Spill Related Properties of IFO180 Fuel Oil

for

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by

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1. INTRODUCTION

When oil is spilled in the marine environment its physical and chemical properties will change over time through the processes of evaporation and emulsification. These changes will affect both the fate and behavior of the spill and the opportunities for using countermeasures effectively. For example, an oil may be relatively fluid and non-viscous when initially spilled, but may become viscous within a short time. It is important to know whether this will happen and how long it will take, defining the so-called Window of Opportunity for countermeasures.

The objective of this study was to conduct simulated oil spill weathering experiments on IFO 180 Fuel Oil. The quantitative results of the tests (involving both fresh and weathered oil) can be used as input to most oil spill models that are used internationally to predict the fate and behavior of spills of specific oils.

2. PHYSICAL PROPERTY TESTS: METHODS AND RESULTS

The laboratory testing described used approximately 3 liters of the fuel oil. The oil was subjected to the analyses outlined in Table 2-1. Test temperatures of 15°C and 25°C were used in the analyses.

A discussion of the methodology of each of these tests is presented in Appendix A, along with an explanation of the effect that each oil property has on spill behavior.

The results of the weathering and analyses of the fuel oil are presented separately in the following section. Complete test results can be found in Appendix B.

Table 2-1 Test Procedures for Spill-Related Analysis of IFO180 Fuel Oil

Property	*Test Temperature(s)*	*Equipment*	*Procedure*
Evaporation	25	Wind Tunnel and ASTM Distillation Apparatus	ASTM D86-90
Density	15 to 25	Anton Paar Densitometer	ASTM D4052-91
Viscosity	15 to 25	Brookfield Viscometer	ASTM D2983-87
Interfacial Tension	25	CSC DuNouy Ring Tensiometer	ASTM D971-82
Pour Point	N/A	ASTM Test Jars and Thermometers	ASTM D97-87
Flash Point	N/A	Pensky-Martens Closed Cup Flash Tester	ASTM D93-90
Emulsion Formation-Tendency and Stability	15	Rotating Flask Apparatus	(Mackay and Zagorski 1982)

2.1 RESULTS

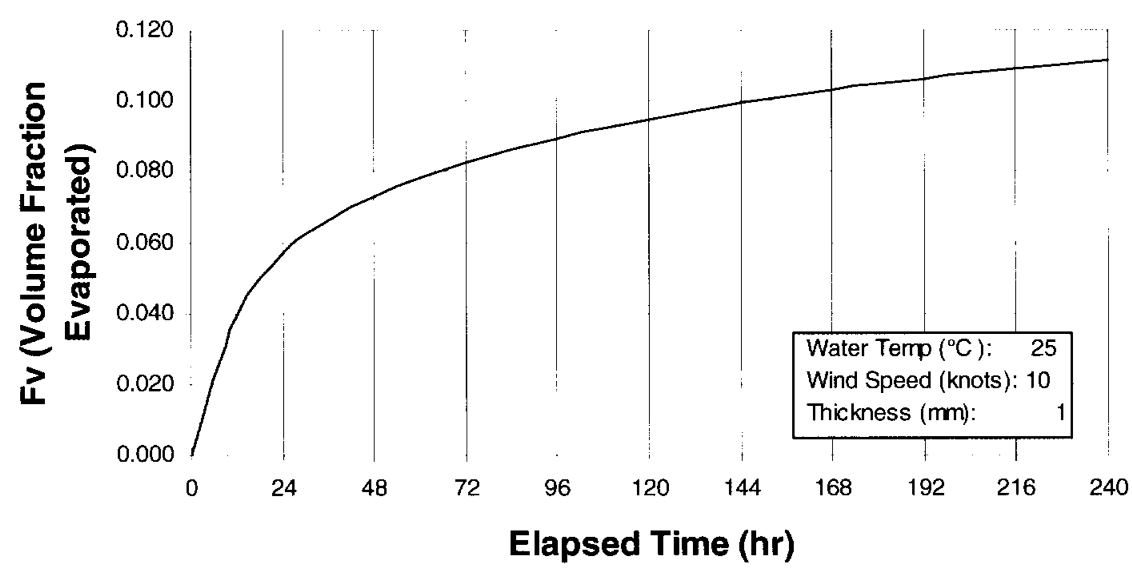
The results of the property analyses on IFO180 Fuel Oil are summarized in Table 2-2. The complete test results can be found in Appendix B. The two levels of evaporation noted in the table represent the amounts evaporated from a two cm-thick slick in the wind tunnel after two days and two weeks of continuous airflow, respectively.

2.1.1 Evaporation

IFO180 Fuel Oil is a black, viscous oil. Approximately 0.9% (by volume) of the oil evaporated after two days in the wind tunnel, and about 4.6% evaporated after two weeks of exposure.

Figure 2-1 is a predicted evaporation curve for a spill involving a 1-mm thick slick in a 10 knot wind at 25°C. Please note that the curve only applies at a water temperature of 25°C. If other temperatures (or slick thicknesses and wind speeds) are of interest, these curves can be generated using the equations in Appendix A and data in Appendix B[1]. Computerized oil spill models automatically do these calculations.

Figure 2-1 Evaporation of IFO180 Fuel Oil



[1] The evaporation curve of the oil in the wind tunnel is shown in Appendix B, plotting the volume fraction of oil evaporated, Fv, on the y-axis versus evaporative exposure, Θ, on the x-axis, where Θ is the unit of time expressed in dimensionless form. Equations described in Appendix A and data in Table 2-2 of Appendix B can be used to convert this curve into a more usable form for estimating oil evaporation under various spill conditions of temperature, elapsed time and wind speed.

Table 2-2 Spill-Related Properties of IFO180 Fuel Oil

Evaporation (Volume %)	0	0.9	4.6
Density (g/cm^3)			
15 °C	0.960	0.964	0.967
25 °C	0.957	0.958	0.960
Dynamic Viscosity (mPa.s)[a]			
15 °C	2471	2849	5060
25 °C	929	1033	1625
Kinematic Viscosity (mm^2/s)			
15 °C	2573	2955	5231
25 °C	970	1079	1692
Interfacial Tension (dyne/cm)			
Oil/ Air	35.1	36.4	38.3
Oil/ Seawater	21.1	21.8	21.8
Pour Point (°C)	-9	0	3
Flash Point (°C)	75	76	89
Emulsion Formation-Tendency and Stability @		15 °C	
Tendency Index	Fairly likely	Not likely	Not likely
Stability Index	Fairly stable	Unstable	Unstable
Water Content	26%	0%	0%
ASTM Modified Distillation	Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
	IBP	275	162
	5	311	245
	10	343	276
	15	378	296
	20	410	319
	25	429	332
	30	438	340
	40	450	360
	50	459	372

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)

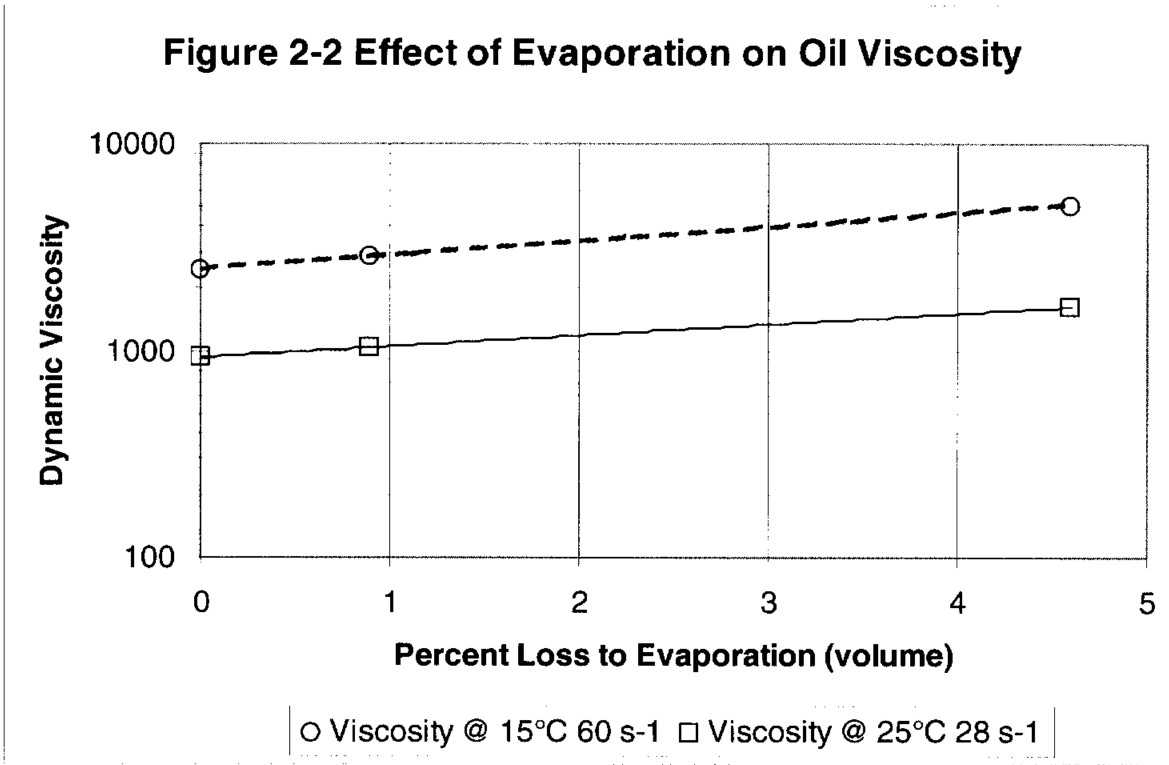
C_1 = 12102

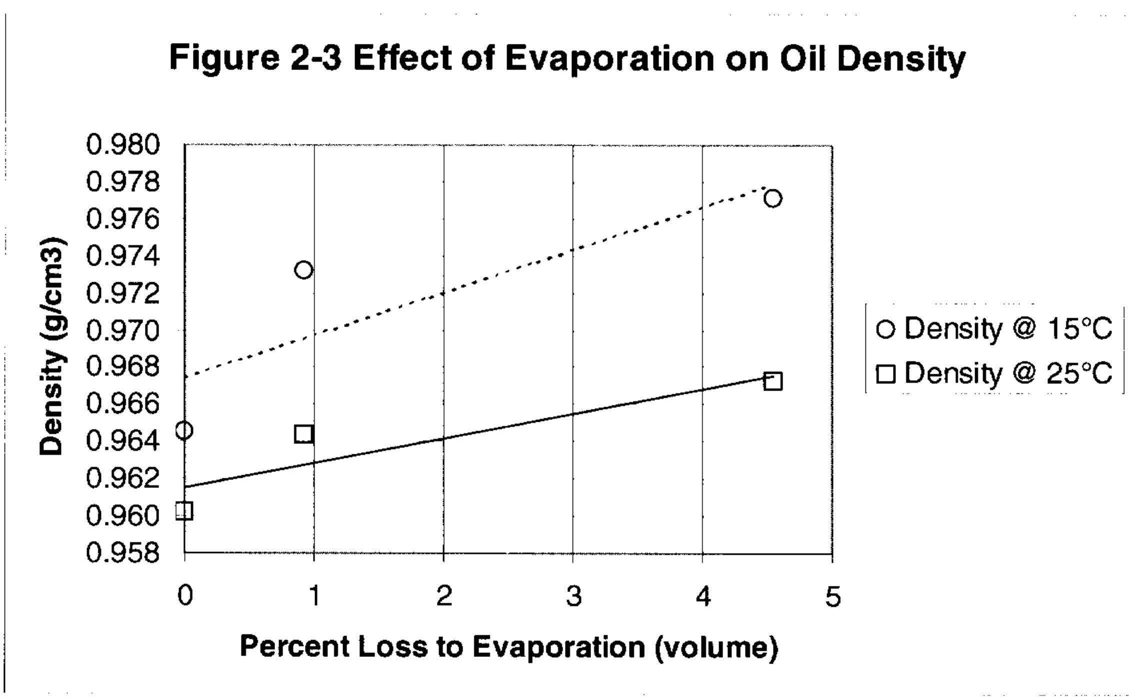
C_2 = 60.58

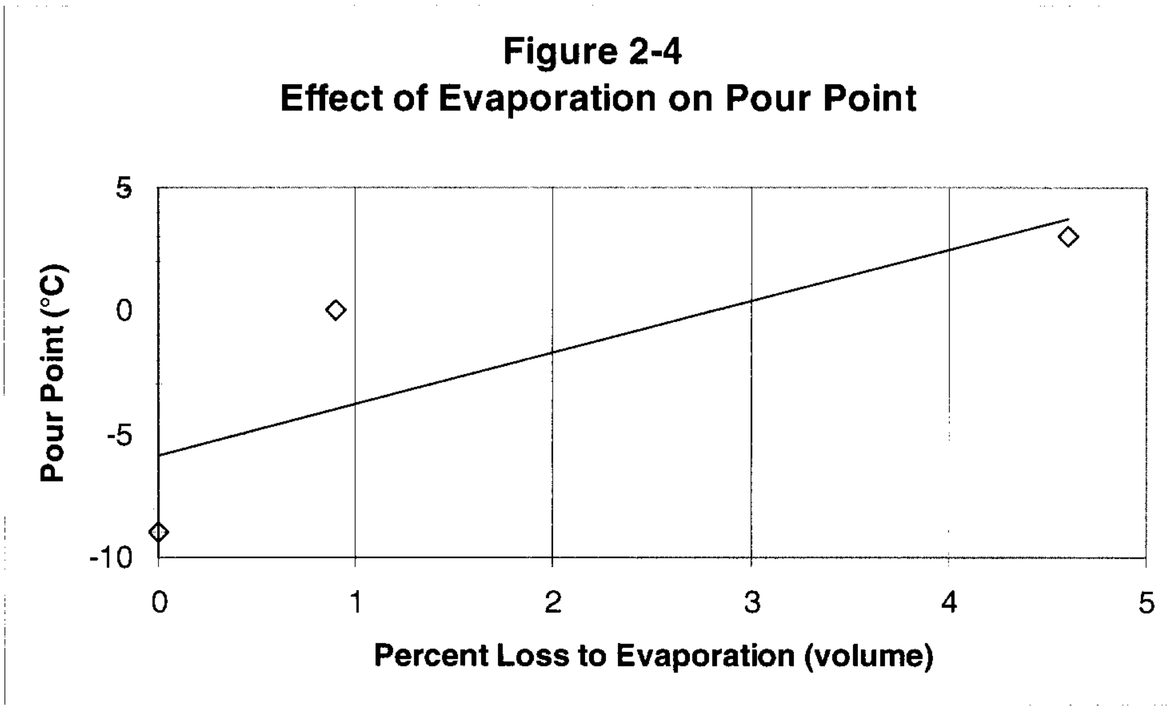
C_3 = 22391

[a] See note in Section 2.1.3.

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







2.1.2 Density

IFO180 Fuel Oil is black and relatively viscous with a fresh oil density of 0.960 g/cm^3 at 15°C (API gravity of 15.9°).

2.1.3 Viscosity

The viscosity of the fresh oil is about 2470 cP (mPa.s) at 15°C. The viscosity increases to 2850 cP after 0.9% evaporation and to 5060 cP after 4.6% evaporation. The viscosity of this fuel oil is highly temperature dependent as seen in Figure 2.2.

Note: The viscosity of this fuel oil was measured by SL Ross and MAR in October of 2003. In both cases the viscosity of the fresh IFO 180 was measured to be about 2000 cP at 16°C, which is somewhat lower than the viscosity measured in this study (2470 cP at 15°C or 2240 cP at 16°C). The following is provided as a possible explanation for the differences in measured viscosities. The standard method for viscosity measurement calls for the sample to be heated in a sealed container to 45°C prior to the measurement to ensure that all waxes and other components are uniformly incorporated in the sample. This step was followed for all viscosity measurements in this study. When a small sample of this fuel oil is heated a small amount of the diluent agent used to blend the fuel oil to meet its viscosity specification evaporates from the sample. Since only small amounts of these diluents are used in these fuel oil blends, the loss of even a small fraction of them may change the viscosity of the oil significantly. We feel that this is the most likely reason for the higher viscosities measured for the fresh fuel oil in this study when compared to previous measurements.

2.1.4 Interfacial Tension

The oil/water interfacial tension of IFO180 Fuel Oil, measured against standard laboratory water with 35 ppt of salt, was 21.1 dynes/cm.

2.1.4 Pour Point

IFO180 Fuel Oil has a pour point of –9 °C when fresh. This increased to 0 °C at 0.9 percent evaporation and 3 °C at 4.6 percent evaporation.

2.1.5 Flash Point

IFO180 Fuel Oil has a flash point of 75 °C when fresh. This rises to 89 °C after 4.6% evaporation.

2.1.6 Emulsification Tendency and Stability

From the viewpoint of spill countermeasures and slick persistence, emulsification is a very negative process because strongly emulsified oils are highly viscous — they can have ten to 100 times the viscosity of the parent oil. It is general believed that oils that have relatively high concentrations of asphaltenes 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 asphaltene concentration increases, the emulsification process begins and usually proceeds quickly thereafter.

Based on the laboratory tests fresh IFO180 Fuel Oil has a moderate tendency to form stable water-in oil emulsions when mixed with seawater. The 0.9 and 4.6% evaporated IFO180 did not form emulsions in the lab tests. This may be due to the increased viscosity of the weathered fuel oil and the inability to mix water droplets into the more viscous oil.

4. References

Mackay, D., W. Stiver and P.A. Tebeau. 1983. Testing of crude oils and petroleum products for environmental purposes. In Proceedings of the 1983 Oil Spill Conference, American Petroleum Institute, Washington, D.C., pp 331-337.

Mackay, D. and W. Zagorski. 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.

Appendix A. Oil Property Test Methodology and Relationship to Spill Behavior

A.1 Evaporation

Evaporation is one of the most significant processes that affects an oil when it is spilled. Evaporation removes the volatile, light hydrocarbons from the oil and leaves behind the heavier fractions.

A wind tunnel was used to determine the evaporative characteristics of selected oils, and to prepare weathered samples for physical property analysis. Three 900-mL samples of oil were withdrawn from the shipping container. One of these was reserved, while the remaining two were poured into shallow metal trays and placed in a wind tunnel operating at a wind speed of approximately 3 m/s, and an air temperature of approximately 20°C. The initial thickness of oil in the trays was 2.0 cm. One sample was removed from the tunnel after two days, and the second after two weeks. Depending on the conditions at a spill site, these durations are typically equivalent to three or four hours and about one day at sea, respectively.

The fresh oil and the weathered samples were then analyzed for the selected physical properties according to the procedures listed in Tables 2-1 in the main text. In addition, the fresh oil was subjected to a modified ASTM distillation (ASTM D86-90, modified in that both liquid and vapor temperature were measured) in order to obtain two oil-specific constants for evaporation prediction purposes. The distillation information was used in conjunction with the wind tunnel data to predict evaporation rates for oil spills at sea.

While in the wind tunnel, the mass of oil remaining in the trays was measured and recorded regularly – hourly during the initial, rapid evaporation phase, reducing to daily after the two-day sample was removed. The elapsed time at each measurement, the initial thickness of oil in the tray, and the wind tunnel conditions were used to determine the evaporative exposure (Mackay et al. 1983), according to:

$$\theta = \frac{Kt}{x_o} \qquad (1)$$

Where:
- θ is evaporative exposure
- K is the mass transfer coefficient (m/s)
- t is elapsed time (s)
- x_o is initial slick thickness (m)

Evaporative exposure provides a means of correlating the rate of evaporation of an oil under the conditions in the wind tunnel (i.e., slick thickness and wind speed) to other environmental conditions at a spill site. The wind tunnel mass transfer coefficient, *K*, from equation 1 was determined by calibrating the wind tunnel with a tray of pure toluene during use. For a spill situation, the mass transfer coefficient can be estimated from:

$$K = 0.0015U^{0.78} \qquad (2)$$

Where:
- U is wind speed [m/s]

For spills at sea, it is difficult to obtain a slick thickness. As such, an average initial thickness, defined as the volume spilled divided by the area of the slick, is substituted for x_o in equation 2. A plot of volume fraction evaporated versus evaporative exposure was prepared for both .oils using the data from the wind tunnel. Included in the plots was the evaporation predicted by the Mackay equation under the conditions in the wind tunnel. The equation is given at the bottom of table 3-1, and is of the form:

$$Fv = \frac{\ln\left[1 + \frac{C_1}{T}\theta \exp\left(C_2 - \frac{C_3}{T}\right)\right]}{\frac{C_1}{T}} \qquad (3)$$

Where:	Fv	is volume fraction evaporated
	C_1, C_2 and C_3	are oil-specific constants
	T	is environmental temperature (K)

The constants C_1, C_2 and C_3 were calculated from the wind tunnel evaporation data, and from the ASTM distillation curve of the fresh oil. The slope and intercept of the distillation curve are used as a measure of the oil's volatility, which allows evaporation rates at temperatures other than that in the wind tunnel to be predicted.
Equations 1, 2 and 3 can be used to estimate oil evaporation under various spill conditions of temperature, elapsed time and wind speed.

A.2 Density

Density, the mass per unit volume of the oil (or emulsion), determines how buoyant an oil is in water. The common unit of density is grams per cubic centimeter (g/cm^3). The density of an oil increases with weathering and decreases with increasing temperature. Density affects the following 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 disperse more easily; and,
- emulsification stability - dense oils form more stable emulsions.

A.3 Viscosity

Viscosity is a measure of the resistance of an oil to flowing, once it is in motion. The common unit of viscosity is the centiPoise (cP); the SI unit is the milliPascal second (mPa·s), which is numerically equivalent to the centiPoise. The viscosity of an 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.4 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. 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. Interfacial tensions (oil/air and oil/water) are 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;
- 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.5 Pour Point

The pour point is the lowest temperature (to the nearest multiple of 3°C) at which an oil will still flow. Below this temperature, the oil develops an internal yield stress and, in essence, solidifies. 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;
- viscosity - an oils viscosity increases dramatically at temperatures below it's pour point;
- dispersion - an oil below its pour point is more difficult to disperse; and,
- recovery, transfer and storage - an oil below its pour point will resist flowing towards skimmers or down inclined surfaces in skimmers, and presents storage and transfer problems.

A.6 Flash Point

The flash point of an oil is the temperature (in °C) 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.7 Emulsion Formation-Tendency and Stability

A water-in-oil emulsion (colloquially named "chocolate mousse") is a stable emulsion of small droplets of water incorporated in oil. Oil spills on a water surface may form stable water-in-oil emulsions, which can have very different characteristics than the parent oil.

The tendency of an oil to form water-in-oil emulsions (or "mousse") and the stability of the emulsion formed are measured by two indices: the Emulsification Tendency Index and the Emulsion Stability Index. The Emulsion Formation-Tendency Index can have a value of low, indicating that the oil will not form an emulsion, or high, indicating that the oil will form an emulsion. The Emulsion Stability Index can be low, which indicates the emulsion is unstable and will break quickly once it is removed from the mixing environment, moderate, which means the emulsion will break within a few hours, and high, which means the oil forms a very stable emulsion that is unlikely to break even after standing for 24 hours.

Both the Tendency Index and Stability Index generally increase with increased degree of evaporation. Colder temperatures generally increase both the Tendency Index and Stability Index (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.

The test procedure for emulsion tendency and stability follows the method now called the Mackay and Zagorski Test (Mackay 1982a, Mackay 1984). Three hundred milliliters of artificial seawater and 30 mL of oil are placed in a 500 mL Fleaker (oil to water ratio of 1:10), and the Fleaker is sealed. The Fleaker is rotated for one hour at a rotation speed of 65 rpm and then allowed to settle for 30 minutes. The fraction of oil that forms an emulsion, f, is determined by measuring the height of the emulsion and the height of the unemulsified oil. Three additional mixing/settling cycles are performed with measurements of f taken at each rotation interval. The tendency of an oil to form an emulsion is given by $f_{initial}$ which is obtained by plotting f versus time, and by extrapolating f to time zero.

The following criteria are used to classify the tendency of a oil to form a stable emulsion:

Range of $f_{initial}$	Emulsion Formation Tendency
0.0 to 0.25	Not likely
0.25 to 0.75	Fairly likely
0.75 to 1.0	Very likely

The stability of a water-in-oil emulsion is obtained by allowing the emulsion to settle for an additional 24 hours, and then measuring the fraction of oil in the emulsion (f_{final}) visually. The stability of the water-in-oil emulsion is classified as follows:

Range of f_{final}	Emulsion Stability
0.0 to 0.25	Unstable
0.25 to 0.75	Fairly stable
0.75 to 1.0	Very Stable

The calculated water content of stable water-in-oil emulsions is also provided.

APPENDIX B. OIL PROPERTY ANALYSIS RESULTS FOR IFO180 FUEL OIL

el Oil

Average Air Temp	
°C	23.9

Volume Weathered(ml)	900
Volume for 2cm thick	900
Tray thickness (m)	0.02

T	298.2	K
K	0.00526366	m/s
x	0.001	m

Modeling Inputs:	
Temp(°C)	25
Wind Speed (knots)	10
Thickness (mm)	1

Mass of Oil		Fm		Oil	Fv			Automated				
Tray x (g)	Tray y (g)	Tray x	Tray y	Density (g/cm^3)	Tray x	Tray y	Evaporative Exposure (Corrected)	Model Evaporate (Fv)	Model Evaporate (Fv)	Elapsed Time 2 (hr)	Evaporative Exposure 2	Model Evaporation 2 (Fv)
851.3	834.8	0.000	0.000	0.958	0.000	0.000	0	0.000	0.000	0	0	0.000
850.9	834.4	0.000	0.000	0.958	0.001	0.001	381	0.000	0.000	12	227390	0.039
850.7	834.1	0.001	0.001	0.958	0.001	0.001	856	0.000	0.000	24	454780	0.057
847.5	831.3	0.004	0.004	0.958	0.005	0.005	21023	0.006	0.006	36	682170	0.066
846.8	830.6	0.005	0.005	0.958	0.006	0.005	28443	0.008	0.008	48	909561	0.073
844.0	828.0	0.009	0.008	0.958	0.009	0.009	52510	0.013	0.013	60	1136951	0.078
	817.8		0.020	0.959		0.022	133368	0.025	0.025	72	1364341	0.083
	814.7		0.024	0.960		0.026	158862	0.028	0.028	84	1591731	0.086
	813.7		0.025	0.960		0.027	165521	0.028	0.028	96	1819121	0.089
	810.5		0.029	0.960		0.031	182834	0.030	0.030	108	2046511	0.092
	808.6		0.031	0.960		0.034	220980	0.033	0.033	120	2273901	0.095
	807.4		0.033	0.960		0.035	249043	0.036	0.036	132	2501291	0.097
	802.8		0.038	0.961		0.041	329330	0.041	0.041	144	2728682	0.099
	801.0		0.040	0.961		0.044	357202	0.043	0.043	156	2956072	0.101
	799.5		0.042	0.961		0.046	381270	0.044	0.044	168	3183462	0.103
										180	3410852	0.105
										192	3638242	0.106
										204	3865632	0.108
										216	4093022	0.109
										228	4320412	0.110
										240	4547803	0.112

	2-day	2-week		2-day	2-week
Fm	0.009	0.042	Fv	0.009	0.046

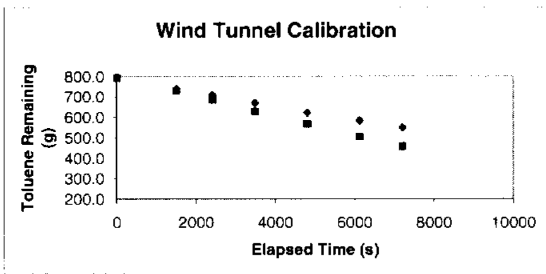
Wind Tunnel Calibration **Toluene**

Tray Mass (g)

Elapsed Time (s)	Mass Toluene Tray 1 (g)	Tray 4 (g)
0	799.3	791.2
1500	739.1	730.2
2400	710.2	685.0
3480	670.6	628.1
4800	623.1	568.1
6120	583.9	505.4
7200	551.7	459.1

	Tray 1	Tray 4
slope	-0.03431367	-0.046969

E (kg/s)	-4.0641E-05	
Wind Tunnel Temperature, T (K)	297.0824052	23.92 °C
Toluene Vapor Pressure, P (kPa)	3.587	
Ideal Gas Constant (R, kPa.m^3/kg.mol.K)	8.314	
Molecular Weight of Toluene (W, kg/kg.mol)	92.13	
Tray Area (A, m^2)	0.0479	
K = ERT/APW (m/s)	-0.00634181	



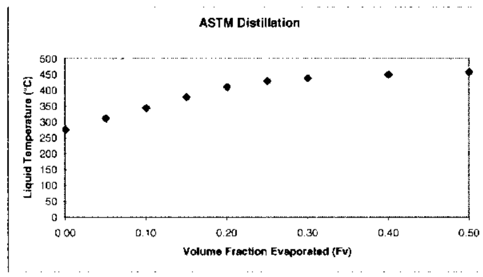
ASTM Distillation **IFO180 Fuel Oil**

200 ml Fresh oil

Volume Distilled (mL)	Fraction Distilled (Fv)	Temperature Liquid (°C)	Vapor (°C)
IBP	0.00	275	162
10	0.05	311	245
20	0.10	343	276
30	0.15	378	296
40	0.20	410	319
50	0.25	429	332
60	0.30	438	340
80	0.40	450	360
100	0.50	459	372

slope 322.5
intercept 323.6

Distillation Constant A (slope, K) 322.5
Distillation Constant B (intercept, K) 596.8



Mackay Constants **IFO180 Fuel Oil**
(automated)

Point	Fv	Tb/T	H	ln(H)
1	0.000	2.009	1.360E-06	-13.508
2	0.001	2.010	8.159E-07	-14.019
3	0.003	2.012	1.795E-07	-15.533
4	0.005	2.014	1.220E-07	-15.920
5	0.007	2.017	1.396E-07	-15.784
6	0.015	2.026	1.628E-07	-15.631
7	0.024	2.035	1.567E-07	-15.669
8	0.027	2.038	1.935E-07	-15.458
9	0.029	2.041	2.381E-07	-15.251
10	0.033	2.044	6.413E-08	-16.562
11	0.035	2.046	5.504E-08	-16.715
12	0.038	2.050	7.370E-08	-16.423
13	0.042	2.055	8.302E-08	-16.304
14	0.045	2.057	8.010E-08	-16.340
15	0.023	2.034	1.194E-07	-15.941

	Calculated	Corrected
Fv vs. Theta B (-slope)	37.519029	38
Fv vs. Theta A (intercept)	60.584965	61.4

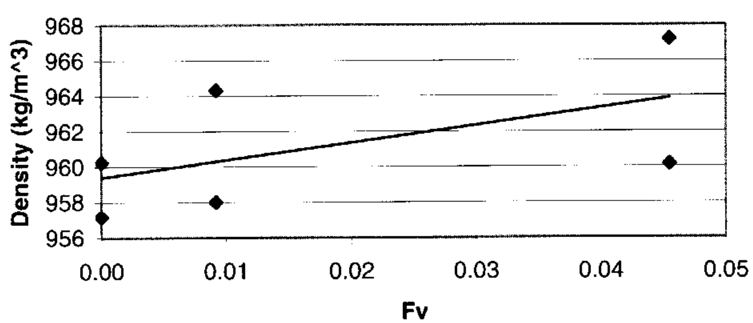
Density — IFO180 Fuel Oil

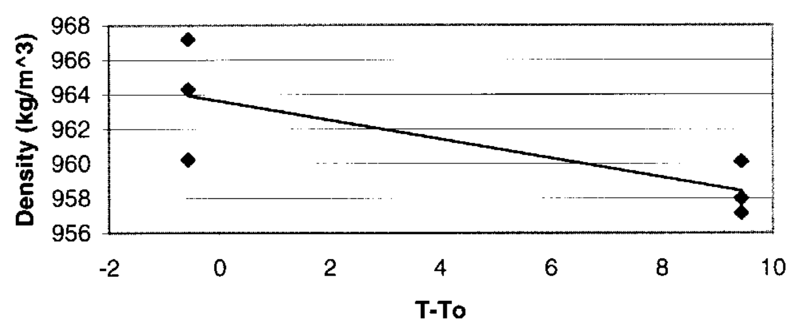
Mass Evaporated (Fm)	Density (g/cm^3)	Temperature (°C)
0	0.960	15.8
0	0.957	25.5
0.01	0.964	15.5
0.01	0.958	25.0
0.04	0.967	15.3
0.04	0.960	25.2
0	0.957	23.92
0.01	0.959	23.92
0.04	0.961	23.92

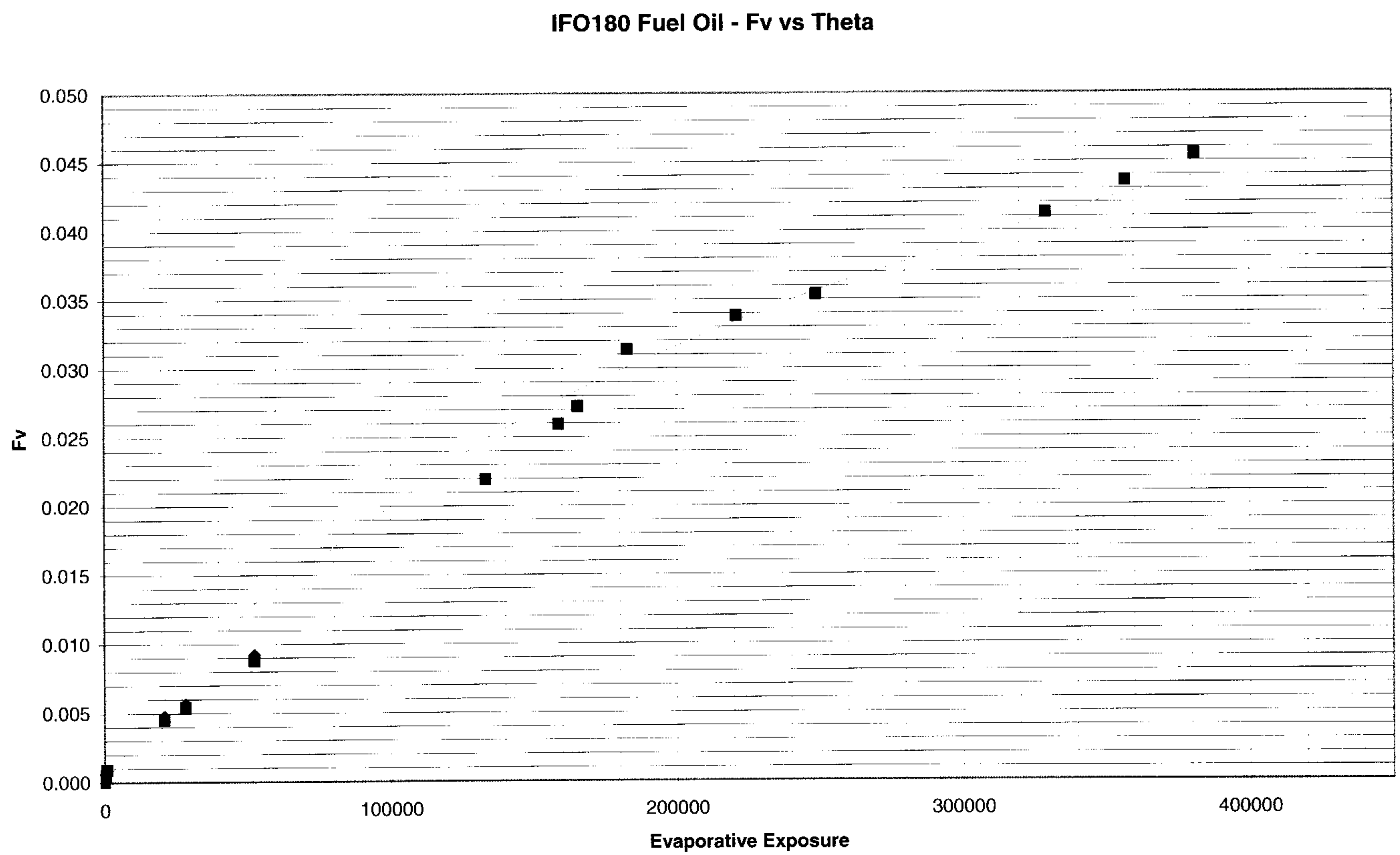
slope	0.077
intercept	0.958
r^2	0.975

Temperature (°C)	Density (kg/m^3)	Volume Evaporated (Fv)	T-To (K)	Density (g/cc)
15	960	0	-0.56	0.960
15	964	0.009	-0.56	0.964
15	967	0.046	-0.56	0.967
25	957	0	9.44	0.957
25	958	0.009	9.44	0.958
25	960	0.046	9.44	0.960
15.5	967	0.000		0.967

Density Constant 1 (slope, kg/m^3)	98.034
Standard Density Temperature, To (K)	288.72
Density Constant 2 ($kg/K.m^3$)	0.549
Standard Density (kg/m^3)	960.074
API Gravity @ 15.5°C	15.88






IFO180 Fuel Oil - Fv vs Theta
Fv
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
0
100000
200000
300000
400000
Evaporative Exposure

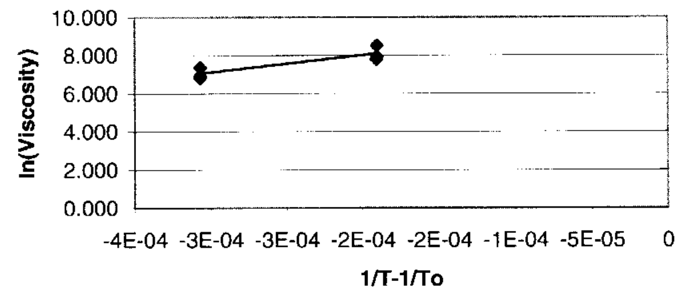
Viscosity — IFO180 Fuel Oil

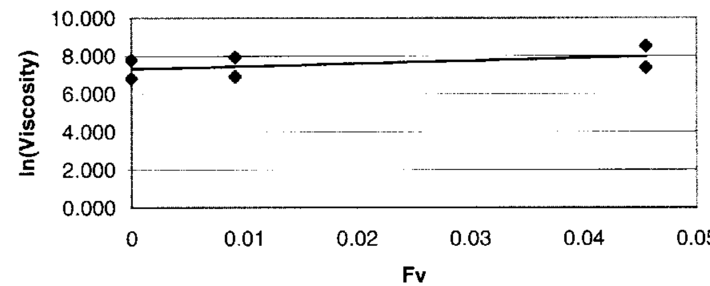
Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	2423.0	15.2	14.0	CP-52	28.0	7.793
0	893.0	25.4	30.0	CP-42	60.0	6.795
0.01	2792.0	15.2	14.0	CP-52	28.0	7.935
0.01	992.2	25.4	30.0	CP-42	60.0	6.900
0.04	4890.0	15.3	14.0	CP-52	28.0	8.495
0.04	1535.0	25.5	30.0	CP-42	60.0	7.336

Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	2470.9	15.0	7.812	-0.000190564
0	928.6	25.0	6.834	-0.000306842
0.01	2849.2	15.0	7.955	-0.000190443
0.01	1033.3	25.0	6.940	-0.000306842
0.05	5059.5	15.0	8.529	-0.000190443
0.05	1624.7	25.0	7.393	-0.000306842

Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	10723.99
Viscosity Constant 1	14.05
Viscosity Constant 2 (K^{-1})	8964.97

Volume Evaporated (Fv)	Viscosity 15°C (cP)	Viscosity 25°C (cP)
0	2470.9	928.6
0.01	2849.2	1033.3
0.05	5059.5	1624.7





Pour Point — IFO180 Fuel Oil

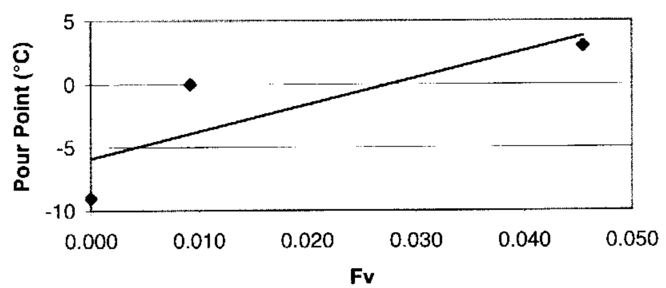
Test Results

Fv	Pour Point Measured (°C)	Pour Point Reported (°C)
0.000	-11	-9
0.009	-1	0
0.046	0	3

slope 181.1215
intercept -7.304454

Pour Point Constants for SLR Spill Model

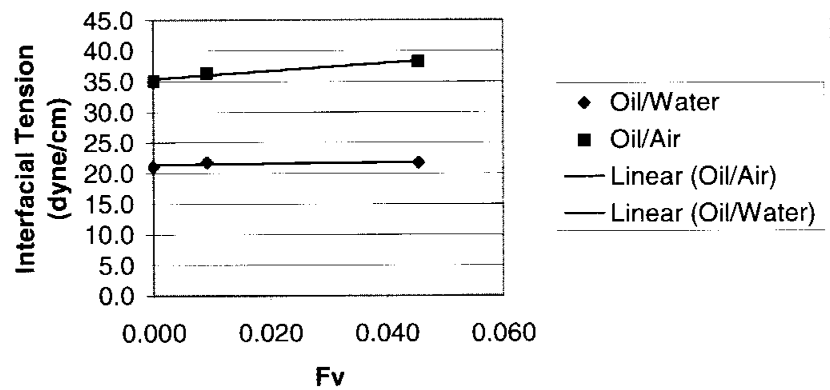
Initial Pour Point (K)	265.8455
Pour Point Constant	0.681304



Interfacial Tension — IFO180 Fuel Oil

Fv	Interfacial Tension Oil/Water (dyne/cm)	Interfacial Tension Oil/Air (dyne/cm)
0.000	21.1	35.1
0.009	21.8	36.4
0.046	21.8	38.3
slope	9.852	66.019
intercept	21.370	35.379

Oil/Water Interfacial Tension (dyne/cm)	21.370
Oil/Water Interfacial Tension Constant	0.461
Oil/Air Interfacial Tension (dyne/cm)	35.379
Oil/Air Interfacial Tension Constant	1.866



Flash Point — IFO180 Fuel Oil

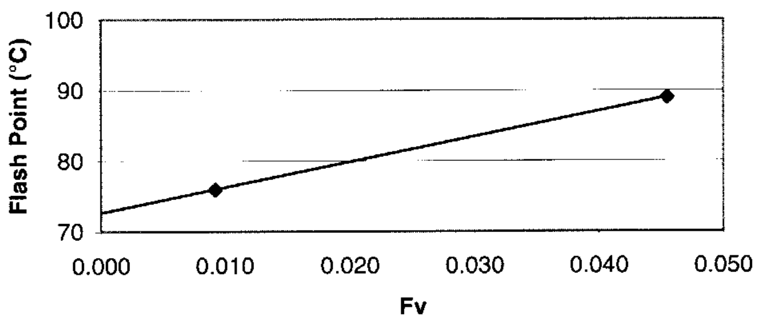
Test Results

Fv	Flash Point Measured (°C)
0.000	75
0.009	76
0.046	89

slope 321.917148
intercept 347.276814

Flash Point Constants for SL Ross Spill Model

Initial Flash Point (K)	347.277
Flash Point Constant	0.927



SL Ross Model

Modeling Constants — **IFO180 Fuel Oil**

Standard Density	960.074	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	98.034	kg/m3
Density Constant 2	0.54931	kg/K.m3
Standard Viscosity	10723.98821	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	14.0547	
Viscosity Constant 2	8964.97	K-1
Oil/Water Interfacial Tension	21.3702	dyne/cm
Air/Oil Interfacial Tension	35.3789	dyne/cm
Oil/Water Interfacial Tension Constant	0.46103	
Air/Oil Interfacial Tension Constant	1.86604	
Initial Pour Point	265.846	K
Pour Point Constant	0.68130	
ASTM Distillation Constant A (slope)	322.543	K
ASTM Distillation Constant B (intercept)	596.790	K
Emulsification Delay	9999999999	
Initial Flash Point	347.277	K
Flash Point Constant	0.92698	
Fv vs. Theta A	61.40000	
Fv vs. Theta B	38.00000	
B.Tg	12256.65	
B.To	22678.02	

Emulsification Formation - Tendency and Stability

IFO180 Fuel Oil

Conclusions:	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Fairly likely	Not likely	Not likely
Stability Index	Fairly stable	Unstable	Unstable
Water Content (after 24 hr)	26%	0%	0%

Test Results

300ml H_2O @	15.2 °C
mixing done @	15.0 °C
settling done @	24.2 °C
Final 24 hr done @	15.0 °C
two replicates of each oil	

All measurements in mm	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
	#1		#2		#3		#4		#5		#6	
	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil	Emulsion	Free Oil
Start	0	10	0	10	0	10	0	10	0	10	0	10
After first hour mixing	12	0	13	0	13	0	11	0	12	0	11	0
plus 10 minutes	12	0	13	0	11	0	12	0	11	0	11	0
plus 20 minutes	11	0	13	0	11	0	12	0	12	0	12	0
plus 30 minutes	12	0	12	0	12	0	11	0	11	0	11	0
After second hour mixing	14	0	15	0	14	0	13	0	12	0	13	0
plus 10 minutes	14	0	15	0	14	0	14	0	13	0	13	0
plus 20 minutes	13	0	13	0	12	0	13	0	12	0	12	0
plus 30 minutes	13	0	13	0	12	0	12	0	12	0	12	0
After third hour mixing	15	0	16	0	14	0	14	0	13	0	13	0
plus 10 minutes	14	0	14	0	13	0	13	0	12	0	12	0
plus 20 minutes	14	0	14	0	13	0	13	0	12	0	12	0
plus 30 minutes	14	0	14	0	13	0	13	0	12	0	12	0
After fourth hour mixing	14	0	16	0	14	0	13	0	11	0	12	0
plus 10 minutes	15	0	16	0	13	0	13	0	12	0	13	0
plus 20 minutes	15	0	15	0	13	0	13	0	12	0	12	0
plus 30 minutes	15	0	13	0	12	0	12	0	12	0	12	0
plus 24 hour	13	0	14	0	0	10	0	10	0	10	0	10

Viscosity Measurements with Brookfield DV-III+ Rheometer

Viscosity								
Temperature	15.0				25.0			
	Viscosity	RPM	Spindle	Shear Rate	Viscosity	RPM	Spindle	Shear Rate
Fresh	2423.0	14.0	CP-52	28.0	893.0	30.0	CP-42	60.0
2 Day Weathered	2792.0	14.0	CP-52	28.0	992.2	30.0	CP-42	60.0
2 Week Weathered	4890.0	14.0	CP-52	28.0	1535.0	30.0	CP-42	60.0
		30.0						

	Spindle	RPM	% Torque	Viscosity	Shear Rate	Temp	
				cP		°C	
Fresh	CP-52	1	1.4				
		2	2.8				
		4	5.4	2679.0	8.0	15.2	
		6	7.8	2580.0	12.0	15.2	
		8	10.4	2580.0	16.0	15.2	
		10	12.9	2560.0	20.0	15.2	
		12	15.4	2547.0	24.0	15.2	
		14	17.8	2423.0	28.0	15.2	<==
2 Day Weathered	CP-52	1	1.6				
		2	3.1				
		4	5.9	2927.0	8.0	15.2	
		6	8.7	2877.0	12.0	15.3	
		8	11.5	2853.0	16.0	15.2	
		10	14.3	2838.0	20.0	15.3	
		12	17.0	2811.0	24.0	15.3	
		14	19.7	2792.0	28.0	15.2	<==
2 Week Weathered	CP-52	1	2.8				
		2	5.4	5358.0	4.0	15.2	
		4	10.5	5209.0	8.0	15.2	
		6	15.5	5126.0	12.0	15.2	
		8	20.2	5011.0	16.0	15.2	
		10	25.0	4961.0	20.0	15.3	
		12	29.8	4928.0	24.0	15.3	
		14	34.5	4890.0	28.0	15.3	<==
Fresh	CP-42	15	6.7	886.4	30.0	25.4	
		30	13.5	893.0	60.0	25.4	<==
		45	20.0	882.0	90.0	25.5	
		60	26.6	879.8	120.0	25.4	
		90	39.6	873.1	180.0	25.5	
		120	52.3	864.9	240.0	25.4	
		180	77.8	857.7	360.0	25.4	
		250	-over-				
2 Day Weathered	CP-42	15	7.6	1005.0	30.0	25.4	
		30	15.0	992.2	60.0	25.4	<==
		45	22.3	983.4	90.0	25.3	
		60	29.5	975.7	120.0	25.4	
		90	43.7	963.5	180.0	25.4	
		120	58.0	959.1	240.0	25.4	
		180	86.2	950.3	360.0	25.4	
		250	-over-				
2 Week Weathered	CP-42	15	11.7	1548.0	30.0	25.5	
		30	23.2	1535.0	60.0	25.5	<==
		45	34.5	1521.0	90.0	25.5	
		60	45.9	1518.0	120.0	25.5	
		90	68.3	1506.0	180.0	25.5	
		120	90.8	1502.0	240.0	25.5	
		180	-over-				