s-1
	S7	2018-05-14	9:40 AM	144.0	0.99398	46600	@100s-1

CHV run #4	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-09-25	10:00 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-09-25	11:00 AM	1.0	0.96872	3230	@100s-1
	S2	2018-09-25	1:00 PM	3.0	0.98027	8000	@100s-1
sample	S3	2018-09-25	4:00 PM	6.0	0.98144	10950	@100s-1
	S4	2018-09-26	10:00 AM	24.0	0.98762	19800	@100s-1
	S5	2018-09-27	10:00 AM	48.0	0.99052	28800	@100s-1
	S6	2018-09-28	10:40 AM	72.7	0.99492	27550	@100s-1
	S7	2018-10-02	10:00 AM	168.0	0.99522	24750	@100s-1
	S8	2018-10-03	10:00 AM	192.0	0.99195	22100	@100s-1
	S9	2018-10-04	10:00 AM	216.0	0.99632	21400	@100s-1

Table D - 5: CLB Runs

CLB run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-08-28	9:50 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-08-28	10:50 AM	1.0	0.98461	20100	@100s-1
	S2	2017-08-28	12:50 PM	3.0	0.99256	38400	@100s-1
sample	S3	2017-08-28	3:50 PM	6.0	0.98316	18300	@100s-1
	S4	2017-08-29	9:50 AM	24.0	0.99426	55400	@100s-1
	S5	2017-08-30	9:50 AM	48.0	0.99680	50200	@100s-1
	S6	2017-08-31	9:50 AM	72.0	0.99715	38450	@100s-1
	S7	2017-09-01	9:50 AM	96.0	0.99900	38900	@100s-1
	S8	2017-09-05	9:50 AM	192.0	1.00049	48950	@100s-1

CLB run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-01-18	10:10 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2018-01-18	11:10 AM	1.0	0.97284	22600	@100s-1
	S2	2018-01-18	12:10 PM	2.0	0.97973	42700	@25s-1
sample	S3	2018-01-18	4:10 PM	6.0	0.98895	139300	@25s-1
	S4	2018-01-19	10:10 AM	24.0	0.99200	179700	@25s-1
	S5	2018-01-22	10:10 AM	96.0	0.99764	273750	@25s-1
	S6	2018-01-23	10:10 AM	120.0	0.99537	169900	@25s-1
	S7	2018-01-24	10:20 AM	144.2	0.99442	234700	@25s-1
	S8	2018-01-25	10:10 AM	168.0	0.99987	179600	@25s-1

CLB run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-03-22	9:15 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-03-22	10:15 AM	1.0	0.96902	16700	@25s-1
	S2	2018-03-22	12:15 PM	3.0	0.98272	41600	@25s-1
sample	S3	2018-03-22	3:15 PM	6.0	0.98341	45900	@25s-1
	S4	2018-03-23	9:15 AM	24.0	0.9637	8650	@25s-1
	S5	2018-03-26	9:30 AM	96.3	0.99049	20200	@25s-1
	S6	2018-03-27	9:15 AM	120.0	0.99117	15170	@25s-1
	S7	2018-03-28	9:15 AM	144.0	0.99193	20000	@25s-1
	S8	2018-03-29	9:20 AM	168.1	0.9919	15100	@25s-1

CLB run #4	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-08-09	9:30 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-08-09	10:30 AM	1.0	0.97246	13100	@100s-1
	S2	2018-08-09	12:30 PM	3.0	0.98752	26300	@100s-1
sample	S3	2018-08-09	3:30 PM	6.0	0.97792	28000	@100s-1
	S4	2018-08-10	9:30 AM	24.0	1.00132	24100	@100s-1
	S5	2018-08-11	10:15 AM	48.8	1.00378	23600	@100s-1
	S6	2018-08-13	9:30 AM	96.0	1.00492	29100	@100s-1
	S7	2018-08-14	9:30 AM	120.0	1.00783	57900	@25s-1
	S8	2018-08-15	9:30 AM	144.0	0.99144	107000	@25s-1

Table D – 6: CRW Runs

CRW run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-10-11	10:25 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-10-11	11:25 AM	1.0	0.82085	3	@500s-1
	S2	2017-10-11	1:25 PM	3.0	0.83058	8	@500s-1
sample	S3	2017-10-11	4:25 PM	6.0	0.83711	11	@500s-1
	S4	2017-10-12	10:25 AM	24.0	0.85149	24	@500s-1
	S5	2017-10-13	10:25 AM	48.0	0.86323	42	@100s-1
	S6	2017-10-16	10:25 AM	120.0	0.87517	136	@100s-1

CRW run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-01-10	11:00 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2018-01-10	12:00 PM	1.0	0.82019	8	@500s-1
	S2	2018-01-10	2:00 PM	3.0	0.82914	36	@100s-1
sample	S4	2018-01-11	11:00 AM	24.0	0.84805	124	@100s-1
	S5	2018-01-12	11:00 AM	48.0	0.85425	270	@100s-1
	S6	2018-01-15	11:00 AM	120.0	0.86914	880	@100s-1
	S7	2018-01-16	11:00 AM	144.0	0.86738	920	@100s-1
	S8	2018-01-17	11:00 AM	168.0	0.86771	1050	@100s-1

Table D – 7: HFO Runs

HFO run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-09-14	10:20 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-09-14	11:20 AM	1.0	0.98746	6550	@100s-1
	S2	2017-09-14	1:20 PM	3.0	0.98828	6800	@100s-1
sample	S3	2017-09-14	4:20 PM	6.0	0.98934	8750	@100s-1
	S4	2017-09-15	10:20 AM	24.0	0.99517	2450	@100s-1
	S5	2017-09-16	12:35 PM	50.3	0.99515	3420	@100s-1
	S6	2017-09-18	10:20 AM	96.0	0.99402	4140	@100s-1
	S7	2017-09-19	10:20 AM	120.0	0.99629	4000	@100s-1
	S8	2017-09-20	10:20 AM	144.0	0.99680	3750	@100s-1
	S9	2017-09-21	10:20 AM	168.0	0.99619	3800	@100s-1

HFO run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-01-29	10:00 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2018-01-29	11:00 AM	1.0	0.99552	108500	@25s-1
	S2	2018-01-29	1:00 PM	3.0	1.00041	128500	@25s-1
sample	S3	2018-01-29	4:00 PM	6.0	1.00113	134100	@25s-1
	S4	2018-01-30	10:00 AM	24.0	1.00010	171700	@25s-1
	S5	2018-01-31	10:00 AM	48.0	1.00166	201700	@25s-1
	S6	2018-02-01	10:00 AM	72.0	1.00090	225000	@25s-1
	S7	2018-02-02	10:00 AM	96.0	0.99868	241600	@25s-1
	S8	2018-02-05	10:00 AM	168.0	1.00286	260900	@25s-1

HFO run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-06-05	9:20 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-06-05	10:20 AM	1.0	1.00062	93600	@100s-1
	S2	2018-06-05	12:20 PM	3.0	0.97972	103300	@100s-1
sample	S3	2018-06-05	3:20 PM	6.0	1.00058	80500	@100s-1
	S4	2018-06-06	9:20 AM	24.0	1.00096	93900	@100s-1
	S5	2018-06-07	9:20 AM	48.0	0.99792	102300	@100s-1

HFO run #4	(0C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-06-25	9:20 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-06-25	10:20 AM	1.0	1.0008	114200	@100s-1
	S2	2018-06-25	12:20 PM	3.0	1.00177	103200	@100s-1
sample	S3	2018-06-25	3:20 PM	6.0	1.00334	103500	@100s-1
	S4	2018-06-26	9:20 AM	24.0	0.99389	104200	@100s-1
	S5	2018-06-27	9:20 AM	48.0	0.98461	194800	@25s-1
	S6	2018-06-28	9:20 AM	72.0	1.00211	76800	@25s-1
	S7	2018-06-29	9:20 AM	96.0	1.0016	70400	@25s-1
	S8	2018-07-03	9:20 AM	192.0	0.99328	42800	@25s-1

HFO run #5	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-07-04	9:20 AM	Time (hrs)	g/mL	cP	SR
R5	S1	2018-07-04	10:20 AM	1.0	0.98731	6000	@100s-1
	S2	2018-07-04	12:20 PM	3.0	0.99027	6550	@100s-1
sample	S3	2018-07-04	3:20 PM	6.0	0.98994	7460	@100s-1
	S4	2018-07-05	9:20 AM	24.0	1.00363	12200	@100s-1
	S5	2018-07-06	9:20 AM	48.0	1.00447	19300	@100s-1
	S6	2018-07-09	9:30 AM	120.2	1.00939	19000	@100s-1
	S7	2018-07-10	9:20 AM	144.0	1.00846	21800	@100s-1

HFO run #6	(20C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-07-11	9:30 AM	Time (hrs)	g/mL	cP	SR
R6	S1	2018-07-11	10:30 AM	1.0	0.98728	6040	@100s-1
	S2	2018-07-11	12:30 PM	3.0	0.98924	7700	@100s-1
sample	S3	2018-07-11	3:30 PM	6.0	0.98983	7400	@100s-1
	S4	2018-07-12	9:50 AM	24.3	0.98953	9000	@100s-1
	S5	2018-07-13	9:20 AM	47.8	0.99389	18900	@100s-1
	S6	2018-07-16	9:30 AM	120.0	0.95209	3700	@100s-1
	S7	2018-07-17	9:30 AM	144.0	0.99193	3400	@100s-1

HFO run #7	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-10-18	10:40 AM	Time (hrs)	g/mL	cP	SR
R7	S1	2018-10-18	11:40 AM	1.0	0.98815	6600	@100s-1
	S2	2018-10-18	1:20 PM	2.7	0.98407	7700	@100s-1
sample	S3	2018-10-18	4:20 PM	5.7	0.99439	9100	@100s-1
	S4	2018-10-19	10:20 AM	23.7	0.99888	13100	@100s-1
	S5	2018-10-20	12:35 PM	49.9	1.00655	18300	@100s-1
	S6	2018-10-22	10:20 AM	95.7	1.00838	19700	@100s-1
	S7	2018-10-23	10:20 AM	119.7	1.00909	22500	@100s-1
	S8	2018-10-24	10:20 AM	143.7	1.00983	16600	@100s-1

HFO run #8	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2019-01-09	9:30 AM	Time (hrs)	g/mL	cP	SR
R8	S1	2019-01-09	10:30 AM	1.0	0.9874	7300	@100s-1
	S2	2019-01-09	12:30 PM	3.0	0.98792	8100	@100s-1
sample	S3	2019-01-09	3:30 PM	6.0	0.99024	9400	@100s-1
	S4	2019-01-10	9:30 AM	24.0	0.9931	17100	@100s-1
	S5	2019-01-11	9:30 AM	48.0	0.99509	20800	@100s-1
	S6	2019-01-14	9:30 AM	120.0	0.9952	31150	@100s-1
	S7	2019-01-15	9:30 AM	144.0	0.99729	33300	@100s-1
	S8	2019-01-16	9:30 AM	168.0	0.99665	31600	@100s-1

Table D – 8: LSB Runs

LSB run #1	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-05-04	10:10 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-05-04	11:10 AM	1.0	0.89925	40	@100s-1
	S2	2017-05-04	1:10 PM	3.0	0.90898	72	@100s-1
sample	S3	2017-05-04	4:10 PM	6.0	0.91433	110	@100s-1
	S4	2017-05-05	10:10 AM	24.0	0.93002	400	@100s-1
	S5	2017-05-06	11:10 AM	49.0	0.95034	2015	@100s-1
	S7	2017-05-08	10:15 AM	96.1	0.96006	3910	@100s-1
	S8	2017-05-09	10:10 AM	120.0	0.96330	4300	@100s-1
	S9	2017-05-11	10:10 AM	168.0	0.96394	4400	@100s-1
	S10	2017-05-12	10:10 AM	192.0	0.96272	5000	@100s-1
	S11	2017-05-15	10:10 AM	264.0	0.96597	4920	@100s-1
	S12	2017-05-17	10:10 AM	312.0	0.95015	5100	@100s-1
	S13	2017-05-19	10:10 AM	360.0	0.97028	6200	@100s-1
	S14	2017-05-23	10:10 AM	456.0	0.96491	4820	@100s-1

LSB run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-10-18	10:30 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2017-10-18	11:30 AM	1.0	0.88632	46	@100s-1
	S2	2017-10-18	1:30 PM	3.0	0.90429	116	@100s-1
sample	S3	2017-10-18	4:30 PM	6.0	0.91245	207	@100s-1
	S4	2017-10-19	10:30 AM	24.0	0.92660	360	@100s-1
	S5	2017-10-20	10:30 AM	48.0	0.95722	1064	@100s-1
	S6	2017-10-23	10:30 AM	120.0	0.94283	2135	@100s-1
	S7	2017-10-24	10:30 AM	144.0	0.94804	2512	@100s-1

LSB run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-05-15	9:30 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-05-15	10:30 AM	1.0	0.89974	43	@200s-1
	S2	2018-05-15	12:30 PM	3.0	0.91309	125	@100s-1
sample	S3	2018-05-15	3:30 PM	6.0	0.91568	190	@100s-1
	S4	2018-05-16	9:30 AM	24.0	0.92529	350	@100s-1
	S5	2018-05-17	9:30 AM	48.0	0.93656	550	@100s-1
	S6	2018-05-18	9:30 AM	72.0	0.9539	1775	@100s-1
	S7	2018-05-22	9:30 AM	168.0	0.95931	4000	@100s-1

LSB run #4	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-08-28	9:25 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-08-28	10:25 AM	1.0	0.89197	20	@200s-1
	S2	2018-08-28	12:25 PM	3.0	0.90832	50	@100s-1
sample	S3	2018-08-28	3:25 PM	6.0	0.90885	60	@100s-1
	S4	2018-08-29	9:35 AM	24.2	0.93862	330	@100s-1
	S5	2018-08-30	9:25 AM	48.0	0.94352	540	@100s-1
	S6	2018-08-31	9:25 AM	72.0	0.9522	610	@100s-1
	S7	2018-09-04	8:00 AM	166.6	0.97497	3350	@100s-1

LSB run #5	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-09-18	9:30 AM	Time (hrs)	g/mL	cP	SR
R5	S1	2018-09-18	10:30 AM	1.0	0.897	44	@100s-1
	S2	2018-09-18	12:30 PM	3.0	0.90603	60	@100s-1
sample	S3	2018-09-18	3:40 PM	6.2	0.91144	85	@100s-1
	S4	2018-09-19	9:30 AM	24.0	0.92135	190	@100s-1
	S5	2018-09-20	9:30 AM	48.0	0.92714	265	@100s-1
	S6	2018-09-21	9:30 AM	72.0	0.9546	1045	@100s-1
	S7	2018-09-24	9:30 AM	144.0	0.9551	2600	@100s-1

Table D – 9: MSB Runs

MSB run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
R1	START	2017-09-26	10:10 AM	Time (hrs	g/mL	cP	SR
	S1	2017-09-26	11:10 AM	1.0	0.89635	31	@100s-1
sample	S2	2017-09-26	1:10 PM	3.0	0.90526	52	@100s-1
	S3	2017-09-26	4:10 PM	6.0	0.90946	84	@100s-1
	S4	2017-09-27	10:10 AM	24.0	0.91788	159	@100s-1
	S5	2017-09-28	10:10 AM	48.0	0.92198	200	@100s-1
	S6	2017-09-29	10:10 AM	72.0	0.92436	261	@100s-1
	S7	2017-10-02	10:10 AM	144.0	0.92804	346	@100s-1
	S8	2017-10-03	10:10 AM	168.0	0.92837	379	@100s-1

MSB run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
R2	START	2017-11-06	10:30 AM	Time (hrs	g/mL	cP	SR
	S1	2017-11-06	11:30 AM	1.0	0.89121	56	@100s-1
sample	S2	2017-11-06	1:30 PM	3.0	0.90863	144	@100s-1
	S3	2017-11-06	5:30 PM	7.0	0.91588	313	@100s-1
	S4	2017-11-07	10:30 AM	24.0	0.92522	643	@100s-1
	S5	2017-11-08	10:30 AM	48.0	0.92904	952	@100s-1
	S6	2017-11-09	10:30 AM	72.0	0.93206	1805	@100s-1
	S7	2017-11-10	10:30 AM	96.0	0.93442	1350	@100s-1
	S8	2017-11-13	10:30 AM	168.0	0.93653	2300	@100s-1

Table D – 10: MSW Runs

MSW run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-09-07	9:45 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-09-07	10:45 AM	1.0	0.87110	23	100s-1
	S2	2017-09-07	12:45 PM	3.0	0.87959	43	100s-1
sample	S3	2017-09-07	3:45 PM	6.0	0.88393	57	100s-1
	S4	2017-09-08	9:45 AM	24.0	0.89514	117	100s-1
	S5	2017-09-10	12:45 PM	75.0	0.93431	723	100s-1
	S6	2017-09-11	9:45 AM	96.0	0.94163	520	100s-1
	S7	2017-09-12	9:45 AM	120.0	0.93329	435	100s-1

MSW run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-12-14	11:00 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2017-12-14	12:00 PM	1.0	0.87648	111	100s-1
	S2	2017-12-14	2:00 PM	3.0	0.88782	250	100s-1
sample	S3	2017-12-14	5:00 PM	6.0	0.89117	350	100s-1
	S4	2017-12-15	11:00 AM	24.0	0.90050	675	100s-1
	S5	2017-12-18	11:00 AM	96.0	0.91415	2600	100s-1
	S6	2017-12-19	11:00 AM	120.0	0.91782	1950	100s-1
	S7	2017-12-20	11:00 AM	144.0	0.91701	2750	100s-1
	S8	2017-12-21	11:00 AM	168.0	0.91704	2300	100s-1
	S9	2017-12-27	11:40 AM	312.7	0.92405	2200	100s-1

MSW run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-04-16	9:05 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-04-16	10:05 AM	1.0	0.87875	253	100s-1
	S2	2018-04-16	12:05 PM	3.0	0.88684	377	100s-1
sample	S3	2018-04-16	3:05 PM	6.0	0.89045	614	100s-1
	S4	2018-04-17	9:05 AM	24.0	0.89178	885	100s-1
	S5	2018-04-18	9:05 AM	48.0	0.89393	1052	100s-1
	S6	2018-04-19	9:05 AM	72.0	0.89835	1365	100s-1
	S7	2018-04-20	9:05 AM	96.0	0.8985	1230	100s-1
	S8	2018-04-23	9:05 AM	168.0	0.90089	1540	100s-1

MSW run #4	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-08-02	9:30 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-08-02	10:30 AM	1.0	0.87313	17	100s-1
	S2	2018-08-02	12:30 PM	3.0	0.88164	40	100s-1
sample	S3	2018-08-02	3:30 PM	6.0	0.88527	57	100s-1
	S4	2018-08-03	9:30 AM	24.0	0.89369	130	100s-1
	S5	2018-08-04	9:30 AM	48.0	0.90495	240	100s-1
	S6	2018-08-07	9:30 AM	120.0	0.92786	475	100s-1
	S7	2018-08-08	9:30 AM	144.0	0.93204	610	100s-1

MSW run #5	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-11-06	9:45 AM	Time (hrs)	g/mL	cP	SR
R5	S1	2018-11-06	10:45 AM	1.0	0.87987	160	100s-1
	S2	2018-11-06	12:45 PM	3.0	0.8962	110	100s-1
sample	S3	2018-11-06	3:45 PM	6.0	0.95819	260	100s-1
	S4	2018-11-07	9:45 AM	24.0	0.95778	670	100s-1
	S5	2018-11-08	9:45 AM	48.0	0.94296	1300	100s-1
	S6	2018-11-09	9:45 AM	72.0	0.94929	1100	100s-1
	S7	2018-11-12	9:45 AM	144.0	0.93589	2300	100s-1

Table D – 11: NDB Runs

NDB run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-07-05	10:00 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-07-05	11:00 AM	1.0	0.85573	9	500s-1
	S2	2017-07-05	1:00 PM	3.0	0.86411	13	250s-1
sample	S3	2017-07-05	4:00 PM	6.0	0.86710	16	250s-1
	S4	2017-07-06	10:00 AM	24.0	0.87876	30	100s-1
	S5	2017-07-07	10:00 AM	48.0	0.88278	40	100s-1
	S6	2017-07-10	10:00 AM	120.0	0.94368	150	100s-1
	S7	2017-07-11	10:00 AM	144.0	0.94441	560	100s-1
	S8	2017-07-12	10:00 AM	168.0	0.89293	237	100s-1
	S9	2017-07-13	10:00 AM	192.0	0.96008		
	S10	2017-07-14	10:00 AM	216.0	0.97870		

NDB run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-10-26	10:35 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2017-10-26	11:35 AM	1.0	0.85887	13	500s-1
	S2	2017-10-26	1:35 PM	3.0	0.86814	21	500s-1
sample	S3	2017-10-26	4:35 PM	6.0	0.87337	26	500s-1
	S4	2017-10-27	10:35 AM	24.0	0.88611	30	100s-1
	S5	2017-10-28	11:50 AM	49.3	0.88704	87	100s-1
	S6	2017-10-30	10:35 AM	96.0	0.95347	976	100s-1
	S7	2017-10-31	10:35 AM	120.0	0.95408	1262	100s-1
	S8	2017-11-01	10:35 AM	144.0	0.95068	1397	100s-1
	S9	2017-11-02	10:35 AM	168.0	0.89525	1397	100s-1
	S10	2017-11-03	10:35 AM	192.0	0.90217		

Table D – 12: SYB Runs

SYB run #1	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-12-06	10:30 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-12-06	11:30 AM	1.0	0.95590	1100	100s-1
	S2	2017-12-06	1:30 PM	3.0	0.96055	1650	100s-1
sample	S3	2017-12-06	4:30 PM	6.0	0.96259	2130	100s-1
	S4	2017-12-07	10:30 AM	24.0	0.97132	4050	100s-1
	S5	2017-12-08	10:30 AM	48.0	0.97455	6650	100s-1
	S6	2017-12-11	10:30 AM	120.0	0.97845	7100	100s-1
	S7	2017-12-12	10:30 AM	144.0	0.98198	9350	100s-1
	S8	2017-12-13	10:30 AM	168.0	0.98222	10000	100s-1

SYB run #2	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2018-02-16	10:10 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2018-02-16	11:10 AM	1.0	0.96057	2927	100s-1
	S2	2018-02-16	1:10 PM	3.0	0.95933	2556	100s-1
sample	S3	2018-02-16	4:10 PM	6.0	0.96108	3040	100s-1
	S4	2018-02-17	10:10 AM	24.0	0.97408	11460	100s-1
	S5	2018-02-18	10:10 AM	48.0	0.97451	12020	100s-1
	S6	2018-02-19	10:10 AM	72.0	0.97633	14737	100s-1
	S7	2018-02-20	10:10 AM	96.0	0.97746	16686	100s-1
	S8	2018-02-21	10:10 AM	120.0	0.97814	18091	100s-1
	S9	2018-02-22	10:10 AM	144.0	0.98331	41565	100s-1
	S10	2018-02-23	10:10 AM	168.0	0.98665	43564	100s-1
	S11	2018-02-26	10:10 AM	240.0	0.99051		

SYB run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-05-23	9:40 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-05-23	10:40 AM	1.0	0.96336	3250	100s-1
	S2	2018-05-23	12:40 PM	3.0	0.96999	5200	100s-1
sample	S3	2018-05-23	3:40 PM	6.0	0.97086	8600	100s-1
	S4	2018-05-24	9:40 AM	24.0	0.97729	13900	100s-1
	S5	2018-05-25	9:40 AM	48.0	0.9805	23400	100s-1
	S6	2018-05-28	9:40 AM	120.0	0.98394	21300	100s-1
	S7	2018-05-29	9:40 AM	144.0	0.9899	18900	100s-1

SYB run #4	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-08-20	9:25 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-08-20	10:25 AM	1.0	0.95709	860	100s-1
	S2	2018-08-20	12:25 PM	3.0	0.96105	1510	100s-1
sample	S3	2018-08-20	3:25 PM	6.0	0.9635	1920	100s-1
	S4	2018-08-21	9:25 AM	24.0	0.98046	2370	100s-1
	S5	2018-08-22	9:25 AM	48.0	0.977	4100	100s-1
	S6	2018-08-23	9:25 AM	72.0	0.97782	4850	100s-1
	S7	2018-08-24	9:25 AM	96.0	0.97574	5775	100s-1
	S8	2018-08-27	9:25 AM	168.0	0.97437	8500	100s-1

Table D – 13: SYN Runs

SYN run #1	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-06-05	9:50 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-06-05	10:50 AM	1.0	0.88923	26	100s-1
	S2	2017-06-05	12:50 PM	3.0	0.89422	31	100s-1
sample	S3	2017-06-05	3:50 PM	6.0	0.89702	38	100s-1
	S4	2017-06-06	9:50 AM	24.0	0.90698	62	100s-1
	S5	2017-06-07	9:50 AM	48.0	0.93599	70	100s-1
	S6	2017-06-08	9:50 AM	72.0	0.93937	82	100s-1
	S7	2017-06-09	9:50 AM	96.0	0.96221	92	100s-1
	S8	2017-06-12	9:50 AM	168.0	0.96807		

SYN run #2	(20C, 0salt, 0sediment)				20°C		
	START	2017-06-13	10:00 AM	Time (hrs)	g/mL		
R2	S1	2017-06-13	11:00 AM	1.0	0.88356	12	500s-1
	S2	2017-06-13	1:00 PM	3.0	0.88767	15	500s-1
sample	S3	2017-06-13	4:00 PM	6.0	0.89000	17	500s-1
	S4	2017-06-14	10:00 AM	24.0	0.89596	25	500s-1
	S5	2017-06-15	10:00 AM	48.0	0.89802	28	100s-1
	S6	2017-06-16	10:00 AM	72.0	0.90044	34	100s-1
	S7	2017-06-19	10:00 AM	144.0	0.90383	40	100s-1
	S8	2017-06-20	10:00 AM	168.0	0.90524	44	100s-1

SYN run #3	(20C, 0salt, 0sediment)				20°C		
	START	2017-10-04	10:35 AM	Time (hrs)	g/mL		
R3	S1	2017-10-04	11:35 AM	1.0	0.88448	12	500s-1
	S2	2017-10-04	1:35 PM	3.0	0.88886	16	500s-1
sample	S3	2017-10-04	4:35 PM	6.0	0.89145	19	500s-1
	S4	2017-10-05	10:35 AM	24.0	0.89701	27	500s-1
	S5	2017-10-06	10:35 AM	48.0	0.8998	32	100s-1
	S6	2017-10-10	10:35 AM	144.0	0.90464	45	100s-1

Table D – 14: WCS Runs

WCS run #1	(0C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-05-25	10:05 AM	Time (hrs)	g/mL	cP	SR
R1	S1	2017-05-25	11:05 AM	1.0	0.96670	9000	100s-1
	S2	2017-05-25	1:05 PM	3.0	0.98096	35200	100s-1
sample	S3	2017-05-25	4:05 PM	6.0	0.98737	57200	100s-1
	S4	2017-05-26	10:05 AM	24.0	0.98575	46600	100s-1
	S5	2017-05-27	11:05 AM	49.0	0.99722	45100	100s-1
	S6	2017-05-29	10:05 AM	96.0	0.99465	37900	100s-1
	S7	2017-05-30	10:05 AM	120.0	0.94630	59200	100s-1
	S8	2017-05-31	10:05 AM	144.0	0.99151	44600	100s-1
	S9	2017-06-01	10:05 AM	168.0	0.99236		

WCS run #2	(20C, 0salt, 0sediment)				Density	Viscosity	
	START	2017-08-17	9:45 AM	Time (hrs)	g/mL	cP	SR
R2	S1	2017-08-17	10:45 AM	1.0	0.97016	4700	100s-1
	S2	2017-08-17	12:45 PM	3.0	0.97900	10500	100s-1
sample	S3	2017-08-17	3:45 PM	6.0	0.98432	14400	100s-1
	S4	2017-08-18	9:45 AM	24.0	0.98824	29000	100s-1
	S5	2017-08-19	9:45 AM	48.0	0.99088	38450	100s-1
	S6	2017-08-21	9:45 AM	96.0	0.99081	39200	100s-1
	S7	2017-08-22	9:45 AM	120.0	0.99369	45700	100s-1
	S8	2017-08-23	9:45 AM	144.0	0.99295	46900	100s-1
	S9	2017-08-24	9:45 AM	168.0	0.99454	53100	100s-1

WCS run #3	(0C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-03-13	10:40 AM	Time (hrs)	g/mL	cP	SR
R3	S1	2018-03-13	11:40 AM	1.0	0.96015	6870	100s-1
	S2	2018-03-13	1:40 PM	3.0	0.96779	8770	100s-1
sample	S3	2018-03-13	4:40 PM	6.0	0.97714	21200	100s-1
	S4	2018-03-14	10:40 AM	24.0	0.97834	47600	100s-1
	S5	2018-03-15	10:55 AM	48.3	0.976	27500	100s-1
	S6	2018-03-16	10:40 AM	72.0	0.97867	25800	100s-1
	S7	2018-03-19	11:00 AM	144.3	0.98402	50800	100s-1
	S8	2018-03-20	10:52 AM	168.2	0.9857	58800	100s-1
	S9	2018-03-21	10:15 AM	191.6	0.98825	78100	100s-1

WCS run #4	(20C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-04-04	10:00 AM	Time (hrs)	g/mL	cP	SR
R4	S1	2018-04-04	11:00 AM	1.0	0.95931	640	100s-1
	S2	2018-04-04	1:00 PM	3.0	0.93013	1200	100s-1
sample	S3	2018-04-04	4:00 PM	6.0	0.98419	1680	100s-1
	S4	2018-04-05	10:00 AM	24.0	0.98321	3000	100s-1
	S5	2018-04-06	10:00 AM	48.0	0.99139	4350	100s-1
	S6	2018-04-09	10:00 AM	120.0	1.00209	7100	100s-1
	S7	2018-04-10	10:00 AM	144.0	0.98921	5500	100s-1
	S8	2018-04-11	10:00 AM	168.0	0.98709	6100	100s-1

WCS run #5	(20C, 35salt, 1000sediment)				Density	Viscosity	
	START	2018-09-05	9:40 AM	Time (hrs)	g/mL	cP	SR
R5	S1	2018-09-05	10:40 AM	1.0	0.97231	5950	100s-1
	S2	2018-09-05	12:40 PM	3.0	0.97766	11600	100s-1
sample	S3	2018-09-05	3:40 PM	6.0	0.98926	21600	100s-1
	S4	2018-09-06	9:40 AM	24.0	0.99419	15800	100s-1
	S5	2018-09-07	9:40 AM	48.0	0.99985	19400	100s-1
	S6	2018-09-10	9:40 AM	120.0	1.00161	30700	100s-1
	S7	2018-09-11	9:40 AM	144.0	1.00341	24500	100s-1

WCS run #6	(20C, 0salt, 1000sediment)				Density	Viscosity	
	START	2018-10-25	10:10 AM	Time (hrs)	g/mL	cP	SR
R6	S1	2018-10-25	11:10 AM	1.0	0.95962	1850	100s-1
	S2	2018-10-25	1:10 PM	3.0	0.97654	9800	100s-1
sample	S3	2018-10-25	4:10 PM	6.0	0.98378	14500	100s-1
	S4	2018-10-26	10:10 AM	24.0	0.99062	24000	100s-1
	S5	2018-10-27	10:10 AM	48.0	0.99246	35000	100s-1
	S6	2018-10-29	10:10 AM	96.0	0.99388	24600	100s-1
	S7	2018-10-30	10:10 AM	120.0	0.99483	33600	100s-1
	S8	2018-10-31	10:10 AM	144.0	0.98633	24500	100s-1
	S9	2018-11-01	10:10 AM	168.0	0.99695	24300	100s-1
	S10	2018-11-02	9:30 AM	191.3	0.99783	25500	100s-1

APPENDIX E – POROUS MEDIA TEST DATA

Substrate: Pebbles	1	2	3	4	5	6	7	8	9	10	11	12	13	14
OIL	**AHS**	**ANS**	**AWB**	**CHV**	**CLB**	**CRW**	**HFO**	**LSB**	**MSB**	**MSW**	**NDB**	**SYB**	**SYN**	**WCS**
moisture content of the substrate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Mass of Media in Pail (g)	25830	26080	25860	26040	25040	25330	25380	25260	25240	25510	25380	26120	25170	25360
Measure top of substrate (cm)	26	26.5	26	26	26	26	26	26	25	26	26	26	26	26
Mass of oil used (g)	189.3	172.92	201.36	184.06	216.64	173.76	179.8	174.47	172.39	170.02	175.34	188.26	179.37	201.17
Initial containment ring size (cm diameter)	13 cm disk	13 cm disk	13 cm Disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk
Add +/- 6L of water. Mass of water + container	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5
Sample # of water for BTEX	GAHS	GANS	GAWB	GCHV	GCLB	GCRW	GHFO	GLSB	GMSB	GMSW	GNDB	GSYB	GSYN	GWCS
Top size and shape of oil (%coverage)	13 cm Disk	13 cm stain	13 cm disc	13 cm disk	13 cm disk	100 % The oil was evenly dispersed by the water.	13 cm disk	13 cm disk	13 cm disk	13 cm stain	13 cm stain	13 cm disk (well defined)	No clearly visible oil yet the surface is oily	13 cm disc
2.5 cm size and shape of oil (% coverage)	13 cm Disk	11 cm stain (most of the substrate has visible signs of oil	14 cm disk	13 cm ovoid	14 cm disk	14 cm stain not very visible	14 cm disk	10 cm disk	10 cm disk	8 cm stain?	Stain	13 cm blob	No clearly visible oil yet the surface is oily	11 cm blob
5 cm size and shape of oil (% coverage)	14 cm Disk	10 X 12cm ovoid	14 cm disk	11 X15 cm ovoid	14 cm blob	14 cm stain not very visible	14 cm disk	6 cm stain	10 cm blob	7 cm stain?	Stain	14 cm blob	No clearly visible oil yet the surface is oily	12 X 14 ovoid
7.5 cm size and shape of oil (% coverage)	10cm X 13cm Ovoid	10 X 11 ovoid	14 cm disk	12 cm blob	14 cm blob	14 cm stain not very visible	14 cm blob	6 cm stain	8 cm blob	? Stain	Stain	14 cm blob	No clearly visible oil yet the surface is oily	10 X 13 ovoid
10 cm size and shape of oil (% coverage)	10cm X 13cm Ovoid	11 cm ovoid	10 cm blob	9 cm disk	13 cm blob	14 cm stain not very visible	13 cm blob	5 cm stain	10 cm disk	? Stain	Stain	11 cm blob	No clearly visible oil yet the surface is oily	13 cm ovoid
12.5 cm size and shape of oil (% coverage)	8 X 10cm Ovoid	10 cm ovoid	12 cm disk	9 cm blob	12 cm blob	14 cm stain not very visible	11 cm blob	9 cm stain	10 cm stain	? Stain	Stain	13 cm blob	No clearly visible oil yet the surface is oily	12X 15 blob
15 cm size and shape of oil (% coverage)	10 cm Disk	10 cm ovoid	10 cm blob	7 X 10cm blob	11 cm blob	14 cm stain not very visible	10 cm blob	7 cm stain	10 cm stain	? Stain	Stain	10 cm blob	No clearly visible oil yet the surface is oily	12 cm ovoid
17.5 cm size and shape of oil (% coverage)	9 cm ovoid	9 X 11 cm ovoid	5 X 13 cm blob	7 cm blob	11 cm blob	14 cm stain not very visible	10 cm blob	7 cm stain	8 X 3 cm stain	? Stain	Stain	10 cm blob	No clearly visible oil yet the surface is oily	9 X 13 blob
20 cm size and shape of oil (% coverage)	10 cm ovoid	10 cm ovoid	6 X15 blob	7 cm dick	11 cm blob	14 cm stain not very visible	8 cm stain	6 cm stain	9 cm blob	? Stain	No stain, but oil is visible under UV light	9 cm blob	No clearly visible oil yet the surface is oily	9 cm blob
22.5 cm size and shape of oil (% coverage)	8 cm ovoid	10 X 12 ovoid	6 X 10 blob	6 cm disk	11 cm blob	14 cm stain not very visible	scattered stain	7 cm stain	9 cm blob	? Stain	No stain, but oil is visible under UV light	8 cm blob	No clearly visible oil yet the surface is oily	8 X 10 cm blob
25 cm size and shape of oil (% coverage)	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer	Water / Oil layer
27.5 cm size and shape of oil (% coverage)						The oil separated into a larger uv patch and a smaller visible patch.								

Table E - 1: Pebble Porous Media Results

Substrate: Sand	1	2	3	4	5	6	7	8	9	10	11	12	13	14
OIL	**AHS**	**ANS**	**AWB**	**CHV**	**CLB**	**CRW**	**HFO**	**LSB**	**MSB**	**MSW**	**NDB**	**SYB**	**SYN**	**WCS**
moisture content of the substrate	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Mass of Media in Pail (g)	22640	22480	22830	23280	22560	22600	23290	22910	23180	24200	23130	23110	23140	23250
Measure top of substrate (cm)	26.5	26	26	27	26.5	27	26.5	26	26	26	26	26	26	26
Mass of oil used (g)	191.5	178.83	164.96	199.15	190.25	140.18	208.94	166.55	158.86	172.64	171	176.39	154.53	185.12
Initial containment ring size (cm diameter)	disk. Cap was fc	15 cm Disk	15 cm disk	14cm disk	14cm disk	15 cm disk	with a 5cm arc.	13 cm disk	13 cm disk	13 cm disk	13 cm disk	13 cm disk	16cm disk	13 cm disk
Add +/- 6L of water. Mass of water + container	4.5L	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Sample # of water for BTEX	SAHS	SANS	SAWB	SCHV	SCLB	SCRW	SHFO	SLSB	SMSB	SMSW	SNBD	SSYB	SSYN	SWCS
Top size and shape of oil (%coverage)	15 cm disk	100% coverage	95% coverage	100 % w darker 15cm disk	100%	100%	14cm disk	100%	100%	100%	100%	100%	100%	100%
2.5 cm size and shape of oil (% coverage)	15 cm disk	17 cm stain	16 cm disk	15 cm disk	15 cm disk	100% with 12cm disk	5X1 cm stain along edge.	16 cm disk	15 cm inner, 17 cm outer disk	15 cm disk	18 cmdisk	15 cm disk	19 cm disk	17 cm disk
5 cm size and shape of oil (% coverage)	10 cm disk	18 cm stain	15 x 11cm elipse	15 cn disk	15 X 13cm	100% with 10 cm stain	3 X 1 cm stain along edge.	18 cm disk	11 cm / 16 cm	12 cm ovoid	18 cm disk	16 cm disk	19 cm disk	16 cm disk
7.5 cm size and shape of oil (% coverage)	8 cm irregular disk	15 cm stain	3 cm stain	12 X 8cm elipse	10 cm disk	100% with 8 cm stain	0	18 cm disk	10 cm / 16 cm	4 cm stain	19 cm disk	16 cm disk	19 cm disk	15 X 13 cm ovoid
10 cm size and shape of oil (% coverage)	0	14 cm disk	0	6 X4cm elipse	0	100% with 5 cm stain		16 X 15cm ovoid	15 cm disk	0	19 cm disk	15 cm disk	19 cm disk	11X8 cm ovoid
12.5 cm size and shape of oil (% coverage)		14 cm disk		0		100% with 0 stain		14 X 12 cm ovoid	14 cm disk		20 cm X 17 cm disk	13 cm disk	17 cm disk	dot
15 cm size and shape of oil (% coverage)		13 cm disk with a 3cm centre target				100% with 0		7 cm disk	9 cm X 8 cm ovoid		17 cm disk	7 cm disk	17 cm disk	0
17.5 cm size and shape of oil (% coverage)		10 cm disk				19 cm		0	0		13 cm disk	0	15 cm disk	
20 cm size and shape of oil (% coverage)		5 cm disk				17 cm					0		10 cm disk	
22.5 cm size and shape of oil (% coverage)		0				12 cm							3 cm disk	
25 cm size and shape of oil (% coverage)						9 cm							0	
27.5 cm size and shape of oil (% coverage)														

Table E - 2: Sand Porous Media Results

Substrate: Artificial Soil	1	2	3	4	5	6	7	8	9	10	11	12	13	14
OIL	**AHS**	**ANS**	**AWB**	**CHV**	**CLB**	**CRW**	**HFO**	**LSB**	**MSB**	**MSW**	**NDB**	**SYB**	**SYN**	**WCS**
moisture content of the substrate	15	15	15	15	15	15	15	15	15	15	15	15	15	15
Mass of Media in Pail (g)	15290	15120	17170	15140	13790	13620	14580	14400	15070	14620	15220	14690	15720	13480
Measure top of substrate (cm)	26	26	28	26	26	26	26	26	26	26	26	25	26	25
Mass of oil used (g)	184	164.14	172.39	173.02	172.72	133.75	175.7	152.52	163.93	156.63	158.44	167	182.45	184.86
Initial containment ring size (cm diameter)	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring	13 cm ring
Add +/- 6L of water. Mass of water + container	6	6	6	6	6	6	6	6	6	6	6	6	6	6
Sample # of water for BTEX	AAHS	AANS	AAWB	ACHV	ACLB	ACRW	AHFO	ALSB	AMSB	AMSW	ANDB	ASYB	ASYN	AWCS
Top size and shape of oil (%coverage)	13 cm disk shape	100%	100% with a 14 cm target	100% with a 13cm target	14 cm disk	Interference due to organics layer	13 cm disk. Single blob	Interference due to organics layer	Interference due to organics layer	Interference due to organics layer	Interference due to organics layer	Interference due to organics layer	Interference due to organics layer	14 cm blob
2.5 cm size and shape of oil (% coverage)	14 cm disk	15 cm disk	15cm disk with a 5 cm target	14 cm blob	11 cm dosk	17 cm disk	0	13 cm stain	17 cm disk	15 cm disk	18 cm blob	15 cm blob	17 cm blob	14 cm disk
5 cm size and shape of oil (% coverage)	3 X 9 cm stain	14 cm blob	0	8 x 10 cm blob	0	16 cm blob		15 cm stain	15 cm disk	12 X 15 cm disk	15 cm blob	9 cm blob	14 x 17 blob	10 x 14cm blob
7.5 cm size and shape of oil (% coverage)	0	5 cm blob		6 X 14 cm faint stain		11 cm blob		5 x 10 cm stain	10 x 12 cm blob	12 cm disk	13 cm blob	0	12 x 14 cm blob	4 x 8 cm blob
10 cm size and shape of oil (% coverage)		0		0		0		0	3 cm spot	6 x 10 cm blob	6 cm blob		0	0
12.5 cm size and shape of oil (% coverage)									0	0	0			
15 cm size and shape of oil (% coverage)														
17.5 cm size and shape of oil (% coverage)														
20 cm size and shape of oil (% coverage)														
22.5 cm size and shape of oil (% coverage)														
25 cm size and shape of oil (% coverage)														
27.5 cm size and shape of oil (% coverage)														

Table E - 3: Artificial Soil Porous Media Results

Photos from Small Bench Scale Tests

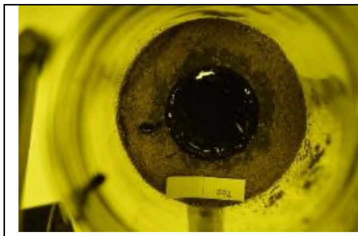
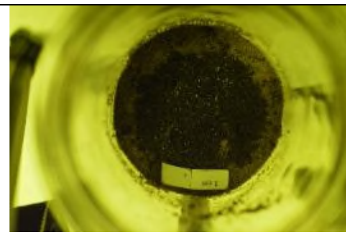
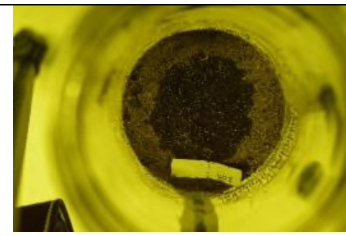
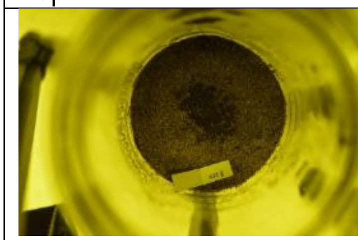
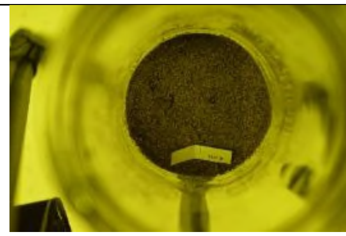
 Top	 1cm	 2cm
 3cm	 4cm	

Figure E-0-1: *AHS Sand*

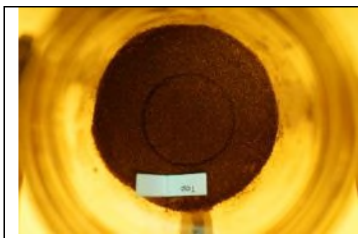
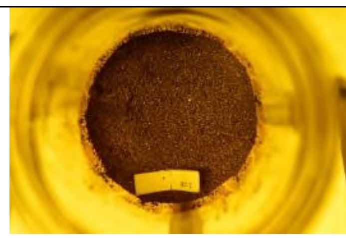
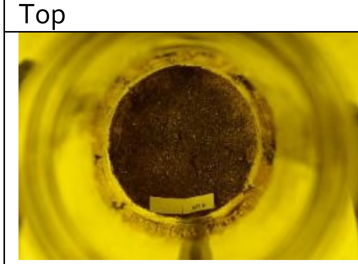
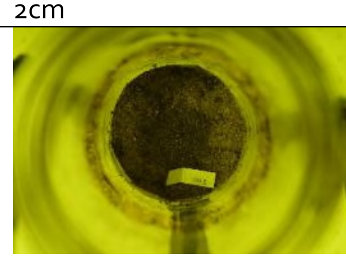
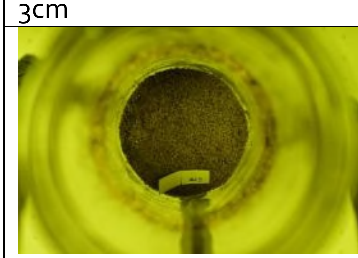
 Top	 1cm	 2cm
 3cm	4cm	 5cm
 6cm		

Figure E-0-2: *ANS Sand*

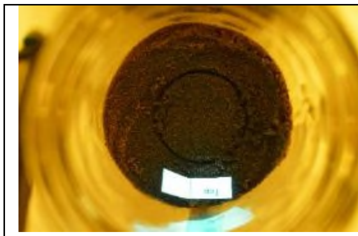
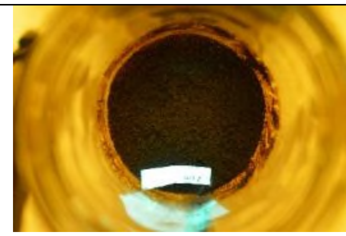
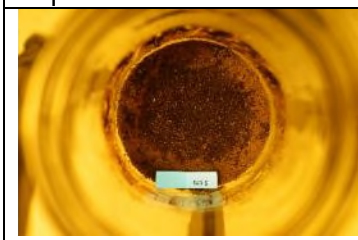
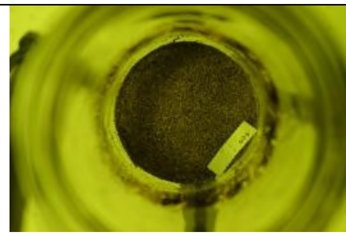
 Top	 1cm	 2cm
 3cm	 4cm	

Figure E-0-3: *AWB Sand*

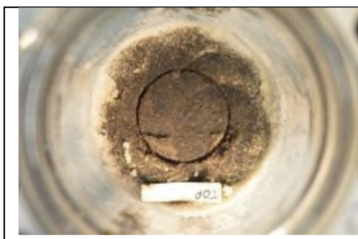
 Top	 1cm	 2cm
 3cm	4cm	5cm

Figure E-0-4: *AWB Sand (Silica Grade 70)*

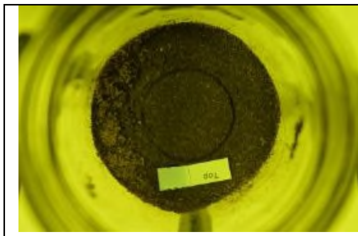
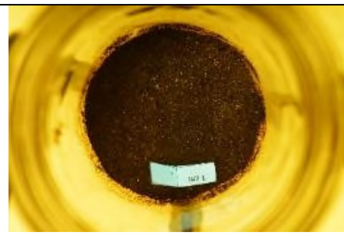
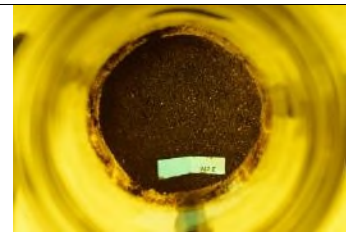
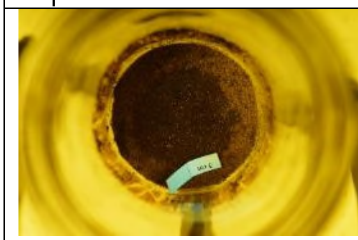
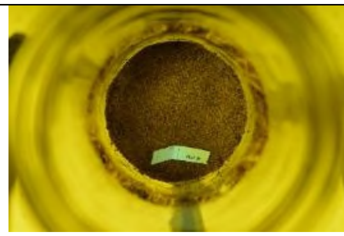
 Top	 1cm	 2cm
 3cm	 4cm	

Figure E-0-5: *CHV Sand*

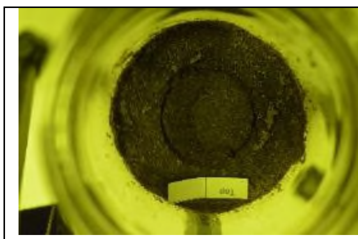
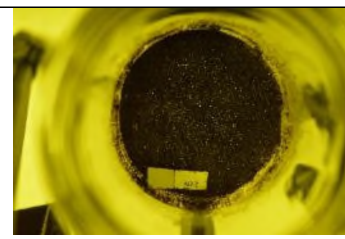
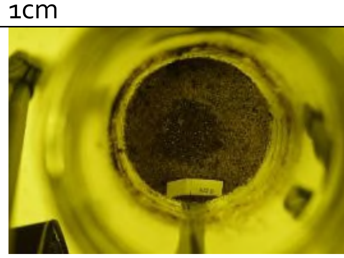
 Top	 1cm	 2cm
 3cm	 4cm	

Figure E-0-6: *CLB Sand*

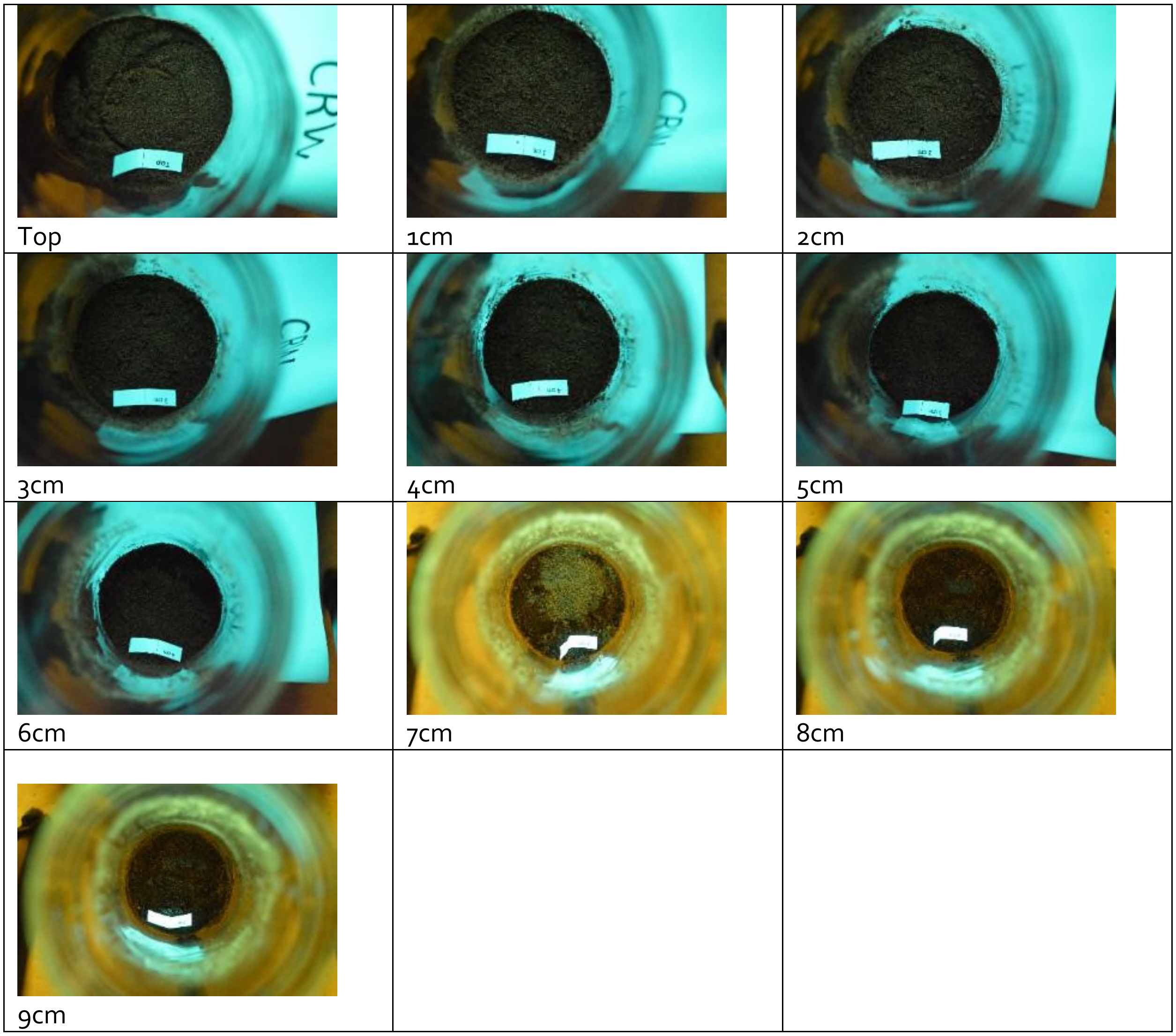


Figure E-0-7: *CRW Sand*

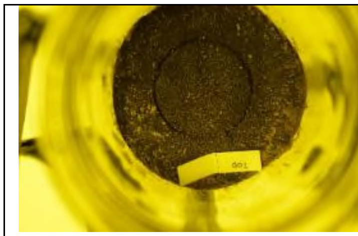
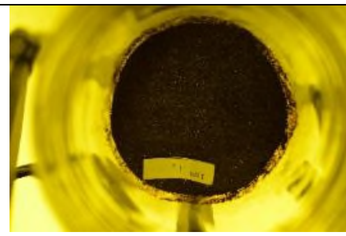
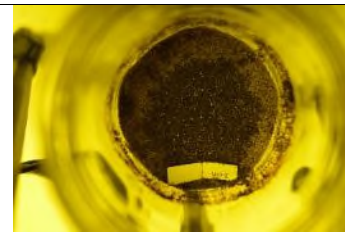
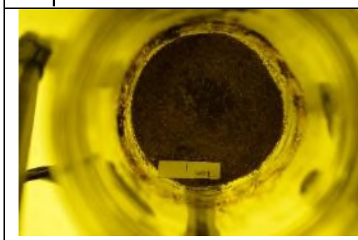
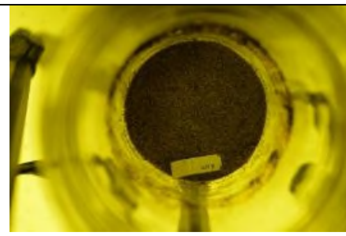
 Top	 1cm	 2cm
 3cm	 4cm	

Figure E-0-8: *HFO Sand*

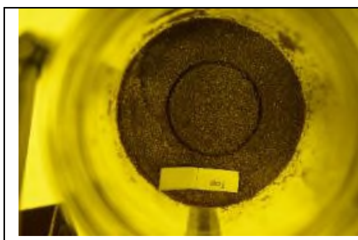
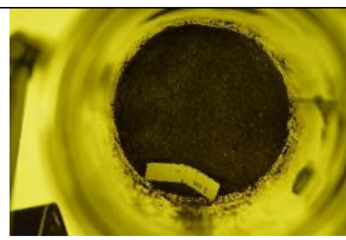
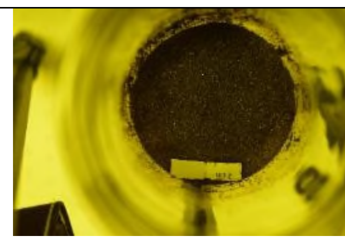
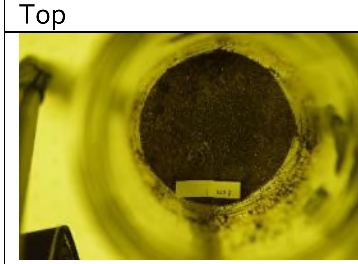
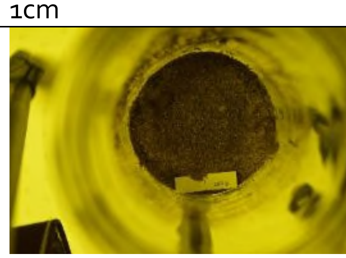
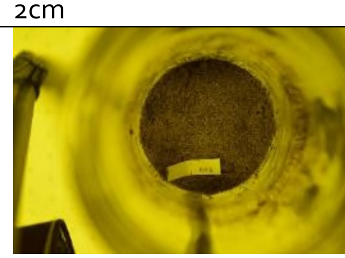
 Top	 1cm	 2cm
 3cm	 4cm	 5cm

Figure E-0-9: *LSB Sand*

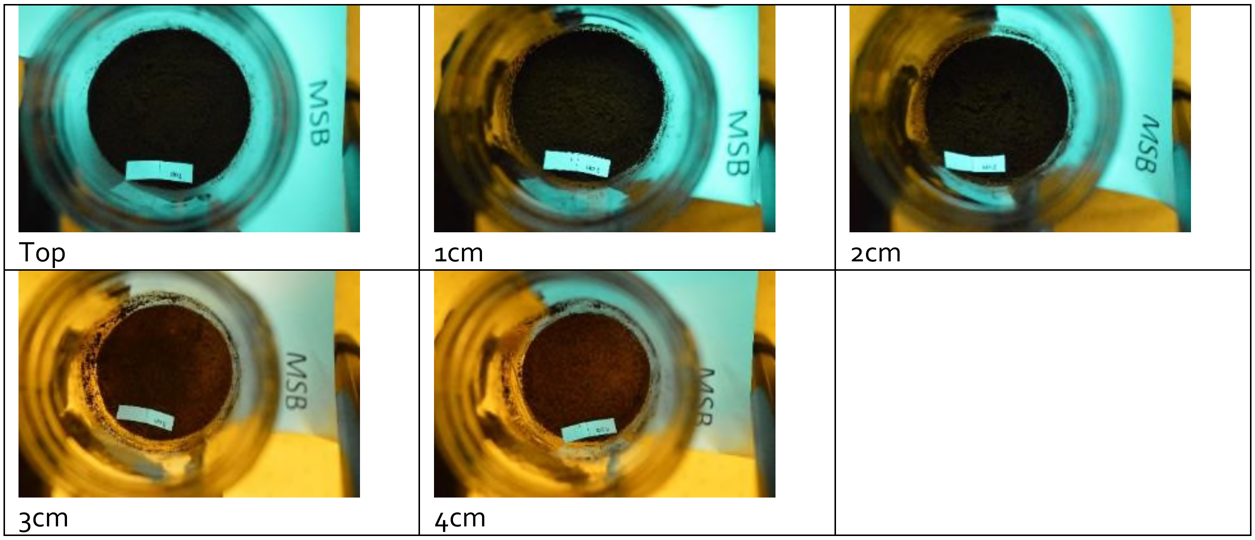


Figure E-0-10: *MSB Sand*

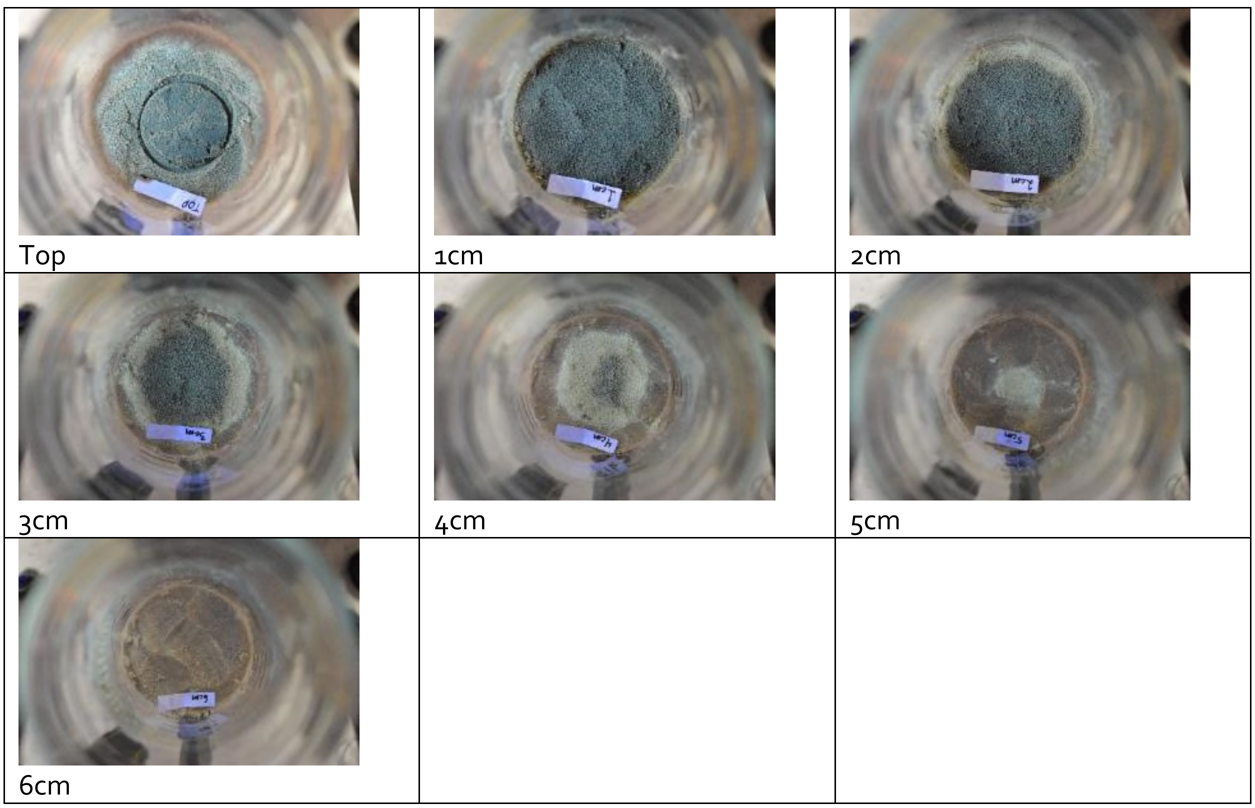


Figure E-0-11: *MSB Sand (Silica Grade 70)*

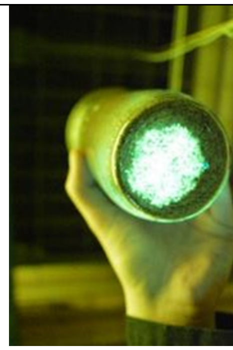
	 Bottom of test vessel	

Figure E-0-12: *NDB Sand*

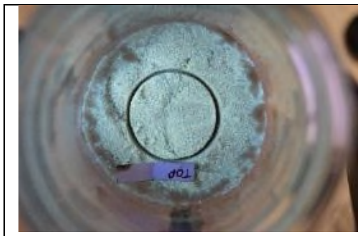
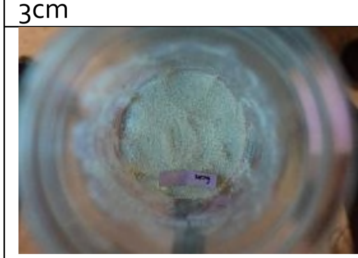
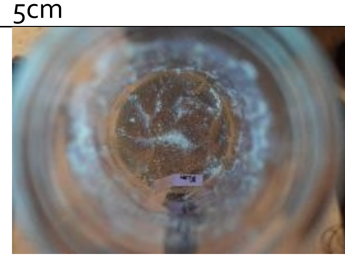
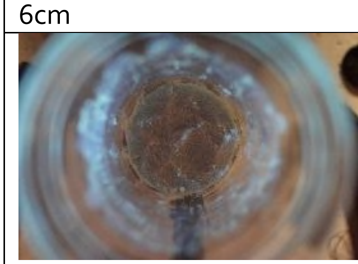
 Top	 1cm	 2cm
 3cm	 4cm	 5cm
 6cm	 7cm	 8cm
 9cm halo from glass		

Figure E-0-13: *NDB Sand (Silica Grade 70)*

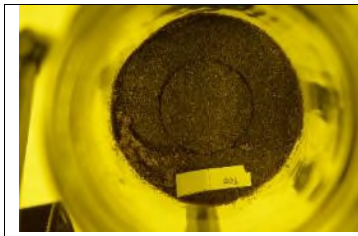
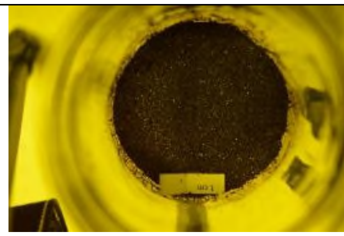
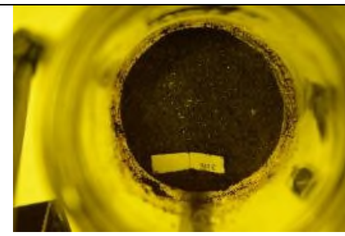
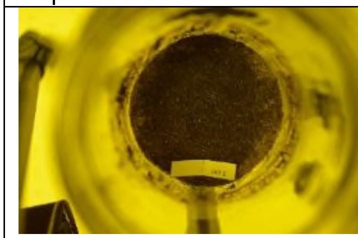
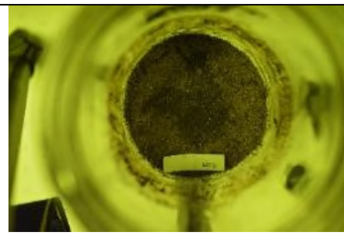
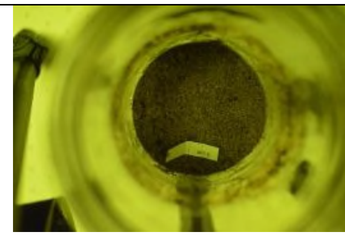
 Top	 1cm	 2cm
 3cm	 4cm	 5cm

Figure E-0-14: *SYB Sand*

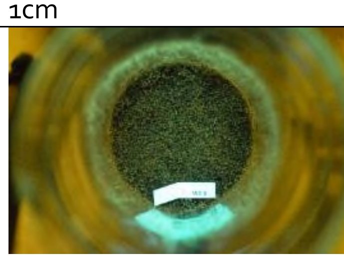
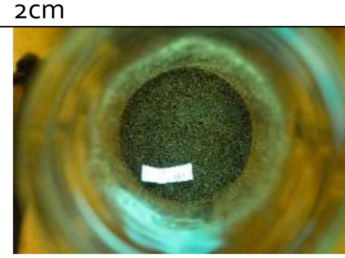
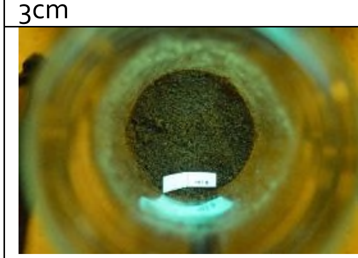
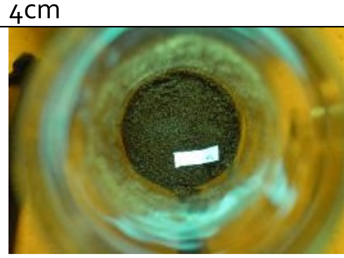
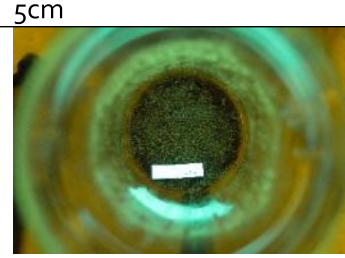
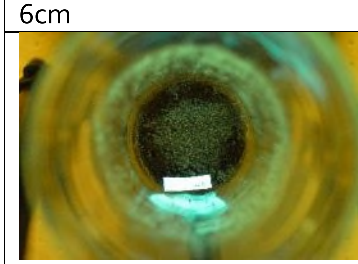
 Top	 1cm	 2cm
 3cm	 4cm	 5cm
 6cm	 7cm	 8cm
 9cm		

Figure E-0-15: *SYN Sand*

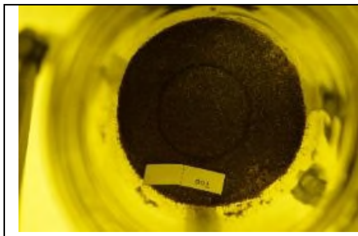
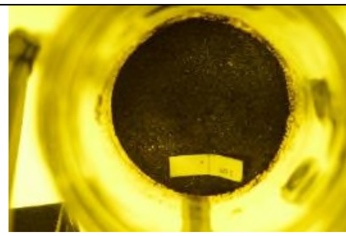
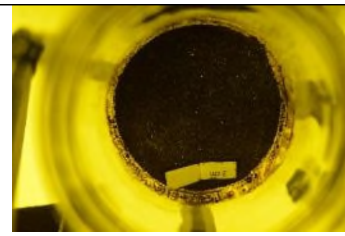
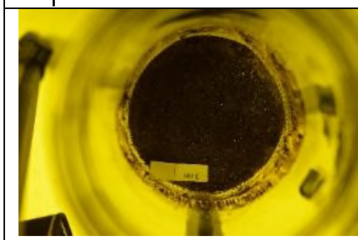
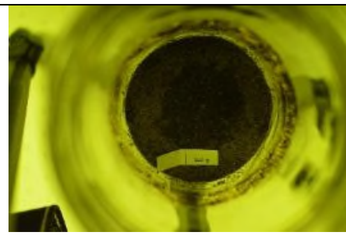
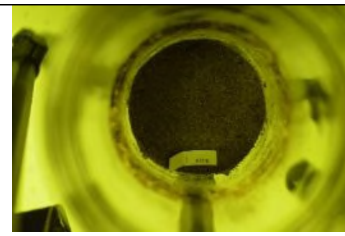
 Top	 1cm	 2cm
 3cm	 4cm	 5cm

Figure E-0-16: *WSC Sand*

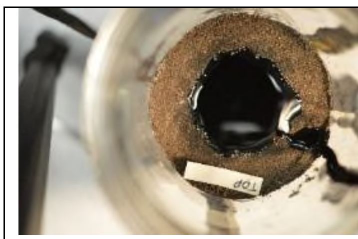
 Top	 1cm	 2cm
 3cm		

Figure E-0-17: *AHS AS*

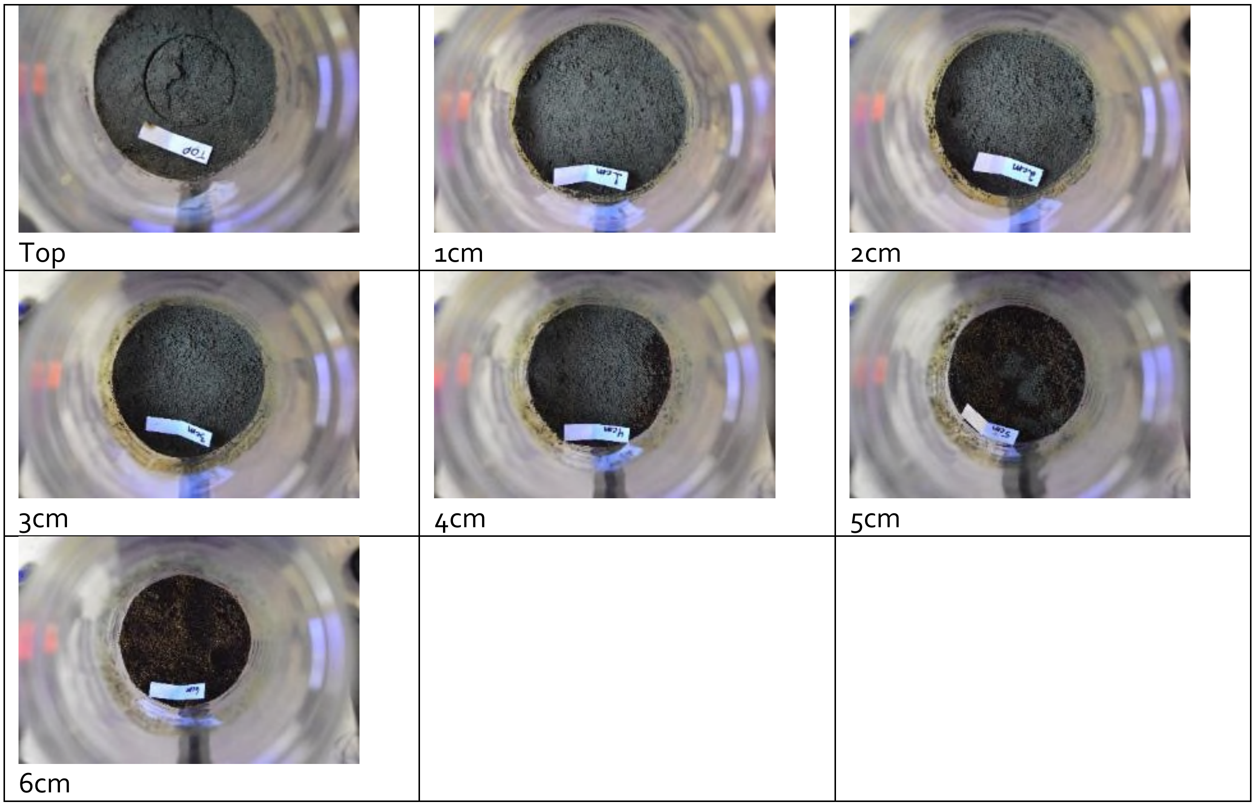


Figure E-0-18: *ANS AS*

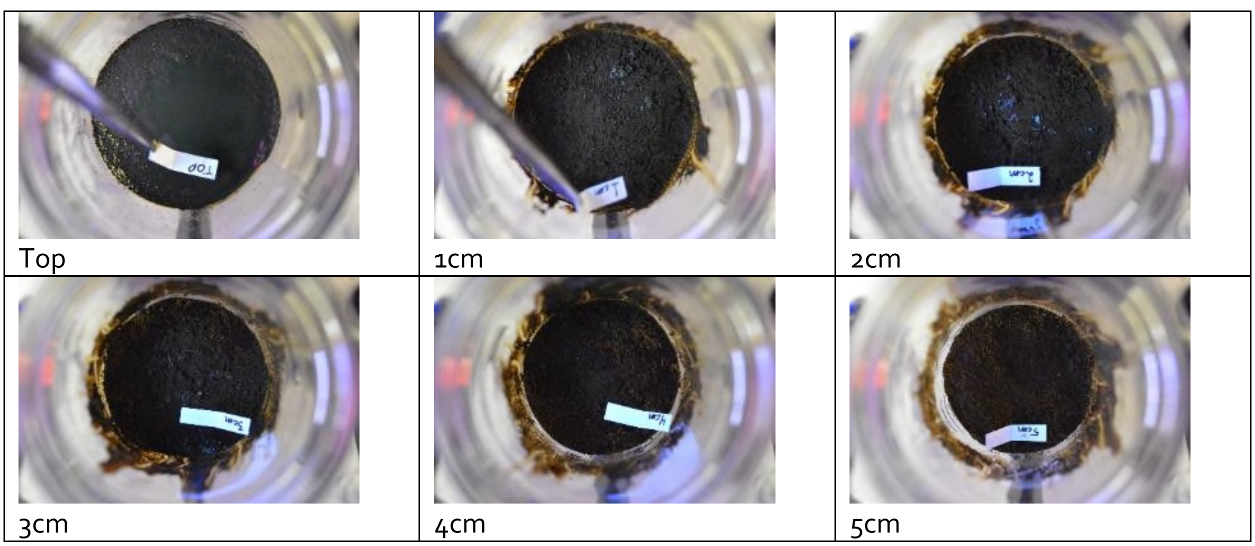


Figure E-0-19: *AWB AS*

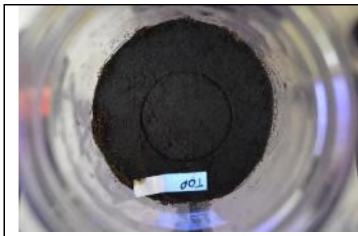
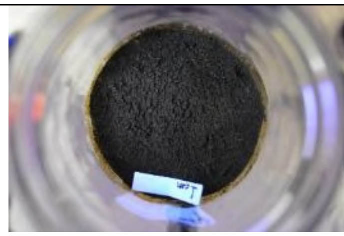
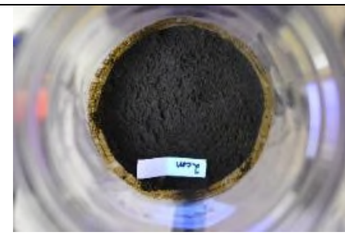
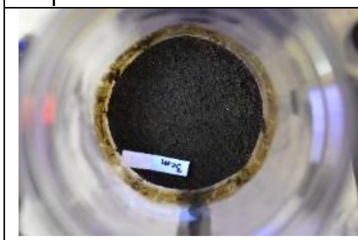
 Top	 1cm	 2cm
 3cm	 4cm	

Figure E-0-20: *CHV AS*

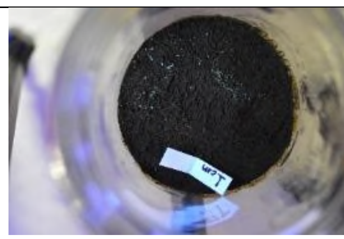
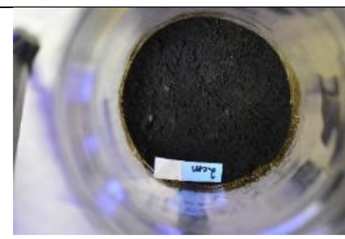
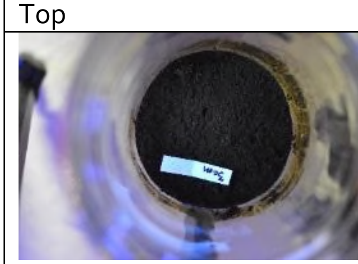
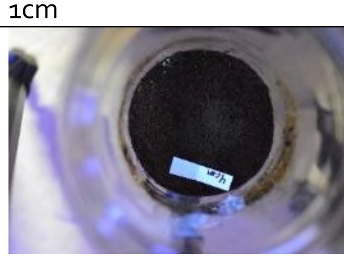
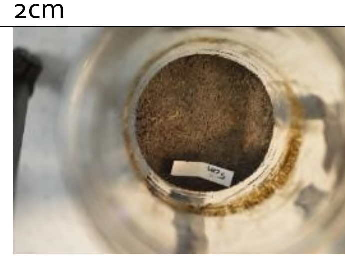
 Top	 1cm	 2cm
 3cm	 4cm	 5cm

Figure E-0-21: *CLB AS*

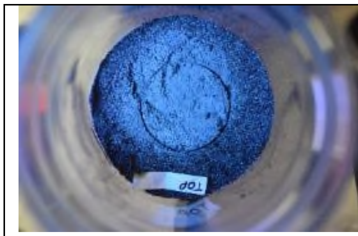
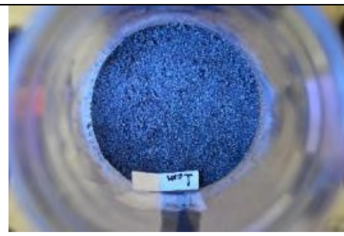
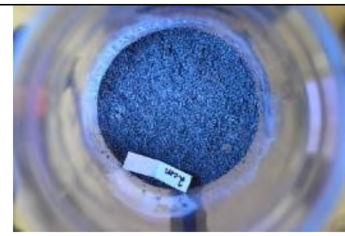
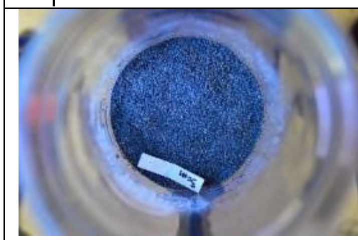
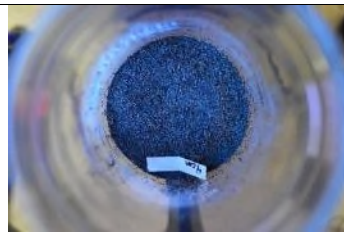
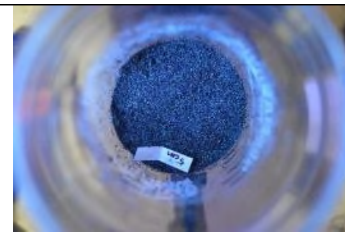
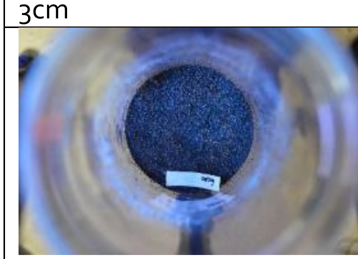
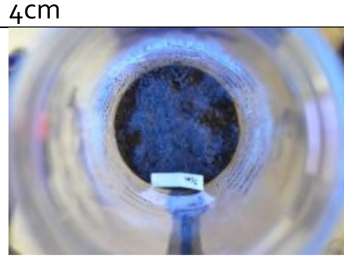
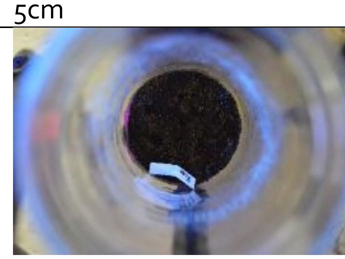
 Top	 1cm	 2cm
 3cm	 4cm	 5cm
 6cm	 7cm	 8cm

Figure E-0-22: *CRW AS*

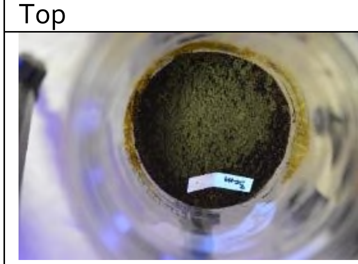
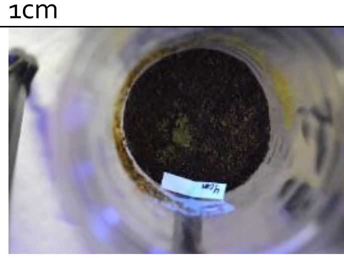
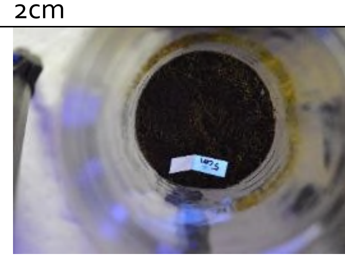
 Top	 1cm	 2cm
 3cm	 4cm	 5cm

Figure E-0-23: *HFO AS*

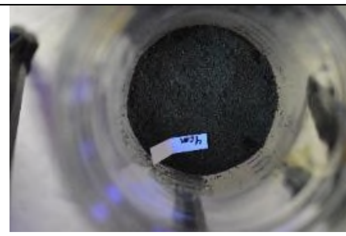
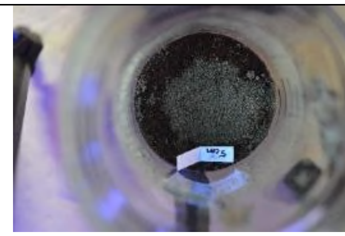
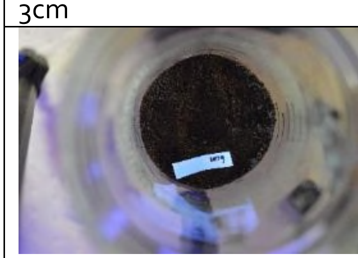
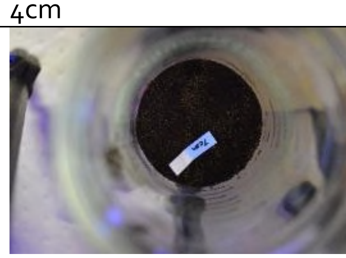
 Top	 1cm	 2cm
 3cm	 4cm	 5cm
 6cm	 7cm	

Figure E-0-24: *LSB AS*

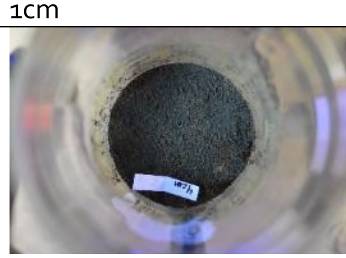
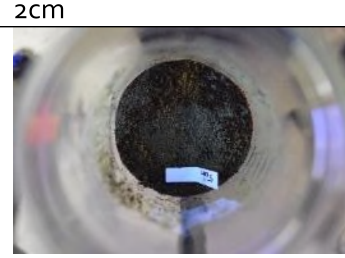
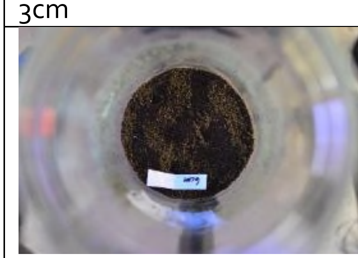
 Top	 1cm	 2cm
 3cm	 4cm	 5cm
 6cm		

Figure E-0-25: *MSB AS*

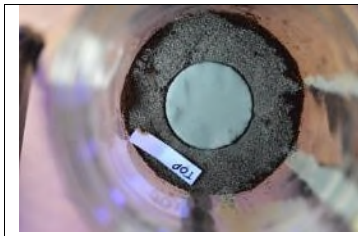
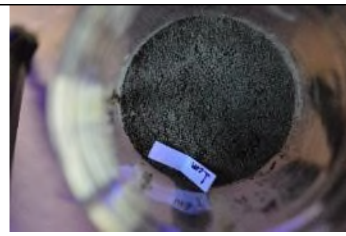
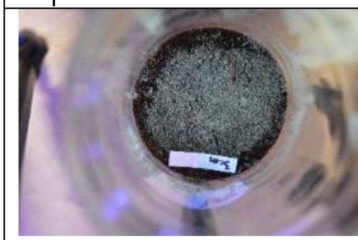
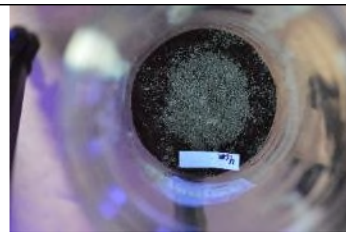
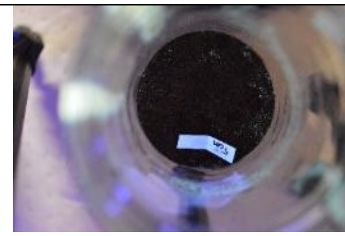
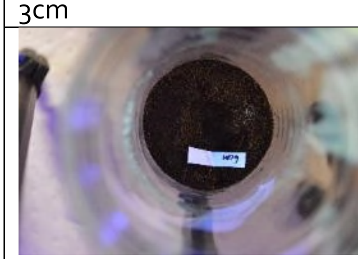
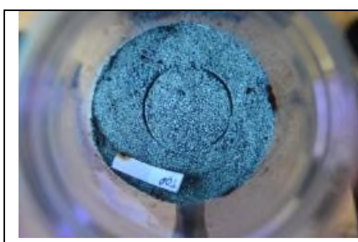
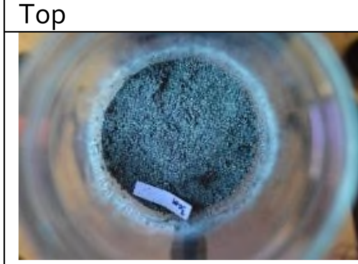
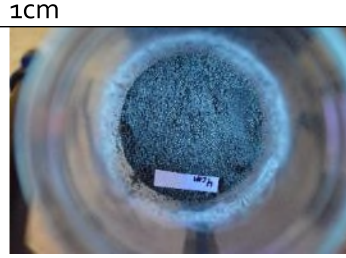
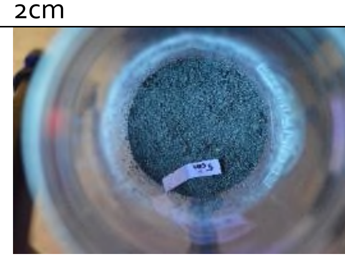
 Top	 1cm	 2cm
 3cm	 4cm	 5cm
 6cm		

Figure E-0-26: *MSW AS*

 Top	 1cm	 2cm
 3cm	 4cm	 5cm

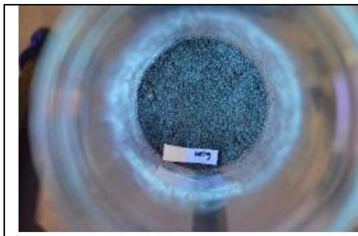
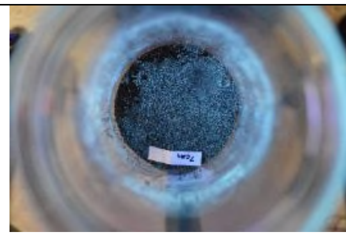
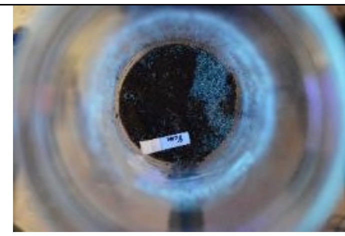
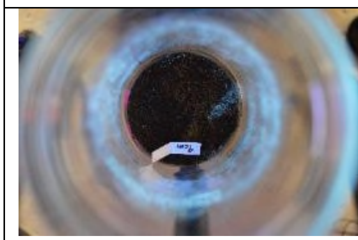
 6cm	 7cm	 8cm
 9cm		

Figure E-0-27: *NDB AS*

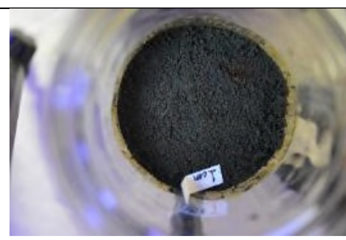
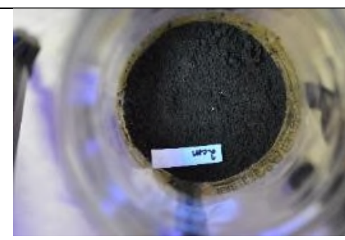
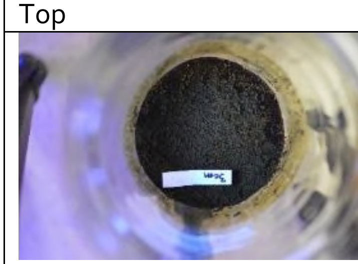
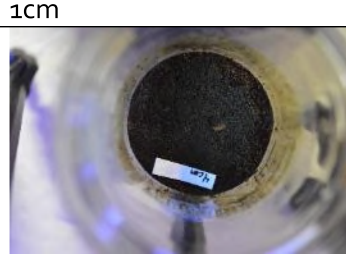
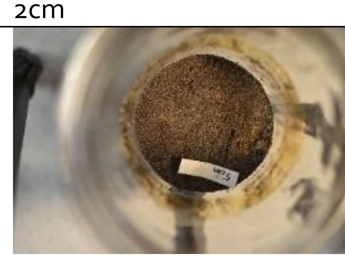
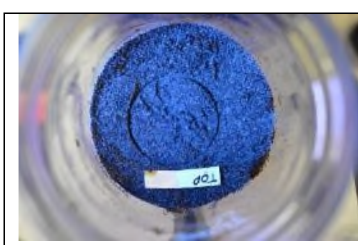
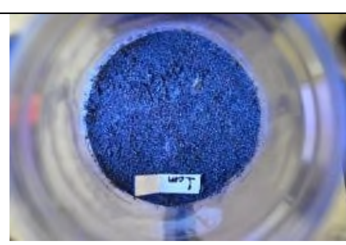
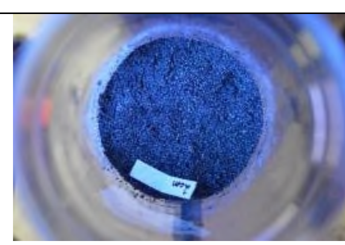
 Top	 1cm	 2cm
 3cm	 4cm	 5cm

Figure E-0-28: *SYB AS*

 Top	 1cm	 2cm

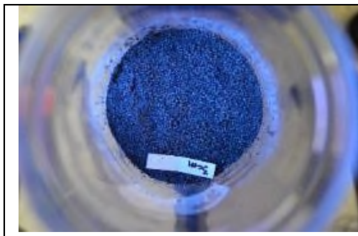
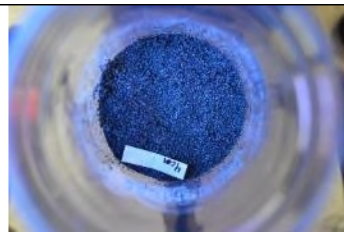
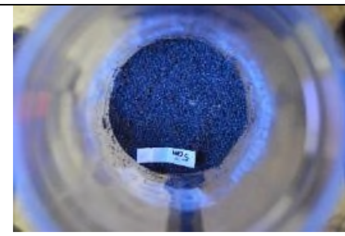
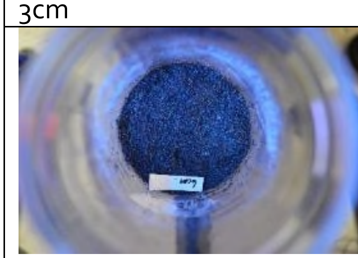
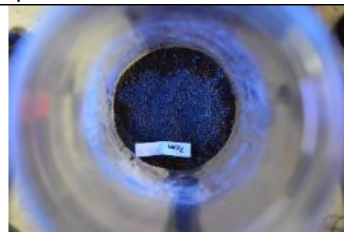
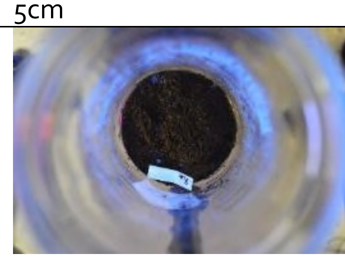
 3cm	 4cm	 5cm
 6cm	 7cm	 8cm

Figure E-0-29: *SYN AS*

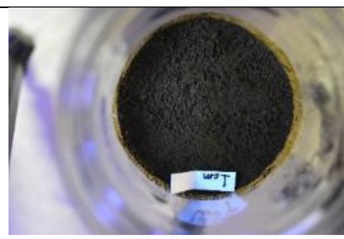
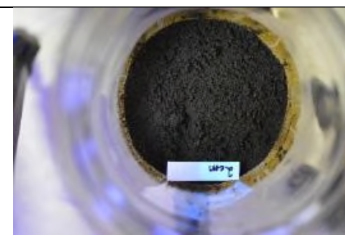
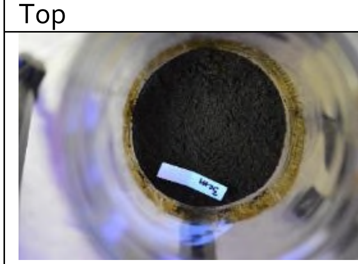
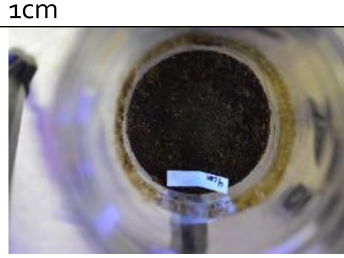
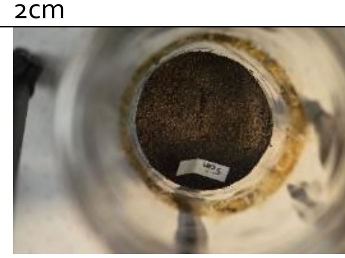
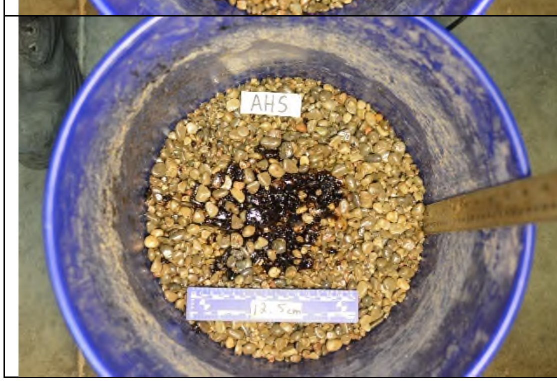
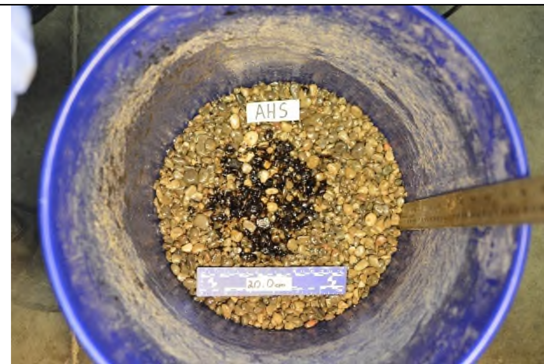
 Top	 1cm	 2cm
 3cm	 4cm	 5cm

Figure E-0-30: *WCS AS*

Photos from Large Bench Scale Tests

AHS Test with Pebbles





ANS Test with PEBBLES


ANS
5.0cm

ANS
7.5cm

ANS
12.5cm

ANS
15.0cm

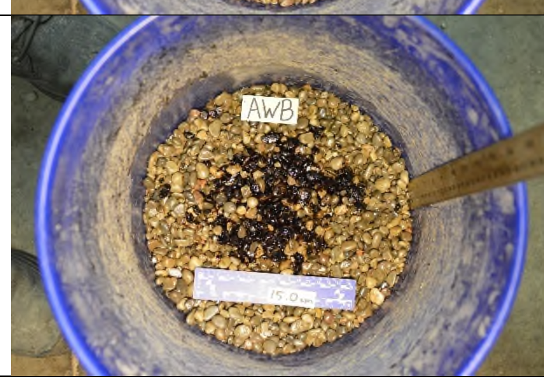
ANS
17.5cm

ANS
20.0cm

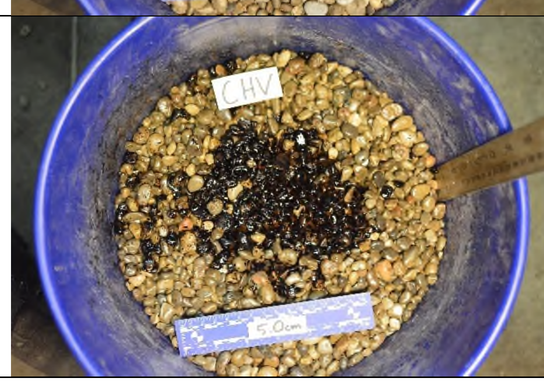
ANS
22.5cm

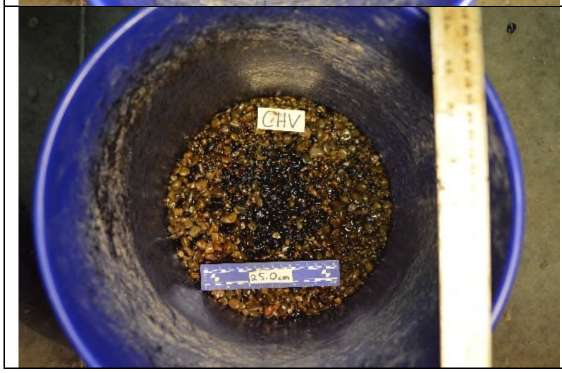
ANS
25.0cm

AWB Test in PEBBLES



CHV Test with PEBBLES





CLB Test in PEBBLES


CLB

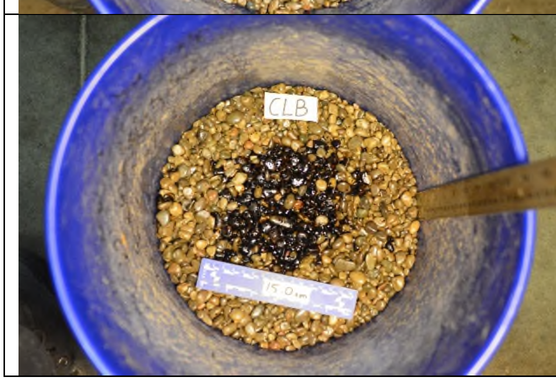

CLB
Top


CLB
2.5cm


CLB
5.0cm


CLB
7.5cm


CLB
10.0cm


CLB
15.0cm


CLB
17.5cm

CRW Test in PEBBLES


CRW
7.5cm


CRW
10.0cm


CRW
12.5cm


CRW
15.0cm

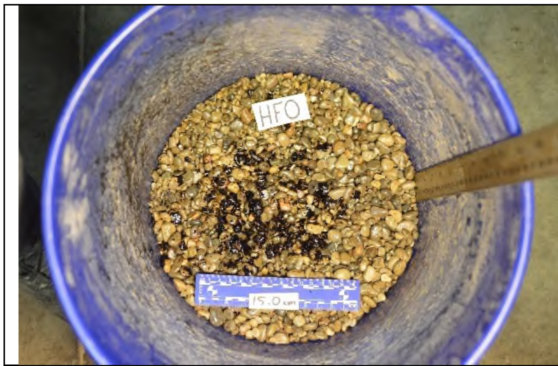

CRW
17.5cm


CRW
20.0cm


CRW
22.5cm

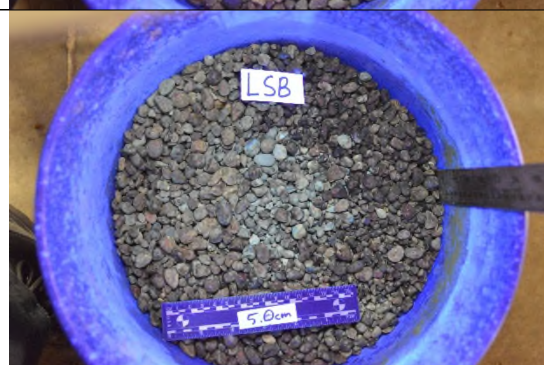

CRW
25.0cm

HFO Test in PEBBLES

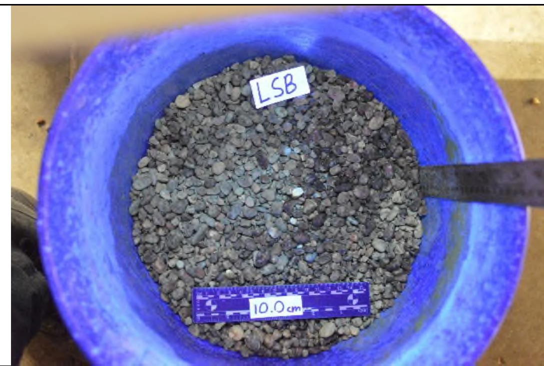
	
	
	

LSB Test in PEBBLES

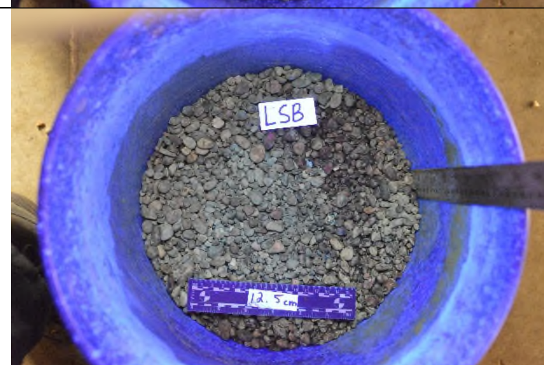
	

LSB Top	LSB Top
LSB 2.5cm	LSB 2.5cm
LSB 5.0cm	LSB 5.0cm
LSB 7.5cm	LSB 7.5cm


LSB
10.0cm


LSB
10.0cm


LSB
12.5cm

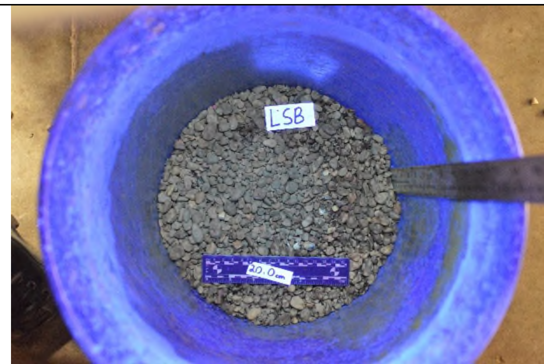

LSB
12.5cm

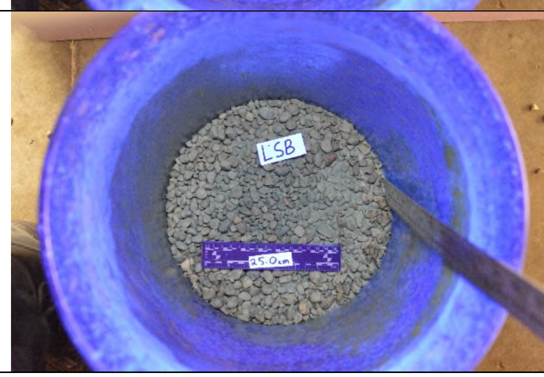

LSB
15.0cm


LSB
15.0cm


LSB
17.5cm


LSB
17.5cm





MSB Test in PEBBLES


MSB
2.5cm


MSB
5.0cm


MSB
7.5cm


MSB
10.0cm

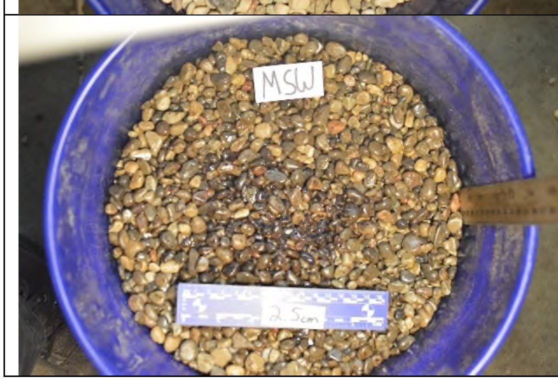

MSB
12.5cm


MSB
15.0cm


MSB
17.5cm


MSB
20.0cm

MSW Test in PEBBLES




MSW
7.5 cm


MSW
10.0 cm


MSW
12.5 cm


MSW
15.0 cm


MSW
17.5 cm

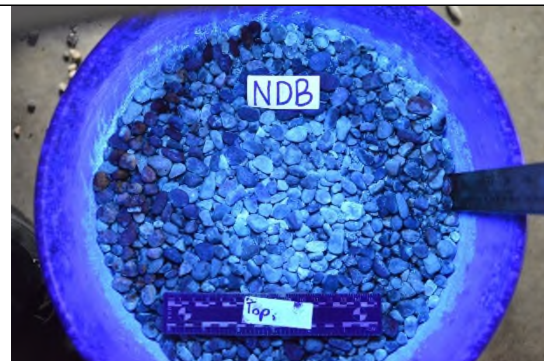

MSW
20.0 cm


MSW
22.5 cm


MSW
25.0 cm

NDB Test in PEBBLES

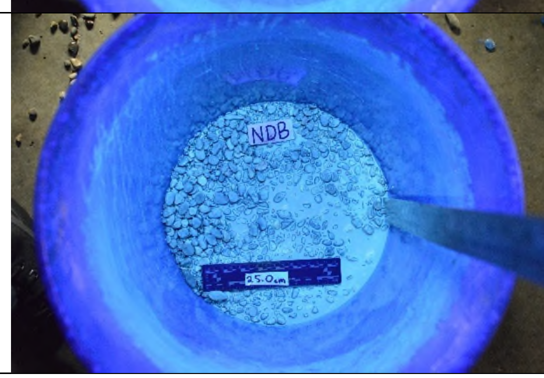

NDB
12.5 cm

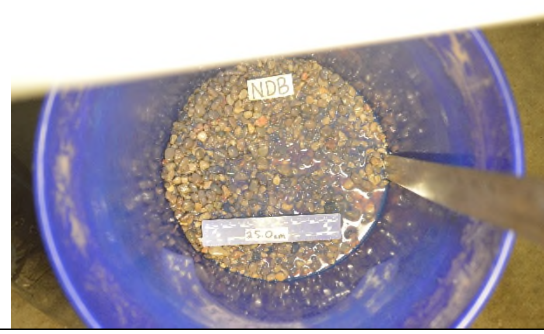

NDB
15.0 cm


NDB
17.5 cm

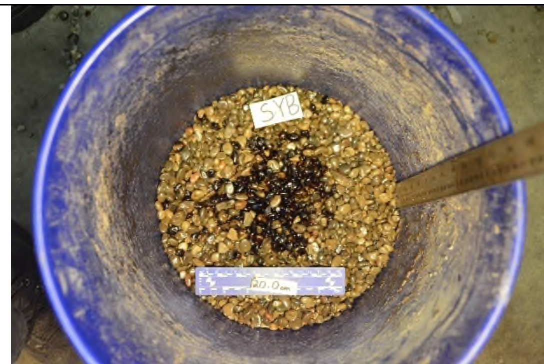

NDB
20.0 cm


NDB
22.5 cm

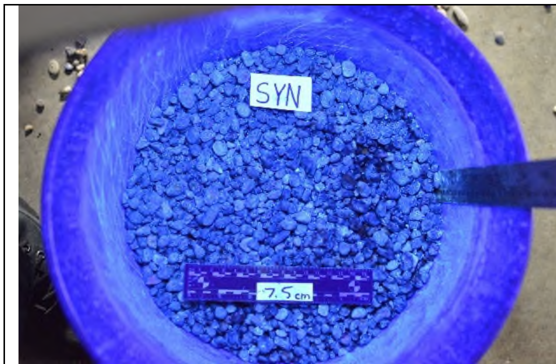

NDB
25.0 cm


NDB
25.0 cm

SYB Test in PEBBLES



SYN Test in PEBBLES


SYN
7.5cm


SYN
10.0cm

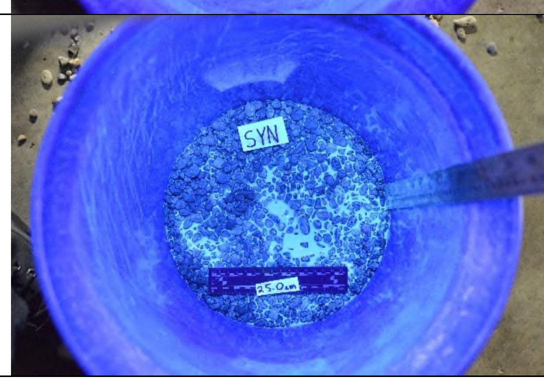

SYN
12.5cm


SYN
15.0cm

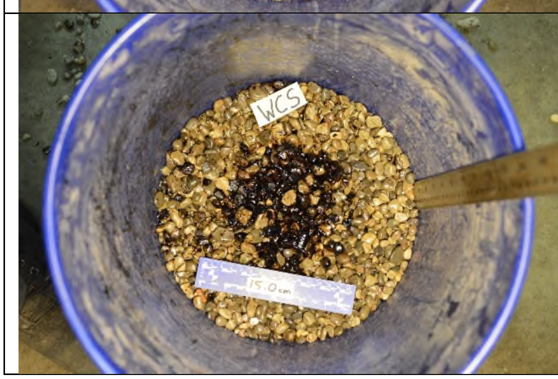

SYN
17.5cm

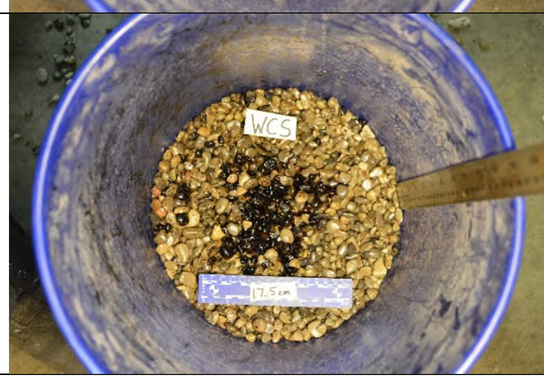

SYN
20.0cm

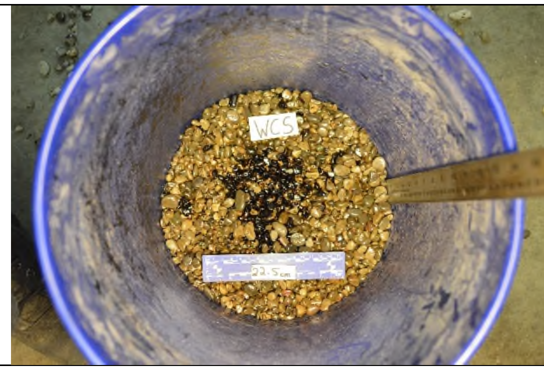

SYN
22.5cm

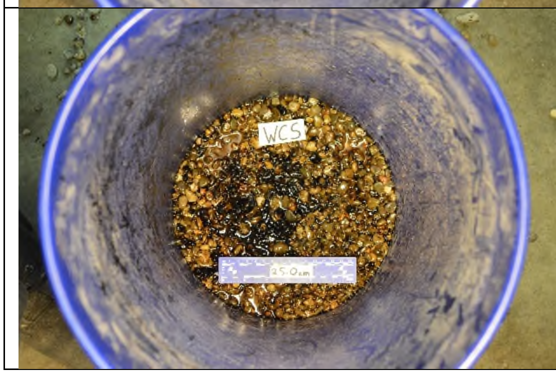

SYN
25.0cm

WCS Test in PEBBLES

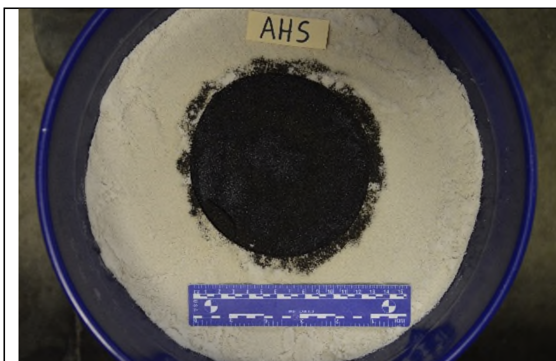


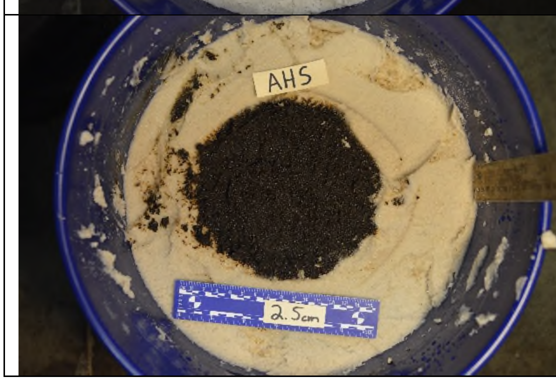


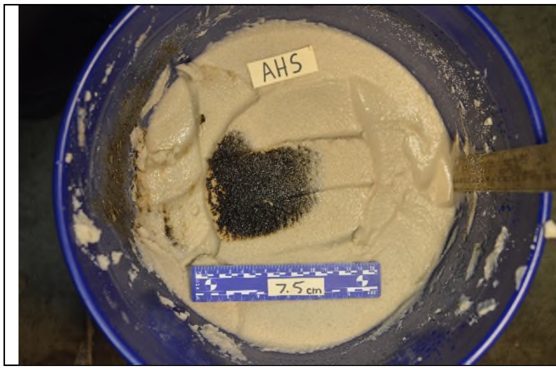




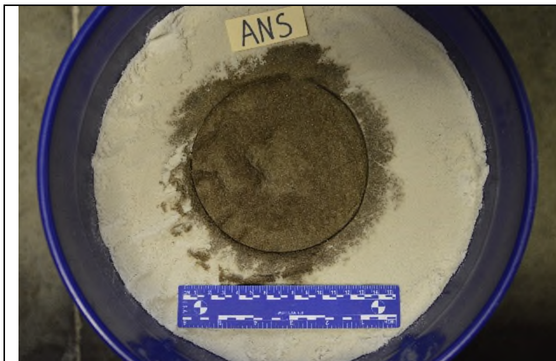
AHS Test in SAND







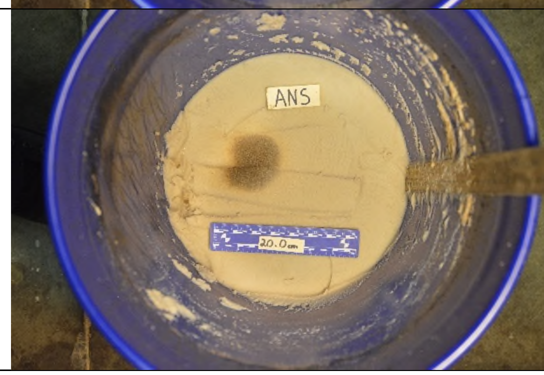
ANS Test in SAND




ANS
12.5cm

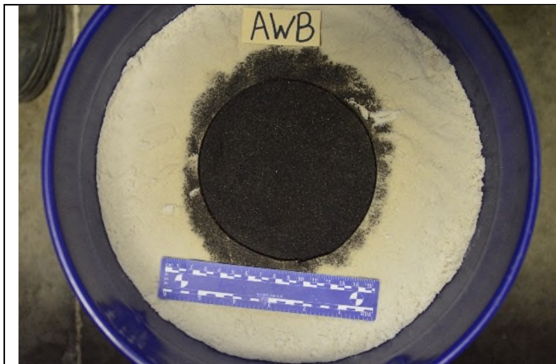

ANS
15.0cm

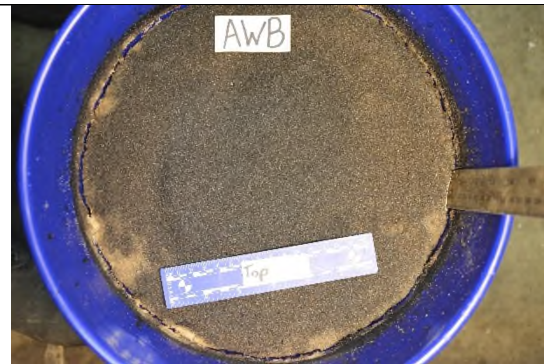

ANS
17.5cm

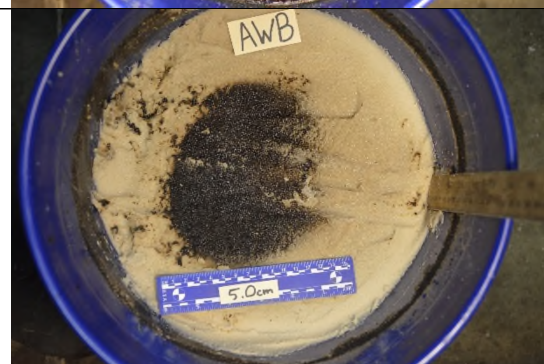

ANS
20.0cm

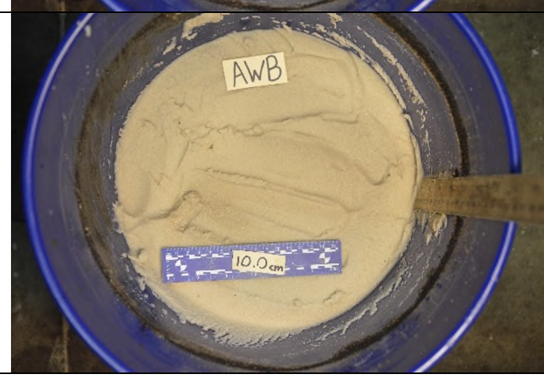

ANS
22.5cm

AWB Test in SAND

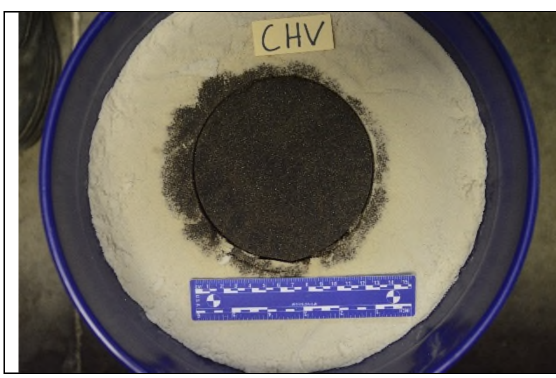


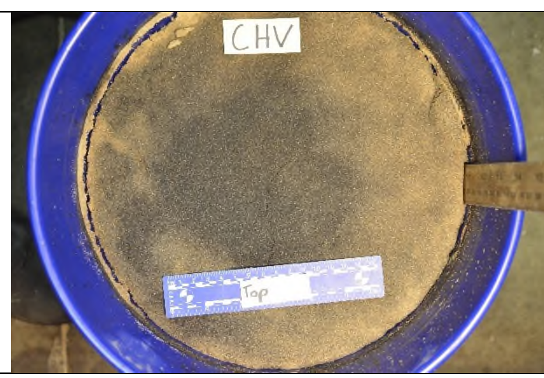


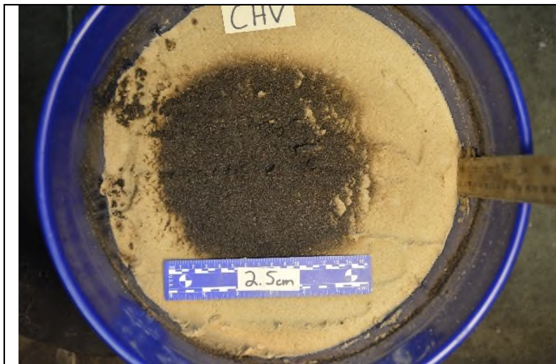


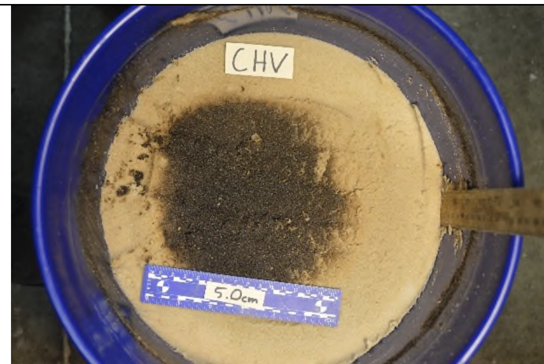


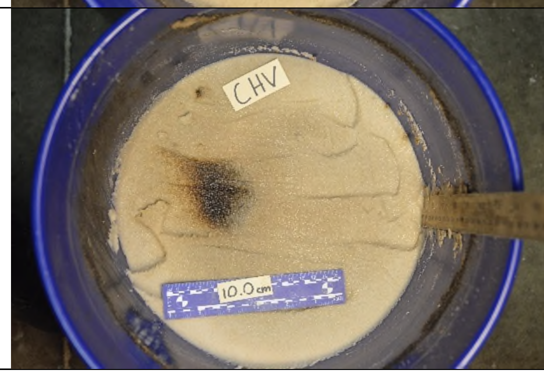
CHV Test in SAND

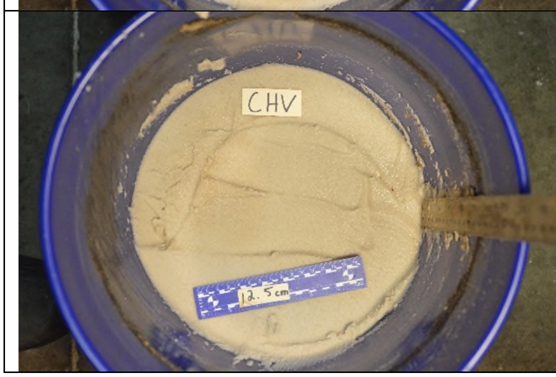




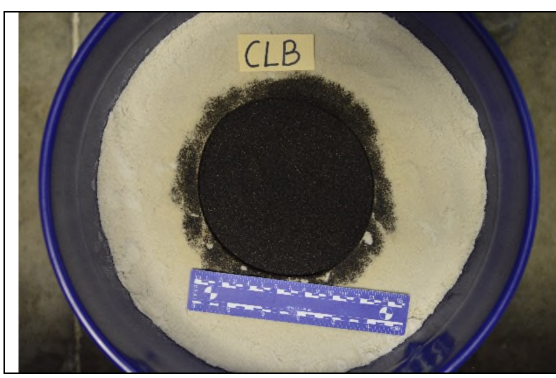


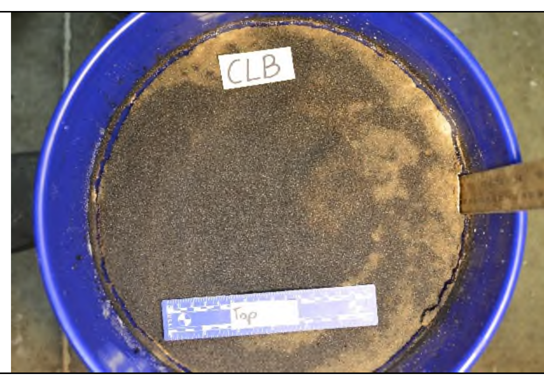


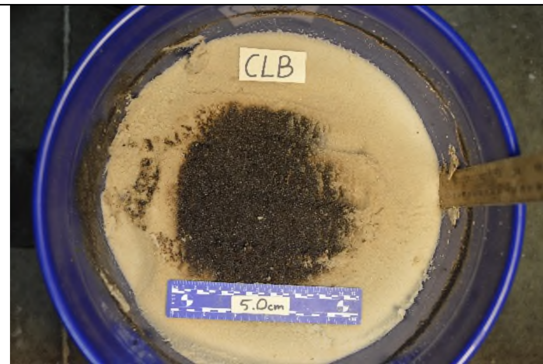


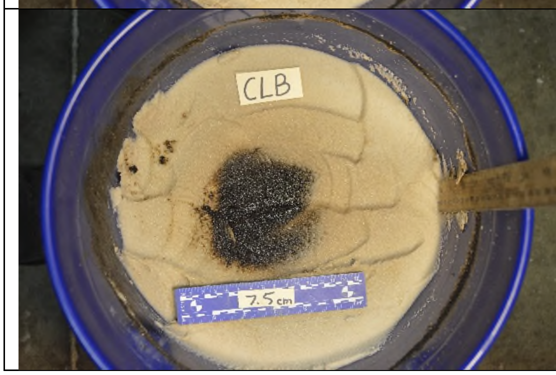


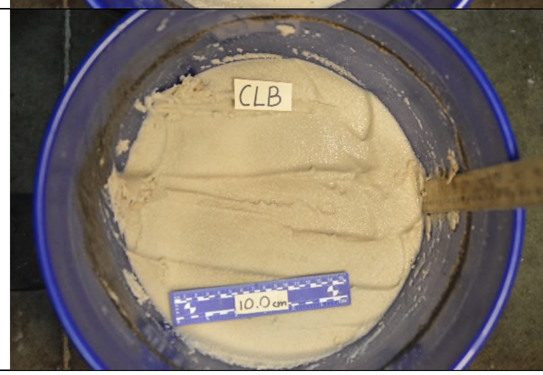
CLB Test in SAND



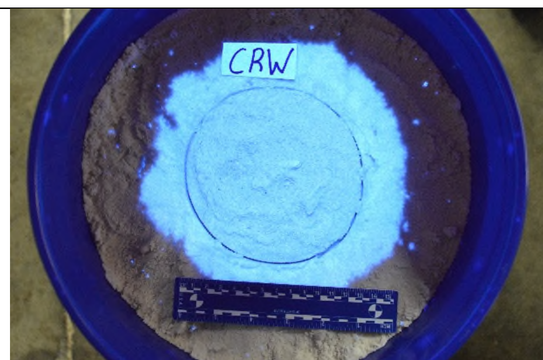


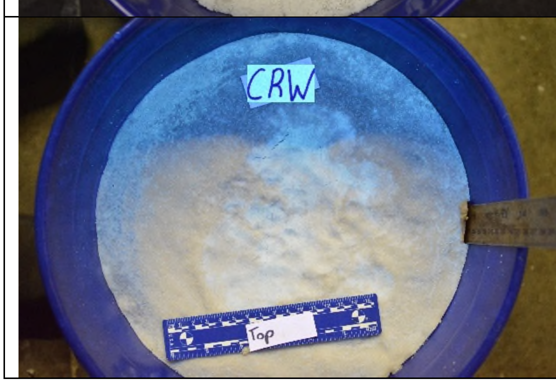


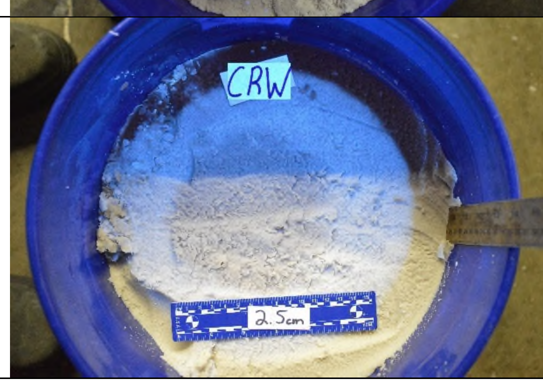


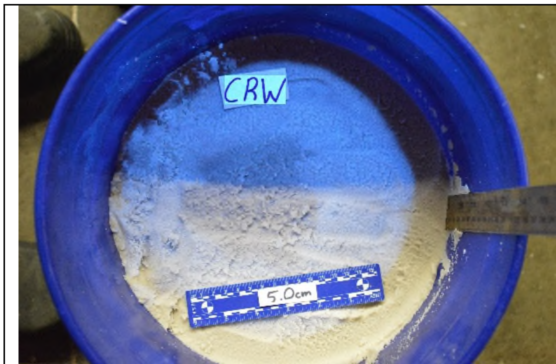


CRW Test in SAND

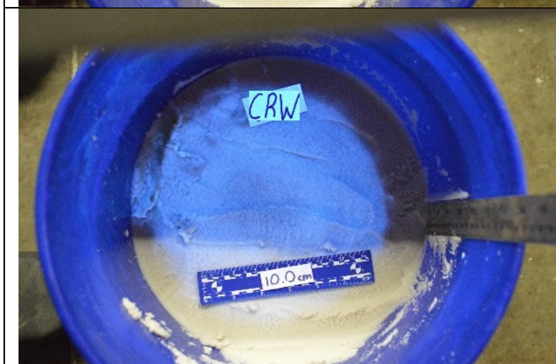







CRW
5.0cm


CRW
7.5cm


CRW
10.0cm

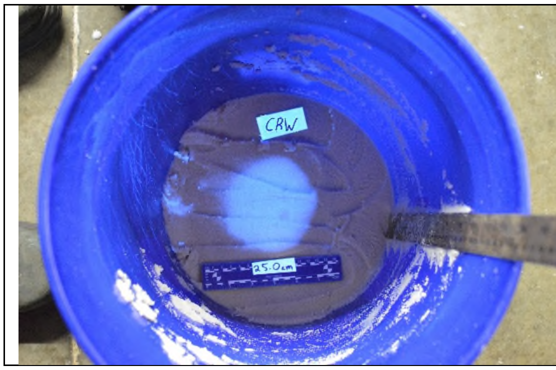

CRW
12.5cm


CRW
15.0cm

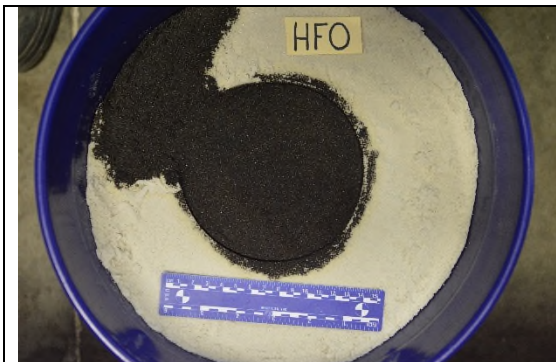

CRW
17.5cm

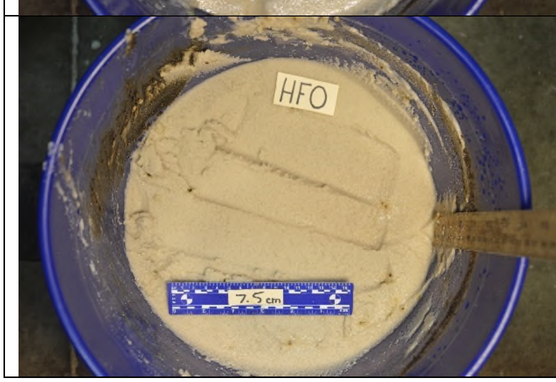

CRW
20.0cm


CRW
22.5cm

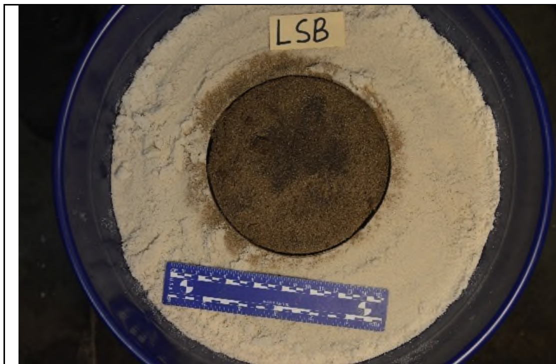


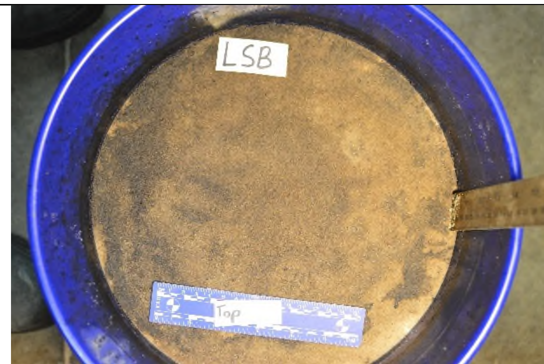
HFO Test in SAND

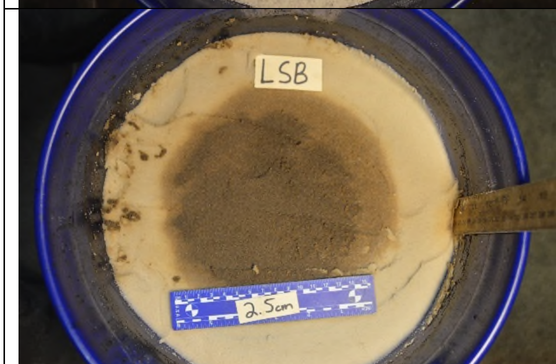


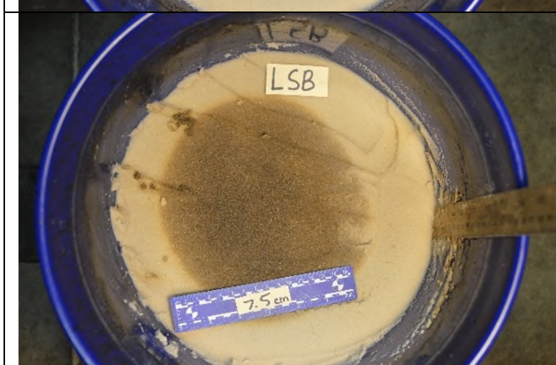


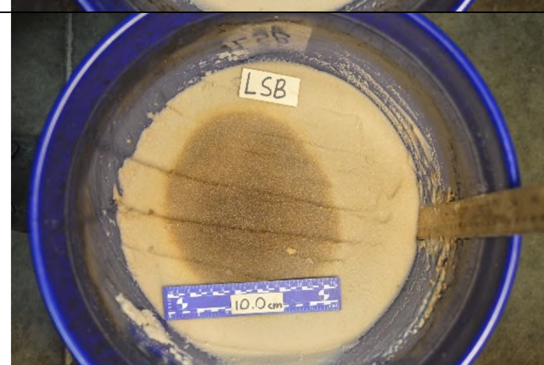
LSB Test in SAND

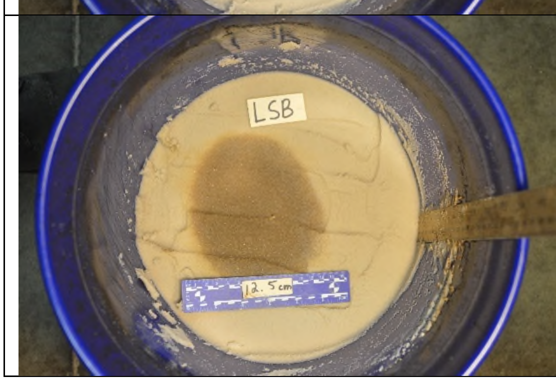


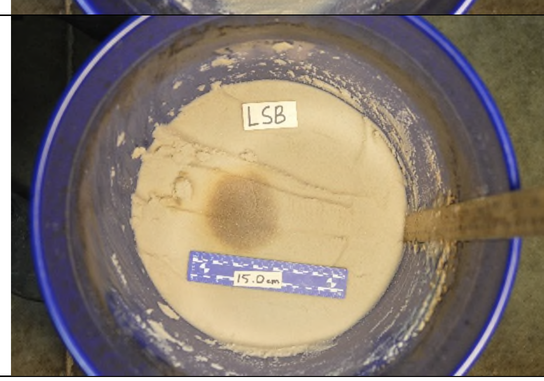


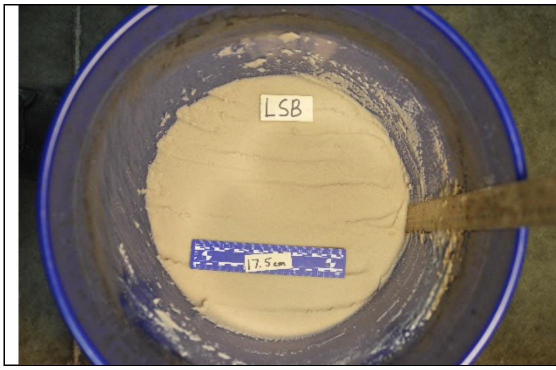




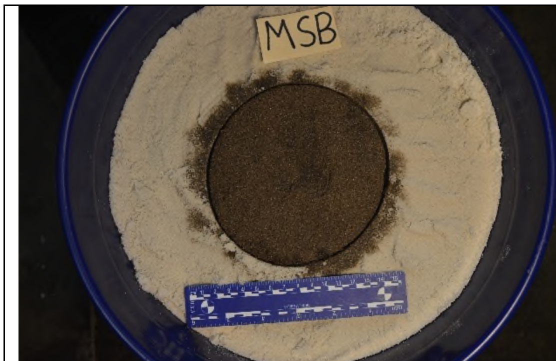


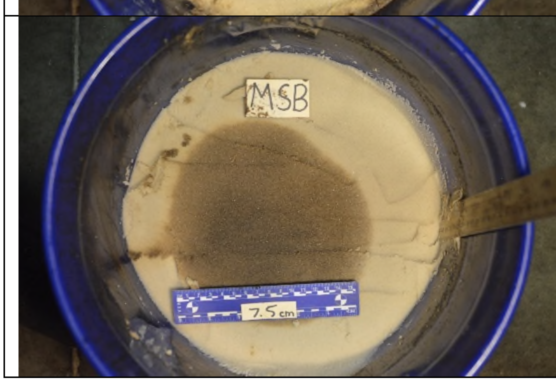


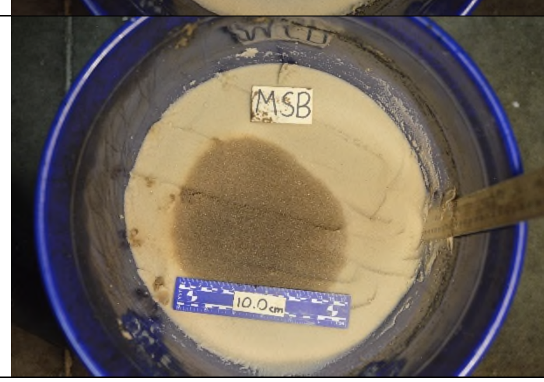


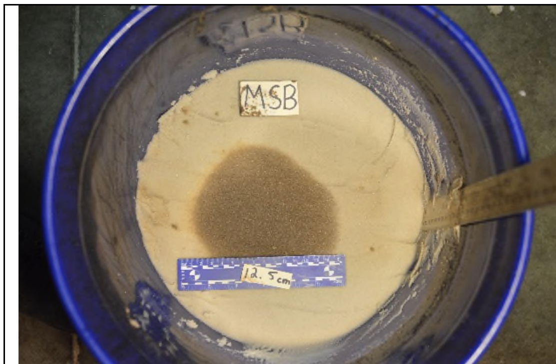


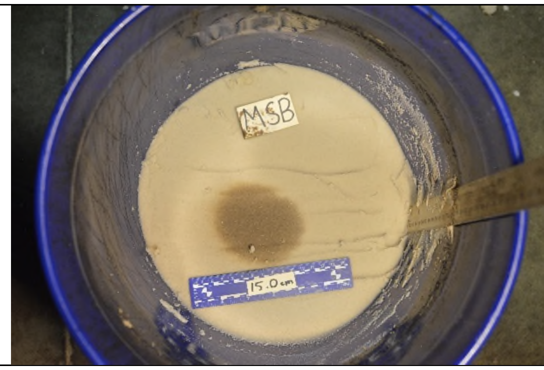
MSB Test in SAND

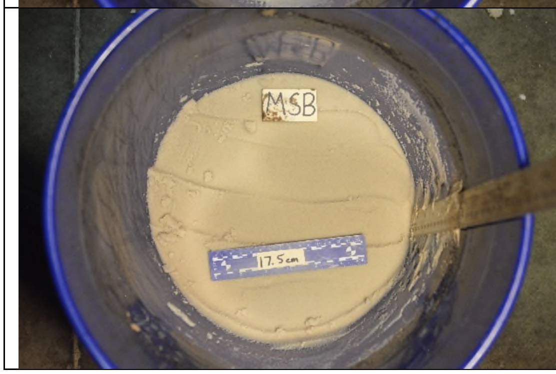




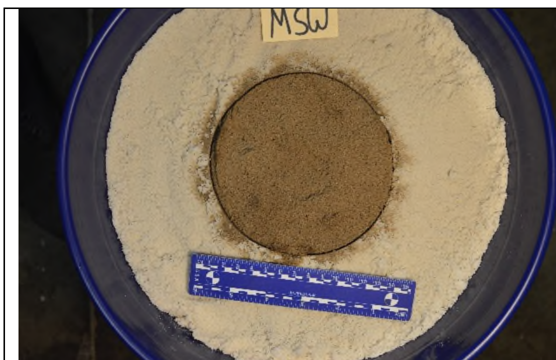


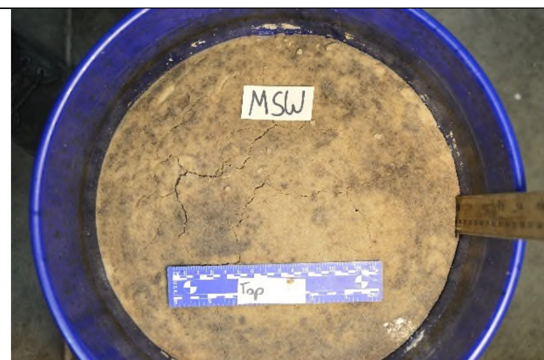


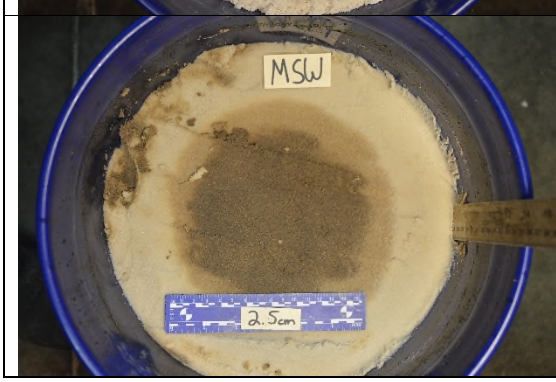


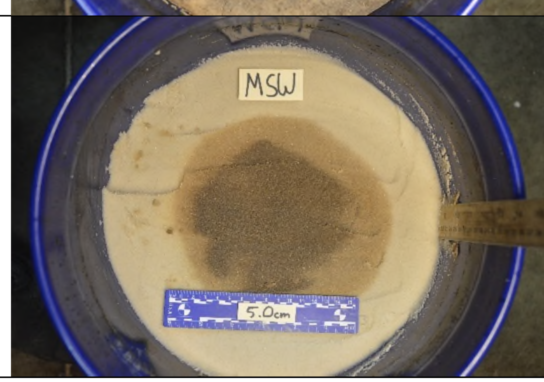


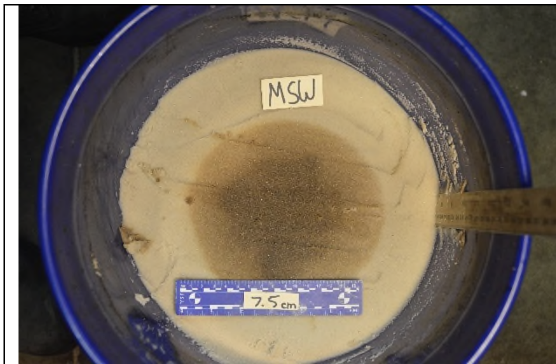
MSW Test in SAND

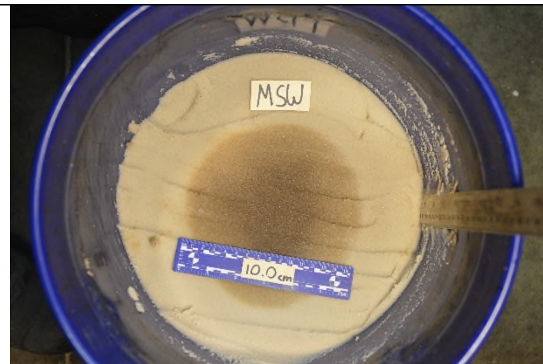


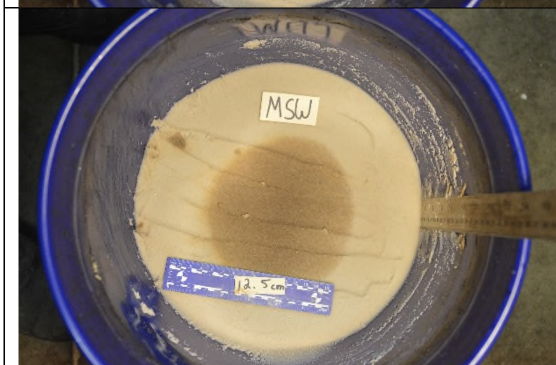


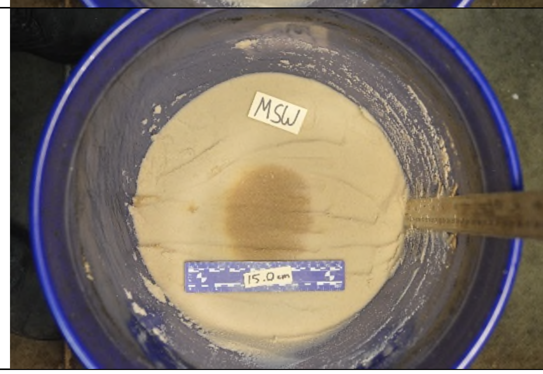


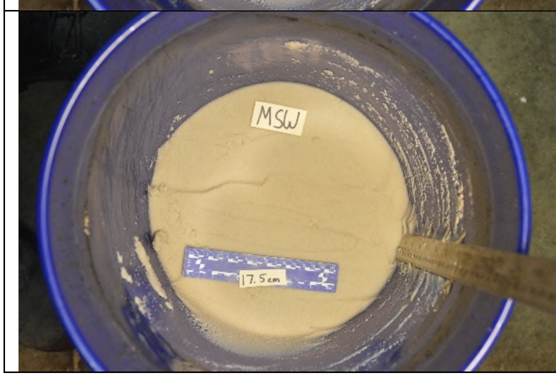




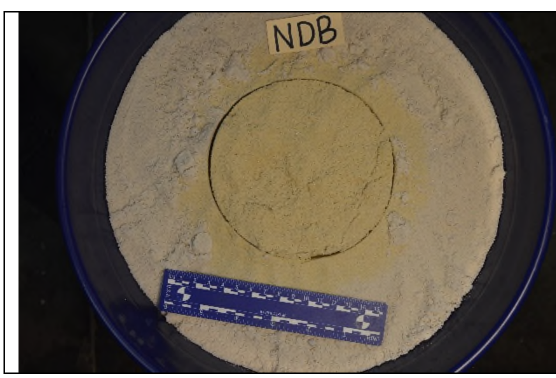


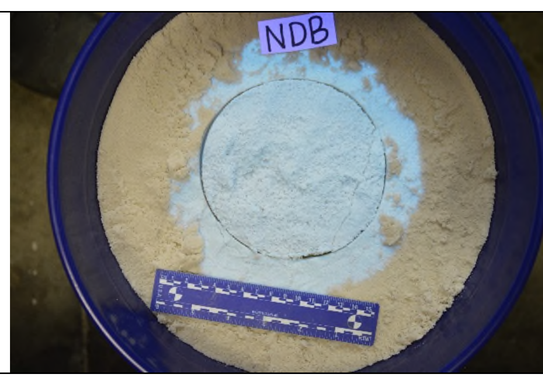


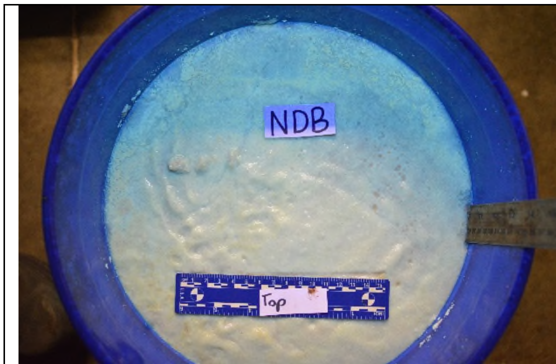
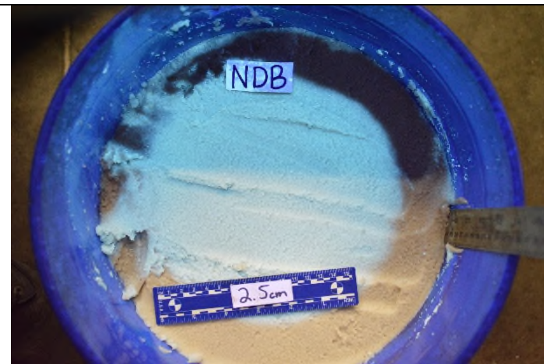
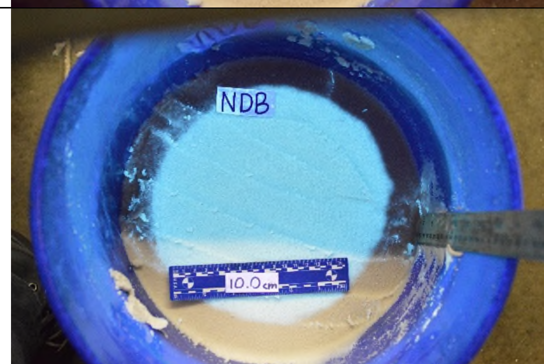
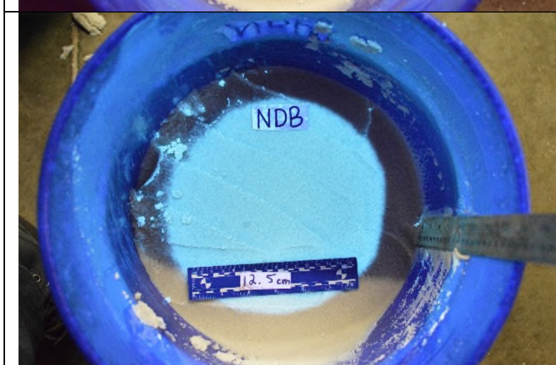
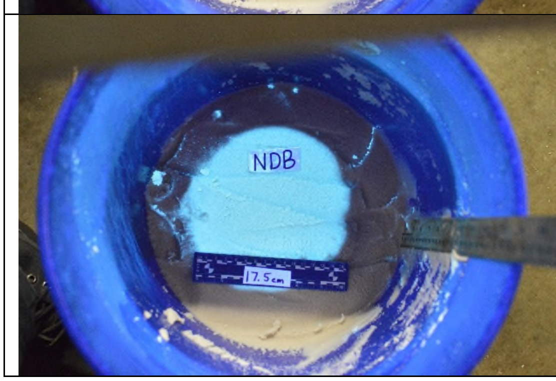


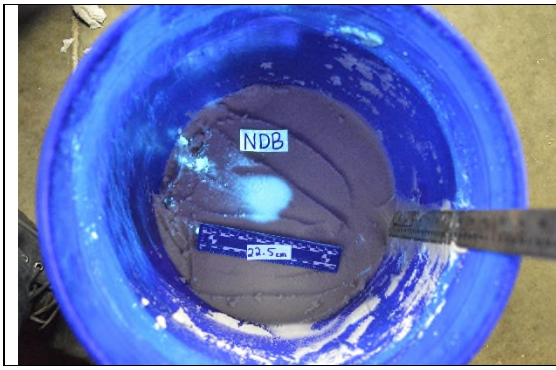


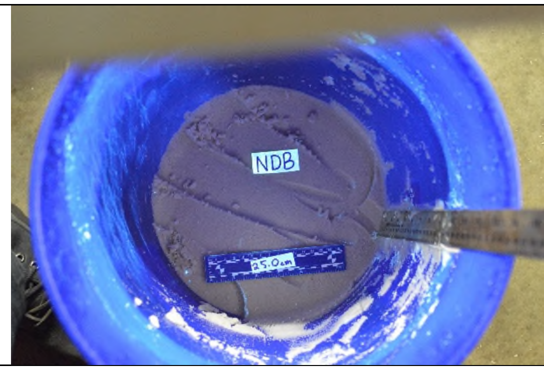
NDB Test in SAND



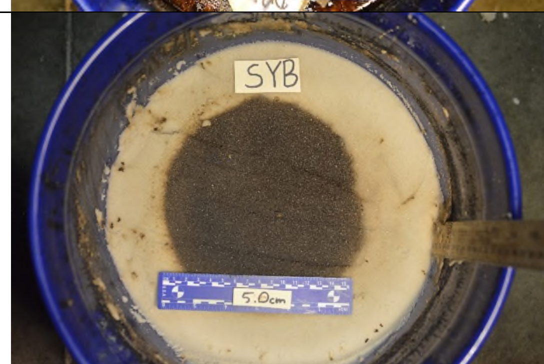


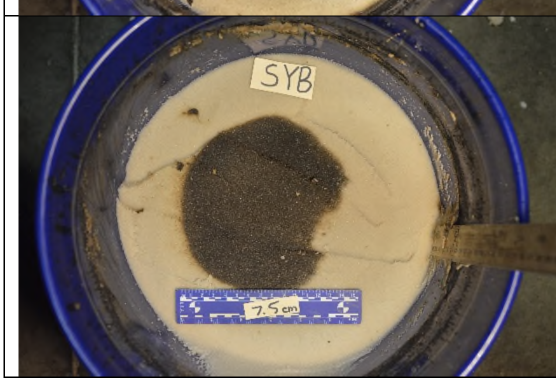
NDB Top	NDB 2.5cm
NDB 7.5cm	NDB 10.0cm
NDB 12.5cm	NDB 15.0cm
NDB 17.5cm	NDB 20.0cm

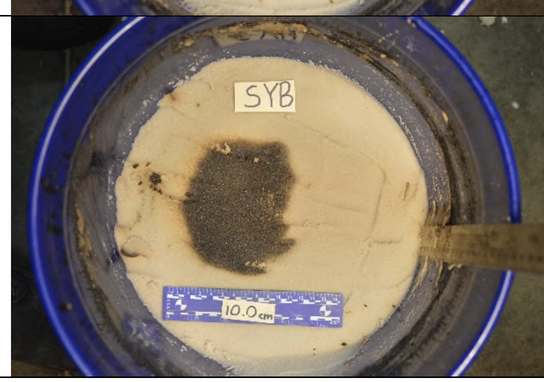


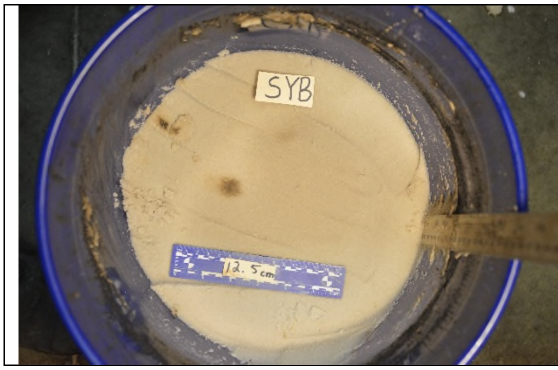


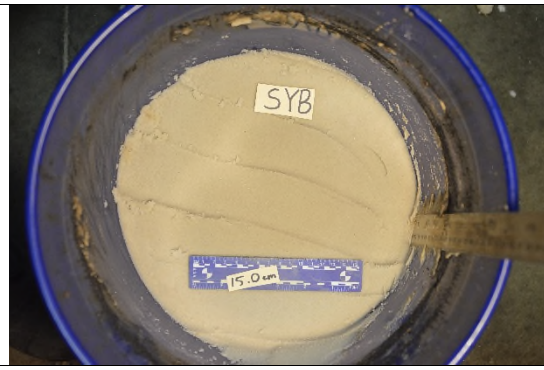
SYB Test in SAND

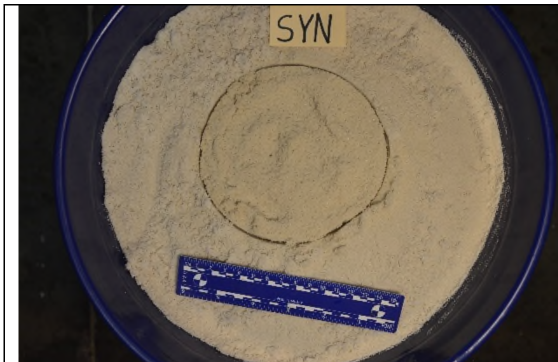


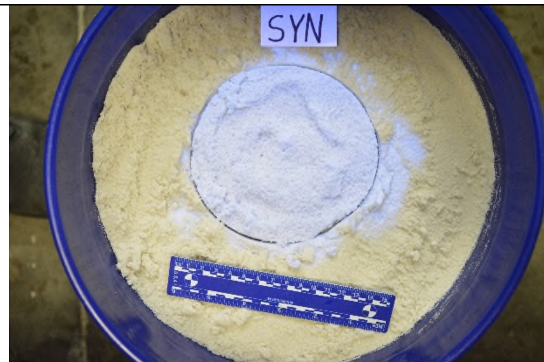


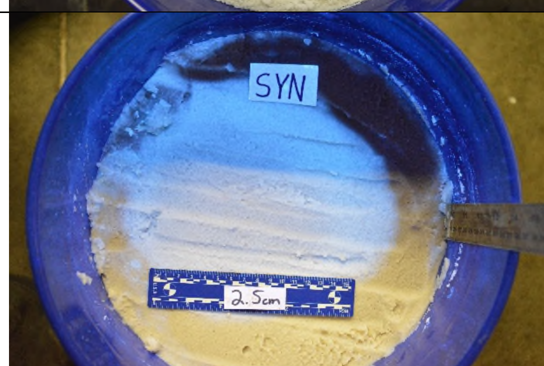


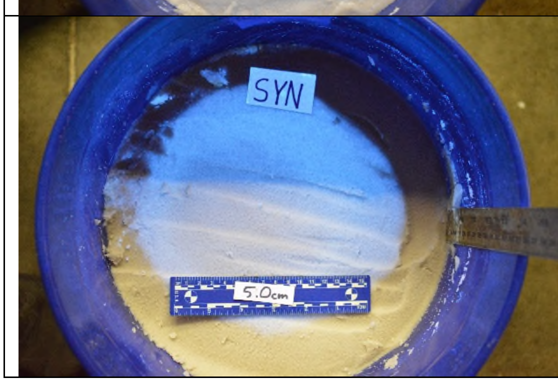


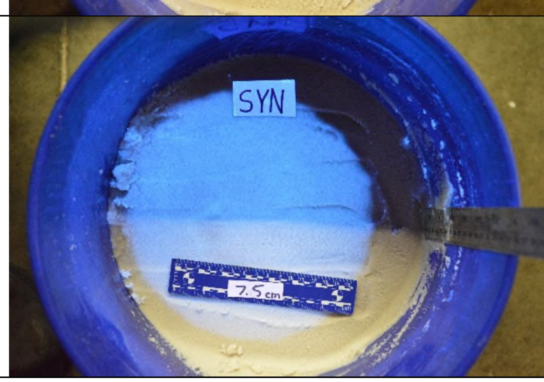
SYN Test in SAND

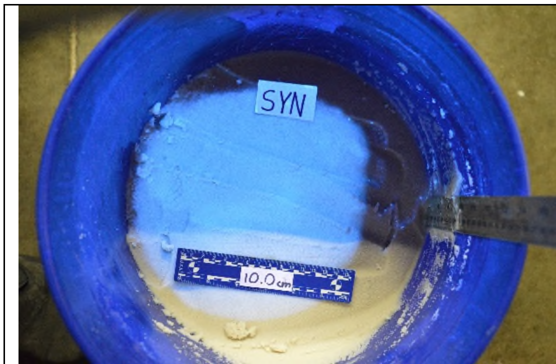


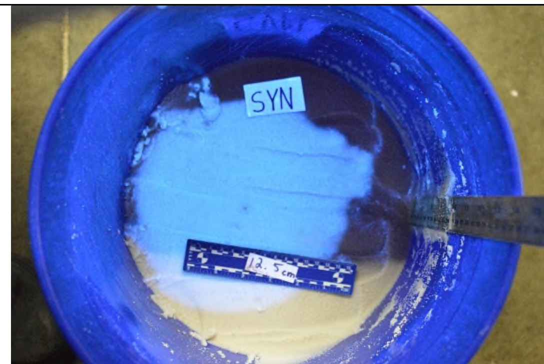


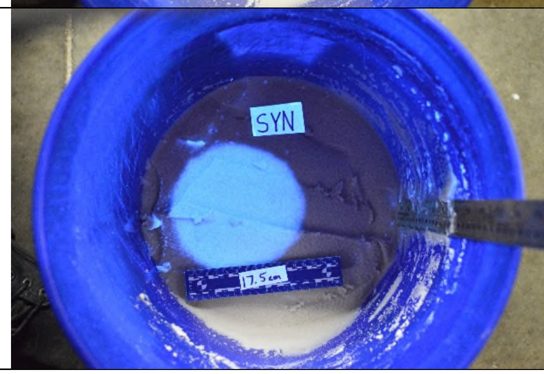


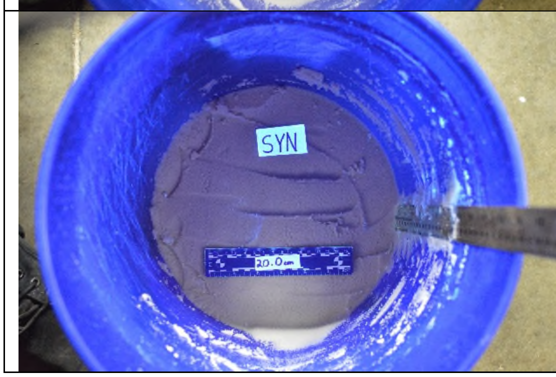




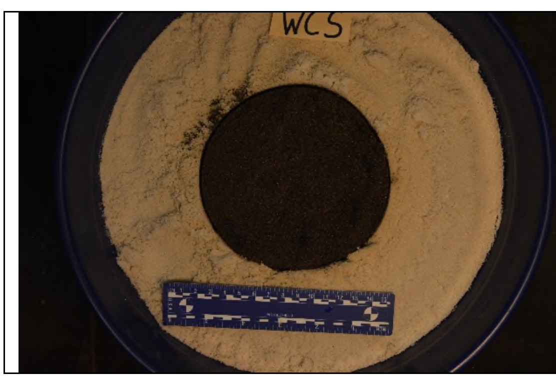


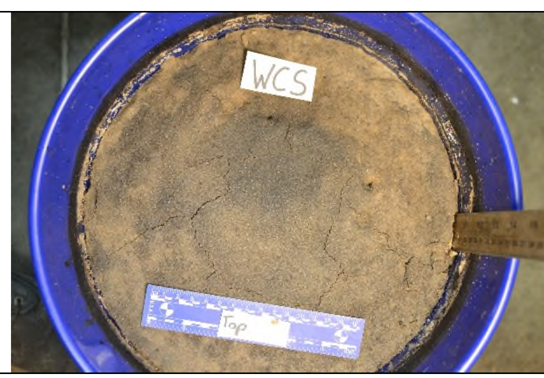


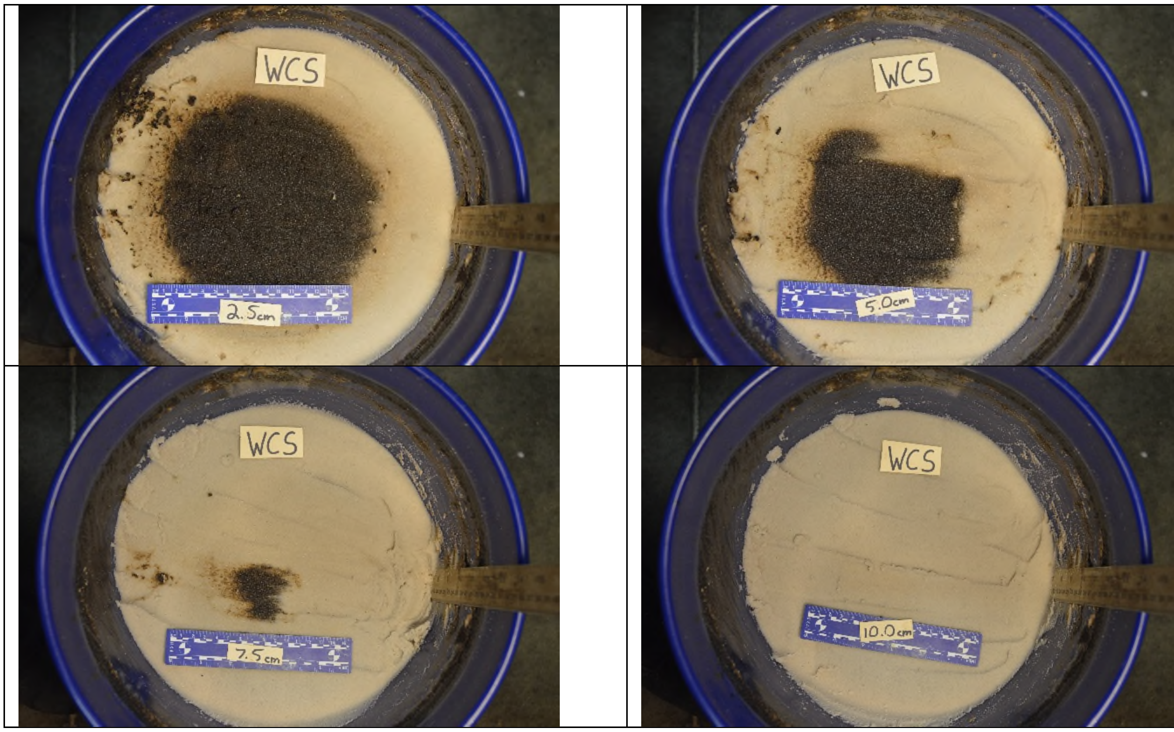




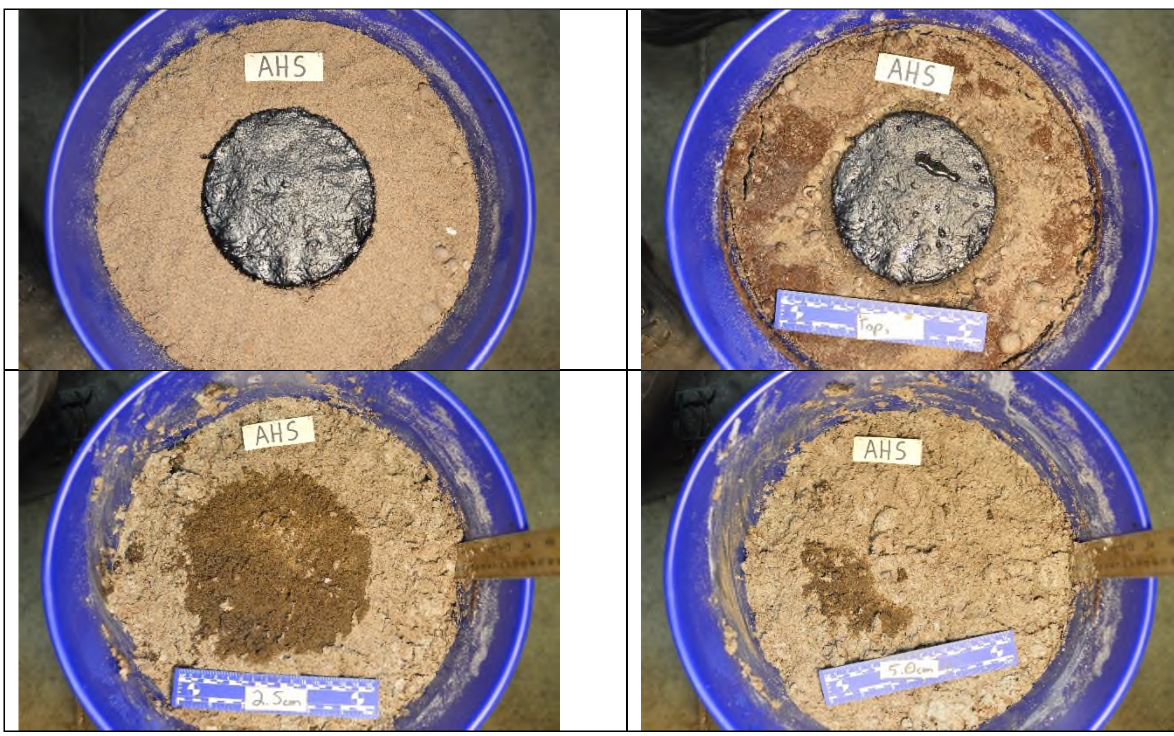
WCS Test in SAND

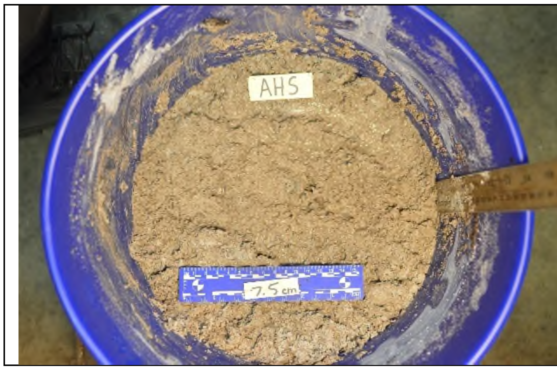






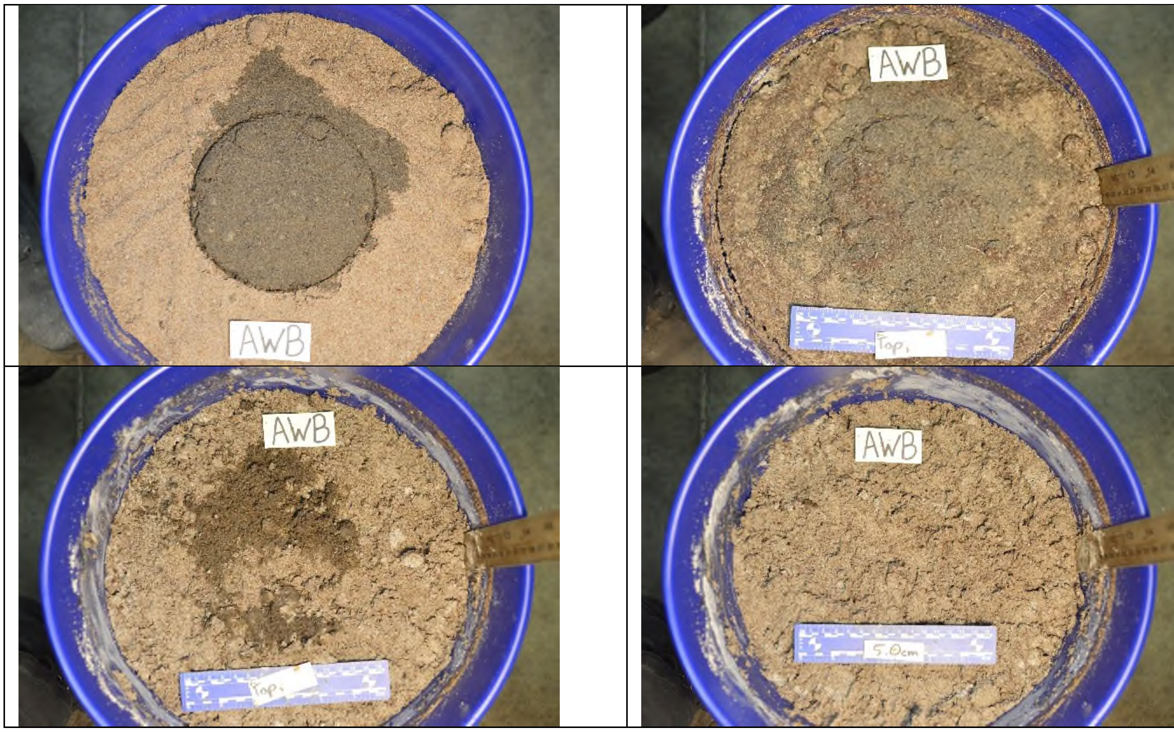
AHS Test in SOIL



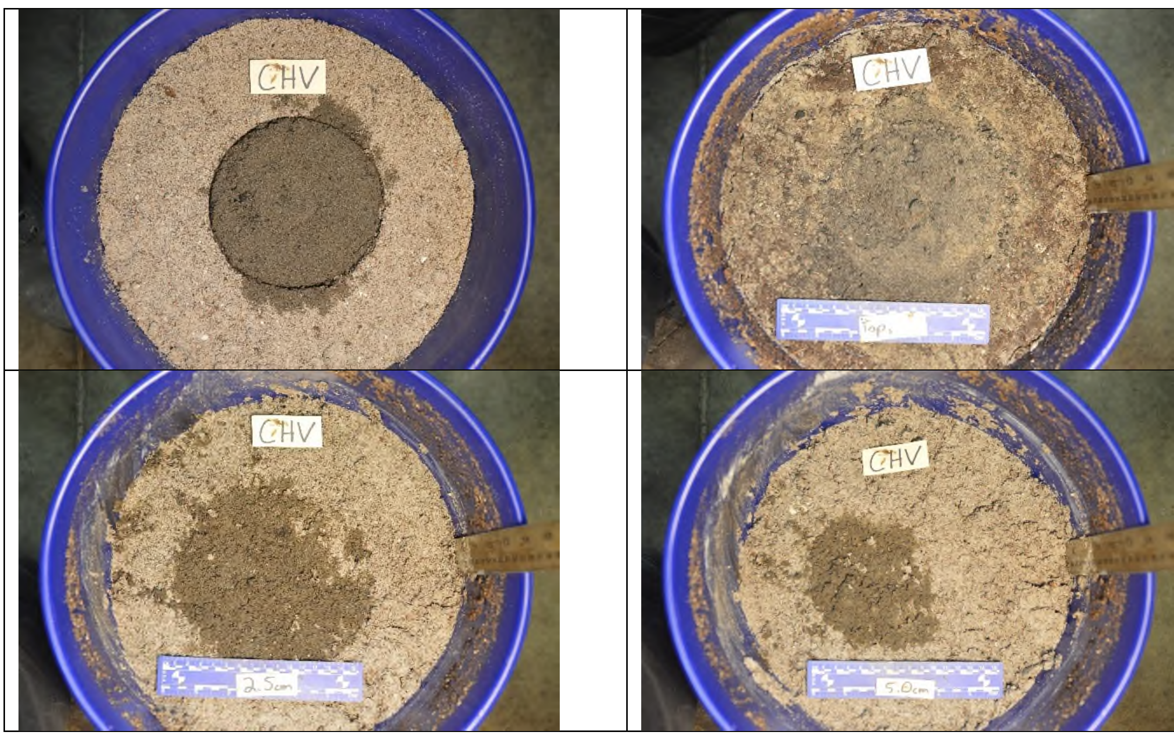


ANS Test in SOIL

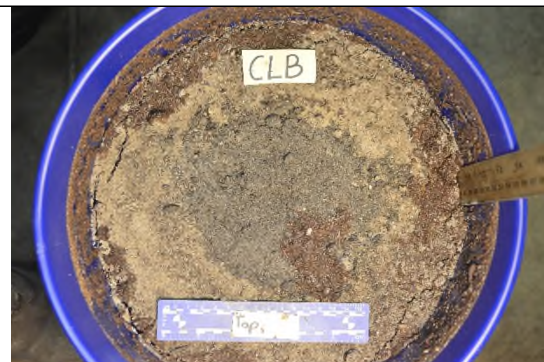
AWB Test in SOIL



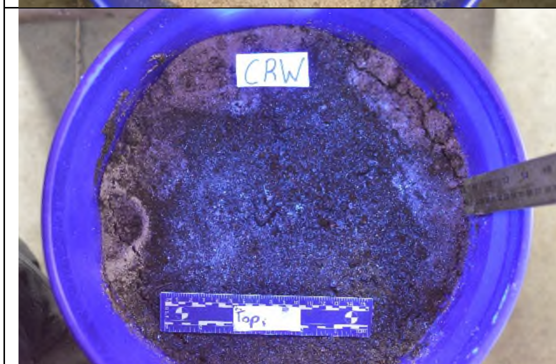
CHV Test in SOIL

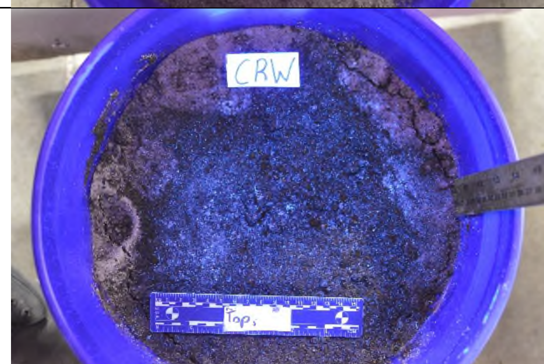


CLB Test in SOIL

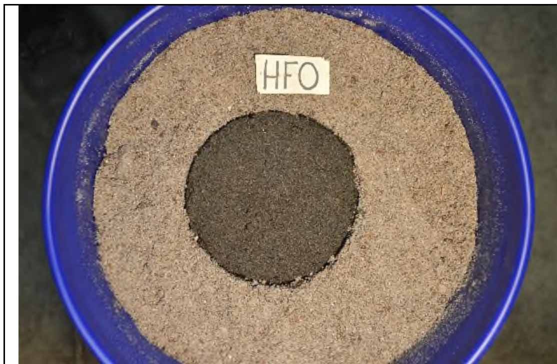


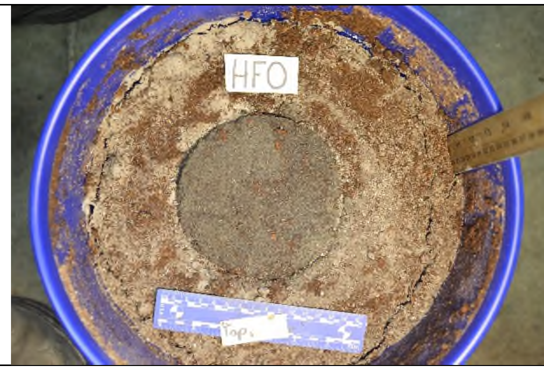
CRW Test in SOIL



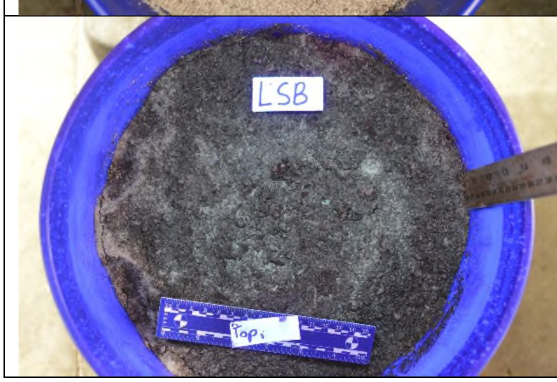


HFO Test in SOIL

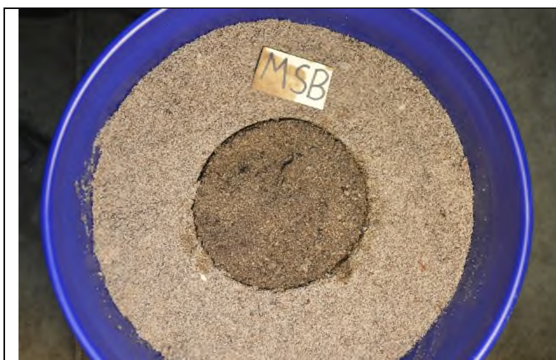


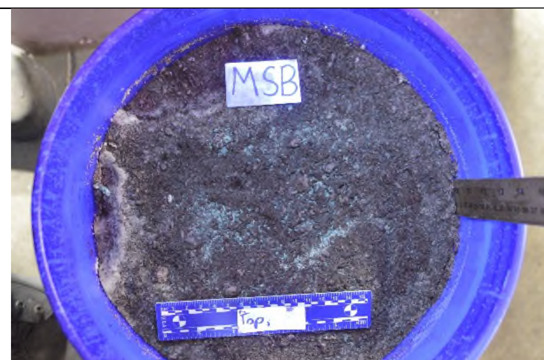


LSB Test in SOIL



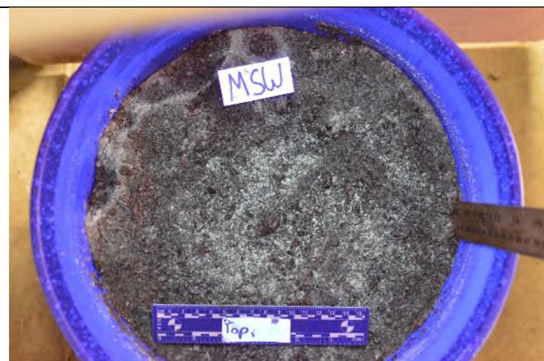
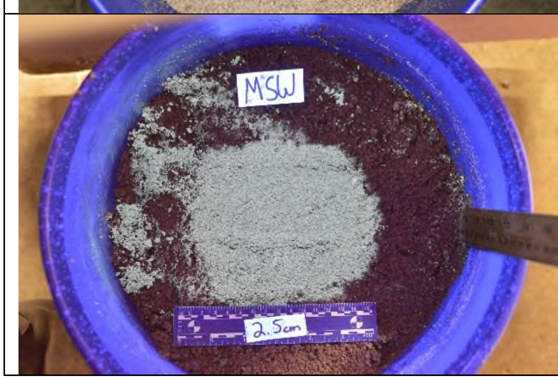
MSB Test in SOIL



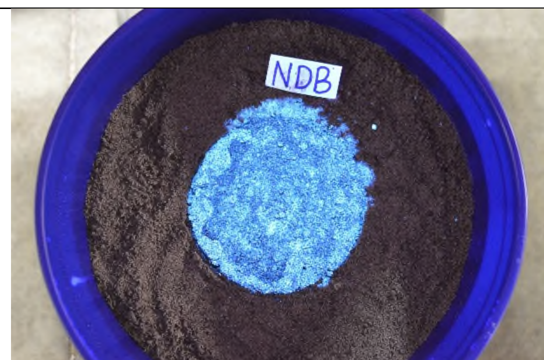


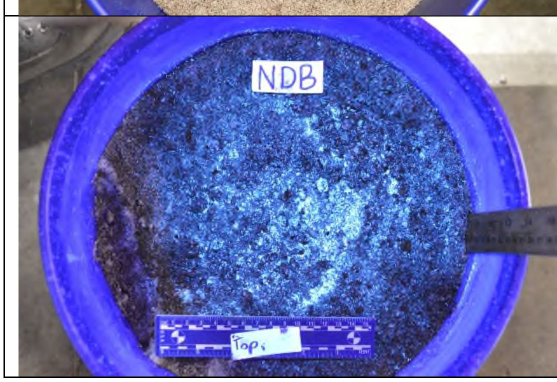
	
	

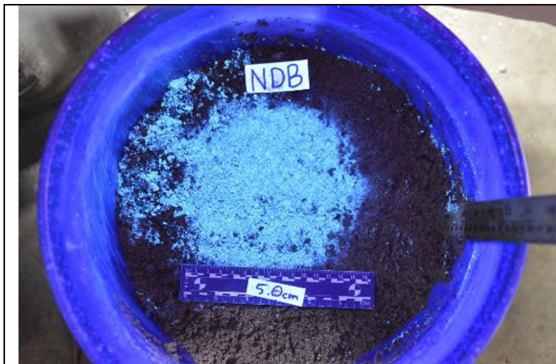
MSW Test in SOIL

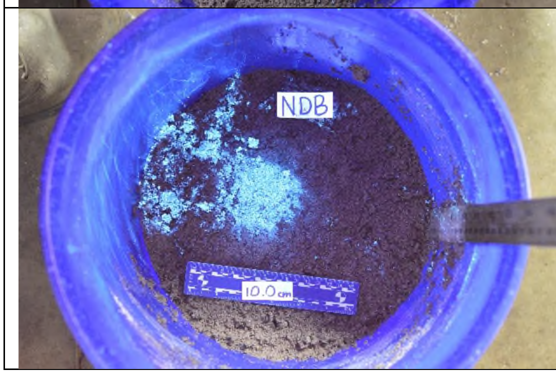
	
	

NDB Test in SOIL









SYB Test in SOIL

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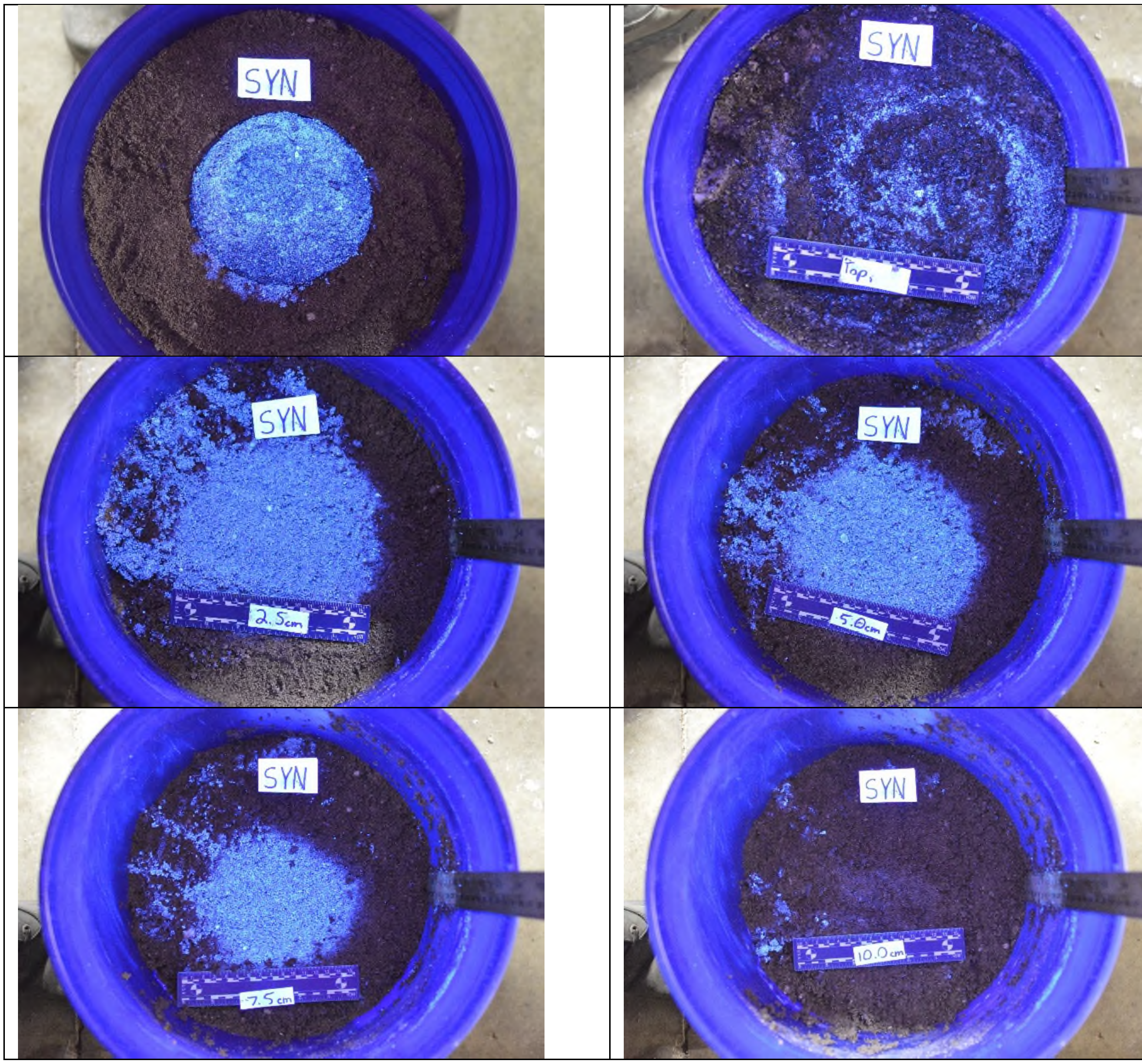
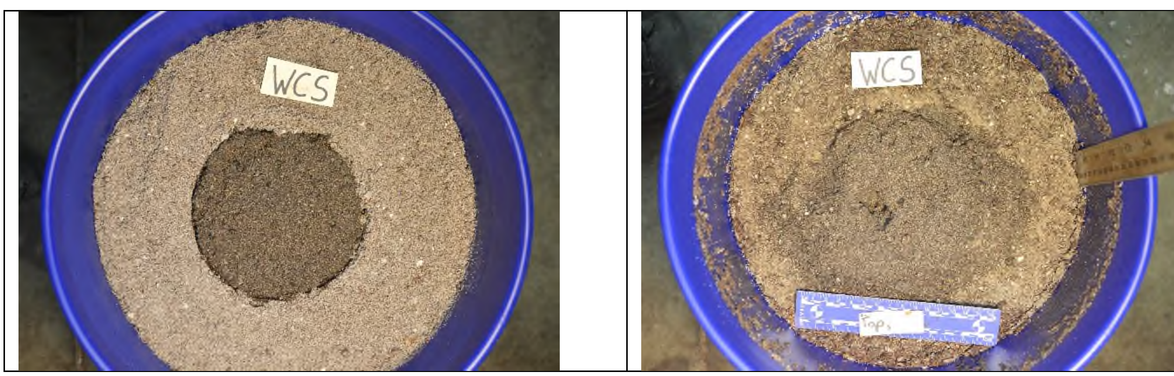
SYN Test in SOIL

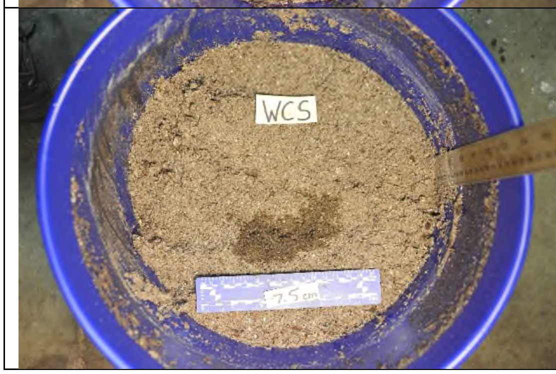


WCS Test in SOIL




WCS
2.5cm


WCS
5.0cm


WCS
7.5cm


WCS
10.0cm

APPENDIX F – BEACH ADHESION TESTING PROTOCOL DEVELOPMENT

F.1 SUMMARY

1. Load Media into Beach Trays
2. Mount Trays on rack in wave tank
3. Apply oil sample to dry media in horizontal strip 10 cm wide from 25 cm through 35 cm height band
4. Set up the wave generation programming for applicable wave heights and breaking waves
5. Confirm camera systems are synchronized and start cameras
6. Start wave generation for test period (3 hrs)
7. At end of test, shut down cameras and offload images/video for processing
8. Recover any oil that migrated away from Beach Tray for quantification analysis
9. Recover oil from Media using toluene extraction
10. Determine oil collection based upon oil from pre-weighed sorbents + extracted oil
11. Process images/video to determine if “end-point” target is reached during test run.

F.2 TEST VARIABLES

1. Oil type	• 14 oils (to be weathered - 2 day equivalents) o Albian Heavy Synthetic (AHS) o Alaskan North Slope (ANS) o Access Western Blend (AWB) o Conventional Heavy (CHV) o Cold Lake Blend (CLB) o Condensate (CRW) o Bunker C/Heavy Fuel Oil (HFO) o Light Sour Blend (LSB) o Medium Sour Blend (MSB) o Mixed Sweet Blend (MSW) o U.S. Bakken (NDB) o Synbit (SYB) o Synthetic Sweet Blend (SYN) o Western Canadian Select (WCS)
2. Oil weathering	• Slightly weathered oil to be used. Not a critical variable unless want to compare oil behaviour within first 24 hours with oil weathered >24 hours, in most cases oil is not onshore <24 hours
3. Oil Application	• Oil applied to dry sediments for maximum adhesion scenario
4. Sediment size	• Sand is hard to work with in wave tanks. • Experience (at the COST tanks) indicates runs with sand can have high variability and poor replication due to sediment movement • Selected (a) small pebble and (b) large pebble sizes as (a) movement within test cell by 10 cm and 20 cm waves and (b) not moved even by

	25 cm waves: so: (a) is a test of abrasion plus wave washing, and (b) a test of wave washing only
5. Sediment surface texture	• (a) has a mixture of surface textures from smooth to pitted • (b) all smooth

6. Sediment shape	• Standard terms for grains/ pebbles/cobble are Sphere, Blade, Roller, Disc
	  ◦ (a) PEA GRAVEL: largely spherical with some angularity (3/8", 10mm)
	  ◦ (b) RED PEBBLES (~1" – 2") rounded and predominantly Spherical so lower initiation of transport threshold; GRAY PEBBLES (~1" – 2") rounded and predominantly Disc to Blade with some Spheres and Rollers, so not easily rolled by wave wash:
	• PEA GRAVEL (SML PBL) and RED PEBBLES (LRG PBL) preferred for oil/sediment contrast analysis

7. Sediment Angularity	• Standard terms are Very Angular through Rounded
8. Wave height/energy	• minimal movement of media: redistributed of oil only by 5 cm waves (low energy) (more of a flooding event) • some movement of PEA GRAVEL within test cell in 10 cm wave. • abrasion + redistributed by 20 cm and 25 cm waves (high energy)
9. Duration of wave activity	• Single runs related to a 3-hour high-water slack period • Double runs (two test sets) with a minimum 12-hour drying period (over night) between runs • Use a 30 second (twinned) wave period (time between waves) for wave profile results in a breaking wave followed quickly by a non-breaking wave = 4 waves/minute = 720 waves over a 3-hour period. Very pronounced at higher wave heights (15 cm +) • Practical selection as can do two sets of tests/day

PRELIMINARY CONCEPT OF SUITE OF TESTS (numbered #1 through #40)

Sediment Type	Oil Types	Wave Height	Test Duration	# of Runs*	Comments
LRG RED PBL	10	High	2 tides	20	Left overnight
SML PBL	10	Low	1 tide	10	
SML PBL	10	High	1 tide	10	
OPTIONAL (to further study impact of shape differences)					
LRG RED PBL	2	20	1 tide	2	ANS, CLB
LRG GRAY PBL	2	20	1 tide	2	ANS, CLB
TOTAL				44	

*SUPERCEDED by selection of all 14 oils for the suite of tests vs the original plan of 10 oils

F.3 SEDIMENT PARAMETERS

(a) Screened particles that pass a 3/8" (~9.5mm) sieve and are retained on a No. 4 (0.475 mm) sieve: i.e. 4.75 – 9.5 mm = SMALL PEBBLES ("smP" in Sergy et al. 2017)
(b) Screen particles that pass a 2" (50.8 mm) sieve = VERY LARGE PEBBLES ("vlrgP" in Sergy et al. 2017)

Standard Size Classification:

Granule 2-4 mm
Pebble 4-64 mm

The size of media selected for this series of runs all fall within the "Pebble" range. As a reference, Sergy et al. classified the size of media in the following manner:

Table 0–1 Pebble Sizes

Descriptor	Actual Size of Media
Small Pebble:	4.75 – 9.5 mm
Medium Pebbles	9.5 – 19 mm
Large pebbles	19 – 37.5 mm
Very Large Pebbles	37.5 – 75 mm

(Sergy et al. 2017)

F.4 PROTOCOLS

"End-Point" Testing Targets:

During testing, measurements will be made to determine if the oil has been cleaned or flushed from the beach media to a point that no further action would be required during a spill scenario (or may be determined to be more disruptive than natural attenuation). In particular, we monitor the runs and make a determination if an "End Point" has been reached. This is being defined as to the point in each testing (time, number of waves) that the surface oiling reaches the following:

- COAT <0.1cm
- < 10% distribution
- No rainbow sheen

Oil Application

The beach media is oiled in the following manner:

- 10-cm across-beach band with bottom of the band being at the midpoint of the beach (from 25cm through 35cm of the 50cm "height") Encompassing an area of approximately 500 cm^2.
- 250 mL of oil per test = ~ 0.5 cm thick loading

Sampling - Measurements:

Run cameras for each test
Analyze every 10 waves for contrast analysis

- oil - always destructive sampling
- three sample bands (starting from bottom of tray) 0-25 cm, 25-35 cm*, 35-50 cm
- (*this band is where the oil is originally applied)
- toluene extraction for oil volume remaining
- oil collection on pre-weighed sorbents + solvent extraction. Calculate percentage of oil lost (washed into the water column). Of the remaining oil on the media, calculate percentage in the three bands.

Image Capture - Video:

with "Cue Cards" (Run #01; Run #02, etc.); Time, Oil Type, Wave Profile, Water Temperature
Time Lapse Pictures – approx. vertical for image analysis
Video x2 – 1 side and 1 top view. Clips for temporary analysis. Additional Slow Motion video for first few waves to demonstrate movement or lack of movement within the beach area.

Procedural Checklist:

Cameras – time synchronized - set – running – activated
Oil retention on plate
Cue cards etc - White Board Run Summary cue

- Wave control programming checklist
- Tray set checklist
- Surrogate (pretray setting) breaking wave location checklist
- Wave tank/water height checklist
- Oil volume checklist
- Video checklist

Double Wave Phenomenon:

Slightly at 10 cm – much more pronounced at 15+ cm

Sediment/Media Analyses:

Grain size – sieve analysis of about ½ bag of the small pebbles
RED/GRAY Pebbles: random 50 particles – determine 3 dimensional measurements for sphericity and angularity.

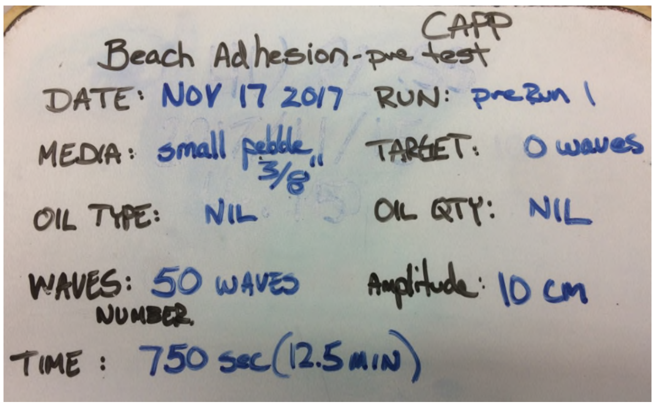
F.5 SHAKE-DOWN TEST RUNS

Three Run Set

Initially plan all three runs with 50 waves = ~12.5 minutes

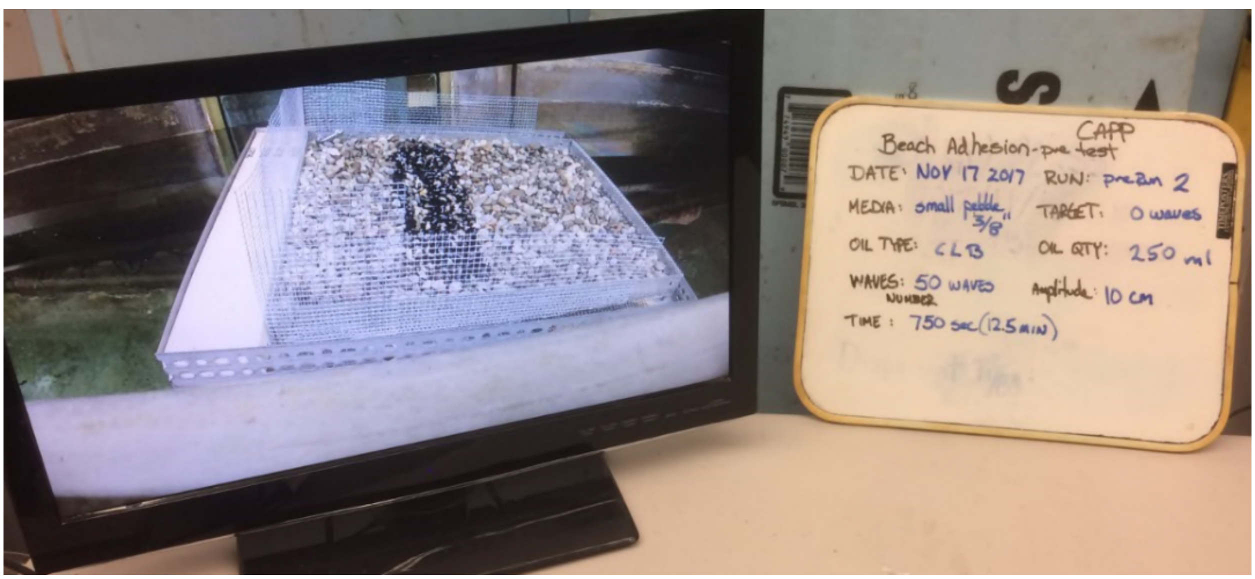
# 1 = SM PB at 10 cm wave height	w/o oil
# 2.1 = SM PB at 10 cm with same tray	w oil
# 2.2 = SM PB at 20 cm with same tray	w oil

Test Run "A" ("1")



Used to check camera function, beach placement, and wave generation.

Test Run "B" ("2.1")



Unweathered Cold Lake – approximately a medium viscosity oil

50% remobilization within first 10 waves; 90% by 50 waves.

Oil was easily flushed through the sediments by the 10-cm waves, even more when switched to the 20-cm waves on run 2.2

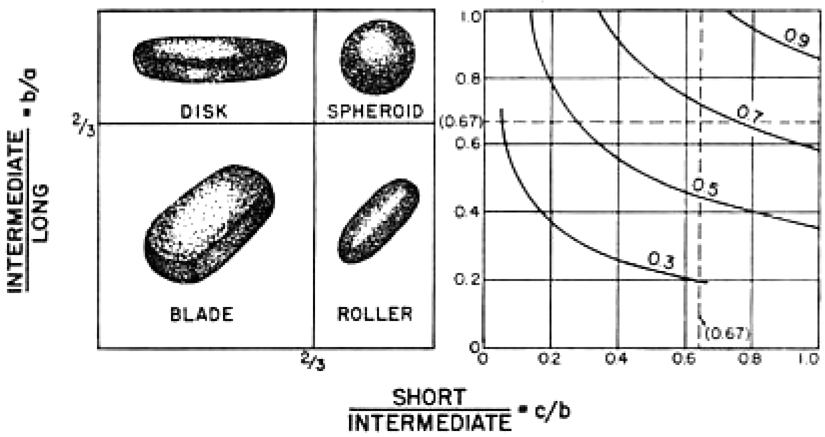
F.6 ATTACHMENT - SEDIMENT PARAMETERS

Sphericity

Sphericity is 1 when the two volumes coincides while a thin, needle-like particle has a sphericity of nearly 0.

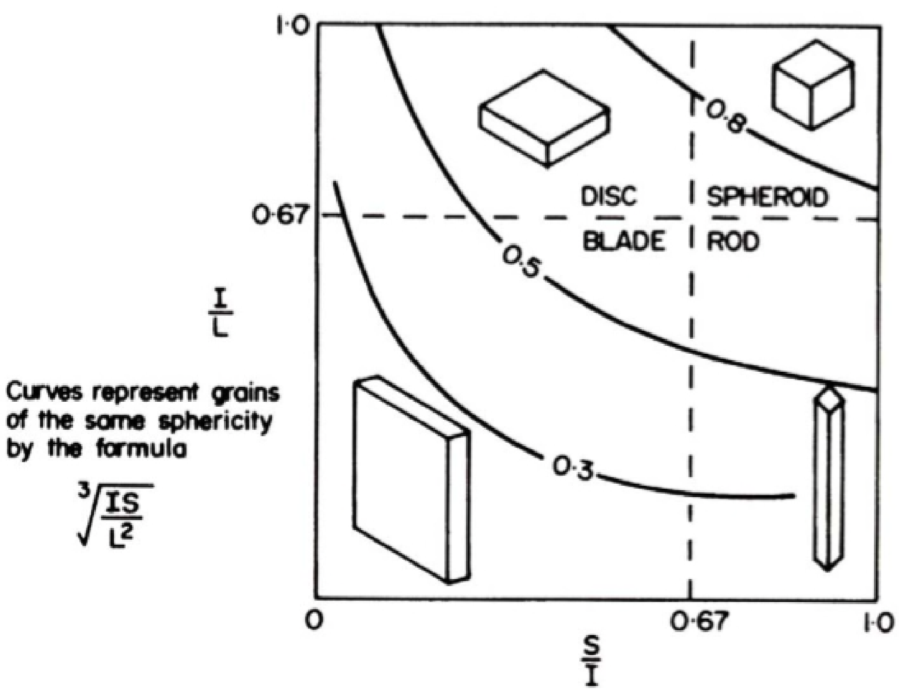
Width/length y/x = b/a

Thickness/width z/y = c/b

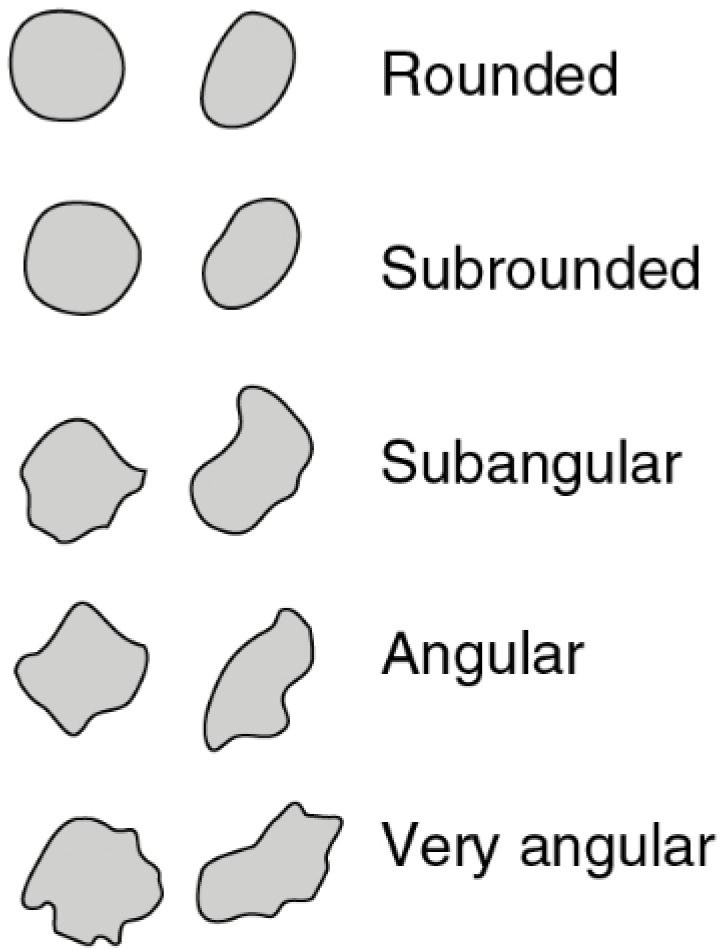


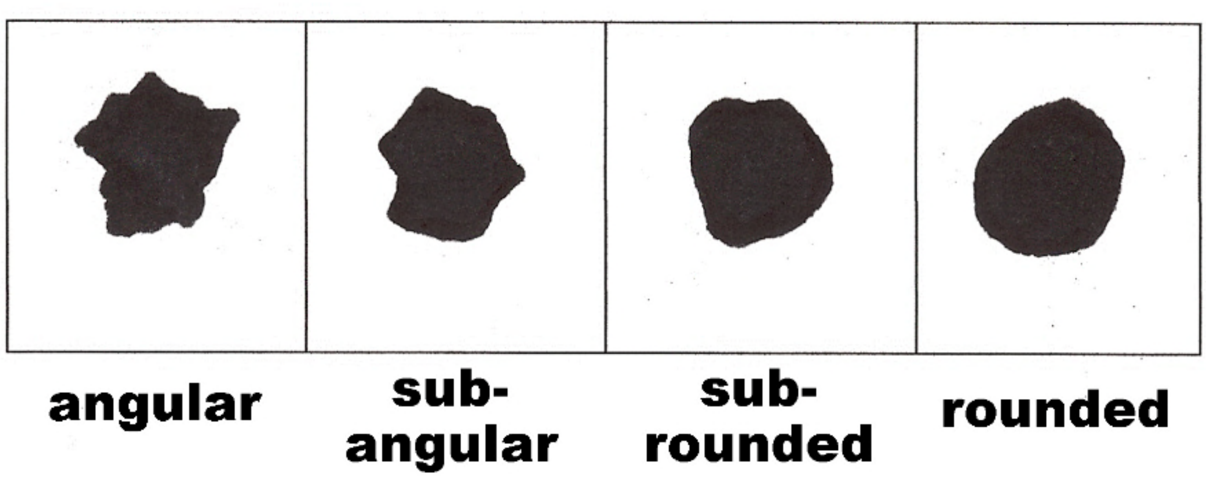
5 x 4 x 3 = 0.8 and 0.75 = 0.8 sphericity (spheroid)

5 x 2 x 1 = 0.4 and 0.5 = 0.4 sphericity (blade)



Angularity


Rounded
Subrounded
Subangular
Angular
Very angular


angular
sub-angular
sub-rounded
rounded

Grey Rock Dimensions

Rock	Length	Width	Depth	Face SA	Total SA	Volume
#	(mm)	(mm)	(mm)	(cm^2)	(cm^2)	(cm^3)
Avg	62.3	45.8	24.6	28.9	111.6	72.6
AveDev	7.8	6.5	5.5	6.9	26.1	25.7
Max	87.7	82.1	42.6	53.4	179.7	159.2
Min	40.4	10.1	12.1	4.7	23.6	5.9
1	71	50.4	34.9	35.8	156.3	124.9
2	72.5	55.7	22.9	40.4	139.5	92.5
3	73.4	52	24.6	38.2	138.0	93.9
4	61.9	53.8	42	33.3	163.8	139.9
5	75.4	50.2	22.4	37.9	132.0	84.8
6	87.7	52.7	25.8	46.2	164.9	119.2
7	67.1	62.1	30.1	41.7	161.1	125.4
8	67.5	42.4	31.6	28.6	126.7	90.4
9	72.8	61.2	25.8	44.6	158.3	114.9
10	68.8	59.6	29.8	41.0	158.5	122.2
11	65.3	55.7	29.3	36.4	143.7	106.6
12	82.1	51.1	28.4	42.0	159.6	119.1
13	76.5	49.1	17.8	37.6	119.8	66.9
14	63.1	55.7	28	35.1	136.8	98.4
15	64	56.8	27.9	36.4	140.1	101.4
16	73	51.2	23.5	37.4	133.1	87.8
17	73.3	54.8	22.5	40.2	138.0	90.4
18	64.3	54.4	29.7	35.0	140.5	103.9
19	59.2	51.9	19.1	30.7	103.9	58.7
20	60.4	45.3	19.2	27.4	95.3	52.5
21	50.9	38.7	23.5	19.7	81.5	46.3
22	55.6	25.5	25.4	14.2	69.6	36.0
23	53.7	32.6	27	17.5	81.6	47.3
24	68	57.6	32.5	39.2	160.0	127.3
25	52.7	43.3	36.3	22.8	115.3	82.8
26	58.1	42.5	22.9	24.7	95.5	56.5
27	46.4	10.1	12.6	4.7	23.6	5.9
28	57.9	43.7	21.4	25.3	94.1	54.1
29	70.7	47.7	32	33.7	143.2	107.9
30	59.3	45.7	33.3	27.1	124.1	90.2
31	76.4	57.5	28.4	43.9	163.9	124.8
32	81.1	50	19.3	40.6	131.7	78.3
33	69.2	54	42.6	37.4	179.7	159.2
34	73.8	45	26.1	33.2	128.4	86.7
35	58.6	24.8	37.1	14.5	90.9	53.9
36	67	48.4	24.1	32.4	120.5	78.2
37	63.2	35.3	19.9	22.3	83.8	44.4
38	66.3	39.7	19.3	26.3	93.6	50.8
39	61.4	48	21.3	29.5	105.5	62.8
40	75.4	54.2	18	40.9	128.4	73.6
41	65	82.1	23.6	53.4	176.2	125.9
42	56.8	39.7	17.7	22.5	79.3	39.9
43	56.1	50.3	22.5	28.2	104.3	63.5
44	59.1	54.3	22.4	32.1	115.0	71.9
45	63.3	49.4	38.6	31.3	149.5	120.7
46	54.4	42.7	17.4	23.2	80.2	40.4
47	64.8	46.5	32.6	30.1	132.8	98.2
48	58.8	40.8	26.4	24.0	100.6	63.3
49	61.9	44.3	22.5	27.4	102.6	61.7
50	56.9	47	25.3	26.7	106.1	67.7
51	55.3	44.6	26.3	24.7	101.9	64.9
52	57.7	43.6	26.3	25.2	103.6	66.2
53	53.3	43.3	26	23.1	96.4	60.0
54	57.3	44.6	16.7	25.6	85.1	42.7
55	48.5	48.9	17.6	23.7	81.7	41.7
56	52.2	52.7	28.2	27.5	114.2	77.6
57	61.7	48.3	37.7	29.8	142.5	112.4
58	52.1	36.8	12.1	19.2	59.9	23.2
59	40.4	39.3	15.6	15.9	56.6	24.8
60	50.4	40.3	15.1	20.3	68.0	30.7
61	58.8	37.9	14	22.3	71.6	31.2
62	61.1	38.9	16.6	23.8	80.7	39.5
63	70.3	30.3	32.1	21.3	107.2	68.4

Red Rock Dimensions

Rock	Length	Width	Depth	Face SA	Total SA	Volume
#	(mm)	(mm)	(mm)	(cm^2)	(cm^2)	(cm^3)
Avg	71.1	53.4	35.2	38.4	165.1	137.2
AveDev	9.0	7.0	6.5	8.2	32.8	40.5
Max	102.9	68.0	52.7	63.3	250.6	249.7
Min	47.6	26.8	15.7	12.8	48.9	20.0
1	53.6	46.1	32.3	24.7	113.8	79.8
2	78.2	65.3	45.3	51.1	232.1	231.3
3	71.5	49	52.7	35.0	197.1	184.6
4	71.4	63.9	51.9	45.6	231.7	236.8
5	71.5	55.7	38.6	39.8	177.8	153.7
6	59.9	52.3	42.1	31.3	157.1	131.9
7	81.9	58.4	41.1	47.8	211.0	196.6
8	62.5	57.3	22.2	35.8	124.8	79.5
9	82.9	60.2	28.8	49.9	182.2	143.7
10	80.4	64.6	43.4	51.9	229.7	225.4
11	86.7	54.5	43.1	47.3	216.2	203.7
12	87.8	60.9	33.7	53.5	207.2	180.2
13	75.5	41.8	34.8	31.6	144.8	109.8
14	67.9	57.1	27.6	38.8	146.5	107.0
15	93.1	53.2	32.2	49.5	193.3	159.5
16	78.8	57.9	32	45.6	178.7	146.0
17	77.6	67.6	27.6	52.5	185.1	144.8
18	75.3	50.4	30.9	38.0	153.6	117.3
19	77.1	60.5	36.8	46.6	194.6	171.7
20	61.1	49.7	25.6	30.4	117.5	77.7
21	88.1	55	32.3	48.5	189.4	156.5
22	65.1	57.5	42.4	37.4	178.8	158.7
23	83.7	62.5	38.7	52.3	217.8	202.4
24	73.6	67.5	44.4	49.7	224.7	220.6
25	64	47.2	24.3	30.2	114.5	73.4
26	90.1	54.9	23.5	49.5	167.1	116.2
27	69	62.2	34.3	42.9	175.8	147.2
28	60.7	46.4	18.7	28.2	96.4	52.7
29	96.8	65.4	36.7	63.3	245.7	232.3
30	71.5	54.5	47.3	39.0	197.1	184.3
31	60.4	52.7	42.2	31.8	159.1	134.3
32	67.3	56.7	45.6	38.2	189.4	174.0
33	72.2	49.2	27.8	35.5	138.5	98.8
34	58.6	49.9	38.8	29.2	142.7	113.5
35	63.1	62.8	45.5	39.6	193.8	180.3
36	54.7	38.1	25.1	20.8	88.3	52.3
37	77.6	46.5	26.3	36.1	137.4	94.9
38	62.9	43.5	38.4	27.4	136.4	105.1
39	73.2	49.2	33.6	36.0	154.3	121.0
40	57.2	37	41.6	21.2	120.7	88.0
41	80.4	35.3	16.2	28.4	94.2	46.0
42	80.7	39.8	38.7	32.1	157.5	124.3
43	72.3	54.4	39.2	39.3	178.0	154.2
44	73.5	67.4	24.6	49.5	168.4	121.9
45	102.9	57.3	41.4	59.0	250.6	244.1
46	91.8	58.8	35.7	54.0	215.5	192.7
47	79	57.5	33.6	45.4	182.6	152.6
48	99.2	62.8	32.9	62.3	231.2	205.0
49	68.2	59	29.9	40.2	156.5	120.3
50	70	49.6	38.7	34.7	162.0	134.4
51	74.5	55	35.9	41.0	174.9	147.1
52	65.7	58.9	47.3	38.7	195.3	183.0
53	76.2	50.3	37.8	38.3	172.3	144.9
54	68.5	52.9	19.4	36.2	119.6	70.3
55	78.4	61.6	51.7	48.3	241.3	249.7
56	73.5	47.6	29.5	35.0	141.4	103.2
57	88	55.4	33.1	48.8	192.4	161.4
58	89.7	64.4	41.3	57.8	242.8	238.6
59	68.9	58.3	35.3	40.2	170.1	141.8
60	67.2	62	44.2	41.7	197.5	184.2
61	65.4	50.7	32.4	33.2	141.5	107.4
62	65.5	68	45.5	44.5	210.6	202.7
63	66.8	57.6	40	38.5	176.5	153.9

Grey Rock Dimensions - continued

Rock #	Length (mm)	Width (mm)	Depth (mm)	Face SA (cm^2)	Total SA (cm^2)	Volume (cm^3)
64	52.3	44.3	20.5	23.2	85.9	47.5
65	46.8	40.1	20.9	18.8	73.9	39.2
66	48	39.8	20.7	19.1	74.6	39.5
67	65.5	37.8	17.2	24.8	85.1	42.6
68	72.8	48	28	34.9	137.5	97.8
69	62.7	49.6	18.1	31.1	102.9	56.3
70	73.5	49.8	19.4	36.6	121.0	71.0
71	59.1	37.1	18.7	21.9	79.8	41.0
72	67.2	44.8	19.1	30.1	103.0	57.5
73	79.8	49.9	32.7	39.8	164.5	130.2
74	62.1	42.7	35.4	26.5	127.2	93.9
75	75.3	50.8	27.8	38.3	146.6	106.3
76	70.8	51.2	18.8	36.2	118.4	68.1
77	46.7	32.1	12.9	15.0	50.3	19.3
78	63.5	33.8	29.1	21.5	99.6	62.5
79	55.2	44.9	28.4	24.8	106.4	70.4
80	72.5	51.4	33.4	37.3	157.3	124.5
81	53.3	45.6	15.3	24.3	78.9	37.2
82	66.2	45.1	16.2	29.9	95.8	48.4
83	46.3	37.4	14.9	17.3	59.6	25.8
84	60.7	54.2	29.4	32.9	133.4	96.7
85	52.1	48.7	15.6	25.4	82.2	39.6
86	47.7	42.8	15.2	20.4	68.3	31.0
87	59	50	28.5	29.5	121.1	84.1
88	64	43.9	14.4	28.1	87.3	40.5
89	55.4	51.1	26.4	28.3	112.9	74.7
90	54	37.8	19.9	20.4	77.4	40.6
91	48.9	44.1	28.4	21.6	96.0	61.2
92	53.1	35.9	15.6	19.1	65.9	29.7
93	63.1	37.2	30.1	23.5	107.3	70.7
94	56.6	46.8	29.2	26.5	113.4	77.3
95	69.2	49.8	27.1	34.5	133.4	93.4
96	63.1	44.1	23.6	27.8	106.3	65.7
97	56.6	33.8	24.2	19.1	82.0	46.3
98	58.5	40.1	32.5	23.5	111.0	76.2
99	67	60.5	25	40.5	144.8	101.3
100	65.1	48.9	22	31.8	113.8	70.0
101	50.8	39.8	22.8	20.2	81.8	46.1
102	56.7	41.4	30	23.5	105.8	70.4
103	83.5	41.8	34.3	34.9	155.8	119.7
104	51.7	32.7	19	16.9	65.9	32.1
105	49.9	40	22.2	20.0	79.8	44.3
106	49.4	42.7	24.2	21.1	86.8	51.0
107	51.7	33.4	16.2	17.3	62.1	28.0
108	69.7	48.6	20.4	33.9	116.0	69.1
109	81.2	52.2	25.9	42.4	153.9	109.8
110	67.6	51	23.2	34.5	124.0	80.0
111	76.1	47.4	31.5	36.1	149.9	113.6
112	63.1	56.3	16.7	35.5	110.9	59.3
113	57.1	43.3	30	24.7	109.7	74.2
114	76.8	43.4	42.2	33.3	168.1	140.7
115	73.3	60.6	18.2	44.4	137.6	80.8
116	41.6	36.4	26.5	15.1	71.6	40.1
117	66.9	43.2	34.5	28.9	133.8	99.7
118	62.3	53.1	29.1	33.1	133.3	96.3
119	59.7	56.9	21.8	34.0	118.8	74.1
120	59.3	42.7	21	25.3	93.5	53.2
121	64.8	39.8	21.7	25.8	97.0	56.0
122	66.4	45.9	18.8	30.5	103.2	57.3
123	87.3	46.4	22.4	40.5	140.9	90.7
124	64	56.3	21.2	36.0	123.1	76.4
125	63.7	53.9	31.9	34.3	143.7	109.5
126	79.7	42.3	29.1	33.7	138.4	98.1
127	57	47.9	37.3	27.3	132.9	101.8
128	58.3	40.2	24.5	23.4	95.1	57.4
129	54.3	37.2	13.9	20.2	65.8	28.1
130	54.1	34.4	27	18.6	85.0	50.2
131	57	48.5	17.8	27.6	92.8	49.2
132	52.1	41.4	22.5	21.6	85.2	48.5

Red Rock Dimensions - continued

Rock #	Length (mm)	Width (mm)	Depth (mm)	Face SA (cm^2)	Total SA (cm^2)	Volume (cm^3)
64	60.1	56.5	43.4	34.0	169.1	147.4
65	57.1	52.1	40.1	29.7	147.1	119.3
66	71.7	58.1	33.4	41.7	170.0	139.1
67	60.2	54.1	47.5	32.6	173.7	154.7
68	79.6	56.1	31.8	44.7	175.6	142.0
69	80.6	57.7	32	46.5	181.5	148.8
70	73.4	52	32.1	38.2	156.8	122.5
71	74.6	52	33.7	38.8	162.9	130.7
72	60	61.1	40.2	36.7	170.7	147.4
73	70.9	61.8	28	43.8	161.9	122.7
74	71	40.5	43.6	28.8	154.7	125.4
75	70.2	48.9	32.3	34.3	145.6	110.9
76	55.5	39.5	36.2	21.9	112.6	79.4
77	63.6	48.9	32.9	31.1	136.2	102.3
78	48.1	52	47.9	25.0	145.9	119.8
79	68.2	65.8	35.2	44.9	184.1	158.0
80	66.1	59.6	39.6	39.4	178.3	156.0
81	67.2	46.6	27.7	31.3	125.7	86.7
82	72.3	35.7	33.2	25.8	123.3	85.7
83	81.4	58.1	32.6	47.3	185.5	154.2
84	62.6	40.1	27.7	25.1	107.1	69.5
85	59.9	43.9	21.5	26.3	97.2	56.5
86	67.4	55.4	41.6	37.3	176.8	155.3
87	58.1	38.4	31.9	22.3	106.2	71.2
88	48.7	44.8	26.2	21.8	92.6	57.2
89	47.6	26.8	15.7	12.8	48.9	20.0
90	58	38.2	31.5	22.2	104.9	69.8
91	48.3	42.7	30.2	20.6	96.2	62.3

APPENDIX G – OIL FACT SHEETS

Information within the fact sheets reflect results from laboratory bench-scale and flume testing at meso-scale under specific conditions. Results from actual spills in the environment may diverge from the data presented. The fact sheets were developed as a tool for spill responders to help determine appropriate countermeasures. Each spill is unique and the fate and behaviour of an oil will depend upon environmental conditions at the time of the spill.

Disclaimer

This fact sheet does not purport to address any or all hazards with responding to spills of crude oil or similar products. Proper Personal Protective Equipment should always be worn. Consult SDS.

Introduction

Albian Heavy Synthetic (AHS):	**An unconventional heavy sour partially upgraded, 19.6° API (60°C/15.6°C).**

What to Expect

Freshwater: Once in the fresh aqueous environment AHS will float initially. Based on 5-day testing in a flume tank, evaporative losses over the first day in warm (20°C) water conditions will cause the density to increase to a point close to that of fresh water which increases the risk of submergence. This time is extended up to a couple of days for cold (0°C) water conditions.

Marine Environment: Based on 5-day testing in a flume tank with sediment laden water, AHS is expected to initially float. However, as the oil weathers it increases its bulk density and consequently increases the risk of submergence in a matter of days at warmer temperatures (20°C range) as the density begins to approach that of the marine environment. No submergence was observed during the 5-day testing. Weathering processes slow under cooler temperatures.

Additional Highlights: Rapid weathering under warm conditions (near 20°C) will cause the density to increase close to that of fresh water – increasing the risk of submergence. This process slows if the environmental conditions are cooler. AHS can rapidly become too viscous to emulsify because of weathering. However, if it encounters an energetic freshwater or marine environment before it becomes very viscous, some emulsification is possible. Rapid response using spill countermeasures would be needed to counter risk of submergence. Evaporative losses of approximately 15-20% by volume would be expected within the first few hours of a spill, tapering off to 20-25% loss by the first few days depending upon the environmental conditions.

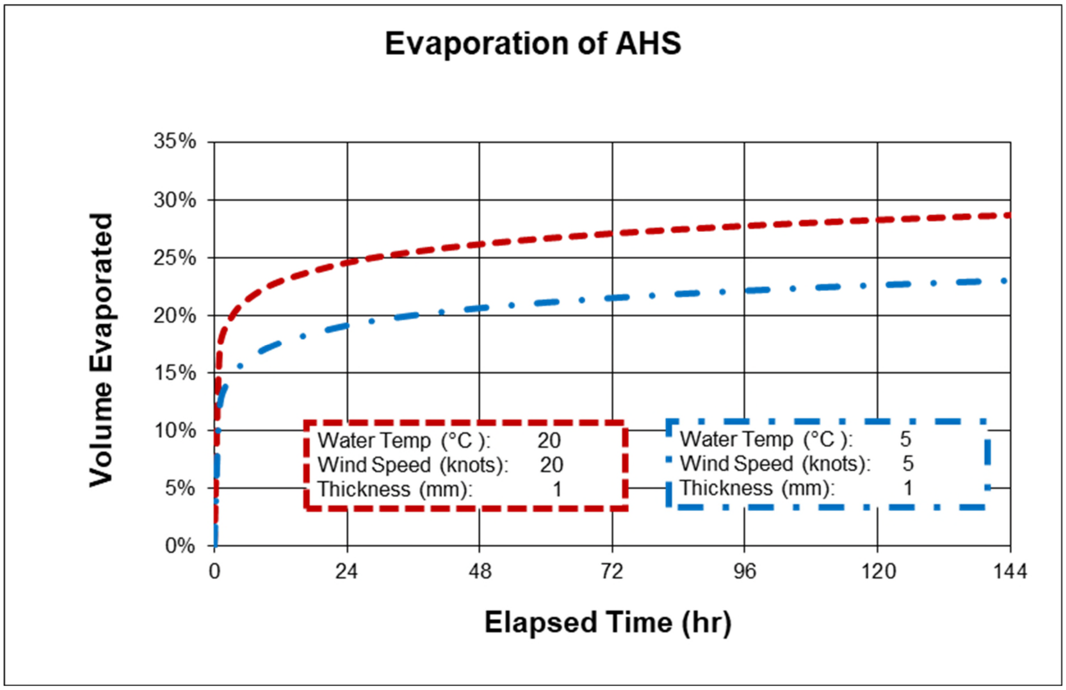
Oil Properties

Initial (fresh) Flash Point (°C): **lower than -10°C** Weathered (24% loss) Flash Point (°C): **30°C**	Initial (fresh) Pour Point (°C): **-33°C** Weathered (27% loss) Pour Point (°C): **12°C**
Initial Density (g/cm^3) @ 0°C: **0.948** @15°C: **0.937** @20°C: **0.933**	Initial Viscosity (cP) @ 0°C: **809** @15°C: **229** @20°C: **172**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

If AHS encounters an energetic freshwater or marine environment while it is still fresh or lightly weathered (to approximately 20% volumetric loss), some emulsification is very likely (stable or meso-stable). Depending on the environment (turbulent water, warm conditions), AHS can rapidly weather and quickly become too viscous to emulsify further. A meso-stable emulsion is brown and viscous, a water content ranging from 35% - 83%, and a viscosity increase of up to 45x the parent oil. A stable emulsion is a brown gel/semi-solid, with water contents in the 65% - 93% range, and viscosity increase on the order of 1000x the parent oil on average.

Interaction with suspended sediment and shorelines

AHS demonstrated a low propensity of interaction with suspended sediment in fresh water and marine water, so Oil-Mineral Aggregate (OMA) formation is expected to be low or unlikely.

This oil displayed high adhesion properties, with residues persisting for extended periods of time on simulated shorelines (beach substrates) subjected to repeated wave action. This oil would have low risk for remobilization after impacting shorelines (dependant upon local conditions).

Lightly weathered AHS would have a comparatively low tendency to penetrate deep into sandy or cobble shorelines. Penetration would slow and become increasingly limited as the oil weathers and becomes more viscous. Impacts from weathered oil would be expected to remain at or very near the surface.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.948	0.966	0.979	0.997	1.001
	20°C	0	0.933	1.003	1.010	1.013	-

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	1000	0.933	1.011	1.017	-	1.023

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	800	34,000	56,000	59,000	91,000
20°C	0	130	72,000	310,000	347,000	-

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Laboratory and Meso-Scale Testing*". Report is available on www.CrudeMonitor.Ca

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

Disclaimer

This fact sheet does not purport to address any or all hazards with responding to spills of crude oil or similar products. Proper Personal Protective Equipment should always be worn. Consult SDS.

Introduction

Alaska North Slope (ANS): A conventional medium, 32.5° API (60°F/15.6°C).

What to Expect

Freshwater: In fresh aqueous environments, ANS will initially float. Based on 5-day testing in a flume tank, evaporative losses should not result in the density approaching that of fresh water under either warm (20°C) or cold (0°C) water conditions.

Marine Environment: Although no tests were conducted in this study on ANS under marine environment conditions, it is expected (based upon the result of previous testing) to remain floating for extended periods of time allowing for a wide range of countermeasures including containment and recovery operations.

Additional Highlights: Rapid weathering under warm conditions (near 20°C) will increase density and viscosity, but ANS should remain floating and viable for conventional and non-conventional countermeasures. High interactions with sediments may reveal increased risk of submergence when subjected to high sediment loadings in water. ANS does not show a propensity to form emulsions when fresh. However, after weathering to 30% loss ANS formed a meso-stable emulsion at a cold temperature (0°C), while additional weathering was required to form unstable emulsions under warmer conditions (20°C). Evaporative losses of approximately 30-35% by volume would be expected within the first few hours of a spill, tapering off to 40-45% loss by the first few days depending upon the environmental conditions.

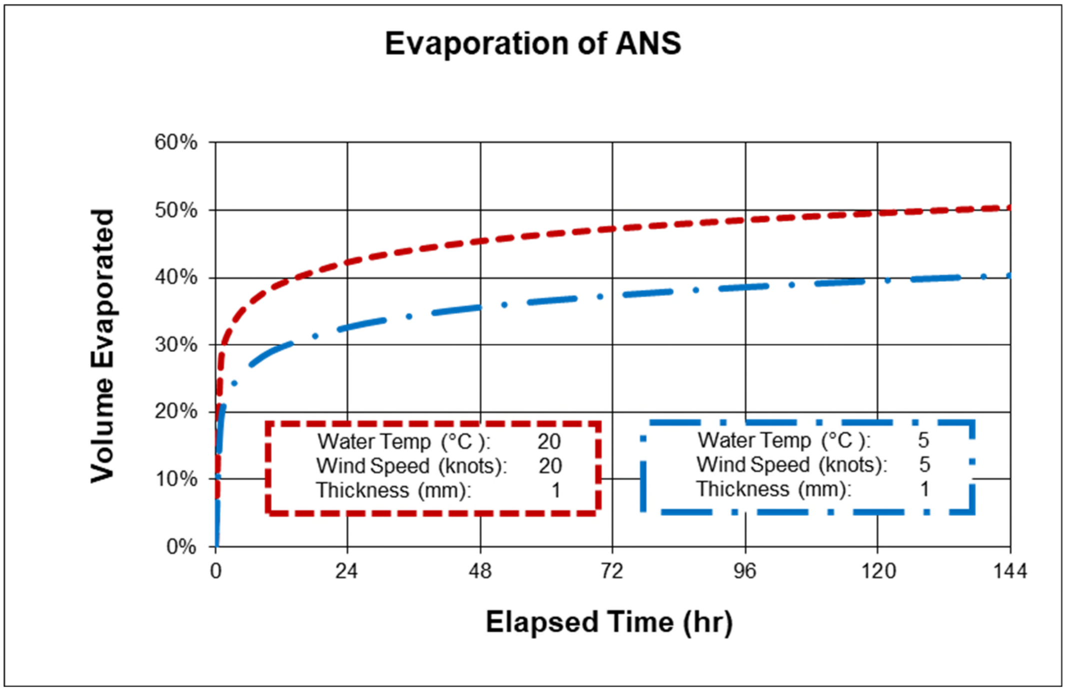
Oil Properties

Initial (fresh) **Flash Point** (°C): **lower than -15°C** Weathered (42% loss) Flash Point (°C): **136°C**	Initial (fresh) **Pour Point** (°C): **-24°C** Weathered (42% loss) Pour Point (°C): **6°C**
Initial Density (g/cm^3) @ 0°C: **0.874** @15°C: **0.863** @20°C: **0.859**	Initial Viscosity (cP) @ 0°C: **22** @15°C: **11** @20°C: **9**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

ANS has no tendency to form stable emulsions. Once weathered to 30% volume loss, ANS is moderately likely to form meso-stable emulsions in seawater at low temperatures. At 38% weathered, it is moderately likely to form entrained or unstable emulsion. A meso-stable emulsion is brown and viscous, a water content ranging from 35% - 83%, and a viscosity increase of up to 45x the parent oil. An entrained emulsion looks black, and is embedded with large water droplets providing a water content in the 26-62% range, and exhibits a viscosity increase of up to 13x greater than the parent oil.

Interaction with suspended sediment and shorelines

ANS demonstrated a moderate to high propensity of interaction with suspended sediment (minerals) in water, so Oil-Mineral Aggregate (OMA) formation is expected in water with high sediment load.

ANS displayed low adhesion properties, with residues not persisting for extended periods of time on simulated shorelines (beach substrates) subjected to repeated wave action (many hundreds of wave impacts). This oil would have high risk for remobilization after impacting shorelines (dependent upon local conditions).

Lightly weathered ANS has a high tendency to penetrate deep into sandy or cobble shorelines. Penetration would slow and become increasingly limited as the oil weathers further and becomes more viscous.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.874	0.924	0.931	0.935	0.942
	20°C	0	0.859	0.919	0.929	0.935	0.956

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	***No test conducted under this condition, expected to float***					

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	22	300	1,500	1,200	2,100
20°C	9	110	240	370	1,100

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing*". Report is available on www.CrudeMonitor.Ca

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

Disclaimer

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Introduction

Access Western Blend (AWB): An unconventional heavy sour, 22.7° API (60°F/15.6°C).

What to Expect

Freshwater: Once in the fresh aqueous environment, AWB will initially float. Based on 5-day testing in a flume tank, evaporative losses resulted in the density starting to increase, and within the first few days was reaching that of water. Oil may begin shedding neutrally buoyant droplets or blobs into the water column.

Marine Environment: AWB is expected to remain floating for significant periods of time allowing for rapid response operations.

Highlighted behaviour: Initial rapid evaporative losses in warm conditions (near 20°C), which slow by the first 24 hour mark. Depending on the environment, AWB can rapidly become too viscous to readily emulsify due to evaporative losses. However, if it encounters an energetic freshwater or marine environment before it becomes highly viscous, significant emulsification is possible. Evaporative losses of approximately 15-20% by volume would be expected within the first few hours of a spill, tapering off to 25-30% loss by the first few days depending on the environmental conditions.

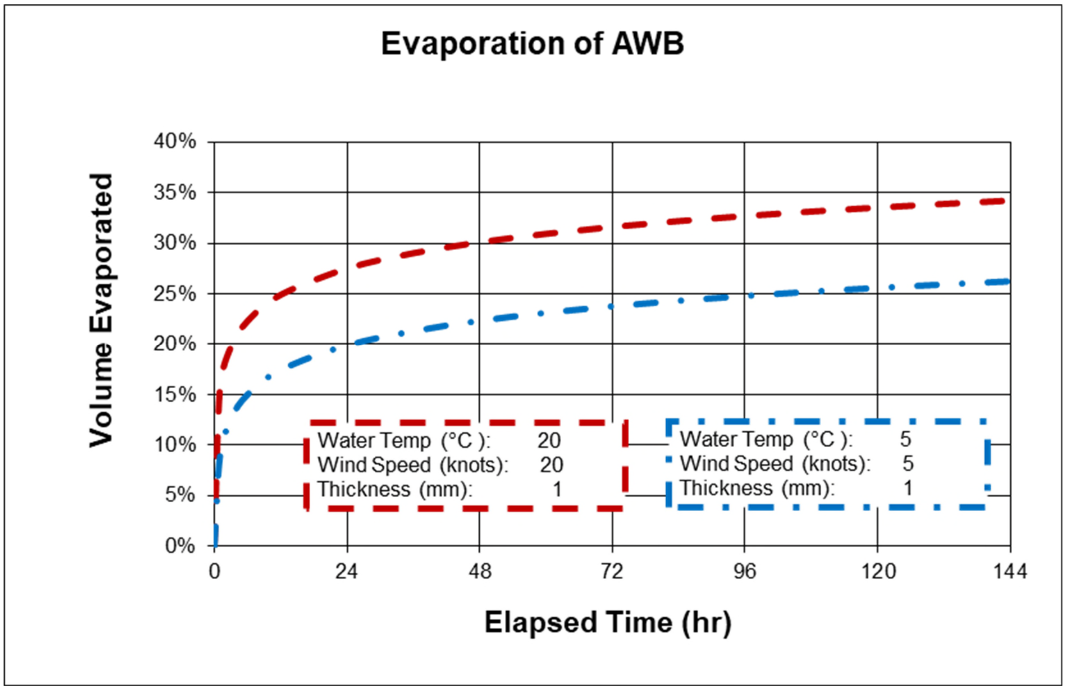
Oil Properties

Initial (fresh) Flash Point (°C): **lower than -10°C** Weathered (27% loss) Flash Point (°C): **33°C**	Initial (fresh) Pour Point (°C): **-36°C** Weathered (27% loss) Pour Point (°C): **12°C**
Initial Density (g/cm^3) @ 0°C: **0.929** @15°C: **0.918** @20°C: **0.914**	Initial Viscosity (cP) @ 0°C: **2100** @15°C: **450** @20°C: **275**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

If AWB encounters an energetic freshwater or marine environment before it becomes viscous, weak emulsification is probable (entrained emulsion likely). Depending on the environment (turbulent water, warm conditions), AWB can rapidly weather due to evaporative losses and other processes, and become too viscous to emulsify further. A resultant increase in viscosity and volume of emulsion would occur with emulsification. An entrained water emulsion looks black, may have a water content approaching 40%, and a viscosity increase of up to 10x the parent oil. The degree of viscosity increase and slick volume increase is highly dependant upon environmental conditions.

Interaction with suspended sediment and shorelines

AWB demonstrated a low-to-moderate propensity of interaction with suspended sediment in fresh water and marine water, so Oil-Mineral Agglomeration (OMA) formation is expected to be low.

This oil displayed high adhesion properties, with residues persisting for extended periods of time on simulated shorelines (beach substrates) subjected to repeated wave action. This oil would have low risk for remobilization after impacting shorelines (dependant upon local conditions).

Lightly weathered oil has a comparatively low tendency to penetrate into sandy or cobble shorelines. Penetration would slow substantially as the oil weathers and becomes more viscous. Impacts from weathered oil would be expected remain at or very near the surface when dealing with shorelines of smaller sized substrates with small void spacing.

Oil Weathering - Submergence Potential[2]

Results presented below are taken from Flume Tank Testing – actual measurements.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.929	0.993	0.996	1.004	1.005
	20°C	0	0.914	0.998	1.000	0.998	1.005

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 72hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	*No test conducted under this condition, expected to float*					
	20°C	1000	0.914	1.001	1.008	1.012	1.012

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are taken from Flume Tank Testing – actual measurements.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	2,100	290,000	320,000	330,000	220,000
20°C	0	280	61,000	120,000	280,000	350,000

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

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1.0 Introduction

Conventional Heavy (CHV): A conventional heavy pool, 21.6° API (60°F/15.6°C).

What to Expect
Freshwater: When in the fresh aqueous environment, CHV will initially float. Based on 5-day testing in a flume tank, the oil will weather in a slow but steady fashion. As the oil weathers over the first few days, it begins to approach the density of water and the risk of submergence increases. No submergence was observed during testing.
Marine Environment: Although testing in a marine environment was not conducted on CHV in this study, it is expected to weather in a similar mode as it did in the freshwater testing and should resist submergence for a longer period of time.
Highlighted behaviour: The oil will initially float on water, but as it weathers over the first few days the risk of submergence in a freshwater environment will increase dramatically as the density approaches that of water. This risk is reduced in a marine environment. The oil viscosity will increase dramatically when subjected to cold conditions. Evaporative losses of approximately 15-20% by volume would be expected in the first few hours of a spill, tapering off to 25-30% loss by the first few days depending upon the environmental conditions.

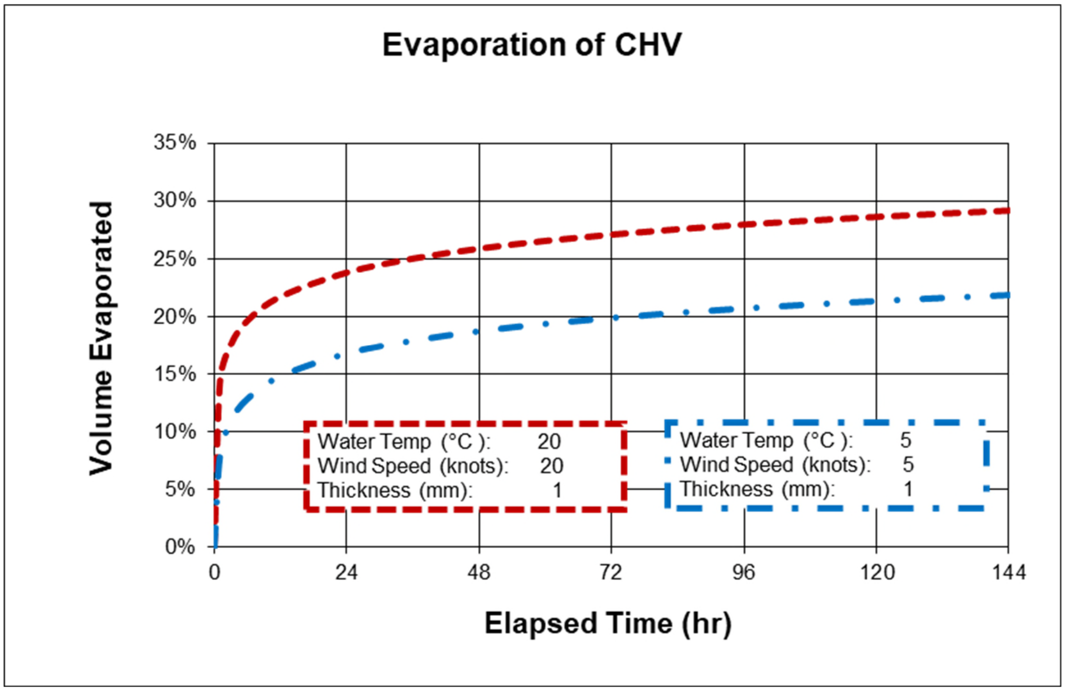
2.0 Initial Properties

Initial (fresh) Flash Point (°C): **lower than -10°C** Weathered (25% loss) Flash Point (°C): **79°C**	Initial (fresh) Pour Point (°C): **-42°C** Weathered (27% loss) Pour Point (°C): **0°C**
Initial Density (g/cm^3) @ 0°C: **0.936** @15°C: **0.924** @20°C: **0.921**	Initial Viscosity (cP) @ 0°C: **565** @15°C: **208** @20°C: **154**

3.0 Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



4.0 Emulsification Potential

One characteristic of CHV is that it will likely only form entrained water emulsions. An entrained water emulsion looks black, with large water droplets; has water contents after 24 hours settling of 26% to 62% averaging 42%; and the emulsion viscosity is 13x greater than the parent oil on average.

5.0 Interaction with suspended sediment and shorelines

CHV demonstrated a moderate-to-high propensity of interaction with certain suspended sediment in fresh water, so Oil-Mineral Aggregate (OMA) formation is expected to be moderate when minerals loadings are high.

This oil displayed high adhesion properties, with residues moderately persisting for periods of time on simulated shorelines (beach substrates) subjected to repeated wave action. This oil would have moderate to low risk for remobilization after impacting shorelines (dependant upon local conditions).

Lightly weathered CHV would have a moderate tendency to penetrate into sandy or cobble shorelines. Penetration would slow substantially as the oil weathers and becomes more viscous. Impacts from weathered oil would be expected remain at or very near the surface when dealing with shorelines of smaller sized substrates with small void spacing.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.936	0.987	0.989	0.996	0.998
	20°C	0	0.921	0.978	0.981	0.987	0.992

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	***No test conducted under this condition, expected to float***					

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP) [3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	570	47,000	86,000	171,000	222,000
20°C	0	150	12,000	20,000	28,000	32,000

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

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Introduction

Cold Lake Blend (CLB): Unconventional heavy sour, 22.4° API (60°F/15.6°C).

What to Expect

Freshwater: When spilled the oil will initially float on water. As CLB weathers, its density will begin to approach that of water and the risk of submergence will be present. Weathering due to evaporation slows after the first 24 hours and the density may plateau just under the density of water for some time (days). No submergence was observed during 5-day flume tank testing.

Marine Environment: Similar behaviour to that experienced in the freshwater tests, with the density seemingly plateauing right around 1 g/mL, which is lower than the density of marine environment. The oil should float for long periods (tested for 6 days).

Highlighted behaviour: Oil weathers quickly for the first 24 hours and the density approaches that of fresh water which increases the risk of submergence. In a marine environment the oil should remain floating for long periods of time (tested to 6 days with very slow changes in density past the first 24 hours). Evaporative losses of approximately 15-20% by volume would be expected in the first few hours of a spill, tapering off to 25-30% loss by the first few days depending upon the environmental conditions.

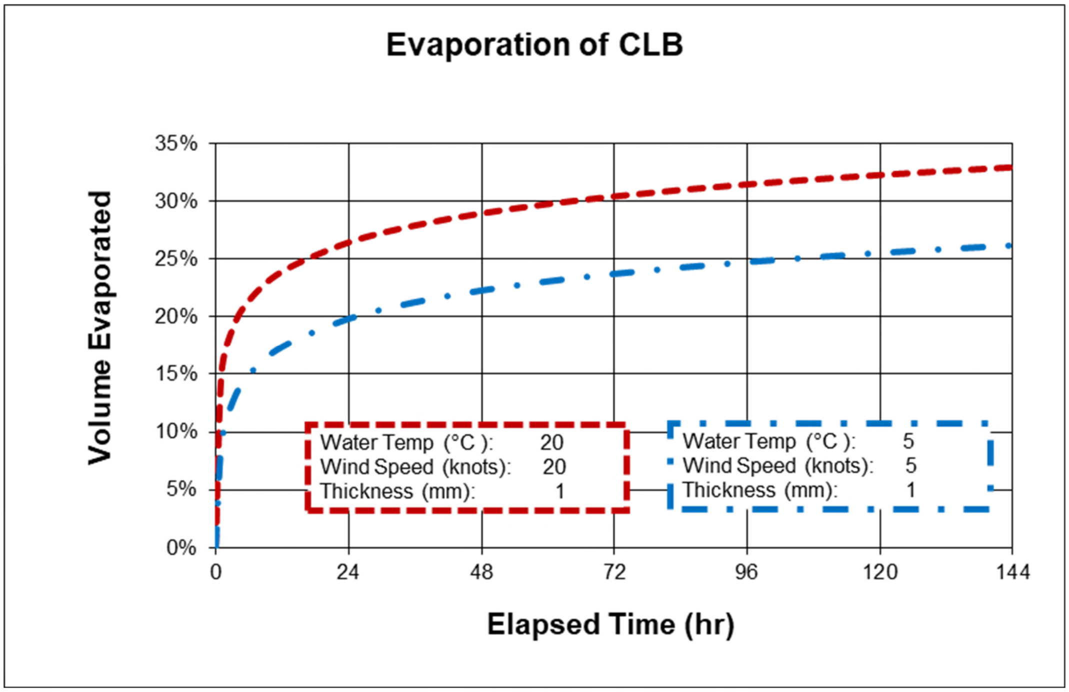
Oil Properties

Initial (fresh) Flash Point (°C): **lower than -10°C** Weathered (26% loss) Flash Point (°C): **50°C**	Initial (fresh) Pour Point (°C): **-39°C** Weathered (26% loss) Pour Point (°C): **6°C**
Initial Density (g/cm^3) @ 0°C: **0.930** @15°C: **0.920** @20°C: **0.916**	Initial Viscosity (cP) @ 0°C: **663** @15°C: **258** @20°C: **156**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

Fresh CLB is likely to form entrained water emulsions under cold conditions (0°C). As it weathers under cold conditions, it quickly becomes too viscous to emulsify further to any large extent. When weathering under warm conditions (20°C) it is likely to form entrained water emulsions when fresh through light weathering (14% volumetric loss). As it weathers further, it too becomes too viscous to emulsify further to any large extent. (An entrained water emulsion looks black, with large water droplets; has water contents after 24 hours settling of 26% to 62% averaging 42%; and the emulsion viscosity is 13x greater than the parent oil on average).

Interaction with suspended sediment and shorelines

CLB demonstrated a low to moderate propensity of interaction with certain suspended sediment in fresh water, so Oil-Mineral Aggregate (OMA) formation is expected to be up to moderate when mineral loadings are very high.

This oil displayed moderate-to-high adhesion properties, with residues lightly persisting for periods of time on simulated shorelines (beach substrates) subjected to repeated wave action. This oil would have moderate to low risk for remobilization after impacting shorelines (dependant upon local conditions).

Lightly weathered oil would have a low tendency to penetrate into sandy or cobble shorelines. Penetration would slow substantially as the oil weathers and becomes more viscous. Impacts from weathered oil would be expected remain at or very near the surface.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 96hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.930	0.989	0.992	0.998	0.995
	20°C	0	0.920	0.983	0.994	0.999	1.000

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	1000	0.920	0.978	1.001	1.004	1.008

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 96hr*	*Time 120hr*
~0°C	0	660	190,000	220,000	273,750	210,000
20°C	0	160	18,000	55,000	38,900	49,000

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

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Introduction

Condensate (CRW): Conventional light sweet, 57.7° API, (60°F/15.6°C).

What to Expect

Freshwater: CRW is extremely light and will spread rapidly if spilled. Because it is so light, it will also weather (evaporate) and disperse very quickly. A high evaporation rate would be expected for the initial 6 hours, slowing after that time period. No risk of sinking.

Marine Environment: Although no tests were conducted under marine environment conditions in the 2020 study, CRW is expected to weather (evaporate) very quickly during the initial 6 hour period, slowing after that. It will also naturally begin a dispersion process. There is no risk of sinking in a marine environment.

Highlighted behaviour: Rapid weathering (evaporation) in the first 6 hour period, slowing after that. Rapid spreading would occur due to low viscosity, no risk of sinking due to low density. Expected to evaporate and disperse naturally in the water. Weather to 60-65% volumetric loss due to evaporation within the first few hours, and up to approximately 80-85% loss expected in a matter of days due to evaporation plus additional losses due to natural dispersion would be expected in a spill depending upon the environmental conditions.

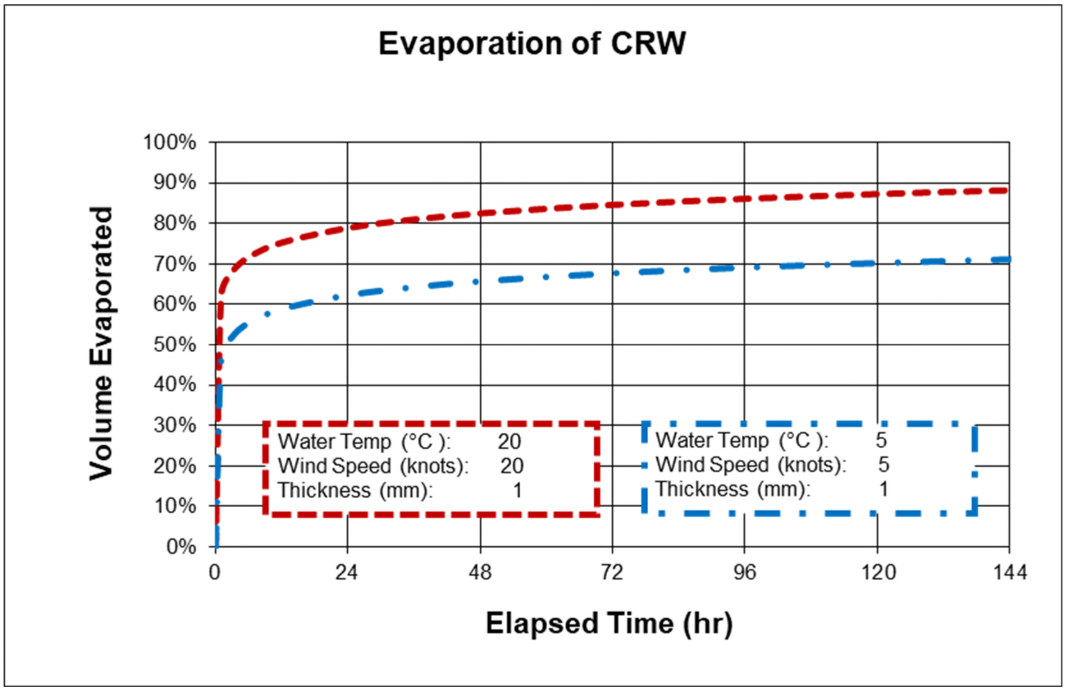
Oil Properties

Initial (fresh) Flash Point (°C): **lower than -12°C** Weathered (80% loss) Flash Point (°C): **148°C**	Initial (fresh) Pour Point (°C): **-57°C** Weathered (80% loss) Pour Point (°C): **15°C**
Initial Density (g/cm^3) @ 0°C: **0.760** @15°C: **0.748** @20°C: **0.744**	Initial Viscosity (cP) @ 0°C: **<3** @15°C: **<3** @20°C: **<3**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

CRW is unlikely to form water emulsions under cold (0°C) and warm (20°C) conditions. Any water picked up would become entrained or incorporated as an unstable emulsion. An unstable emulsion may have between 1% through 23% water content, and the viscosity would be similar to that of the parent oil.

Interaction with suspended sediment and shorelines

CRW demonstrated a moderate to high propensity of interaction with suspended sediment (minerals) in fresh water, so Oil-Mineral Aggregate (OMA) formation is expected to be moderate if mineral loadings are high.

This oil displayed low adhesion properties, with residues not persisting on simulated shorelines (beach substrates) subjected to repeated wave action (many hundreds of wave impacts). This oil would have high risk for remobilization after impacting shorelines unless stranded (dependant upon local conditions).

Partially weathered oil would have a high tendency to penetrate deep into sandy or cobble shorelines. Penetration would continue as the oil weathers because viscosity increases are slight.

Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.760	0.829[3]	0.848	0.854	0.869
	20°C	0	0.744	0.837	0.851	0.863	0.875

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	***No test conducted under this condition, expected to float***					

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[4]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	1	36+	124	352	800
20°C	0	1	11	26	42	136

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Measurement taken from 3 hour reading. No 6 hour reading for this specific run.
[4] Oil/Emulsion sample measured directly from samples taken from flume tank.

Disclaimer

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Introduction

Heavy Fuel Oil (HFO): Bunker fuel or residual fuel oil (historical marine use), 11.6° API (60°F/15.6°C).

What to Expect

Freshwater: HFO will initially float when spilled on water, although there is a risk of submergence which increases substantially as the temperature drops towards 0°C. The oil will weather very slowly, with a density hovering close to the density of fresh water. High sediment loadings increase the risk of submergence.

Marine Environment: HFO will weather slowly with a density close to that of fresh water – it should remain floating for an extended period of time. The risk of submergence will slowly increase over time, particularly in an environment with high sediment loadings.

Additional Highlights: Fresh HFO starts off dense (close to density of fresh water), but weathers slowly. It should initially remain floating unless environmental conditions are cool or it is exposed to high sediment loadings which can dramatically increase the risk of submergence. Low evaporative volumetric losses of around 1-2% would be expected in the first few hours, climbing to approximately 3-6% volumetric losses by the first few days depending upon the environmental conditions.

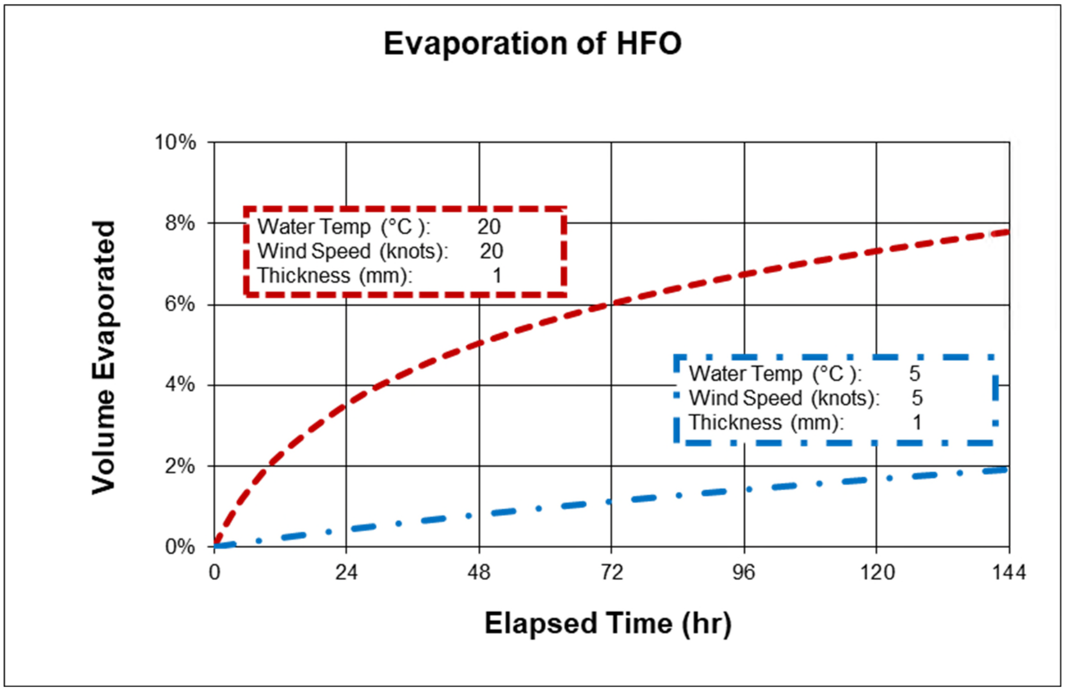
Oil Properties

Initial (fresh) Flash Point (°C): **67°C** Weathered (4% loss) Flash Point (°C): **133°C**	Initial (fresh) Pour Point (°C): **3°C** Weathered (4% loss) Pour Point (°C): **12°C**
Initial Density (g/cm^3) @ 0°C: **1.001** @15°C: **0.990** @20°C: **0.986**	Initial Viscosity (cP) @ 0°C: **116,000** @15°C: **10,300** @20°C: **5,000**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

HFO is unlikely to form water emulsions under cold (0°C) conditions. It likely will, however, form unstable emulsions when fresh and slightly weathered. As the viscosity increases, the tendency to form emulsions diminishes rapidly. An unstable emulsion may have between 1% through 23% water content, and the viscosity would be similar to that of the parent oil.

Interaction with suspended sediment and shorelines

Weathered HFO demonstrated a low propensity of interaction with suspended sediment in fresh water during Oil-Mineral Aggregate (OMA) testing. However, flume tank testing demonstrated interactions under high sediment loadings (1000 ppm) which pushed the bulk density of the slick, which had a starting density approaching that of water, past its tipping point causing gross submergence in fresh water.

This oil displayed moderate adhesion properties, with residues lightly persisting for periods of time on simulated shorelines (beach substrates) subjected to repeated wave action. This oil would have moderate to low risk for after impacting shorelines (dependant upon local conditions).

Fresh oil would have a low tendency to penetrate deeply into sandy or cobble shorelines. Penetration would not be largely affected as the oil weathers because the weathering process is very slow. Impacts from the oil would be expected remain at or very near the surface.

Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	1.001	1.001	1.000	1.002	1.003
	20°C	0	0.986	0.989	0.995	0.995	0.996

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	1000	0.986	0.990	1.004	1.004	1.009

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	116,000	134,000	172,000	200,000	260,000
20°C	0	5,000	9,400	17,000	21,000	31,000

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

Disclaimer

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Introduction

Light Sour Blend (LSB): Conventional light sour pool, 37.2° API (60°F/15.6°C).

What to Expect

Freshwater: LSB is expected to float for long periods of time, with low to moderate risk of submergence as it weathers over an extended time. Weathering via evaporation will occur rapidly during the first 6-12 hours, slowing after that.

Marine Environment: Although no tests were conducted under marine environmental conditions in the 2020 study, LSB is expected to remain floating for long periods of time, allowing for a wide range of spill countermeasures to be implemented.

Additional Highlights: Initial rapid weathering may not impact viscosity as much as many other oils. Flume tank testing showed viscosity remaining low (under 10,000 cP) after many weeks of exposure at a low temperature. The oil does have the potential, however, to form meso-stable emulsions once it becomes weathered which can have a noticeable impact on viscosity. Evaporative losses of approximately 35-40% by volume would be expected within the first few hours of a spill, tapering off to 50-55% loss by the first few days. As with many other oils, the behaviour will be highly dependent upon environmental conditions – which impact weathering and the emulsification phenomenon.

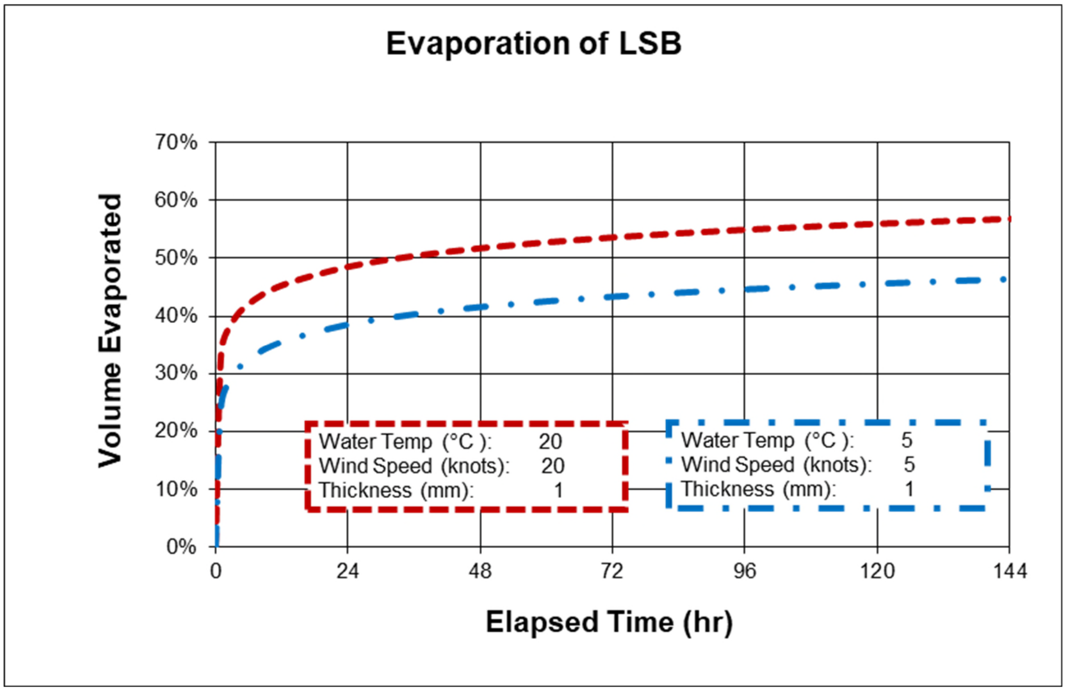
Oil Properties

Initial (fresh) Flash Point (°C): **less than -10°C** Weathered (49% loss) Flash Point (°C): **143°C**	Initial (fresh) Pour Point (°C): **less than -51°C** Weathered (49% loss) Pour Point (°C): **15°C**
Initial Density (g/cm^3) @ 0°C: **0.850** @15°C: **0.839** @20°C: **0.835**	Initial Viscosity (cP) @ 0°C: **10** @15°C: **6** @20°C: **6**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

Fresh through moderately weathered LSB is very likely to form meso-stable water emulsions under cold (0°C) conditions. Under warm conditions (20°C) the fresh oil is initially unlikely to form emulsions but as it becomes moderately weathered, it quickly transitions to form meso-stable emulsions.

A meso-stable emulsion is a brown viscous liquid with water content in the 35% to 85% range, with an emulsion viscosity up to 45x greater than the oil on average.

Interaction with suspended sediment and shorelines

LSB did not demonstrate a propensity to interact with suspended sediments in fresh water during the flume testing.

This oil displayed low adhesion properties, with residues not persisting on simulated shorelines (beach substrates) subjected to repeated wave action. This oil would have high risk for remobilization after impacting shorelines (dependant upon local conditions).

Fresh oil would have a high tendency to penetrate into sandy and cobble shorelines. Penetration would slow slightly as the oil weathers because viscosity increases are limited. Impacts from weathered oil would be expected to penetrate past the surface.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.850	0.914	0.930	0.950	0.963
	20°C	0	0.835	0.909	0.939	0.944	0.975

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	***No test conducted under this condition, expected to float***					

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	10	110	400	2,000	4,300
20°C	0	6	60	330	540	3,400

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

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Introduction

Medium Sour Blend (MSB): Conventional medium sour pool, 35.5° API (60°F/15.6°C).

What to Expect

Freshwater: MSB will remain floating for an extended period of time. Weathering (evaporative losses) are expected to start off quickly (for the first 12 hours) then continue at a much slower rate. Density increases are slight, while viscosity impacts may be affected by emulsification.

Marine Environment: Not tested in a marine environment, but expected to remain floating for extended periods of time allowing for a wide range of spill countermeasures.

Additional Highlights: Evaporative losses of approximately 30-35% by volume would be expected within the first few hours of a spill, tapering off to 45-50% volumetric loss by the first few days depending upon the environmental conditions. MSB is expected to remain light and retain a low viscosity under many conditions which may cause increased spreading.

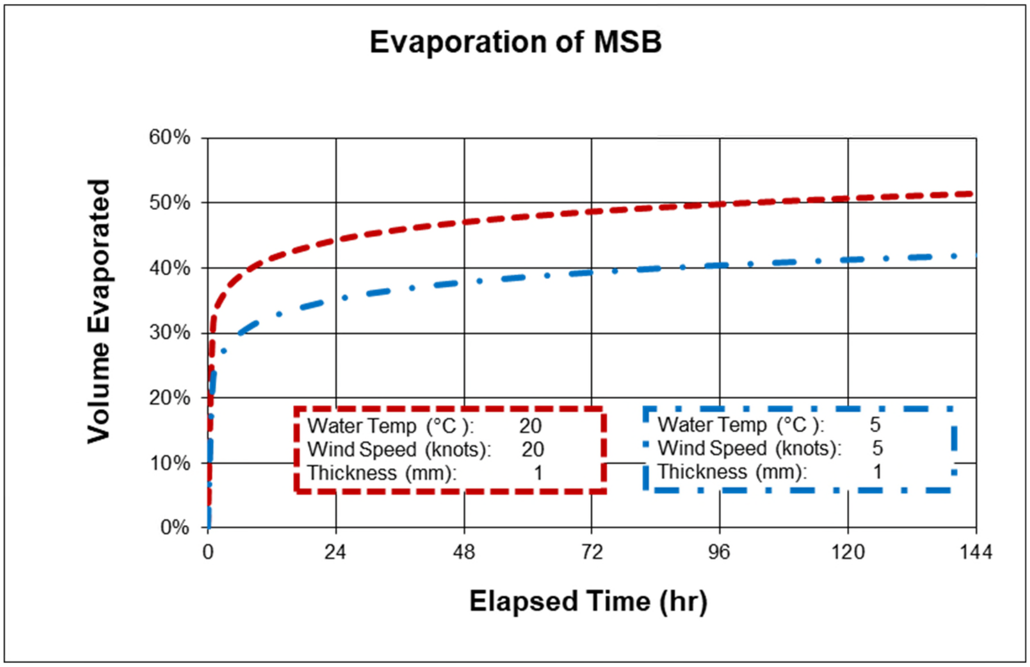
Oil Properties

Initial (fresh) Flash Point (°C): **less than -12°C** Weathered (44% loss) Flash Point (°C): **144°C**	Initial (fresh) Pour Point (°C): **less than -46°C** Weathered (44% loss) Pour Point (°C): **9°C**
Initial Density (g/cm^3) @ 0°C: **0.859** @15°C: **0.848** @20°C: **0.844**	Initial Viscosity (cP) @ 0°C: **15** @15°C: **8** @20°C: **7**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

MSB is unlikely to form stable emulsions when fresh, but that changes once weathering processes begin. At cool (0°C) temperatures, lightly weathered oil was found to be very likely to form stable emulsions. As the oil became more heavily weathered, it transitioned to form meso-stable emulsions. Under warm conditions (20°C), the oil is unlikely to form an emulsion until it becomes more heavily weathered. At that point, it is very likely to form an entrained (weak) emulsion.

A stable emulsion is a brown gel/solid, with water content in the 65% to 93% range, and an emulsion viscosity up to 1000x greater than the parent oil. A meso-stable emulsion is a brown viscous liquid with water content in the 35% to 85% range, with an emulsion viscosity up to 45x greater than the oil on average. Finally an entrained water emulsion looks black with large water droplets, has a water content in the 26% to 62% range, and an emulsion viscosity up to 13x greater than the oil.

Interaction with suspended sediment and shorelines

MSB demonstrated a moderate-to-high propensity of interaction with suspended sediment in water, so Oil-Mineral Aggregate (OMA) formation is expected to be moderate in high sediment loadings conditions.

This oil displayed low adhesion properties, with residues not persisting on simulated shorelines (beach substrates) subjected to repeated wave action (many hundreds of wave impacts). This oil would have high risk for remobilization after impacting shorelines (dependant upon local conditions).

Fresh oil would have high tendency to penetrate into sandy or cobble shorelines. Penetration would slow slightly as the oil weathers because viscosity increases are limited. Impacts from weathered oil would be expected to penetrate past the surface.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.859	0.916	0.925	0.929	0.937
	20°C	0	0.844	0.909	0.918	0.922	0.928

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	***No test conducted under this condition, expected to float***					

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering – Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	15	310	640	950	1,400
20°C	0	7	84	160	200	350

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

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Introduction

Mixed Sweet Blend (MSW): Conventional light sweet pool, 35.5° API (60°F/15.6°C).

What to Expect
Freshwater: MSW is expected to remain floating for an extended period of time. Based on 5-day testing in a flume, evaporative losses and other weathering processes should not result in the density approaching that of fresh water under either warm (20°C) or cold (0°C) water conditions. Oil viscosity increases would likely be impacted by emulsification.
Marine Environment: Expected to remain floating for extended periods of time, allowing for a wide range of spill countermeasures. Evaporative losses during weathering would be high during the initial 12 hour period of a spill, slowing substantially after that.
Additional Highlights: This low density oil remained light, and kept a low viscosity (less than 5,000 cP) during flume testing under a range of conditions. Evaporative losses of approximately 30-35% by volume would be expected within the first few hours of a spill, tapering off to 50-55% loss by the first few days depending upon the environmental conditions.

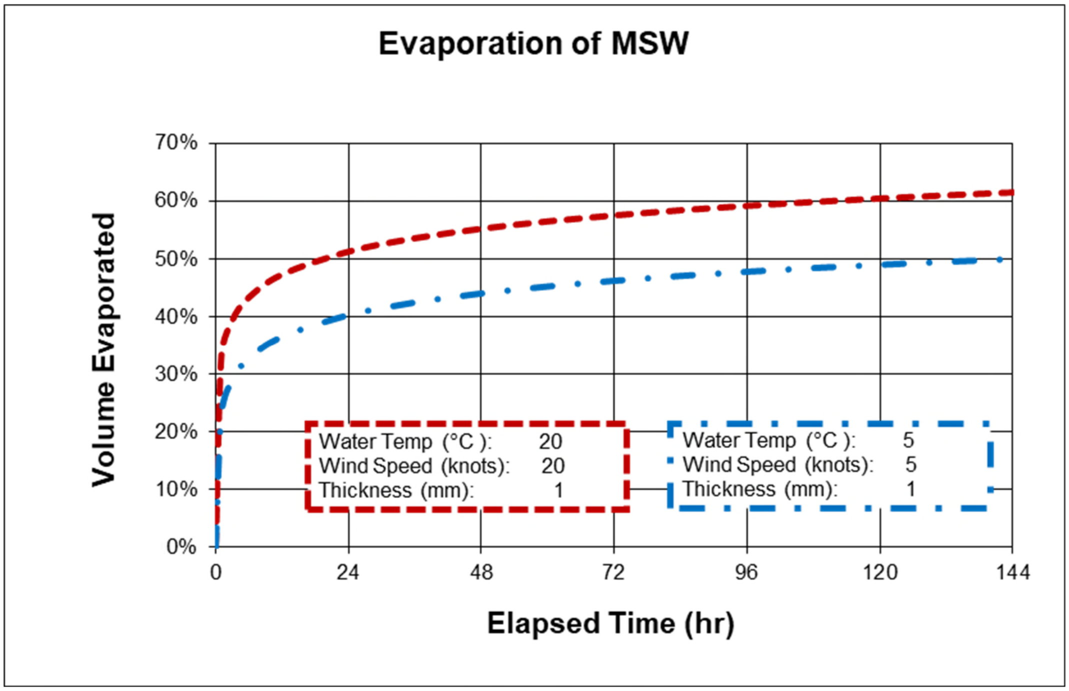
Oil Properties

Initial (fresh) Flash Point (°C): **less than -12°C** Weathered (49% loss) Flash Point (°C): **88°C**	Initial (fresh) Pour Point (°C): **-24°C** Weathered (49% loss) Pour Point (°C): **15°C**
API Gravity (60°F/15.6°C): **35.5°** Initial Density (g/cm^3) @ 0°C: **0.832** @15°C: **0.820** @20°C: **0.816**	Initial Viscosity (cP) @ 0°C: **10** @15°C: **5** @20°C: **5**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

At cooler temperatures (0°C) fresh MSW is very likely to form unstable emulsions, transitioning to stable emulsions as it begins to weather. Emulsification tendencies drop off as the oil weathers more heavily and the relatively low pour point increases its impact on behaviour. At warmer temperatures (20°C) the fresh oil is initially unlikely to form emulsions; however, as it weathers it has a very likely tendency to form meso-stable emulsions.

A meso-stable emulsion is a brown viscous liquid with water content in the 35% to 85% range, with an emulsion viscosity up to 45x greater than the oil on average.

Interaction with suspended sediment and shorelines

MSW demonstrated a low-to-moderate propensity of interaction with suspended sediment in fresh water, so Oil-Mineral Aggregate (OMA) formation is expected to be low.

This oil displayed low adhesion properties, with residues not persisting on simulated shorelines (beach substrates) subjected to repeated wave action. This oil would have a high risk for remobilization after impacting shorelines (dependant upon local conditions).

Fresh oil would have a moderate to high tendency to penetrate into sandy and cobble shorelines. Penetration would slow and become increasingly limited as the oil weathers further and/or emulsifies.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 96hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.832	0.891	0.901	0.914	0.918
	20°C	0	0.816	0.884	0.895	0.942	0.942

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	1000	0.816	0.885	0.894	0.905	0.928

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 96hr*	*Time 120hr*
~0°C	0	10	390	1200	2,600	3,200
20°C	0	5	57	120	520	435

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.

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Introduction

North Dakota Bakken (NDB): Conventional light, 42.6° API (60°F/15.6°C).

What to Expect

Freshwater: This light oil is expected to remain floating for an extended period of time. Evaporative losses would be high over the initial 24 hour period, slowing substantially after that. Based on 5-day testing in a flume tank, evaporative losses should not result in the density approaching that of fresh water under either warm (20°C) or cold (0°C) water conditions. Oil viscosity should remain low resulting in rapid and ongoing spreading of oil, thinning the slick and accelerating the weathering process.

Marine Environment: Although not tested in marine environment, it is expected to behave in a similar manner to the freshwater results.

Additional Highlights: Evaporative losses of approximately 35-40% by volume within the first few hours of a spill, tapering off to 55-60% loss after a couple of days. Viscosity should remain low which will assist in spreading and accelerate weathering processes. This oil should not emulsify unless conditions are cold and/or the oil has weathered extensively.

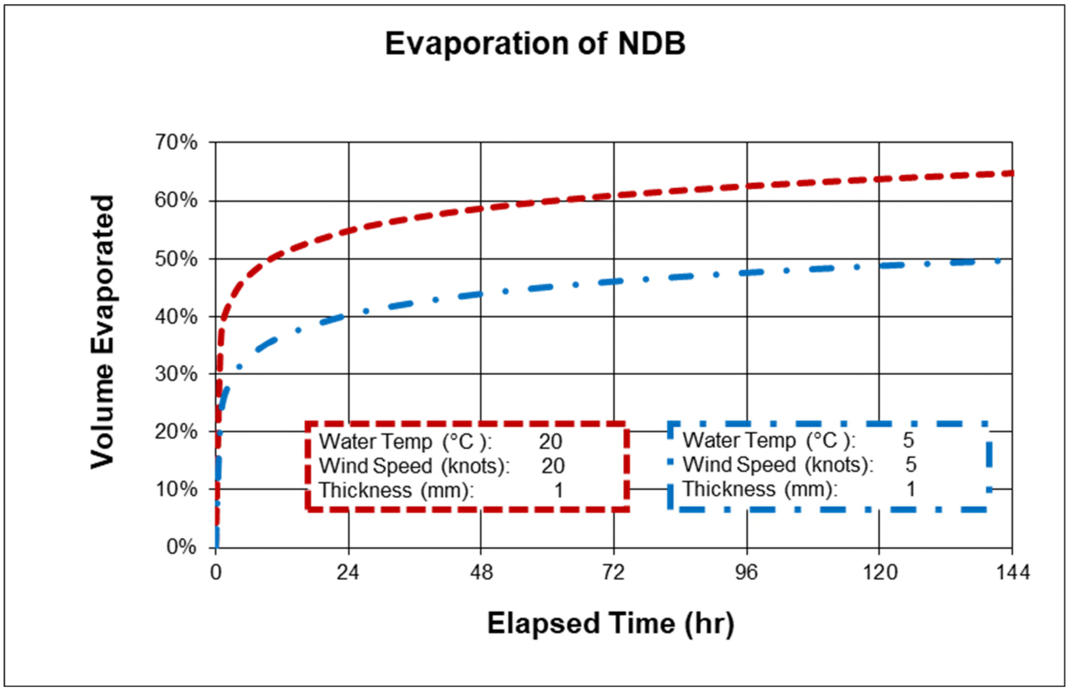
Oil Properties

Initial (fresh) Flash Point (°C): **less than -10°C** Weathered (56% loss) Flash Point (°C): **141°C**	Initial (fresh) Pour Point (°C): **-54°C** Weathered (56% loss) Pour Point (°C): **-18°C**
Initial Density (g/cm^3) @ 0°C: **0.842** @15°C: **0.813** @20°C: **0.809**	Initial Viscosity (cP) @ 0°C: **4** @15°C: **3** @20°C: **3**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

At cooler temperatures (0°C), NDB is unlikely to form stable emulsions until it has weathered and lost approximately half of its initial volume, at which point it becomes very likely to form meso-stable emulsions. At warmer temperatures (20°C), it is unlikely to form emulsions. A meso-stable emulsion is a brown viscous liquid with water content in the 35% to 85% range, with an emulsion viscosity up to 45x greater than the oil on average.

Interaction with suspended sediment and shorelines

NDB demonstrated a low to moderate propensity of interaction with suspended sediment in fresh water, so Oil-Mineral Aggregate (OMA) formation is expected to be low unless mineral concentrations are very high.

This oil displayed low adhesion properties, with residues not persisting on simulated shorelines (beach substrates) subjected to repeated wave action (hundreds of wave impacts). This oil would have a high risk for remobilization after impacting shorelines (dependant upon local conditions).

Slightly weathered oil would have a high tendency to penetrate into sandy and cobble shorelines. This behaviour would continue for some time because the oil viscosity does not increase dramatically as the oil continues to weather.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.824	0.873	0.886	0.887	0.954
	20°C	0	0.813	0.867	0.879	0.883	0.944

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	***No test conducted under this condition, expected to float***					

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP) [3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	4	28	30	87	1,300
20°C	0	3	15	30	40	150

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing*". Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

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Introduction

Synbit Blend (SYB): Blend of unconventional heavy and synthetic, 20.5° API (60°F/ 15.6°C).

What to Expect

Freshwater: SYB is expected to initially float if spilled in a fresh aqueous environment. Based on 5-day testing in a flume tank, oil density readings remained below the density of fresh water in both warm (20°C) and cold (0°C) water testing. Extended testing beyond 5 days showed the density slowly rising into the medium risk level. Initial rapid weathering (evaporative losses) would occur during the first 12 - 24 hours after a spill, slowing dramatically after that period.

Marine Environment: The oil is expected to float for an extended period of time in the marine environment, allowing for a wide range of countermeasures including containment and recovery operations.

Additional Highlights: Evaporative losses of approximately 10-15% by volume would be expected within the first few hours of a spill, tapering off to 20-25% loss by the first few days depending upon the environmental conditions.

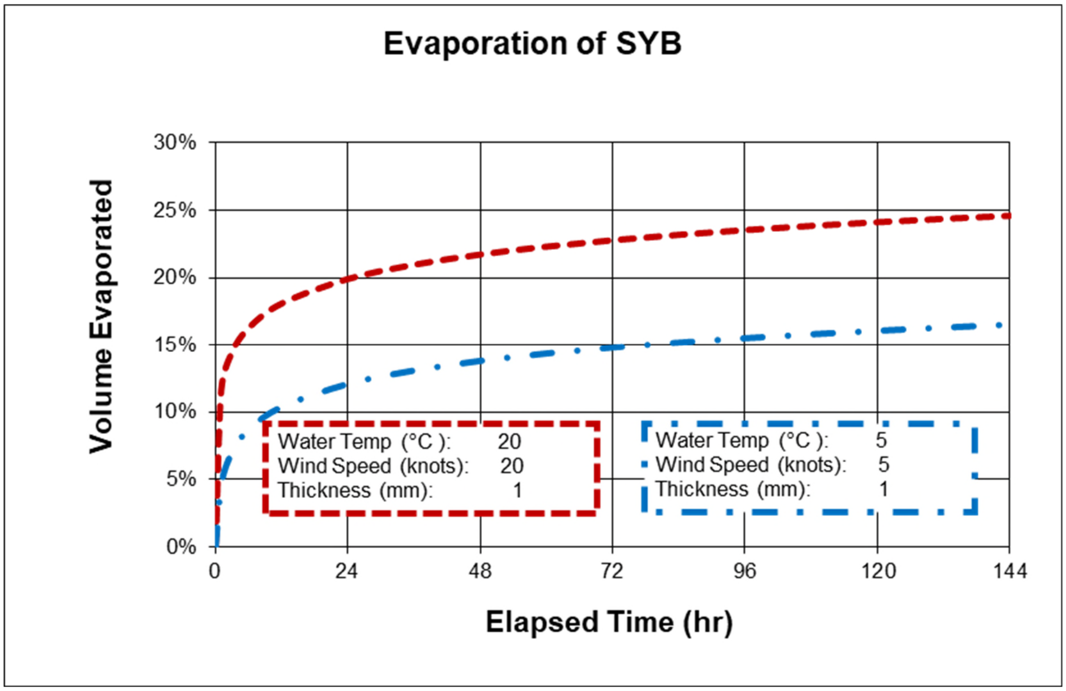
Oil Properties

Initial (fresh) Flash Point (°C): **less than -10°C** Weathered (20% loss) Flash Point (°C): **133°C**	Initial (fresh) Pour Point (°C): **-42°C** Weathered (20% loss) Pour Point (°C): **0°C**
Initial Density (g/cm^3) @ 0°C: **0.941** @15°C: **0.931** @20°C: **0.928**	Initial Viscosity (cP) @ 0°C: **587** @15°C: **194** @20°C: **144**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

In cold conditions (0°C) water temperature, SYB is likely to form meso-stable emulsions when fresh, reducing in stability as it weathers forming entrained emulsions at around 10% weathered (volumetric loss due to evaporation). In warm conditions (20°C), fresh and lightly weathered SYB formed meso-stable emulsions, while more extensively weathered samples generated entrained emulsions.

A meso-stable emulsion is a brown viscous liquid with water content in the 35% to 85% range, with an emulsion viscosity up to 45x greater than the oil on average. An entrained water emulsion retains the colour of the parent oil embedded with large water droplets and has a water content ranging from 26% to 42% with a viscosity near 10x that of the parent oil.

Interaction with suspended sediment and shorelines

SYB demonstrated a moderate to high propensity of interaction with suspended sediment in water, so Oil-Mineral Aggregate (OMA) formation is expected in water with high sediment load.

This oil displayed moderate adhesion properties, with residues not persisting for extended periods of time on simulated shorelines (beach substrates) subjected to repeated wave action (many hundreds of wave impacts). This oil would have high risk for remobilization after impacting shorelines (dependent upon local conditions).

Fresh oil would have a ready tendency to penetrate into sandy and cobble shorelines. Penetration would slow somewhat as the oil weathers and becomes more viscous.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.941	0.961	0.974	0.975	0.978
	20°C	0	0.928	0.963	0.971	0.975	0.978

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	1000	0.928	0.963	0.981	0.977	0.976

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	587	3,000	11,500	12,000	18,000
20°C	0	144	2,100	4,100	6,700	7,100

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

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2.0 Introduction

Synthetic (SYN): Unconventional sweet blend, 33.3° API (60°F/15.6°C).

What to Expect

Freshwater: Based upon 5-day testing in a flume tank, SYN will float for an extended period of time in the fresh aqueous environment. Weathering of the oil slick did not result in the density increasing past the low risk range except for the final reading of the cold water (0°C) run, where it moved into the mid risk range. The oil viscosity remained at a low reading (under 100 cP) over the durations of the test in 20°C and 0°C water temperatures.

Marine Environment: Although not tested in the marine environment, it is expected to float for an extended period of time. SYN is not likely to form a stable emulsion.

Highlighted behaviour: SYN will float for an extended period of time and is not likely to form stable emulsions. Evaporative losses of 20-25% by volume would be expected in the first few hours of a spill, increasing to 30-35% loss by the first few days depending upon the environmental conditions.

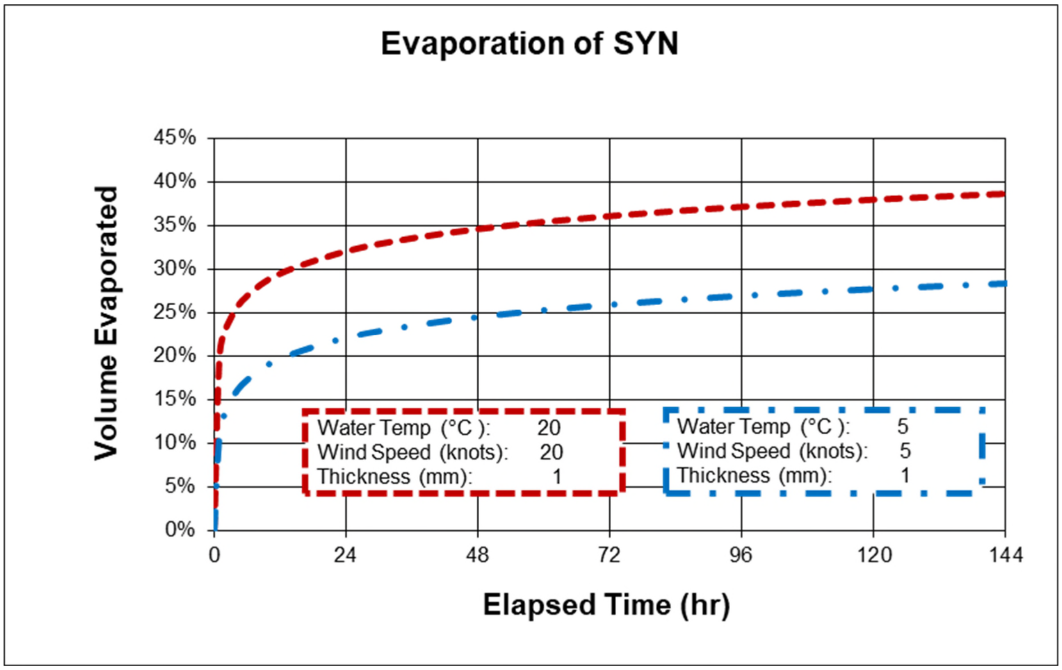
2.0 Initial Properties

Initial (fresh) Flash Point (°C): **less than -12°C** Weathered (34% loss) Flash Point (°C): **139°C**	Initial (fresh) Pour Point (°C): **-51°C** Weathered (34% loss) Pour Point (°C): **-18°C**
Initial Density (g/cm^3) @ 0°C: **0.870** @15°C: **0.859** @20°C: **0.855**	Initial Viscosity (cP) @ 0°C: **12** @15°C: **7** @20°C: **6**

3.0 Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



4.0 Emulsification Potential

SYN is unlikely to form stable emulsions.

5.0 Interaction with suspended sediment and shorelines

Fresh SYN demonstrated a low propensity of interaction with suspended sediment in fresh water during flume tests, so Oil-Mineral Aggregate (OMA) formation is expected to be low or unlikely.

This oil displayed low adhesion properties, with residues not persisting on simulated shorelines (beach substrates) which were subjected to repeated wave action (many hundreds of wave impacts). This oil would have high risk for remobilization after impacting shorelines (dependant upon local conditions).

Slightly weathered oil would have a high tendency to penetrate into sandy or cobble shorelines. Penetration would not be highly impacted as the oil weathers because its viscosity remains light. Highly weathered oil would be expected to readily penetrate the surfaces of shorelines.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.870	0.897	0.907	0.936	0.968
	20°C	0	0.855	0.890	0.896	0.898	0.904

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	***No test conducted under this condition, expected to float***					

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water (35‰ salt) Density: 1.026 g/mL (approximately)		

Oil Weathering – Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	12	38	62	70	92
20°C	0	6	20	26	31	42

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.

Disclaimer

This fact sheet does not purport to address any or all hazards with responding to spills of crude oil or similar products. Proper Personal Protective Equipment should always be worn. Consult SDS.

Introduction

Western Canadian Select (WCS): Unconventional heavy sour, 33.3° API (60°F/15.6°C).

What to Expect

Freshwater: Based upon 5-day testing in a flume tank, WCS will initially float if spilled into a fresh aqueous environment. As it weathers its density will begin to approach that of water and the risk of submergence will be present. Accelerated weathering (evaporation) is expected over the initial 12 – 24 hours, slowing substantially after that time period. Flume tank testing showed the density plateauing just under the density of water, although no submergence was observed during 5 day flume testing.

Marine Environment: WCS is expected to remain floating for an extended period of time. After rapid weathering (evaporative losses) during the initial 12 – 24 hours, the density should plateau near the density of *fresh* water, possibly higher if it emulsifies. This would allow for the use of conventional and unconventional response options.

Additional Highlights: Evaporative losses of approximately 15-20% by volume are expected within the first few hours of a spill, tapering off to 25-30% evaporative loss by the first few days depending upon the environmental conditions.

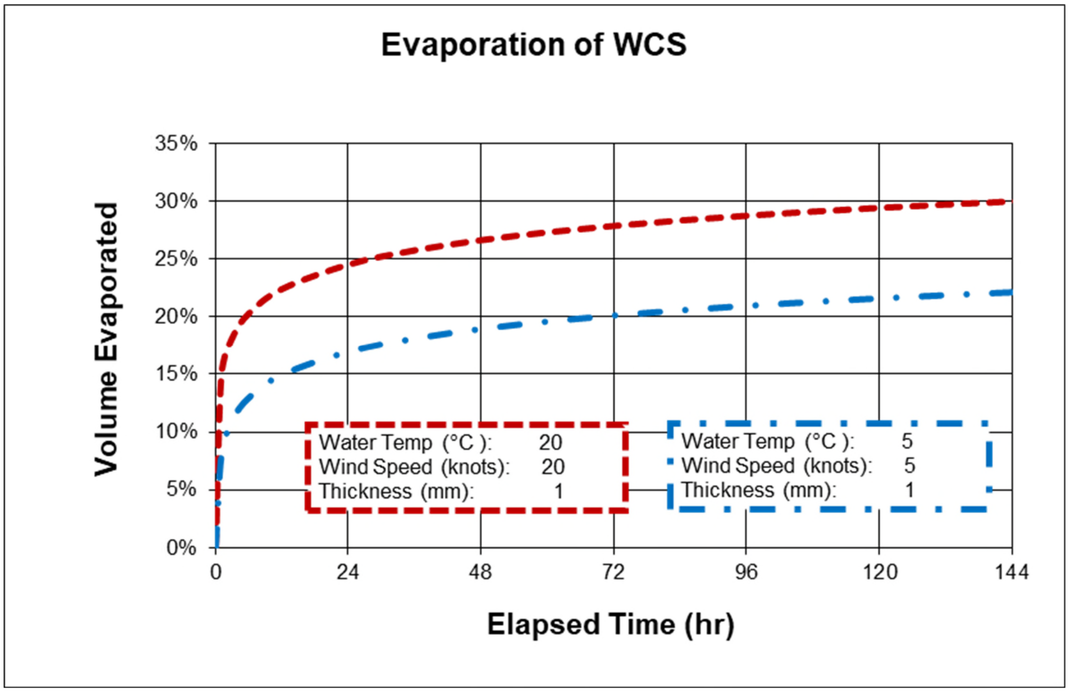
Oil Properties

Initial (fresh) Flash Point (°C): **less than -15°C** Weathered (25% loss) Flash Point (°C): **58°C**	Initial (fresh) Pour Point (°C): **-42°C** Weathered (25% loss) Pour Point (°C): **18°C**
Initial Density (g/cm^3) @ 0°C: **0.935** @15°C: **0.924** @20°C: **0.921**	Initial Viscosity (cP) @ 0°C: **1,600** @15°C: **410** @20°C: **200**

Evaporation Potential

SLROSM (SL Ross Model) outputs of two scenarios are shown below[1]:

[1] Actual evaporation will depend upon specific spill conditions encountered such as the volume of oil, water and air temperatures, and wind speed.



Emulsification Potential

Under both cold (0°C) and warm (20°C) water conditions, fresh WCS is very likely to form meso-stable emulsions. As it begins to weather, it becomes more prone to forming entrained or unstable emulsions until it weathers past its pour point and no longer emulsifies further.

A meso-stable emulsion is a brown viscous liquid with a water content of 35% to 83% and an emulsion viscosity 45x that of the parent oil. An entrained water emulsion looks black, has large water droplets, water content ranging from 26% to 62%, and an emulsion viscosity 13x greater than the parent oil. An unstable emulsion looks like the original oil, has a water content from 1% to 23%, and a viscosity similar to the parent oil.

Interaction with suspended sediment and shorelines

WCS demonstrated a moderate-to-high propensity of interaction with suspended sediment in fresh water, so Oil-Mineral Aggregate (OMA) formation is expected to be moderate when mineral loadings are high.

This oil displayed moderate adhesion properties, with residues not persisting on simulated shorelines (beach substrates) subjected to repeated wave action (many hundreds of wave impacts). This oil would have moderate risk for remobilization after impacting shorelines (dependent upon local conditions).

Lightly weathered oil would have a moderate tendency to penetrate into sandy or cobble shoreline. Penetration would slow substantially as the oil weathers and becomes more viscous. Impacts from weathered oil would be expected remain at or very near the surface.

Oil Weathering - Submergence Potential[2]

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Fresh Water, River	~0°C	0	0.935	0.987	0.986	0.997	0.994
	20°C	0	0.921	0.984	0.988	0.991	0.994

LEGEND	Submergence Potential:	Density
	Low	below 0.96 g/mL
	Mid	between 0.96 and 0.98 g/mL
	High	above 0.98 g/mL
Fresh water density: 1.000 g/mL (approximately)		

Marine Water – Oil/Emulsion Density Range (g/mL)

	Temp	Sediment (ppm)	*Time 0 hr (g/mL)*	*Time 6 hr (g/mL)*	*Time 24hr (g/mL)*	*Time 48hr (g/mL)*	*Time 120hr (g/mL)*
Marine Water, Ocean	~0°C	***No test conducted under this condition, expected to float***					
	20°C	1000	0.921	0.989	0.994	1.000	1.002

LEGEND	Submergence Potential:	Density
	Low	below 0.99 g/mL
	Mid	between 0.99 and 1.01 g/mL
	High	above 1.01 g/mL
Ocean Water Density: 1.026 g/mL (approximately)		

Oil Weathering - Viscosity

Results presented below are actual measurements from the Flume Tank Tests.

Fresh Water – Oil/Emulsion Viscosity Range (cP)[3]

Temp	Sediment (ppm)	*Time 0hr*	*Time 6hr*	*Time 24hr*	*Time 48hr*	*Time 120hr*
~0°C	0	1,600	57,000	47,000	45,000	59,000
20°C	0	200	14,000	29,000	38,000	46,000

Detailed technical information can be found in the "SL Ross (2020) *Comparison of the Behaviour of Spilled Conventional and Unconventional Oils through Lab- and Meso-Scale Testing"*. Report is available on www.CrudeMonitor.Ca.

[2] Submergence potential is an increase in oil density approaching water density and/or adherence to sediments.
[3] Oil/Emulsion sample measured directly from samples taken from flume tank.