Technical Data Report

Properties and Fate of Hydrocarbons Associated with Hypothetical Spills at the Marine Terminal and in the Confined Channel Assessment Area

ENBRIDGE NORTHERN GATEWAY PROJECT

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Abbreviations

ASTM	American Society for Testing and Materials
CCAA	confined channel assessment area
CLB	Cold Lake bitumen diluted with condensate
CRW	CRW condensate
Hayco	Hay and Company Consultants
MKH	MacKay River heavy bitumen diluted with Suncor synthetic light oil
Project	Enbridge Northern Gateway Project
rpm	revolutions per minute
SLROSM	SL Ross oil spill model
SYN	Syncrude synthetic light oil

1 Introduction

Northern Gateway Pipelines Limited Partnership (Northern Gateway) proposes to construct and operate the Enbridge Northern Gateway Project (the Project), which is an export oil pipeline and an import condensate pipeline between an initiating station near Bruderheim, Alberta and marine and tank terminals (the Kitimat Terminal) near Kitimat, British Columbia.

The purpose of this document is to investigate the possible behaviour of oil and condensate spills in the marine environment within the confined channel assessment area (CCAA) for the purpose of oil spill response planning. An assessment of the effects of spills on the terrestrial environment is also available (see the Environmental and Socio-economic Assessment, Volume 7B). For brevity, when oil or oils are referred to generically in this report, it should be understood that this includes condensates, unless specific hydrocarbons are named.

When oil is spilled in the marine environment, its physical and chemical properties change over time through evaporation and emulsification. These changes affect both the fate and behaviour of the spill and the effectiveness of countermeasures. For example, 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.

The objectives of this study are to:

- conduct simulated oil spill weathering laboratory experiments for a range of hydrocarbons considered representative of those that will be part of the Project
- complete oil fate modelling for these oils in spill examples developed for the CCAA. The results of the fate modelling will be used for spill response planning.

The following oils were selected for this analysis:

- Syncrude synthetic light oil (SYN)
- CRW condensate (CRW)
- Cold Lake bitumen diluted with condensate (CLB)
- MacKay River heavy bitumen diluted with Suncor synthetic light oil (MKH)

2 Physical Property Tests: Methods

The test oils were subjected to the analyses outlined in Table 2-1. Test temperatures of 1°C and 15°C were chosen as the end values for possible seasonal water temperatures in the CCAA.

Table 2-1 Test Procedures Used for Spill-Related Oil Analysis

Property	Test Temperature (°C)	Equipment	Procedure
Evaporation	20	Wind Tunnel and ASTM Distillation Apparatus	ASTM D86-90
Density	1 and 15	Anton Paar Densitometer	ASTM D4052-91
Viscosity	1 and 15	Brookfield Viscometer	ASTM D2983-87
Interfacial Tension	15	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	1	Rotating Flask Apparatus	Mackay and Zagorski 1982
NOTE: N/A – not applicable ASTM – American Society for Testing and Materials			

The following sections outline the methods used for each of these tests and provide a brief explanation of the effect that each oil property has on spill behaviour.

2.1 Evaporation

Evaporation is an important process affecting spilled oil. Evaporation removes the volatile hydrocarbons from the crude oil and leaves behind the heavier fractions.

A wind tunnel was used to determine the evaporative characteristics of the selected oils and to prepare weathered samples for physical property analysis. The same procedure was followed for each of the four test oils. 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 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 Table 2-1. In addition, the fresh oil was subjected to a modified ASTM distillation (ASTM D86-90, modified in that both liquid and vapour temperature were measured) 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 hourly during the initial, rapid evaporation phase and 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:

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

where: θ (theta) 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 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, the mass transfer coefficient can be estimated from:

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

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 1.

A plot of volume fraction evaporated versus evaporative exposure was prepared for both crude oils using the data from the wind tunnel. The evaporation predicted by the Mackay equation under the conditions in the wind tunnel was included in the plots. The equation is of the form:

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

where: Fv is volume fraction evaporated

C_1, C_2 and C_3 are oil-specific constants

Tk 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 crude oil. The slope and intercept of the distillation curve are used as a measure of the oil's volatility, which allows prediction of evaporation rates at temperatures other than that in the wind tunnel.

Equations 1, 2 and 3 can be used to estimate oil evaporation under various spill conditions of temperature, elapsed time and wind speed.

2.2 Density

Density, the mass per unit volume of the oil (or emulsion), determines how buoyant oil is in water. The common unit of density is grams per cubic centimetre (g/cm^3). The density of oil increases with weathering and decreases with increasing temperature. Density affects the following processes:

- sinking – if oil density exceeds that of surrounding water, it will sink
- spreading – in early stages of a spill, denser oils spread faster
- natural dispersion – denser oils disperse more easily
- emulsification stability – denser oils form more stable emulsions

2.3 Viscosity

Viscosity is a measure of the resistance of oil to flowing, once it is in motion. The common unit of viscosity is the centiPoise (cP); the metric unit is the milliPascal second (mPa·s), which is numerically equivalent to the centiPoise. The viscosity of oil increases as weathering progresses and decreases with increasing temperature. Viscosity is one of the most important properties for spill behaviour 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
- recovery and transfer operations – more viscous oils are generally harder to skim and more difficult to pump

2.4 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 and water interfacial tension to allow a given mixing energy (i.e., sea state) to produce smaller oil droplets. Interfacial tensions (oil and air and oil and water) are insensitive to temperature, but are affected by evaporation. Interfacial tension affects the following processes:

- spreading – interfacial tensions determine how fast oils spread and whether they form a sheen
- natural and chemical dispersion – oils with high interfacial tensions are more difficult to disperse
- emulsification rates and stability

- mechanical recovery – oleophilic skimmers (e.g., rope-mop and belt skimmers) work best on oils with moderate to high interfacial tensions

2.5 Pour Point

The pour point is the lowest temperature (to the nearest multiple of 3°C) at which 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 – oil viscosity increases dramatically at temperatures below the pour point
- dispersion – oils below their pour points are more difficult to disperse
- recovery, transfer and storage – oils below their pour points resist flowing toward skimmers or down inclined surfaces in skimmers and present storage and transfer problems

2.6 Flash Point

The flash point of oil is the temperature (in degrees centigrade [°C]) 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. It is an important safety issue.

2.7 Emulsion Formation-Tendency and Stability

A water-in-oil emulsion (colloquially called “chocolate mousse”) is a stable emulsion of small droplets of water incorporated in oil. Oil spills on water may form stable water-in-oil emulsions that can have very different characteristics than the parent crude oil.

The tendency of oil to form water-in-oil emulsions 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 low value, indicating that the oil will not form an emulsion, or a high value, 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 removed from the mixing environment
- moderate, which means the emulsion will break within a few hours
- 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 increases in the spill's volume, viscosity increases (that 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 and Zagorski 1982). Precisely 300 ml 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 revolutions per minute (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 and settling cycles are performed with measurements of f taken at each rotation interval. The tendency of oil to form an emulsion is given by $f_{initial}$, obtained by plotting f versus time and by extrapolating f to time zero.

The criteria in Table 2-2 are used to classify the tendency of a crude oil to form a stable emulsion.

Table 2-2 Emulsion Formation Tendency Criteria

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 stabilities of the water-in-oil emulsions are classified as shown in Table 2-3.

Table 2-3 Emulsion Stability Criteria

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 contents of stable water-in-oil emulsions are also determined.

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 10 to 100 times the viscosity of the parent oil. It is generally believed that oils with relatively high concentrations of asphaltenes are most likely to form stable water-in-oil emulsions. Some heavy oils do not easily form emulsions because the high viscosity of the oil prevents the uptake of water. Some light or medium oils do not form an emulsion immediately, but once evaporation occurs and the asphaltene concentration increases, the emulsification process begins and usually proceeds quickly thereafter.

2.8 Oil Adhesion

The adhesion characteristic of an oil is determined by measuring the quantity of oil or petroleum product that remains on a surface after being wet with oil then allowed to drain. Adhesion is measured as the mass of oil per unit area that remains on a steel needle after a thirty-minute drain time. The method developed by the Emergencies Science and Technology Division of Environment Canada is as follows. The oil is homogenized for 30 minutes. A penetrometer needle (specified in ASTM D5, Standard Test Method for

Penetration of Bituminous Materials) is hung from the balance into the draft shield, allowed to come to rest and then weighed. It is convenient if the balance can be tarred with the needle hanging from the balance. An aliquot of sample is poured into a vessel with a depth greater than 4 cm. The vessel is elevated using a lab-jack until the sample reaches the top of the needle. Care must be taken to immerse only the stainless steel needle and not the brass support. The needle is allowed to rest in the oil for 30 seconds and then the vessel lowered. The needle is hung undisturbed for 30 minutes. After the needle has been allowed to hang fee of the oil for 30 minutes, the needle and remaining sample is weighed. Four replicate measurements are made for each sample.

3 Physical Property Tests: Results

The key results of the laboratory analyses completed on the four study oils are provided in this section. Oil property summary tables and several graphs showing oil property variations versus temperature and percentage evaporated are provided for each of the oils tested. Detailed data tables and notes from the laboratory study are provided in Appendix A.

3.1 Properties of Syncrude Synthetic Oil

Table 3-1 provides a summary of the physical properties measured for Syncrude Synthetic Light Oil (SYN).

About 24% of the SYN evaporated after two days in the wind tunnel and about 30% evaporated after two weeks of exposure.

Figure 3-1 is a predicted evaporation curve for a SYN spill involving a 1-mm thick slick in a 10-m/s wind at 15°C. The curve applies only at a water temperature of 15°C. If other temperatures (or slick thicknesses and wind speeds) occur, these curves can be generated using the equations in Section 2.1 or with computerized oil spill models designed to do these calculations.

Figures 3-2, 3-3 and 3-4 show the effect of evaporation on the properties of oil viscosity, density and pour point. SYN likely will not form stable emulsions even in cold water conditions and after evaporative losses of up to 30% by volume.

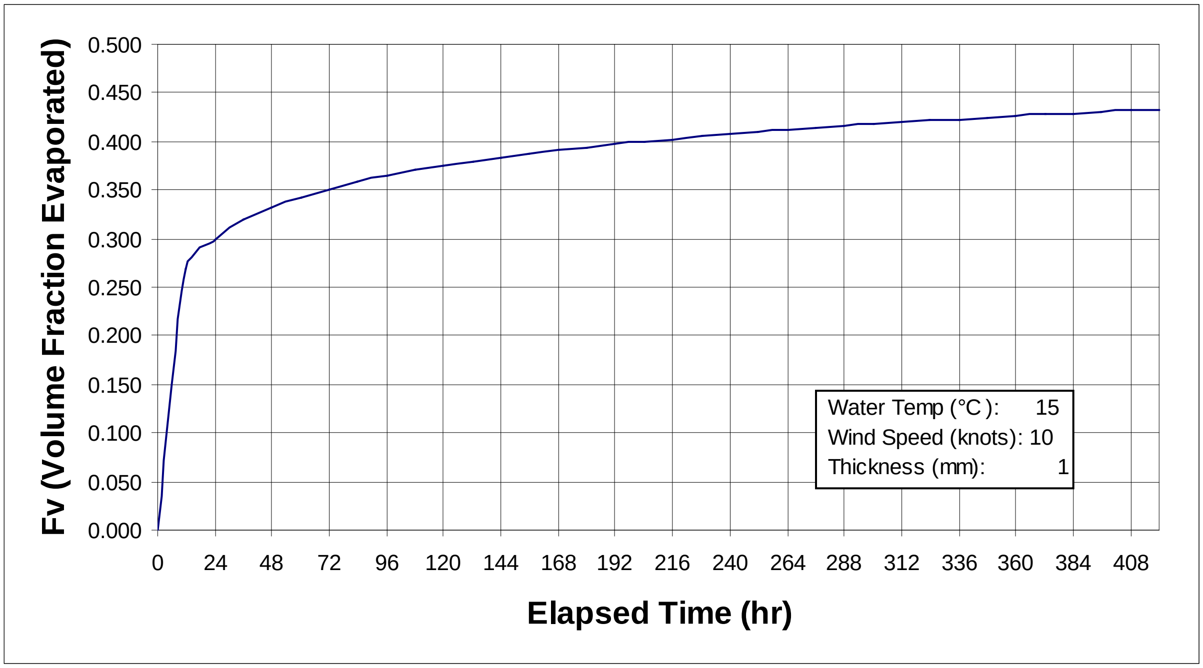


Figure 3-1 Evaporation of Syncrude Synthetic Light Oil versus Time

Table 3-1 Spill-Related Properties of Syncrude Synthetic Light Oil

Spill-related properties	Syncrude Synthetic Light Oil		
Evaporation (Volume %)	0	23.68	29.91
Adhesion (g/m^2)	18	40	19
Density (g/cm^3)			
1 °C	0.886	0.930	0.936
15 °C	0.873	0.918	0.926
Dynamic Viscosity (mPa.s)			
1 °C	11.9	128.4	234.7
15 °C	6.0	43.1	81.1
Kinematic Viscosity (mm^2/s)			
1 °C	13.4	138.1	250.7
15 °C	6.8	46.9	87.6
Interfacial Tension (dyne/cm)			
Oil/ Air	28.1	31.5	41.1
Oil/ Seawater	26.3	28.9	27.2
Pour Point (°C)	<-24	-24	-21
Flash Point (°C)	Equipment limit -5	23.5	129
Emulsion Formation-Tendency and Stability @		1 °C	
Tendency	Unlikely	Unlikely	Likely
Stability	Unstable	Unstable	Entrained
Water Content	0%	23%	26%
Emulsion Formation-Tendency and Stability @		15 °C	
Tendency	Unlikely	Unlikely	Likely
Stability	Unstable	Unstable	Entrained
Water Content	0%	0%	33%
ASTM Modified Distillation	Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
	IBP	99	44
	5	156	71
	10	201	88
	15	245	118
	20	287	155
	25	316	238
	30	338	271
	40	373	282
	50	402	344

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 = 6190
C_2 = 13.70
C_3 = 6728

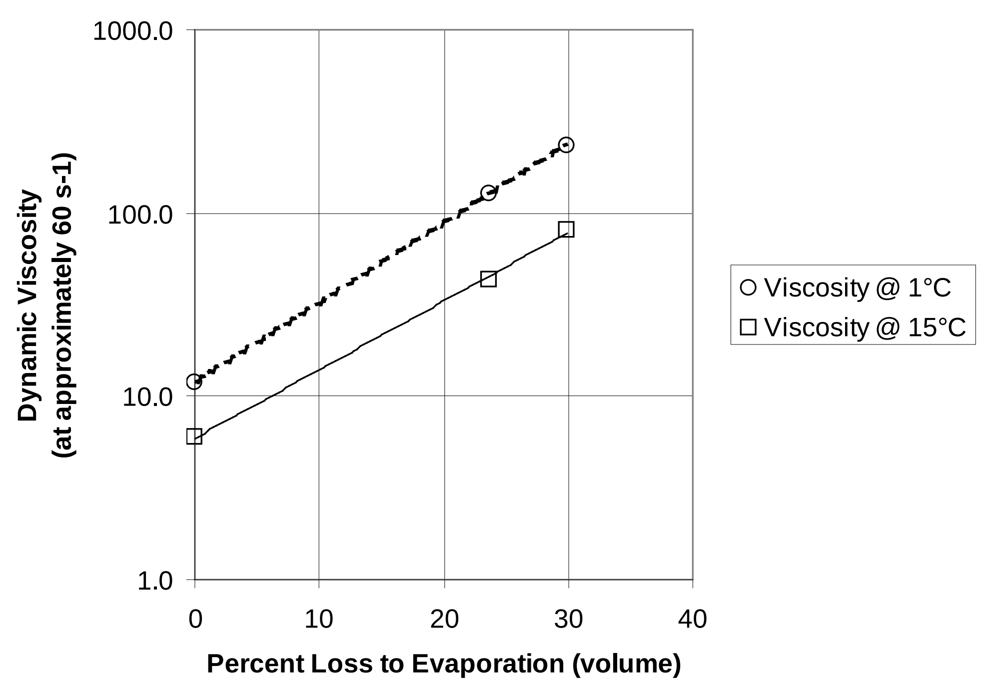


Figure 3-2 **Effect of Evaporation on Viscosity: Syncrude Synthetic Light Oil**

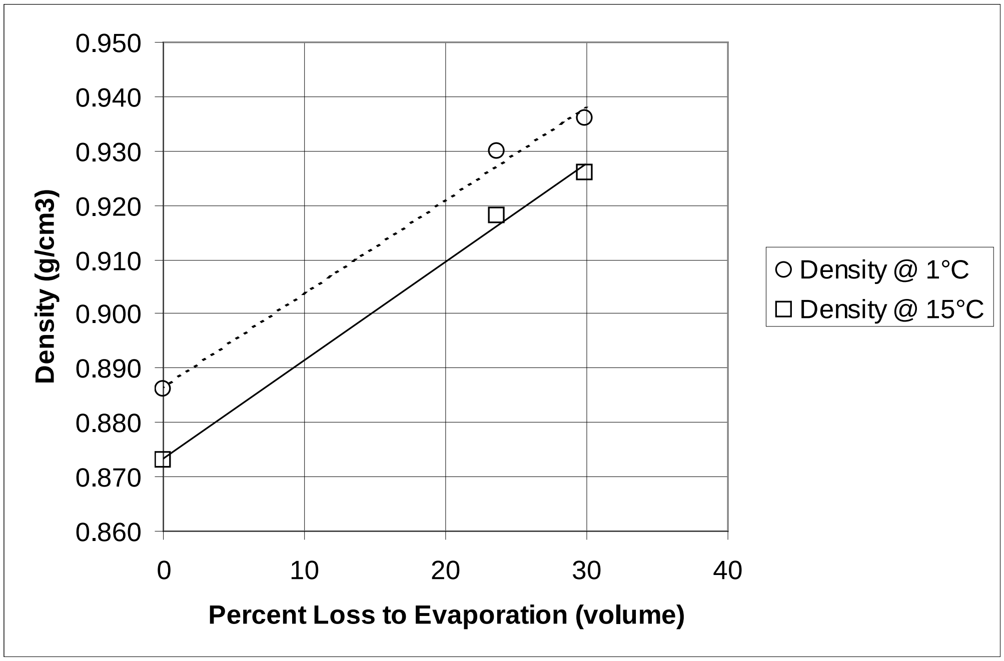


Figure 3-3 **Effect of Evaporation on Density: Syncrude Synthetic Light Oil**

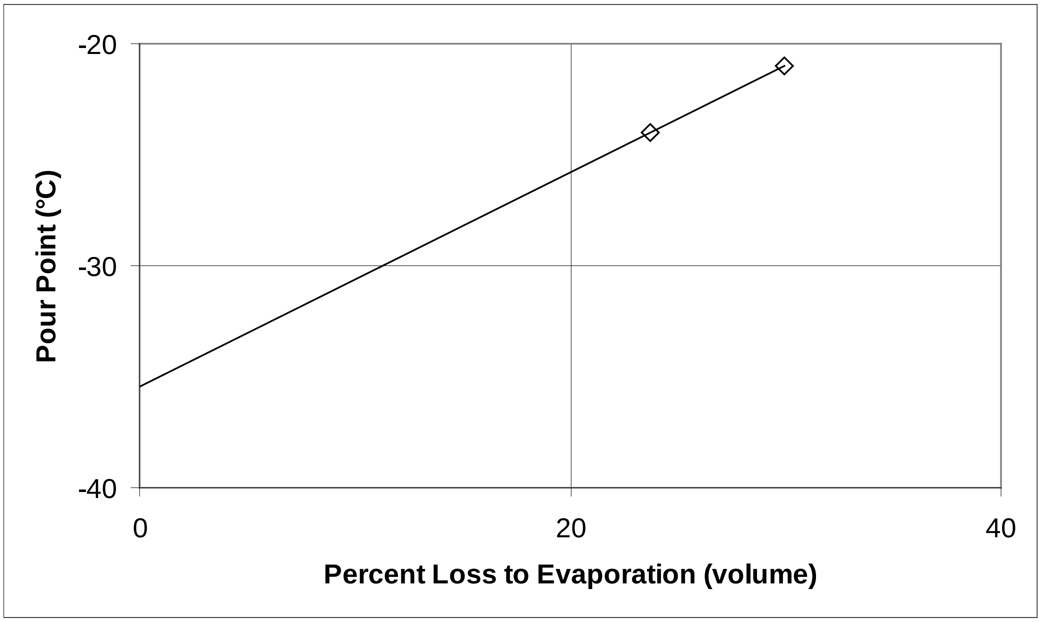


Figure 3-4 Effect of Evaporation on Pour Point: Syncrude Synthetic Light Oil

3.2 Properties of CRW Condensate

Table 3-2 provides a summary of the physical properties measured for CRW condensate (CRW).

About 57% of the CRW evaporated after two days in the wind tunnel and about 75% evaporated after two weeks of exposure.

Figure 3-5 is a predicted evaporation curve for a spill of CRW involving a 1-mm thick slick in a 10-m/s wind at 15°C. The curve applies only at a water temperature of 15°C. If other temperatures (or slick thicknesses and wind speeds) occur, these curves can be generated using the equations in Section 2.1 or with computerized oil spill models designed to do these calculations.

Figures 3-6, 3-7 and 3-8 show the effect of evaporation on the properties of oil viscosity, density and pour point. CRW will not form stable emulsions even in cold water conditions and after evaporative losses of up to 75%, by volume.

Table 3-2 Spill-Related Properties of CRW Condensate

Spill-related properties	CRW Condensate		
Evaporation (Volume %)	0	56.78	75.14
Adhesion (g/m^2)	2	3	16
Density (g/cm^3)			
1 °C	0.744	0.823	0.869
15 °C	0.734	0.810	0.852
Dynamic Viscosity (mPa.s)			
1 °C	0.6	2.4	13.9
15 °C	0.6	6.1	6.3
Kinematic Viscosity (mm^2/s)			
1 °C	0.8	2.9	16.0
15 °C	0.8	7.5	7.3
Interfacial Tension (dyne/cm)			
Oil/ Air	21.7	23.8	25.7
Oil/ Seawater	10.2	11.3	11.9
Pour Point (°C)	<-25	<-22	<-23
Flash Point (°C)	Below -5°C	9	41.5
Emulsion Formation-Tendency and Stability @		1 °C	
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content	0%	0%	5%
Emulsion Formation-Tendency and Stability @		15 °C	
Tendency	Unlikely	Unlikely	Unlikely
Stability	Unstable	Unstable	Unstable
Water Content	0%	0%	0%
ASTM Modified Distillation			
	Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
	IBP	55	40
	5	60	47
	10	65	52
	15	70	56
	20	75	61
	25	81	67
	30	89	73
	40	106	89
	50	128	108

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 = 1946
C_2 = 2.47
C_3 = 2372

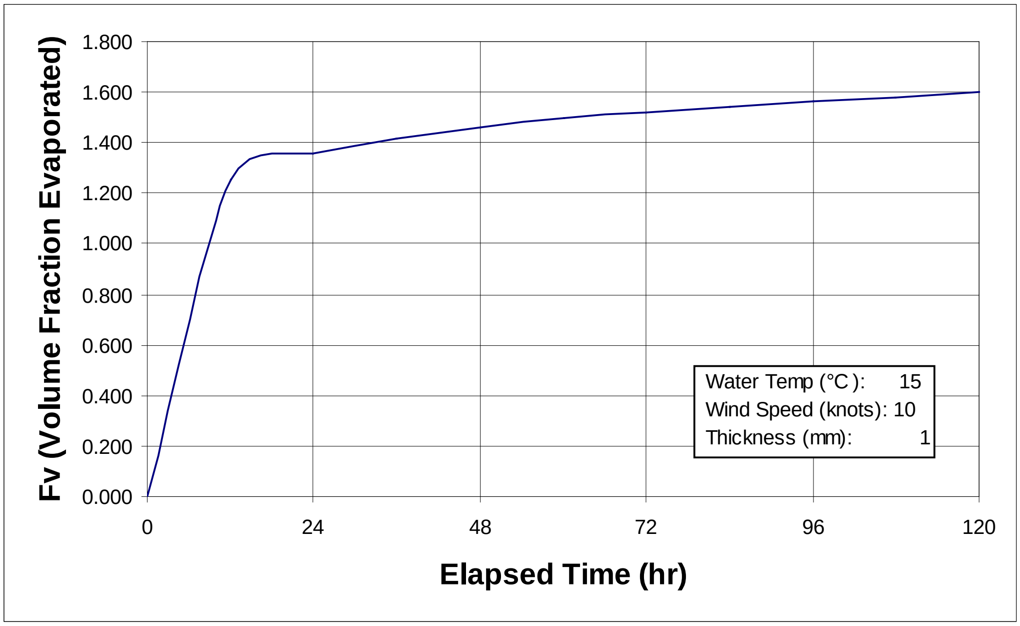


Figure 3-5 **Evaporation of CRW Condensate**

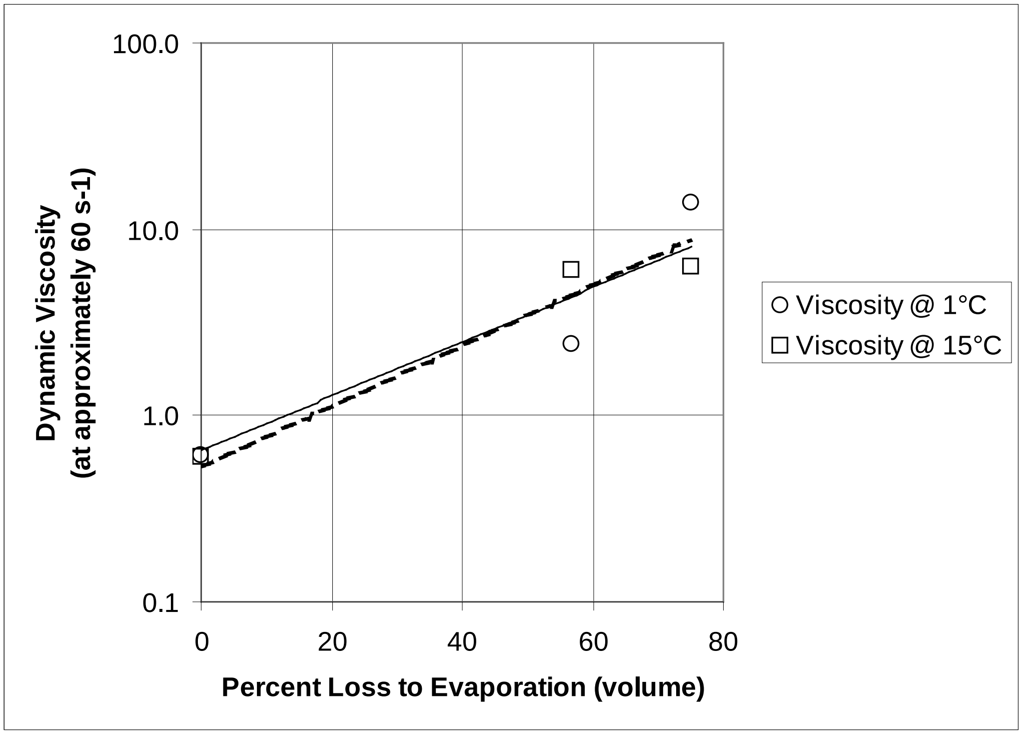


Figure 3-6 **Effect of Evaporation on Viscosity: CRW Condensate**

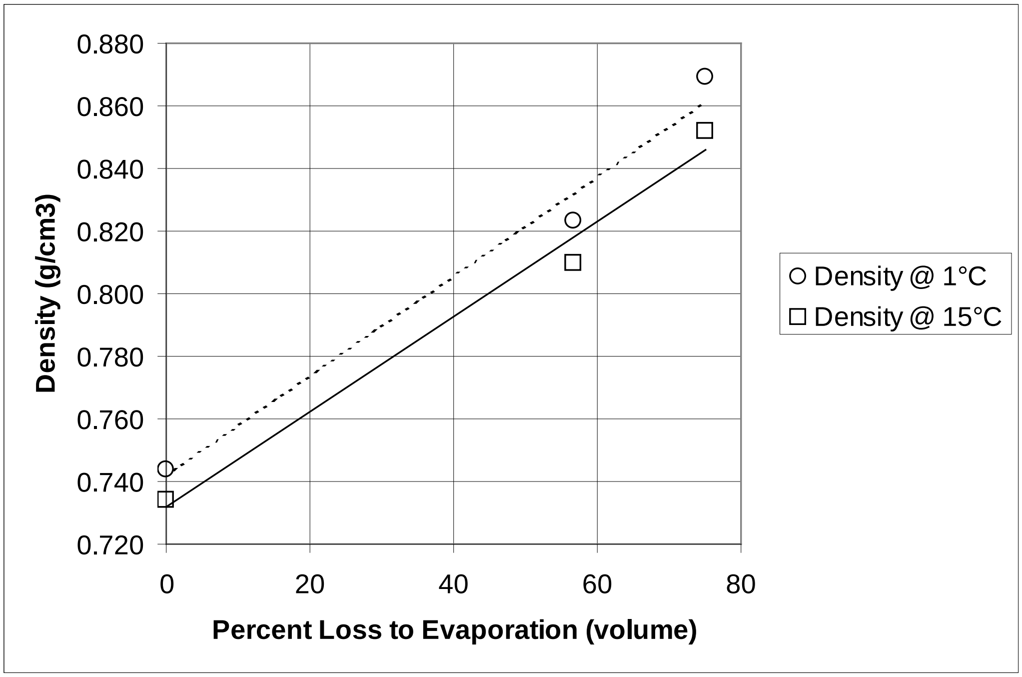


Figure 3-7 Effect of Evaporation on Density: CRW Condensate

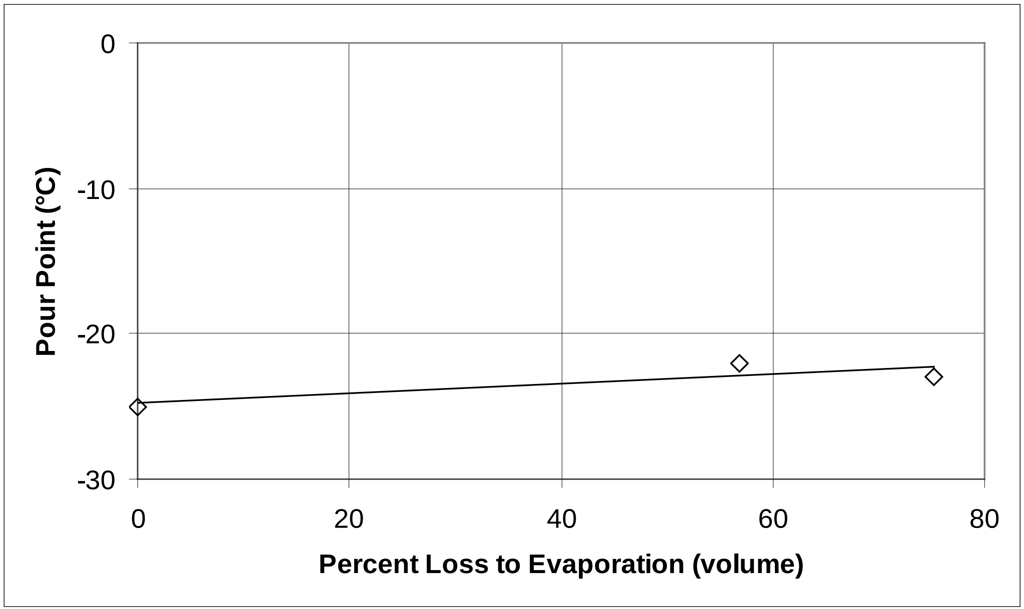


Figure 3-8 Effect of Evaporation on Pour Point: CRW Condensate

3.3 Properties of Cold Lake Bitumen Diluted with Condensate

Table 3-3 provides a summary of the physical properties measured for Cold Lake bitumen diluted with condensate (CLB).

About 14% of the CLB evaporated after two days in the wind tunnel and about 17% evaporated after two weeks of exposure.

Figure 3-9 is a predicted evaporation curve for a CLB spill involving a 1-mm thick slick in a 10-m/s wind at 15°C. The curve applies only at a water temperature of 15°C. If other temperatures (or slick thicknesses and wind speeds) occur, these curves can be generated using the equations in Section 2.1 or with computerized oil spill models designed to do these calculations.

Figures 3-10, 3-11 and 3-12 show the effect of evaporation on the properties of oil viscosity, density and pour point on CLB. This oil will not form stable emulsions even in cold water conditions and after evaporative losses of up to 17% by volume. This is primarily because of the high viscosity of the parent oil.

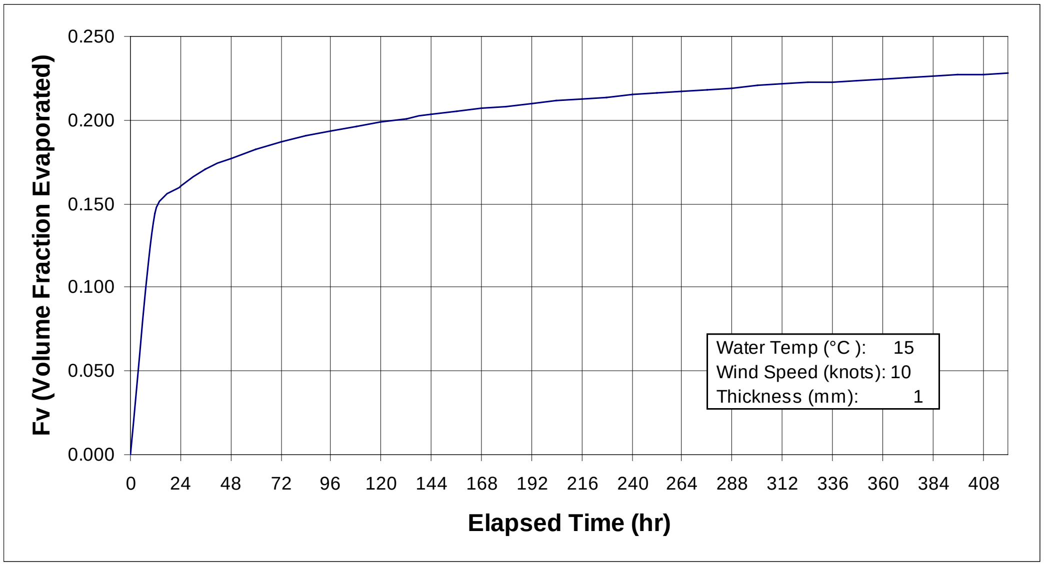


Figure 3-9 Evaporation of Cold Lake Bitumen Diluted with Condensate

Table 3-3 Spill-Related Properties of Cold Lake Bitumen Diluted with Condensate (CL

Spill-related properties	Cold Lake Bitumen Diluted with Condensate		
Evaporation (Volume %)	0	14.28	16.99
Adhesion (g/m^2)	98	146	131
Density (g/cm^3)			
1 °C	0.948	0.987	0.990
15 °C	0.936	0.977	0.981
Dynamic Viscosity (mPa.s)			
1 °C	1363.0	57548.0	98625.0
15 °C	368.0	9227.0	14486.0
Kinematic Viscosity (mm^2/s)			
1 °C	1437.8	58306.0	99621.2
15 °C	393.2	9444.2	14766.6
Interfacial Tension (dyne/cm)			
Oil/ Air	35.3	36.8	38.5
Oil/ Seawater	23.2	24.7	>27
Pour Point (°C)	Equipment Limit <-24	-15	-12
Flash Point (°C)	-4.5	Equipment Limit 4	Equipment Limit 4
Emulsion Formation-Tendency and Stability @		1 °C	
Tendency Index	Likely	Unlikely	Unlikely
Stability Index	Entrained	Unstable	Unstable
Water Content	41%	0%	23%
Emulsion Formation-Tendency and Stability @		14 °C	
Tendency Index	Very likely	Unlikely	Unlikely
Stability Index	Meso-stable	Unstable	Unstable
Water Content	53%	0%	0%
ASTM Modified Distillation			
	Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
	IBP	74	36
	5	118	59
	10	187	62
	15	283	105
	20	358	227
	25	390	282
	30	408	321
	40	428	336

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 = 12191
C_2 = 8.20
C_3 = 5239

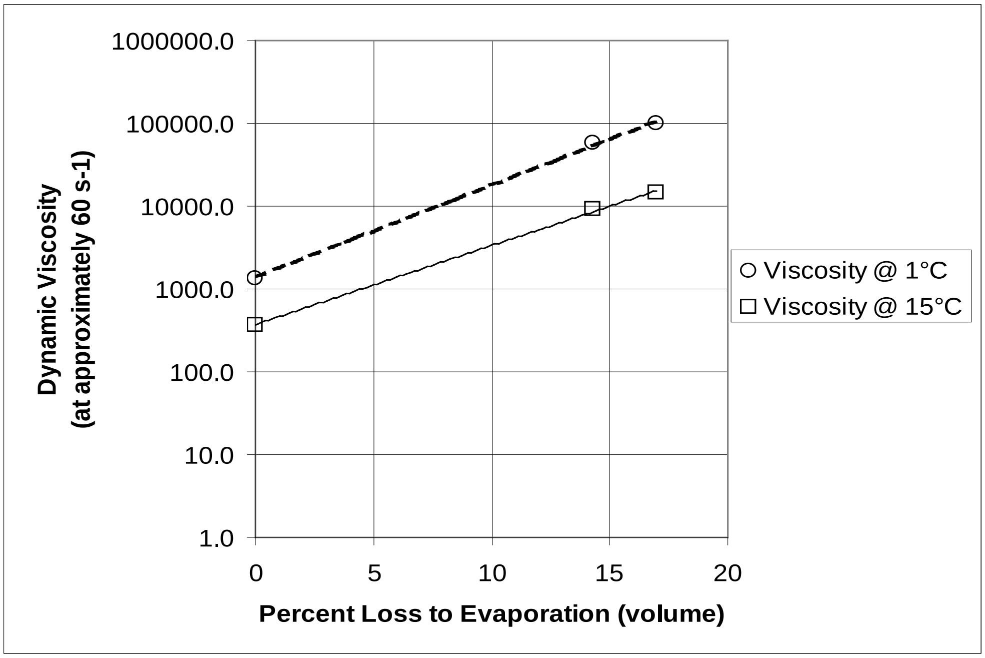


Figure 3-10 Effect of Evaporation on Viscosity: Cold Lake Bitumen Diluted with Condensate

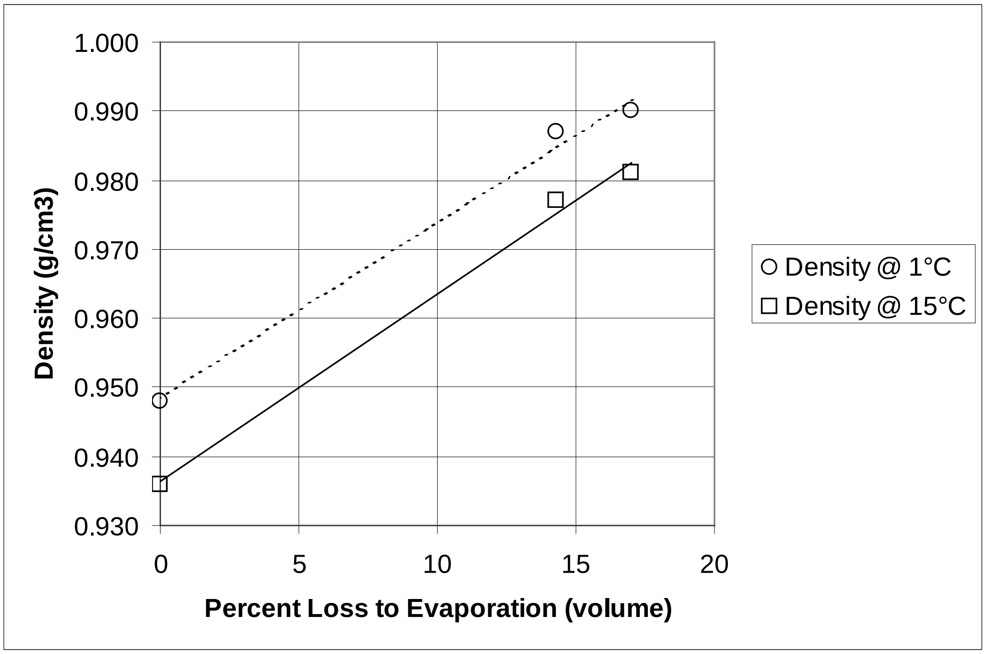


Figure 3-11 Effect of Evaporation on Density: Cold Lake Bitumen Diluted with Condensate

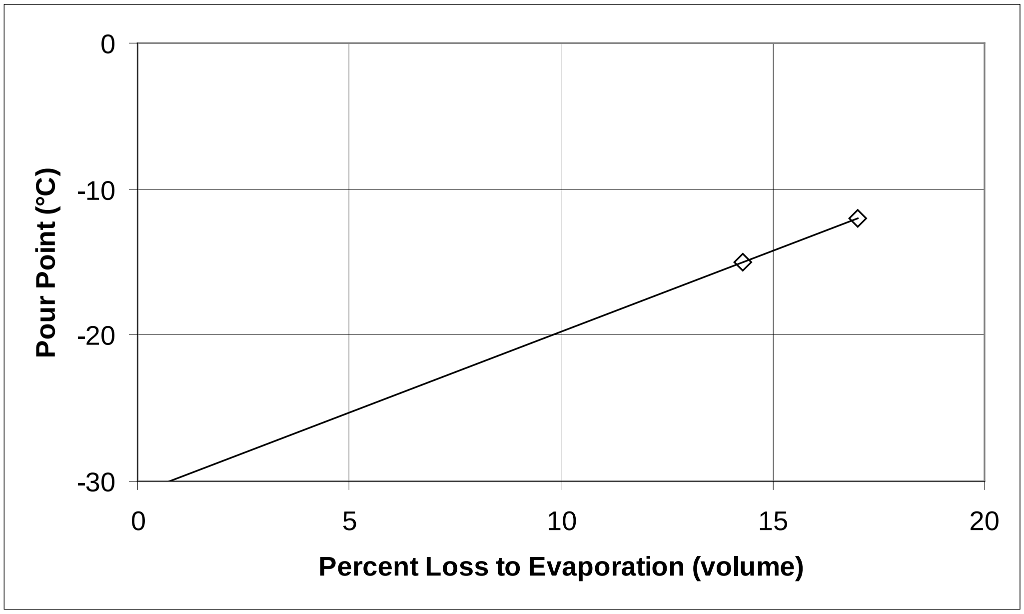


Figure 3-12 **Effect of Evaporation on Pour Point: Cold Lake Bitumen Diluted with Condensate**

3.4 Properties of MacKay River Heavy Bitumen Diluted with Synthetic Light Oil

Table 3-4 provides a summary of the physical properties measured for the MacKay River Heavy bitumen diluted with synthetic light oil (MKH).

About 9% of the MKH evaporated after two days in the wind tunnel and about 13% evaporated after two weeks of exposure.

Figure 3-13 is a predicted evaporation curve for a MKH spill involving a 1-mm thick slick in a 10-m/s wind at 15°C. The curve applies only at a water temperature of 15°C. If other temperatures (or slick thicknesses and wind speeds) occur, these curves can be generated using the equations in Section 2.1 or with computerized oil spill models designed to do these calculations.

Figures 3-14, 3-15 and 3-16 show the effect of evaporation on the properties of oil viscosity, density and pour point on MKH. MKH will likely form stable emulsions when fresh and slightly weathered. If emulsions do not form during the early stages of the oil spill, they may not form after the oil has the opportunity to evaporate and become more viscous. In modelling spill scenarios, it has been assumed that emulsions will form at the time of the spill, to be conservative.

Table 3-4 Spill-Related Properties of MacKay Heavy Bitumen Diluted with Synthetic Light Oil

Spill-related properties	MacKay River Heavy Bitumen Diluted with Synthetic Light Oil		
Evaporation (Volume %)	0	8.85	12.87
Adhesion (g/m^2)	52	57	60
Density (g/cm^3)			
1 °C	0.952	0.970	0.977
15 °C	0.943	0.965	0.970
Dynamic Viscosity (mPa.s)			
1 °C	977.0	6487.0	15205.0
15 °C	241.9	1377.0	2573.0
Kinematic Viscosity (mm^2/s)			
1 °C	1026.3	6687.6	15562.9
15 °C	256.5	1426.9	2652.6
Interfacial Tension (dyne/cm)			
Oil/ Air	29.9	31.1	32.0
Oil/ Seawater	13.6	13.7	14.1
Pour Point (°C)	<-24	<-23	-18
Flash Point (°C)	10	83	104
Emulsion Formation-Tendency and Stability @		1 °C	
Tendency	Very likely	Unlikely	Unlikely
Stability	Meso-stable	Unstable	Unstable
Water Content	57%	9%	13%
Emulsion Formation-Tendency and Stability @		15 °C	
Tendency	Very likely	Likely	Unlikely
Stability	Meso-stable	Entrained	Unstable
Water Content	51%	26%	13%
ASTM Modified Distillation	Evaporation (% volume)	Liquid Temperature (°C)	Vapour Temperature (°C)
	IBP	118	30
	5	252	127
	10	309	215
	15	348	248
	20	368	290
	25	380	313
	30	393	332
	40	414	350
	47.5	427	356

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 = 14416
C_2 = 71.14
C_3 = 23665

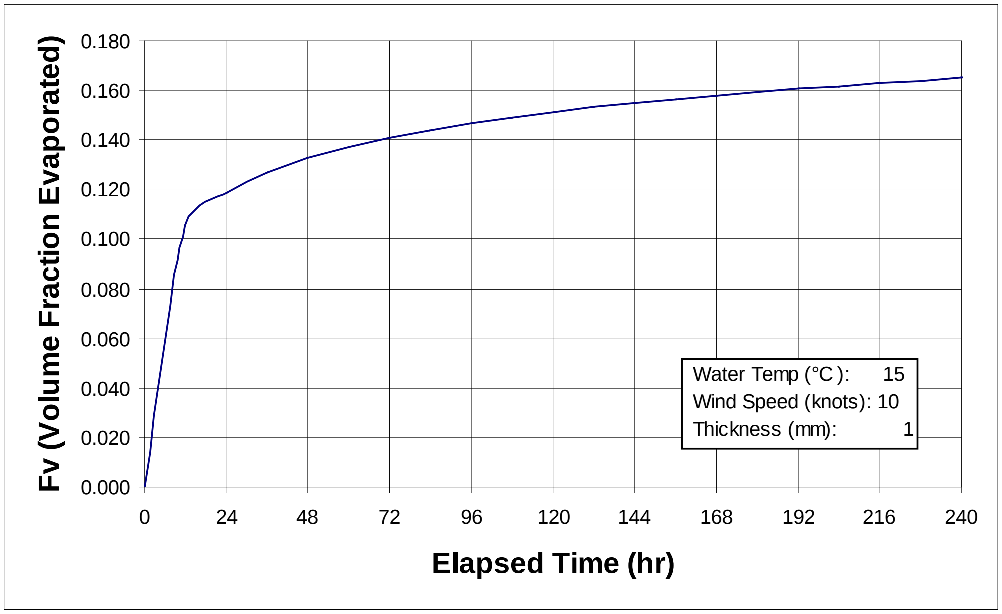


Figure 3-13 **Evaporation of MacKay River Heavy Bitumen Diluted with Synthetic Light Oil**

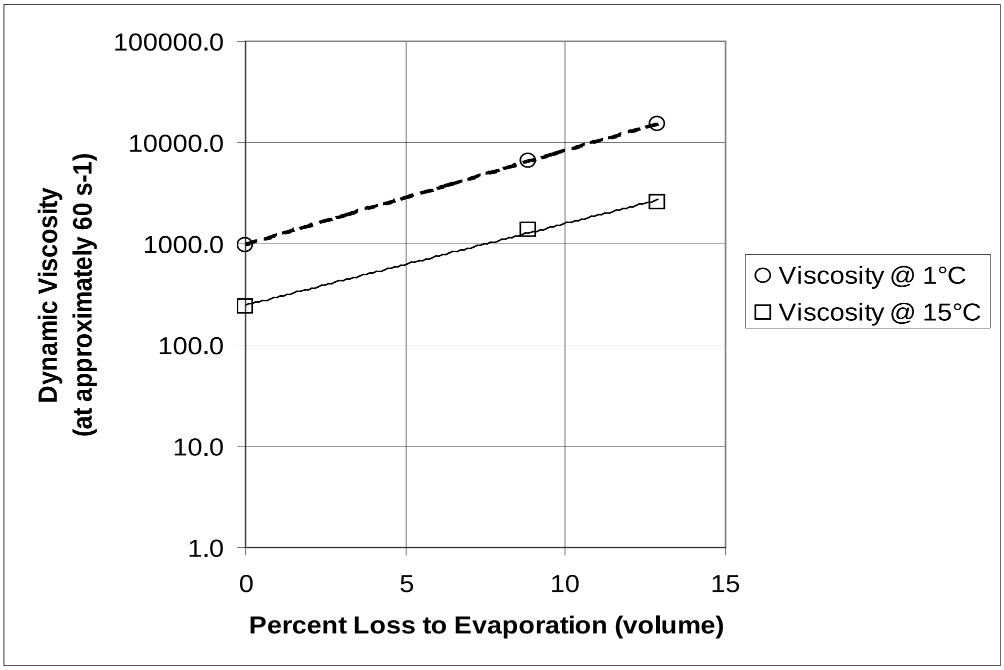


Figure 3-14 **Effect of Evaporation on Viscosity: MacKay River Heavy Bitumen Diluted with Synthetic Light Oil**

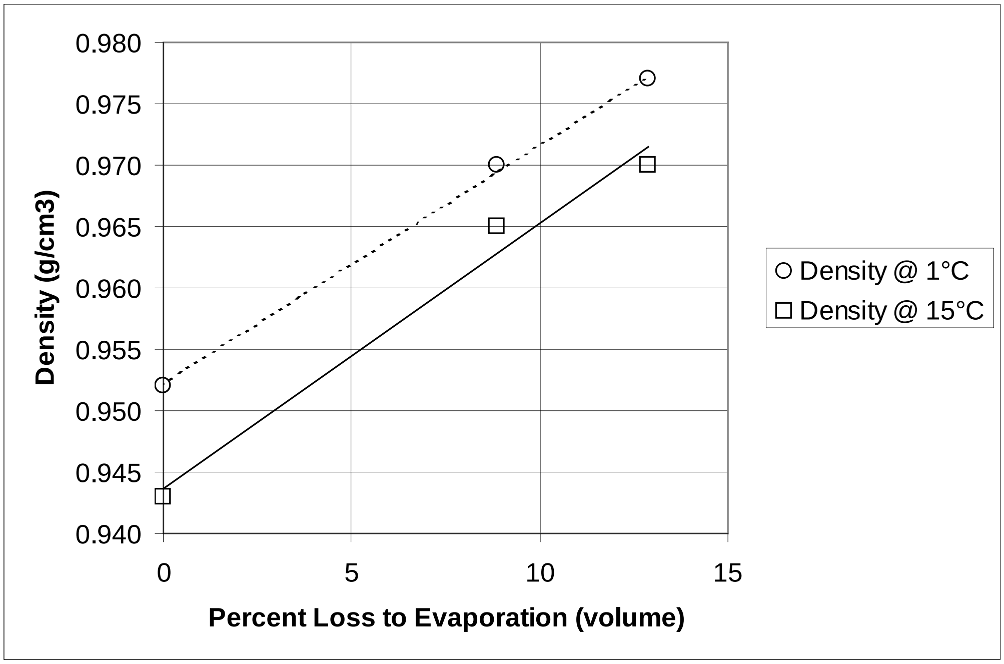


Figure 3-15 Effect of Evaporation on Density: MacKay River Heavy Bitumen Diluted with Synthetic Light Oil

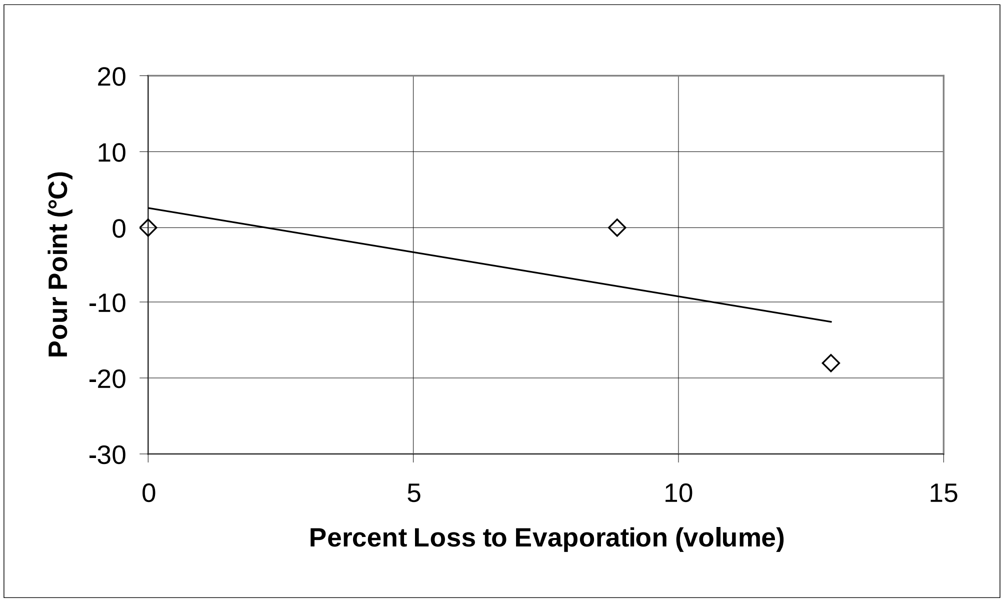


Figure 3-16 Effect of Evaporation on Pour Point: MacKay River Heavy Bitumen Diluted with Synthetic Light Oil

3.5 Comparison of Adhesion Results with Other Oils

Adhesion tests were conducted on the fresh and weathered test oils to provide a guide to the “stickiness” of these oils if they were to come into contact with shorelines or infrastructure. The detailed oil adhesion measurements collected for the four oils are provided in Table 3-5. Adhesion values for a number of other relatively well-known oils (both when fresh and after artificial weathering) are also provided in this table for comparison. Adhesion values and standard deviations are provided for various weathered states of the oils (percent evaporated). The shading in Table 3-5 is used to separate the data by weathered oil state.

Table 3-5 Oil Adhesion Results

Oil Name	Fresh Oil Viscosity (cP@15°C)	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation
Data Gathered for the Project													
Condensate (CRW)	0.6	0	2	1	57	3	1	75	16	1			
Synthetic light oil (SYN)	6	0	18	2	24	40	4	30	19	5			
Cold Lake bitumen-condensate (CLB)	368	0	98	3	14	146	6	17	131	7			
MacKay River Heavy bitumen-synthetic (MKH)	242	0	52	7	9	57	18	13	60	12			
Fuel Oil #2 (home heating oil)	3	0	6	2									
Environment Canada Data [1]													
Alaska North Slope (Middle Pipeline)	16	0	28	2	31	33	5						
Alaska North Slope (SOCSEX)	21	0	22	5	15	19	3	22	32	9			
Alaska North Slope (Southern Pipeline)	18	0	28	4	30	30	2						
Alberta Sweet Mixed Blend	7	0	13	1	14	22	1	26	35	1	39	61	4
Arab Heavy	43	0	31	1	9	30	7	16	34	3	24	56	3
Arab Light	14	0	14	2	12	18	2	24	21	2			
Arabian Medium	29	0	26	5	13	28	2	21	39	5	31	65	5
Asphalt Charged Stock	>4x106	0	1,534	-									
Aviation Gasoline	1	0	1	1	33	1	1	60	1	1			
Brent Blend	6	0	12	1	14	20	3	26	36	2	40	53	8

Table 3-5 Oil Adhesion Results (cont'd)

Oil Name	Fresh Oil Viscosity (cP@15°C)	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation	Evaporation (%)	Adhesion (g/m^2)	Standard Deviation
Bunker C Fuel Oil (Alaska)	8,706	0	85	9	8	421	55						
Catalytic Cracking Feed	780	0	116	7	2	124	23						
Diesel Fuel Oil (Alaska)	2	0	2	1	37	11	2						
Diesel Fuel Oil (Southern U.S.A., 1994)	5	0	9	1	8	8	1	16	15	2			
Ekofisk	5	0	7	2	37	23	3						
Federated (1994)	4	0	2	2	16	17	2	28	26	1	42	25	3
Gulfaks	13	0	23	2	10	35	3	19	31	30			
Heavy Reformate	1,321	0	80	9									
Hibernia (1999)	13	0	12	1	10	27	4	21	51	8	33	160	8
IF-30 Fuel Oil	236	0	34	5									
Intermediate Fuel Oil 180	2,324	0	49	8	8	129	13						
Intermediate Fuel Oil 300	14,470	0	91	21	5	358	35						
Jet A/Jet A-1	2	0	1	0	12	0	0	23	1	0	37	6	3
Louisiana	8	0	18	2	10	22	1	21	27	3	32	34	2
Lubricating Oil (Air Compressor)	220	0	34	3									
Lubricating Oil (Gear)	620	0	48	3									
Sakhalin	4	0	8	2	42	29	4						

Table 3-5 Oil Adhesion Results (cont'd)

Oil Name	**Fresh Oil Viscosity** (cP@15°C)	**Evaporation (%)**	**Adhesion (g/m^2)**	**Standard Deviation**	**Evaporation (%)**	**Adhesion (g/m^2)**	**Standard Deviation**	**Evaporation (%)**	**Adhesion (g/m^2)**	**Standard Deviation**	**Evaporation (%)**	**Adhesion (g/m^2)**	**Standard Deviation**
Scotian Light	1	0	0	0	25	2	1	44	3	0	64	9	1
Soybean Oil	73	0	15	3									
Terra Nova (1994)	18	0	10	3	12	19	3	24	38	5	34	80	10
White Rose	30	0	23	2	9	26	1	15	46	3	24	63	5
Zaire	362	0	58	0	6	92	19	14	161	40	23	33	56

NOTE:
[1] Data collected at http://www.etc-cte.ec.gc.ca/databases/spills_e.html

4 Fate Modelling for Marine Spills

4.1 Background

Two elements must be modelled in an oil spill scenario for use in spill response planning:

- the path that the oil travels
- the properties or fate of the hydrocarbon as it travels

This section describes the properties or fate of the oil with time after a spill under the prevailing environmental conditions for the spill scenario. The fate and trajectory elements are inter-related, so the trajectory and oil property prediction results were determined to be consistent, compatible and ultimately integrated into a final product.

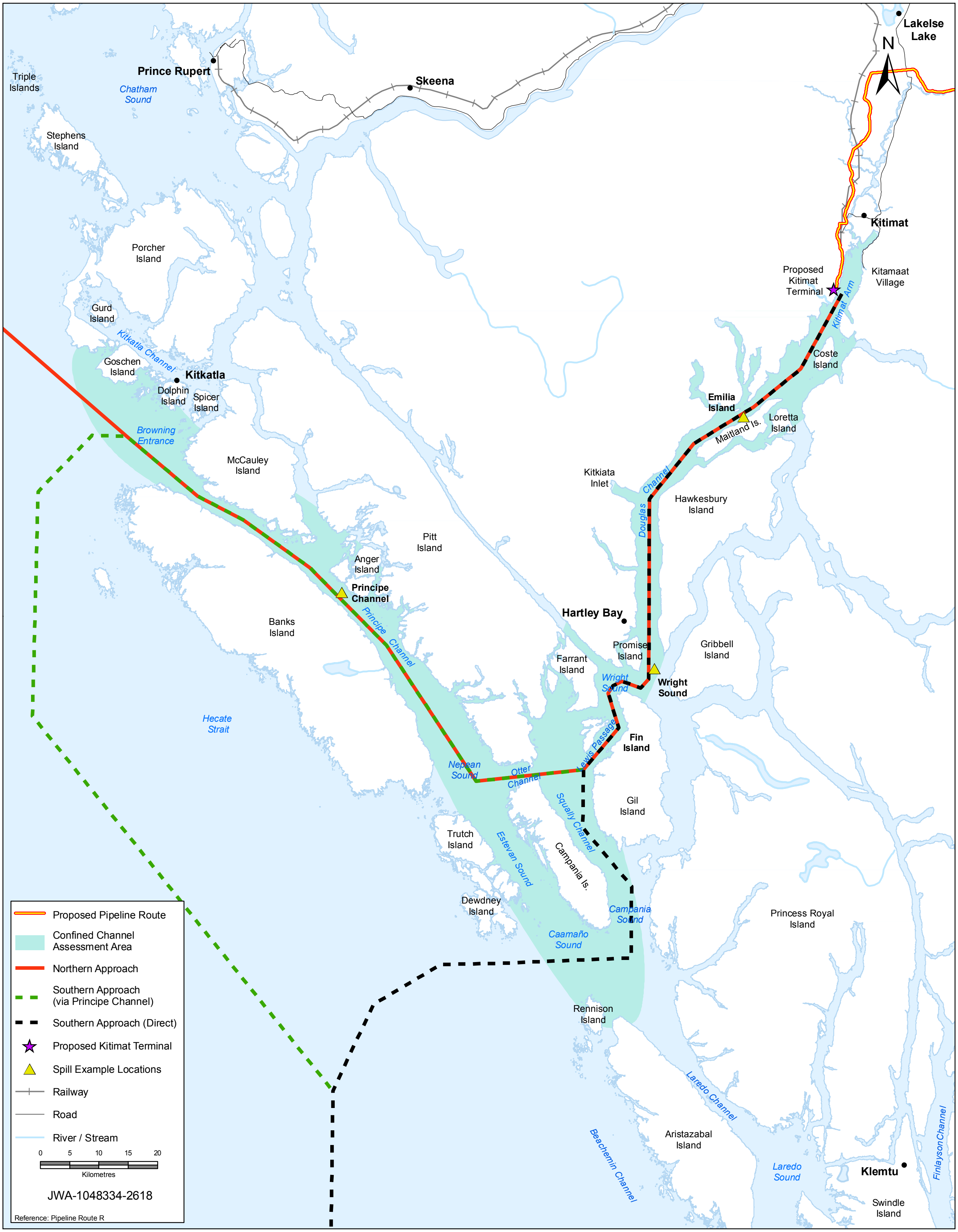
The following reasonable scenarios have been defined and modelled.

Instantaneous spills of 188 m^3 of MKH, 188 m^3 of SYN, 167 m^3 of CRW and a 12 m^3 spill of MKH have been considered for the loading terminal in Kitimat based on preliminary spill volumes provided by GEM in early 2008. Revised spill volumes have been calculated and are similar. For fate modelling, it has been assumed that the oil will be on the surface in the form of 1.0 m^3 parcels of oil.

Three representative sites along the vessel traffic routes from the loading terminal to unrestricted waters have been selected to assess environmental effects and spill response. A spill size of 10,000 m^3 has been selected for tanker spills due to grounding and 36,000 m^3 for a collision. Results presented below are based on preliminary spill volumes of 10,000 m^3 for all spill scenarios and as a minimum requirement for the purpose of spill response planning.

For oil fate modelling purposes, it has been assumed that the oil from these tanker spills will be on the surface in the form of individual parcels each with a volume of 50 m^3. This is a reasonable volume given the initial rapid spill of oil, spreading characteristics and typical water currents in the CCAA (0.25 to 1.0 m/s). The locations of the spill sites for the scenarios are provided in Figure 4-1.

Oil fate modelling has been completed for each of the four spill sites for four seasons. The seasonal breakdown used in the analysis of the environmental data was as follows: winter (December, January and February), spring (March, April and May), summer (June, July and August) and fall (September, October and November). Oil fate models have been developed primarily for open ocean prediction of spill behaviour. The oil dispersion algorithms use wind speed as an indicator of sea roughness to determine the rate of oil loss from the surface. The relationship between wind speed and sea state used in these dispersion models is based on open ocean conditions. Spills in the CCAA will occur in waters with limited fetch when compared to the open ocean. To account for this, a wind reduction factor was developed by Hay and Company Consultants (Hayco) for each spill scenario. The factor reduces the wind speed used in the oil dispersion algorithm such that the sea state used in the oil fate modelling matches that in the limited fetch environment. The wind-reduction factors developed by Hayco for each of the sites and seasons are shown in Table 4-1.



REFERENCES: NTDB Topographic Mapsheets provided by the Majesty the Queen in Right of Canada, Department of Natural Resources. All rights reserved.

CONTRACTOR:
Jacques Whitford AXYS Ltd.

PREPARED BY:
gem Gateway Environmental Management Team

PREPARED FOR:
ENBRIDGE NORTHERN GATEWAY PIPELINES

ENBRIDGE NORTHERN GATEWAY PROJECT

Spill Example Locations in the Confined Channel Assessment Area

FIGURE NUMBER: 4-1

DATE: 20100118

SCALE: 1:900,000

AUTHOR: NP

APPROVED BY: CM

PROJECTION: UTM 9

DATUM: NAD 83

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Table 4-1 Meteorological Inputs for Fate Modelling

Site	Season	Average Wind Speed (m/s)	Average Temp_{air} (ºC)	Average $\text{Temp}_{\text{water}}$ (ºC)	Wind Factor	Reduced Wind Speed (m/s)
Emilia Island	Winter	3.98	4.30	6.39	0.65	2.58
	Spring	2.99	7.08	6.86	0.67	2.01
	Summer	3.12	14.24	13.27	0.66	2.07
	Fall	3.29	8.92	8.70	0.65	2.14
Principe Channel	Winter	6.54	4.30	6.67	0.59	3.87
	Spring	4.85	7.08	6.69	0.66	3.21
	Summer	3.89	14.24	9.84	0.73	2.83
	Fall	6.18	8.92	8.50	0.61	3.75
Marine Terminal	Winter	5.63	4.30	6.01	0.52	2.92
	Spring	5.27	7.08	6.74	0.58	3.04
	Summer	5.94	14.24	12.49	0.55	3.27
	Fall	5.78	8.92	8.61	0.56	3.22
Wright Sound	Winter	5.31	4.30	6.74	0.50	2.66
	Spring	3.68	7.08	6.85	0.58	2.13
	Summer	2.88	14.24	12.50	0.68	1.96
	Fall	4.91	8.92	8.51	0.52	2.53

Hayco provided a representative average wind speed, and air and water temperatures for each spill location and season modelled. These data are shown in Table 4-1. These data were used in the SL Ross oil spill model (SLROSM), along with the specific oil property data collected from the oil analysis described in Section 3, to predict the general fate of the oil for each spill scenario.

Preliminary modelling has shown that the two diluted bitumen oils exhibit a similar long-term fate so only one, MKH, was included in the final detailed assessment. MKH is more likely to form a water-in-oil emulsion and, thus, is the more conservative choice of the two oils with respect to spill behaviour and response.

The general fate information (oil property changes with time, percentage evaporated and percentage dispersed) was then delivered to Hayco, who appended the oil fate results to a stochastic model. The stochastic model was used to select the most probable specific spill scenario for each location that matched the typical behaviour of spills in that season. A “real-time” time series of varying winds, water temperatures and air temperatures were selected by Hayco for specific spill scenario modelling in each of the four seasons. These time series of environmental conditions were used in oil fate modelling for specific scenarios, presented as mass balance figures in TERMPOL Section 3.15.

The general behaviour of the three oils considered are discussed based on the modelling results for one of the specific scenarios. This is followed by a series of graphs that summarize the fate predictions for each of the specific spill scenarios for the three oils selected for detailed fate assessment. Time histories of slick width, emulsion water content, emulsion (or oil) viscosity, emulsion (or oil) density, percentage of oil evaporated and percentage of oil dispersed are provided for each spill location and season.

4.2 General Fate of the Three Oils

Preliminary modelling has shown that the two diluted bitumen oils (CLB and MKH) exhibit a similar long-term fate so only one of these oils, MKH, was included in the final detailed assessment.

CRW is a light oil that will evaporate and disperse quickly once spilled. SYN is light, but will evaporate and disperse at a slower rate than the CRW condensate. MKH is a persistent oil that will likely form a water-in-oil emulsion that is slow to evaporate and disperse. Table 4-3 provides an example of the property changes with time that can be expected from 10,000 m^3 spills of these oils. The data in Table 4-3 are for the Principe Channel summer scenario. There are differences in the spill behaviour for the different spill sites and seasons. Figures in Sections 4.3 through 4.9 show detailed oil behaviour and properties for each spill site and season.

Table 4-2 Example Oil Property Changes with Time (Principe Channel 10,000 m3 Summer Tanker Spill)

Time (h)	**Water Content**	**Viscosity** (cP)	**Density** (g/ml)	**Pour Point** (°C)	**Evaporated** (%)	**Dispersed** (%)
Oil Type						
12						
CRW	0	24	0.894	-22	64	36
SYN	0	40	0.915	-29	17	3
MKH	24	2000	0.975	-27	5	1
24						
CRW	-	-	-	-	-	-
SYN	0	80	0.925	-25	23	15
MKH	65	30,000	0.989	-25	8	3
48						
CRW	-	-	-	-	-	-
SYN (after 40 hours)	0	270	0.950	-21	25	75
MKH	75	100,000	1.01	-22	10	3
120						
CRW	-	-	-	-	-	-
SYN	-	-	-	-	-	-
MKH	75	150,000	1.01	-20	13	7

The following general observations can be made regarding the oil properties shown in Table 4-3:

- The only oil that is likely to emulsify is MKH. If this oil emulsifies, it will attain very high viscosities and densities. It is unlikely to sink in a marine environment, but will be easily overwashed by water. About 80% of the oil from spills will be on the surface after 120 hours under summer conditions at the Principe Channel site.
- The CRW will completely evaporate and disperse after about a 12-hour exposure.
- The SYN will survive on the surface for about 95 hours with 27% of the oil evaporating and 73% dispersing over this time.

None of the oils will reach pour points where the oil will be a semi-solid at ambient temperatures.

4.3 Hypothetical Marine Terminal Spill, Oil Fate Results

The figures in Section 4.3 show detailed oil behaviour and properties for the hypothetical marine terminal spill scenario for each season, as follows:

- summer – Figures 4-2 to 4-7
- fall – Figures 4-8 to 4-13
- winter – Figures 4-14 to 4-19
- spring – Figures 4-20 to 4-25

4.3.1 Hypothetical Summer Spill

Seasonal average environmental input data used for the summer scenarios have been derived from the months of June, July and August. The MRB short form used in these figures is equivalent to MKH - MacKay River Heavy bitumen used elsewhere in the modelling.

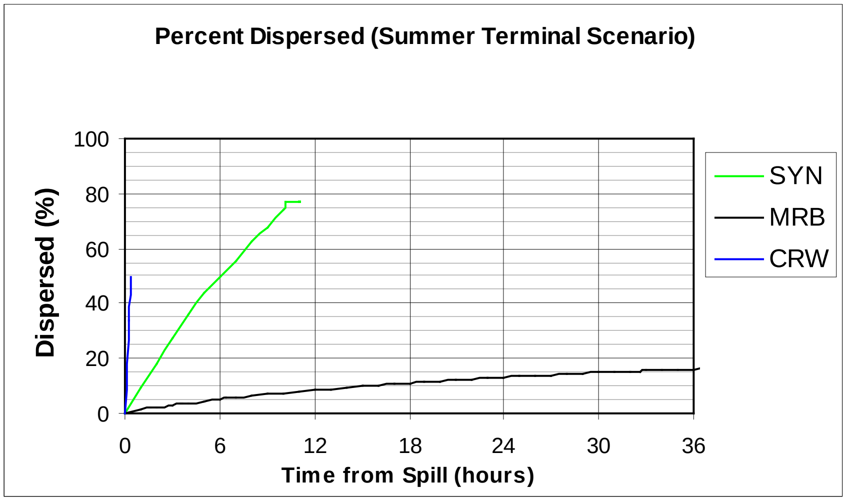


Figure 4-2 Marine Terminal Scenario (Summer) – Percent Dispersed

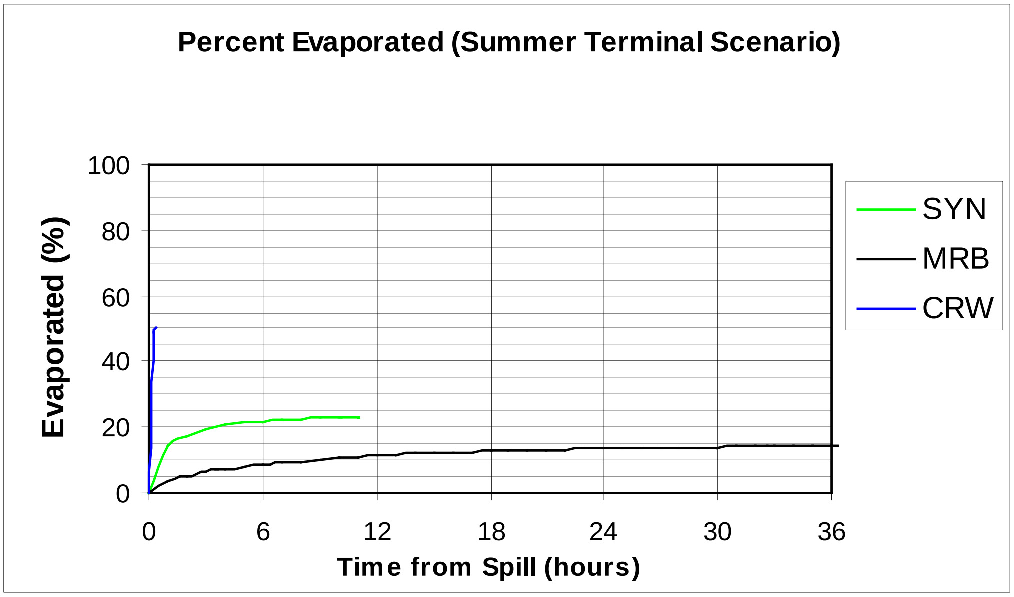


Figure 4-3 Marine Terminal Scenario (Summer) – Percent Evaporated

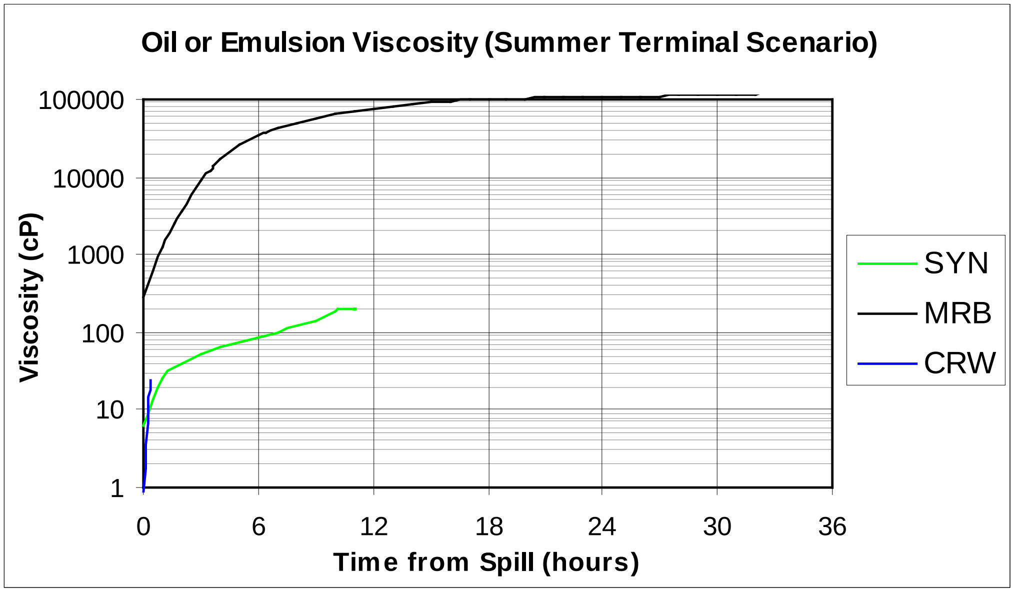


Figure 4-4 Marine Terminal Scenario (Summer) – Oil or Emulsion Viscosity

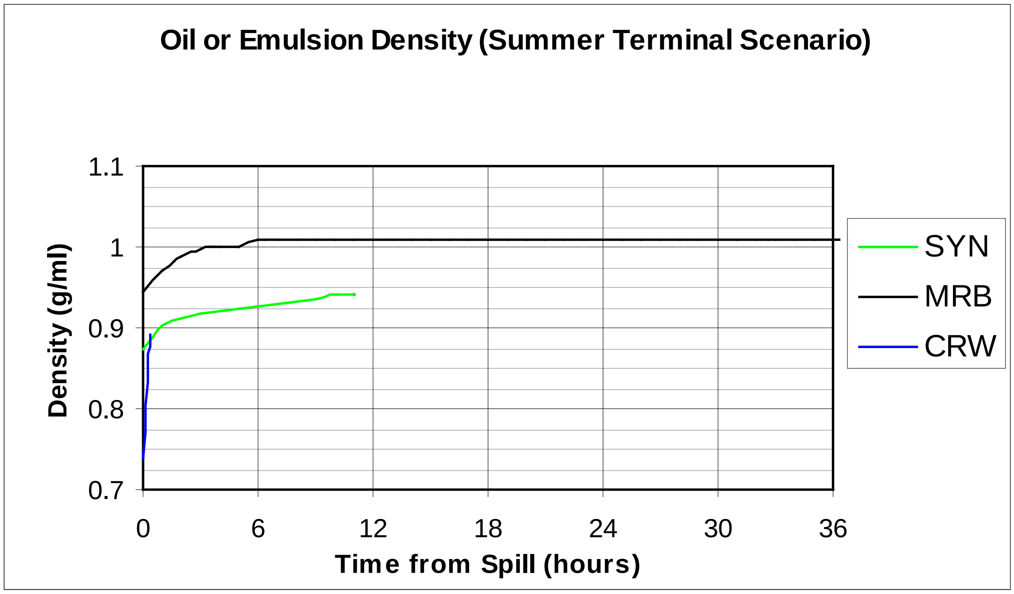


Figure 4-5 **Marine Terminal Scenario (Summer) – Oil or Emulsion Density**

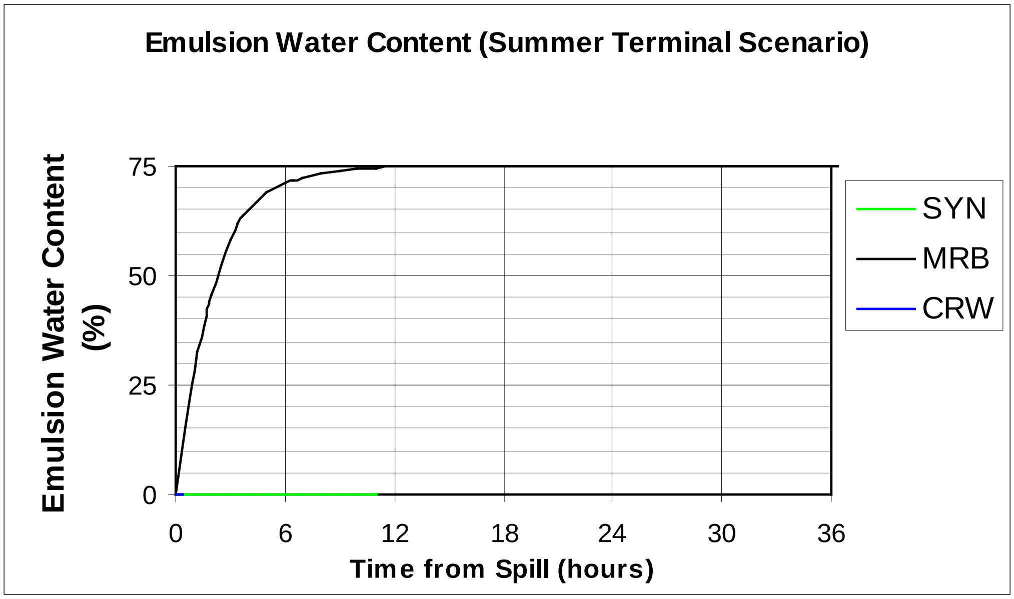


Figure 4-6 **Marine Terminal Scenario (Summer) – Emulsion Water Content**

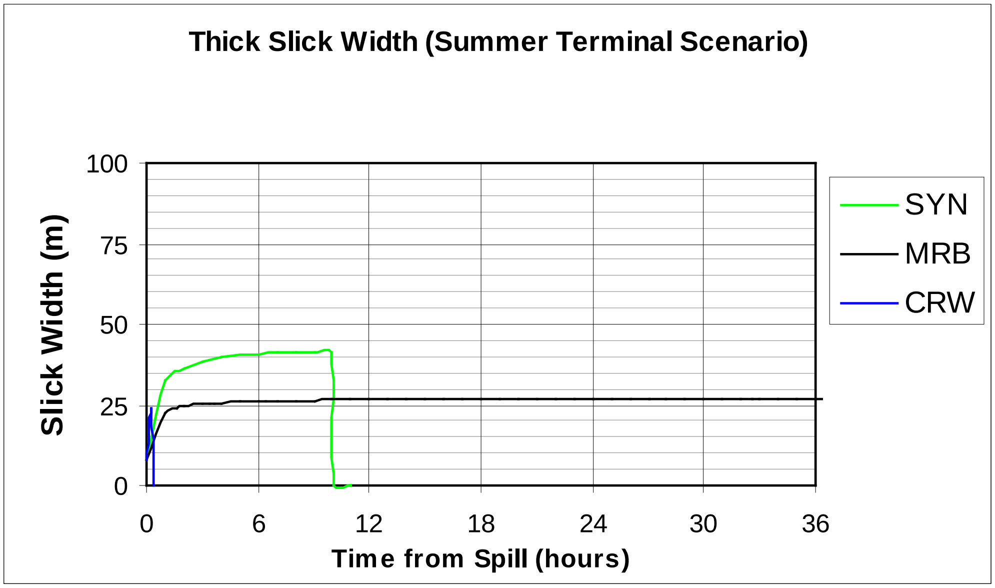


Figure 4-7 Marine Terminal Scenario (Summer) – Thick Slick Width

4.3.2 Hypothetical Fall Spill

Seasonal average environmental input data used for the fall scenarios have been derived from the months of September, October and November. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

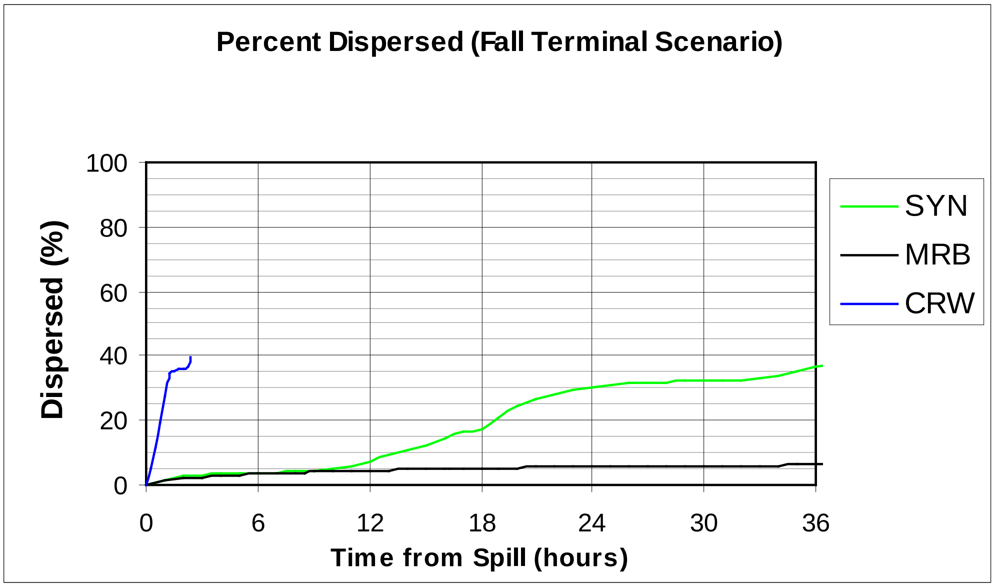


Figure 4-8 Marine Terminal Scenario (Fall) – Percent Dispersed

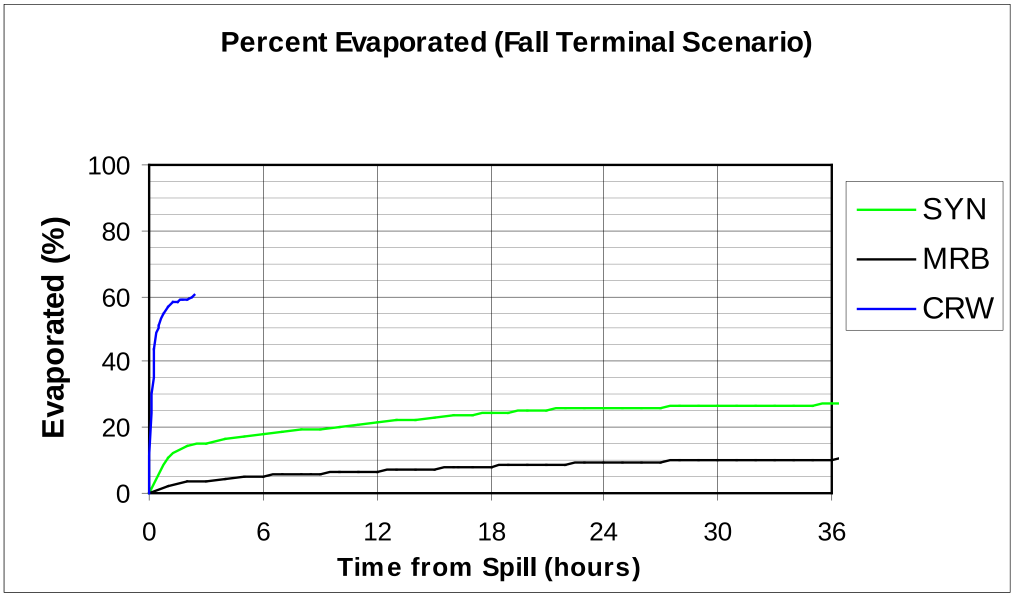


Figure 4-9 Marine Terminal Scenario (Fall) – Percent Evaporated

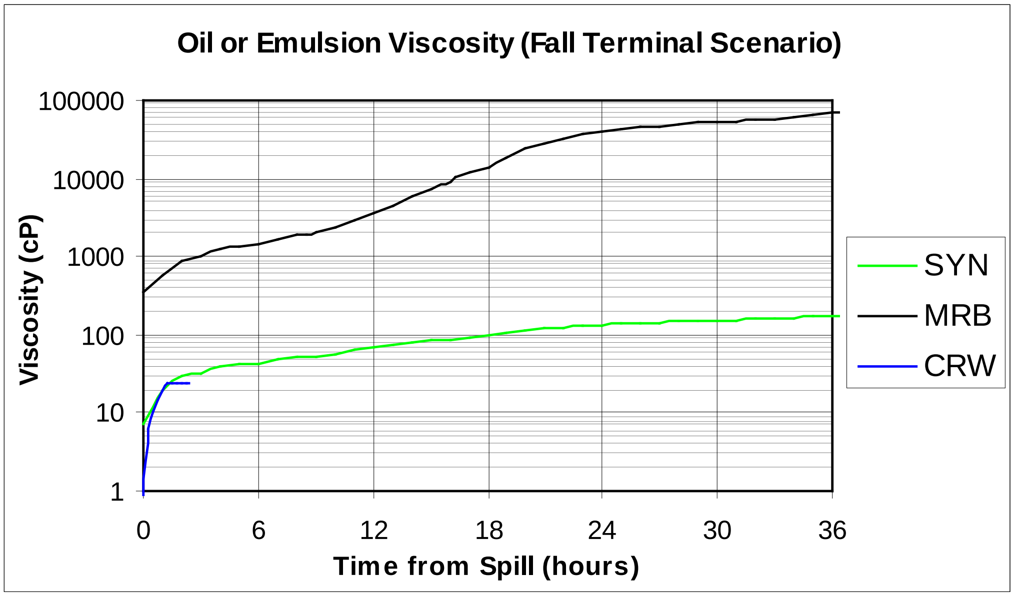


Figure 4-10 Marine Terminal Scenario (Fall) – Oil or Emulsion Viscosity

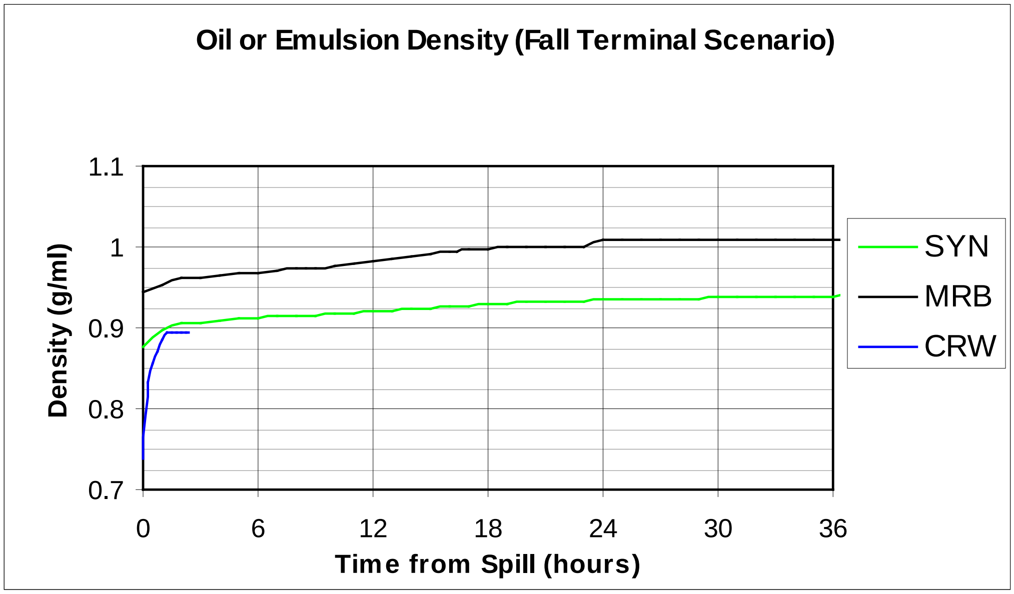


Figure 4-11 Marine Terminal Scenario (Fall) – Oil or Emulsion Density

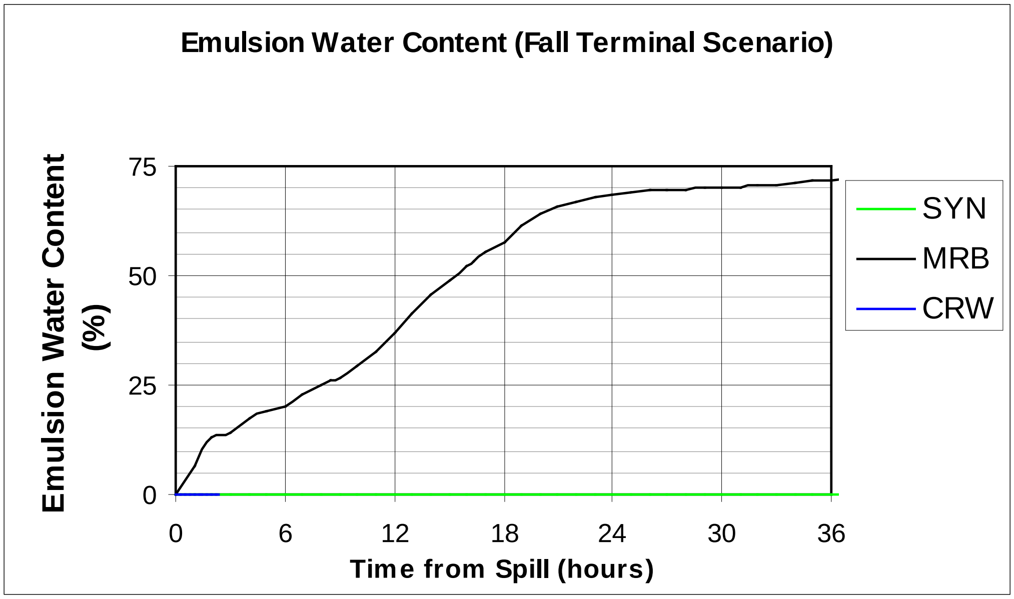


Figure 4-12 Marine Terminal Scenario (Fall) – Emulsion Water Content

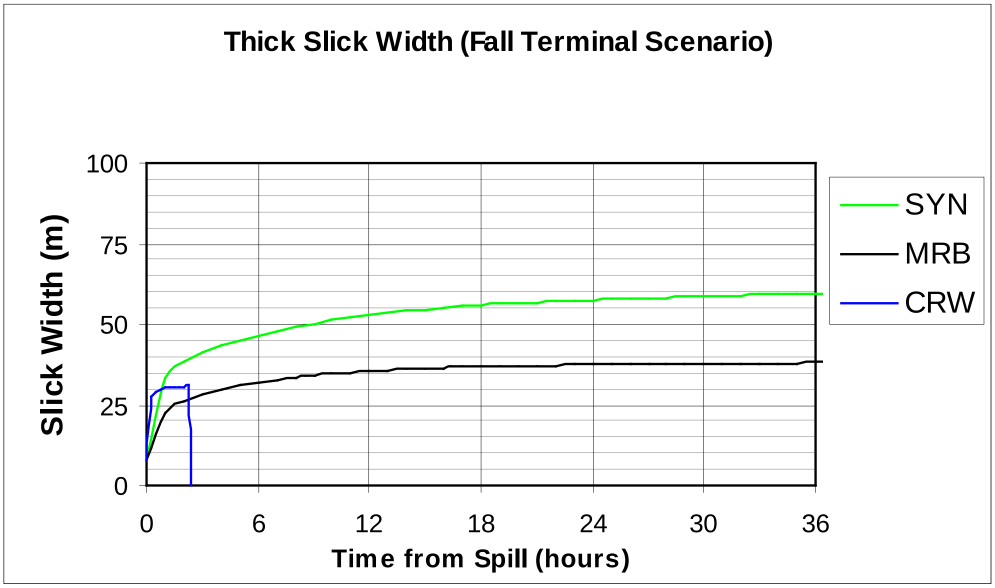


Figure 4-13 Marine Terminal Scenario (Fall) – Thick Slick Width

4.3.3 Hypothetical Winter Spill

Seasonal average environmental input data used for the winter scenarios have been derived from the months of December, January and February. The MRB short form used in these figures is equivalent to MKH- MacKay River Heavy bitumen used elsewhere in the modelling.

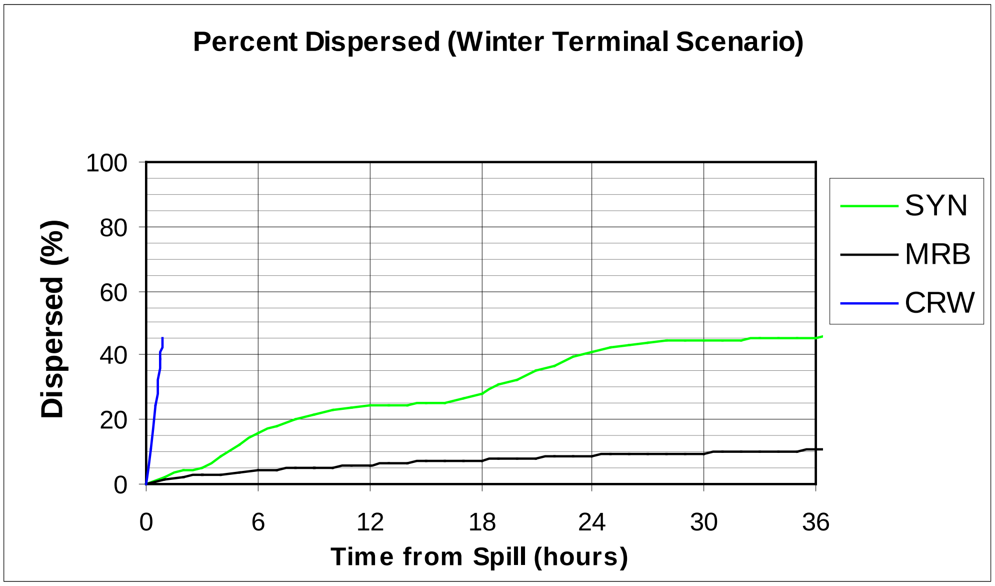


Figure 4-14 Marine Terminal Scenario (Winter) – Percent Dispersed

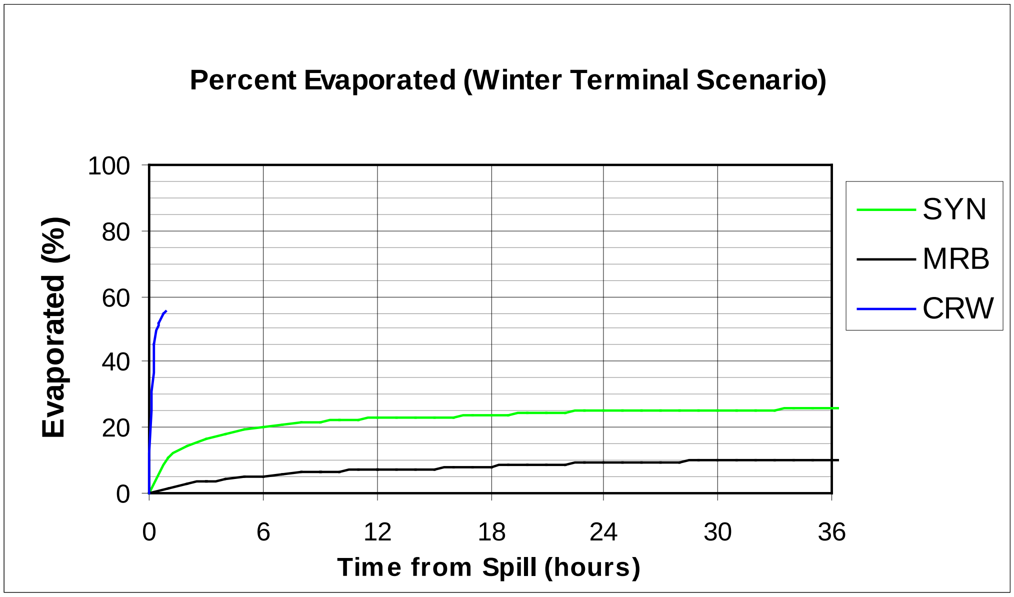


Figure 4-15 Marine Terminal Scenario (Winter) – Percent Evaporated

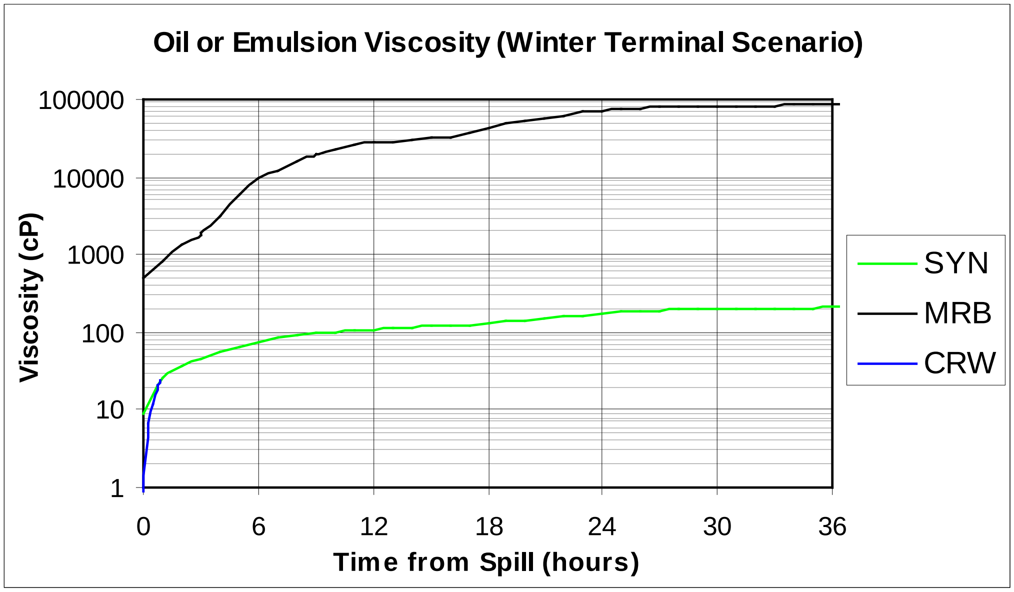


Figure 4-16 Marine Terminal Scenario (Winter) – Oil or Emulsion Viscosity

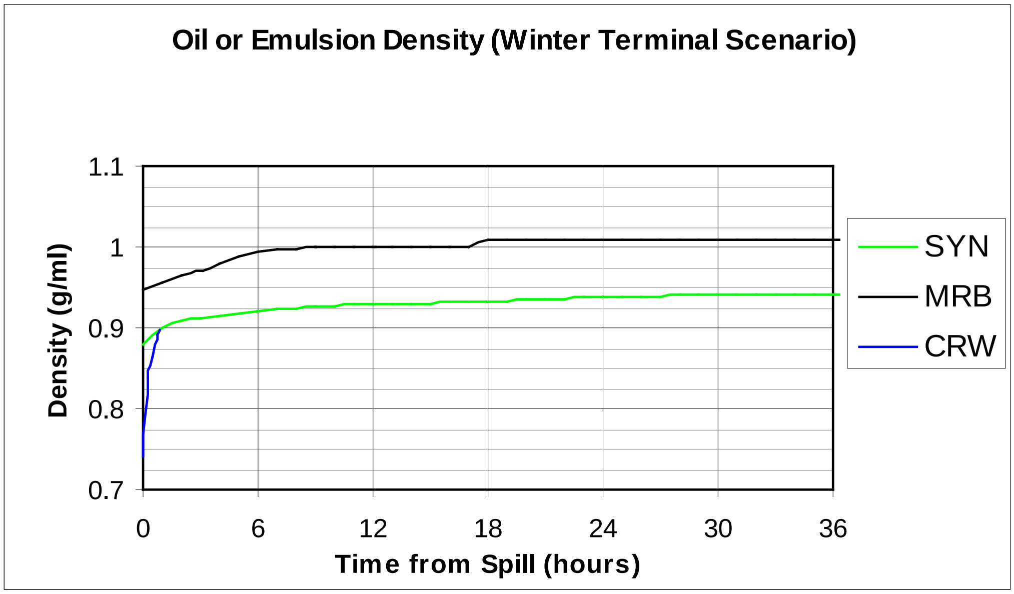


Figure 4-17 **Marine Terminal Scenario (Winter) – Oil or Emulsion Density**

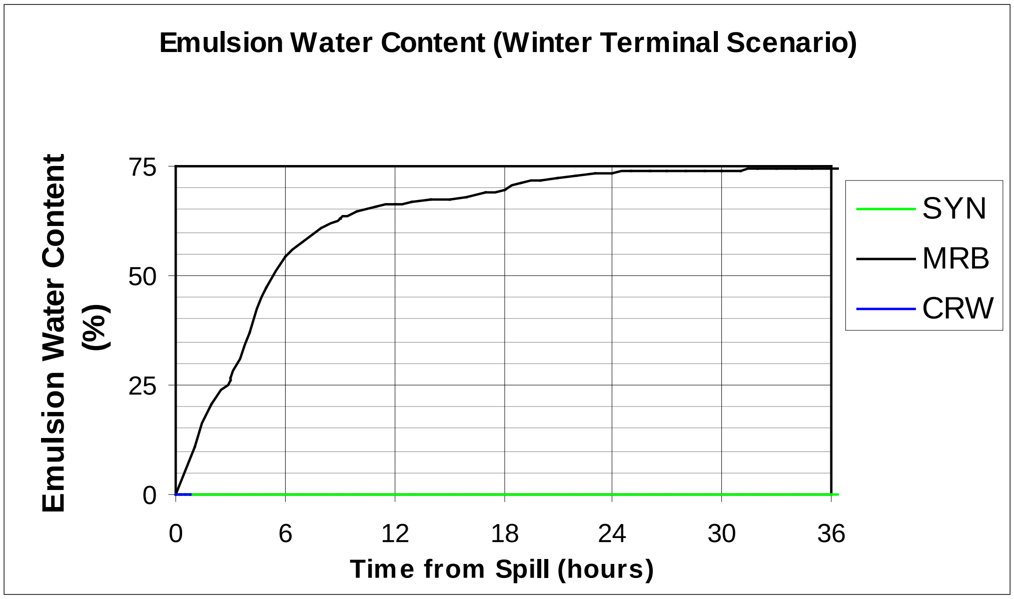


Figure 4-18 **Marine Terminal Scenario (Winter) – Emulsion Water Content**

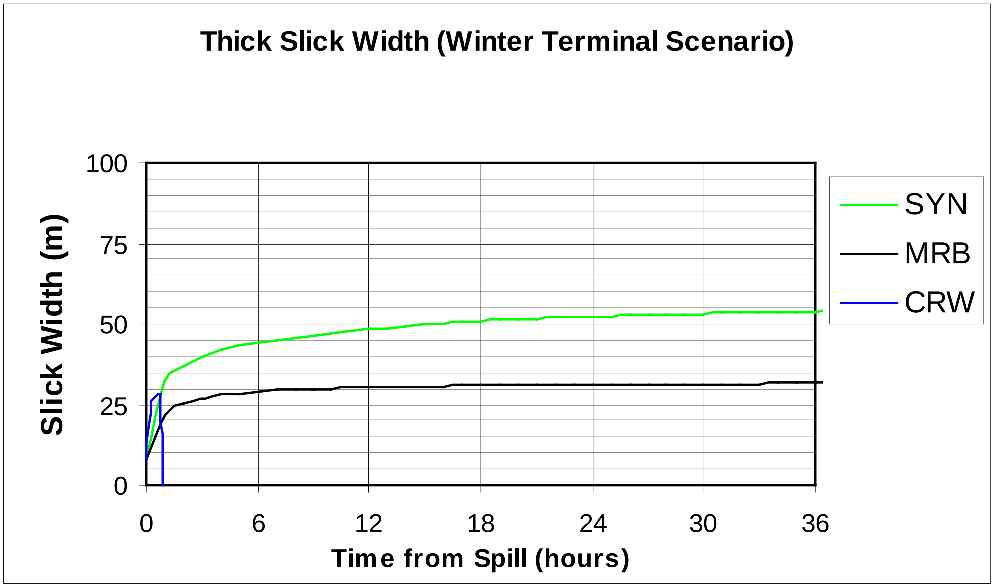


Figure 4-19 Marine Terminal Scenario (Winter) – Thick Slick Width

4.3.4 Hypothetical Spring Spill

Seasonal average environmental input data used for the spring scenarios have been derived from the months of March, April and May. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

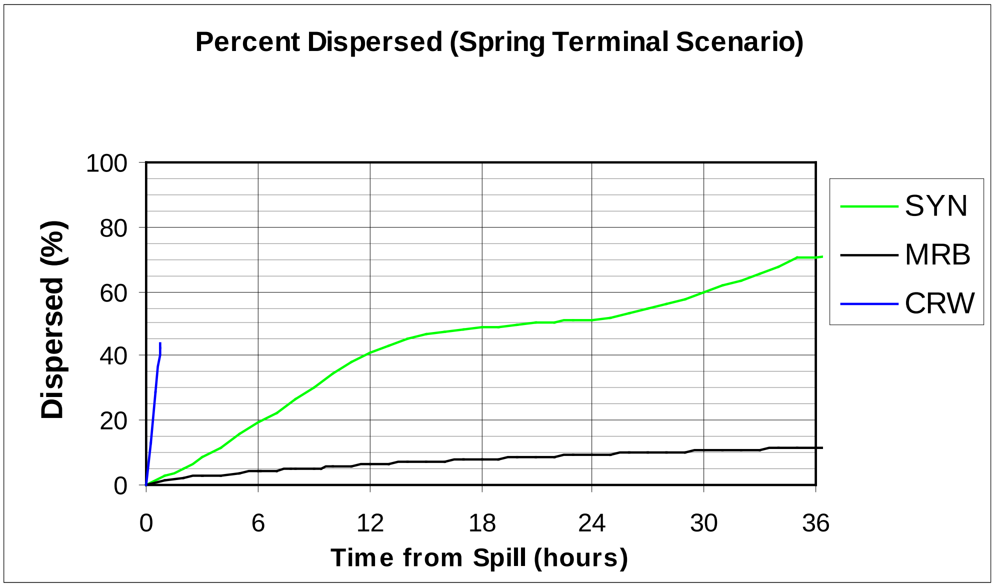


Figure 4-20 Marine Terminal Scenario (Spring) – Percent Dispersed

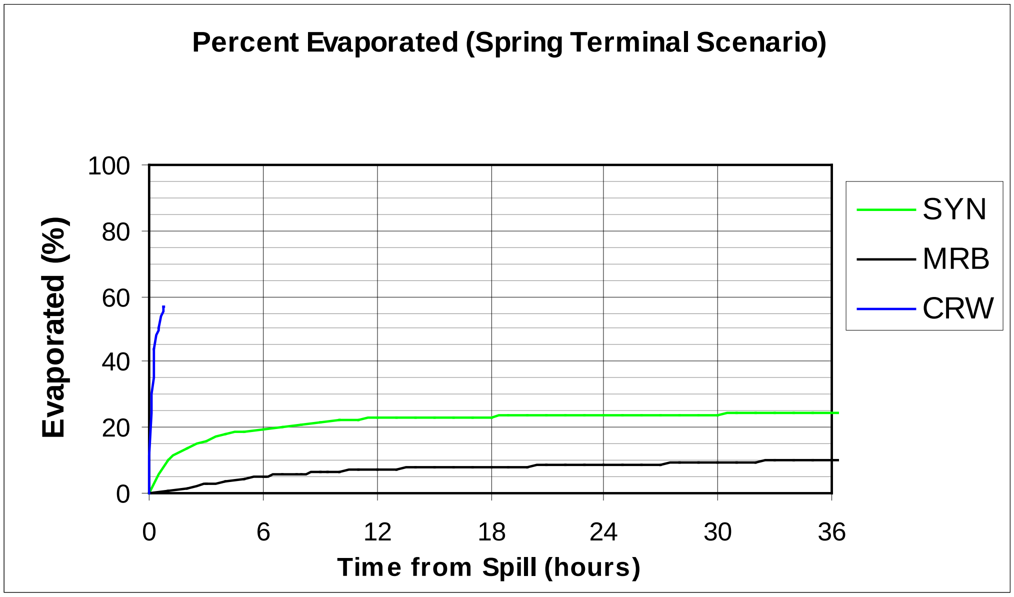


Figure 4-21 Marine Terminal Scenario (Spring) – Percent Evaporated

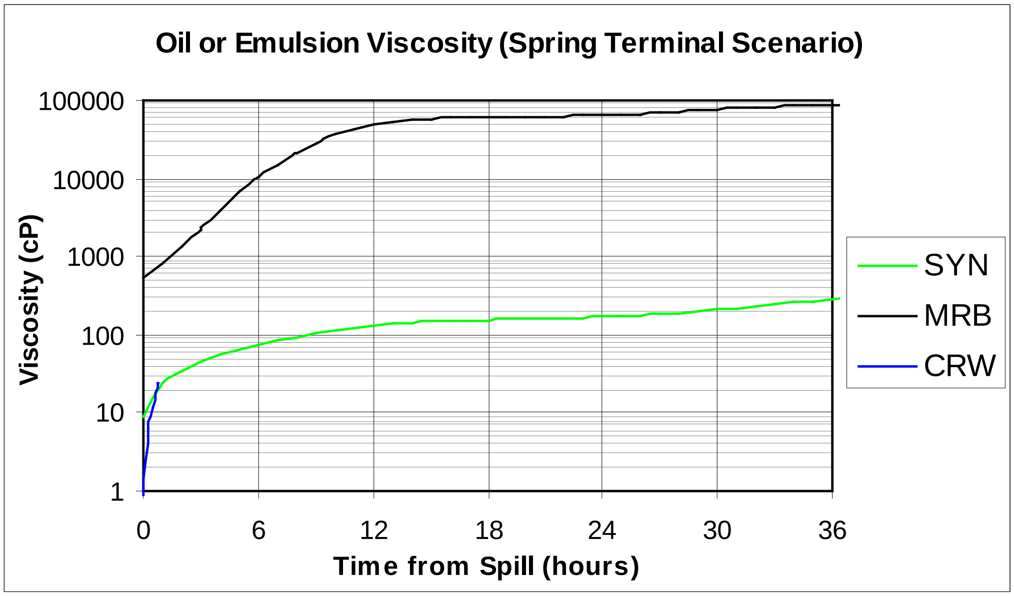


Figure 4-22 Marine Terminal Scenario (Spring) – Oil or Emulsion Viscosity

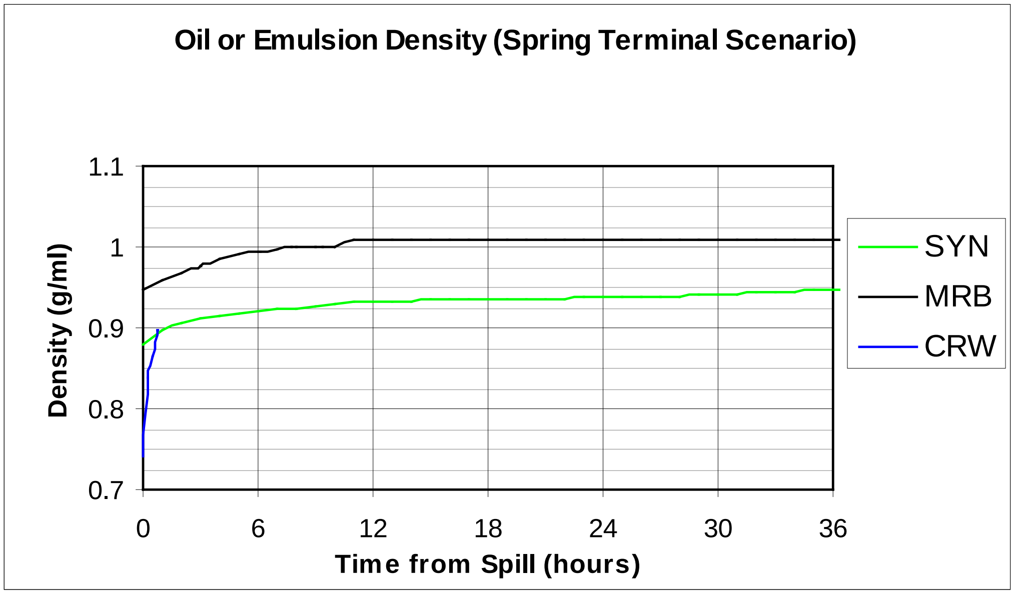


Figure 4-23 Marine Terminal Scenario (Spring) – Oil or Emulsion Density

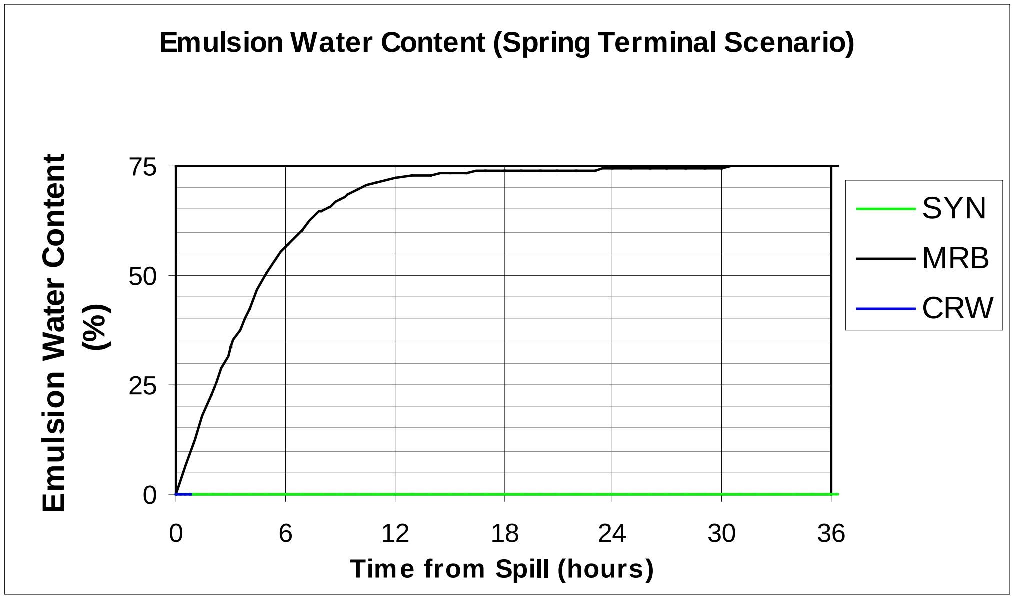


Figure 4-24 Marine Terminal Scenario (Spring) – Emulsion Water Content

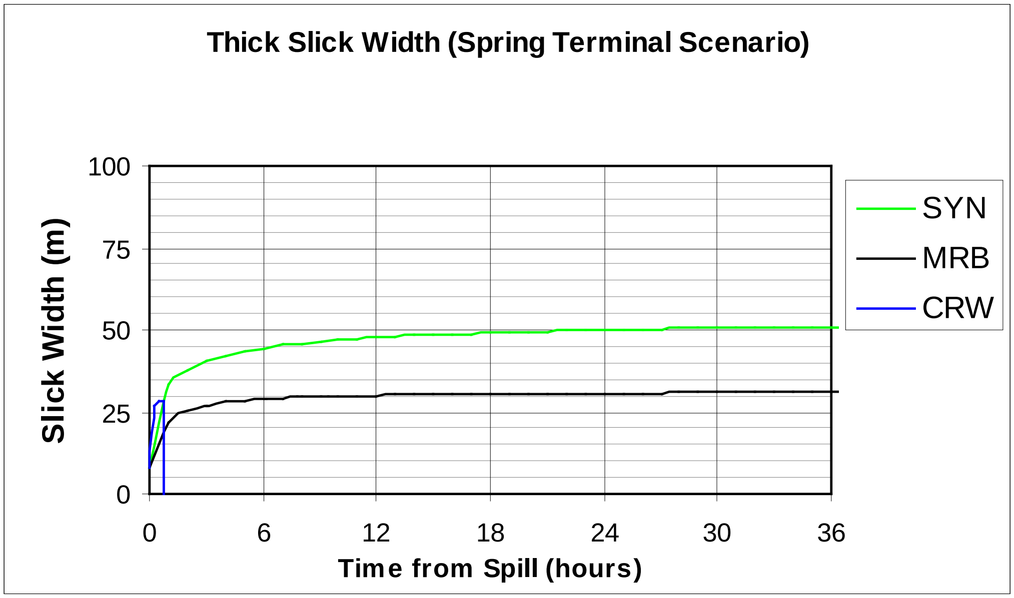


Figure 4-25 Marine Terminal Scenario (Spring) – Thick Slick Width

4.4 Emilia Island Hypothetical Tanker Spill, Oil Fate Results

The figures in Section 4.4 show detailed oil behaviour and properties for the Emilia Island hypothetical spill for each season, as follows:

- summer – Figures 4-26 to 4-31
- fall – Figures 4-32 to 4-37
- winter – Figures 4-38 to 4-43
- spring – Figures 4-44 to 4-49

4.4.1 Hypothetical Summer Spill

Seasonal average environmental input data used for the summer scenarios have been derived from the months of June, July and August. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

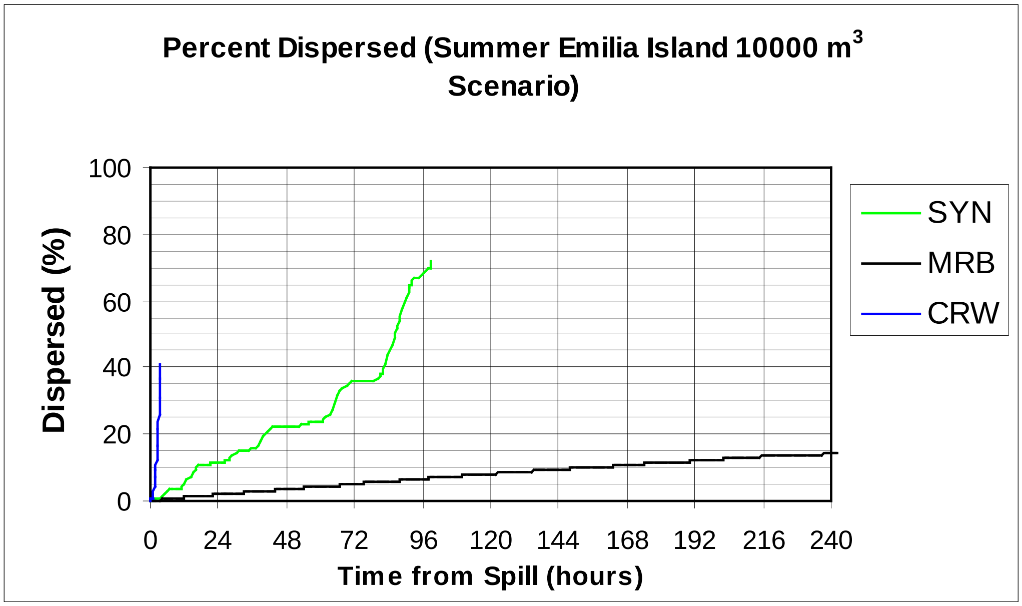


Figure 4-26 Emilia Island Tanker Spill Scenario (Summer) – Percent Dispersed

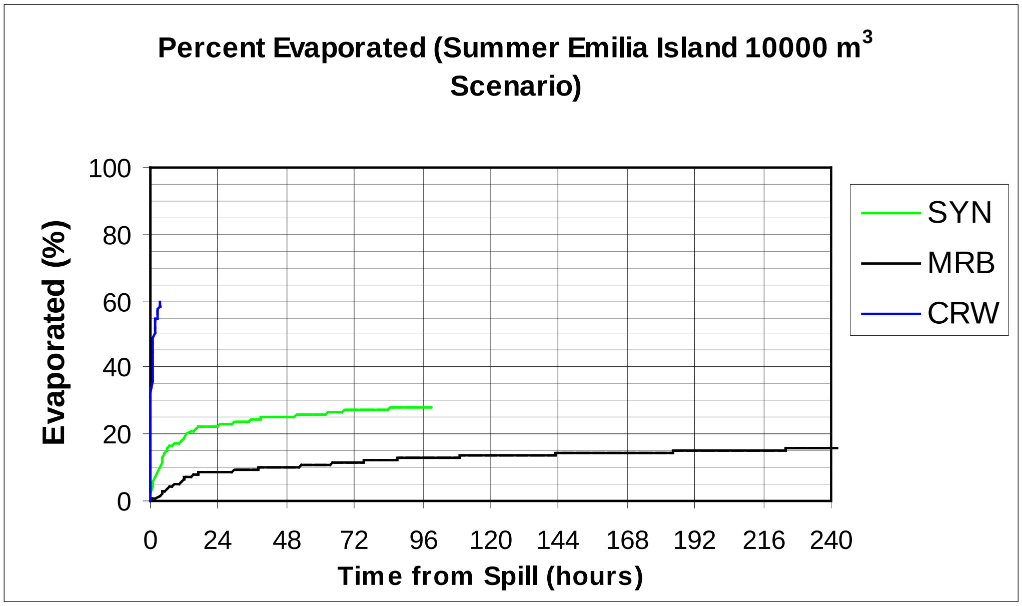


Figure 4-27 Emilia Island Tanker Spill Scenario (Summer) – Percent Evaporated

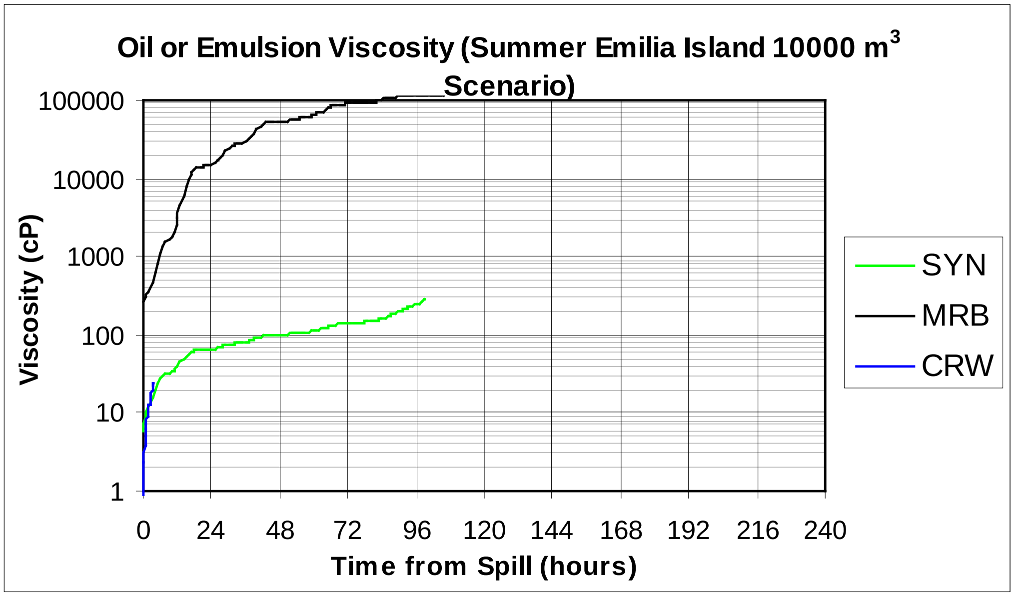


Figure 4-28 Emilia Island Tanker Spill Scenario (Summer) – Oil or Emulsion Viscosity

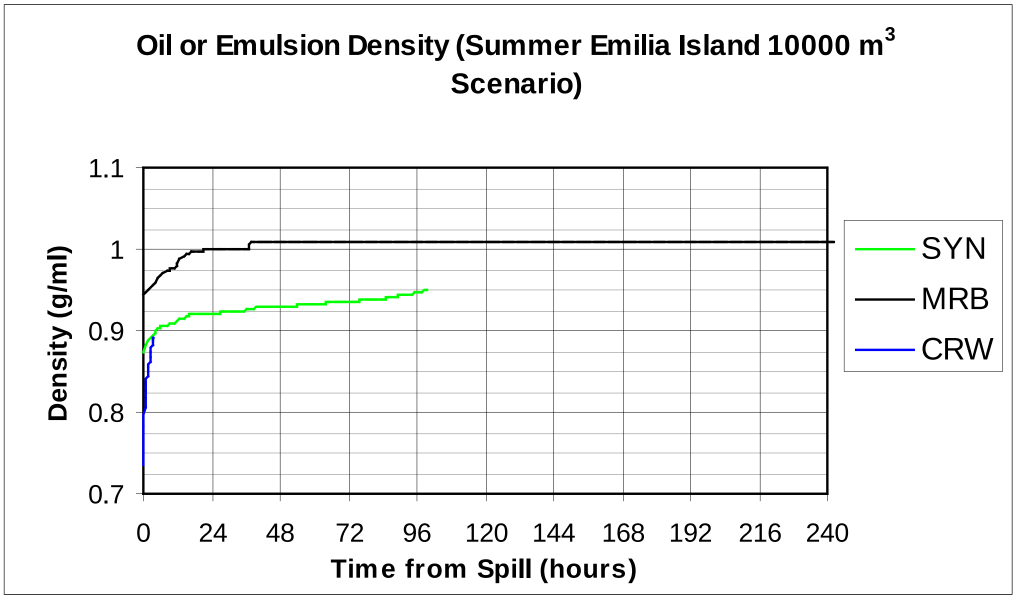


Figure 4-29 Emilia Island Tanker Spill Scenario (Summer) – Oil or Emulsion Density

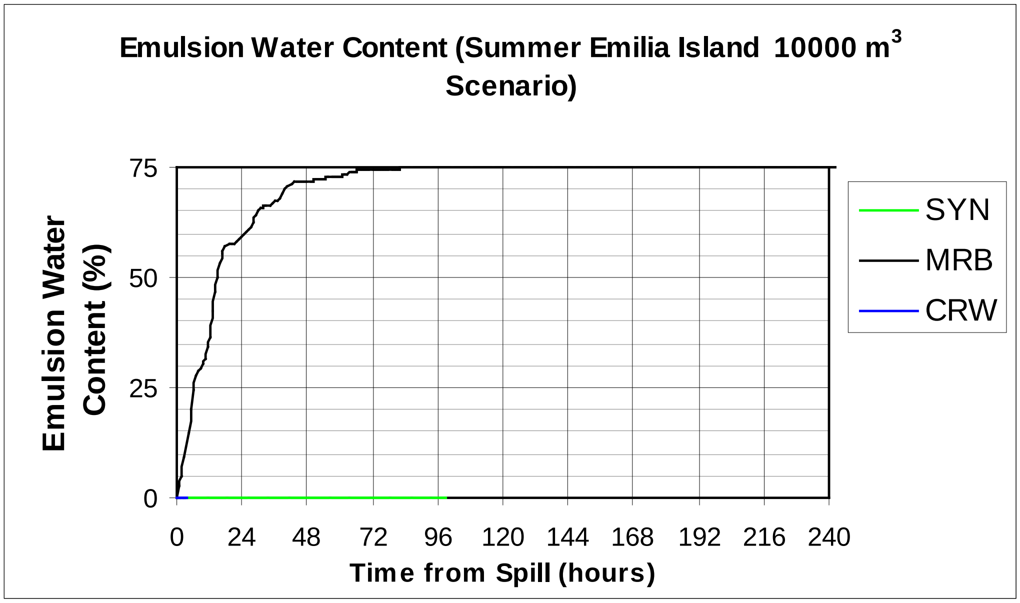


Figure 4-30 Emilia Island Tanker Spill Scenario (Summer) – Emulsion Water Content

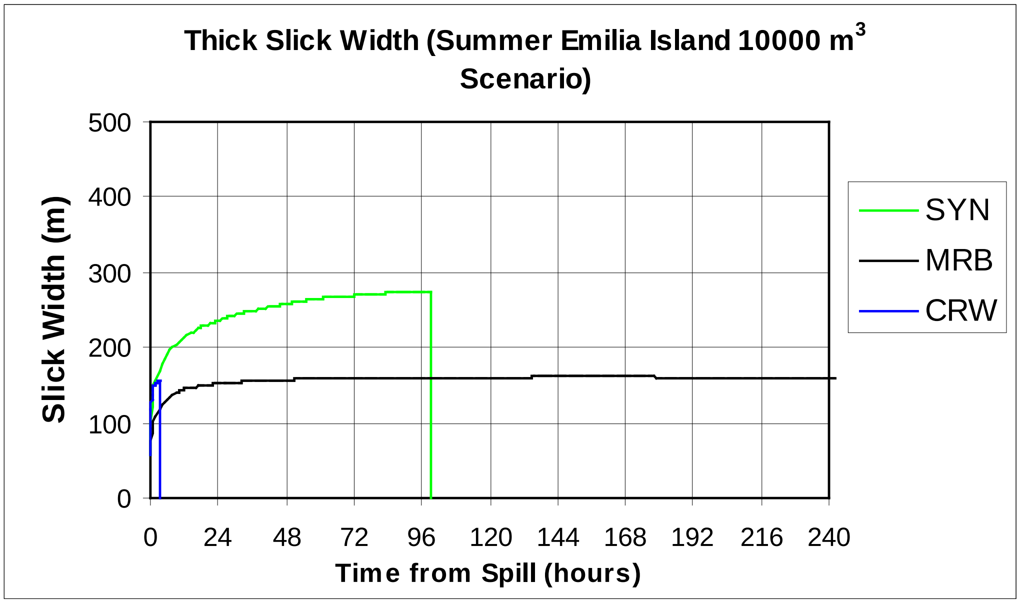


Figure 4-31 Emilia Island Tanker Spill Scenario (Summer) – Thick Slick Width

4.4.2 Hypothetical Fall Spill

Seasonal average environmental input data used for the fall scenarios have been derived from the months of September, October and November. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

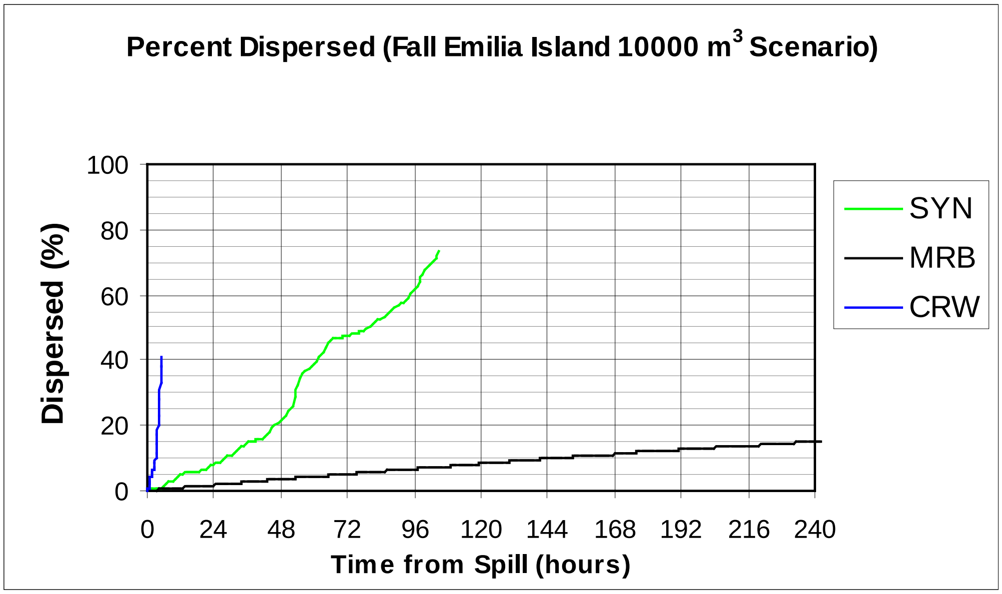


Figure 4-32 Emilia Island Tanker Spill Scenario (Fall) – Percent Dispersed

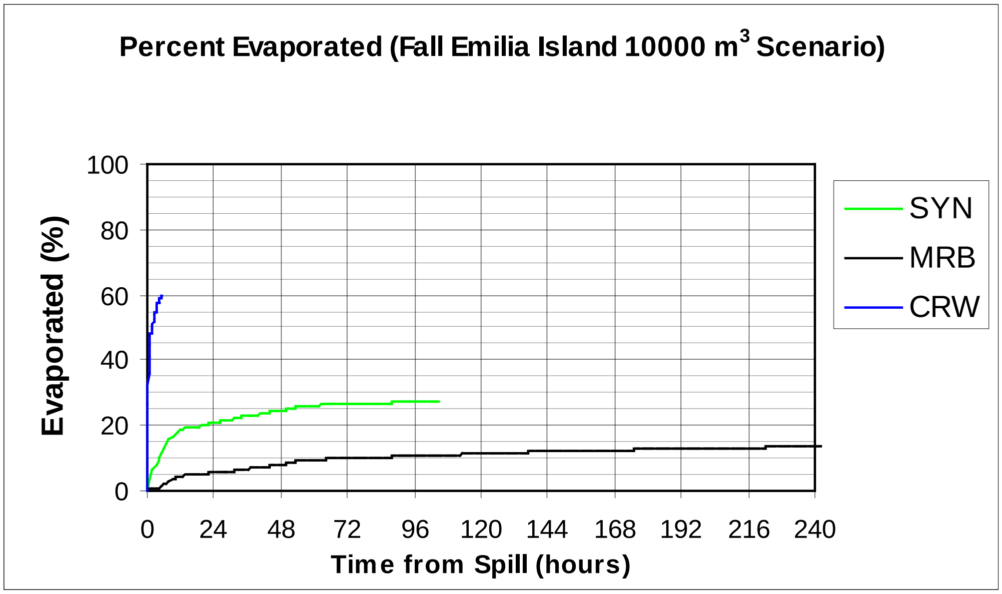


Figure 4-33 Emilia Island Tanker Spill Scenario (Fall) – Percent Evaporated

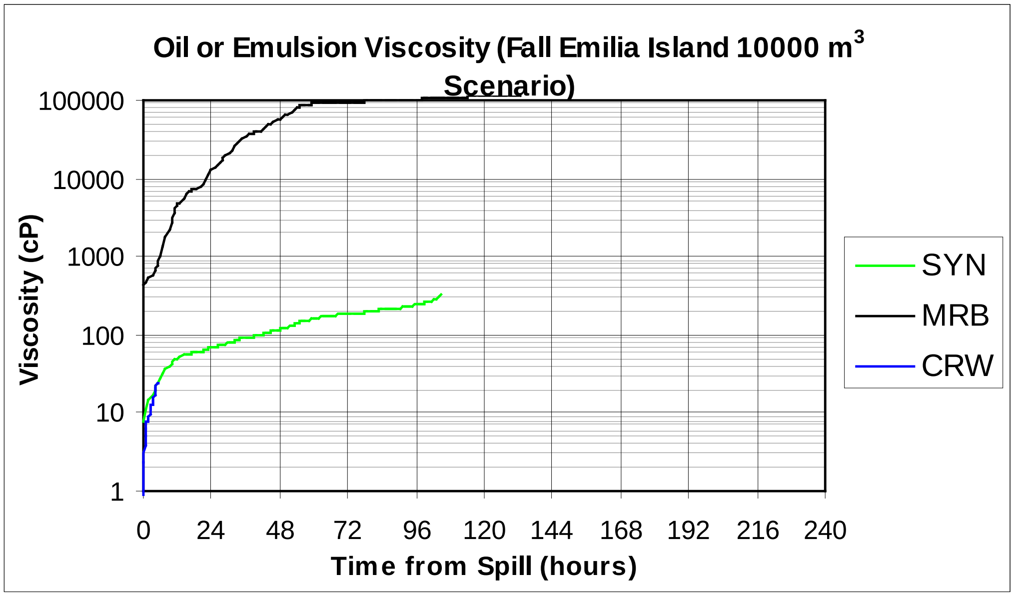


Figure 4-34 Emilia Island Tanker Spill Scenario (Fall) – Oil or Emulsion Viscosity

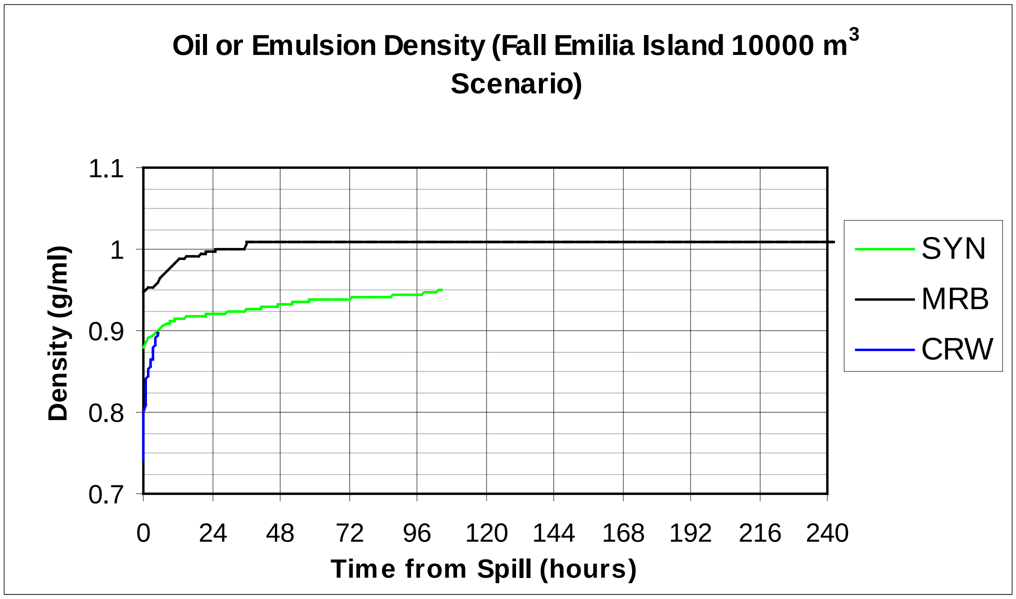


Figure 4-35 Emilia Island Tanker Spill Scenario (Fall) – Oil or Emulsion Density

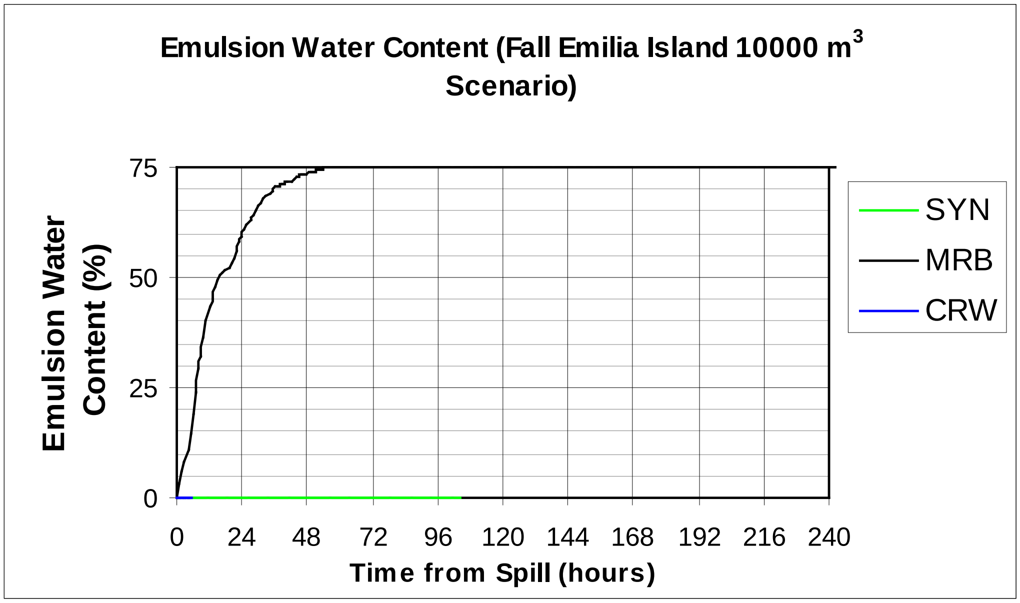


Figure 4-36 Emilia Island Tanker Spill Scenario (Fall) – Emulsion Water Content

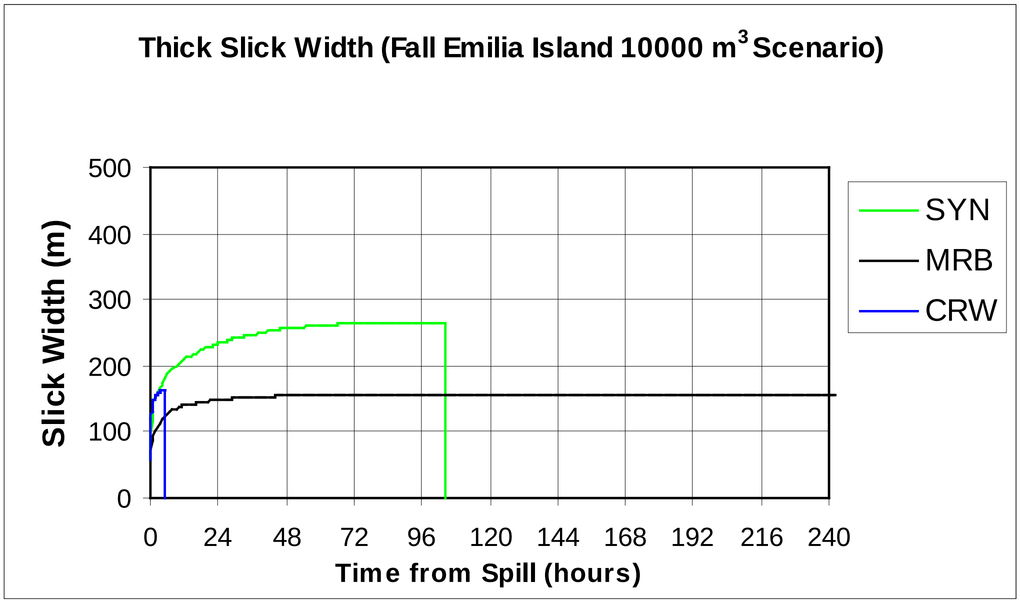


Figure 4-37 Emilia Island Tanker Spill Scenario (Fall) – Thick Slick Width

4.4.3 Hypothetical Winter Spill

Seasonal average environmental input data used for the winter scenarios have been derived from the months of December, January and February. The MRB short form used in these figures is equivalent to MKH- MacKay River Heavy bitumen used elsewhere in the modelling.

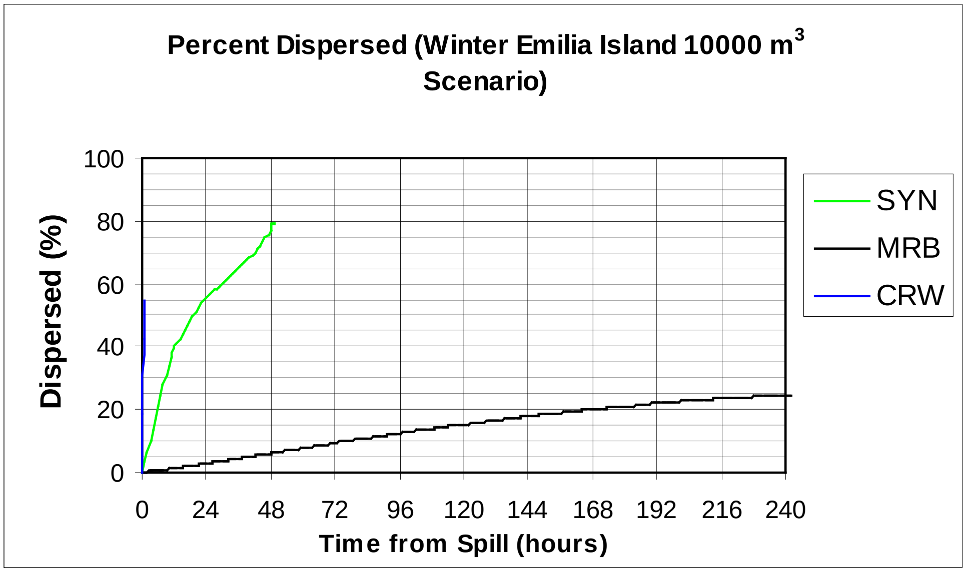


Figure 4-38 Emilia Island Tanker Spill Scenario (Winter) – Percent Dispersed

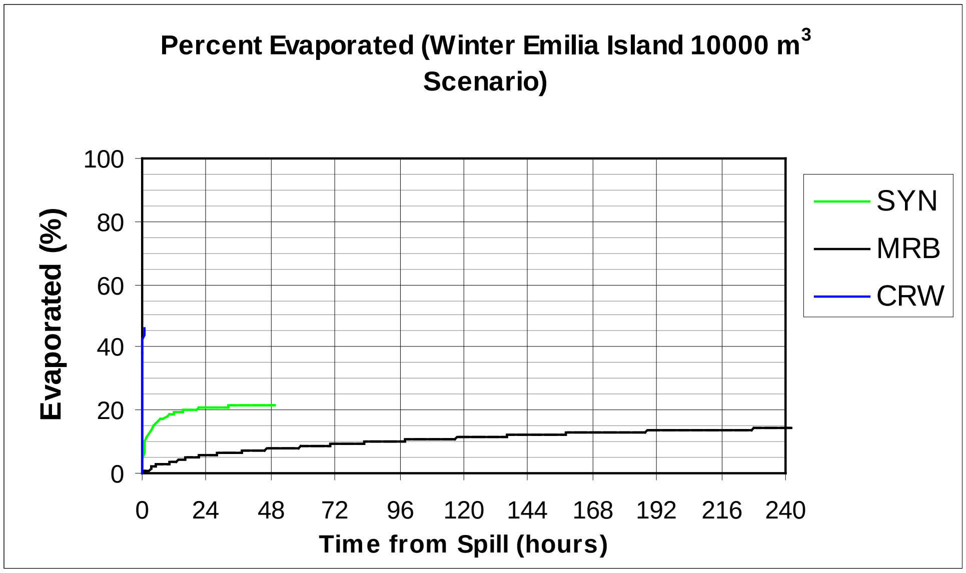


Figure 4-39 Emilia Island Tanker Spill Scenario (Winter) – Percent Evaporated

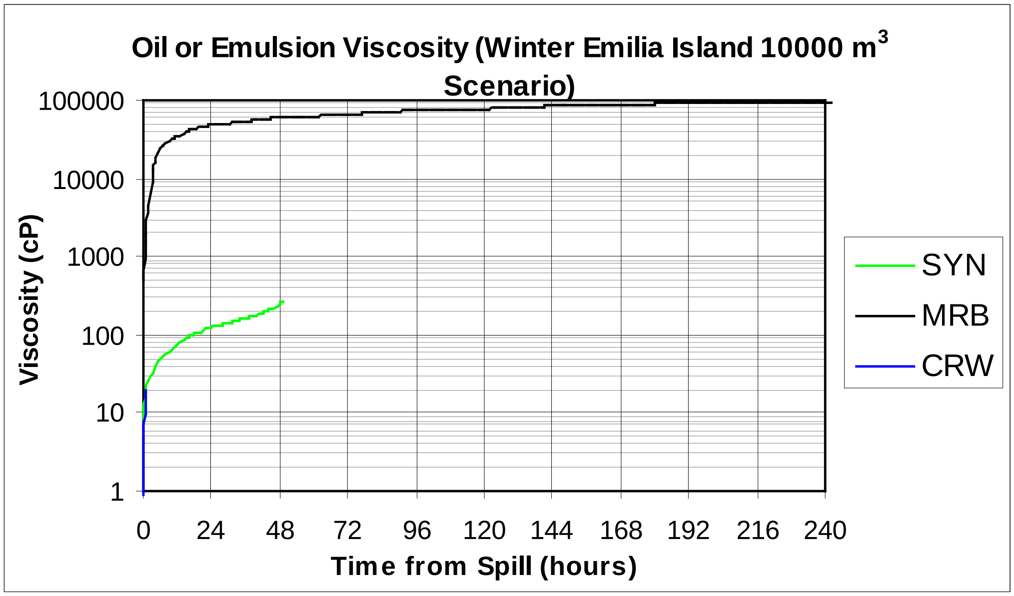


Figure 4-40 **Emilia Island Tanker Spill Scenario (Winter) – Oil or Emulsion Viscosity**

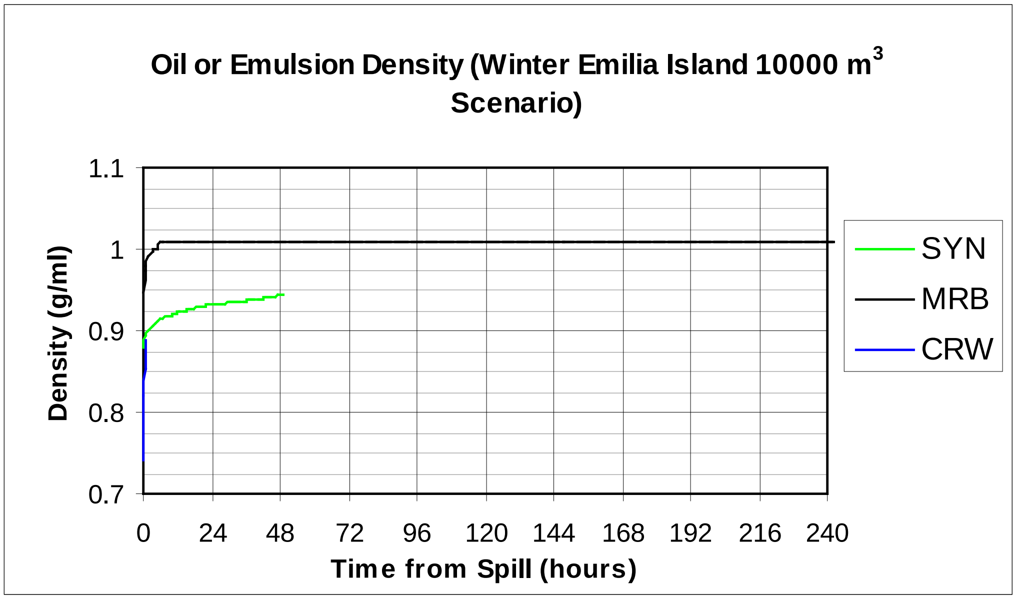


Figure 4-41 **Emilia Island Tanker Spill Scenario (Winter) – Oil or Emulsion Density**

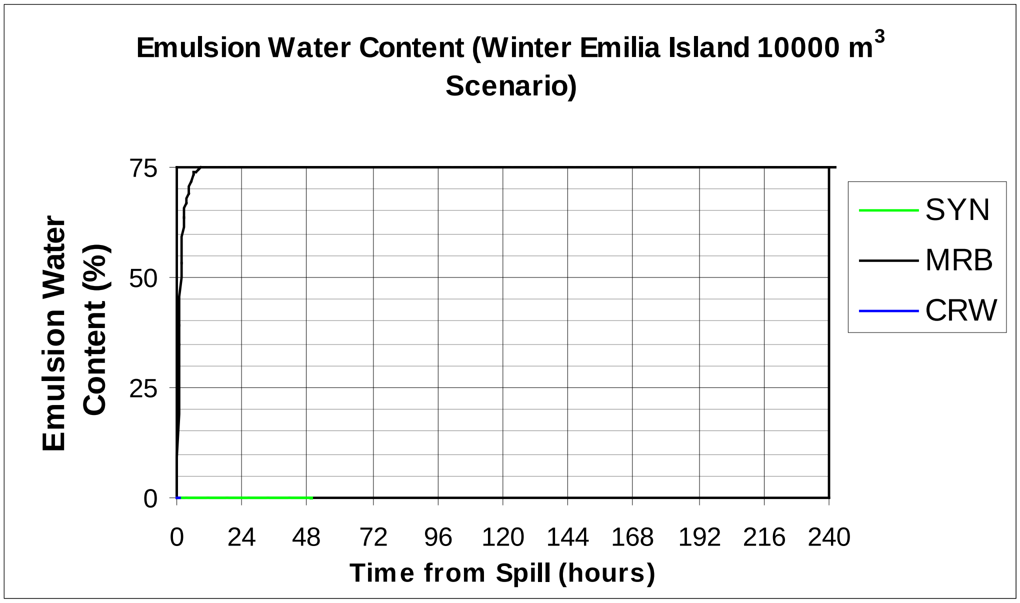


Figure 4-42 **Emilia Island Tanker Spill Scenario (Winter) – Emulsion Water Content**

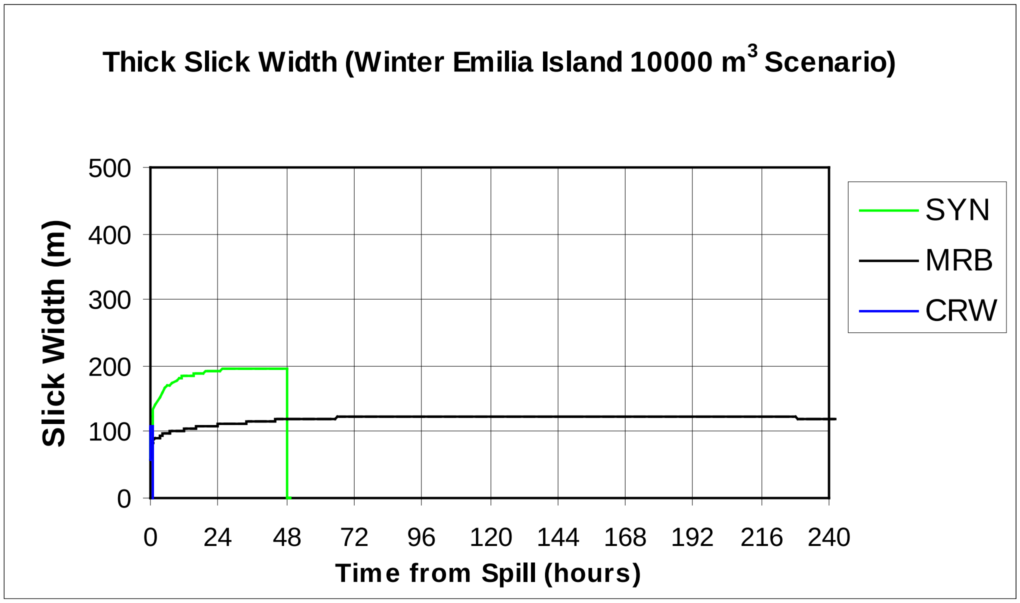


Figure 4-43 **Emilia Island Tanker Spill Scenario (Winter) – Thick Slick Width**

4.4.4 Hypothetical Spring Spill

Seasonal average environmental input data used for the spring scenarios have been derived from the months of March, April and May. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

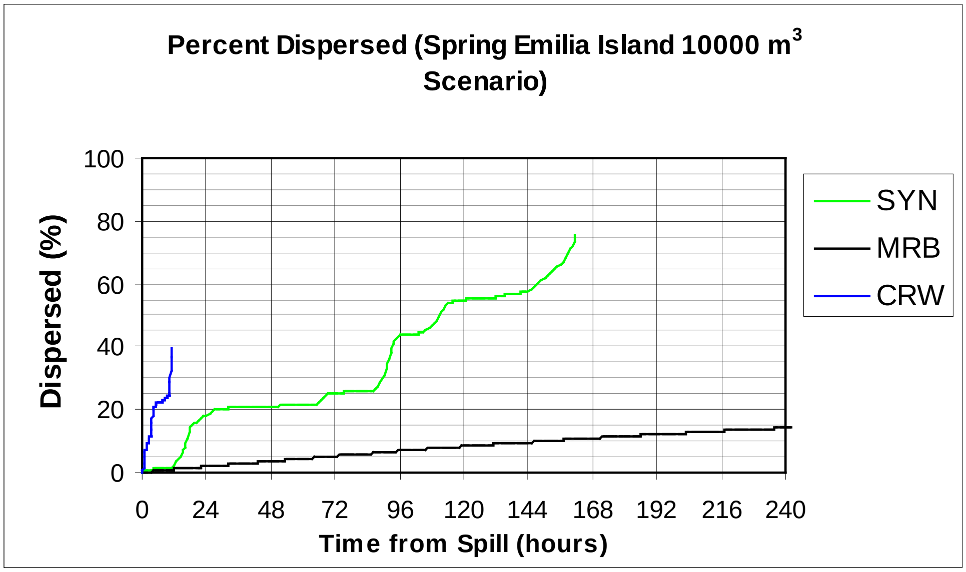


Figure 4-44 Emilia Island Tanker Spill Scenario (Spring) – Percent Dispersed

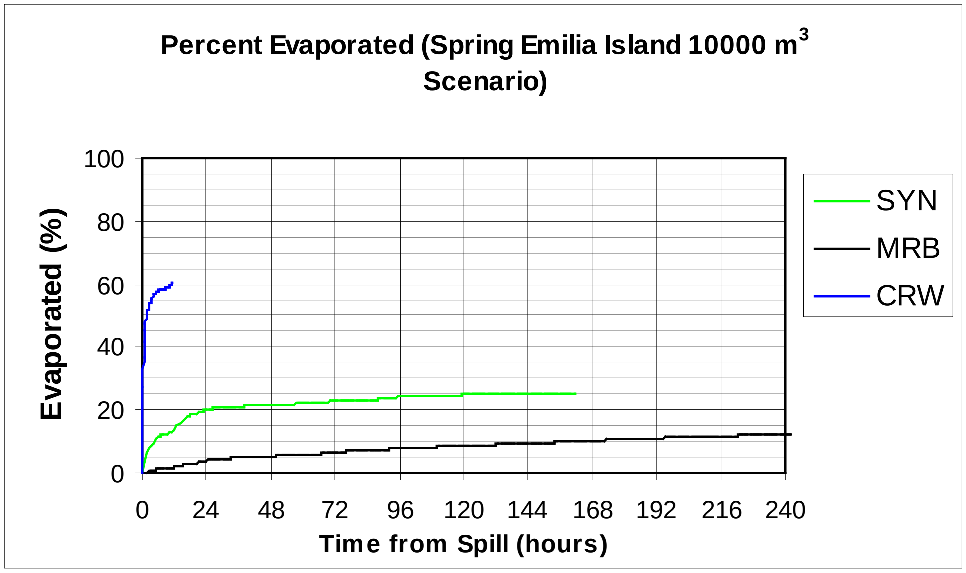


Figure 4-45 Emilia Island Tanker Spill Scenario (Spring) – Percent Evaporated

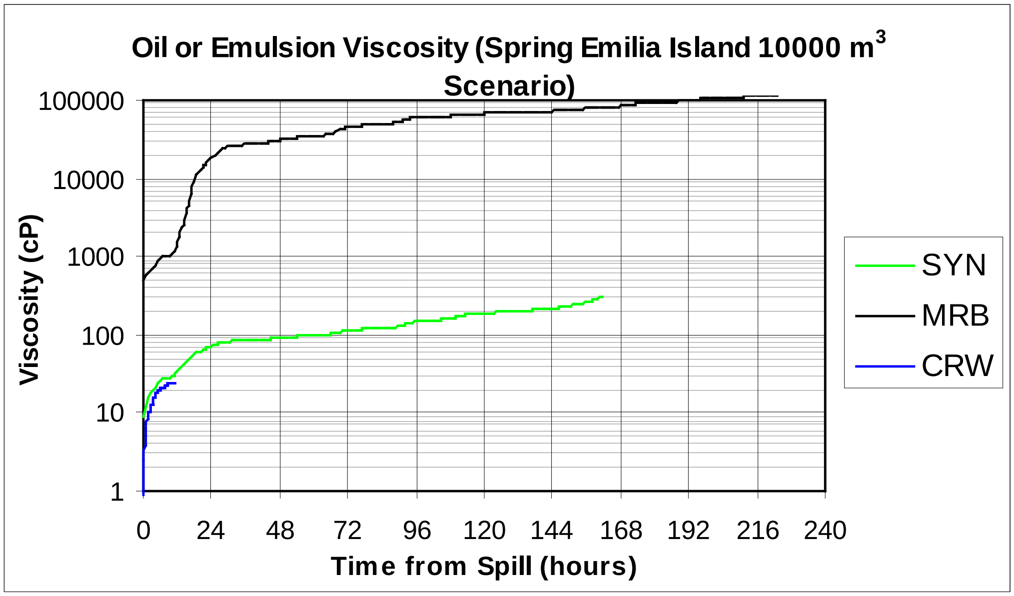


Figure 4-46 **Emilia Island Tanker Spill Scenario (Spring) – Oil or Emulsion Viscosity**

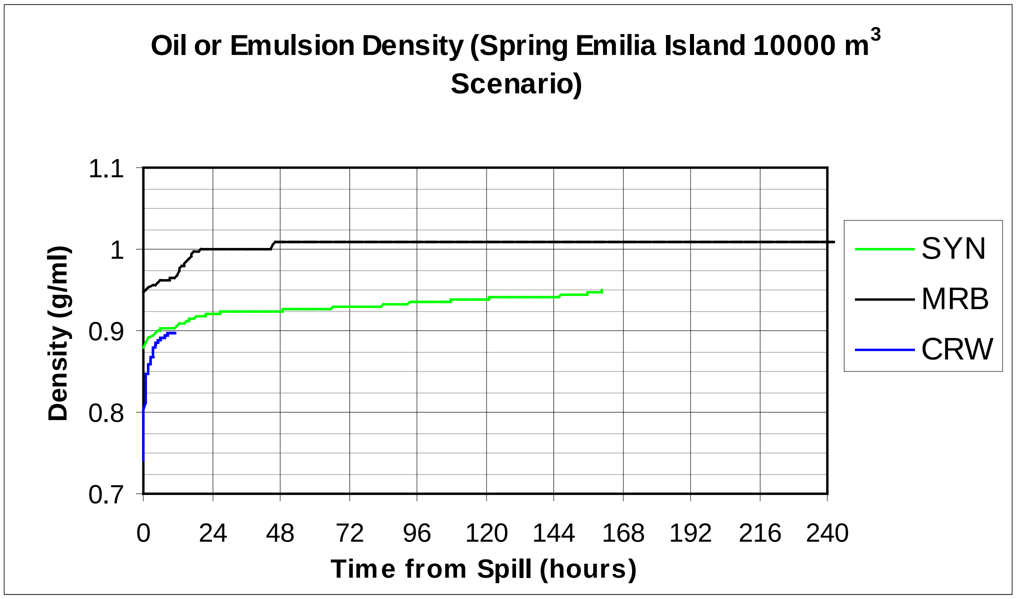


Figure 4-47 **Emilia Island Tanker Spill Scenario (Spring) – Oil or Emulsion Density**

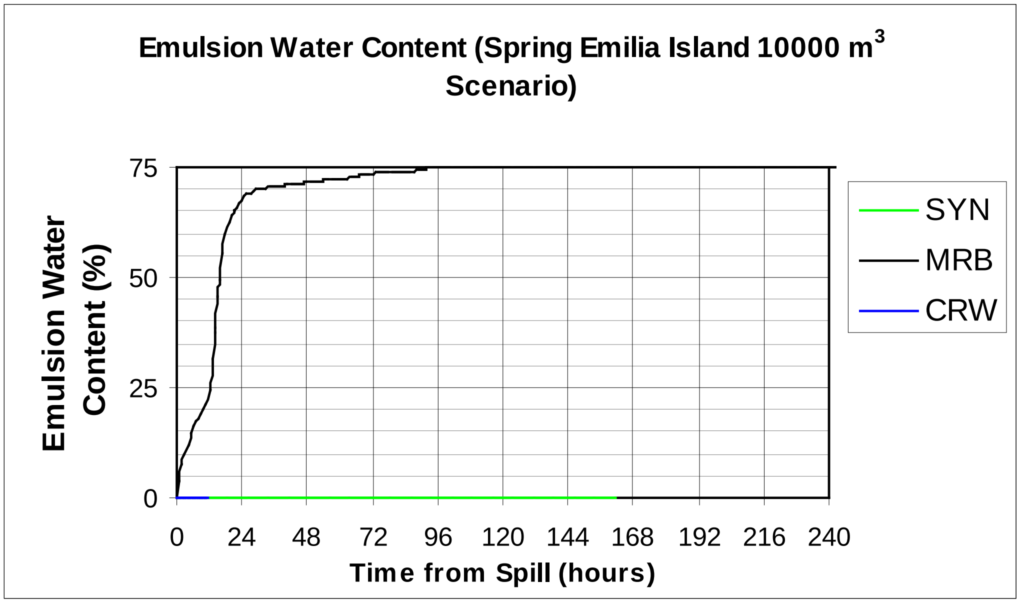


Figure 4-48 Emilia Island Tanker Spill Scenario (Spring) – Emulsion Water Content

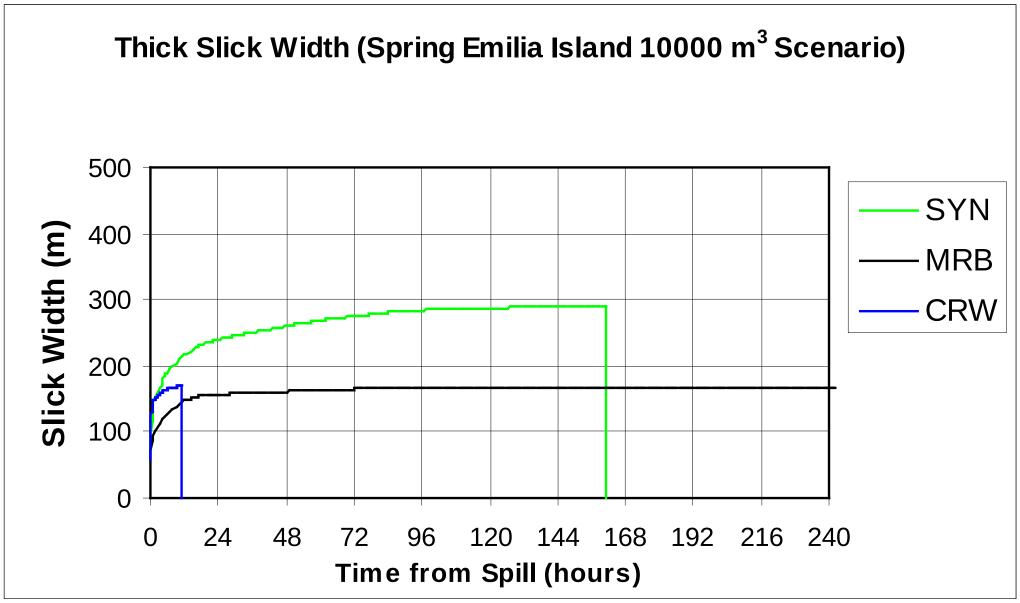


Figure 4-49 Emilia Island Tanker Spill Scenario (Spring) – Thick Slick Width

4.5 Principe Channel Hypothetical Tanker Spill, Oil Fate Results

The figures in Section 4.5 show detailed oil behaviour and properties for the Principe Channel hypothetical tanker spill for each season, as follows:

- summer – Figures 4-50 to 4-55
- fall – Figures 4-56 to 4-61
- winter – Figures 4-62 to 4-67
- spring – Figures 4-68 to 4-73

4.5.1 Hypothetical Summer Spill

Seasonal average environmental input data used for the summer scenarios have been derived from the months of June, July and August. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

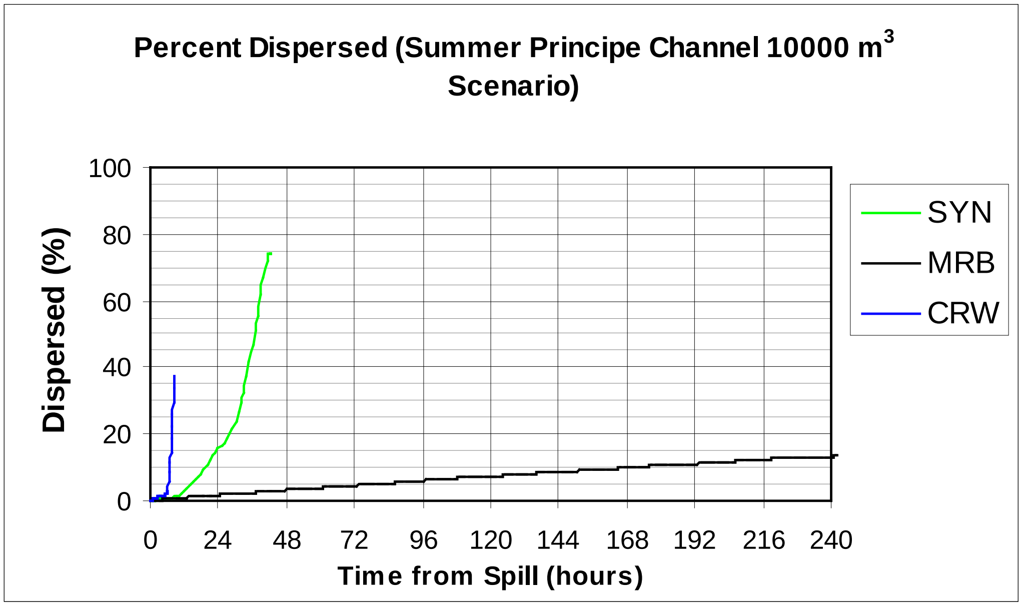


Figure 4-50 **Principe Channel Tanker Spill Scenario (Summer) – Percent Dispersed**

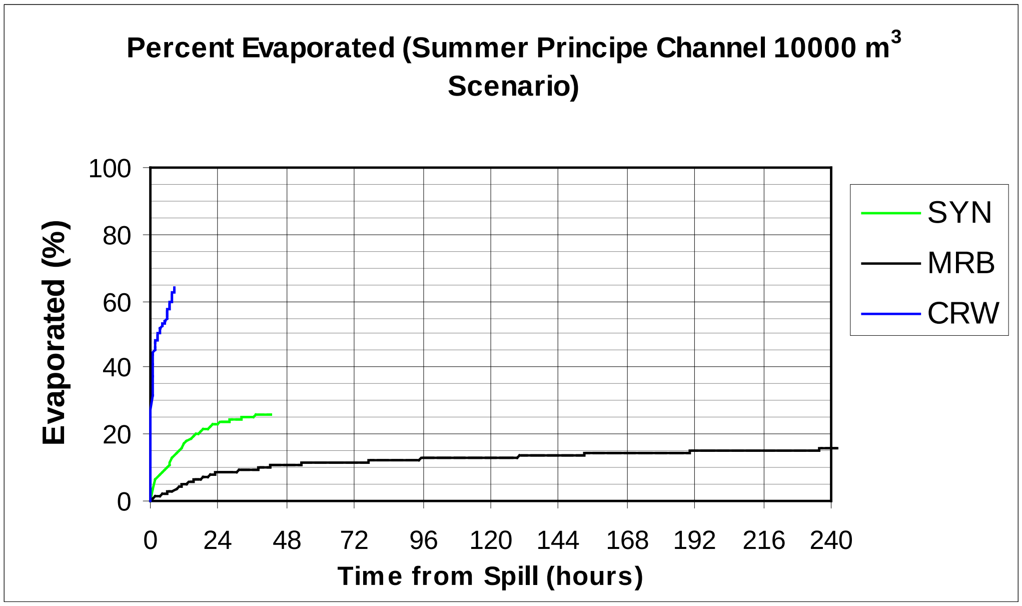


Figure 4-51 Principe Channel Tanker Spill Scenario (Summer) – Percent Evaporated

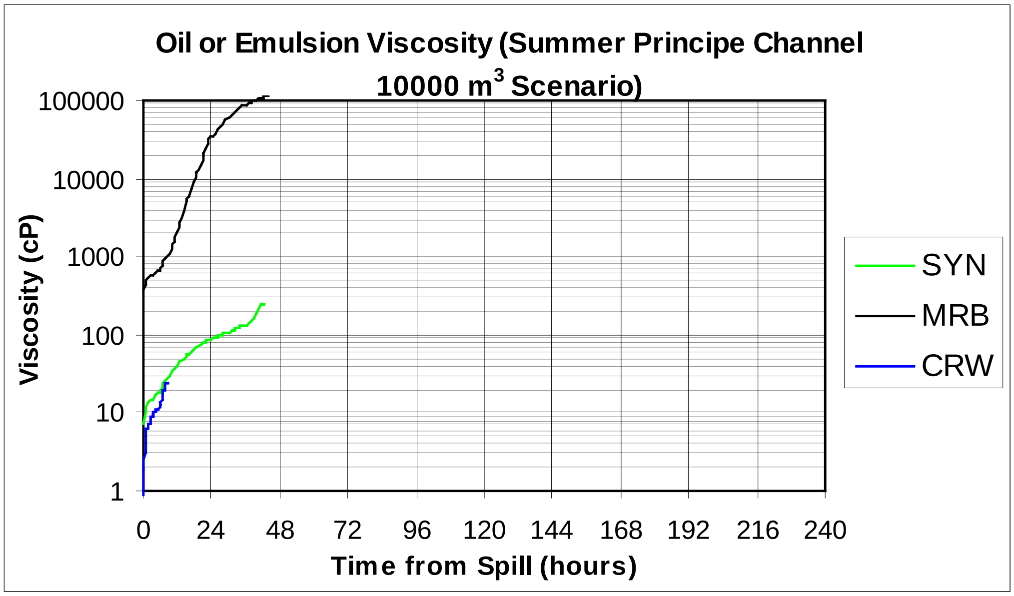


Figure 4-52 Principe Channel Tanker Spill Scenario (Summer) – Oil or Emulsion Viscosity

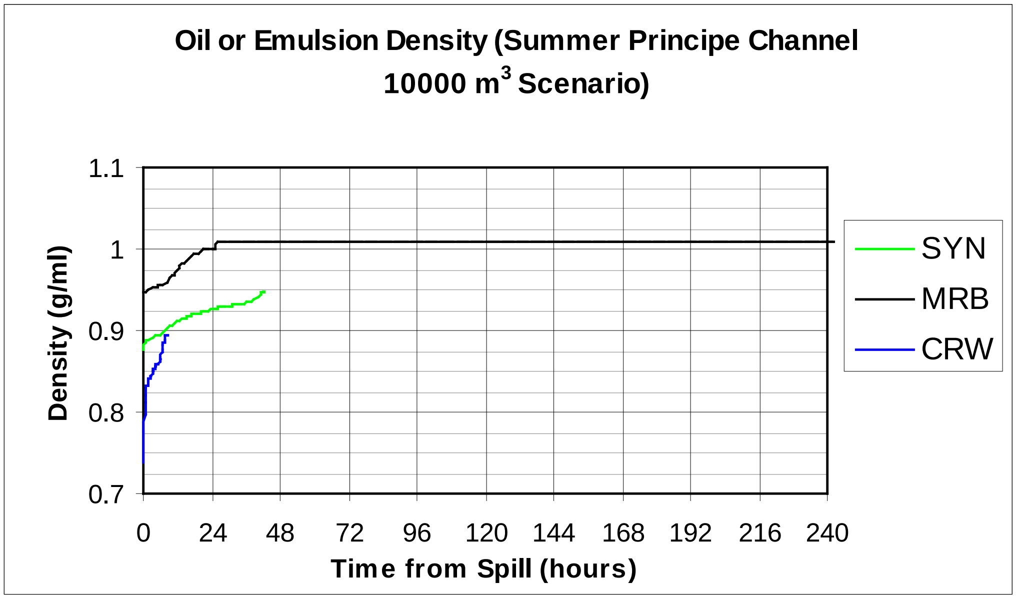


Figure 4-53 Principe Channel Tanker Spill Scenario (Summer) – Oil or Emulsion Density

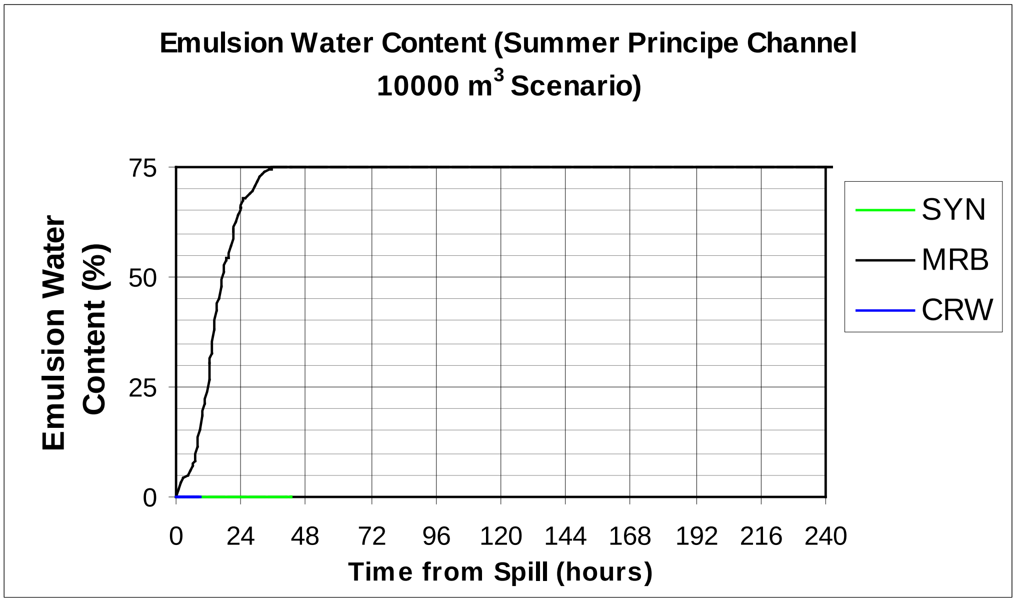


Figure 4-54 Principe Channel Tanker Spill Scenario (Summer) – Emulsion Water Content

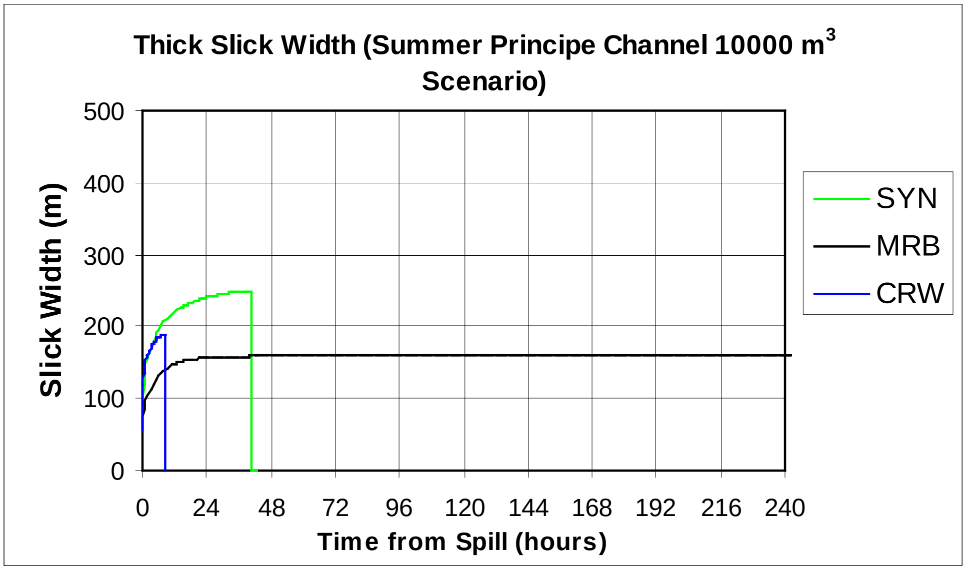


Figure 4-55 Principe Channel Tanker Spill Scenario (Summer) – Thick Slick Width

4.5.2 Hypothetical Fall Spill

Seasonal average environmental input data used for the fall scenarios have been derived from the months of September, October and November. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

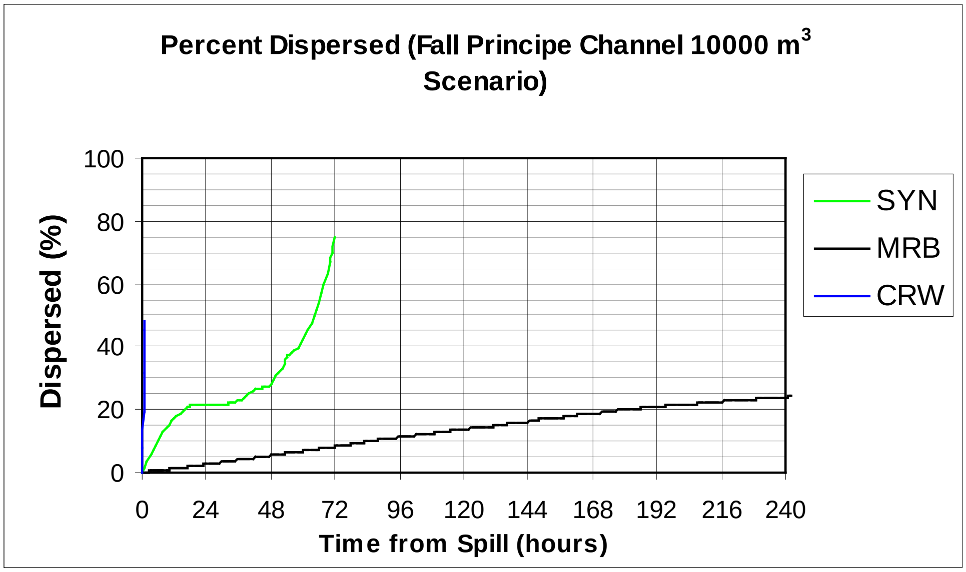


Figure 4-56 Principe Channel Tanker Spill Scenario (Fall) – Percent Dispersed

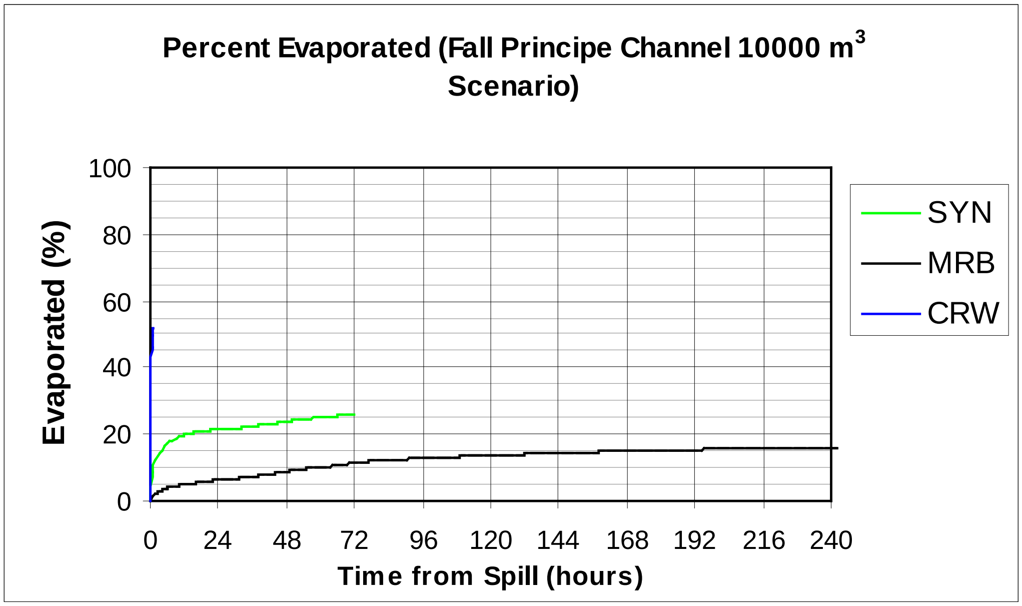


Figure 4-57 Principe Channel Tanker Spill Scenario (Fall) – Percent Evaporated

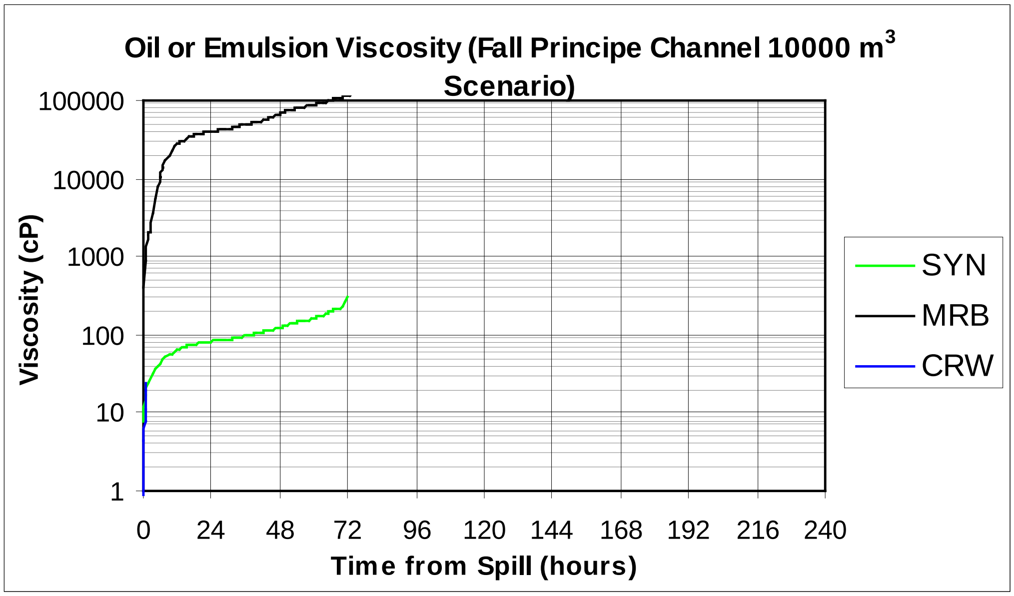


Figure 4-58 Principe Channel Tanker Spill Scenario (Fall) – Oil or Emulsion Viscosity

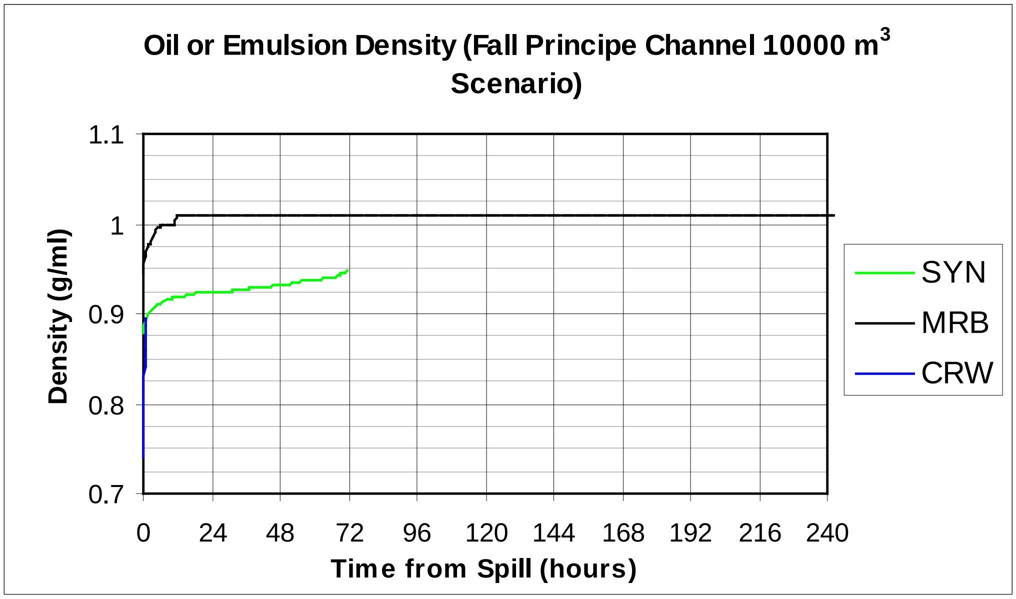


Figure 4-59 Principe Channel Tanker Spill Scenario (Fall) – Oil or Emulsion Density

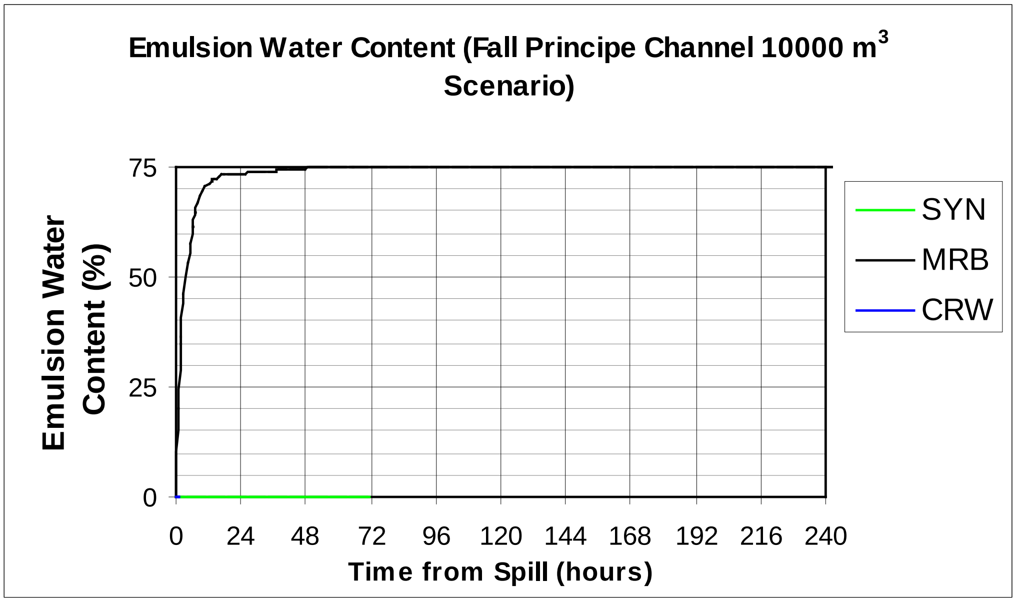


Figure 4-60 Principe Channel Tanker Spill Scenario (Fall) – Emulsion Water Content

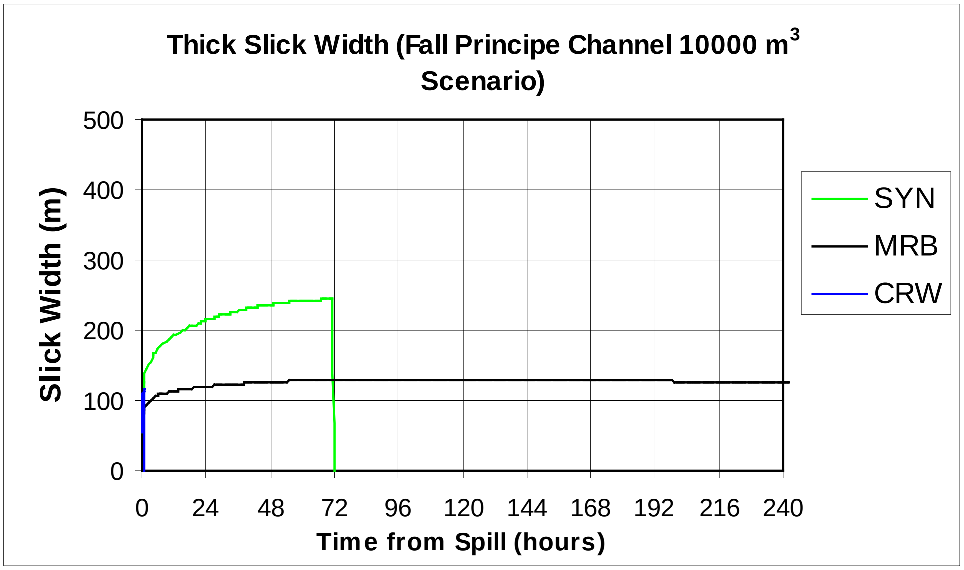


Figure 4-61 Principe Channel Tanker Spill Scenario (Fall) – Thick Slick Width

4.5.3 Hypothetical Winter Spill

Seasonal average environmental input data used for the winter scenarios have been derived from the months of December, January and February. The MRB short form used in these figures is equivalent to MKH- MacKay River Heavy bitumen used elsewhere in the modelling.

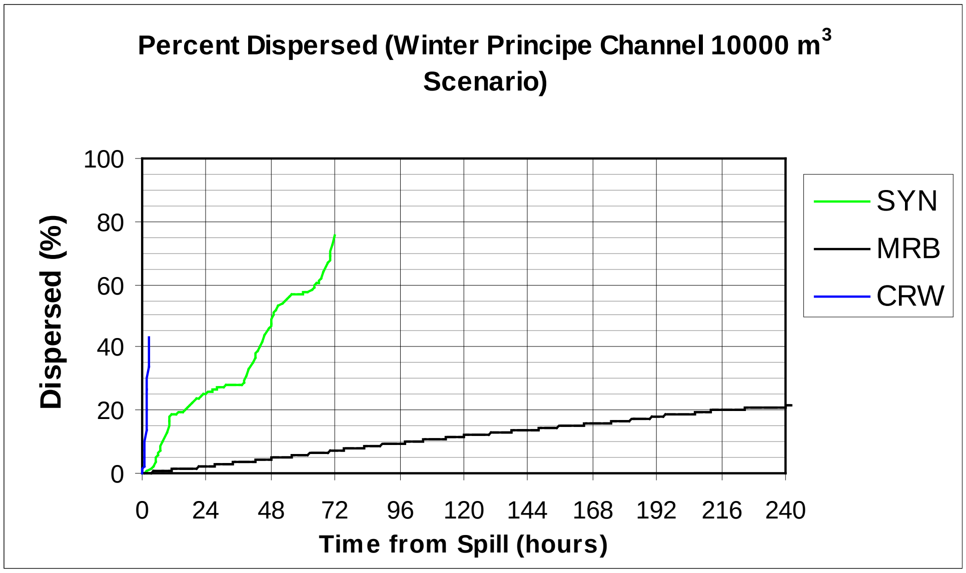


Figure 4-62 Principe Channel Tanker Spill Scenario (Winter) – Percent Dispersed

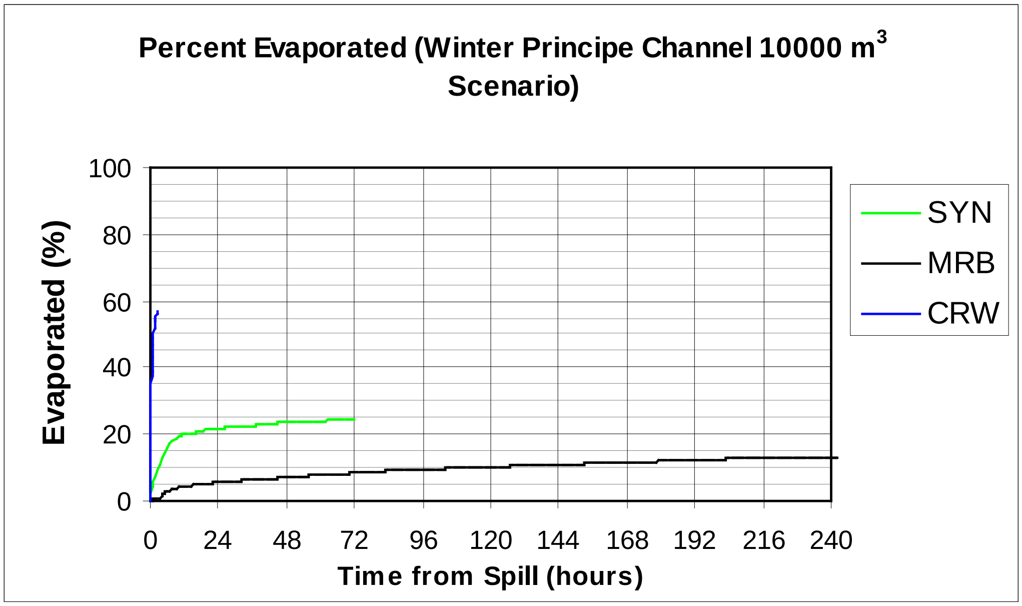


Figure 4-63 Principe Channel Tanker Spill Scenario (Winter) – Percent Evaporated

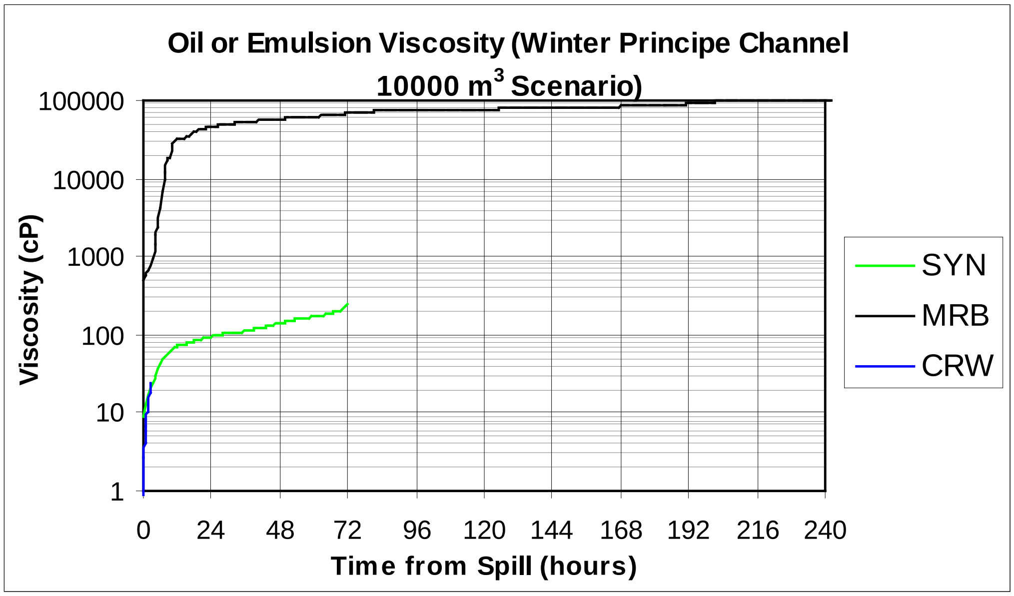


Figure 4-64 Principe Channel Tanker Spill Scenario (Winter) – Oil or Emulsion Viscosity

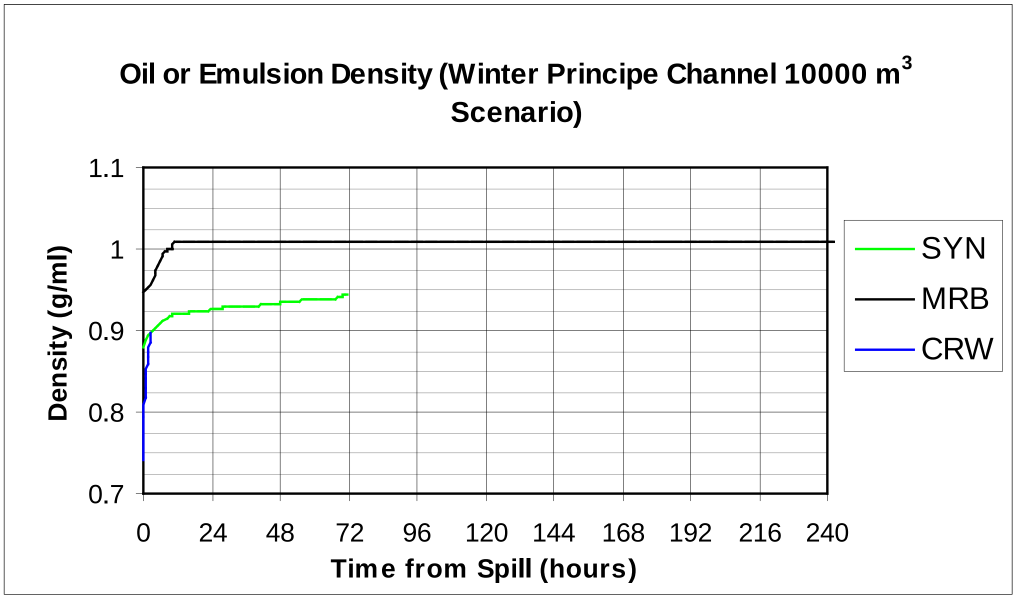


Figure 4-65 **Principe Channel Tanker Spill Scenario (Winter) – Oil or Emulsion Density**

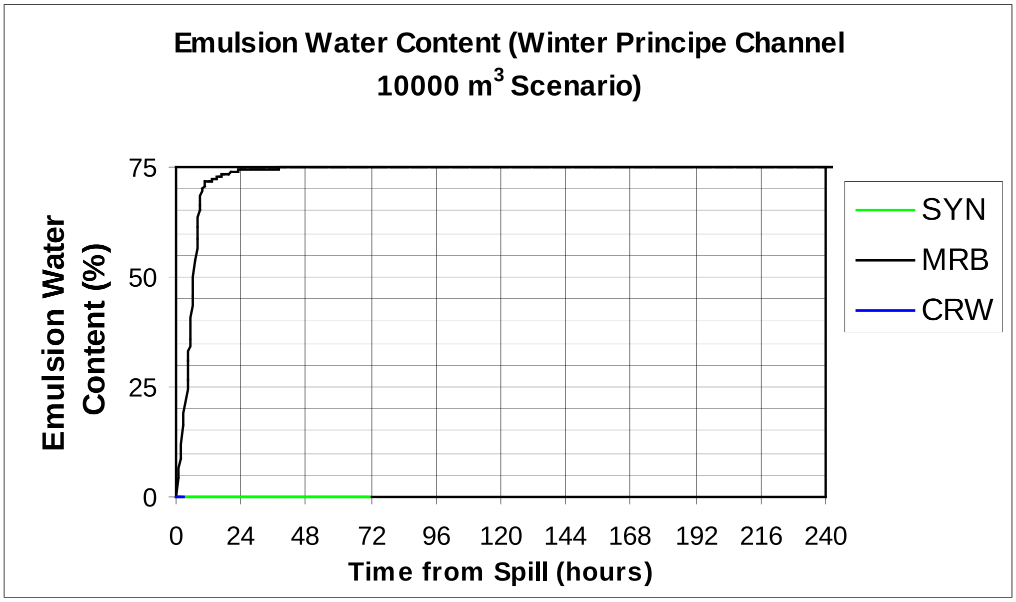


Figure 4-66 **Principe Channel Tanker Spill Scenario (Winter) – Emulsion Water Content**

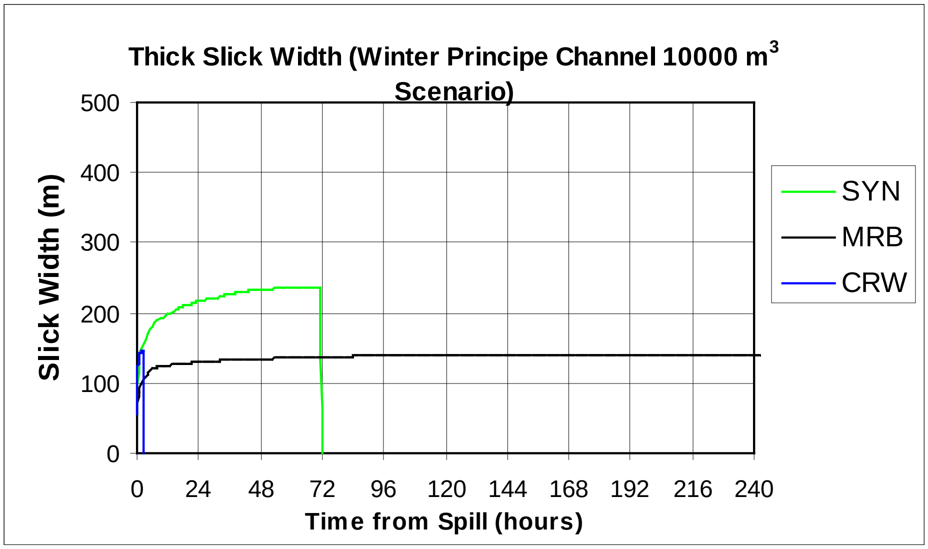


Figure 4-67 Principe Channel Tanker Spill Scenario (Winter) – Thick Slick Width

4.5.4 Hypothetical Spring Spill

Seasonal average environmental input data used for the spring scenarios have been derived from the months of March, April and May. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

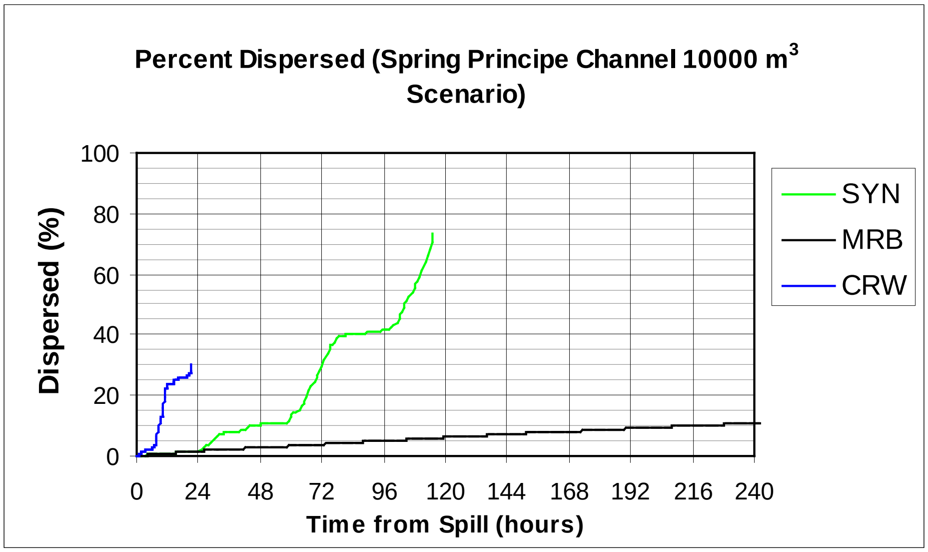


Figure 4-68 Principe Channel Tanker Spill Scenario (Spring) – Percent Dispersed

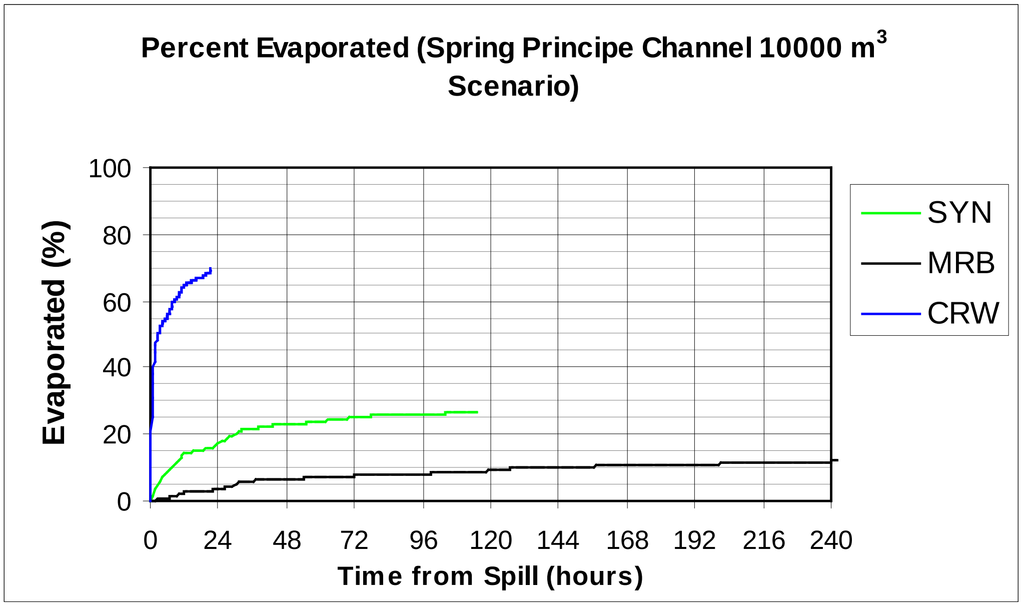


Figure 4-69 Principe Channel Tanker Spill Scenario (Spring) – Percent Evaporated

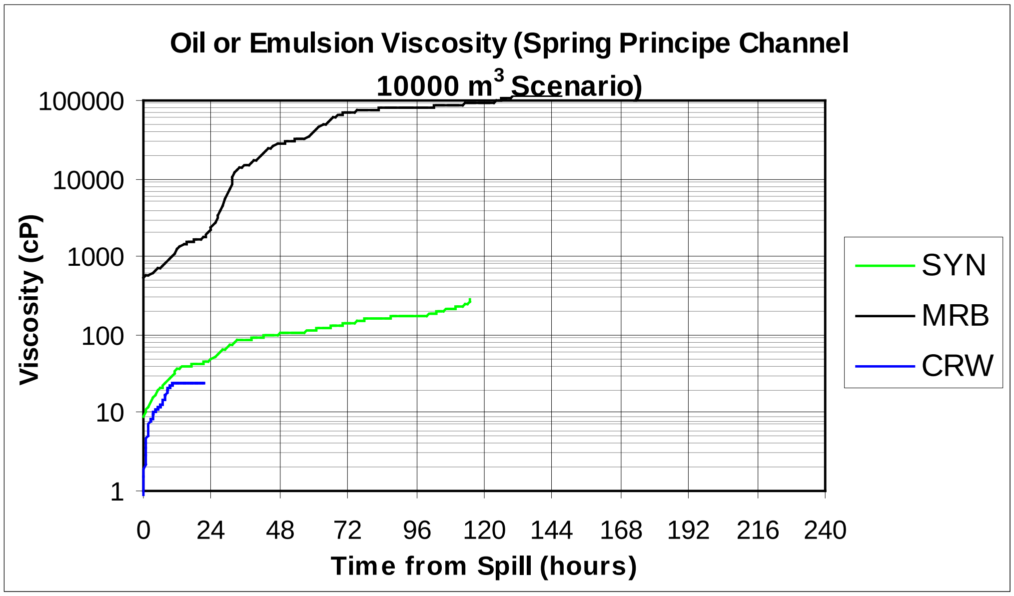


Figure 4-70 Principe Channel Tanker Spill Scenario (Spring) – Oil or Emulsion Viscosity

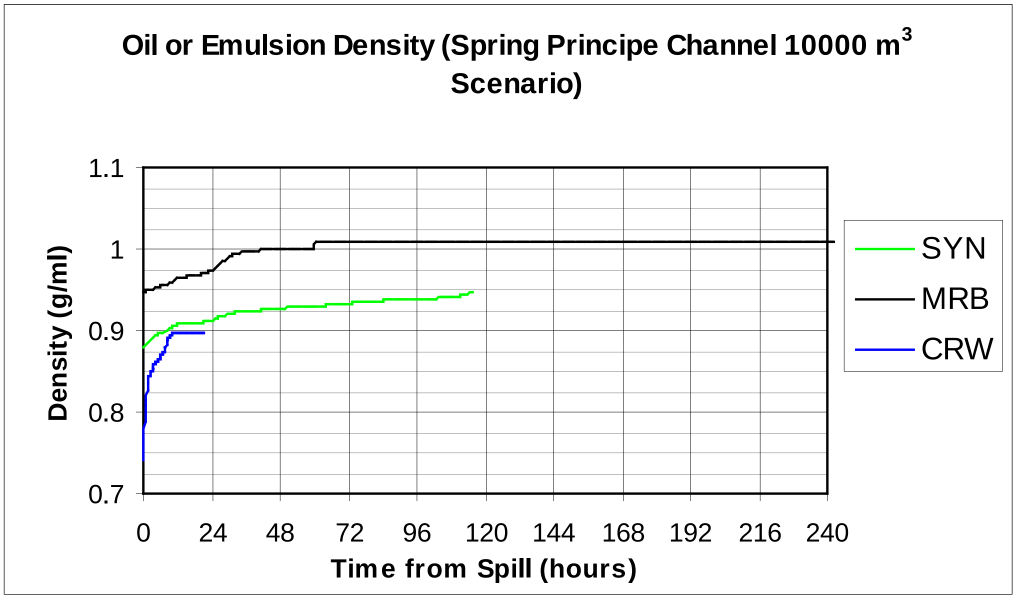


Figure 4-71 **Principe Channel Tanker Spill Scenario (Spring) – Oil or Emulsion Density**

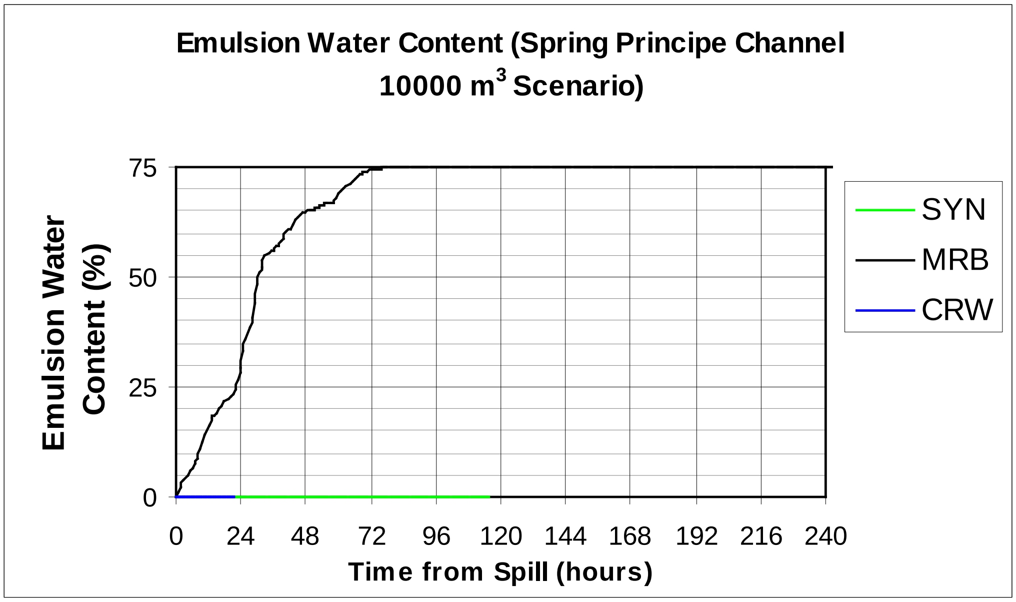


Figure 4-72 **Principe Channel Tanker Spill Scenario (Spring) – Emulsion Water Content**

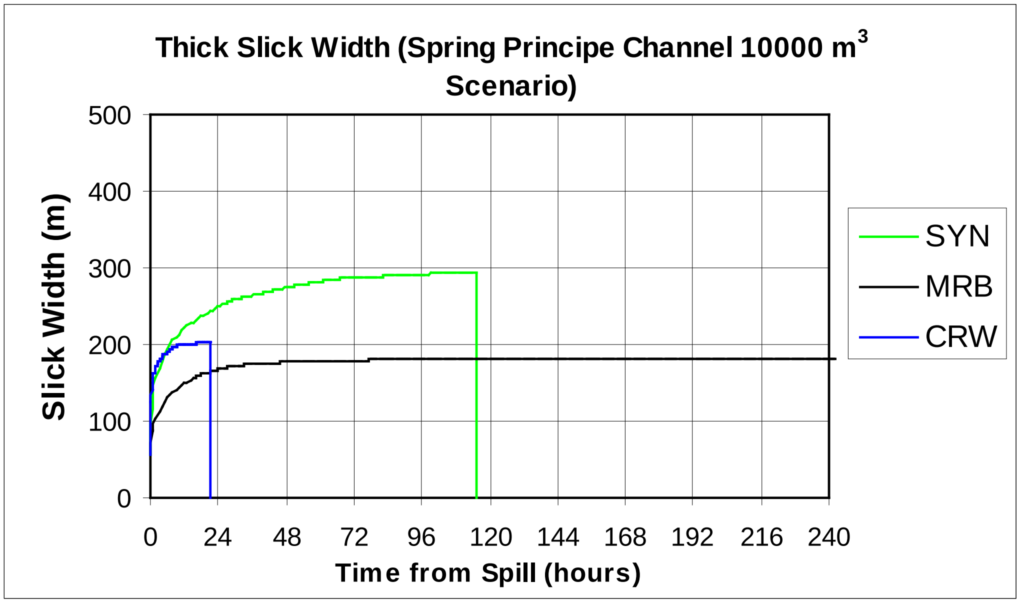


Figure 4-73 **Principe Channel Tanker Spill Scenario (Spring) – Thick Slick Width**

4.6 Wright Sound Hypothetical Tanker Spill, Oil Fate Results

The figures in Section 4.6 show detailed oil behaviour and properties for the Wright Sound hypothetical tanker spill for each season, as follows:

- summer – Figures 4-74 to 4-79
- fall – Figures 4-80 to 4-85
- winter – Figures 4-86 to 4-91
- spring – Figures 4-92 to 4-97

A spill size of 10,000 m^3 was initially selected for tanker spills. Although mass balance results presented in TERMPOL Section 3.15 are based on a 36,000 m^3 spill scenario, the results shown there incorporate information from the results below for the purpose of spill response planning.

4.6.1 Hypothetical Summer Spill

Seasonal average environmental input data used for the summer scenarios have been derived from the months of June, July and August. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

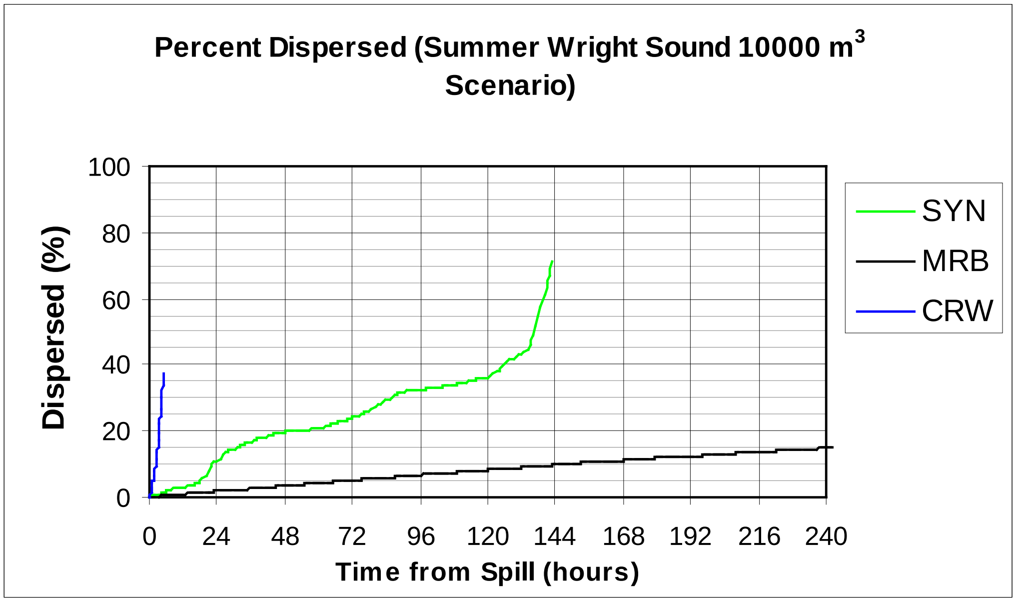


Figure 4-74 Wright Sound Tanker Spill Scenario (Summer) – Percent Dispersed

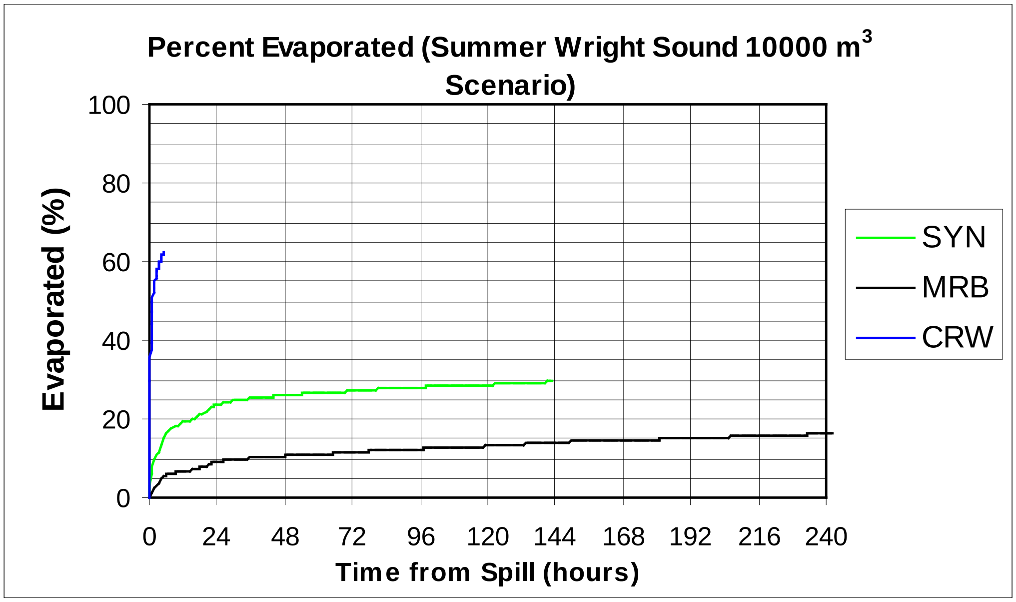


Figure 4-75 Wright Sound Tanker Spill Scenario (Summer) – Percent Evaporated

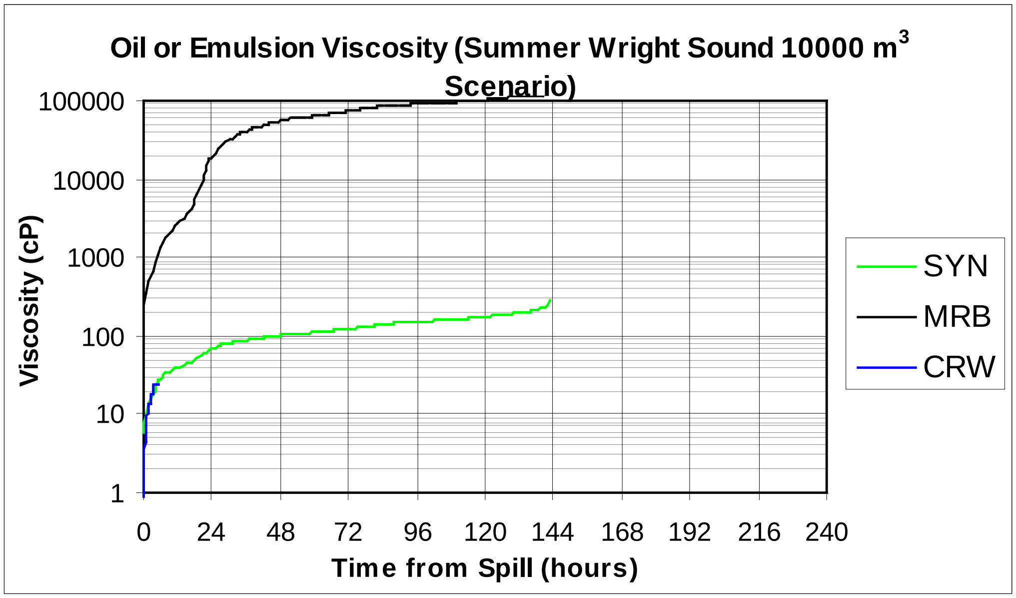


Figure 4-76 Wright Sound Tanker Spill Scenario (Summer) – Oil or Emulsion Viscosity

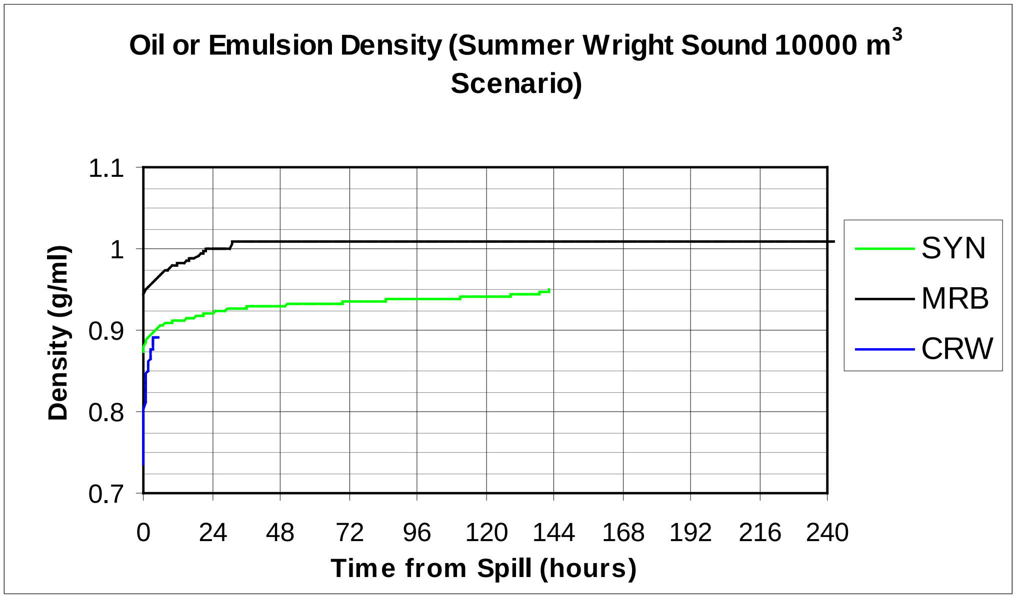


Figure 4-77 Wright Sound Tanker Spill Scenario (Summer) – Oil or Emulsion Density

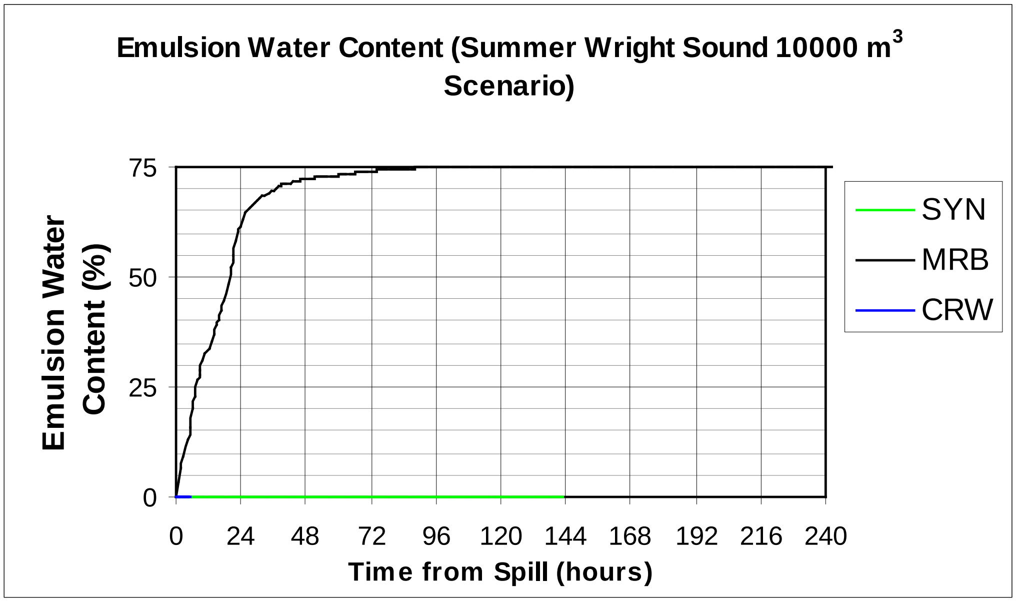


Figure 4-78 Wright Sound Tanker Spill Scenario (Summer) – Emulsion Water Content

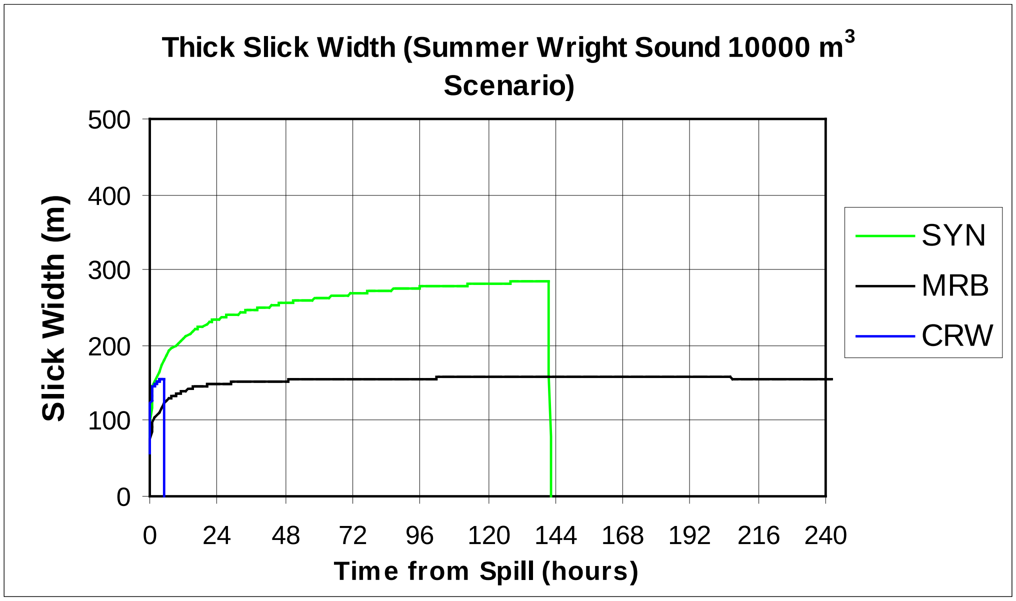


Figure 4-79 Wright Sound Tanker Spill Scenario (Summer) – Thick Slick Width

4.6.2 Hypothetical Fall Spill

Seasonal average environmental input data used for the fall scenarios have been derived from the months of September, October and November. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

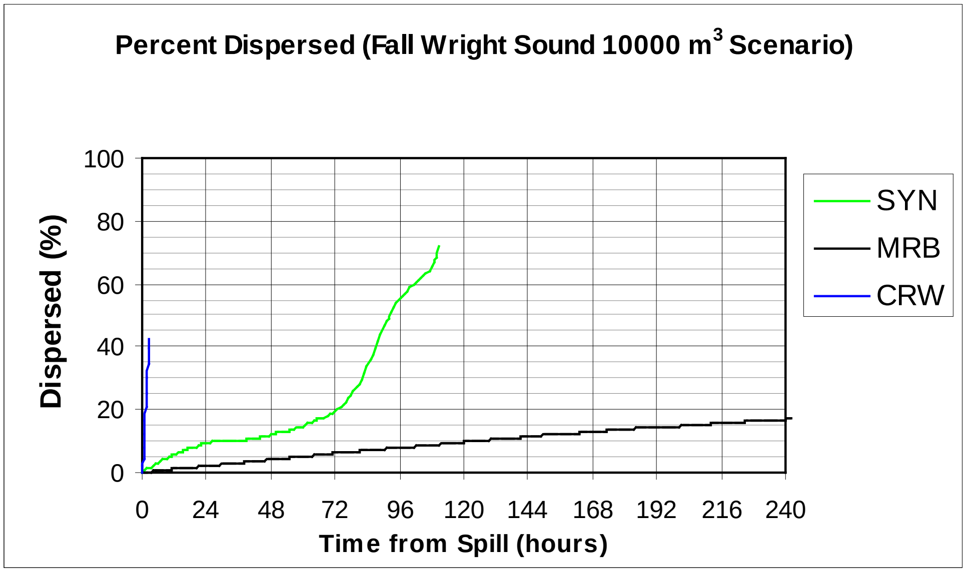


Figure 4-80 Wright Sound Tanker Spill Scenario (Fall) – Percent Dispersed

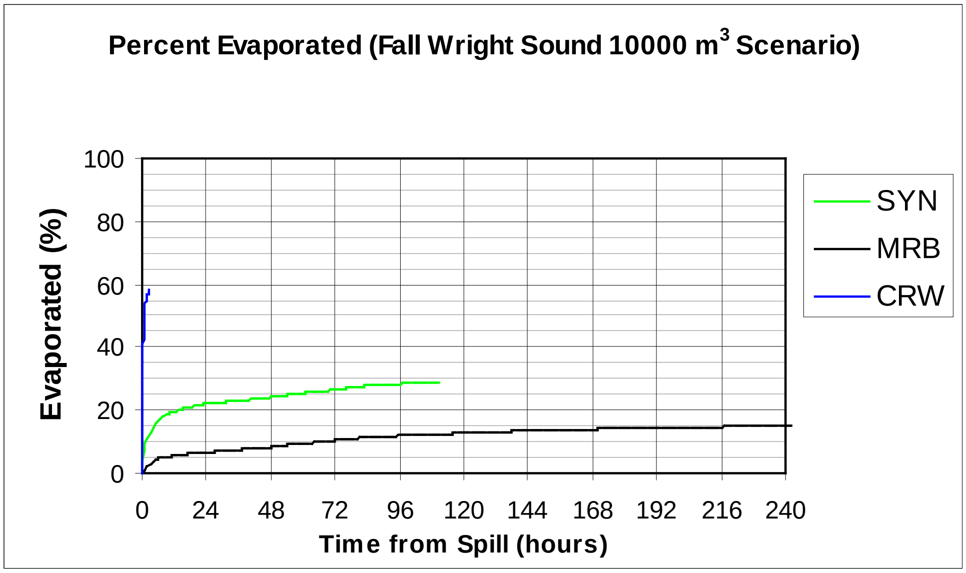


Figure 4-81 Wright Sound Tanker Spill Scenario (Fall) – Percent Evaporated

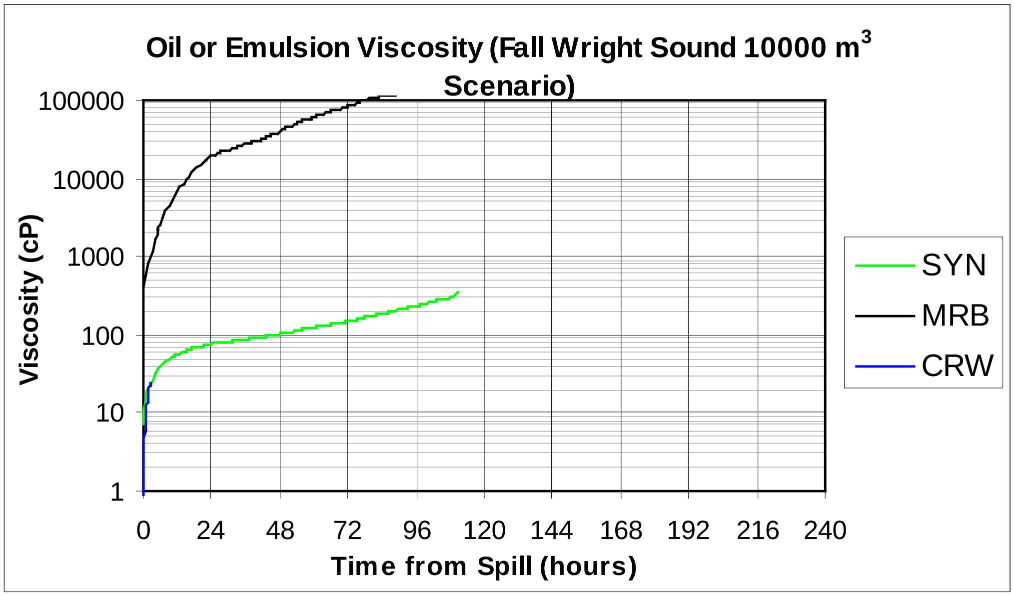


Figure 4-82 Wright Sound Tanker Spill Scenario (Fall) – Oil or Emulsion Viscosity

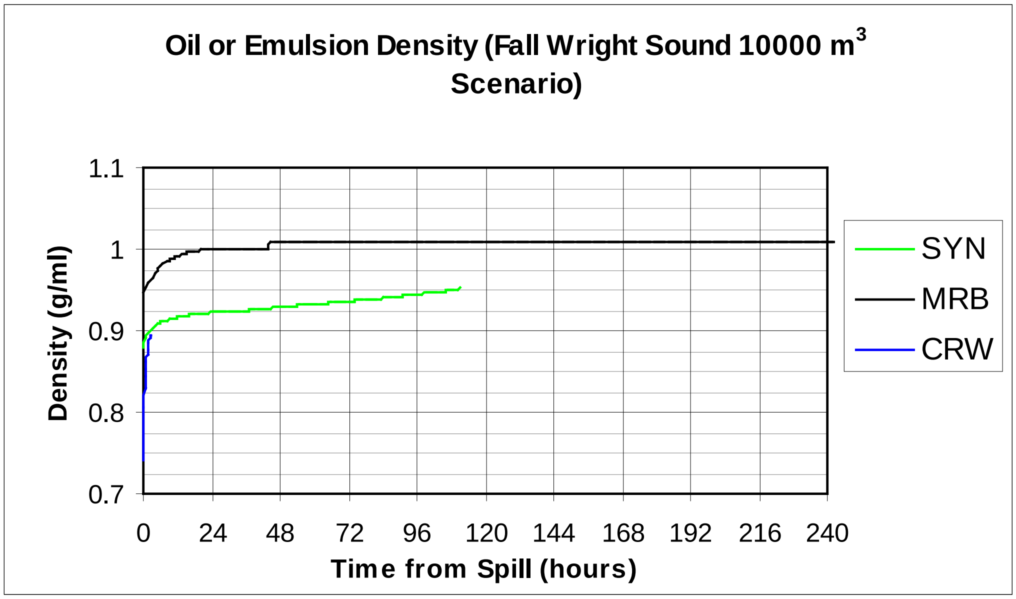


Figure 4-83 Wright Sound Tanker Spill Scenario (Fall) – Oil or Emulsion Viscosity

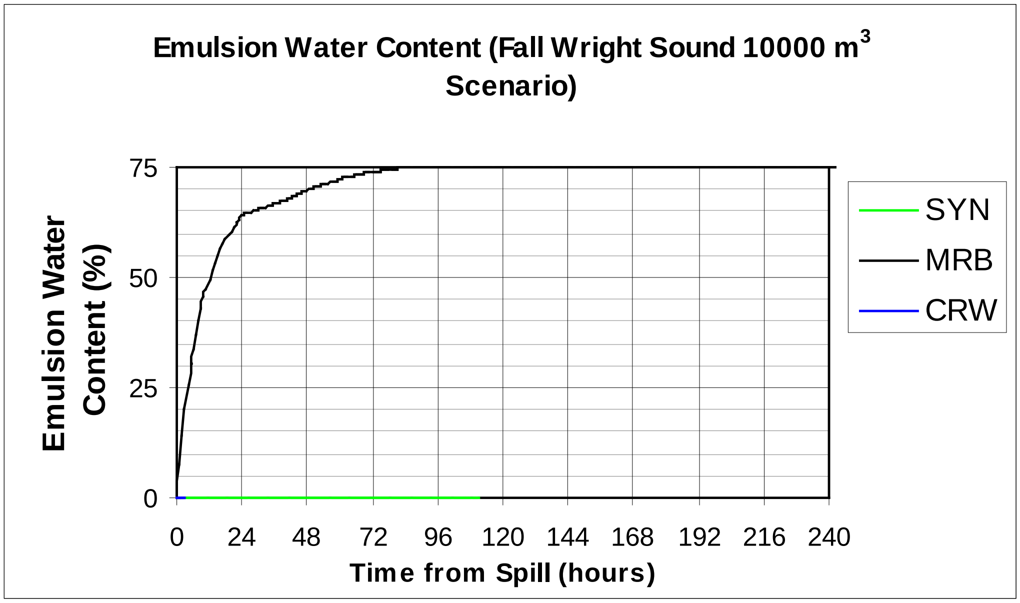


Figure 4-84 Wright Sound Tanker Spill Scenario (Fall) – Emulsion Water Content

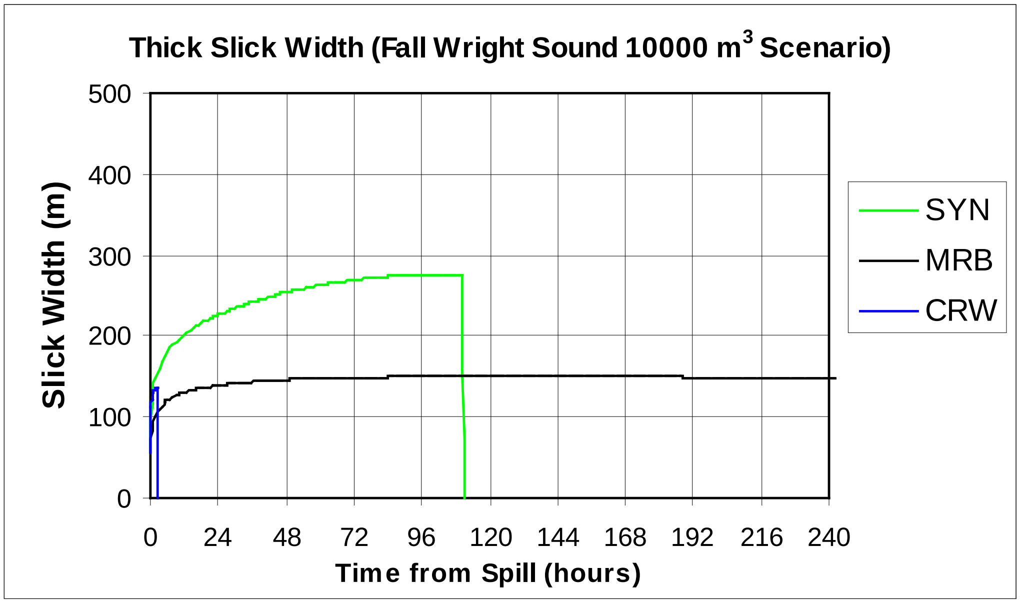


Figure 4-85 Wright Sound Tanker Spill Scenario (Fall) – Thick Slick Width

4.6.3 Hypothetical Winter Spill

Seasonal average environmental input data used for the winter scenarios have been derived from the months of December, January and February. The MRB short form used in these figures is equivalent to MKH- MacKay River Heavy bitumen used elsewhere in the modelling.

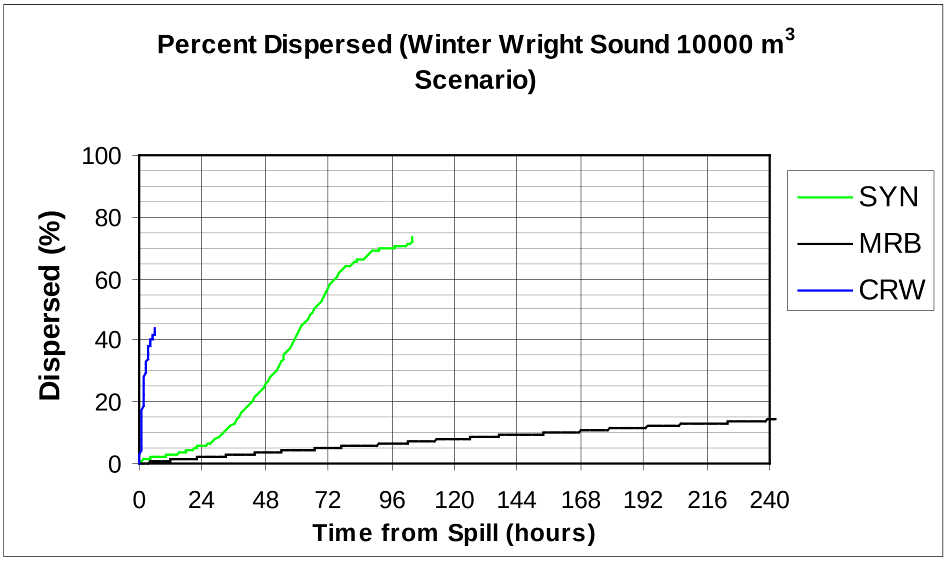


Figure 4-86 Wright Sound Tanker Spill Scenario (Winter) – Percent Dispersed

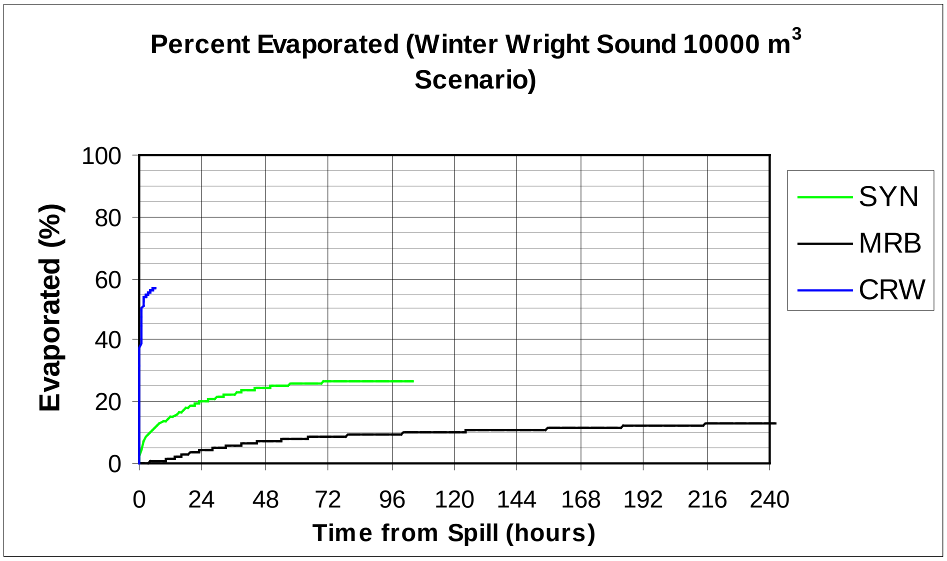


Figure 4-87 Wright Sound Tanker Spill Scenario (Winter) – Percent Evaporated

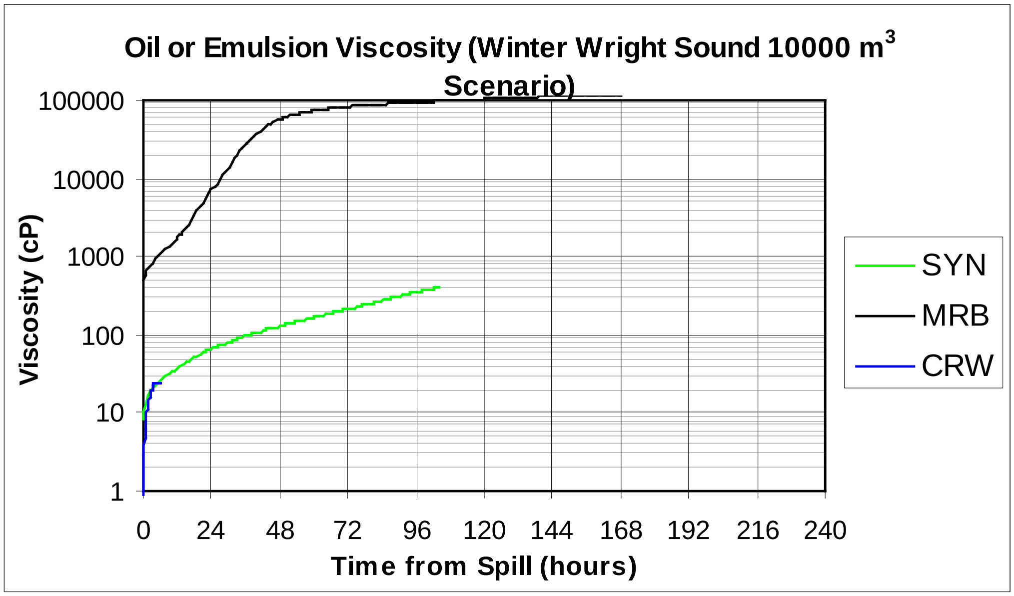


Figure 4-88 Wright Sound Tanker Spill Scenario (Winter) – Oil or Emulsion Viscosity

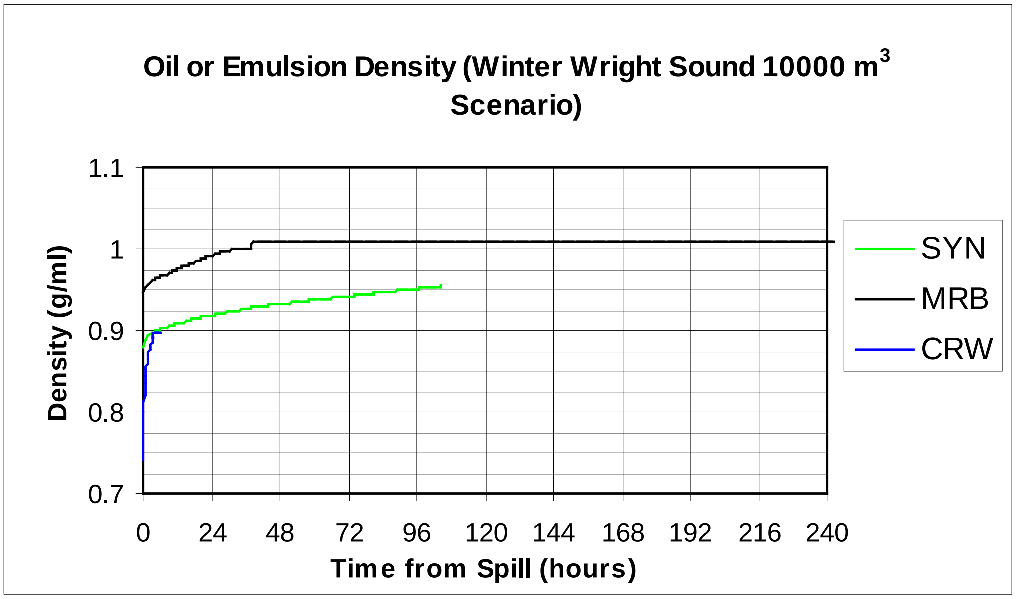


Figure 4-89 Wright Sound Tanker Spill Scenario (Winter) – Oil or Emulsion Density

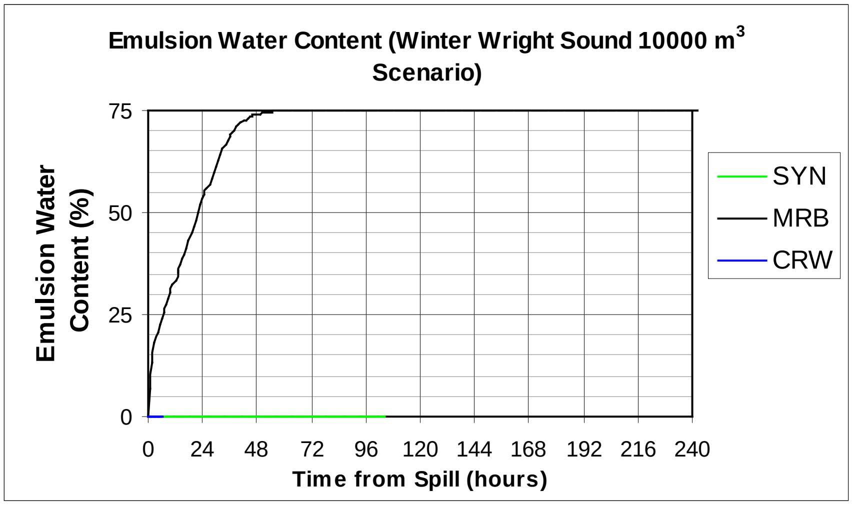


Figure 4-90 Wright Sound Tanker Spill Scenario (Winter) – Emulsion Water Content

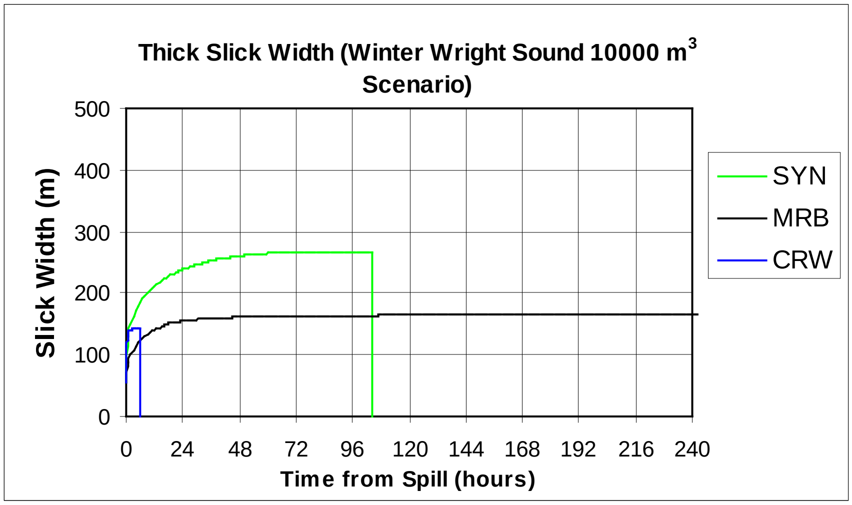


Figure 4-91 Wright Sound Tanker Spill Scenario (Winter) – Thick Slick Width

4.6.4 Hypothetical Spring Spill

Seasonal average environmental input data used for the spring scenarios have been derived from the months of March, April and May. The MRB short form used in these figures is equivalent to MKH-MacKay River Heavy bitumen used elsewhere in the modelling.

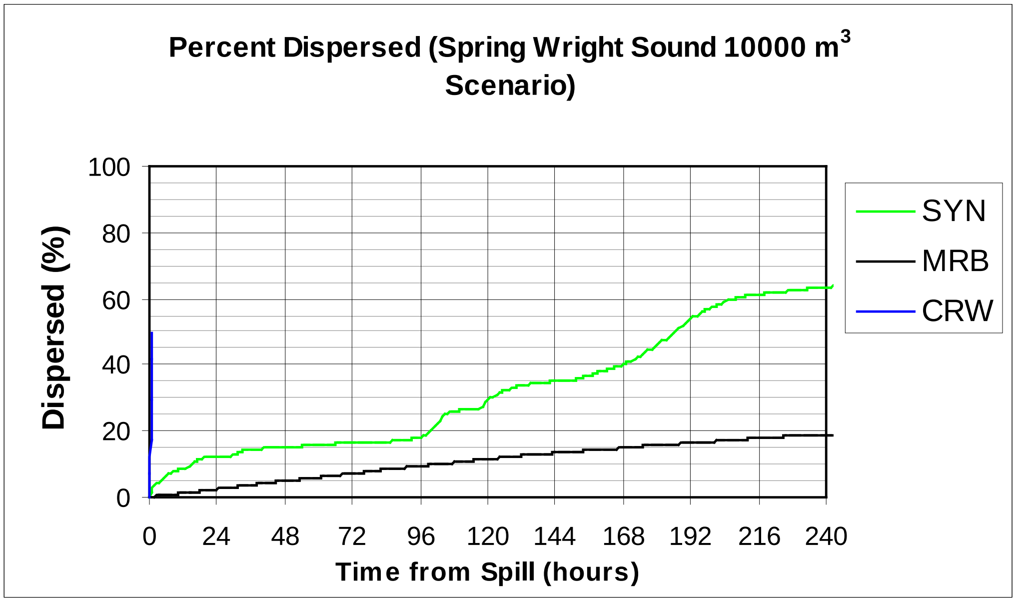


Figure 4-92 Wright Sound Tanker Spill Scenario (Spring) – Percent Dispersed

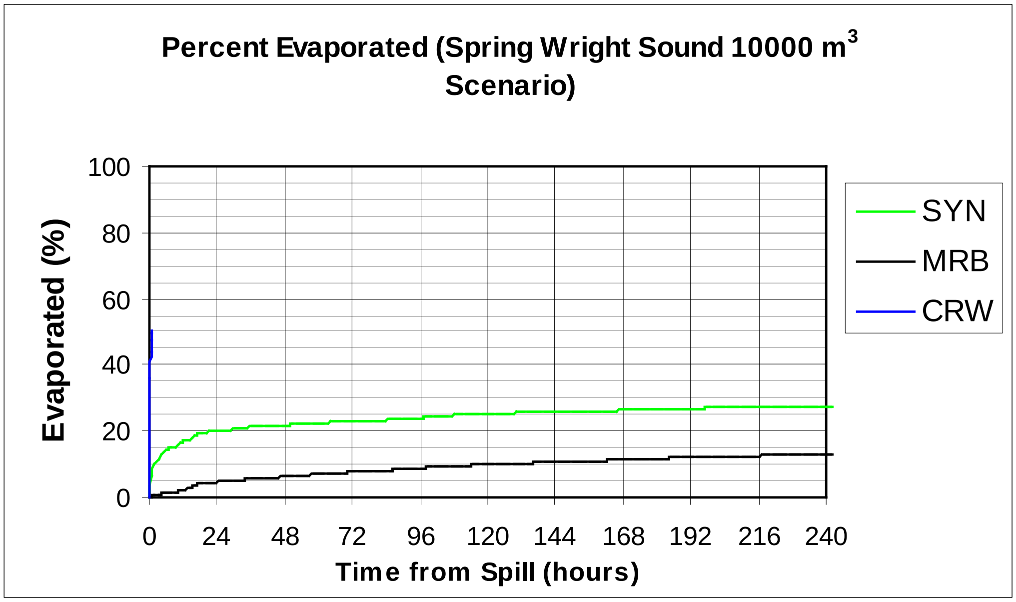


Figure 4-93 Wright Sound Tanker Spill Scenario (Spring) – Percent Evaporated

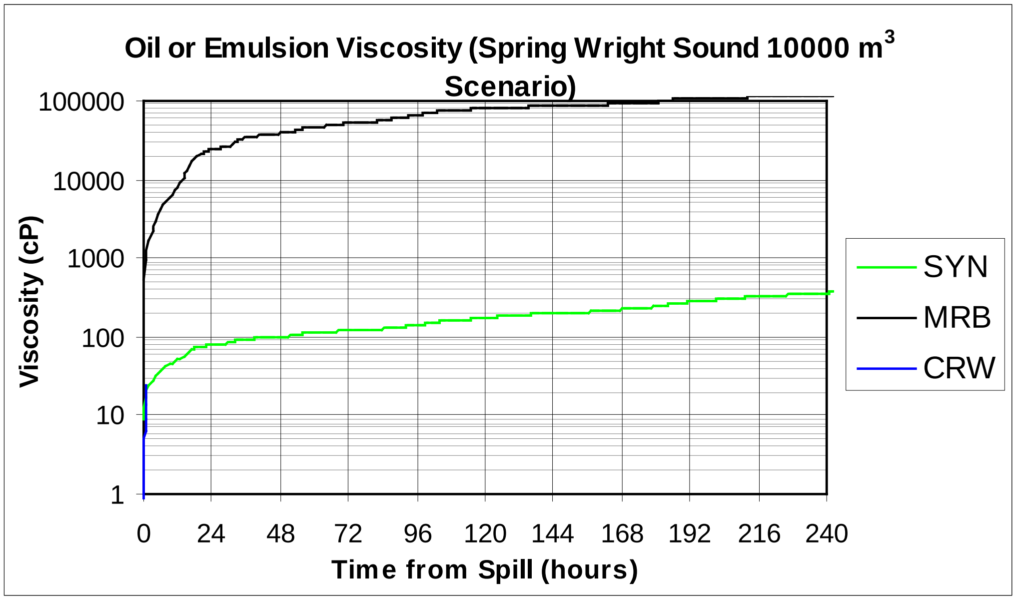


Figure 4-94 **Wright Sound Tanker Spill Scenario (Spring) – Oil or Emulsion Viscosity**

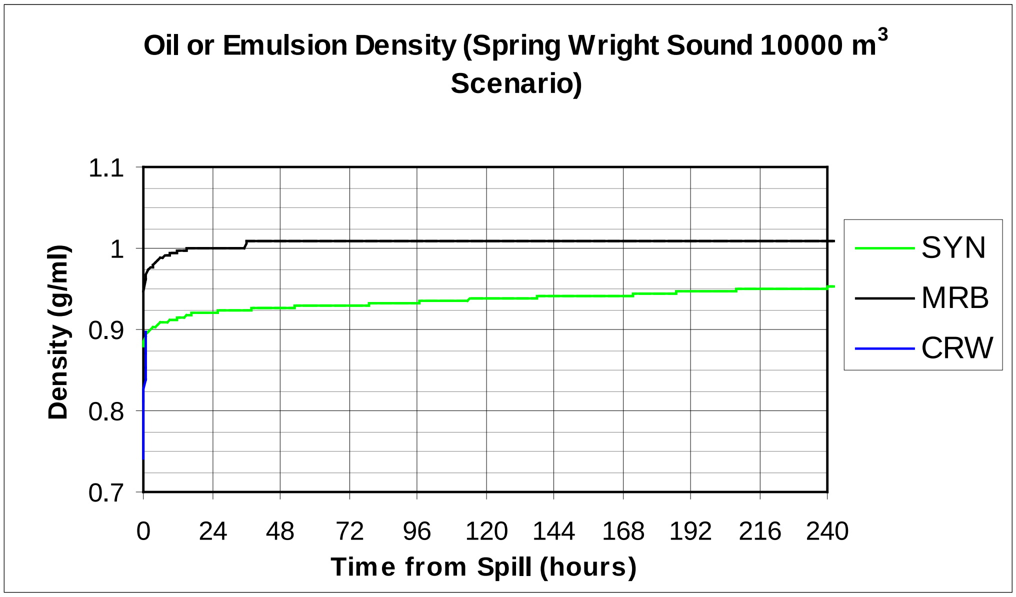


Figure 4-95 **Wright Sound Tanker Spill Scenario (Spring) – Oil or Emulsion Density**

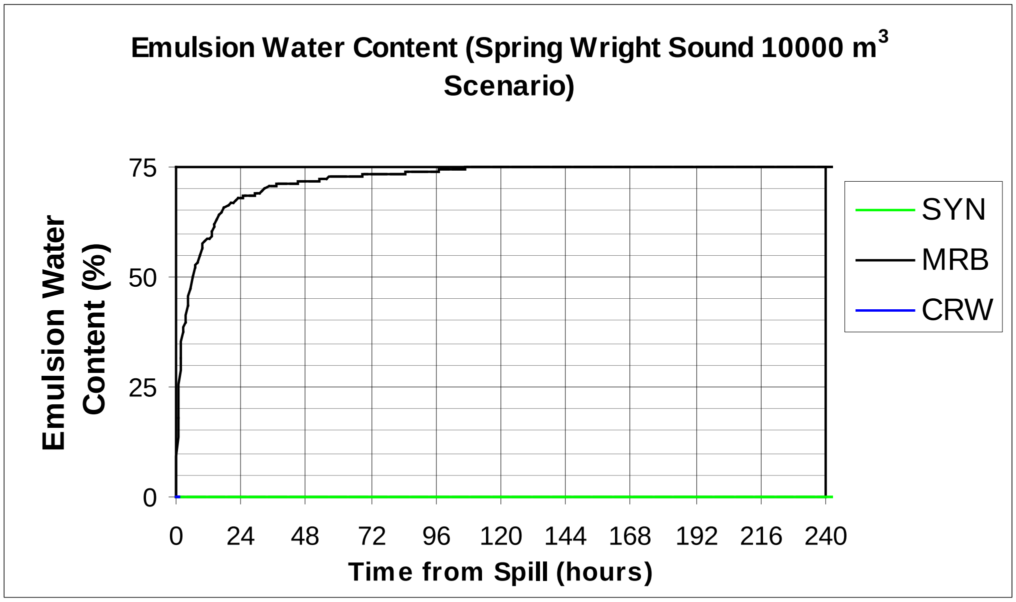


Figure 4-96 Wright Sound Tanker Spill Scenario (Spring) – Emulsion Water Content

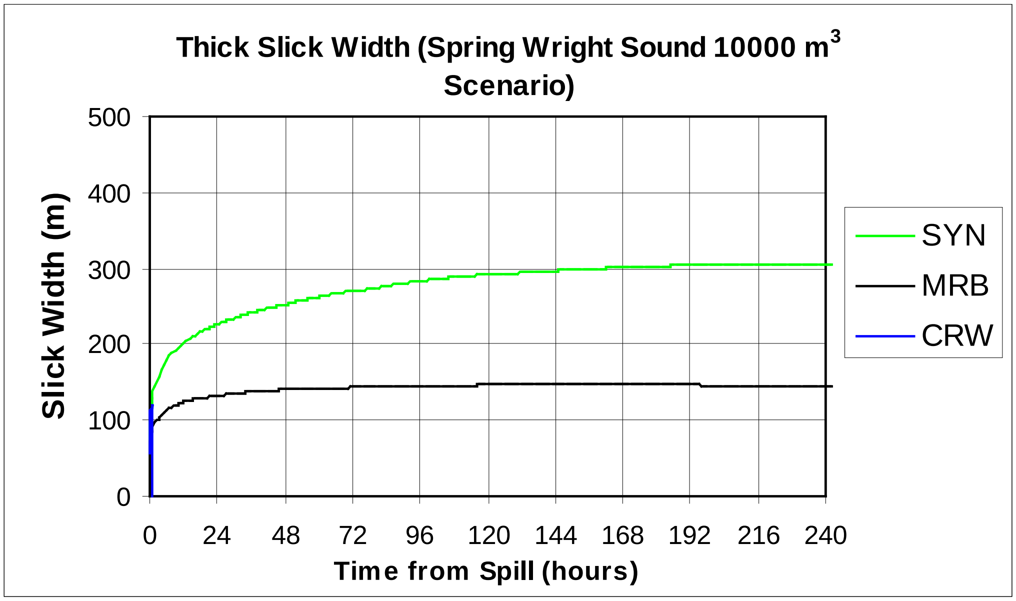


Figure 4-97 Wright Sound Tanker Spill Scenario (Spring) – Thick Slick Width

5 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, DC. 331-337.

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

Appendix A Oil Property Analysis Data Sheets

A.1 Syncrude Synthetic Light Oil

Oil Weathering

Syncrude Synthetic Light Oil

	2 Day Tray x	2 Week Tray y	Average Air Temp °C
Tray Mass (g)	241.5	243.1	16.8

Volume Weathered(ml) 900
Volume for 2cm thick 969.5
Tray thickness (m) 0.018566

288.2 K
0.00526366 m/s
0.001 m
Automated

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

Date/Time	Mass of Oil + Tray 2 Day (g)	Mass of Oil + Tray 2 Week (g)	Mass of Oil 2 Day (g)	Mass of Oil 2 Week (g)	Fm 2 Day	Fm 2 Week	Oil Density ($\mathrm{g/cm^3}$)	Fv 2 Day	Fv 2 Week	Evaporative Exposure (Corrected)	Model Evaporate (Fv)	Elapsed Time 2 (hr)	Evaporative Exposure 2
17/10/2005 11:01	1021.2	1022.1	779.7	779.0	0.000	0.000	0.872	0.000	0.000	0	0.000	0	0
17/10/2005 11:29	1001.9	1003.0	760.4	759.9	0.025	0.025	0.877	0.031	0.030	616	0.032	12	227390
17/10/2005 11:59	991.9	993.1	750.4	750.0	0.038	0.037	0.880	0.046	0.046	1276	0.052	24	454780
17/10/2005 12:28	983.7	985.2	742.2	742.1	0.048	0.047	0.882	0.059	0.058	1913	0.065	36	682170
17/10/2005 12:59	975.2	976.8	733.7	733.7	0.059	0.058	0.884	0.072	0.071	2595	0.077	48	909561
17/10/2005 13:29	968.2	970.2	726.7	727.1	0.068	0.067	0.886	0.083	0.082	3255	0.085	60	1136951
17/10/2005 13:59	962.6	964.7	721.1	721.6	0.075	0.074	0.888	0.092	0.090	3915	0.093	72	1364341
17/10/2005 15:00	951.3	953.2	709.8	710.1	0.090	0.088	0.891	0.109	0.108	5256	0.105	84	1591731
17/10/2005 16:00	942.6	944.7	701.1	701.6	0.101	0.099	0.893	0.122	0.121	6576	0.114	96	1819121
17/10/2005 16:49	936.3	938.8	694.8	695.7	0.109	0.107	0.895	0.132	0.130	7653	0.121	108	2046511
18/10/2005 10:40	885.3	885.8	643.8	642.7	0.174	0.175	0.909	0.208	0.209	31207	0.184	120	2273901
18/10/2005 13:25	881.8	882.2	640.3	639.1	0.179	0.180	0.910	0.213	0.214	34835	0.189	132	2501291
18/10/2005 15:30	879.4	880.1	637.9	637.0	0.182	0.182	0.911	0.217	0.217	37584	0.192	144	2728682
18/10/2005 16:45	878.0	878.5	636.5	635.4	0.184	0.184	0.911	0.219	0.220	39234	0.194	156	2956072
19/10/2005 9:26	866.2	867.3	624.7	624.2	0.199	0.199	0.914	0.236	0.236	61248	0.215	168	3183462
19/10/2005 11:06	865.6	866.8	624.1	623.7	0.200	0.199	0.914	0.237	0.237	63447	0.217	180	3410852
19/10/2005 12:33	removed	865.9		622.8		0.201	0.915		0.238	65360	0.218	192	3638242
19/10/2005 14:41		865.3		622.2		0.201	0.915		0.239	68175	0.220	204	3865632
19/10/2005 15:43		864.9		621.8		0.202	0.915		0.239	69539	0.221	216	4093022
19/10/2005 16:39		864.7		621.6		0.202	0.915		0.240	70770	0.222	228	4320412
20/10/2005 9:30		858.0		614.9		0.211	0.917		0.249	93004	0.234	240	4547803
20/10/2005 16:08		855.9		612.8		0.213	0.917		0.252	101757	0.239	252	4775193
21/10/2005 15:31		850.1		607.0		0.221	0.919		0.261	132612	0.251	264	5002583
24/10/2005 9:14		838.9		595.8		0.235	0.922		0.277	219327	0.274	276	5229973
24/10/2005 16:30		838.0		594.9		0.236	0.922		0.278	228915	0.276	288	5457363
25/10/2005 9:05		836.1		593.0		0.239	0.923		0.281	250797	0.281	300	5684753
25/10/2005 15:14		835.1		592.0		0.240	0.923		0.282	258912	0.282	312	5912143
26/10/2005 8:41		833.4		590.3		0.242	0.924		0.285	281938	0.286	324	6139534
26/10/2005 9:52		833.2		590.1		0.243	0.924		0.285	283499	0.286	336	6366924
26/10/2005 16:55		833.1		590.0		0.243	0.924		0.285	292802	0.288	348	6594314
27/10/2005 7:45		831.8		588.7		0.244	0.924		0.287	312375	0.291	360	6821704
27/10/2005 16:55		830.7		587.6		0.246	0.924		0.289	324470	0.293	372	7049094
28/10/2005 9:14		829.2		586.1		0.248	0.925		0.291	346001	0.296	384	7276484
28/10/2005 16:00		828.6		585.5		0.248	0.925		0.292	354929	0.297	396	7503874
31/10/2005 9:20		823.6		580.5		0.255	0.926		0.299	441138	0.307	408	7731264
31/10/2005 11:00		823.3		580.2		0.255	0.926		0.299	443337	0.307	420	7958655
		removed											

	2-day	2-week
Fm	0.200	0.255

	2-day	2-week
Fv	0.237	0.299

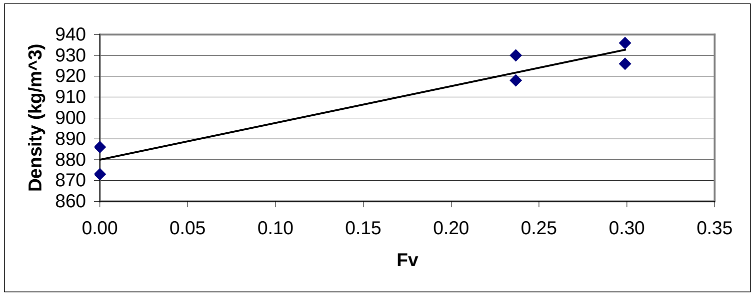
Density **Syncrude Synthetic Light Oil**

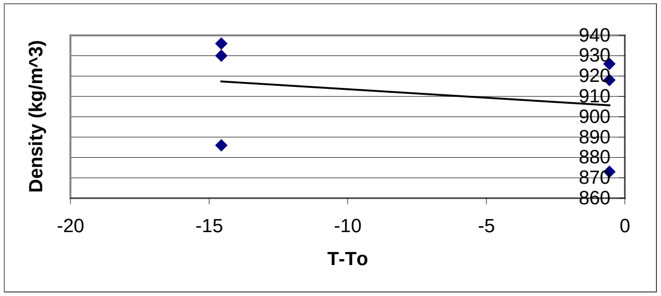
Mass Evaporated (Fm)	Density (g/cm^3)	Temperature (°C)
0	0.886	1.0
0	0.873	15.0
0.20	0.930	1.0
0.20	0.918	15.0
0.26	0.936	1.0
0.26	0.926	15.0
0	0.871	16.78
0.20	0.916	16.78
0.26	0.925	16.78

slope	0.214
intercept	0.872
r^2	0.996

Temperature (°C)	Density (g/cm^3)	Density (kg/m^3)	Volume Evaporated (Fv)	T-To (K)
1	0.886	886	0	-14.56
1	0.930	930	0.237	-14.56
1	0.936	936	0.299	-14.56
15	0.873	873	0	-0.56
15	0.918	918	0.237	-0.56
15	0.926	926	0.299	-0.56
15.5	0.926	926	0.281	

Density Constant 1 (slope, kg/m^3)	176.548
Standard Density Temperature, To (K)	288.72
Density Constant 2 (kg/K.m^3)	0.833
Standard Density (kg/m^3)	872.480
API Gravity @ 15.5°C	30.68





Wind Tunnel Calibration **Toluene**

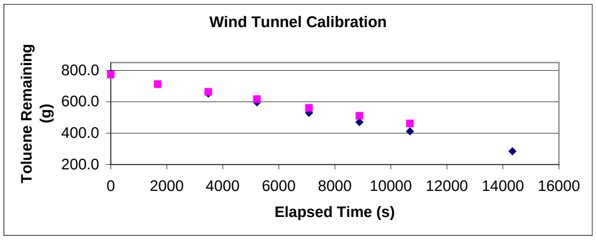
Tray Mass (g)

Elapsed Time (s)	Mass Toluene Tray 2 (g)	Tray 5 (g)	Tray 8 (g)	Tray 11 (g)
0	780.7	773.7	779.3	781.6
1680	712.2	711.9	718.5	709.0
3480	652.5	663.0	672.7	654.7
5220	596.2	616.5	628.6	604.2
7080	529.6	560.7	576.2	543.1
8880	470.3	510.4	529.3	490.0
10680	411.4	461.3	483.9	438.1
14340	284.6	345.1	367.6	310.1

	Tray 2	Tray 5	Tray 8	Tray 11
slope	-0.034187817	-0.0292102	-0.027839	-0.031914
E (kg/s)	-3.41878E-05	-2.921E-05	-2.78E-05	-3.19E-05

Wind Tunnel Temperature, T (K) 289.9420576 16.78 °C
Toluene Vapor Pressure, P (kPa) 2.442
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) 0.048475

	Tray 2	Tray 5	Tray 8	Tray 11	average
K = ERT/APW (m/s)	-0.007556702	-0.00645647	-0.006153	-0.007054	-0.006805



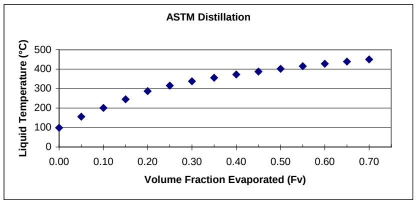
ASTM Distillation **Syncrude Synthetic Light Oil**

200 ml Fresh oil

Volume Distilled (mL)	Fraction Distilled (Fv)	Temperature Liquid (°C)	Vapor (°C)
IBP	0.00	99	44
10	0.05	156	71
20	0.10	201	88
30	0.15	245	118
40	0.20	287	155
50	0.25	316	238
60	0.30	338	271
70	0.35	356	297
80	0.40	373	282
90	0.45	388	331
100	0.50	402	344
110	0.55	415	348
120	0.60	428	355
130	0.65	439	360
140	0.70	450	376
150	0.75		

slope 421.1
intercept 184.5

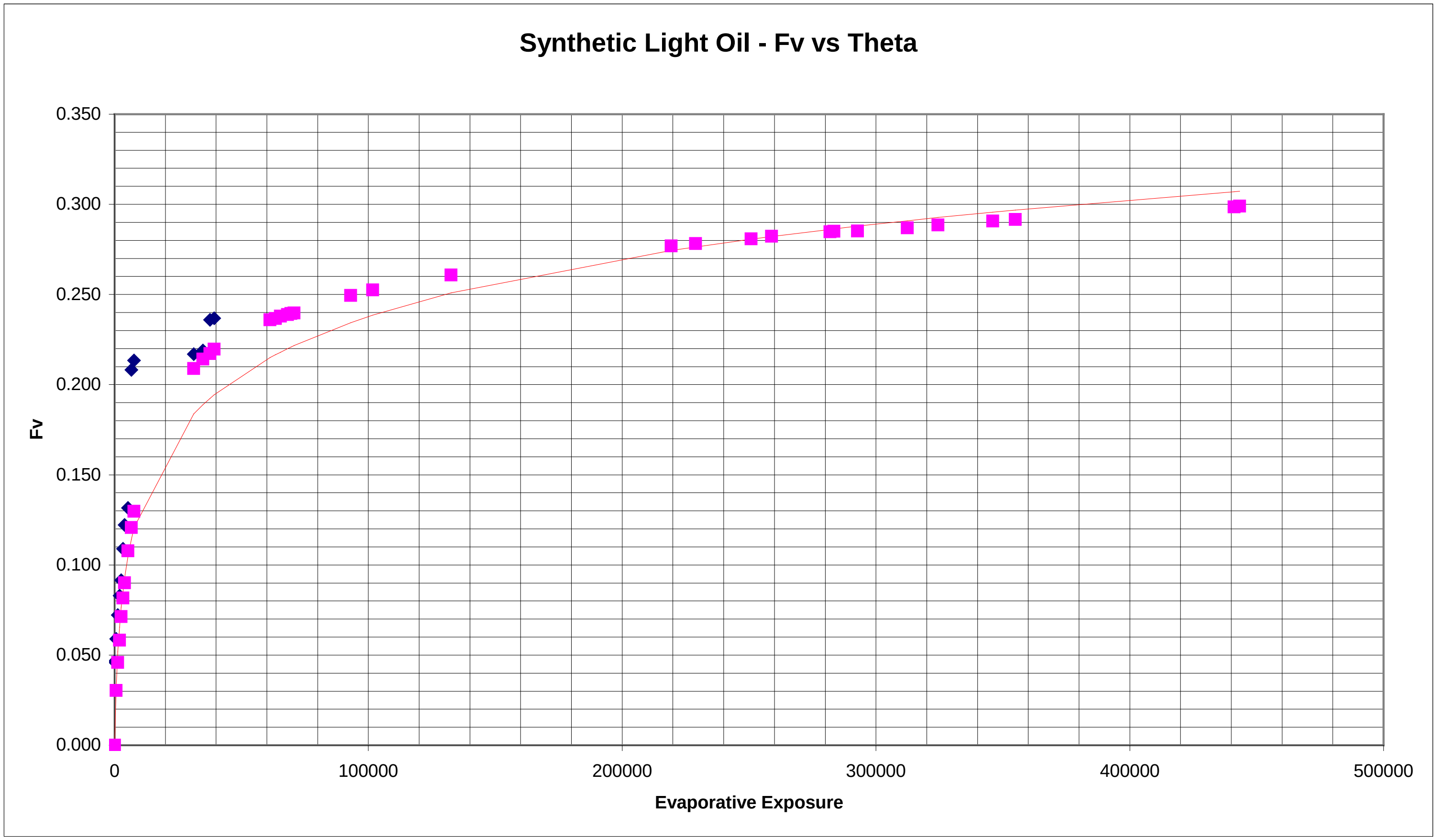
Distillation Constant A (slope, K) 421.1
Distillation Constant B (intercept, K) 457.7



Mackay Constants **Syncrude Synthetic Light Oil**
(automated)

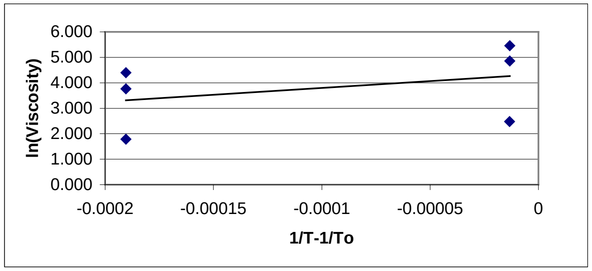
Point	Fv	Tb/T	H	ln(H)
1	0.015	1.601	4.928E-05	-9.918
2	0.038	1.634	2.363E-05	-10.653
3	0.052	1.654	1.940E-05	-10.850
4	0.065	1.673	1.919E-05	-10.861
5	0.077	1.690	1.551E-05	-11.074
6	0.086	1.703	1.288E-05	-11.260
7	0.099	1.722	1.317E-05	-11.237
8	0.114	1.744	9.838E-06	-11.529
9	0.125	1.760	8.325E-06	-11.696
10	0.169	1.824	3.361E-06	-12.603
11	0.212	1.886	1.456E-06	-13.440
12	0.216	1.892	1.120E-06	-13.703
13	0.218	1.896	1.420E-06	-13.465
14	0.228	1.909	7.419E-07	-14.114
15	0.236	1.922	3.304E-07	-14.923
16	0.237	1.923	6.833E-07	-14.196
17	0.238	1.925	3.095E-07	-14.988
18	0.239	1.926	4.258E-07	-14.669

	calculated	adjusted
Fv vs. Theta B (-slope)	13.95749	14.7
Fv vs. Theta A (intercept)	12.52347	13.7

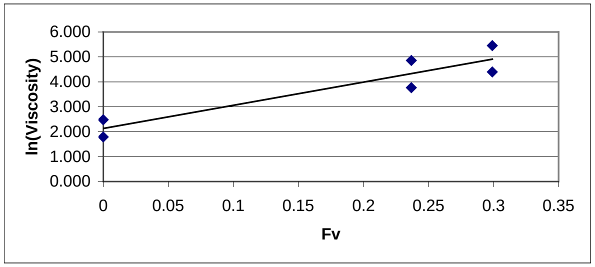

Synthetic Light Oil - Fv vs Theta
Fv
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
0
100000
200000
300000
400000
500000
Evaporative Exposure

Viscosity Syncrude Synthetic Light Oil

Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	11.9	1.0	30.0	CP-42	115.0	2.477
0	6.0	15.0	30.0	CP-42	115.0	1.787
0.20	128.4	1.0	30.0	CP-42	115.0	4.855
0.20	43.1	15.0	30.0	CP-42	115.0	3.764
0.26	234.7	1.0	30.0	CP-42	115.0	5.458
0.26	81.1	15.0	30.0	CP-42	115.0	4.396



Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	11.9	1.0	2.477	-1.3353E-05
0	6.0	15.0	1.787	-0.000190443
0.24	128.4	1.0	4.855	-1.322E-05
0.24	43.1	15.0	3.764	-0.000190443
0.30	234.7	1.0	5.458	-1.322E-05
0.30	81.1	15.0	4.396	-0.000190443



Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	12.50
Viscosity Constant 1	9.30
Viscosity Constant 2 (K^{-1})	5355.65

Volume Evaporated (Fv)	Viscosity 1°C (cP)	Viscosity 15°C (cP)
0	11.9	6.0
0.24	128.4	43.1
0.30	234.7	81.1

Pour Point

Syncrude Synthetic Light Oil

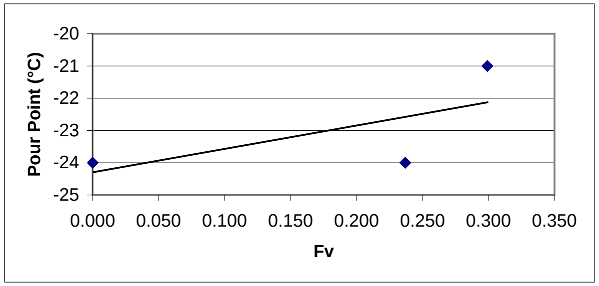
Test Results

Fv	Pour Point Measured (°C)	Pour Point Reported (°C)
0.000	< -25	-24
0.237	-26	-24
0.299	-23.3	-21

slope	43.40142
intercept	-36.27954

Pour Point Constants for SLR Spill Model

Initial Pour Point (K)	236.8705
Pour Point Constant	0.183228

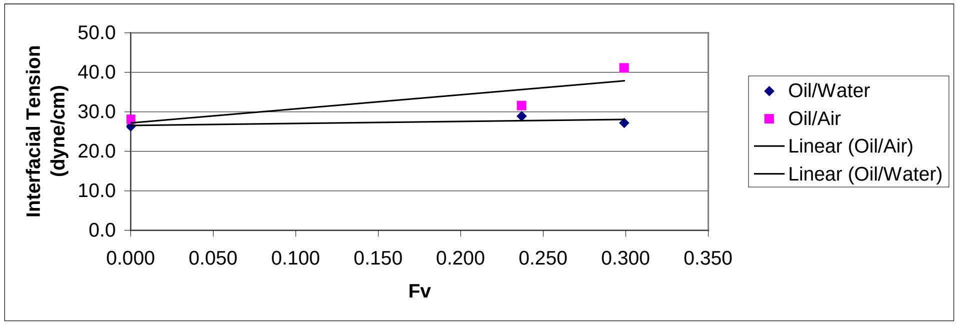


Interfacial Tension

Syncrude Synthetic Light Oil

Fv	Interfacial Tension Oil/Water (dyne/cm)	Interfacial Tension Oil/Air (dyne/cm)	Dial Reading Oil/Water (dyne/cm)	Dial Reading Oil/Air (dyne/cm)	Correction Factor Oil/Water	Correction Factor Oil/Air
0.000	26.3	28.1	26.1	31.2	1.01	0.90
0.237	28.9	31.5	27.0	35.1	1.07	0.90
0.299	27.2	41.1	25.4	45.7	1.07	0.90
slope	5.053	35.605				
intercept	26.563	27.200				

Oil/Water Interfacial Tension (dyne/cm)	26.563
Oil/Water Interfacial Tension Constant	0.190
Oil/Air Interfacial Tension (dyne/cm)	27.200
Oil/Air Interfacial Tension Constant	1.309



Flash Point **Syncrude Synthetic Light Oil**

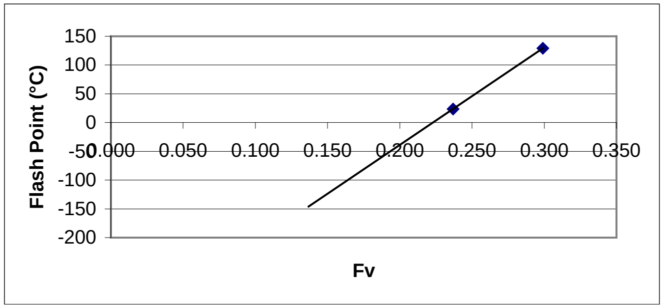
Test Results

Fv	Flash Point Measured (°C)	
0.000	-5	Equipment limit
0.237	23.5	
0.299	129	

slope	357.336727
intercept	258.483699

Flash Point Constants for SLR Spill Model

Initial Flash Point (K)	258.484
Flash Point Constant	1.382



SL Ross Model

Modeling Constants	**Syncrude Synthetic Light Oil**		
Standard Density	872.480	kg/m3	
Standard Density Temperature	288.720	K	
Density Constant 1	176.548	kg/m3	
Density Constant 2	0.83333	kg/K.m3	
Standard Viscosity	12.50101	cP	
Standard Viscosity Temperature	273.160	K	
Viscosity Constant 1	9.3049		
Viscosity Constant 2	5355.65	K-1	
Oil/Water Interfacial Tension	26.5626	dyne/cm	
Air/Oil Interfacial Tension	27.1997	dyne/cm	
Oil/Water Interfacial Tension Constant	0.19021		
Air/Oil Interfacial Tension Constant	1.30902		
Initial Pour Point	236.870	K	NB Initial Pour Point <-24°C
Pour Point Constant	0.18323		
ASTM Distillation Constant A (slope)	421.099	K	
ASTM Distillation Constant B (intercept)	457.676	K	
Emulsification Delay	9999999999		
Initial Flash Point	258.484	K	
Flash Point Constant	1.38243		
Fv vs. Theta A	13.70000		
Fv vs. Theta B	14.70000		
B.Tg	6190.15		
B.To	6727.84		

Emulsification Formation - Tendency and Stability **Syncrude Synthetic Light Oil**

Test Results - 1°C

300ml H2O @	1.0	°C
oil @	44.0	°C
mixing done @	1.0	°C
settling done @	1.0	°C
Final 24 hr done @	1.0	°C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	#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	0	10	0	10	13	0	13	0	14	0	15	0
plus 10 minutes	0	10	0	10	12	0	12	0	13	0	14	0
plus 20 minutes	0	10	0	10	12	0	12	0	13	0	14	0
plus 30 minutes	0	10	0	10	12	0	12	0	13	0	14	0
After second hour mixing	11	0	11	0	14	0	14	0	15	0	16	0
plus 10 minutes	11	0	0	10	14	0	14	0	14	0	15	0
plus 20 minutes	0	10	11	0	14	0	13	0	14	0	15	0
plus 30 minutes	11	0	11	0	13	0	13	0	14	0	15	0
After third hour mixing	11	0	11	0	15	0	15	0	15	0	17	0
plus 10 minutes	11	0	11	0	15	0	15	0	14	0	16	0
plus 20 minutes	0	10	11	0	14	0	14	0	14	0	16	0
plus 30 minutes	0	10	11	0	14	0	14	0	14	0	16	0
After fourth hour mixing	0	10	0	10	15	0	16	0	14	0	13	0
plus 10 minutes	0	10	0	10	14	0	14	0	13	0	15	0
plus 20 minutes	0	10	0	10	14	0	14	0	12	0	14	0
plus 30 minutes	0	10	0	10	14	0	14	0	13	0	15	0
plus 24 hour	0	10	0	10	13	0	13	0	13	0	14	0

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Unlikely	Unlikely	Likely
Stability Index	Unstable	Unstable	Entrained
Water Content (after 24 hr)	0%	23%	26%

Test Results - 15°C

300ml H2O @	15.0 °C
oil @	40.0 °C
mixing done @	14.0 °C
settling done @	14.0 °C
Final 24 hr done @	15.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	#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	0	9	0	10	0	10	0	10	17	0	12	0
plus 10 minutes	0	9	0	10	0	10	0	10	14	0	0	10
plus 20 minutes	0	10	0	10	0	10	0	10	13	0	11	0
plus 30 minutes	0	10	0	10	0	10	0	10	13	0	11	0
After second hour mixing	0	9	0	9	0	9	0	8	16	0	0	10
plus 10 minutes	0	9	0	9	0	10	0	10	18	0	0	10
plus 20 minutes	0	9	0	9	0	10	0	10	14	0	0	10
plus 30 minutes	0	9	0	10	0	10	0	10	14	0	0	10
After third hour mixing	0	9	0	9	0	10	0	10	17	0	0	10
plus 10 minutes	0	9	0	9	0	9	0	9	15	0	0	10
plus 20 minutes	0	9	0	9	0	10	0	10	14	0	11	0
plus 30 minutes	0	9	0	9	0	10	0	10	13	0	11	0
After fourth hour mixing	0	10	0	10	0	9	0	9	17	0	12	0
plus 10 minutes	0	10	0	10	0	9	0	9	16	0	11	0
plus 20 minutes	0	10	0	10	0	10	0	10	15	0	11	0
plus 30 minutes	0	10	0	10	0	10	0	10	15	0	0	10
plus 24 hour	0	10	0	10	0	10	0	10	5	10	2	7

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Unlikely	Unlikely	Likely
Stability Index	Unstable	Unstable	Entrained
Water Content (after 24 hr)	0%	0%	33%

Viscosity Measurements with Brookfield DV-III+ Rheometer

Viscosity

Temperature	1				15			
	Viscosity	RPM	Spindle	Shear Rate	Viscosity	RPM	6.0	Shear Rate
Fresh	11.9	30.0	CP-42	115.0	6.0	30.0	CP-42	115.0
2 Day Weathered	128.4	30.0	CP-42	115.0	43.1	30.0	CP-42	115.0
2 Week Weathered	234.7	30.0	CP-42	115.0	81.1	30.0	CP-42	115.0

Measurements @ °C 15.0

	Spindle	RPM	% Torque	Viscosity cP	Shear Rate	Temp °C	
Fresh	CP-42	15	0.6	5.1	57.6	15.0	
		30	1.4	6.0	115.0	15.0	<=====
		45	2.3	6.5	173.0	15.0	
		60	3.1	6.6	230.0	15.0	
		90	5.5	7.8	346.0	15.0	
		120	5.3	5.7	461.0	15.0	
		180	7.6	5.4	691.0	15.0	
		250	11.3	5.8	960.0	15.0	
2 Day Weathered	CP-42	15	4.9	41.8	57.6	15.0	
		30	10.1	43.1	115.0	15.0	<=====
		45	15.2	43.2	173.0	15.0	
		60	20.3	43.3	230.0	15.0	
		90	30.5	43.4	346.0	15.0	
		120	40.6	43.3	461.0	15.0	
		180	60.8	43.2	691.0	15.0	
		250	84.8	43.4	960.0	15.0	
2 Week Weathered	CP-42	15	10.0	85.3	57.6	15.0	
		30	19.0	81.1	115.0	15.0	<=====
		45	27.8	79.1	173.0	15.0	
		60	36.2	77.2	230.0	15.0	
		90	53.2	75.7	346.0	15.0	
		120	74.1	79.0	461.0	15.0	
		180	-over-		691.0	15.1	
Fresh	CP-42	15	1.3	11.1	57.6	1.0	
		30	2.8	11.9	115.0	1.0	<=====
		45	4.3	12.2	173.0	1.0	
		60	5.8	12.4	230.0	1.0	
		90	8.8	12.5	346.0	1.0	
		120	11.8	12.6	461.0	1.0	
		180	17.8	12.7	691.0	1.0	
		250	24.8	12.7	960.0	1.0	
2 Day Weathered	CP-42	15	15.6	133.1	57.6	1.1	
		30	30.1	128.4	115.0	1.0	<=====
		45	44.1	125.4	173.0	1.0	
		60	58.0	123.7	230.0	1.0	
		90	85.9	122.2	346.0	1.0	
		120	-over-		461.0	1.0	
2 Week Weathered	CP-42	15	29.1	248.3	57.6	1.0	
		30	55.0	234.7	115.0	1.0	<=====
		45	83.7	238.1	173.0	1.0	
		60	-over-	368.6	230.0	1.0	

A.2 MacKay River Heavy Bitumen Diluted with Synthetic Light Oil

Oil Weathering **MacKay River Bitumen Diluted with Synthetic Light Oil**

	2 Day Tray x	2 Week Tray y	Average Air Temp °C
Tray Mass (g)	242.3	241.7	16.5

Volume Weathered(ml)	900
Volume for 2cm thick	969.5
Tray thickness (m)	0.018566

Modeling Inputs:	
Temp(°C)	288.2 K
Wind Speed (knots)	0.00526366 m/s
Thickness (mm)	0.001 m

Date/Time	Mass of Oil + Tray 2 Day (g)	Mass of Oil + Tray 2 Week (g)	Mass of Oil 2 Day (g)	Mass of Oil 2 Week (g)	Fm 2 Day	Fm 2 Week	Oil Density (g/cm^3)	Fv 2 Day	Fv 2 Week	Evaporative Exposure (Corrected)	Automated Model Evaporate (Fv)	Elapsed Time 2 (hr)	Evaporative Exposure 2
11/11/2005 10:46	1078.0	1076.9	835.7	835.2	0.000	0.000	0.943	0.000	0.000	0	0.000	0	0
11/11/2005 11:17	1067.2	1066.1	824.9	824.4	0.013	0.013	0.946	0.017	0.017	630	0.012	12	227390
11/11/2005 11:45	1064.2	1063.0	821.9	821.3	0.017	0.017	0.947	0.021	0.021	1198	0.019	24	454780
11/11/2005 12:35	1058.6	1058.3	816.3	816.6	0.023	0.022	0.949	0.029	0.029	2214	0.027	36	682170
11/11/2005 13:30	1055.5	1054.7	813.2	813.0	0.027	0.027	0.950	0.034	0.034	3330	0.034	48	909561
11/11/2005 14:30	1051.5	1051.1	809.2	809.4	0.032	0.031	0.951	0.040	0.040	4549	0.039	60	1136951
11/11/2005 15:30	1048.5	1048.9	806.2	807.2	0.035	0.034	0.952	0.045	0.043	5767	0.043	72	1364341
12/11/2005 8:30	1028.7	1027.8	786.4	786.1	0.059	0.059	0.959	0.075	0.075	26481	0.072	84	1591731
12/11/2005 19:30	1023.7	1023.3	781.4	781.6	0.065	0.064	0.960	0.082	0.081	39884	0.080	96	1819121
13/11/2005 10:36	1019.3	1019.1	777.0	777.4	0.070	0.069	0.962	0.089	0.088	58283	0.087	108	2046511
14/11/2005 8:42	removed	1015.8		774.1		0.073	0.963		0.092	85211	0.095	120	2273901
14/11/2005 11:47		1014.9		773.2		0.074	0.963		0.094	88968	0.096	132	2501291
14/11/2005 15:31		1014.0		772.3		0.075	0.963		0.095	93517	0.097	144	2728682
15/11/2005 7:47		1012.2		770.5		0.077	0.964		0.098	113337	0.100	156	2956072
15/11/2005 15:05		1010.9		769.2		0.079	0.964		0.100	122231	0.102	168	3183462
16/11/2005 8:04		1008.8		767.1		0.082	0.965		0.103	142925	0.105	180	3410852
16/11/2005 13:53		1008.0		766.3		0.082	0.965		0.104	150012	0.106	192	3638242
16/11/2005 16:42		1007.1		765.4		0.084	0.966		0.105	153444	0.106	204	3865632
17/11/2005 7:50		1006.1		764.4		0.085	0.966		0.107	171884	0.109	216	4093022
17/11/2005 15:54		1005.0		763.3		0.086	0.966		0.108	181712	0.110	228	4320412
18/11/2005 8:01		1003.5		761.8		0.088	0.967		0.111	201350	0.112	240	4547803
18/11/2005 16:16		1002.9		761.2		0.089	0.967		0.111	211402	0.113	252	4775193
21/11/2005 9:07		997.9		756.2		0.095	0.969		0.119	290419	0.119	264	5002583
21/11/2005 17:08		997.4		755.7		0.095	0.969		0.120	300187	0.120	276	5229973
22/11/2005 9:46		996.4		754.7		0.096	0.969		0.121	320454	0.121	288	5457363
22/11/2005 16:30		995.0		753.3		0.098	0.970		0.123	328658	0.122	300	5684753
23/11/2005 9:40		994.2		752.5		0.099	0.970		0.124	349575	0.123	312	5912143
23/11/2005 17:00		993.8		752.1		0.099	0.970		0.125	358510	0.123	324	6139534
24/11/2005 9:35		992.7		751.0		0.101	0.970		0.126	378716	0.125	336	6366924
25/11/2005 10:45		991.1		749.4		0.103	0.971		0.129	409381	0.126	348	6594314
		removed											

	2-day	2-week
Fm	0.070	0.103

	2-day	2-week
Fv	0.089	0.129

Oil Weathering **MacKay River Bitumen Diluted with Synthetic Light Oil**

	2 Day Tray x	2 Week Tray y	Average Air Temp °C
Tray Mass (g)	242.3	241.7	16.5

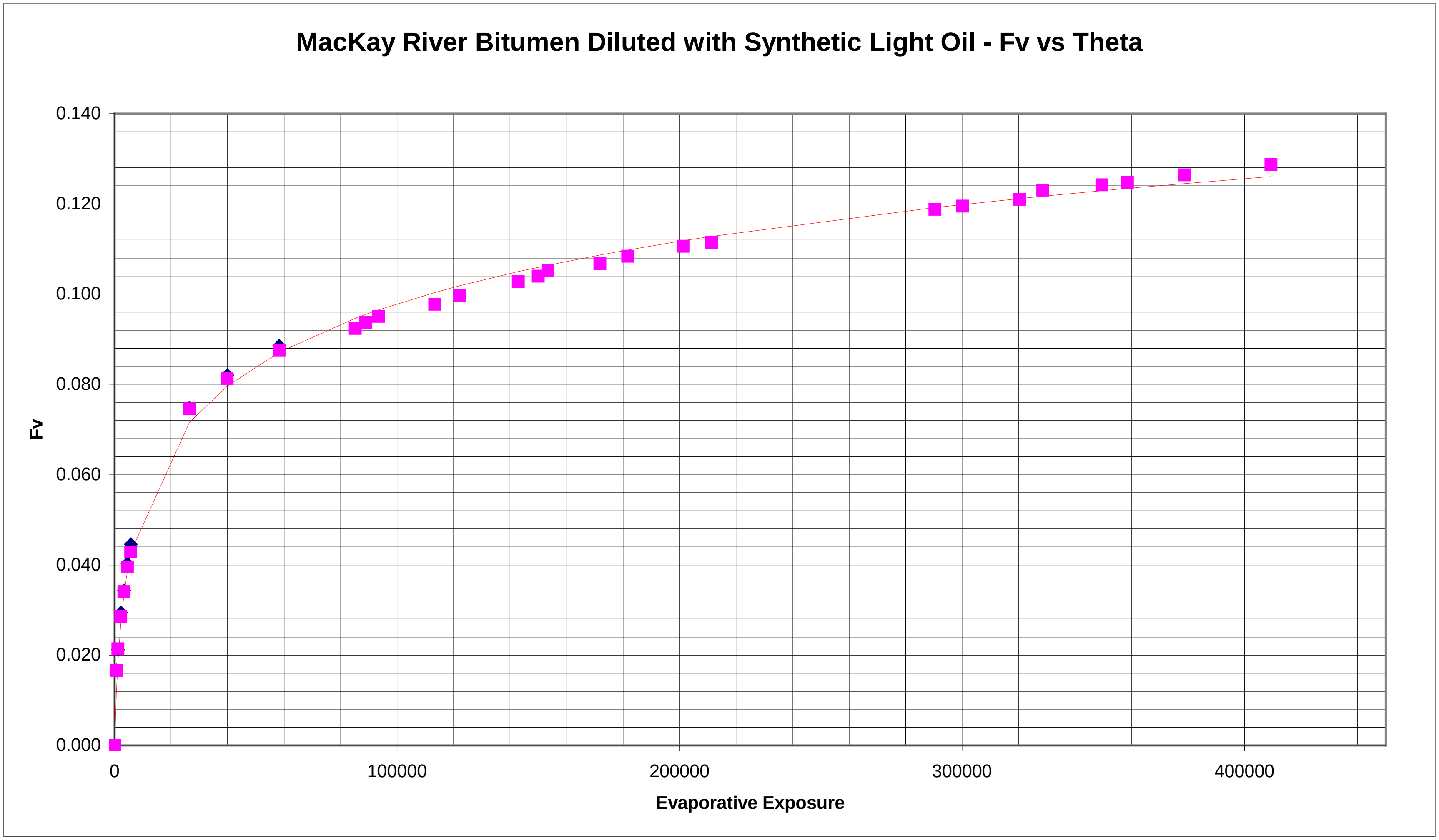
Volume Weathered(ml)	900
Volume for 2cm thick	969.5
Tray thickness (m)	0.018566

	Modeling Inputs:
288.2 K	Temp(°C)
0.00526366 m/s	Wind Speed (knots)
0.001 m	Thickness (mm)

Date/Time	Mass of Oil + Tray 2 Day (g)	Mass of Oil + Tray 2 Week (g)	Mass of Oil 2 Day (g)	Mass of Oil 2 Week (g)	Fm 2 Day	Fm 2 Week	Oil Density (g/cm^3)	Fv 2 Day	Fv 2 Week	Evaporative Exposure (Corrected)	Automated Model Evaporate (Fv)	Elapsed Time 2 (hr)	Evaporative Exposure 2
11/11/2005 10:46	1078.0	1076.9	835.7	835.2	0.000	0.000	0.943	0.000	0.000	0	0.000	0	0
11/11/2005 11:17	1067.2	1066.1	824.9	824.4	0.013	0.013	0.946	0.017	0.017	630	0.012	12	227390
11/11/2005 11:45	1064.2	1063.0	821.9	821.3	0.017	0.017	0.947	0.021	0.021	1198	0.019	24	454780
11/11/2005 12:35	1058.6	1058.3	816.3	816.6	0.023	0.022	0.949	0.029	0.029	2214	0.027	36	682170
11/11/2005 13:30	1055.5	1054.7	813.2	813.0	0.027	0.027	0.950	0.034	0.034	3330	0.034	48	909561
11/11/2005 14:30	1051.5	1051.1	809.2	809.4	0.032	0.031	0.951	0.040	0.040	4549	0.039	60	1136951
11/11/2005 15:30	1048.5	1048.9	806.2	807.2	0.035	0.034	0.952	0.045	0.043	5767	0.043	72	1364341
12/11/2005 8:30	1028.7	1027.8	786.4	786.1	0.059	0.059	0.959	0.075	0.075	26481	0.072	84	1591731
12/11/2005 19:30	1023.7	1023.3	781.4	781.6	0.065	0.064	0.960	0.082	0.081	39884	0.080	96	1819121
13/11/2005 10:36	1019.3	1019.1	777.0	777.4	0.070	0.069	0.962	0.089	0.088	58283	0.087	108	2046511
14/11/2005 8:42	removed	1015.8		774.1		0.073	0.963		0.092	85211	0.095	120	2273901
14/11/2005 11:47		1014.9		773.2		0.074	0.963		0.094	88968	0.096	132	2501291
14/11/2005 15:31		1014.0		772.3		0.075	0.963		0.095	93517	0.097	144	2728682
15/11/2005 7:47		1012.2		770.5		0.077	0.964		0.098	113337	0.100	156	2956072
15/11/2005 15:05		1010.9		769.2		0.079	0.964		0.100	122231	0.102	168	3183462
16/11/2005 8:04		1008.8		767.1		0.082	0.965		0.103	142925	0.105	180	3410852
16/11/2005 13:53		1008.0		766.3		0.082	0.965		0.104	150012	0.106	192	3638242
16/11/2005 16:42		1007.1		765.4		0.084	0.966		0.105	153444	0.106	204	3865632
17/11/2005 7:50		1006.1		764.4		0.085	0.966		0.107	171884	0.109	216	4093022
17/11/2005 15:54		1005.0		763.3		0.086	0.966		0.108	181712	0.110	228	4320412
18/11/2005 8:01		1003.5		761.8		0.088	0.967		0.111	201350	0.112	240	4547803
18/11/2005 16:16		1002.9		761.2		0.089	0.967		0.111	211402	0.113	252	4775193
21/11/2005 9:07		997.9		756.2		0.095	0.969		0.119	290419	0.119	264	5002583
21/11/2005 17:08		997.4		755.7		0.095	0.969		0.120	300187	0.120	276	5229973
22/11/2005 9:46		996.4		754.7		0.096	0.969		0.121	320454	0.121	288	5457363
22/11/2005 16:30		995.0		753.3		0.098	0.970		0.123	328658	0.122	300	5684753
23/11/2005 9:40		994.2		752.5		0.099	0.970		0.124	349575	0.123	312	5912143
23/11/2005 17:00		993.8		752.1		0.099	0.970		0.125	358510	0.123	324	6139534
24/11/2005 9:35		992.7		751.0		0.101	0.970		0.126	378716	0.125	336	6366924
25/11/2005 10:45		991.1		749.4		0.103	0.971		0.129	409381	0.126	348	6594314
		removed											

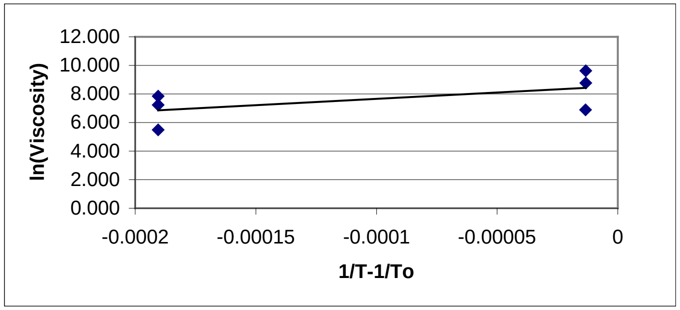
	2-day	2-week
Fm	0.070	0.103

	2-day	2-week
Fv	0.089	0.129

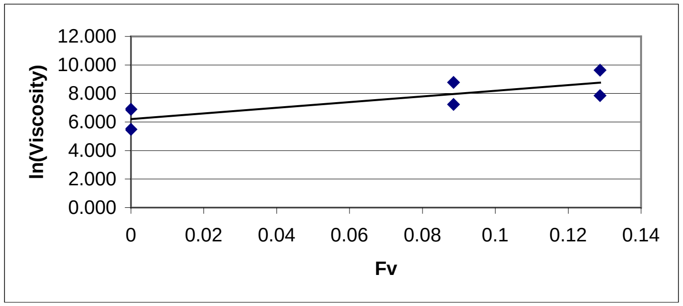

MacKay River Bitumen Diluted with Synthetic Light Oil - Fv vs Theta
Fv
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0
100000
200000
300000
400000
Evaporative Exposure

Viscosity — MacKay River Bitumen Diluted with Synthetic Light Oil

Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	977.0	1.0	8.0	CP-42	30.7	6.884
0	241.9	15.0	30.0	CP-42	115.0	5.489
0.07	6487.0	1.0	16.0	CP-52	32.0	8.778
0.07	1377.0	15.0	5.0	CP-42	19.2	7.228
0.10	15205.0	1.0	8.0	CP-52	16.0	9.629
0.10	2573.0	15.0	2.0	CP-42	7.7	7.853



Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	977.0	1.0	6.884	-1.3353E-05
0	241.9	15.0	5.489	-0.000190443
0.09	6487.0	1.0	8.778	-1.322E-05
0.09	1377.0	15.0	7.228	-0.000190443
0.13	15205.0	1.0	9.629	-1.322E-05
0.13	2573.0	15.0	7.853	-0.000190443



Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	1079.44
Viscosity Constant 1	19.96
Viscosity Constant 2 (K^{-1})	8888.80

Volume Evaporated (Fv)	Viscosity 1°C (cP)	Viscosity 15°C (cP)
0	977.0	241.9
0.09	6487.0	1377.0
0.13	15205.0	2573.0

Pour Point — MacKay River Bitumen Diluted with Synthetic Light Oil

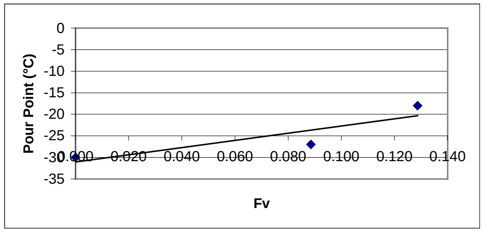
Test Results

Fv	Pour Point Measured (°C)	Pour Point Reported (°C)	
0.000	< -24	-30	made up
0.089	< -23	-27	made up
0.129	-20	-18	

slope	83.46126
intercept	-31.04413

Pour Point Constants for SLR Spill Model

Initial Pour Point (K)	242.1059
Pour Point Constant	0.34473

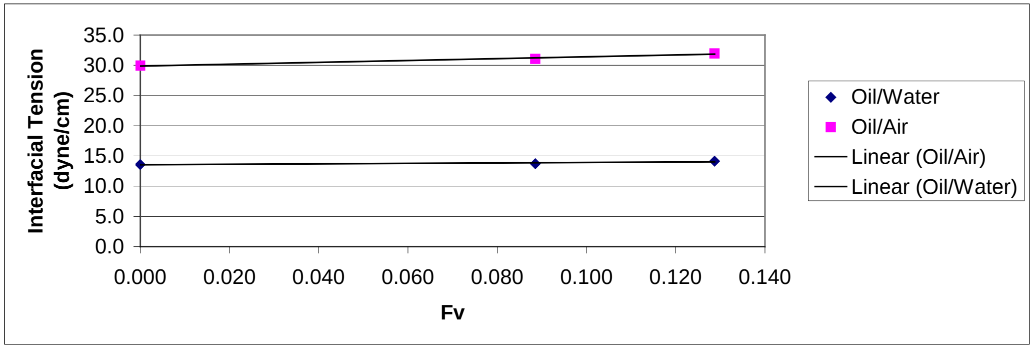


Interfacial Tension — MacKay River Bitumen Diluted with Synthetic Light Oil

Fv	Interfacial Tension Oil/Water (dyne/cm)	Interfacial Tension Oil/Air (dyne/cm)	Dial Reading Oil/Water (dyne/cm)	Dial Reading Oil/Air (dyne/cm)	Correction Factor Oil/Water	Correction Factor Oil/Air
0.000	13.6	29.9	13.5	33.3	1.01	0.90
0.089	13.7	31.1	13.2	34.5	1.04	0.90
0.129	14.1	32.0	13.5	35.5	1.05	0.90

	Oil/Water	Oil/Air
slope	3.759	15.235
intercept	13.539	29.872

Oil/Water Interfacial Tension (dyne/cm)	13.539
Oil/Water Interfacial Tension Constant	0.278
Oil/Air Interfacial Tension (dyne/cm)	29.872
Oil/Air Interfacial Tension Constant	0.510



Flash Point **MacKay River Bitumen Diluted with Synthetic Light Oil**

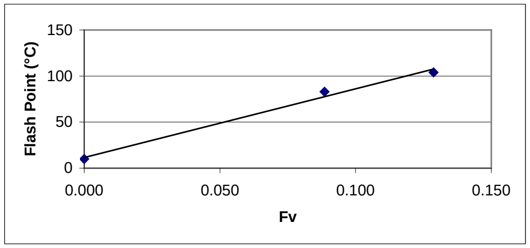
Test Results

Fv	Flash Point Measured (°C)
0.000	10
0.089	83
0.129	104

slope	745.817474
intercept	284.805734

Flash Point Constants for SLR Spill Model

Initial Flash Point (K)	284.806
Flash Point Constant	2.619



SL Ross Model

Modeling Constants	**MacKay River Bitumen Diluted with Synthetic Light Oil**		
Standard Density	942.640	kg/m3	
Standard Density Temperature	288.720	K	
Density Constant 1	205.934	kg/m3	
Density Constant 2	0.50000	kg/K.m3	
Standard Viscosity	1079.44062	cP	
Standard Viscosity Temperature	273.160	K	
Viscosity Constant 1	19.9568		
Viscosity Constant 2	8888.80	K-1	
Oil/Water Interfacial Tension	13.5395	dyne/cm	
Air/Oil Interfacial Tension	29.8717	dyne/cm	
Oil/Water Interfacial Tension Constant	0.27760		
Air/Oil Interfacial Tension Constant	0.51000		
Initial Pour Point	242.106	K	NB: Fresh and 2-day Pour Point below -23°C
Pour Point Constant	0.34473		thus Initial value and slope are "made up"
ASTM Distillation Constant A (slope)	336.244	K	
ASTM Distillation Constant B (intercept)	551.943	K	
Emulsification Delay	0		
Initial Flash Point	284.806	K	
Flash Point Constant	2.61869		
Fv vs. Theta A	71.13872		
Fv vs. Theta B	42.87505		
B.Tg	14416.46		
B.To	23664.59		

Emulsification Formation - Tendency and Stability

MacKay River Bitumen Diluted with Synthetic Light Oil

Test Results - 1°C

300ml H2O @	1.5 °C
oil @	40.0 °C
mixing done @	1.0 °C
settling done @	1.0 °C
Final 24 hr done @	1.0 °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	14	0	13	0	13	0	11	0	11	0	12	0
plus 10 minutes	13	0	13	0	13	0	12	0	13	0	14	0
plus 20 minutes	13	0	13	0	11	0	11	0	13	0	14	0
plus 30 minutes	14	0	13	0	12	0	11	0	12	0	12	0
After second hour mixing	15	0	13	0	12	0	11	0	12	0	14	0
plus 10 minutes	15	0	15	0	12	0	12	0	0	0	13	0
plus 20 minutes	14	0	14	0	11	0	12	0	0	0	12	0
plus 30 minutes	16	0	14	0	12	0	12	0	0	0	12	0
After third hour mixing	16	0	15	0	12	0	12	0	0	0	12	0
plus 10 minutes	17	0	17	0	13	0	12	0	0	0	12	0
plus 20 minutes	17	0	17	0	12	0	12	0	0	0	12	0
plus 30 minutes	17	0	17	0	11	0	12	0	0	0	12	0
After fourth hour mixing	23	0	23	0	16	0	12	0	11	0	12	0
plus 10 minutes	20	0	20	0	12	0	11	0	0	0	12	0
plus 20 minutes	20	0	21	0	11	0	11	0	0	0	12	0
plus 30 minutes	18	0	21	0	11	0	11	0	11	0	12	0
plus 24 hour	23	0	24	0	11	0	11	0	11	0	12	0

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Very likely	Unlikely	Unlikely
Stability Index	Meso-stable	Unstable	Unstable
Water Content (after 24 hr)	57%	9%	13%

Test Results - 15°C

300ml H2O @	15.0 °C
oil @	40.0 °C
mixing done @	14.0 °C
settling done @	14.0 °C
Final 24 hr done @	15.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	#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	21	0	21	0	12	0	12	0	13	0	14	0
plus 10 minutes	20	0	19	0	11	0	12	0	12	0	13	0
plus 20 minutes	20	0	19	0	11	0	0	10	12	0	13	0
plus 30 minutes	20	0	19	0	0	10	0	10	12	0	13	0
After second hour mixing	23	0	23	0	15	0	15	0	14	0	15	0
plus 10 minutes	22	0	23	0	12	0	12	0	13	0	14	0
plus 20 minutes	22	0	22	0	12	0	12	0	12	0	13	0
plus 30 minutes	21	0	21	0	13	0	12	0	13	0	13	0
After third hour mixing	25	0	24	0	14	0	14	0	15	0	16	0
plus 10 minutes	22	0	22	0	12	0	12	0	13	0	15	0
plus 20 minutes	22	0	23	0	12	0	12	0	13	0	14	0
plus 30 minutes	23	0	23	0	12	0	12	0	13	0	14	0
After fourth hour mixing	25	0	25	0	16	0	16	0	15	0	14	0
plus 10 minutes	24	0	24	0	15	0	15	0	14	0	15	0
plus 20 minutes	24	0	24	0	14	0	14	0	14	0	15	0
plus 30 minutes	24	0	24	0	14	0	14	0	14	0	15	0
plus 24 hour	21	0	20	0	13	0	14	0	12	0	11	0

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Very likely	Likely	Unlikely
Stability Index	Meso-stable	Entrained	Unstable
Water Content (after 24 hr)	51%	26%	13%

Viscosity Measurements with Brookfield DV-III+ Rheometer

Viscosity

Temperature		1				15		
	Viscosity	RPM	Spindle	Shear Rate	Viscosity	RPM	6.0	Shear Rate
Fresh	977.0	8.0	CP-42	30.7	241.9	30.0	CP-42	115.0
2 Day Weathered	6487.0	16.0	CP-52	32.0	1377.0	5.0	CP-42	19.2
2 Week Weathered	15205.0	8.0	CP-52	16.0	2573.0	2.0	CP-42	7.7

Measurements @ °C 15.0

	Spindle	RPM	% Torque	Viscosity cP	Shear Rate	Temp °C	
Fresh	CP-42	15	27.2	232.1	57.6	15.0	
		30	56.7	241.9	115.0	15.0	<=====
		45	90.0	256.0	173.0	15.0	
		60	-over-		230.0	15.0	
2 Day Weathered	CP-42	1	9.8	1254.0	3.8	15.0	
		2	20.6	1318.0	7.7	15.0	
		3	31.9	1361.0	11.5	15.0	
		4	42.5	1360.0	15.4	15.0	
		5	53.8	1377.0	19.2	15.0	<=====
2 Week Weathered	CP-42	1	17.4	2227.0	3.8	15.0	
		2	40.2	2573.0	7.7	15.0	<=====
		3	60.2	2569.0	11.5	15.0	
		4	76.9	2461.0	15.4	15.0	
		5	98.7	2527.0	19.2	15.0	
Fresh	CP-42	1	9.9	1267.0	3.8	1.0	
		2	16.8	1075.0	7.7	0.9	
		4	29.1	931.2	15.4	1.0	
		8	61.1	977.0	30.7	1.0	<=====
		10	78.6	1006.0	38.4	1.0	
		12	95.0	1013.0	46.1	1.0	
		14	-over-		53.8	0.9	
2 Day Weathered	CP-52	1	1.2	2381.0	2.0	1.0	
		2	4.5	4465.0	4.0	1.0	
		4	11.0	5457.0	8.0	1.0	
		8	14.5	6077.0	16.0	1.0	
		10	32.2	6390.0	20.0	1.0	
		12	38.9	6433.0	24.0	1.0	
		14	44.9	6364.0	28.0	1.0	
		16	52.3	6487.0	32.0	1.0	<=====
2 Week Weathered	CP-52	1	4.9	9724.0	2.0	1.0	
		2	14.1	13990.0	4.0	1.0	
		4	30.1	14993.0	8.0	1.0	
		8	61.3	15205.0	16.0	1.0	<=====
		10	78.0	15478.0	20.0	1.0	
		12	93.1	15396.0	24.0	1.0	
		14	-over-		28.0	0.9	

A.3 CRW Condensate

Oil Weathering		**CRW Condensate**						Modeling Inputs:
	1.5 Hour	6 Hour	Average Air Temp	Volume Weathered(ml)	900	288.2	K	Temp(°C)
	Tray x	Tray y	°C	Volume for 2cm thick	969.5	0.00526366	m/s	Wind Speed (knots)
Tray Mass (g)	241.5	243.1	16.7	Tray thickness (m)	0.018566	0.001	m	Thickness (mm)

Date/Time	Mass of Oil + Tray 1.5 Hour (g)	Mass of Oil + Tray 6 Hour (g)	Mass of Oil 1.5 Hour (g)	Mass of Oil 6 Hour (g)	Fm 1.5 Hour	Fm 6 Hour	Oil Density (g/cm^3)	Fv 1.5 Hour	Fv 6 Hour	Evaporative Exposure (Corrected)	Automated Model Evaporate (Fv)	Elapsed Time 2 (hr)	Evaporative Exposure 2
19/10/2005 10:29	899.1	896.7	657.6	653.6	0.000	0.000	0.731	0.000	0.000	0	0.000	0	0
19/10/2005 11:03	667.0	666.4	425.5	423.3	0.353	0.352	0.788	0.399	0.399	594	0.395	12	227390
19/10/2005 11:29	619.7	624.7	378.2	381.6	0.425	0.416	0.798	0.473	0.465	1048	0.475	24	454780
19/10/2005 12:05	557.3	565.6	315.8	322.5	0.520	0.507	0.812	0.568	0.556	1677	0.543	36	682170
19/10/2005 12:33	removed	530.6		287.5		0.560	0.821		0.608	2166	0.580	48	909561
19/10/2005 13:13		499.9		256.8		0.607	0.829		0.653	2864	0.621	60	1136951
19/10/2005 13:44		480.9		237.8		0.636	0.833		0.681	3406	0.646	72	1364341
19/10/2005 14:45		456.9		213.8		0.673	0.839		0.715	4471	0.686	84	1591731
19/10/2005 15:43		440.7		197.6		0.698	0.843		0.738	5484	0.716	96	1819121
19/10/2005 16:16		434.1		191.0		0.708	0.845		0.747	6061	0.731	108	2046511
19/10/2005 16:35		431.0		187.9		0.713	0.845		0.751	6392	0.739	120	2273901
		removed											

	1.5 Hour	6 Hour
Fm	0.520	0.713

	1.5 Hour	6 Hour
Fv	0.568	0.751

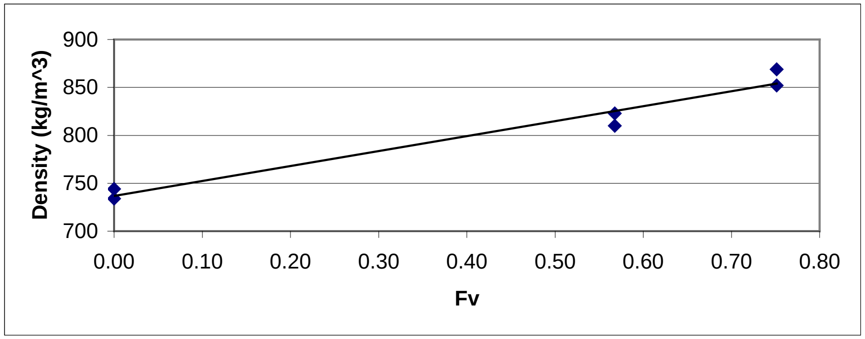
Density CRW Condensate

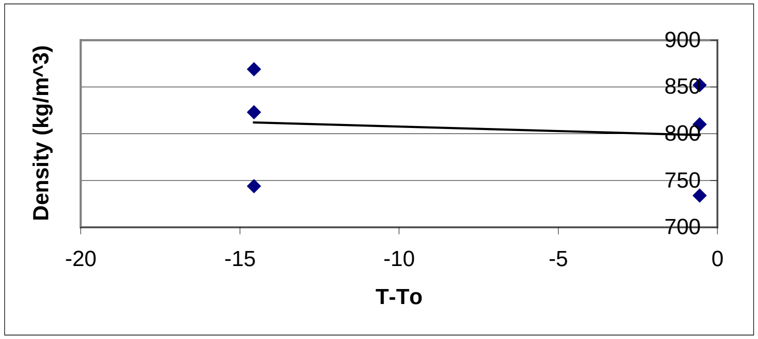
Mass Evaporated (Fm)	Density (g/cm^3)	Temperature (°C)
0	0.744	1.0
0	0.734	15.0
0.52	0.823	1.0
0.52	0.810	15.0
0.71	0.869	1.0
0.71	0.852	15.0
0	0.733	16.71
0.52	0.808	16.71
0.71	0.850	16.71

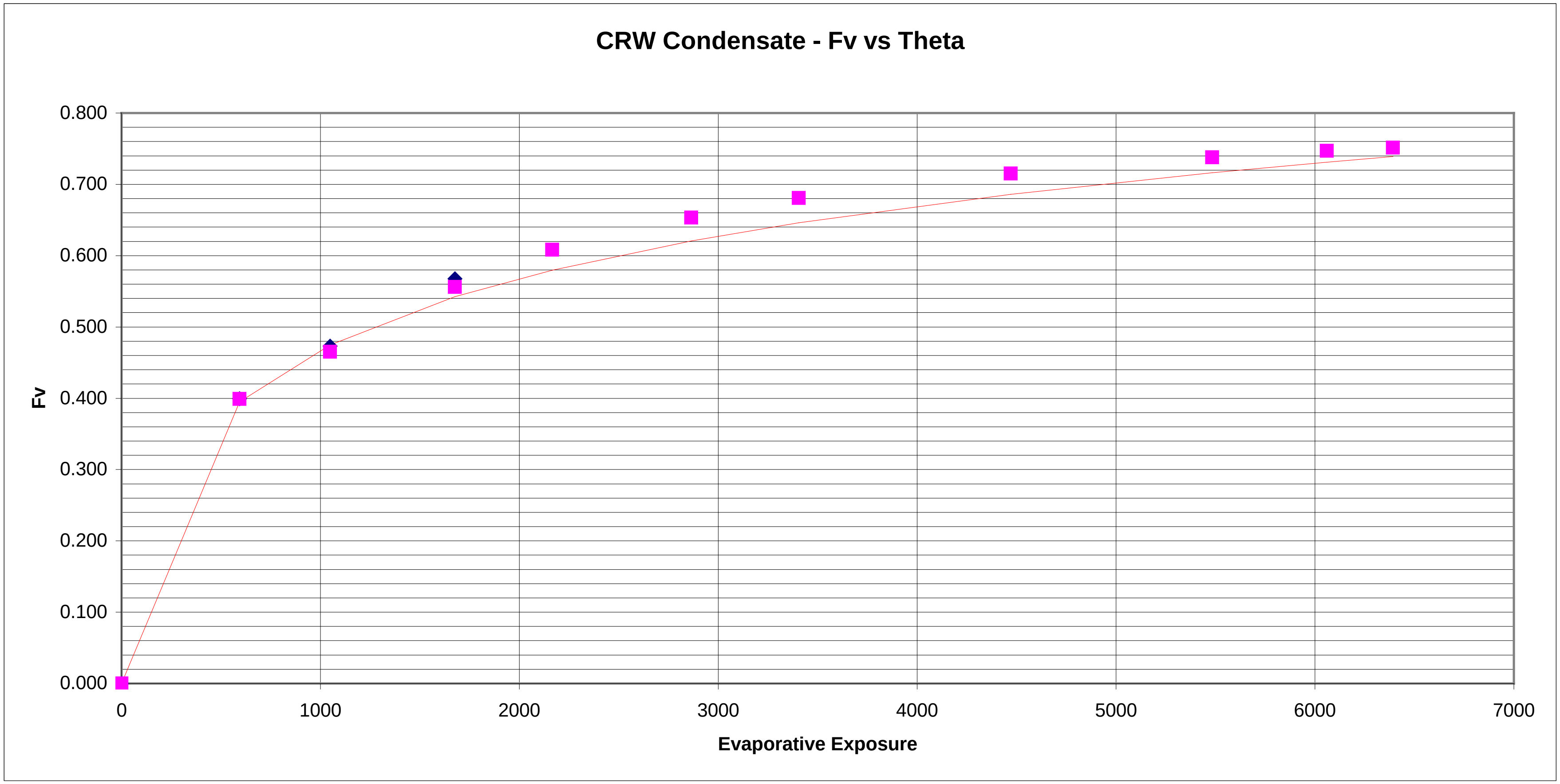
slope	0.160
intercept	0.731
r^2	0.991

Temperature (°C)	Density (g/cm^3)	Density (kg/m^3)	Volume Evaporated (Fv)	T-To (K)
1	0.744	744	0	-14.56
1	0.823	823	0.568	-14.56
1	0.869	869	0.751	-14.56
15	0.734	734	0	-0.56
15	0.810	810	0.568	-0.56
15	0.852	852	0.751	-0.56
15.5	0.851	851	0.000	

Density Constant 1 (slope, kg/m^3)	155.721
Standard Density Temperature, To (K)	288.72
Density Constant 2 (kg/K.m^3)	0.952
Standard Density (kg/m^3)	733.600
API Gravity @ 15.5°C	61.38






CRW Condensate - Fv vs Theta
Fv
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
0
1000
2000
3000
4000
5000
6000
7000
Evaporative Exposure

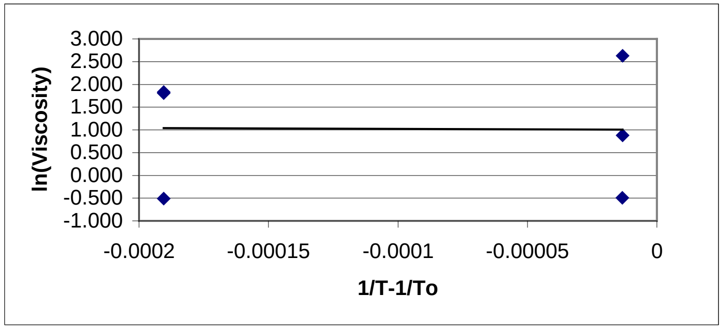
Viscosity CRW Condensate

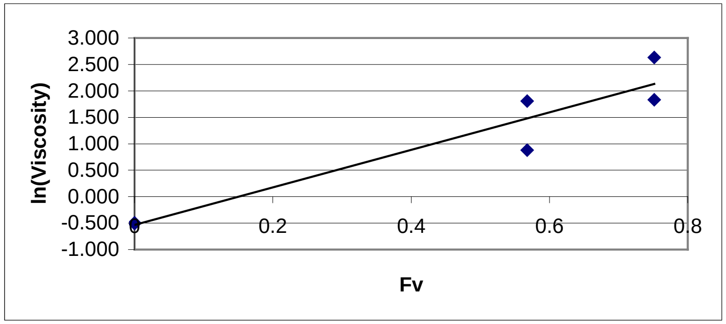
Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	0.6	1.0	250.0	CP-42	960.0	-0.494
0	0.6	15.0	250.0	CP-42	960.0	-0.511
0.52	2.4	1.0	250.0	CP-42	960.0	0.880
0.52	6.1	15.0	250.0	CP-42	960.0	1.807
0.71	13.9	1.0	250.0	CP-42	960.0	2.632
0.71	6.3	15.0	250.0	CP-42	960.0	1.833

Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	0.6	1.0	-0.494	-1.3353E-05
0	0.6	15.0	-0.511	-0.000190443
0.57	2.4	1.0	0.880	-1.322E-05
0.57	6.1	15.0	1.807	-0.000190443
0.75	13.9	1.0	2.632	-1.322E-05
0.75	6.3	15.0	1.833	-0.000190443

Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	0.61
Viscosity Constant 1	3.55
Viscosity Constant 2 (K^{-1})	-204.94

Volume Evaporated (Fv)	Viscosity 1°C (cP)	Viscosity 15°C (cP)
0	0.6	0.6
0.57	2.4	6.1
0.75	13.9	6.3





Pour Point — CRW Condensate

Test Results

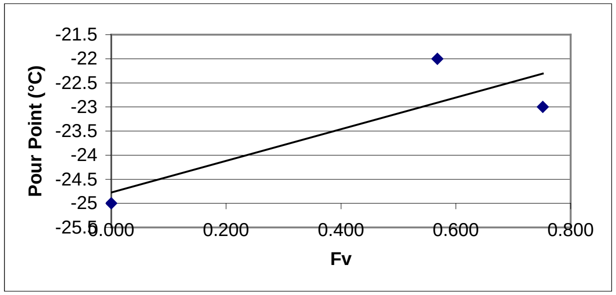
NB All fresh and weathered sample Pour Points below -22°C; Initial and slope "made up

Fv	Pour Point Measured (°C)	Pour Point Reported (°C)
0.000	< -25	-25
0.568	< -22	-22
0.751	< -23	-23

slope 3.282728
intercept -24.7769

Pour Point Constants for SLR Spill Model

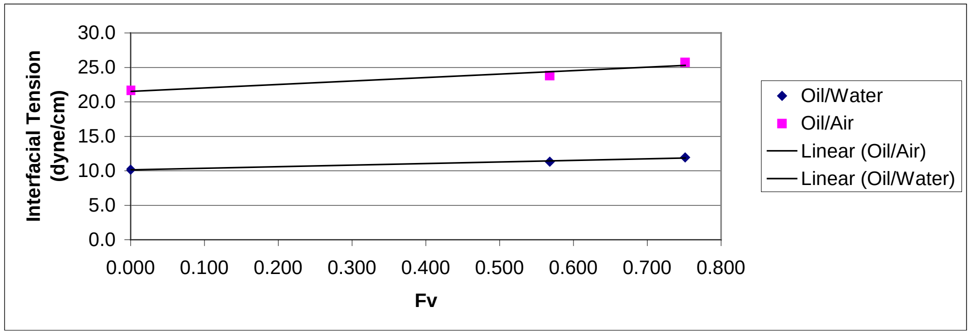
Initial Pour Point (K)	248.373104
Pour Point Constant	0.013216924



Interfacial Tension — CRW Condensate

Fv	Interfacial Tension Oil/Water (dyne/cm)	Interfacial Tension Oil/Air (dyne/cm)	Dial Reading Oil/Water (dyne/cm)	Dial Reading Oil/Air (dyne/cm)	Correction Factor Oil/Water	Correction Factor Oil/Air
0.000	10.2	21.7	11.2	24.4	0.91	0.89
0.568	11.3	23.8	12.3	26.7	0.93	0.89
0.751	11.9	25.7	12.7	28.9	0.94	0.89
slope	2.292	4.997				
intercept	10.136	21.531				

Oil/Water Interfacial Tension (dyne/cm)	10.136
Oil/Water Interfacial Tension Constant	0.226
Oil/Air Interfacial Tension (dyne/cm)	21.531
Oil/Air Interfacial Tension Constant	0.232



Flash Point **CRW Condensate**

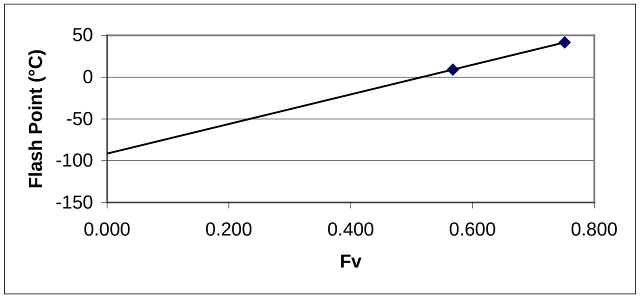
Test Results

Fv	Flash Point Measured (°C)	
0.000		Below -5°C
0.568	9	
0.751	41.5	

slope	176.985043
intercept	181.657629

Flash Point Constants for SLR Spill Model

Initial Flash Point (K)	181.658
Flash Point Constant	0.974



SL Ross Model

Modeling Constants	**CRW Condensate**	
Standard Density	733.600	kg/m3
Standard Density Temperature	288.720	K
Density Constant 1	155.721	kg/m3
Density Constant 2	0.95238	kg/K.m3
Standard Viscosity	0.61072	cP
Standard Viscosity Temperature	273.160	K
Viscosity Constant 1	3.5473	
Viscosity Constant 2	-204.94	K-1
Oil/Water Interfacial Tension	10.1358	dyne/cm
Air/Oil Interfacial Tension	21.5308	dyne/cm
Oil/Water Interfacial Tension Constant	0.22612	
Air/Oil Interfacial Tension Constant	0.23210	
Initial Pour Point	248.373	K
Pour Point Constant	0.01322	
ASTM Distillation Constant A (slope)	263.573	K
ASTM Distillation Constant B (intercept)	321.247	K
Emulsification Delay	9999999999	
Initial Flash Point	181.658	K
Flash Point Constant	0.97428	
Fv vs. Theta A	2.46875	
Fv vs. Theta B	7.38279	
B.Tg	1945.91	
B.To	2371.70	

Emulsification Formation - Tendency and Stability

CRW Condensate

Test Results - 0°C

300ml H2O @	1.0 °C
mixing done @	1.0 °C
settling done @	1.0 °C
Final 24 hr done @	1.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	#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	0	10	0	10	0	10	11	0	10	0	11	0
plus 10 minutes	0	10	0	10	0	10	11	0	11	0	11	0
plus 20 minutes	0	10	0	10	0	10	11	0	10	0	11	0
plus 30 minutes	0	10	0	10	0	10	11	0	10	0	11	0
After second hour mixing	0	10	0	10	0	10	12	0	10	0	11	0
plus 10 minutes	0	10	0	10	0	10	11	0	11	0	11	0
plus 20 minutes	0	10	0	10	0	10	11	0	11	0	12	0
plus 30 minutes	0	10	0	10	0	10	11	0	11	0	11	0
After third hour mixing	0	10	0	10	0	10	10	0	10	0	11	0
plus 10 minutes	0	10	0	10	0	10	11	0	11	0	11	0
plus 20 minutes	0	10	0	10	0	10	11	0	11	0	12	0
plus 30 minutes	0	10	0	10	0	10	11	0	11	0	12	0
After fourth hour mixing	0	9	0	10	0	10	10	0	11	0	11	0
plus 10 minutes	0	10	0	10	0	10	11	0	11	0	12	0
plus 20 minutes	0	10	0	10	0	10	11	0	11	0	11	0
plus 30 minutes	0	10	0	10	0	10	11	0	10	0	11	0
plus 24 hour	0	10	0	10	0	10	10	0	10	0	11	0

Conclusions:	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Unlikely	Unlikely	Unlikely
Stability Index	Unstable	Unstable	Unstable
Water Content (after 24 hr)	0%	0%	5%

Test Results - 15°C

300ml H2O @	15.0 °C
mixing done @	14.0 °C
settling done @	14.0 °C
Final 24 hr done @	15.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	#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	0	9	0	9	0	10	0	10	0	10	0	10
plus 10 minutes	0	10	0	9	0	10	0	10	0	10	0	10
plus 20 minutes	0	10	0	10	0	10	0	10	0	10	0	10
plus 30 minutes	0	10	0	10	0	10	0	10	0	10	0	10
After second hour mixing	0	9	0	9	11	0	11	0	13	0	11	0
plus 10 minutes	0	9	0	9	0	10	0	10	0	10	0	10
plus 20 minutes	0	9	0	9	0	10	0	10	0	10	0	10
plus 30 minutes	0	9	0	9	0	10	0	10	0	10	0	10
After third hour mixing	0	9	0	9	0	10	0	10	0	10	0	10
plus 10 minutes	0	10	0	9	0	10	0	10	0	10	0	10
plus 20 minutes	0	9	0	9	0	10	0	10	0	10	0	10
plus 30 minutes	0	9	0	9	0	10	0	10	0	10	0	10
After fourth hour mixing	0	9	0	9	0	10	0	10	0	10	0	10
plus 10 minutes	0	9	0	9	0	10	0	10	0	10	0	10
plus 20 minutes	0	9	0	9	0	10	0	10	0	10	0	10
plus 30 minutes	0	9	0	9	0	10	0	10	0	10	0	10
plus 24 hour	0	9	0	9	0	10	0	10	0	10	0	10

Conclusions:

	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Unlikely	Unlikely	Unlikely
Stability Index	Unstable	Unstable	Unstable
Water Content (after 24 hr)	0%	0%	0%

Viscosity Measurements with Brookfield DV-III+ Rheometer

Viscosity

Temperature		1.0				15.0		
	Viscosity	RPM	Spindle	Shear Rate	Viscosity	RPM	6.0	Shear Rate
Fresh	0.6	250.0	CP-42	960.0	0.6	250.0	CP-42	960.0
1.5 Hour	2.4	250.0	CP-42	960.0	6.1	250.0	CP-42	960.0
6 Hour	13.9	250.0	CP-42	960.0	6.3	250.0	CP-42	960.0

Measurements @ °C		30.0					
	Spindle	RPM	% Torque	Viscosity cP	Shear Rate	Temp °C	
Fresh	CP-42	250	1.0	0.6	960.0	15.0	<=====
1.5 Hour	CP-42	15	0.0	0.0	57.6	15.0	
		30	0.2	0.9	115.0	15.0	
		45	0.4	1.1	173.0	15.0	
		60	0.8	1.7	230.0	15.0	
		90	3.6	5.1	346.0	15.0	
		120	-1.8	-	461.0	15.0	
		180	3.0	2.1	691.0	15.0	
		250	11.9	6.1	960.0	15.0	<=====
6 Hour	CP-42	15	0.6	5.1	57.6	15.0	
		30	1.3	5.6	115.0	15.0	
		45	2.1	6.0	173.0	15.0	
		60	2.8	6.0	230.0	15.0	
		90	5.4	7.5	346.0	15.0	
		120	4.2	4.5	461.0	15.0	
		180	7.7	5.5	691.0	15.0	
		250	12.2	6.3	960.0	15.0	<=====
Fresh	CP-42	15	0.0	0.0	57.6	1.0	
		30	0.0	0.0	115.0	1.0	
		45	0.0	0.0	173.0	1.0	
		60	0.1	0.2	230.0	1.0	
		90	0.3	0.4	346.0	1.0	
		120	0.5	0.5	461.0	1.0	
		180	0.8	0.6	691.0	1.0	
		250	1.2	0.6	960.0	1.0	<=====
1.5 Hour	CP-42	15	0.1	0.9	57.6	1.0	
		30	0.4	1.7	115.0	1.0	
		45	0.7	2.0	173.0	1.0	
		60	1.0	2.1	230.0	1.0	
		90	1.6	2.3	346.0	1.0	
		120	2.2	2.4	461.0	1.0	
		180	3.4	2.4	691.0	0.9	
		250	4.7	2.4	960.0	0.9	<=====
6 Hour	CP-42	15	1.8	15.4	57.6	1.0	
		30	3.6	15.4	115.0	1.0	
		45	5.3	15.1	173.0	1.0	
		60	7.1	15.1	230.0	1.0	
		90	10.6	15.1	346.0	1.0	
		120	13.9	14.8	461.0	1.0	
		180	20.0	14.2	691.0	1.0	
		250	27.2	13.9	960.0	1.0	<=====

A.4 Cold Lake Bitumen Diluted with Condensate

Oil Weathering — **Cold Lake Bitumen Diluted with Condensate**

	2 Day Tray x	2 Week Tray y	Average Air Temp °C
Tray Mass (g)	241.5	243.1	16.8

Volume Weathered(ml)	900
Volume for 2cm thick	969.5
Tray thickness (m)	0.018566

Modeling Inputs:

288.2	K	Temp(°C)
0.00526366	m/s	Wind Speed (knots)
0.001	m	Thickness (mm)

Automated

Date/Time	Mass of Oil + Tray 2 Day (g)	Mass of Oil + Tray 2 Week (g)	Mass of Oil 2 Day (g)	Mass of Oil 2 Week (g)	Fm 2 Day	Fm 2 Week	Oil Density (g/cm³)	Fv 2 Day	Fv 2 Week	Evaporative Exposure (Corrected)	Model Evaporate (Fv)	Elapsed Time 2 (hr)	Evaporative Exposure 2
17/10/2005 11:01	1049.7	1062.3	808.2	819.2	0.000	0.000	0.935	0.000	0.000	0	0.000	0	0
17/10/2005 11:29	1035.2	1050.0	793.7	806.9	0.018	0.015	0.940	0.024	0.021	616	0.020	12	227390
17/10/2005 11:59	1028.9	1045.2	787.4	802.1	0.026	0.021	0.942	0.033	0.029	1276	0.032	24	454780
17/10/2005 12:28	1023.5	1041.2	782.0	798.1	0.032	0.026	0.944	0.042	0.035	1913	0.039	36	682170
17/10/2005 12:59	1018.9	1037.0	777.4	793.9	0.038	0.031	0.946	0.049	0.042	2595	0.045	48	909561
17/10/2005 13:29	1014.4	1033.8	772.9	790.7	0.044	0.035	0.947	0.056	0.047	3255	0.050	60	1136951
17/10/2005 13:59	1011.4	1030.5	769.9	787.4	0.047	0.039	0.948	0.061	0.053	3915	0.054	72	1364341
17/10/2005 15:00	1005.5	1025.9	764.0	782.8	0.055	0.044	0.950	0.070	0.060	5256	0.060	84	1591731
17/10/2005 16:00	1001.2	1022.4	759.7	779.3	0.060	0.049	0.952	0.077	0.066	6576	0.065	96	1819121
17/10/2005 16:49	998.1	1020.0	756.6	776.9	0.064	0.052	0.953	0.082	0.070	7653	0.068	108	2046511
18/10/2005 10:40	971.5	996.5	730.0	753.4	0.097	0.080	0.963	0.124	0.108	31207	0.101	120	2273901
18/10/2005 13:25	969.1	995.1	727.6	752.0	0.100	0.082	0.964	0.127	0.110	34835	0.103	132	2501291
18/10/2005 15:30	967.1	993.6	725.6	750.5	0.102	0.084	0.964	0.130	0.112	37584	0.105	144	2728682
18/10/2005 16:45	966.2	993.0	724.7	749.9	0.103	0.085	0.965	0.131	0.113	39234	0.106	156	2956072
19/10/2005 9:26	958.8	989.1	717.3	746.0	0.112	0.089	0.966	0.142	0.119	61248	0.117	168	3183462
19/10/2005 11:06	958.1	988.5	716.6	745.4	0.113	0.090	0.967	0.143	0.120	63447	0.118	180	3410852
19/10/2005 12:33	removed	987.6		744.5		0.091	0.967		0.122	65360	0.118	192	3638242
19/10/2005 14:41		987.5		744.4		0.091	0.967		0.122	68175	0.119	204	3865632
19/10/2005 15:43		987.3		744.2		0.092	0.967		0.122	69539	0.120	216	4093022
19/10/2005 16:39		987.0		743.9		0.092	0.967		0.123	70770	0.120	228	4320412
20/10/2005 9:30		984.5		741.4		0.095	0.968		0.127	93004	0.127	240	4547803
20/10/2005 16:08		982.6		739.5		0.097	0.969		0.130	101757	0.129	252	4775193
21/10/2005 15:31		979.1		736.0		0.102	0.971		0.135	132612	0.135	264	5002583
24/10/2005 9:14		970.7		727.6		0.112	0.974		0.148	219327	0.147	276	5229973
24/10/2005 16:30		970.1		727.0		0.113	0.975		0.149	228915	0.148	288	5457363
25/10/2005 9:05		968.1		725.0		0.115	0.976		0.152	250797	0.150	300	5684753
25/10/2005 15:14		967.7		724.6		0.115	0.976		0.153	258912	0.151	312	5912143
26/10/2005 8:41		965.9		722.8		0.118	0.976		0.156	281938	0.153	324	6139534
26/10/2005 9:52		965.4		722.3		0.118	0.977		0.156	283499	0.153	336	6366924
26/10/2005 16:55		965.4		722.3		0.118	0.977		0.156	292802	0.154	348	6594314
27/10/2005 7:45		964.3		721.2		0.120	0.977		0.158	312375	0.155	360	6821704
27/10/2005 16:55		963.2		720.1		0.121	0.978		0.160	324470	0.156	372	7049094
28/10/2005 9:14		962.5		719.4		0.122	0.978		0.161	346001	0.158	384	7276484
28/10/2005 16:00		961.8		718.7		0.123	0.978		0.162	354929	0.158	396	7503874
31/10/2005 9:20		957.6		714.5		0.128	0.980		0.168	441138	0.163	408	7731264
31/10/2005 11:00		956.6		713.5		0.129	0.981		0.170	443337	0.164	420	7958655
		removed											

	2-day	2-week
Fm	0.113	0.129
Fv	0.143	0.170

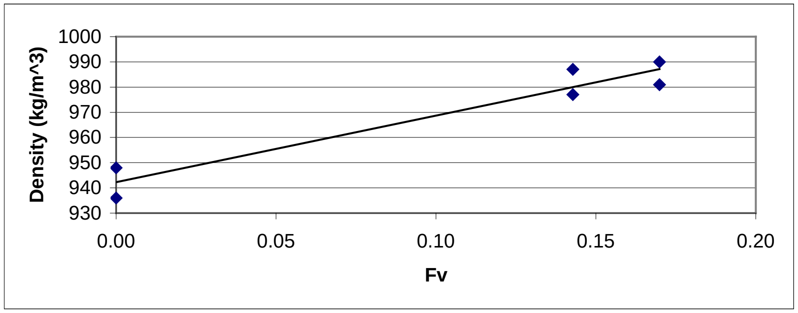
Density **Cold Lake Bitumen Diluted with Condensate**

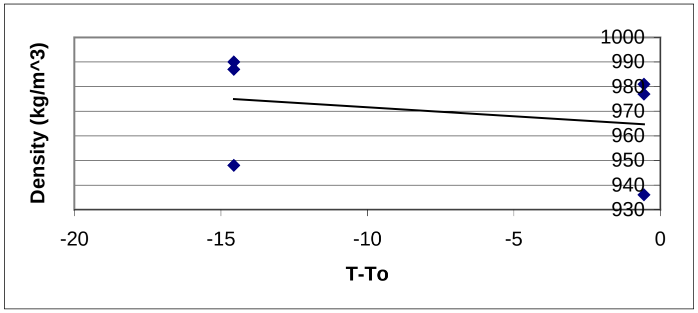
Mass Evaporated (Fm)	Density (g/cm^3)	Temperature (°C)
0	0.948	1.0
0	0.936	15.0
0.113	0.987	1.0
0.113	0.977	15.0
0.129	0.990	1.0
0.129	0.981	15.0
0	0.934	16.78
0.113	0.976	16.78
0.129	0.980	16.78

slope	0.356
intercept	0.935
r^2	0.999

Temperature (°C)	Density (g/cm^3)	Density (kg/m^3)	Volume Evaporated (Fv)	T-To (K)
1	0.948	948	0	-14.56
1	0.987	987	0.143	-14.56
1	0.990	990	0.170	-14.56
15	0.936	936	0	-0.56
15	0.977	977	0.143	-0.56
15	0.981	981	0.170	-0.56
15.5	0.981	981	0.152	

Density Constant 1 (slope, kg/m^3)	264.037
Standard Density Temperature, To (K)	288.72
Density Constant 2 ($kg/K.m^3$)	0.738
Standard Density (kg/m^3)	935.520
API Gravity @ 15.5°C	19.75





Wind Tunnel Calibration **Toluene**

Tray Mass (g)

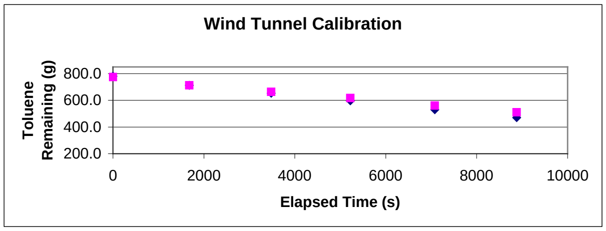
Elapsed Time (s)	Mass Toluene Tray 2 (g)	Tray 5 (g)	Tray 8 (g)	Tray 11 (g)	
0	780.7	773.7	779.3	781.6	
1680	712.2	711.9	718.5	709.0	
3480	652.5	663.0	672.7	654.7	
5220	596.2	616.5	628.6	604.2	
7080	529.6	560.7	576.2	543.1	
8880	470.3	510.4	529.3	490.0	
10680	411.4	461.3	483.9	438.1	
14340	284.6	345.1	367.6	310.1	
	Tray 2	Tray 5	Tray 8	Tray 11	
slope	-0.0342	-0.0292	-0.0278	-0.0319	
E (kg/s)	0.0000	0.0000	0.0000	0.0000	
Wind Tunnel Temperature, T (K)	289.9421	16.7821	°C		
Toluene Vapor Pressure, P (kPa)	2.4420				
Ideal Gas Constant (R, kPa.m^3/kg.mol.K)	8.3140				
Molecular Weight of Toluene (W, kg/kg.mol)	92.1300				
Tray Area (A, m^2)	0.0485				
	Tray 2	Tray 5	Tray 8	Tray 11	average
K = ERT/APW (m/s)	-0.0076	-0.0065	-0.0062	-0.0071	-0.0068

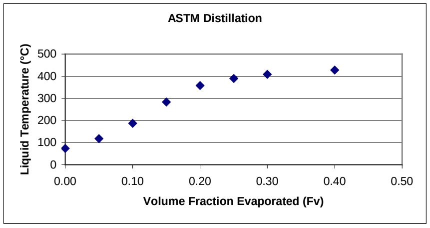
ASTM Distillation
Cold Lake Bitumen Diluted with Condensate
200 ml Fresh oil

Volume Distilled (mL)	Fraction Distilled (Fv)	Temperature Liquid (°C)	Vapor (°C)
IBP	0.00	74	36
10	0.05	118	59
20	0.10	187	62
30	0.15	283	105
40	0.20	358	227
50	0.25	390	282
60	0.30	408	321
80	0.40	428	336

slope 916.1
intercept 120.5

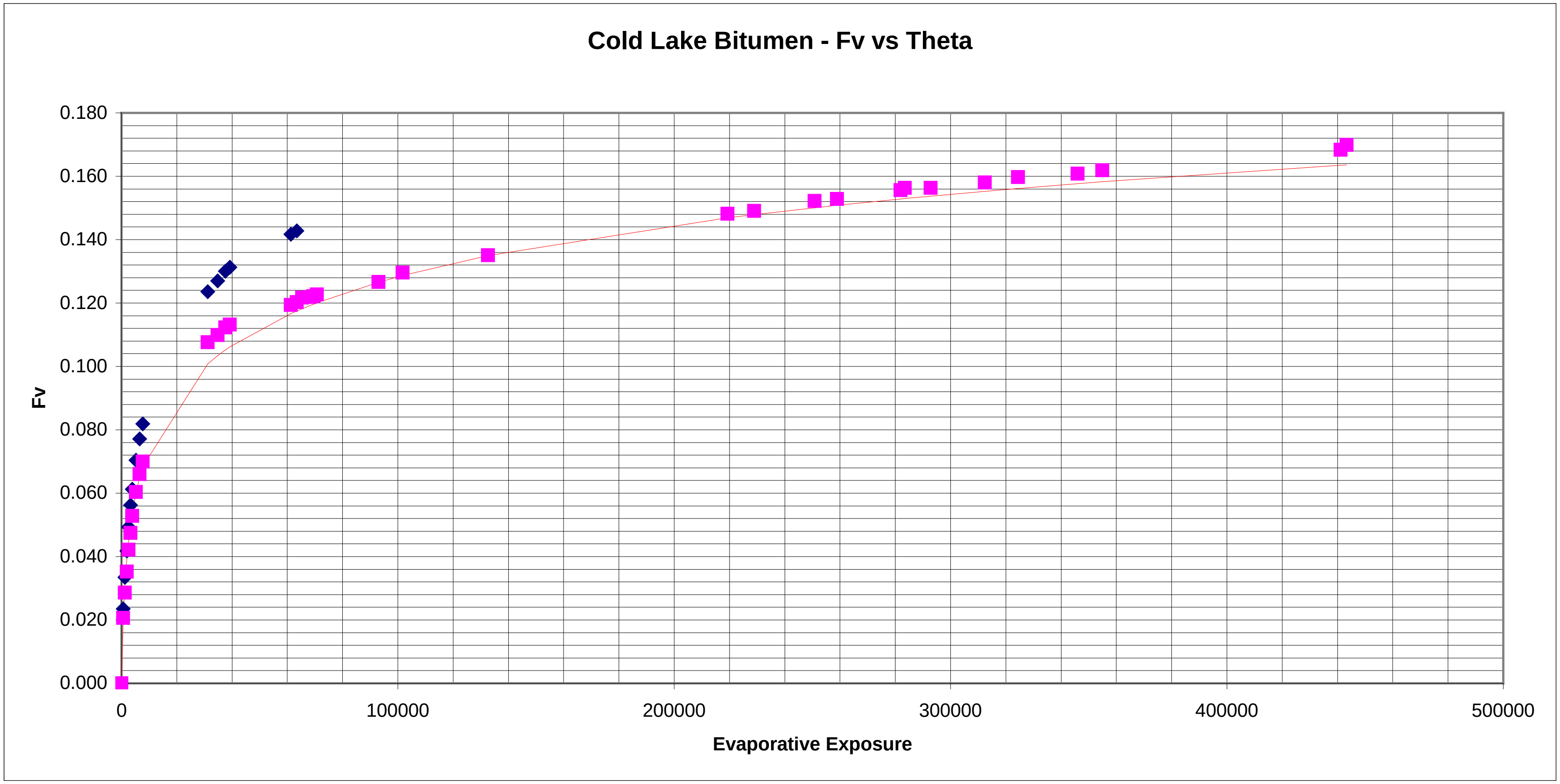
Distillation Constant A (slope, K) 916.1
Distillation Constant B (intercept, K) 393.7





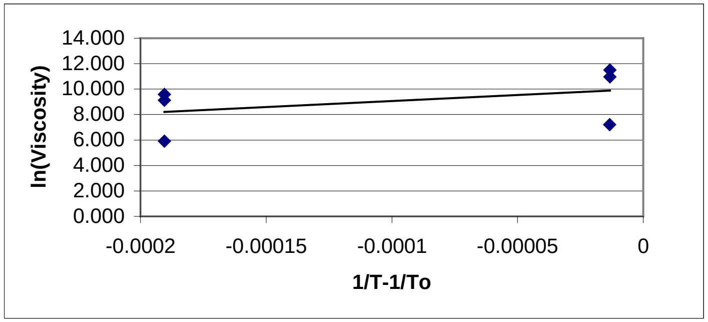
Mackay Constants (automated) **Cold Lake Bitumen Diluted with Condensate**

Point	Fv	Tb/T	H	ln(H)	
1	0.010	1.390	3.349E-05	-10.304	
2	0.025	1.436	1.210E-05	-11.322	
3	0.032	1.459	1.039E-05	-11.475	
4	0.039	1.480	1.017E-05	-11.496	
5	0.045	1.499	7.977E-06	-11.739	
6	0.050	1.516	8.202E-06	-11.711	
7	0.057	1.537	5.603E-06	-12.092	
8	0.063	1.557	4.318E-06	-12.353	
9	0.068	1.573	3.616E-06	-12.530	
10	0.089	1.638	1.601E-06	-13.345	
11	0.109	1.701	6.121E-07	-14.306	
12	0.111	1.709	8.645E-07	-13.961	
13	0.113	1.714	5.758E-07	-14.368	
14	0.116	1.725	2.799E-07	-15.089	
15	0.120	1.736	4.301E-07	-14.659	
16	0.121	1.740	7.410E-07	-14.115	
17	0.122	1.743	5.594E-08	-16.699	
18	0.122	1.743	2.309E-07	-15.281	
				calculated	adjusted
			Fv vs. Theta B (-slope)	13.307068	13.30707
			Fv vs. Theta A (intercept)	8.2047405	8.204741

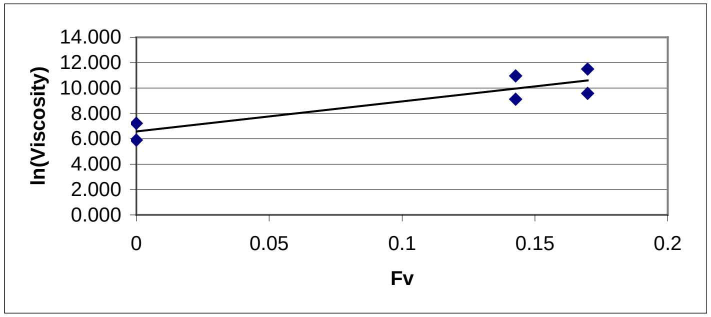

Cold Lake Bitumen - Fv vs Theta
Fv
0.180
0.160
0.140
0.120
0.100
0.080
0.060
0.040
0.020
0.000
0
100000
200000
300000
400000
500000
Evaporative Exposure

Viscosity Cold Lake Bitumen Diluted with Condensate

Mass Evaporated (Fm)	Viscosity (cP)	Temperature (°C)	rpm	Spindle #	Shear Rate (s^{-1})	ln(Viscosity)
0	1363.0	1.0	45.0	CP-52	90.0	7.217
0	368.0	15.0	8.0	CP-42	30.7	5.908
0.11	57548.0	1.0	2.0	CP-52	4.0	10.960
0.11	9227.0	15.0	8.0	CP-52	16.0	9.130
0.13	98625.0	1.0	1.0	CP-52	2.0	11.499
0.13	14486.0	15.0	4.0	CP-52	8.0	9.581



Volume Evaporated (Fv)	Viscosity (cP)	Temperature (°C)	ln(Viscosity)	1/T-1/To (K^{-1})
0	1363.0	1.0	7.217	-1.3353E-05
0	368.0	15.0	5.908	-0.000190443
0.14	57548.0	1.0	10.960	-1.322E-05
0.14	9227.0	15.0	9.130	-0.000190443
0.17	98625.0	1.0	11.499	-1.322E-05
0.17	14486.0	15.0	9.581	-0.000190443



Standard Viscosity Temperature (K)	273.16
Standard Viscosity (cP)	1496.63
Viscosity Constant 1	23.74
Viscosity Constant 2 (K^{-1})	9523.33

Volume Evaporated (Fv)	Viscosity 1°C (cP)	Viscosity 15°C (cP)
0	1363.0	368.0
0.14	57548.0	9227.0
0.17	98625.0	14486.0

Pour Point — Cold Lake Bitumen Diluted with Condensate

Test Results

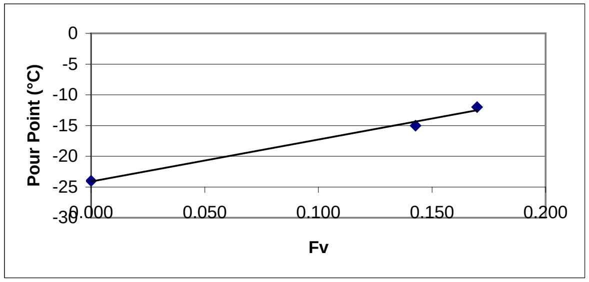
Fv	Pour Point Measured (°C)	Pour Point Reported (°C)
0.000	-25	-24
0.143	-17	-15
0.170	-14	-12

NB Fresh Pour Point <-25°C

slope	61.87233
intercept	-25.11471

Pour Point Constants for SLR Spill Model

Initial Pour Point (K)	248.0353
Pour Point Constant	0.24945



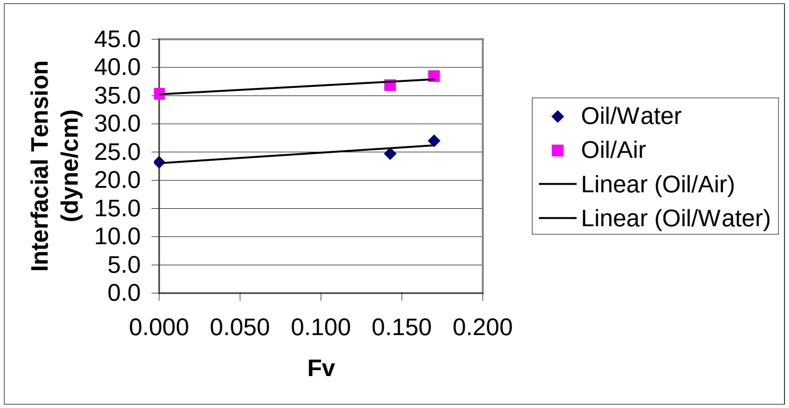
Interfacial Tension — Cold Lake Bitumen Diluted with Condensate

Fv	Interfacial Tension Oil/Water (dyne/cm)	Interfacial Tension Oil/Air (dyne/cm)
0.000	23.2	35.3
0.143	24.7	36.8
0.170	27.0	38.5

NB o/w too viscous for measurement

	Oil/Water	Oil/Air
slope	18.449	15.756
intercept	23.044	35.230

Oil/Water Interfacial Tension (dyne/cm)	23.044
Oil/Water Interfacial Tension Constant	0.801
Oil/Air Interfacial Tension (dyne/cm)	35.230
Oil/Air Interfacial Tension Constant	0.447



Flash Point — Cold Lake Bitumen Diluted with Condensate

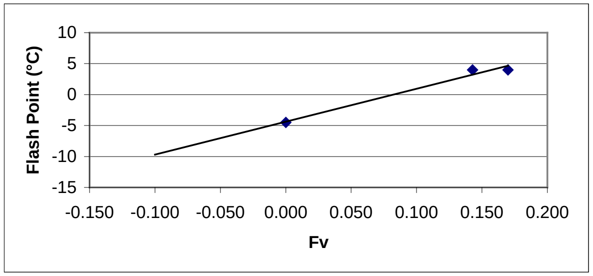
Test Results

Fv	Flash Point Measured (°C)	
0.000	-4.5	
0.143	4	Viscosity prevented lower temperature
0.170	4	Viscosity prevented lower temperature

slope 53.1765774
intercept 268.774857

Flash Point Constants for SLR Spill Model

Initial Flash Point (K)	268.775
Flash Point Constant	0.198



SL Ross Model

Modeling Constants	**Cold Lake Bitumen Diluted with Condensate**		
Standard Density	935.520	kg/m3	
Standard Density Temperature	288.720	K	
Density Constant 1	264.037	kg/m3	
Density Constant 2	0.73810	kg/K.m3	
Standard Viscosity	1496.62699	cP	
Standard Viscosity Temperature	273.160	K	
Viscosity Constant 1	23.7364		
Viscosity Constant 2	9523.33	K-1	
Oil/Water Interfacial Tension	23.0440	dyne/cm	
Air/Oil Interfacial Tension	35.2302	dyne/cm	
Oil/Water Interfacial Tension Constant	0.80060		NB 2-week sample too viscous
Air/Oil Interfacial Tension Constant	0.44722		for o/w measurement
Initial Pour Point	248.035	K	NB Fresh Pour Point <-25°C; used
Pour Point Constant	0.24945		-25 for model constant calcs
ASTM Distillation Constant A (slope)	916.148	K	
ASTM Distillation Constant B (intercept)	393.672	K	
Emulsification Delay	9999999999		
Initial Flash Point	268.775	K	
Flash Point Constant	0.19785		
Fv vs. Theta A	8.20474		
Fv vs. Theta B	13.30707		
B.Tg	12191.24		
B.To	5238.62		

Emulsification Formation - Tendency and Stability

Cold Lake Bitumen Diluted with Condensate

Test Results - 1°C

300ml H2O @	1.0 °C
oil @	44.0 °C
mixing done @	1.0 °C
settling done @	1.0 °C
Final 24 hr done @	1.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	#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	14	0	10	0	11	0	n/a	n/a	n/a	n/a
plus 10 minutes	13	0	14	0	11	0	12	0	n/a	n/a	n/a	n/a
plus 20 minutes	12	0	14	0	11	0	12	0	n/a	n/a	n/a	n/a
plus 30 minutes	12	0	12	0	11	0	12	0	n/a	n/a	n/a	n/a
After second hour mixing	17	0	17	0	10	0	10	0	n/a	n/a	n/a	n/a
plus 10 minutes	14	0	16	0	11	0	11	0	n/a	n/a	n/a	n/a
plus 20 minutes	13	0	15	0	11	0	11	0	n/a	n/a	n/a	n/a
plus 30 minutes	13	0	15	0	12	0	11	0	n/a	n/a	n/a	n/a
After third hour mixing	19	0	18	0	10	0	10	0	n/a	n/a	n/a	n/a
plus 10 minutes	15	0	17	0	11	0	11	0	n/a	n/a	n/a	n/a
plus 20 minutes	15	0	17	0	11	0	11	0	n/a	n/a	n/a	n/a
plus 30 minutes	15	0	17	0	11	0	11	0	n/a	n/a	n/a	n/a
After fourth hour mixing	18	0	19	0	8	0	8	0	n/a	n/a	n/a	n/a
plus 10 minutes	18	0	19	0	8	0	9	0	n/a	n/a	n/a	n/a
plus 20 minutes	16	0	18	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
plus 30 minutes	16	0	18	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
plus 24 hour	17	0	17	0	0	10	0	10	12	0	14	0

Conclusions:	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Likely	Unlikely	Unlikely
Stability Index	Entrained	Unstable	Unstable
Water Content (after 24 hr)	41%	0%	23%

Test Results - 15°C

300ml H2O @	15.0 °C
oil @	39.0 °C
mixing done @	14.0 °C
settling done @	14.0 °C
Final 24 hr done @	14.0 °C

two replicates of each oil

	Fresh Oil				Weathered Two Days				Weathered Two Weeks			
All measurements in mm	#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	25	0	22	0	0	10	0	10	0	6	0	6
plus 10 minutes	24	0	24	0	0	10	0	10	0	6	0	6
plus 20 minutes	24	0	25	0	0	10	0	10	0	5	0	7
plus 30 minutes	22	0	23	0	0	10	0	10	0	5	0	7
After second hour mixing	25	0	29	0	0	8	0	10	0	5	0	6
plus 10 minutes	25	0	26	0	0	10	0	10	0	5	0	6
plus 20 minutes	25	0	26	0	0	10	0	10	0	5	0	7
plus 30 minutes	26	0	28	0	0	10	0	10	0	5	0	7
After third hour mixing	25	0	28	0	0	9	0	9	0	5	0	6
plus 10 minutes	25	0	28	0	0	10	0	10	0	5	0	6
plus 20 minutes	25	0	29	0	0	10	0	10	0	5	0	7
plus 30 minutes	25	0	28	0	0	10	0	10	0	5	0	7
After fourth hour mixing	25	0	30	0	0	?	0	8	0	5	0	6
plus 10 minutes	25	0	32	0	0	10	0	10	0	5	0	7
plus 20 minutes	25	0	32	0	0	10	0	10	0	5	0	7
plus 30 minutes	25	0	31	0	0	10	0	10	0	5	0	7
plus 24 hour	20	0	23	0	0	10	0	10	0	4	0	6

Conclusions:	Fresh Oil	Weathered Two Days	Weathered Two Weeks
Tendency Index	Very likely	Unlikely	Unlikely
Stability Index	Meso-stable	Unstable	Unstable
Water Content (after 24 hr)	53%	0%	0%

Viscosity Measurements with Brookfield DV-III+ Rheometer

Viscosity

Temperature		1				15		
	Viscosity	RPM	Spindle	Shear Rate	Viscosity	RPM	6.0	Shear Rate
Fresh	1363.0	45.0	CP-52	90.0	368.0	8.0	CP-42	30.7
2 Day Weathered	57548.0	2.0	CP-52	4.0	9227.0	8.0	CP-52	16.0
2 Week Weathered	98625.0	1.0	CP-52	2.0	14486.0	4.0	CP-52	8.0

Measurements @ °C 15.0

	Spindle	RPM	% Torque	Viscosity cP	Shear Rate	Temp °C	
Fresh	CP-42	1	2.8	358.4	3.8	15.0	
		2	5.8	371.2	7.7	14.9	
		4	11.6	371.2	15.4	15.0	
		8	23.0	368.0	30.7	15.0	<=====
		10	28.7	367.0	38.4	15.0	
		12	34.5	368.0	46.1	15.0	
		14	40.1	366.6	53.8	15.0	
		16	46.1	368.8	61.4	15.0	
2 Day Weathered	CP-42	1	64.7	8282.0	3.8	15.0	
		2	-over				
	CP-52	1	4.6	9128.0	2.0	15.0	
		2	9.3	9227.0	4.0	15.0	
		4	18.6	9227.0	8.0	15.0	
		8	37.2	9227.0	16.0	15.0	<=====
		10	46.3	9188.0	20.0	15.0	
		12	55.7	9211.0	24.0	15.0	
		14	64.8	9185.0	28.0	15.0	
		16	74.1	9190.0	32.0	15.0	
2 Week Weathered	CP-52	1	6.7	13295.0	2.0	15.1	
		2	14.9	14784.0	4.0	15.0	
		4	29.2	14486.0	8.0	15.0	<=====
		8	59.2	14685.0	16.0	15.0	
		10	75.0	14883.0	20.0	15.0	
		12	90.0	14883.0	24.0	15.0	
		14	-over-		28.0	15.0	
Fresh	CP-52	15	10.3	1363.0	30.0	1.0	
		30	20.7	1369.0	60.0	1.0	
		45	30.9	1363.0	90.0	1.0	<=====
		60	41.0	1356.0	120.0	1.0	
		90	61.1	1347.0	180.0	1.0	
		120	81.0	1339.0	240.0	1.0	
		180	-over-		360.0	1.1	
2 Day Weathered	CP-52	1	29.1	57746.0	2.0	1.0	
		2	58.0	57548.0	4.0	1.0	<=====
		3	87.0	57548.0	6.0	1.0	
		4	-over-		8.0	0.9	
2 Week Weathered	CP-52	1	49.7	98625.0	2.0	1.0	<=====