Spill Related Properties of IFO380 Fuel Oil

for

Minerals Management Service
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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 complete simulated oil spill weathering experiments on IFO380 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 IFO380 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

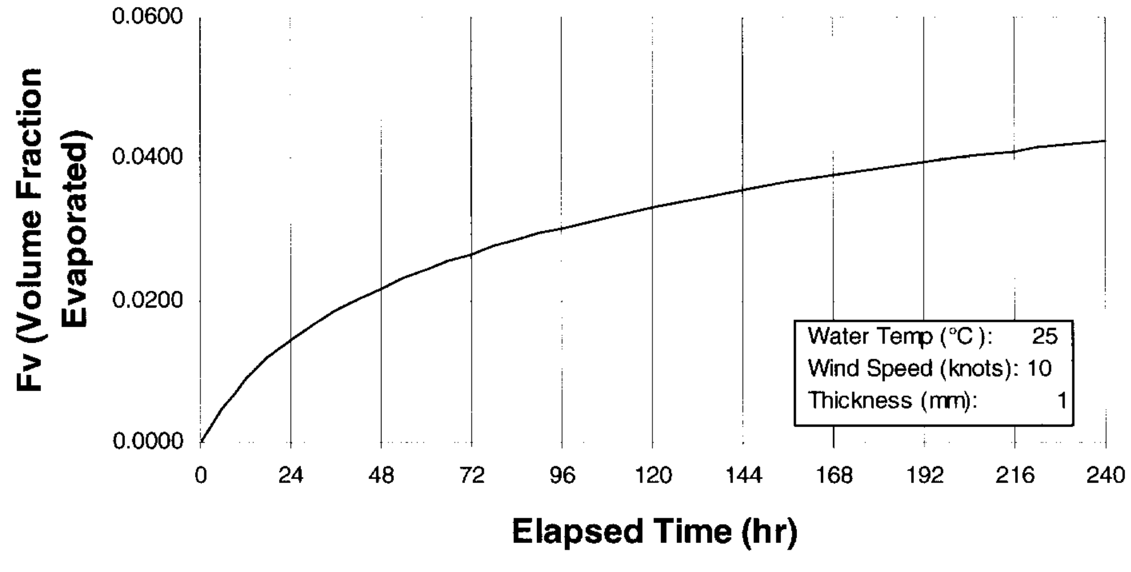
The results of the property analyses on IFO380 are summarized in Table 2-2. The complete test results can be found in Appendix B. The two levels of evaporation noted in the table represent the amounts evaporated from a two cm-thick slick in the wind tunnel after two days and two weeks of continuous airflow, respectively.

2.1.1 Evaporation

IFO380 Fuel Oil is dense, black and viscous. Approximately 0.7% of the oil, by volume, evaporated after two days in the wind tunnel, and about 3.3% 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 IFO380



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[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 IFO380 Fuel Oil

Evaporation (Volume %)	0[a]	0.66	3.30
Density (g/cm^3)			
15 °C	0.979	0.979	0.979
25 °C	0.963	0.967	0.972
Dynamic Viscosity (mPa.s)			
15 °C	9399	10892	13977
25 °C	2492	3139	4165
Kinematic Viscosity (mm^2/s)			
15 °C	9603	11130	14279
25 °C	2587	3246	4283
Interfacial Tension (dyne/cm)			
Oil/ Air	36.4	37.8	39.0
Oil/ Seawater	22.1	20.5	21.8
Pour Point (°C)	6	6	9
Flash Point (°C)	90	91	95
Emulsion Formation-Tendency and Stability @ 13.9 °C			
Tendency Index	Not likely	Not likely	Not likely
Stability Index	Unstable	Unstable	Unstable
Water Content	0%	0%	0%

ASTM Modified Distillation

Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
IBP	295	104
5	330	199
10	366	236
15	399	266
20	421	283
25	433	314
30	439	317
40	448	350
50	455	363

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)
$C_1 = 20261$
$C_2 = 147.78$
$C_3 = 49110$

[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.

Figure 2-2 Effect of Evaporation on Oil Viscosity

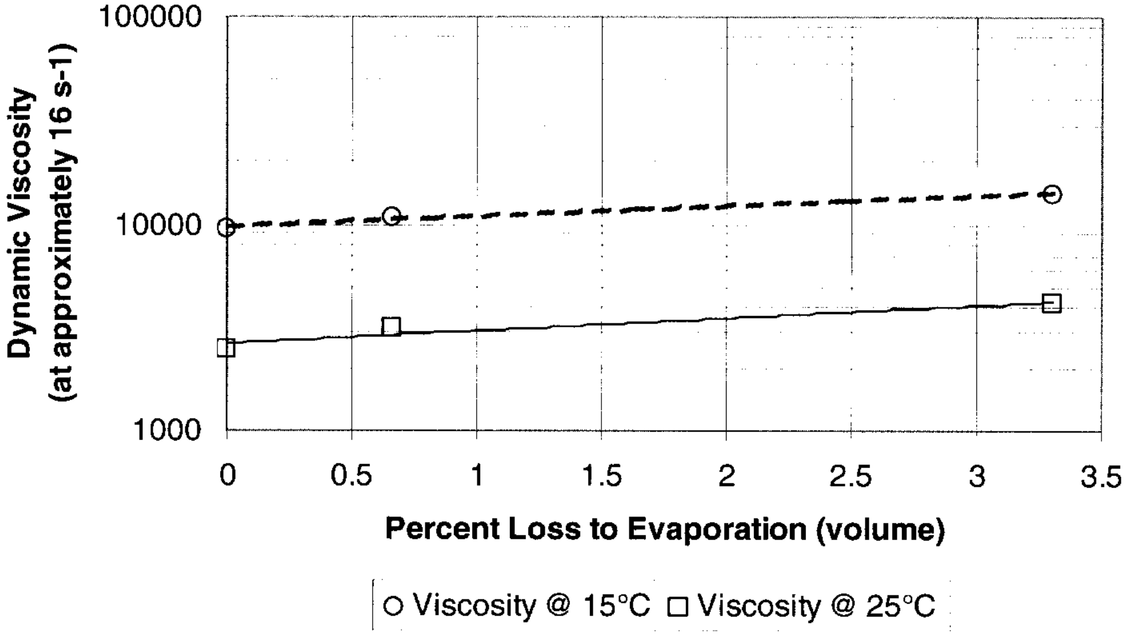


Figure 2-3 Effect of Evaporation on Oil Density

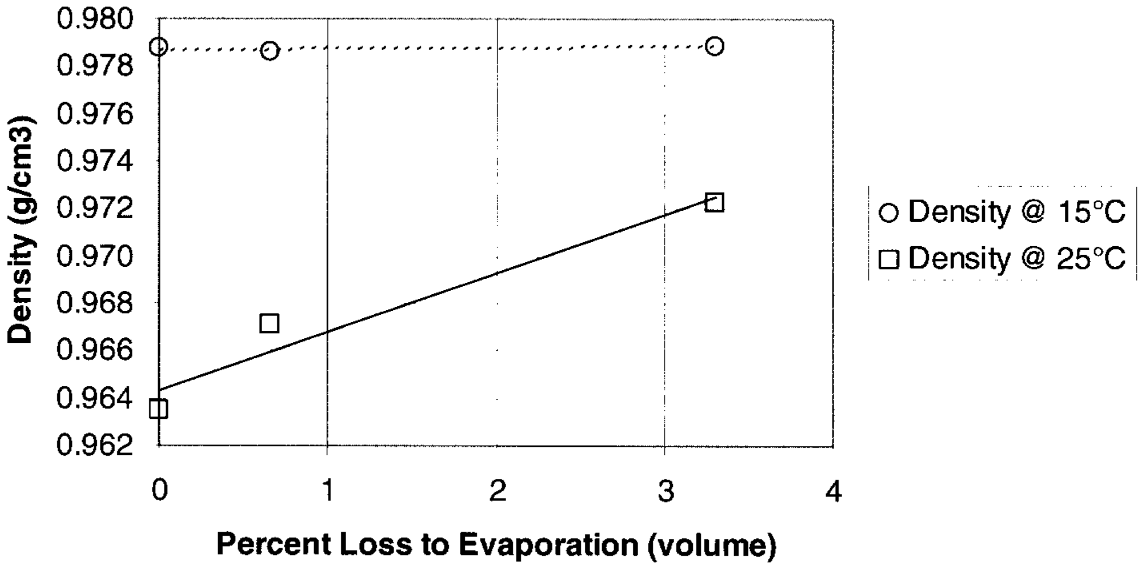
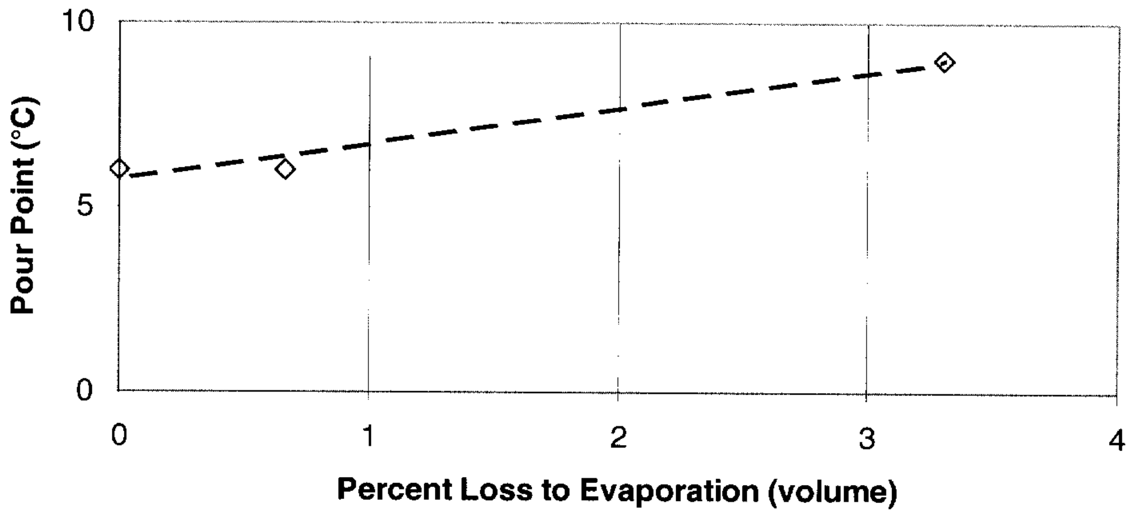


Figure 2-4
Effect of Evaporation on Pour Point



2.1.2 Density

IFO380 is a dense, black, viscous oil, with a density of 0.979 g/cm^3 at 15°C (API gravity of 13°).

2.1.3 Viscosity

At 15^{o}C the viscosity of the fresh IFO 380 is about 9400 cP (mPa.s). The viscosity increases to 10,890 cP after 0.7% evaporation and to 13,980 cP after 3.3% evaporation.

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 380 was measured to be about 7200 cP at 16°C, which is considerably lower than the viscosity measured in this study (9400 cP at 15^{o}C or 8300 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 IFO 380 Fuel Oil, measured against standard laboratory water with 35 ppt of salt, was 22.1 dynes/cm.

2.1.4 Pour Point

IFO380 fuel oil has a pour point of 6°C when fresh. This remains the same at 0.7 percent evaporation and goes to 9°C at 3.3 percent evaporation.

2.1.5 Flash Point

The flash point of IFO380 is 90°C when fresh and rises to 95°C after 3.3% 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 and weathered IFO380 oil has a very weak tendency to form stable water-in oil emulsions when mixed with seawater. While this heavy fuel oil likely has significant concentrations of asphaltenes, the oil's high viscosity is likely preventing the formation of water-in-oil emulsions.

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:

$$\theta = \frac{Kt}{x_o} \tag{1}$$

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:

$$K = 0.0015U^{0.78} \tag{2}$$

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 crude 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 an 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 IFO380 FUEL OIL

IFO380 Fuel Oil

2 Day	2 Week	Average Air Temp		
Tray x	Tray y		°C	
188.5	187.9		28.2	

Volume Weathered(ml)	900	T	298.2	K
Volume for 2cm thick	900	K	0.005264	m/s
Tray thickness (m)	0.02	x	0.001	m

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

Mass of Oil + Tray		Mass of Oil		Fm		Oil	Fv		Evaporative	Model	Automated Model	Elapsed	Evaporative	Model
Tray x	Tray y	Tray x	Tray y	Tray x	Tray y	Density	Tray x	Tray y	Exposure	Evaporate	Evaporate	Time 2	Exposure 2	Evaporation 2
(g)	(g)	(g)	(g)			(g/cm^3)			(Corrected)	(Fv)	(Fv)	(hr)		(Fv)
1039.1	1013.7	850.6	825.2	0.000	0.000	0.960	0.000	0.000	0	0.000	0.000	0	0	0.00000
1035.7	1009.9	847.2	821.4	0.004	0.005	0.962	0.006	0.007	23098	0.006	0.006	12	227390	0.00903
1035.6	1009.8	847.1	821.3	0.004	0.005	0.962	0.006	0.007	24364	0.006	0.006	24	454780	0.01459
1035.5	1009.7	847.0	821.2	0.004	0.005	0.962	0.007	0.007	25629	0.006	0.006	36	682170	0.01863
	1009.6		821.1		0.005	0.962		0.007	27950	0.007	0.007	48	909561	0.02179
	1007.2		818.7		0.008	0.964		0.012	51786	0.011	0.011	60	1136951	0.02440
	1007.1		818.6		0.008	0.964		0.012	54739	0.011	0.011	72	1364341	0.02661
	1006.7		818.2		0.008	0.964		0.013	61067	0.012	0.012	84	1591731	0.02853
	1001.9		813.4		0.014	0.967		0.021	86591	0.015	0.015	96	1819121	0.03024
	1000.8		812.3		0.016	0.967		0.023	174025	0.023	0.023	108	2046511	0.03176
	998.9		810.4		0.018	0.968		0.027	235304	0.026	0.026	120	2273901	0.03315
	998.8		810.3		0.018	0.969		0.027	240050	0.027	0.027	132	2501291	0.03441
	998.2		809.7		0.019	0.969		0.028	267050	0.028	0.028	144	2728682	0.03558
	997.0		808.5		0.020	0.970		0.030	331492	0.031	0.031	156	2956072	0.03666
	996.3		807.8		0.021	0.970		0.031	365454	0.032	0.032	168	3183462	0.03766
	995.3		806.8		0.022	0.971		0.033	426837	0.034	0.034	180	3410852	0.03860
												192	3638242	0.03949
												204	3865632	0.04033
												216	4093022	0.04112
												228	4320412	0.04187
												240	4547803	0.04258

	2-day	2-week		2-day	2-week
Fm	0.004	0.022	Fv	0.007	0.033

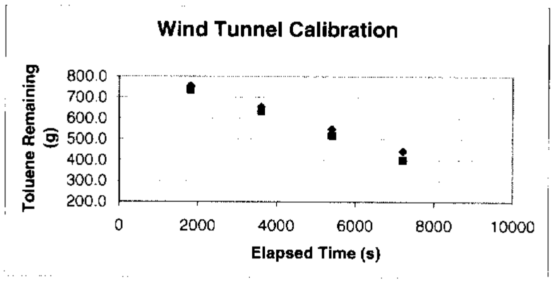
Wind Tunnel Calibration **Toluene**

Tray Mass (g)

Elapsed Time (s)	Mass Toluene	
	Tray 1 (g)	Tray 4 (g)
0	828.3	825.9
1800	755.9	732.9
3600	655.0	632.9
5400	549.6	518.1
7200	443.5	400.3
10500	270.1	231.9
13800	91.5	65.3

	Tray 1	Tray 4
slope	-0.05439394	-0.056061

E (kg/s)	-5.5227E-05	
Wind Tunnel Temperature, T (K)	301.3188831	28.16 °C
Toluene Vapor Pressure, P (kPa)	4.459	
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)	-0.00703133	



ASTM Distillation **IFO380 Fuel Oil**

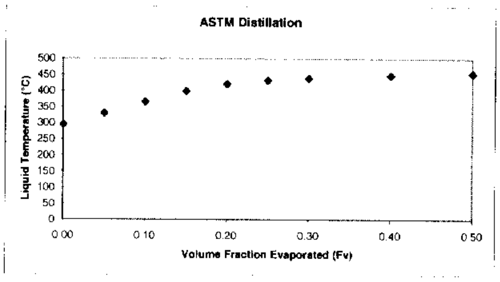
200 ml Fresh oil

Volume Distilled (mL)	Fraction Distilled (Fv)	Temperature	
		Liquid (°C)	Vapor (°C)
IBP	0.00	295	104
10	0.05	330	199
20	0.10	366	236
30	0.15	399	266
40	0.20	421	283
50	0.25	433	314
60	0.30	439	317
80	0.40	448	350
100	0.50	455	363

slope	256.6
intercept	348.8

Distillation Constant A (slope, K)	256.6	0.0
Distillation Constant B (intercept, K)	622.0	273.2

256.608863
621.98659



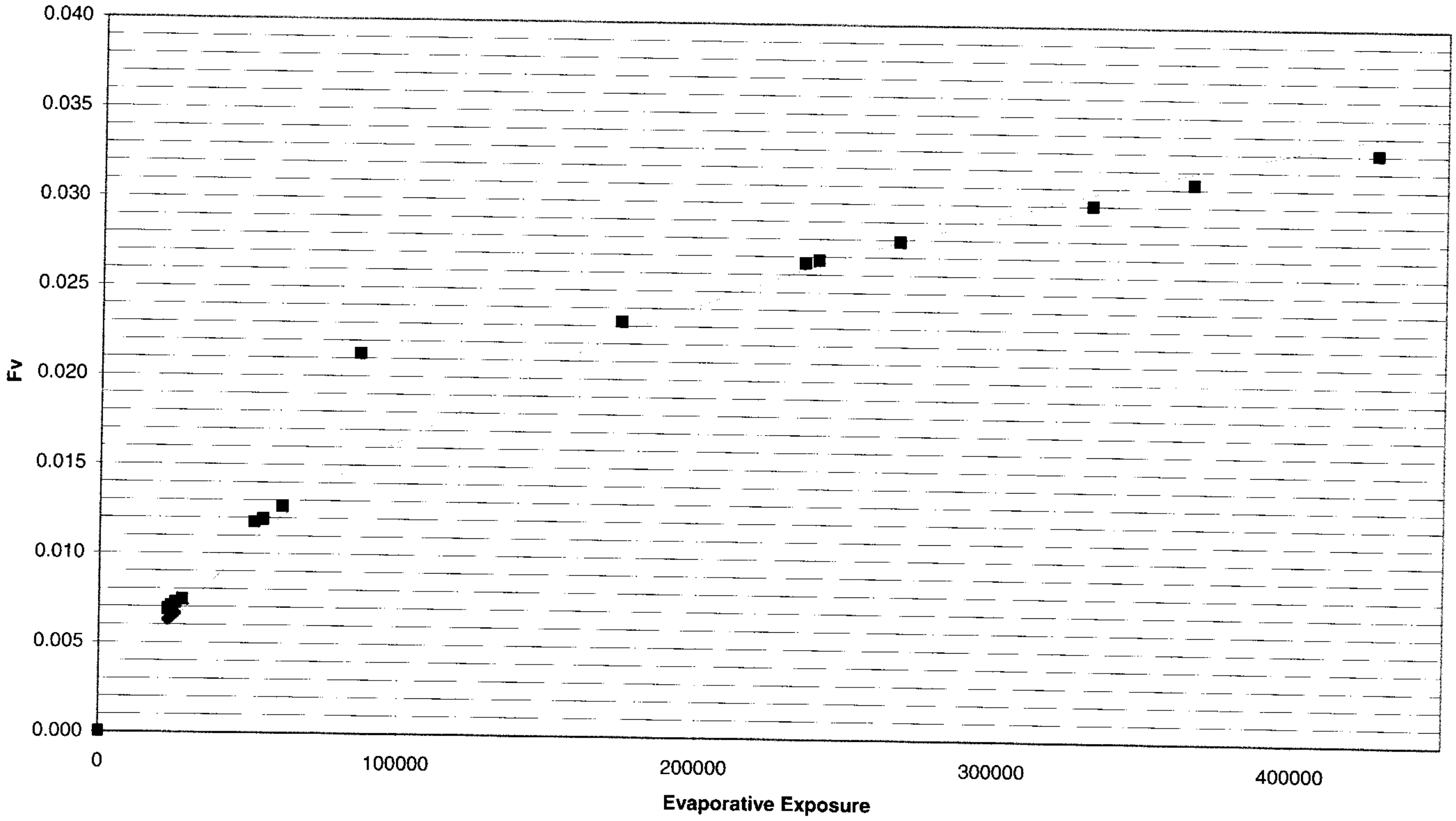
Mackay Constants **IFO380 Fuel Oil**
(automated)

Point	Fv	Tb/T	H	ln(H)
1	0.003	2.067	2.981E-07	-15.026
2	0.007	2.070	1.428E-07	-15.762
3	0.007	2.070	1.428E-07	-15.762
4	0.007	2.070	7.788E-08	-16.368
5	0.010	2.072	1.817E-07	-15.521
6	0.012	2.074	6.101E-08	-16.612
7	0.012	2.075	1.139E-07	-15.988
8	0.017	2.079	3.377E-07	-14.901
9	0.022	2.083	2.251E-08	-17.609
10	0.025	2.085	5.538E-08	-16.709
11	0.027	2.087	3.759E-08	-17.097
12	0.027	2.088	3.962E-08	-17.044
13	0.029	2.089	3.317E-08	-17.222
14	0.031	2.090	3.667E-08	-17.121
15	0.032	2.092	2.895E-08	-17.358
16	0.017	2.078	7.742E-08	-16.374

	Calculated	corrected
Fv vs. Theta B (-slope)	78.95649	78.65
Fv vs. Theta A (intercept)	147.777	147.35

78.65
147.35

IFO380 Fuel Oil - Fv vs Theta



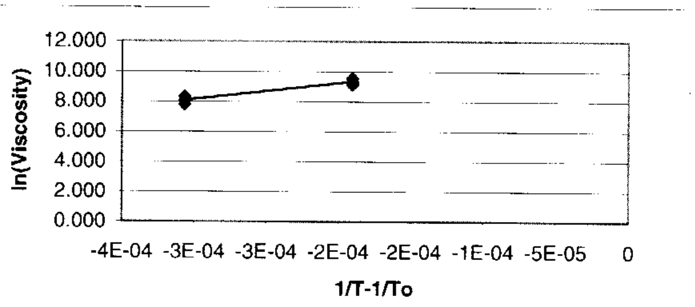
Viscosity **IFO380 Fuel Oil**

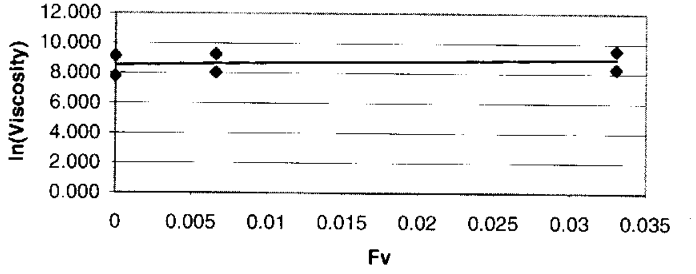
Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	9153.0	15.2	8.0	CP-52	16.0	9.122
0	2332.0	25.5	8.0	CP-52	16.0	7.754
0.00	10493.0	15.3	8.0	CP-52	16.0	9.258
0.00	2605.0	26.5	8.0	CP-52	16.0	7.865
0.02	13643.0	15.2	8.0	CP-52	16.0	9.521
0.02	3473.0	26.5	8.0	CP-52	16.0	8.153

Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	9399.3	15.0	9.148	-0.000190564
0	2492.0	25.0	7.821	-0.000306842
0.01	10892.0	15.0	9.296	-0.000190443
0.01	3139.4	25.0	8.052	-0.000306842
0.03	13977.4	15.0	9.545	-0.000190443
0.03	4164.7	25.0	8.334	-0.000306842

Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	68849.75
Viscosity Constant 1	12.72
Viscosity Constant 2 (K^{-1})	10836.38

Volume Evaporated (Fv)	Viscosity 15°C (cP)	Viscosity 25°C (cP)
0	9399.3	2492.0
0.01	10892.0	3139.4
0.03	13977.4	4164.7





Pour Point

IFO380 Fuel Oil

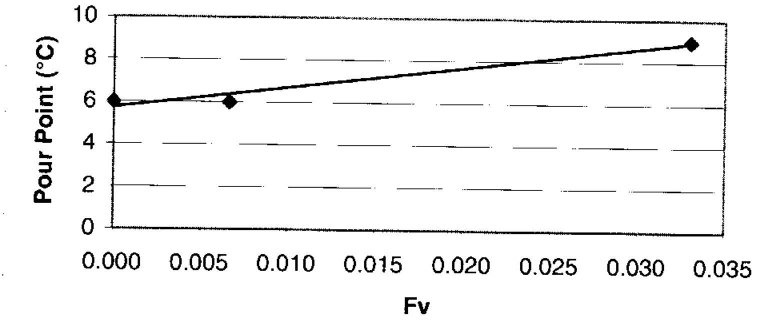
Test Results

Fv	Pour Point	
	Measured (°C)	Reported (°C)
0.000	4.5	6
0.007	5	6
0.033	6.5	9

slope	59.45614
intercept	4.546922

Pour Point Constants For SL Ross Model

Initial Pour Point (K)	277.6969
Pour Point Constant	0.214104

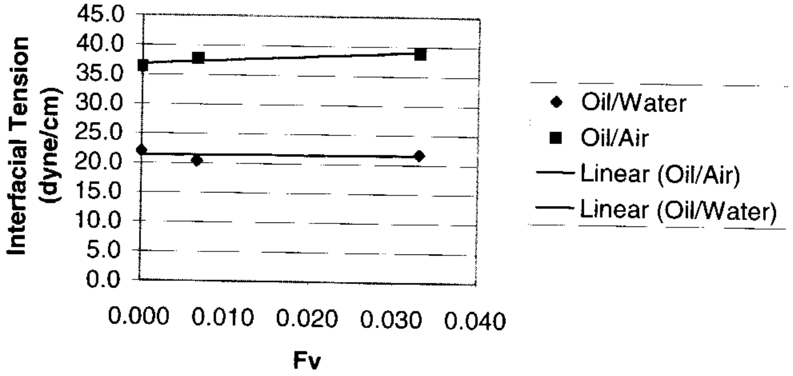


Interfacial Tension

IFO380 Fuel Oil

Fv	Interfacial Tension	
	Oil/Water (dyne/cm)	Oil/Air (dyne/cm)
0.000	22.1	36.4
0.007	20.5	37.8
0.033	21.8	39.0
slope	7.532	69.203
intercept	21.317	36.818

Oil/Water Interfacial Tension (dyne/cm)	21.317
Oil/Water Interfacial Tension Constant	0.353
Oil/Air Interfacial Tension (dyne/cm)	36.818
Oil/Air Interfacial Tension Constant	1.880



Flash Point — IFO380 Fuel Oil

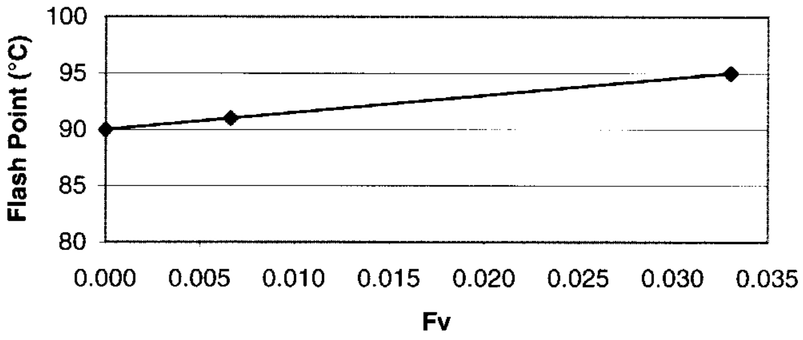
Test Results

Fv	Flash Point Measured (°C)
0.000	90
0.007	91
0.033	95

slope 151.337055
intercept 363.148303

Flash Point Constants for SLR Spill Model

Initial Flash Point (K)	363.148
Flash Point Constant	0.417



SL Ross Model

Modeling Constants

	IFO380 Fuel Oil	
Standard Density	977.898	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	126.365	kg/m3
Density Constant 2	1.11289	kg/K.m3
Standard Viscosity	68849.75005	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	12.7184	
Viscosity Constant 2	10836.38	K-1
Oil/Water Interfacial Tension	21.3170	dyne/cm
Air/Oil Interfacial Tension	36.8180	dyne/cm
Oil/Water Interfacial Tension Constant	0.35331	
Air/Oil Interfacial Tension Constant	1.87959	
Initial Pour Point	277.697	K
Pour Point Constant	0.21410	
ASTM Distillation Constant A (slope)	256.609	K
ASTM Distillation Constant B (intercept)	621.987	K
Emulsification Delay	9999999999	
Initial Flash Point	363.148	K
Flash Point Constant	0.41674	
Fv vs. Theta A	147.35000	
Fv vs. Theta B	78.65000	
B.Tg	20182.29	
B.To	48919.25	

Emulsification Formation - Tendency and Stability

IFO380 Fuel Oil

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

Test Results

300ml H2O @	14.8 °C
mixing done @	13.9 °C
settling done @	24.0 °C
Final 24 hr done @	13.9 °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	13	0	11	0	10	0	11	0	10	0	10	0
plus 10 minutes	10	0	10	0	10	0	10	0	10	0	10	0
plus 20 minutes	10	0	10	0	10	0	10	0	10	0	10	0
plus 30 minutes	10	0	10	0	10	0	10	0	10	0	10	0
After second hour mixing	12	0	12	0	10	0	10	0	11	0	12	0
plus 10 minutes	11	0	11	0	10	0	10	0	11	0	11	0
plus 20 minutes	11	0	11	0	10	0	10	0	11	0	11	0
plus 30 minutes	11	0	11	0	10	0	10	0	10	0	10	0
After third hour mixing	13	0	11	0	12	0	11	0	11	0	11	0
plus 10 minutes	12	0	12	0	12	0	12	0	12	0	12	0
plus 20 minutes	12	0	12	0	12	0	12	0	12	0	12	0
plus 30 minutes	12	0	11	0	10	0	11	0	11	0	11	0
After fourth hour mixing	14	0	13	0	12	0	12	0	11	0	9	0
plus 10 minutes	13	0	12	0	12	0	11	0	12	0	10	0
plus 20 minutes	13	0	12	0	12	0	12	0	12	0	10	0
plus 30 minutes	13	0	12	0	13	0	12	0	12	0	11	0
plus 24 hour	0	10	0	10	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	9153.0	8.0	CP-52	16.0	2332.0	8.0	CP-52	16.0
2 Day Weathered	10493.0	8.0	CP-52	16.0	2605.0	8.0	CP-52	16.0
2 Week Weathered	13643.0	8.0	CP-52	16.0	3473.0	8.0	CP-52	16.0

30.0

	Spindle	RPM	% Torque	Viscosity	Shear Rate	Temp	
				cP		°C	
Fresh	CP-52	1	5.0				
		2	9.7	9,624	4.0	15.3	
		4	18.9	9,376	8.0	15.2	
		6	27.9	9,227	12.0	15.2	
		8	36.9	9,153	16.0	15.2	<==
		10	45.5	9,029	20.0	15.2	
		12	54.3	8,979	24.0	15.2	
		14	63.0	8,930	28.0	15.2	
2 Day Weathered	CP-52	1	5.8	11,510	2.0	15.2	
		2	11.2	11,113	4.0	15.2	
		4	21.8	10,815	8.0	15.3	
		6	32.2	10,650	12.0	15.3	
		8	42.3	10,493	16.0	15.3	<==
		10	52.1	10,339	20.0	15.2	
		12	61.9	10,236	24.0	15.2	
		14	71.8	10,177	28.0	15.2	
2 Week Weathered	CP-52	1	7.5	14,883	2.0	15.3	
		2	14.6	14,486	4.0	15.4	
		4	28.5	14,139	8.0	15.3	
		6	41.9	13,858	12.0	15.2	
		8	55.0	13,643	16.0	15.2	<==
		10	68.0	13,494	20.0	15.3	
		12	80.9	13,378	24.0	15.3	
		14	93.6	13,267	28.0	15.3	
Fresh	CP-52	1	1.4				
		2	2.4				
		4	4.9				
		6	7.1				
		8	9.4	2,332	16.0	25.5	<==
		10	11.8	2,342	20.0	25.5	
		12	14.1	2,332	24.0	25.6	
		14	16.4	2,325	28.0	25.5	
2 Day Weathered	CP-52	1	1.4				
		2	2.7				
		4	5.3				
		6	7.9	2,613	12.0	26.6	
		8	10.5	2,605	16.0	26.5	<==
		10	13.2	2,619	20.0	26.6	
		12	15.7	2,596	24.0	26.6	
		14	18.2	2,580	28.0	26.6	
2 Week Weathered	CP-52	1	1.9				
		2	3.7				
		4	7.2	3,572	8.0	26.5	
		6	10.6	3,506	12.0	26.5	
		8	14.0	3,473	16.0	26.5	<==
		10	17.4	3,453	20.0	26.6	
		12	20.7	3,423	24.0	26.6	
		14	24.1	3,416	28.0	26.6	