European Commission
DG Environment

Properties of Russian Oils and the Applicability of dispersants

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Abbreviations

CEDRE - Centre de documentation de recherché et déxperimentations sur les pollutions accidentelles des eaux
EMSA – European Maritime Safety Agency
HELCOM – Helsinki Commission
IMO - International Maritime Organsisation
ITOPF – International Tanker Owners Pollution Federation Limited
Murmansk Centre of Centre for Standardization, Metrology and Certification
REBCO – Russian Export Blend Crude Oil
SRV Statens RäddningsVerk

Personnel of the partners involved in the project

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1 Abstract

The objective of the project “Recovery of Russian oil and the applicability of dispersants” was to analyse both Russian crude and bunker oil and determine chemical and physical properties, weathering of the oil and whether the oil is dispersible or not. Today the knowledge about Russian oils is limited. Only a few weathering studies have been performed. The information from weathering studies is important for oil spill response. Depending on how the oil will change over time different equipment and strategies have to be choosen for the response operation.
There are about 1800 oil fields in Russia and the different crude oils might be different. In Russia the oils are mixed to obtain a certain quality. Because of the amount of oil fields the crude oil will vary from day to day. The bunker oils are produced from crude oils and will also be different when compared to each other.

In this project one crude oil and one bunker oil were analysed. The crude oil was received from Neste Oil and the bunker oil was received from a ship in Denmark. The origin of the crude oil was from the pipeline between Jaroslavl to Primorsk. The bunker oil was an IFO 380, origin Vysotsk.

The transport of Russian oil through the Baltic Sea is increasing. From Primorsk 74,2 million tons of crude oil were exported in 2007. From the Murmansk area about 10 million tons of crude oil are transported along the Norwegian coast.

Because of the brackish water in the Baltic Sea as well as the low inflow of fresh sea water the Baltic Sea is a vulnerable environment.
Most dispersants are designed for waters with a salinity of 30 ‰ or more. In this study one objective was to find out if there are dispersants that work at lower salinity levels.

Results REBCO
The density which is below 950 g/L and will probably stay at the surface.
This Russian oil could emulsify with great quantities of water and the volume will increase, maximum water content is 72-87 %.
The flashpoint is below 60 °C. To make sure the flashpoint is above 60 °C recovery can not start immediately after oil is leaking into the water.
Mass balance - During winter condition almost no oil will disperse naturally when wind speed is no more than 5 m/s. If the wind is 15 m/s 70 % will be dispersed after five days and the rest will be evaporated and no oil will be at the surface. The pattern is similar at summer conditions.
The crude oil which was analysed was dispersable at 0 and 15 °C. If OSR 62 is used the the REBCO oil is dispersable during winter and summer conditions. In winter conditions the efficiency of the dispersant does not decrease very much. Dasic NS is sensitive to change in salinity

Results IFO 380 Vysotsk
The density which is just below 1000 g/L indicates that the oil might stay at the surface as well as sink into the water column.
The rate of evaporation is very low 2-3 %.
Maximum water content of the emulsion was about 50 % after three days at the laboratory test, the volume of the emulsion will be twice the volume of the spilt oil. The predicted viscosity of the emulsion (5 days) > 100 000 cP.

Mass balance - During winter condition there will be almost no dispersion or evaporation when wind speed is no more than 5 m/s. If the wind is 15 m/s 50 % will be dispersed after five days and the rest will be at the surface. The pattern is similar at summer conditions. The IFO 380 proved to be dispersable at summer temperature if OSR 62 was used. Dasic NS and Corexit 9500 seem to be very sensitive to salinity.

Future work

Further studies of bunker and crude oil transported in the Baltic Sea are important. As mentioned the Russian crude oil is a mixture of different oils. If weathering studies would be done over a period of time we would get information about the range within the results will fall.

One idea that has come up during the process is that if the weathering studies mentioned above it could be useful to make quick analysis of the oil could be done. Density, viscosity and pour-point are interesting properties. If this information is available in case of an incident it is easier to predict the behaviour of the oil as well as to predict how the oil will spread.

The work of this project will continue, at the next meeting of HELCOM Response Group Sweden will propose a way forward. We also hope funding for further weathering studies will be obtained at regional level. As mentioned this kind of information is important to all concerned response organisations.

2 Objective

The objective of the project “Recovery of Russian oil and the applicability of dispersants” was to analyse both Russian crude and bunker oil and determine chemical and physical properties, weathering of the oil and whether the oil is dispersible or not.
The results will increase the knowledge of how these oils will change after a spill as well as to determine how effective dispersants are when used in the response of an oil spill.
If we know about the weathering processes which affect spilt oil we will also be able to choose the equipment that will most likely be successful in a response situation. The weathering processes will change the behaviour of the oil over time after a spill. The main processes are evaporation, emulsification and dispersion

3 Introduction

This project was funded by the European Comission, Swedish Coast Guard, Finnish Environmental Institute, Danish Admiral Fleet, Norwegian Coastal Administration and Environment Agency of Iceland. The cost of the project were about 115 000 Euro and the duration of the project was from April 2007 until October 2008.
Response to oil spill can vary depending on the conditions at the location of the spill. Due to the sensitive ecological conditions in the Baltic Sea area, response to oil should take place by the use of mechanical means as far as possible according to HELCOM recommendation 22/2 (HELCOM, 2008). Within the Bonn Agreement there is a wide range of considerations concerning dispersion. Within the UK application of dispersants is the primary response option and in Sweden dispersants are not used (Bonn, 2008).

In an area like the Baltic Sea the weather conditions do not always favor mechanical response. In cases like this dispersants could be an option to protect wintering birds, spawning areas or other sensitive areas. In case of an oil spill, harmful substances are added to the water as well as to the shore if the oil reaches the shoreline. Knowledge of the chemical and physical properties of the oil is crucial when quick decisions are to be made to optimize the response of an oil spill.

The lack of information about the behaviour of Russian crude oil and bunker oil when the oil is spilt into the sea has been identified at different occasions in the last few years.
1. In 2004 the Swedish Coast Guard arranged a seminar for members of the Copenhagen Agreement where common difficulties concerning response techniques and the effect of the response in case of an oil spill were discussed. One of the conclusions was that it is very important to make sure that authorities responsible for response to oil spills increase their knowledge of Russian oil due to the oil transport Analysis can give a lot of information of chemical and physical properties as well as predict how weathering will change the properties of the oil after an oil spill.

2. In December 2005 European Maritime Safety Agency, EMSA, organised a workshop on the use of oil spill dispersants in European waters. At the workshop it was stated that more information about Russian oils was needed to predict weathering processes and the effectiveness of dispersant application.

3. Within HELCOM there is a project running called “Analysis of new opportunities for usage of dispersants in the Baltic Sea”. At the meeting in Karskrona in 2005 the lack of physical properties of crude oil and fuel oil transported in the Baltic Sea was mentioned as one obstacle to finish the project.

4. One of the suggestions of the Interreg project “Safety at Sea” (2004-2007) was to test at least three Russian crude oils to determine the weathering characteristics.

Dispersion is a process that will occur depending on wave and wind conditions. When the oil is dispersed oil droplets are spread in the water column. Chemical dispersion can, under favourable conditions, reduce both the threat of an oil slick to surface organisms and the amount of oil which will come ashore.
The second EMSA dispersant work shop “Towards a harmonised approach in dispersant usage in the EU” focused on harmonisation of testing and use of dispersants. One of the conclusions was that there are no real barriers to the harmonisation of dispersant product approval testing procedures, but there are regional considerations (such as salinity levels and oils transported) (EMSA, 2008).

3.1 Crude oil

Extract from Safety at Sea 2007. The following information in this section is from report A4 Demo 4 (Safety at Sea 2007) of the interreg project Safety at Sea were crude oil is described as a complex mixture of thousands of chemical components.
The relative compositions vary, giving rise to crude oils with different chemical and physical properties. Typical component groups in crude oils are shown in Figure 1.

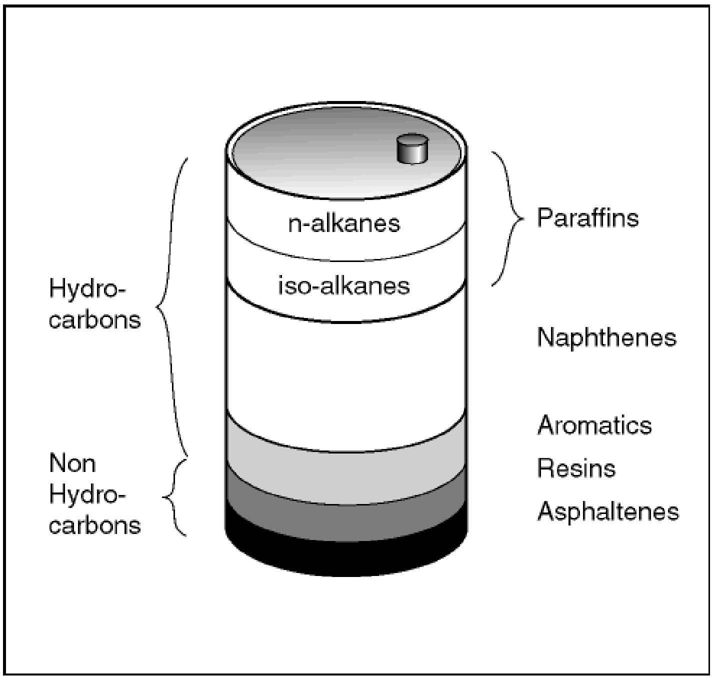

Figure 1 Chemical components in crude oil (Source SINTEF)

In Norway, crude oils are often classified into four categories based on their crude oil properties and properties at sea. The categories are developed by SINTEF and are illustrated in figure 6 section 5,1

- **Naphtenic oils**, characterized by a disrupted n-alkane pattern in the gas chromatogram due to biodegradation of the oil in the reservoir. The content of paraffines is therefore normally low. Typical properties: density 0,86-0,95 kg/m3, low pour point (<-10°C), low wax and asphaltene content, lacking n-alkanes, low to medium evaporation

- **Paraffinic oils**, often characterized by a low density which reflects a high content of light components (paraffines). Typical properties: density 0,80-0,85 kg/m3, medium pour point (ca. -10 to 6°C), medium wax content (<5 wt%), much light n-alkanes, medium to high evaporation

- **Asphaltenic oils**, with a high content of heavier components like aspahltenes and resins. The content of lighter components is correspondingly low, reflected by high density and low evaporation. Typical properties: high density (0,90-0,95 kg/m3), low pour point (<-10°C), high asphaltene content (> 0,4 wt%), low evaporation

- **Waxy oils**, often exhibit high pour points due to a large content of wax components. At low temperatures these oils may solidify at the sea surface, especially if the sea water temperature is 10-15°C below the pour point. Typical properties: high pour point (ca. 6 to 30°C), high wax content (>5 wt%), more heavy paraffins (>C30), medium evaporation

End of extract.

3.2 Fuel oil

Extract from Safety at Sea 2007. The following information in this section is from report A4 Demo 4 (Safety at Sea 2007) of the interreg project Safety at Sea were the following is described.
Crude oil is converted into refined oil products at an oil refinery. All oil refineries employ 'atmospheric distillation' (distillation conducted at atmospheric pressure) as the primary process for the conversion of crude oil into refined oil products (Figure 2). The crude oil is heated and split into 'fractions' on the basis of the range of boiling point. The 'lightest' fraction with the lowest boiling point range is petroleum gas (propane and butane).

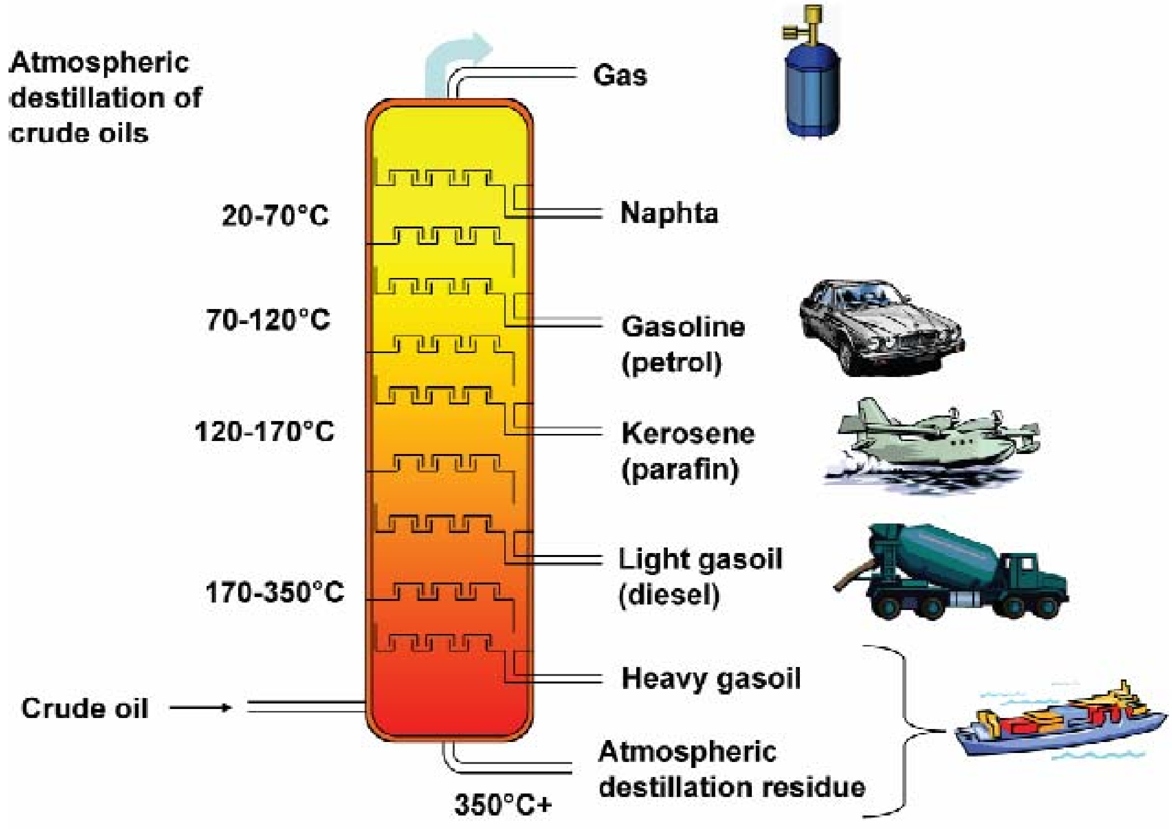

Figure 2 Atmospheric distillation of crude oils (Source SINTEF)

The main products of the atmospheric distillation of crude oil are distillate fuels, such as gasoline (petrol), kerosene (jet fuel), light gas oil (diesel fuel for cars and trucks) and heavy gas oil (fuel for some marine diesel engines in ships). The residue from the crude oil that does not distil below 350°C is known as the 'atmospheric residue' or 'long' residue.
An oil refinery that processes only 'light' crude oils that contain a very high proportion of the distillate fuels may not require any further processing. Some 'light' crude oils can be distilled into naphtha, gasoline, kerosene and diesel fuel and yield only a small proportion of atmospheric residue.
'Heavier' crude oils require more processing because they basically yield a lower proportion of distillate fuels and a higher proportion of atmospheric residue. This atmospheric residue is distilled again (under reduced pressure, although not a pure vacuum) in the 'Vacuum Distillation' process. The reduced pressure enables less volatile oil components to boil at

lower temperature. The distillates from vacuum distillations are Vacuum Distillates, such as Vacuum Gas Oil and some grades of lubricating oils. Not all of the atmospheric residue will be boiled at reduced pressure (at up to a temperature equivalent to 570°C at normal pressure) and some residue will remain. This is known as the ‘vacuum’ (or ‘vac’), or ‘short’ residue.

Distillates produced from paraffinic crude oils are of lower density and viscosity than equivalent materials produced from the heavier, asphaltic crude oil. The pour points of the distillates produced from the paraffinic crude oil are higher due to the higher wax content. Distillates produced by ‘cracking’ are of higher density and higher viscosity than the equivalent boiling range cut isolated by distillation. They also have higher Pour points and the sulphur is concentrated in the distillate by the cracking process.

Atmospheric distillation of the paraffinic crude oil produces a low density and low viscosity residue. The residue from vacuum distillation has a slightly higher density, but a much higher viscosity, being a deeper ‘cut’ into the atmospheric residue.

The densities of the residues from ‘cracking’ processes are much higher because the chemical structure of the oil has been changed by the cracking processes. Cracked residues contain a much higher proportion of unsaturated and aromatic material, compared to distillation residues. This is particularly noticeable for the cat cracker residue, which has a very high density, but the lowest viscosity because it is the residue from cracking a middle distillate fraction and not the whole crude oil. The density of the visbreaker residue is the highest of all the residues, yet its viscosity is between that of the atmospheric and vacuum residues. The asphaltene content of the residues is also increased by the cracking process.

The properties of the residues produced from the asphaltic crude oil also show similar trends, except that the crude oil is heavier, thus giving rise to higher density and viscosity residues in each process. The asphaltic crude oil residues have lower pour points, reflecting the higher wax content of the paraffinic crude oil. Similarly, the residues produced from the asphaltic crude oil have higher asphaltene contents than the equivalent residues produced from the paraffinic crude oil.
End of extract.

3.3 Transport of crude oil and fuel oil

The amount of Russian crude oil transported increases year by year in European waters. Russian crude oil is shipped from the Gulf of Finland, Murmansk and through the Mediterranean Sea. According to BP the Russian Federation exported 491,3 million tons of crude oil in 2007, 12,6 % of the total export of crude oil in the world (BP, 2008). The export of products was 94,4 (BP, 2008) million tons in 2007, bunker oil excluded. The amount of goods transported is also increasing. This increase in “movements” will also increase the risk of an oil spill in European waters.
There are more than 1800 oil fields in Russia. Oil from different fields is often mixed. This can lead to different blends from day to day. It can also mean that similar oils are shipped from Murmansk and the Baltic Sea.

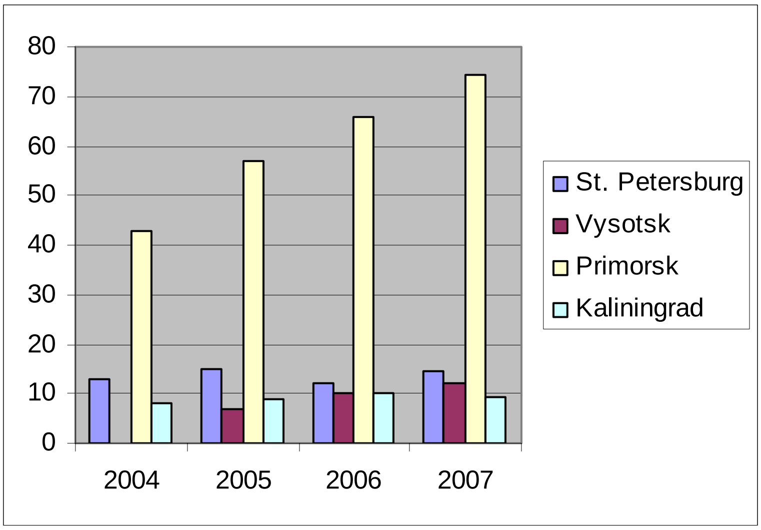

Figure 3 Export of oil from Russian ports in the Baltic Sea, million ton (Semanov, 2008)

In figure 3 the Export from Russian ports in the Baltic Sea during 2007 is presented in million tons.
Vysotsk 12,3 million tons 50 % fuel oil, St. Petersburg 14,7 million tons fuel oil, Primorsk 74,2 million tons crude oil, Kaliningrad 9,2 million tons (Semanov, 2008)

Crude and oil products are also exported from North-West Russia 9,8 millions tons in 2007. The number of voyages and number of tons are presented in figure 4 coast (Norwegian Coastal Administration, 2008). The total number of tons in 2008 was 10753401 tons and the number of voyages was 237. The main reason for this increased shipping of Russian oil is due to the opening of the Varandey terminal.

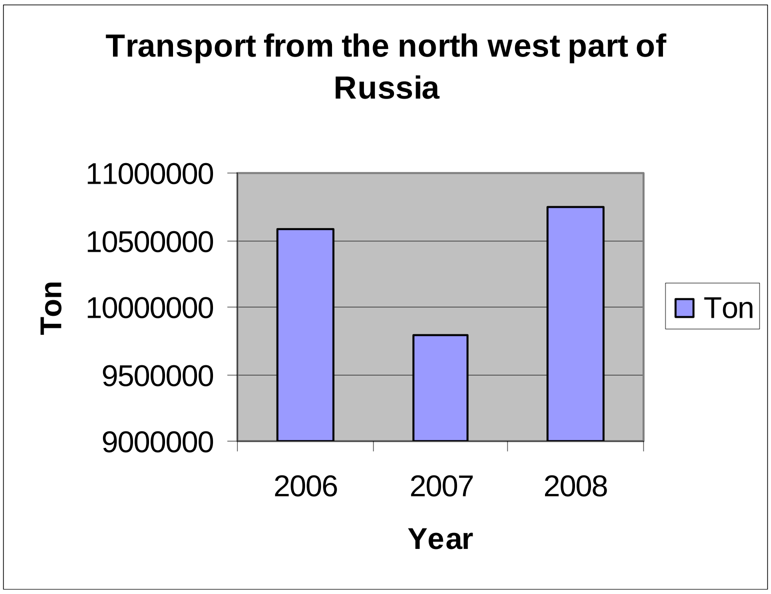

Figure 4 Tons transported and number of voyages along the Norwegian Coast.

In 2006 the oil was transported in 206 shipments, in 2007 212 and in 2008 237 shipments.

3.5 Weathering processes affecting oil

When oil is spilt into the sea several processes will change the properties and behaviour of the oil. These processes are called weathering (IMO, 2005). Some of the processes are:
- evaporation of the lighter products
- emulsification which is incorporation of water droplets into the oil
- dispersion which is oil droplets mixed into the water column. This is a natural process which can be increased by using dispersants.
- dissolution fractions of the oil will be dissolved in the water

Other processes are spreading, photo oxidation, biodegradation, drift of the oil and sedimentation.

The weathering processes are influenced by physical properties of the oil, meteorological conditions and characteristics of the sea water (SRV 1997).

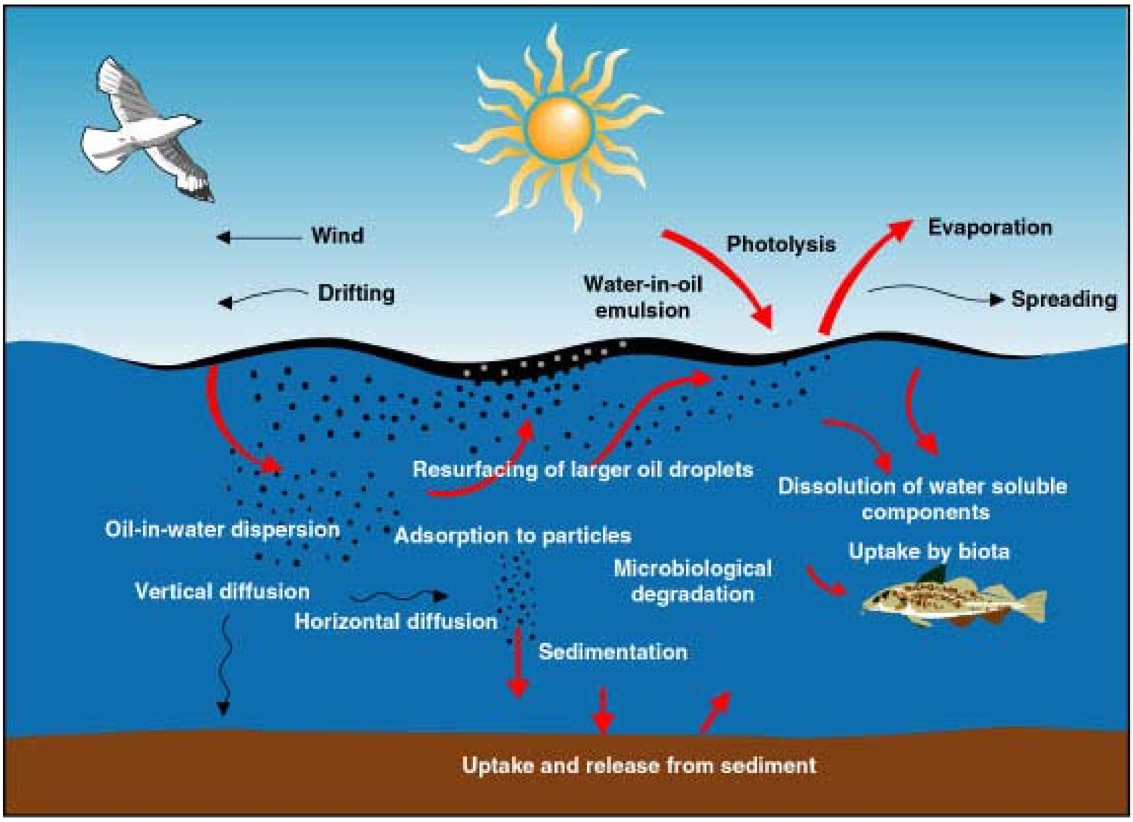

Figure 5 Illustration of the weathering processes the oil is exposed to when spilt at sea (Source SINTEF)

3. Dispersants

Extract from Safety at Sea 2007. The following information in this section is from report A4 Demo 4 (Safety at Sea 2007) of the interreg project Safety at Sea were the following is described concerning dispersants.
One of the means in oil-spill contingency for combating oil slicks is the application of oil spill dispersants. Dispersant are working in the same way as a household soap, stabilizing the formation of small oil droplets, enhancing the mixing of oil into the water. Modern dispersant are non-toxic products. The purpose of using oil spill dispersants is to remove spilled oil from the surface and dilute it into the bulk of the watercolumn as droplets at a faster rate than

occurring naturally. The appropriate use of dispersants could prevent subsequent shoreline pollution or damage to other sensitive areas / resources. A schematic picture of how dispersants work is shown in Figure 3.

Effective use of dispersants depends on chemical interactions between the added chemicals and naturally occurring components within the oil (e.g. wax, asphaltenes, resins). Oils have different chemical composition, causing variations in their ability to interact with the dispersants. This gives a great variation in the potential for use of dispersants between different oils. Viscosity and pour point will also be important to the effect of the use of chemical dispersants. A high viscosity or high pour point of the oil will give poor mixing between oil and chemical dispersant, and will also cause the oil to resist being mixed into the water by wave energy.

There is still much controversy of the use of dispersants in waters with low salinity due to lack of scientific evidence on the effectiveness and impact of dispersants (ITOPF, 2007).

Usually the effectiveness of dispersants increase with increased salinity and increased temperature.

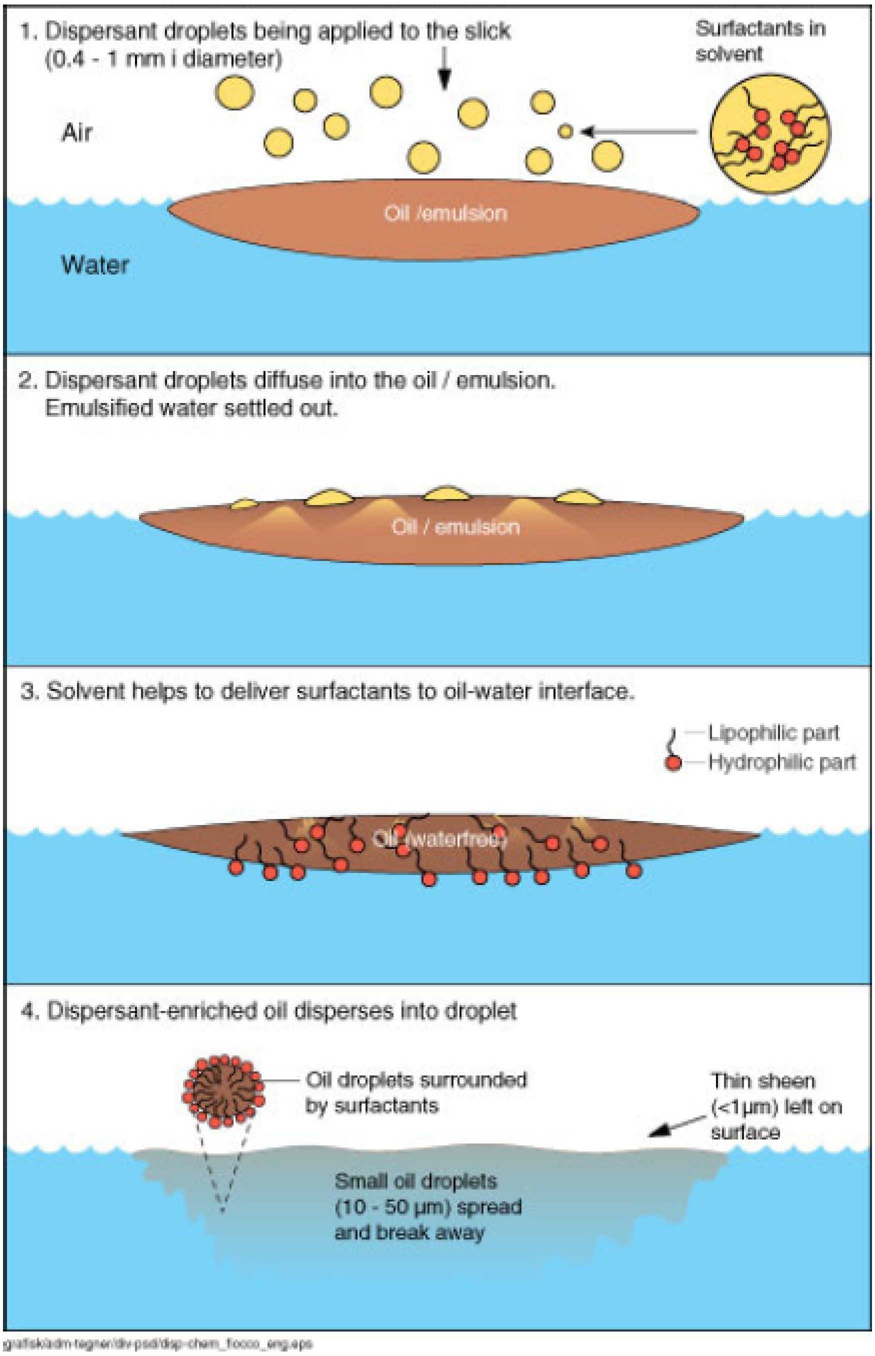

Figure 6 Dispersion of oil into water (Source SINTEF)

End of extract

Due to the sensitive ecological conditions in the Baltic Sea area, response to oil should take place by the use of mechanical means as far as possible as mentioned in the introduction of this chapter.

There are several documents describing how dispersants work as well as descriptions of limitations for use of dispesants. Further reading is available in

- Applicability of Oil Spill Dispresants (EMSA, 2006) www.emsa.europa.eu
- the “Manual on oil pollution” (IMO), www.imo.org

Several non-governmental organizations also have information of dispersants

- CEDRE www.cedre.fr
- SINTEF www.sintef.no
- ITOPF the International Tanker Owners Pollution Federation Limited www.itopf.com
- IPIECA the International Petroleum Industry Environmental Conservation Association www.ipieca.org
- various oil companies
- the interreg project Safety at Sea

4 Method

A project group was established with representatives from the Finish Environmental Institute, the Admiral Danish Fleet, the Norwegian Coastal Administration and the Swedish Coast Guard. At the first meeting both oils and dispersants were selected. Prior to the meeting the contractors CEDRE and SINTEF were consulted especially for the selection of dispersants. The project group had contact by e-mail and phone when necessary during the project. At the end of the project another meeting was held were the results were discussed and also how the results could be transformed for operational use.
The results were presented at a seminar back to back with the HELCOM Response meeting in Warnemünde, Germany in October 2008.

One crude oil REBCO and one fuel oil IFO 380 were selected for analyses.
REBCO the oil is from the pipeline from Jaroslavl to Primorsk. In Jaroslavl different oils are mixed to achieve export specification (Neste Oil, 2007). There are 1800 oil fields in Russia and the oils are usually mixed in pipelines or by train transports. The oil is mixed to fulfil export specifications.

Initially the project group decided that a bunker oil IFO 180 should be analysed. The reason for this choice was that based on experience we know that the heavier the oil is the more difficult it is to disperse the oil. Due to problems with shipments of bunker oil to the laboratory in Norway the decision to use the available IFO 380 was made.
The Vysotsk IFO 380 bunker fuel was shipped from Saybolt in Copenhagen. The origin of the oil was Vysotsk. The bunker oil was sampled from tank 107. Refinery is unknown.

The reason for the choice of one crude oil and one bunker oil was that both kind of oils are shipped through the Baltic Sea. The bunker oil can be found both as bunker oil and as cargo. Although the volume of crude oil outnumbers the volume of bunker oil the results from the weathering studies of bunker oils are important in case of an oil spill.

4.1 Analyses

Analysis of weathering properties was performed at 0 °C and 15 °C which were regarded as winter and summer temperatures of the Baltic Sea. The experimental work in the laboratories is described in Appendix 8.1.

4.2 Dispersability

Two different dispersants were selected to find out if the oils were dispersible.

- Dasic NS is used in the UK, France and Norway. According to the manufacturer (technical data sheet Slickgone NS) the product works on crude oils with high wax content and is also supposed to be effective on heavy oils and emulsions.
- OSR 62 is a fairly modern dispersant and results from previous test have indicated that OSR 62 is more efficient if the salinity is low than for instance Dasic Fresh Water
- The bunker oil was also tested with Corexit 9500 which is used in Norway and France but needs a higher salinity. *This was done by CEDRE but not within the project.*

The weathering of the oils was predicted in SINTEF Oil Weathering Model. The model is described in appendix 8.7 page 55 in this report.

5 Results

5.1 Results from analysis of REBCO from Primorsk

Results from the analysis are presented in table 1. Max. water content of the emulsion was 72-87 %.

Property	**REBCO fresh oil**	**REBCO Oiltopping 150 °C**	**REBCO Oiltopping 200 °C**	**REBCO Oiltopping 250 °C**
Specific gravity (g/l)	0.871	0,898	0,912	0,932
Pour point (°C)	-6	3	9	18
Wax (wt%)	4,9	5,6	6,2	7,2
Asphaltenes (wt%)	1,0	1,2	1,3	1,5
flashpoint				
Viscosity at 13°C (cP)	22	58	142	878
Viscosity of 50% emulsion (cP)	-	567	1315	4995
Viscosity of 75% emulsion (cP)	-	2754	5581	-
Viscosity of max water (cP	-	4257	11244	18145
Max. water content (%)	-	87	82	72

Table 1 Results from analysis of REBCO

SINTEF has developed a concept for tentative categorization of oils into 4 groups, illustrated in Figure 6: The analysed crude oil is caracterized according the system visualised in figure 6.

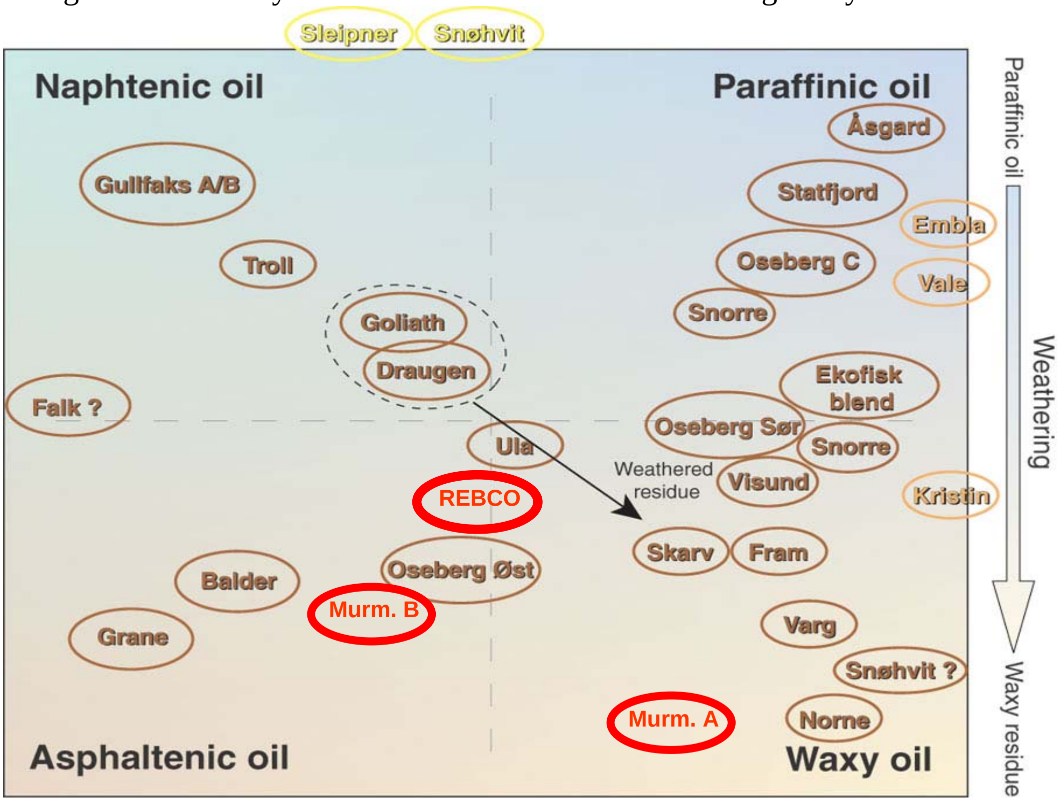

Figure 7 Categorization of a selection of Norwegian crude oils, including three Russian crude oils. (Source SINTEF)

The Russian crude oils have been categorized as shown in Figure 6. The Russian crude oil Murmansk A is categorized among the waxy oils. Russian crude oil Murmansk B, is categorized as an asphaltenic crude oil.
The crude oils Murmansk A and B are crude oils which have been investigated earlier at SINTEF in cooperation with MCSM in Murmansk.

The REBCO crude exhibit features as an intermediate between an asphalthenic and a more paraffinic oil. This means that this REBCO crude oil has a heavy fraction which contains asphaltenes, waxes and paraffins which gives a crude oil with strong emulsifying character.

5.2 Comparsion of three Russian oils

1. Compared to two other Russian crude oils from the Murmansk area (hereafter called Murmansk A and B) that recently has been investigated at SINTEF, REBCO shows the following properties (using 1 day weathering at 5^{o}C sea temperature and 10 m/s wind, as an example):
   - the REBCO crude will have a slightly higher evaporative loss: approx. 30 % evaporation (versus 22 to 26% for Murmansk A and B respectively)
   - will emulsify water significantly faster: approx. 75% water uptake (versus 20% and 70% water for Murmansk A and B respectively)
   - the viscosity of emulsion will be slightly lower: around 35 000cP (versus 53 000 and 45 000 cP for Murmansk A and B respectively)

- there will be a high density of the REBCO and Murmansk B emulsions, in the range 0,995-1,0 kg/L, fairly close to the seawater density
- an intermediate high pour point: around 15°C (versus 30°C and -15°C for Murmansk A and B respectively. This indicates a wide span in pour point for the Russian crudes

5.3 Dispersability Rebco

REBCO is a crude oil that shows to be dispersible when using oil spill dispersants, both at summer and winter conditions. However, no systematic studies for estimating the "time window" for effective use of dispersant, due to the weathering, was performed within this project.

OSR 62 showed to be the overall most effective dispersant of the two dispersants tested under various sea salinities, and is less sensitive to salinity variation.
When OSR 62 was used there was a decrease in efficiency especially at 15 degrees C. About 55 % of the oil was dispersed when OSR 62 was used at salinity of 10 ppm.

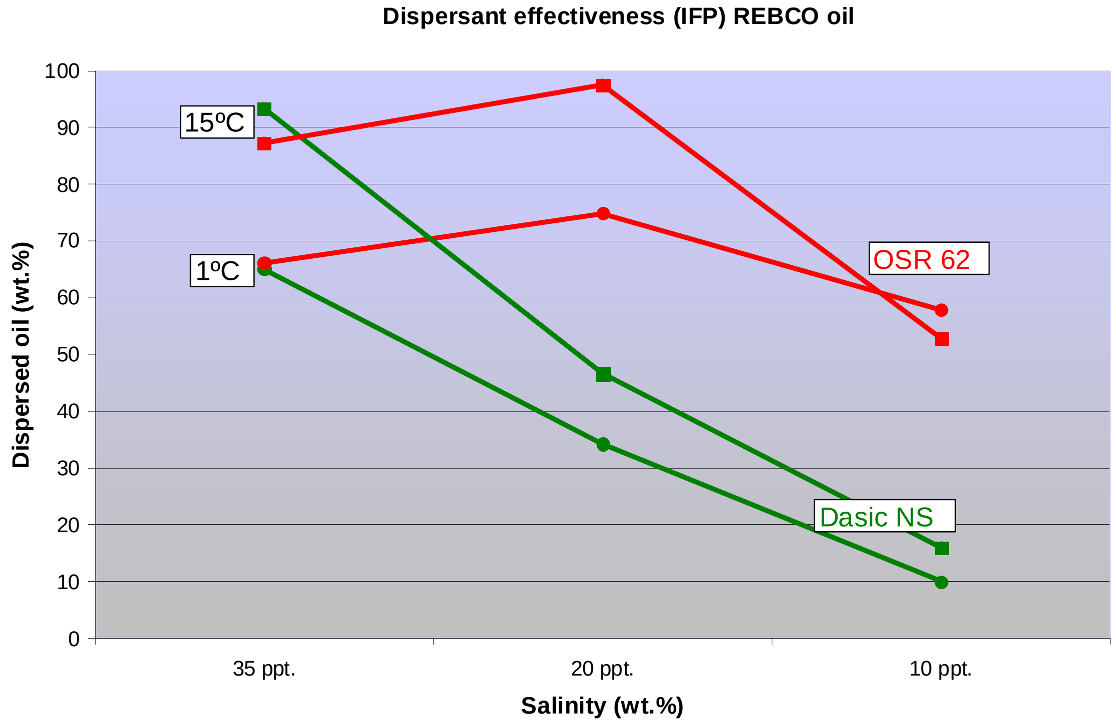

Figure 8 Dispersant effectiveness (IFP) Russian Export Crude Oil (200ºC+ / 50 vol.% emulsion). DER 1:25. Viscosity 1320 cP at 15ºC (viscosity missing at 1ºC).

5.4 Results from analysis of IFO 380 from Vysotsk

Results from the analysis are presented in table 2.

Property	**IFO 380 fresh oil**	**IFO 380 Oiltopping 150 °C**	**IFO 380 Oiltopping 200 °C**	**IFO 380 Oiltopping 250 °C**
Boiling temp. (°C)				
Specific gravity (g/l)	0,992	0.992	0,992	0,995
Pour point (°C)		6	6	3
Wax (wt%)		4,3	4,3	4,4
Asphaltenes (wt%)		10,1	10,1	10,2
Flashpoint	104	104	108	116
Viscosity at 13°C (cP)	14930	14930	15880	22660
Viscosity of max water (cP	31200	31200	30730	86780
Max. water content (%)	17	17	22	54

Table 2 Results from analysis of IFO 380 from Vysotsk

5.5 Comparsion of IFO 380 from Vysotsk with other Russian HFO oils

Vysotsk IFO-380, showed to be fairly comparable to an other Russian IFO-380, taken at the Belakomenka Oil Terminal in Murmansk, that recently has been investigated at SINTEF. Vysotsk IFO-380 also shows similarities in some of the properties with the Fu Shan Hai HFO 380. The following weathering properties are predicted (using 1 day weathering at 5^{o}C sea temperature and 10 m/s wind, as an example):

- the evaporative loss will be very low: less than 2-3 % loss (versus 5% for the IFO-380 Murmansk).
- the emulsification will be fairly low: <20% water in the emulsion (versus 50% for the IFO-380 Fu Shan Hai, but <10% for the IFO-380 Murmansk)
- Viscosity of emulsion will be around 100 000 cP (similar to the IFO-380 Fu Shan Hai and IFO-380 Murmansk)
- the emulsion density will be intermediate high: 0,999 - 1,0 kg/L.
- an intermediate pour point of 2-3^{o}C (similar to the IFO-380 Fu Shan Hai).

5.6 Dispersability Vysotsk IFO 380

Vysotsk IFO-380 oil showed to be dispersible at a low weathering stage under summer conditions. The “time window” for effective use of dispersant due to the weathering was not investigated within the project. At very cold winter conditions (0^{o}C) Vysotsk IFO (having viscosity of 174 000 cP) showed very limited dispersibility. The effectiveness of dispersability are shown in figure 8.

The IFO 380 was dispersable at salinity 35 and 20 Efficiency varying from 53-76 % Table X Appendix . At 10 the efficiency was 69 % when OSR 62 was used. The efficiency of OSR was not depending on the salinity at this temperature.

OSR 62 is the most effective dispersant of the three tested under various sea salinities, and is less sensitive to salinity variation. Even at winter conditions, OSR 62 showed to disperse the IFO bunker oil to a very slight, but significant extent.
Dispersability IFO 380 at 0°C.
At this temperature the efficiency was within the range 0,2-25 %.

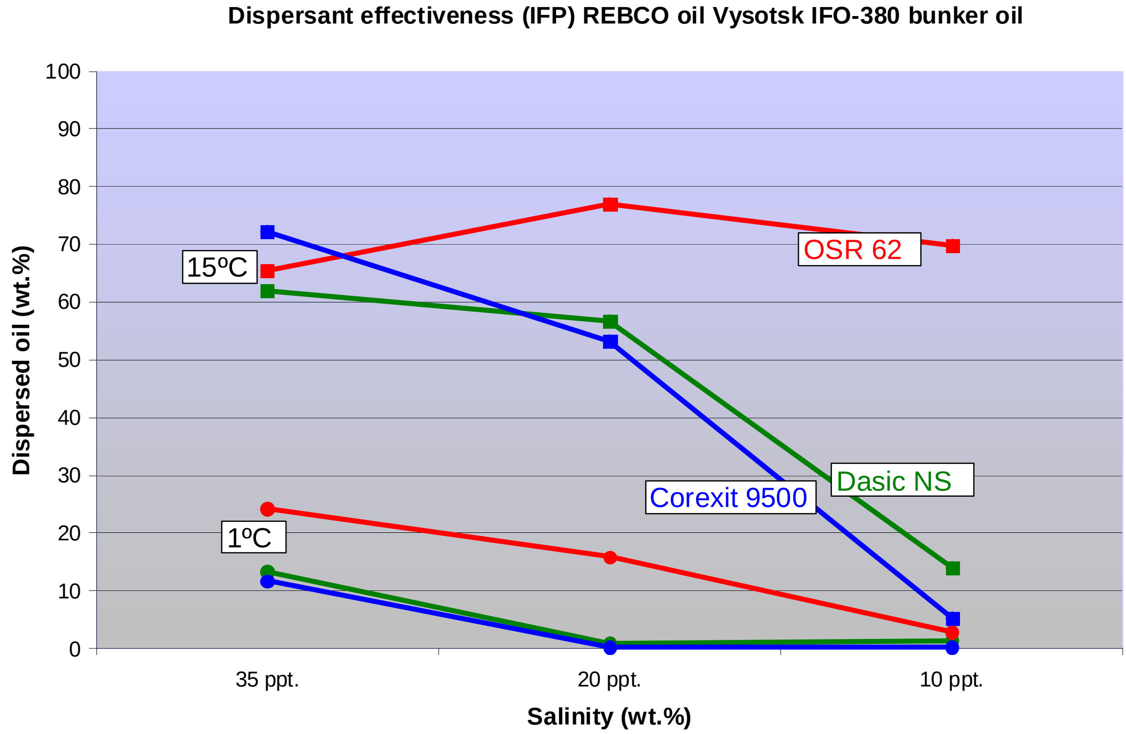

Figure 9 Dispersant effectiveness (IFP) Vysotsk IFO-380 bunker oil.(fresh /150ºC+). DER 1:25. Viscosity 174 000 cP at 0ºC and 14 930 cP at 15ºC.

5.7 Pre-study of IFO 180

Samples of IFO 180 were sent to SINTEF for analysis of fuel oil. Unfortunately the samples of each shipment did not match this means different oils were sent to SINTEF. Initial analyses of the density were made to find out if the samples were from the same oil. The results showed that this was not the case. The density of the samples was within the range of 0,98-1,01 Data from the analysis are presented in Appendix 9 Pre-Analysis of IFO 180.

6 Conclusions

6.1 REBCO

The density which is below 950 g/L indicates that the oil will stay on the surface of the water when spilt. The density of the emulsion (~1000 g/L) will be close to the density of the water. The emulsion could sink during cool condition and rise to the surface when heated by the sun. This was the case at the Fu Shan Hai incident in 2003.

The analysed REBCO oil exhibits features as an intermediate between an asphaltenic and more paraffinic oil. The oil contains heavy fractions and this information is of importance in case of an oil spill. This Russian oil could emulsify with great quantities of water and the volume will increase. This is also reflected by the value of max. water content 72-87% from the analysis. The density which gets close to 1 and this will lead to a situation where specially designed equipment is necessary. Such equipment is only found in limited numbers in the HELCOM and Copenhagen agreement area.

Flash point fresh/one hour < 60 °C. To make sure the flashpoint is above 60 °C recovery can not start until two hour after the spill.
In Sweden there is a rule of thumb which states that it is safe to enter an area of spilt oil after four hours. This is regarding health and safety concerning toxic vapours.

According to the weathering model the emulsion will reach max. water content six hours after the spill. The max. water content will be ~75 % at 5 degrees C and wind speed 5 m/s . This means that the volume is four times the spilt volume of oil. The predicted viscosity of the emulsion (5 days) > 60 000 cP. According to Germany and the Netherlands this should not be a problem in case of recovery by vessels from these countries. At the recovery the viscosity of the emulsion is lowered by mixture of hot water. In settling tanks the oil is separated from the emulsion. The system worked in the recovery following the spill of Prestige.

Mass balance - During winter condition almost no oil will disperse naturally when wind speed is no more than 5 m/s. If the wind is 15 m/s 70 % will be dispersed after five days and the rest will be evaporated and no oil will be at the surface. The pattern is similar at summer conditions.

The REBCO will evaporate slightly more than the two crude oils from the Murmansk area. Still the three oils seem to be similar in this respect.
The REBCO shows to emulsify and the water uptake is 75 % after one day. This means that the volume of the spill will be four times the amount of oil spilt. Quick response is very important. The viscosity will be around 35 000 cP.
When pour points are compared of the Russian oils there is a wide span. This shows that the oils differ quit a lot.

If OSR 62 is used the the REBCO oil is dispersable during winter and summer conditions. In winter conditions the efficiency of the dispersant does not decrease very much. Dasic NS is sensitive to change in salinity. This does not reflect the information before the project. The reason Dasic NS was chosen was that the product had shown better results in conditions with low salinity.

6.2 IFO 380 Vysotsk

The density which is just below 1000 g/L indicates that the oil might stay at the surface as well as sink into the water column. This will be a problem in case of a response operation because there are no good ways to recover oil from the water column.
A very small part of the oil will evaporate 2-3 %. Emulsification is quit low, not more than 20 % after one day. After three days the emulsification is a little higher than 50 %, according to test in the laboratory, which means the volume of the emulsion will be twice the volume of the oil spill.

Flash point of fresh oil/one hour > 100 °C. This means recovery can start immediately after the spill because the flashpoint is above 60 °C.

According to the weathering model the emulsion will reach max. water content several days after the spill. After five days the model predicts a water content of 35 % at 5 °C and wind speed 5 m/s. This means that the volume will almost double within five days. The predicted viscosity of the emulsion (5 days) > 100 000 cP. According to Germany and the Netherlands this should not be a problem in case of recovery by vessels from these countries. At the recovery the viscosity of the emulsion is lowered by mixture of hot water. In settling tanks the oil is separated from the oil. The system worked in the recovery following the spill of Prestige.

Mass balance - During winter condition there will be almost no dispersion or evaporation when wind speed is no more than 5 m/s. If the wind is 15 m/s 50 % will be dispersed after five days and the rest will be at the surface. The pattern is similar at summer conditions.

The IFO 380 seems to remind of the Prestige oil. The viscosity is slightly lower at all temperatures.

The IFO 380 proved to be dispersable at summer temperature if OSR 62 was used. Dasic NS and Corexit 9500 seem to be very sensitive to salinity.

To conclude the crude oil REBCO and the IFO 380 are dispersable at summer temperatures. During winter conditions only the REBCO is dispersable to a great extent.

Dispersability REBCO and Vysotsk IFO 380

Because the results differ as much depending on which dispersant is used in the case of REBCO it is very difficult to draft guidelines for the use of dispersants in the Baltic Sea. It would also be interesting to see if the dispersant effectiveness will decrease if the salinity is below 10 ppt.
In the case of Vysotsk IFO 380 bunker oil it is obvious that the fuel oil can only be dispersed at summer temperature by OSR 62. In this case the salinity does not seem to affect the effectiveness very much.

6.3 Equipment

Pumps of “archimedes” type will be necessary because of the viscosity of both the crude and bunker oil.
During the first two days after a spill of the crude oil “centrifugal pump” can be used.

Sweden

The equipment used by the Swedish Coast Guard has been adapted to recover oil/emulsion with low water content by mechanical recovery. The oil/emulsion is separated from water at the surface. The oil /emulsion is then stored in oil tanks of the recovery vessel.
The advancing systems used on board some of the vessels of the Swedish Coast Guard will work on these oils. The recovery vessels KBV 001-003 which will be delivered in 2009 and 2010 will increase the capacity of recovery of high viscosity oil/emulsion.
The skimmers used by the Swedish Coast Guard will also work in case of an oil spill regarding thin or thick (500-2 million cP) oil. The capacity will depend on the viscosity of the oil/emulsion.

Norway

The Norwegian Coastal Administration and the Norwegian Clean Seas Association for Operating Companies have oil spill resources to fight acute pollution due to spill of crude oil and Heavy Fuel Oils. The recovery equipment consists of seagoing booms and high-capacity oil skimmers both for normal crude oil and high viscous oils. Operational systems and aids for effective use of oil recovery equipment during darkness and in conditions with poor visibility are also available.

Finland

Finnish national oil pollution preparedness is based on mechanical oil recovery according to Helsinki Convention. Finland does not use dispersants.
All government owned pollution response vessels are capable to independent oil recovery which means, that they all have permanently fitted oil recovery brushes build in hull.

The recovery capacity depends - among other things -on the thickness and viscosity of the oil layer and of the recovery vessel's speed. When recovering oil from sea surface the vessels' speed is usually 1-2 knots. If the oil layer would be average 0.5 mm thick and the recovery vessels would have speed of 2 knots, then the Finnish oil recovery fleet would collect total of about 750 m^3/hour.

Denmark

To improve the equipment and techniques for an efficient response at sea for combating high-density oils/orimulsion. Denmark has in the light of the BALTIC CARRIER accident in 2001 received 3 RO-CLEAN DESMI TERMINATOR Combination Skimmer Systems. The system is a wireless controlled free floating self-adjusting weir skimmer head, with belt and disc cassette system (option) for recovery of light to very viscous oils. The system is further more designed with a thruster system for quickly position. The skimmer system incorporates the DESMI DOP-250 pump fitted with an injection flange for heavy oil pumping applications. The system is capable of handling products with very high viscosities, up to 2-3 million cSt. The above system has been used and tested with success by the Danish response vessel during her operation in Spain, the PRESTIGE accident

6.4 Pre-study IFO 180

Initially the project group decided to analyse bunker oil of type IFO 380. Some problems were encountered with some different shipments of the bunker oil. The initial quality check (pre-analysis) of the oils at the laboratory told us that the samples were of different origins. Because of this it was decided to use a IFO 380 oil instead.
The results, in appendix 9, of the Pre-analysis of IFO 180 indicate that the density of the bunker oil is about the same as the density of fresh water. Because the salinity in the Baltic Sea is low this oil might submerge in case of an oil spill. This means that the oil can be transported by currents over great distances without being identified until it comes to shore.

6.5 Recommendations

Further studies of bunker and crude oil are important. This is the case with oil from any country in the Baltic Sea region. There are only a few laboratories with the knowledge and capability to do weathering analysis of crude and bunker oils. It would be useful to perform weathering studies over a period of time. If 8-12 oils would be analysed over a year we would get information about the range within the results will fall. This will make it easier to predict the behaviour of unknown oil.

At the seminar when the results were presented the idea of quick analysis prior departure of oil tankers were discussed. Because weathering studies take a long time and also are expensive it would be useful if a quick analysis of the oil could be done. Density, viscosity and pour-point are interesting properties. If this information is available in case of an incident it is easier to predict the behaviour of the oil as well as to predict how the oil will spread. Once the range of variation of the physical properties is identified the results of quick analyses can be useful to make a qualified estimation of how a unknown oil will behave after an oil spill.

Based on the results of this study it is not possible to create guide lines for the applicability of dispersants. Analyses of the time window in case of use of dispersants should be identified. Of the dispersants included in this project only OSR 62 should be considered in this regard because it showed not to be sensitive to changes in salinity 30-10‰.

During 2007 and 2008 a project involving SINTEF and and “Murmansk Centre for Standardization, Metrology and Certification” has been running. The objective of the project is to upgrade a laboratory in Murmansk to perform weathering studies and chemical characterization of Russian oil and oil products. The project is funded by StatoilHydro. We hope that this will lead to an increase in analysis of Russian oils and that the information will be shared with interested response organisations in other countries to facilitate response to future oil spills.

The work of this project will continue, at the next meeting of HELCOM Response Group. Sweden will propose a way forward for further weathering studies and possible use of dispersants in the Baltic Sea. One way could be to compare results from present weathering studies oils with the results from the oils studied in this project. If this would be done differences and similarities will be identified. This information could be used to determine how to proceed in the future. It would also be interesting to compare the results with future studies made at Murmansk Centre of Centre for Standardization, Metrology and Certification. Those results will increase our knowledge about how the Russian oils differ as well as identify similarities.

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8 Appendixes

8.1 Experimental work

Experimental work; test methods

Test temperatures
Testing of the weathering properties was performed at 0°C and 15°C, which is regarded as typical winter and summer temperatures of the Baltic area.

Bench-scale laboratory testing
To isolate and map the various weathering processes at sea, the oil was exposed to a systematic, stepwise procedure developed at SINTEF (Daling *et al.*, 1990). The weathering process is illustrated in A.1.

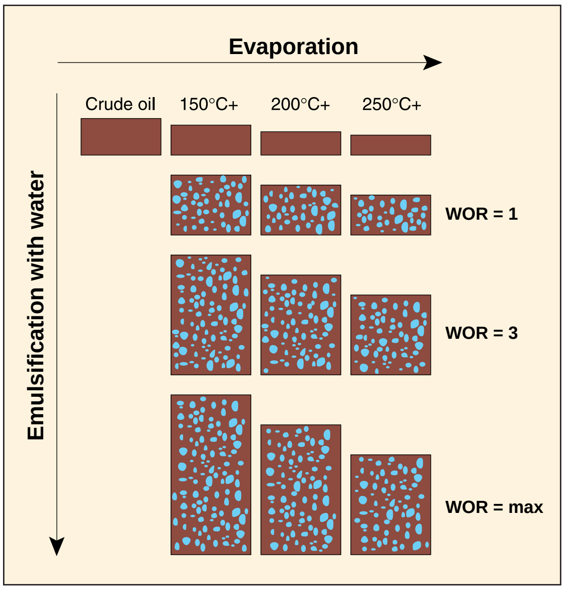

Figure A.1: Bench scale lab. weathering flow chart. WOR=1 (50% water), WOR=3 (75% water).

Evaporation
The evaporation procedure used is described in Stiver and Mackay, 1984. Evaporation of the lighter compounds from the fresh crude oil was carried out as a simple one step distillation, to

vapour temperatures of 150°C, 200°C and 250°C, and resulted in oil residues with evaporation loss corresponding to 0,5-1 hour, 0,5-1 day and 2-5 days weathering on the sea surface. These residues are referred to as 150°C+, 200°C+ and 250°C+, respectively.

Water-in-oil (w/o) emulsification
The w/o-emulsification studies were performed by the rotating cylinders method developed by Mackay and Zagorski, 1982. The method is described in detail by Hokstad *et al.*, 1993.

Oil (30 mL) and seawater (300 mL) are rotated (30 rpm) in separating funnels (0,5 L), see Figure A.2. The emulsification kinetics are mapped by measuring the water content at fixed rotation times. The maximum water content is determined after 24 hours rotation.

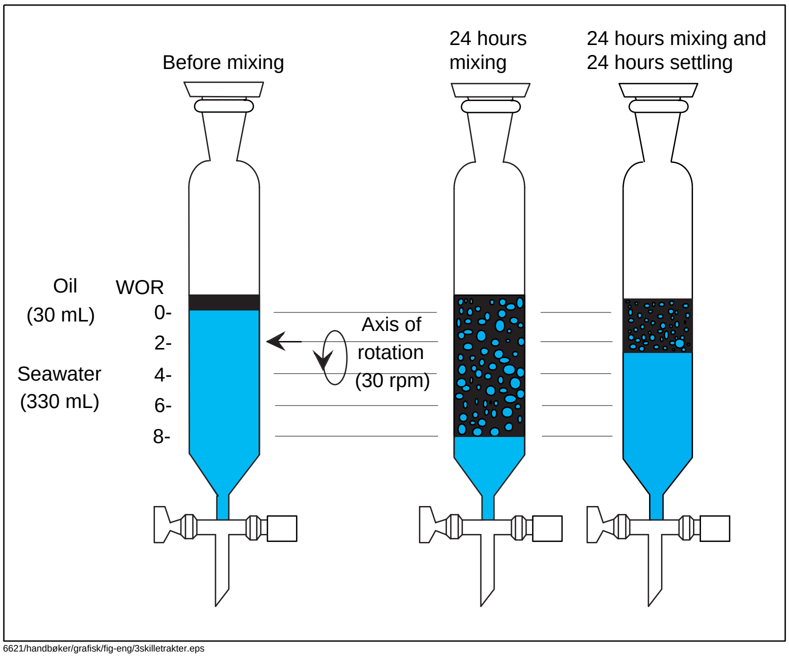

*Figure A.2: Principle of the rotating cylinder method***.**

To test the effectiveness of the emulsion breaker Alcopol O 60 %, two dosages (500 ppm and 2000 ppm relative to the oil volume) were added dropwise to the w/o-emulsion. After a contact period of 5 minutes and a rotation time of 5 minutes (30 rpm), the treated emulsion rested for 24 hours before the amount of water drained from the emulsion was determined.

The distilled residues were emulsified with 50 vol% and 75 vol% water in addition to the maximum water content. Four parallel runs were performed to map the w/o-emulsion kinetics, with the addition of Alcopol O 60 % in two of these. Several physical and chemical properties of the twelve weathered samples (see Figure A.2) were determined. A detailed description of the analyses is given in chapter 0.

Physical and chemical analysis
The viscosity, density, pour point and flash point of the water free residues and w/o emulsions will be determined. The analytical procedures that will be used are given in Table A.1.

Table A.1: Analytical methods used to determine the physical properties.

Physical property	Analytical method	Instrument
Viscosity	McDonagh and Hokstad, 1995	Physica MCR 300

Density	ASTM method D4052-81	Anton Paar, DMA 4500
Pour Point	ASTM method D97	-

The wax and “hard” asphaltene content will be determined using the analytical procedures given in Table A.2

Table A.2: Analytical methods used to determine the chemical properties.

Chemical property	Analytical method
Wax content	Bridiè *et al.*, 1980
“hard” asphaltene	IP 143/90

Chemical dispersability testing
There are several different tests for evaluating the effect of chemical dispersants. Energy input will differ in different tests, and the obtained efficiency will be representative for different wave energies.

IFP (Institute Francais du Petrole test, Bocard *et al*, 1984) is a low energy test estimated to represent low wave energies (2-5 m/s wind speed). A ring beating up and down in the test vessel at a given frequency, gives energy input to the seawater column. The water column is continuously diluted, which gives a more realistic approach to field conditions compared to other tests. The test apparatus is shown in Figure A.3.

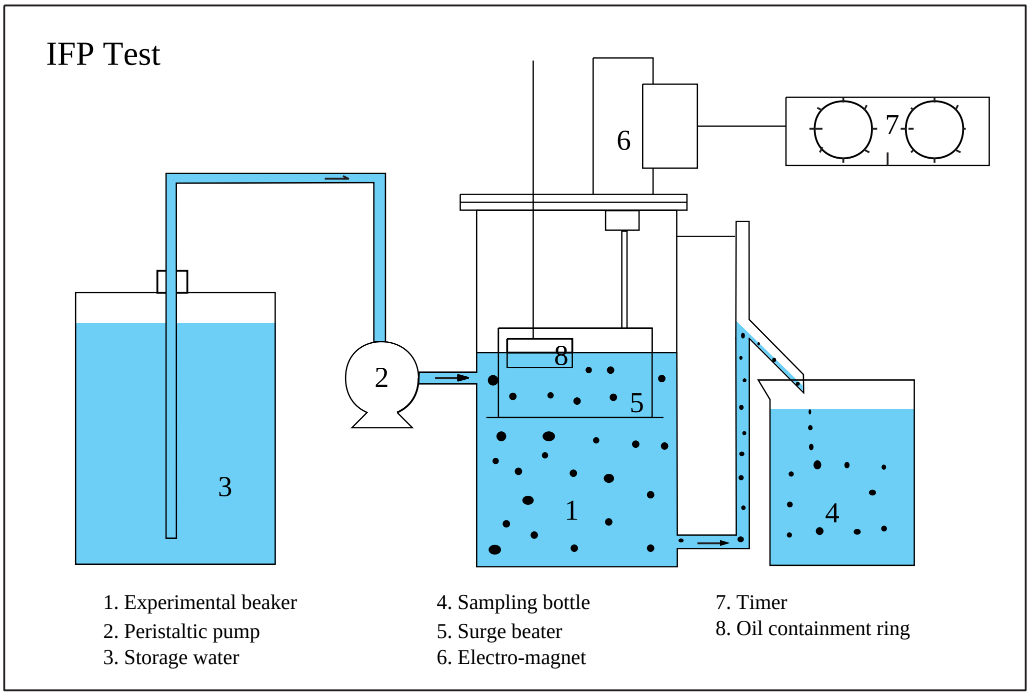

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Figure A.3: IFP test apparatus.

8.2 Experimental data as input to SINTEF Oil Weathering Model

Product Name: RUSSIAN EXPORT CRUDE OIL
Product Type: CRUDE
Location: RUSSIA
Data Source: SINTEF Applied Chemistry
Year: 2008

Lab weathering data:

PROPERTY	FRESH	150+	200+	250+
Boiling temp. (°C)	-	150	200	250
Volume topped (%)	0	15.5	24.9	36.6
Residue (wt. %)	100	87.1	78.6	67.8
Specific gravity (g/l)	0.871	0.898	0.912	0.932
Pour point (°C)	-6	3	9	18
Flash point (°C)	-	-	-	-
Viscosity at 13°C (cP)	22	58	142	878
Viscosity of 50% emulsion (cP)	-	567	1315	4995
Viscosity of 75% emulsion (cP)	-	2754	5581	-
Viscosity of max water (cP)	-	4257	11244	18145
Max. water content (%)	-	87	82	72
Halftime for water uptake (hrs)	-	0.11	0.2	0.2
Stability ratio	-	-	-	-
Yield stress, fresh oil	-	-	-	-
Yield stress 50% water content	-	-	-	-
Yield stress 75% water content	-	-	-	-
Yield stress max water content	-	-	-	-

Product Name: RUSSIAN EXPORT CRUDE OIL
Product Type: CRUDE
Location: RUSSIA
Data Source: SINTEF Applied Chemistry
Year: 2008

Boiling point curve:

Temp.(°C)	Volume(%)	Weight(%)
60.0	3.60	
70.0	4.40	
80.0	6.00	
100.0	7.90	
120.0	10.30	
140.0	13.80	
150.0	15.80	
160.0	18.50	
180.0	22.10	
200.0	26.40	
220.0	29.90	
230.0	31.90	
240.0	33.80	
250.0	36.60	
300.0	44.00	
350.0	49.00	
400.0	52.00	
450.0	55.00	

Product Name: IFO-380 RUSSIAN BUNKER FUEL
Product Type: HEAVY BUNKER
Location: RUSSIA
Data Source: SINTEF Applied Chemistry
Year: 2008

Lab weathering data:

PROPERTY	FRESH	150+	200+	250+
Boiling temp. (°C)	-	-	-	-
Volume topped (%)	0	0	0.5	2.1
Residue (wt. %)	100	100	99.5	98.1
Specific gravity (g/l)	0.992	0.992	0.992	0.995
Pour point (°C)	-	-	6	3
Flash point (°C)	104	104	108	116
Viscosity at 13°C (cP)	14930	14930	15880	22660
Viscosity of 50% emulsion (cP)	-	-	-	-
Viscosity of 75% emulsion (cP)	-	-	-	-
Viscosity of max water (cP)	31200	31200	30730	86780
Max. water content (%)	17	17	22	54
Halftime for water uptake (hrs)	3.6	3.6	6.9	5.7
Stability ratio	1	1	1	1
Yield stress, fresh oil	-	-	-	-
Yield stress 50% water content	-	-	-	-
Yield stress 75% water content	-	-	-	-
Yield stress max water content	-	-	-	-

Product Name: IFO-380 RUSSIAN BUNKER FUEL
Product Type: HEAVY BUNKER
Location: RUSSIA
Data Source: SINTEF Applied Chemistry
Year: 2008

Boiling point curve:

Temp.(°C)	Volume(%)	Weight(%)
150.0	0.00	
200.0	0.50	
250.0	2.10	
300.0	4.00	
350.0	5.00	
400.0	6.50	
450.0	8.50	

8.3 Russian Export Crude Oil, CEDRE laboratory data

Dispersant testing Rebco 200°C+ / 50 % water / 1°C

		Viscosity (mPa.s @ 10 s^{-1})	Efficiency (%)	Average	SD
Salinity 35‰	Dasic NS	5818 5389	68.1 65.1	66.6	2.1
	OSR 62	5818 5389	62.0 70.4	66.2	5.9
Salinity 20‰	Dasic NS	5744 5693	38.3 30.3	34.3	5.7
	OSR 62	5744 5693	80.3 69.5	74.9	7.6
Salinity 10 ‰	Dasic NS	6137 6635	8.0 12.0	10.0	2.8
	OSR 62	6137 6635	57.2 58.6	57.9	1.0

Dispersant testing Rebco 200°C+ / 50 % water / 15°C

		Viscosity (mPa.s @ 10 s^{-1})	Efficiency (%)	Average	SD
Salinity 35‰	Dasic NS	1325 1325 1325	91.0 98.2 90.9	93.4	4.2
	OSR 62	1132 1132	88.1 86.6	87.3	1.1
Salinity 20‰	Dasic NS	1243 1243 1243	43.4 39.9 56.6	46.6	8.8
	OSR 62	1269 1269 1269	104.3 97.2 90.9	97.5	6.7
Salinity 10 ‰	Dasic NS	1121 1121 1121	13.9 14.3 19.6	16.0	3.2
	OSR 62	1311 1311 1311	48.8 57.4 52.4	52.9	4.3

Dispersant testing IFO 380 / 1°C

		Viscosity (mPa.s @ 10 s^{-1})	Efficiency (%)	Average	SD
Salinity 35‰	Dasic NS		1.8 37.3 1.0	13.4	20.7
	OSR 62		33.6 16.8 22.3	24.2	8.6
	Corexit 9500		4.0 19.5	11.8	11.0
Salinity 20‰	Dasic NS		1.7 0.1	0.9	1.1
	OSR 62		8.7 23.1	15.9	10.2
	Corexit 9500		0.6 0.0	0.3	0.4
Salinity 10‰	Dasic NS		1.1 1.7	1.4	0.4
	OSR 62		1.1 4.5	2.8	2.4
	Corexit 9500		0.2 0.2	0.2	0.0

Dispersant testing IFO 380 / 15°C

		Viscosity (mPa.s @ 10 s^{-1})	Efficiency (%)	Average	SD
Salinity 35‰	Dasic NS		59.8 71.7 54.7	62.1	8.7
	OSR 62		52.6 78.4	65.5	18.2
	Corexit 9500		73.3 64.0 79.1	72.1	7.6
Salinity 20‰	Dasic NS		54.2 71.3 44.6	56.7	13.5
	OSR 62		82.0	76.9	5.7

Dispersant testing IFO 380 / 15°C

		Viscosity (mPa.s @ 10 s^{-1})	Efficiency (%)	Average	SD
			70.7 78.1		
	Corexit 9500		37.3 63.1 59.4	53.3	14.0
Salinity 10‰	Dasic NS		18.5 9.5	14.0	6.4
	OSR 62		64.2 75.4	69.8	7.9
	Corexit 9500		4.5 6.1	5.3	1.1

			Oil topping REBCO		
		Fresh oil	150°C	200°C	250°C
Volume topped	% weight	-	12,9	21,4	32,2
	% volume	-	15,5	24,9	36,6
Specific gravity	15°C	0,871	0,898	0,912	0,932
Pour Point	°C	-6	3	9	18
Flash point	°C		-	-	-
Viscosity (mPa.s)	5°C	52	-	-	-
	10°C	33	75	247	1902
	15°C	22	58	142	878
	20°C	16	46	120	478

	Data Rebco					
	n-heptane asphaltenes	% weight	**1.00**	1.15	1.27	**1.47**
	Wax	% weight	**4.90**	5.62	6.23	**7.23**
	Emulsion viscosity @ 10 s^{-1}	Temperature	Fresh oil	150°C	200°C	250°C
	50%	1°C		2540	4292.7	24120.0
		15°C		567	1315	4995
	75%	1°C		No stable	14384	XXX
		15°C		2754	5581	XXX
Max.	Viscosity	15°C		4257	11244	18145
	Max. water content (%)			86.8	82.2	72.3
	Viscosity	1°C				20809.5
	Max. water content (%)					62.9

		Rebco Kinetics of emulsification 0˚C					
		Experiment (Vol. of water incorporated)			Water content (%)		
Time (Hours)	Time (minutes)	150°C+ residue	200°C+ residue	250°C+ residue	150°C+ residue	200°C+ residue	250°C+ re
0	0	0	0	0	0	0	0
0.08	5	20	10	0	40	25	0
0.25	15	30	30	0	50	50	0
0.5	30	50	30	20	63	50	40
1	60	80	40	30	73	57	50
2	120	190	50	50	86	63	63
4	260	190	120	60	86	80	67
6	363	190	125	60	86	81	67
8	480	190	140	70	86	82	70
24	1440	190	140	84	86	82	74

		Rebco Kinetics of emulsification 15˚C					
		Experiment (Vol. of water incorporated)			Water content (%)		
Time (Hours)	Time (minutes)	150°C+ residue	200°C+ residue	250°C+ residue	150°C+ residue	200°C+ residue	250
0	0	0	0	0	0	0	
0.08	5	25	20	10	45	40	
0.17	10	45	25	15	60	45	
0.25	15	60	30	20	67	50	
0.5	30	80	35	60	73	54	
1	60	300	45	85	91	60	
2	120	300	50	105	91	63	
3	200	300	55	105	91	65	
5	300	300	150	105	91	83	
8	480	300	160	105	91	84	
10	600	300	160	105	91	84	
24	1440	300	160	105	91	84	

Måste justeras

8.4 Vysotsk IFO-380 bunker, SINTEF laboratory data

Vysotsk IF-380 bunker fuel 0ºC			
Mixing time	Fresh (150°C+) (vol. % water)	200°C+ (vol. % water)	250°C+ (vol. % water)
Start	0	0	0
5 min	0	0	0
10min	0	0	0
15 min	0	0	0
30 min	1	5	9
1 time	1	9	14
2 timer	8	9	14
4 timer	10	16	20
6 timer	24	16	23
8 timer	28	25	30
24 timer	30	22	36
$t_{0,5}$ (hours)	**3,7**	**2,1**	**3,0**

Vysotsk IF-380 bunker fuel 15ºC			
Mixing time	Fresh (150°C+) (vol. % water)	200°C+ (vol. % water)	250°C+ (vol. % water)
Start	0	0	0
5 min	0	0	0
10min	0	0	0
15 min	0	0	0
30 min	3	0	0
1 time	5	0	0
2 timer	5	0	0
4 timer	12	12	23
6 timer	12	9	33
8 timer	12	9	33
24 timer	19	26	56
$t_{0,5}$ (hours)	**3,9**	**8,2**	**5,8**

8.5 Russian Export Crude Oil (REBCO) - prediction sheets

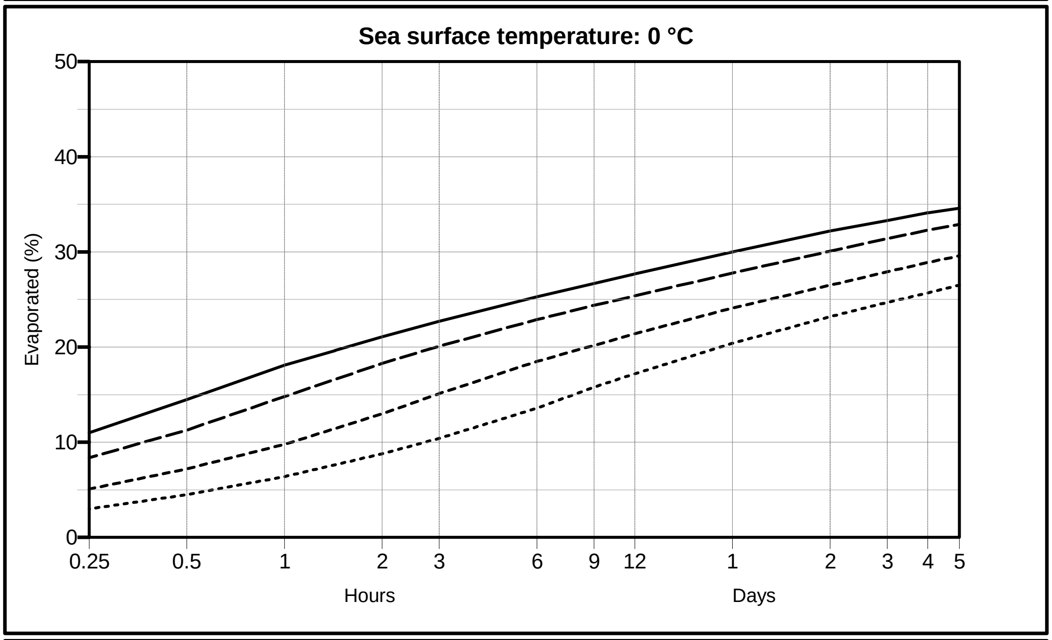
Property: EVAPORATIVE LOSS
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

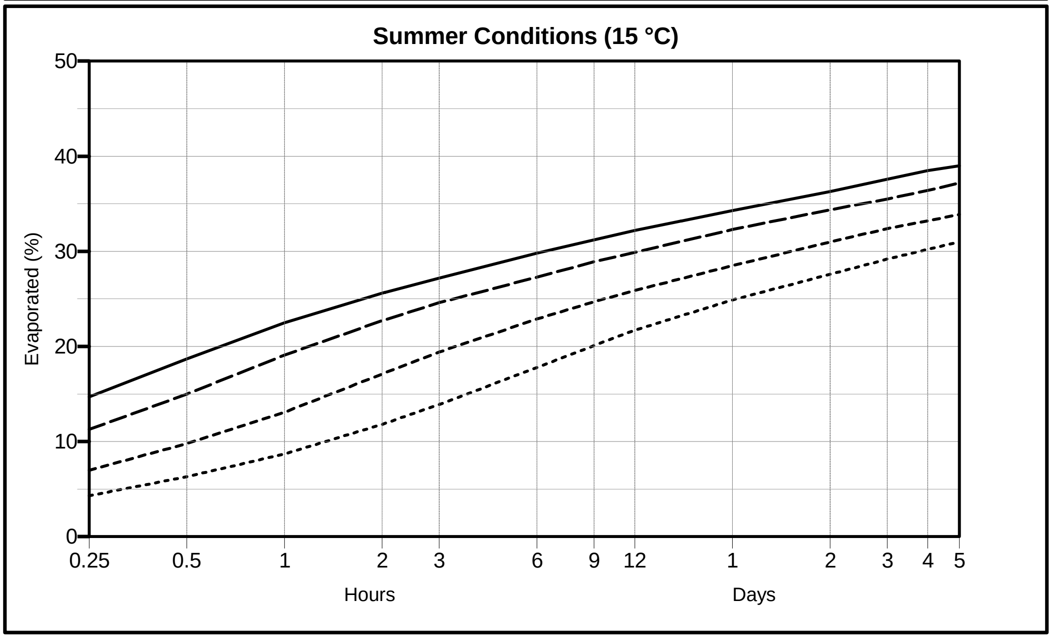
OWModel 3.2

Surface release - Terminal Oil film thickness: 1 mm
Amount/duration of oil spill: 500 metric tons in 360 minute(s)

Pred. date: Oct. 15, 2008

- Wind Speed (m/s): 15
- Wind Speed (m/s): 10
- Wind Speed (m/s): 5
- Wind Speed (m/s): 2





Property: WATER CONTENT
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

SINTEF

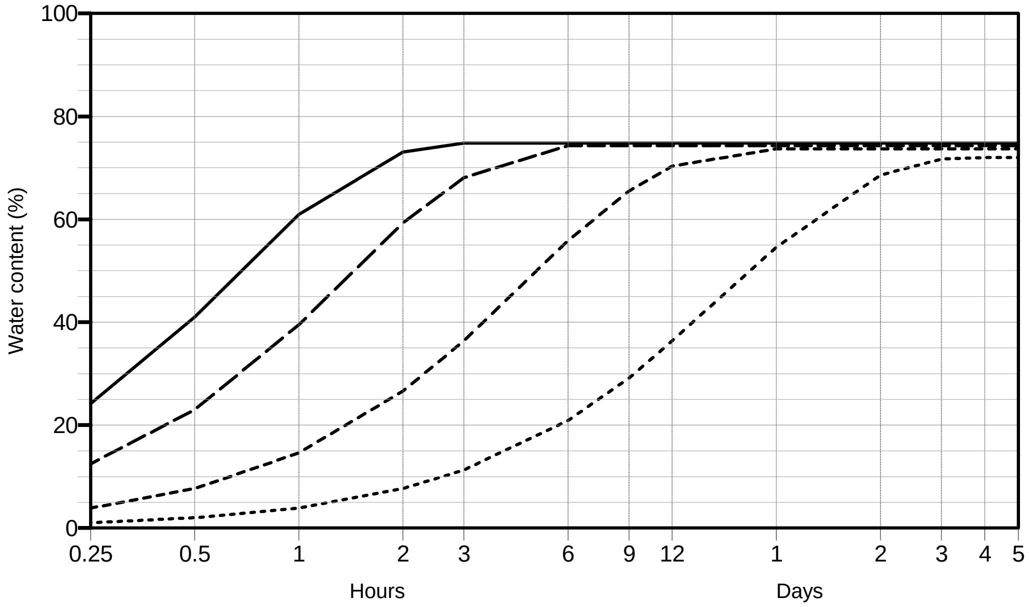
OWModel 3.2
© 2008

Surface release - Terminal Oil film thickness: 1 mm
Amount/duration of oil spill: 500 metric tons in 360 minute(s)

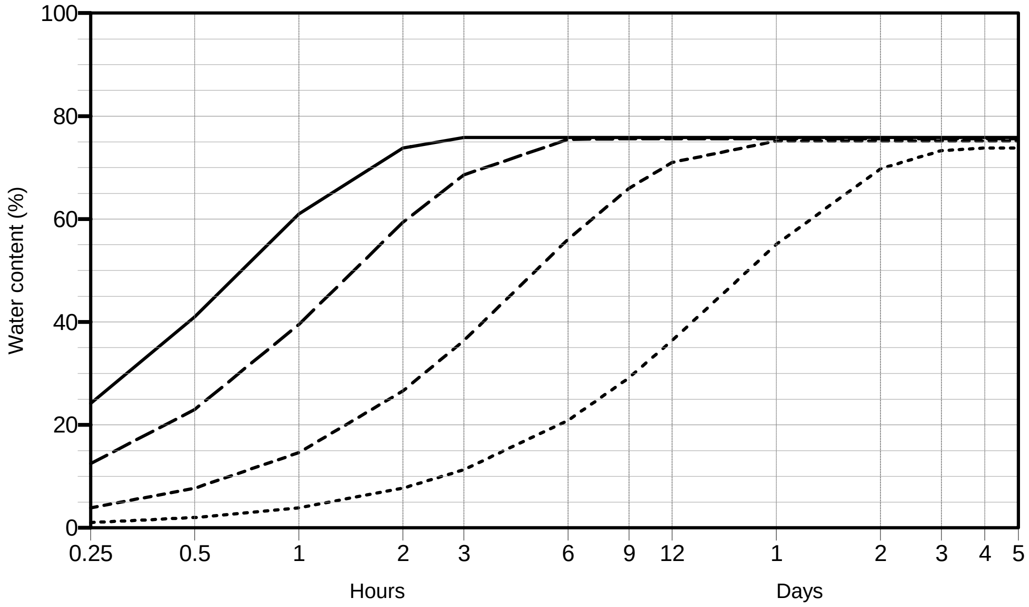
Pred. date: Oct. 15, 2008

Wind Speed (m/s): 15
Wind Speed (m/s): 10
Wind Speed (m/s): 5
Wind Speed (m/s): 2

Sea surface temperature: 0 °C



Summer Conditions (15 °C)



Property: VISCOSITY OF EMULSION
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

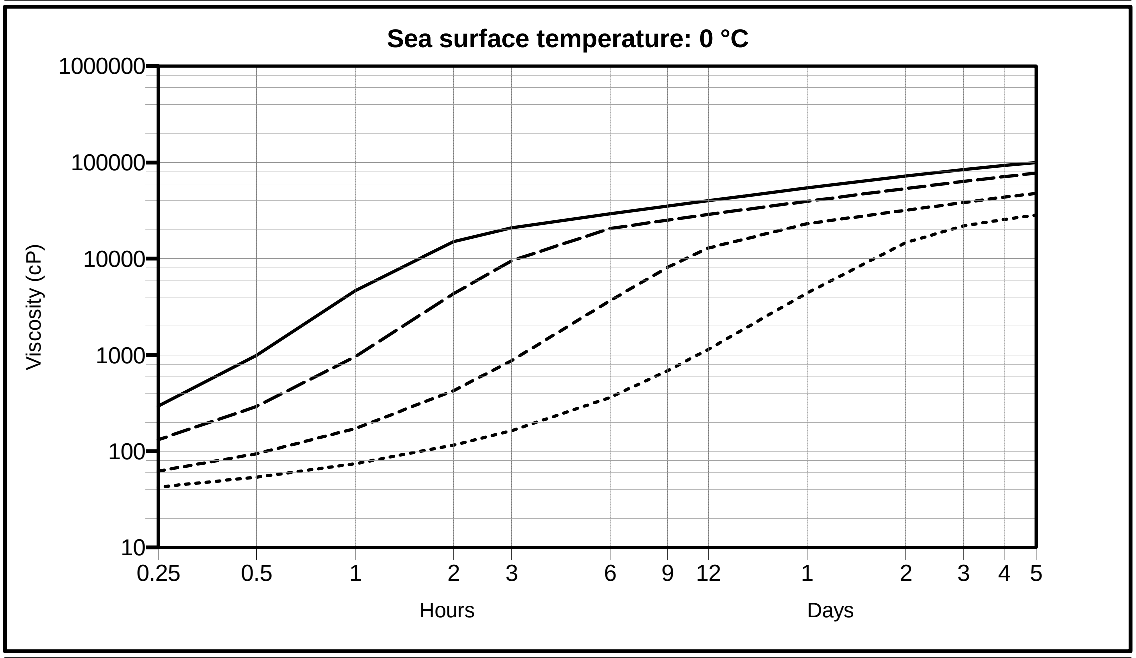
SINTEF

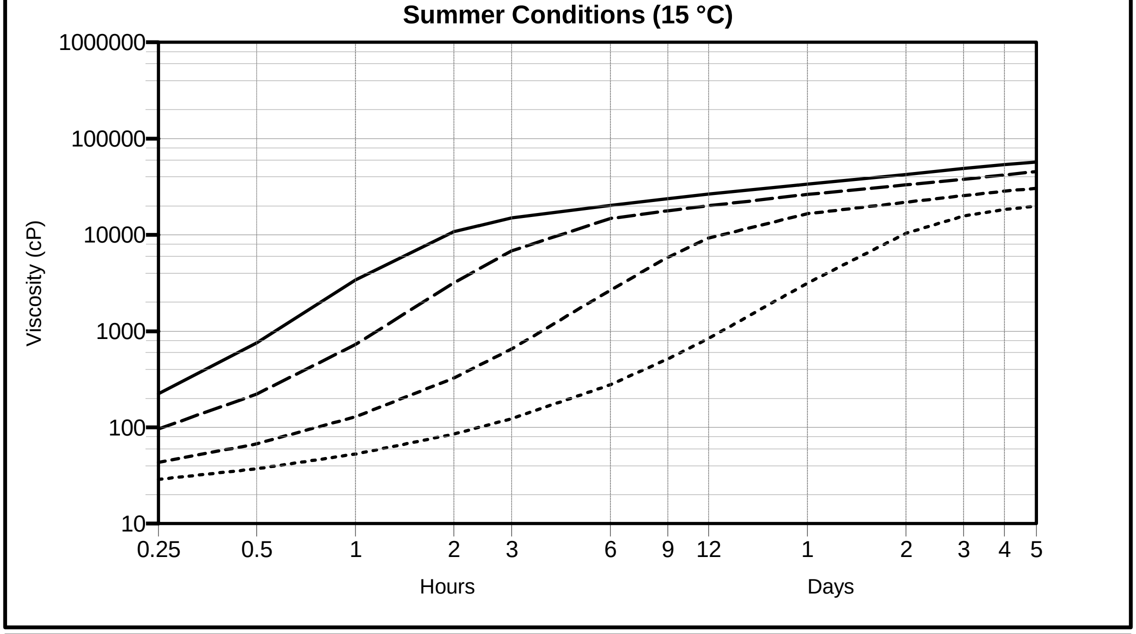
OWModel 3.2

Surface release - Terminal Oil film thickness: 1 mm
Amount/duration of oil spill: 500 metric tons in 360 minute(s)

Pred. date: Oct. 15, 2008

Wind Speed (m/s): 15
Wind Speed (m/s): 10
Wind Speed (m/s): 5
Wind Speed (m/s): 2





Based on viscosity measurements carried out at a shear rate of 10 reciprocal seconds.

Property: DENSITY OF EMULSION
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

SINTEF

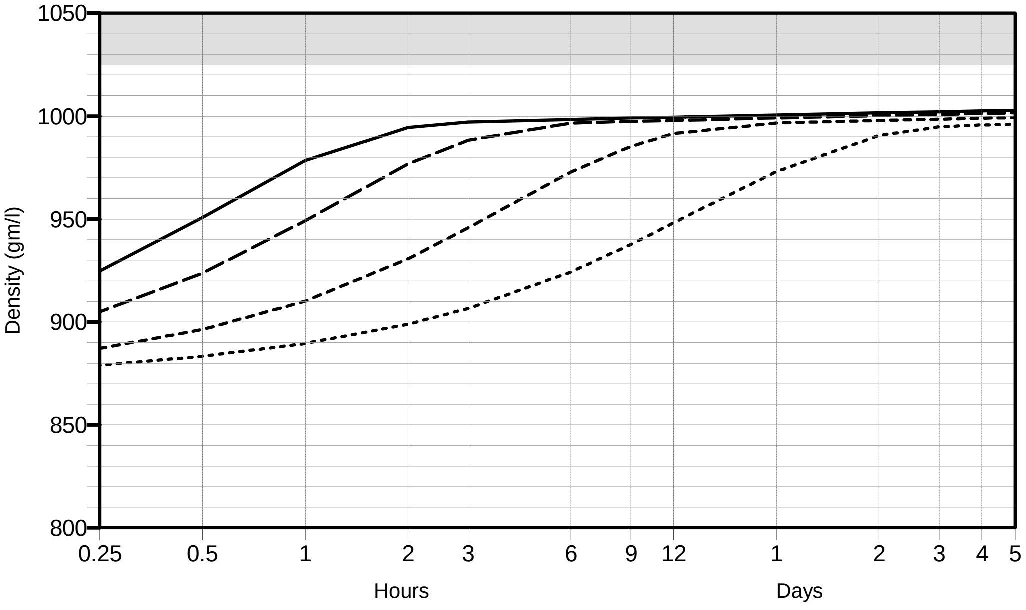
OWModel 3.2
© 2008

Surface release - Terminal Oil film thickness: 1 mm
Amount/duration of oil spill: 500 metric tons in 360 minute(s)

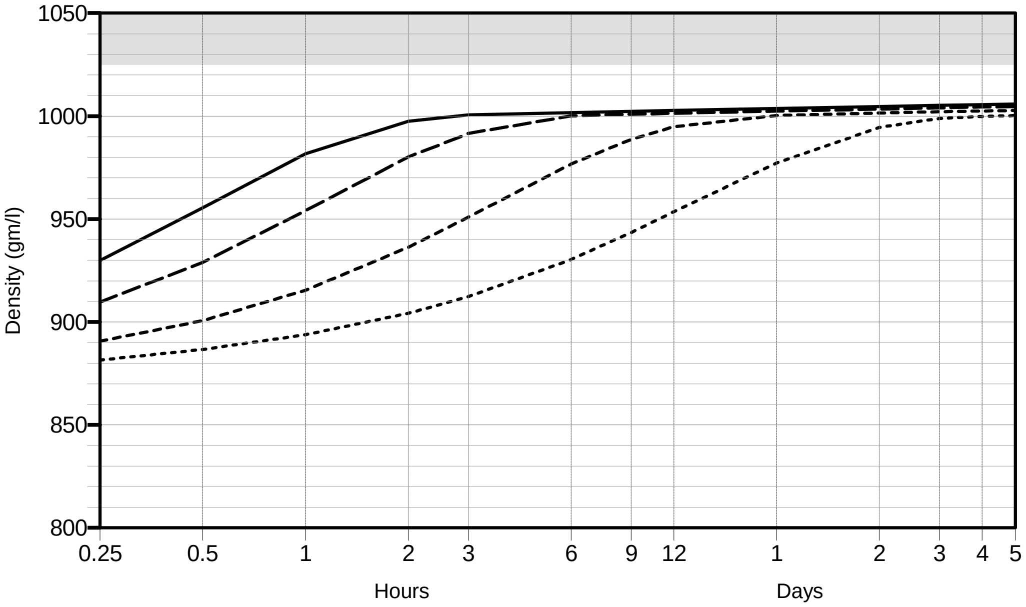
Pred. date: Oct. 15, 2008

- Wind Speed (m/s): 15
- Wind Speed (m/s): 10
- Wind Speed (m/s): 5
- Wind Speed (m/s): 2
- Oil stays on surface (<1025 gm/l)
- Oil sinks (>1025 gm/l)

Sea surface temperature: 0 °C



Summer Conditions (15 °C)



Property: POUR POINT FOR WATER-FREE OIL
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

SINTEF

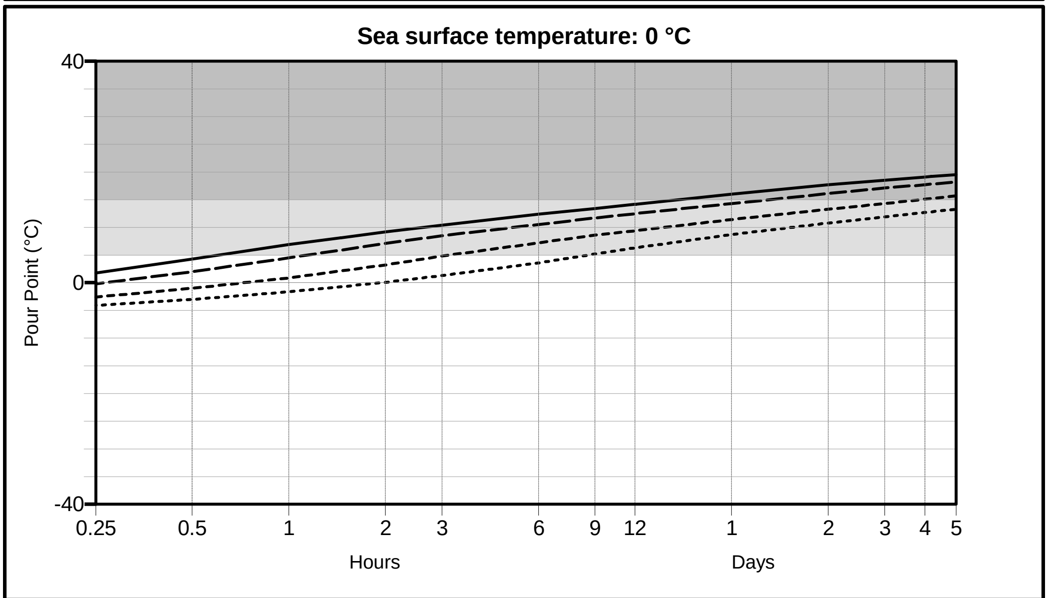
OWModel 3.2
© 2008

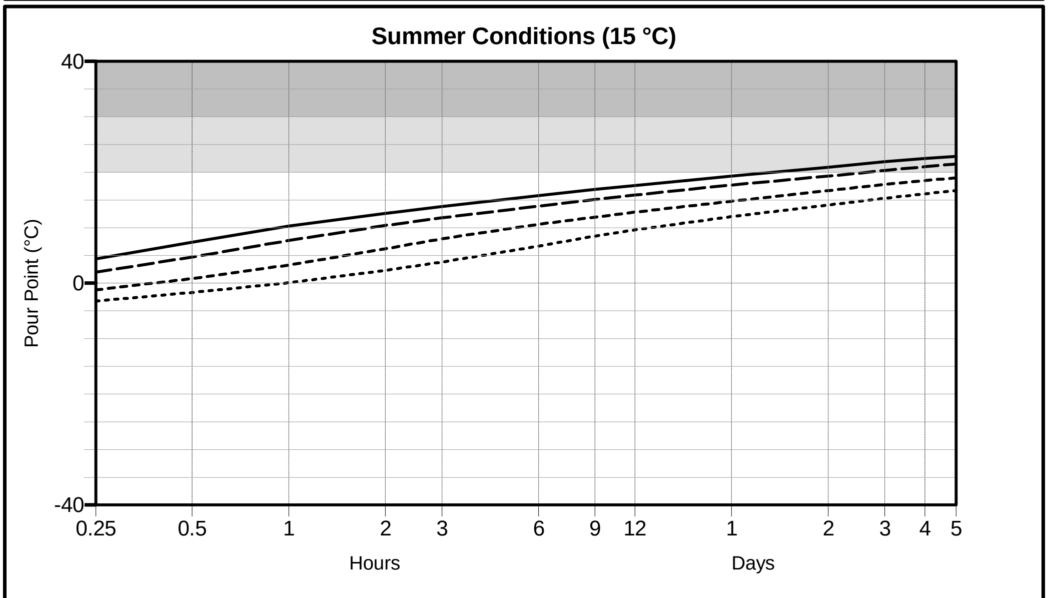
Surface release - Terminal Oil film thickness: 1 mm
Amount/duration of oil spill: 500 metric tons in 360 minute(s)

Pred. date: Oct. 15, 2008

Wind Speed (m/s): 15
Wind Speed (m/s): 10
Wind Speed (m/s): 5
Wind Speed (m/s): 2

Chemically dispersible
Reduced chemical dispersibility
Poorly / slowly chemically dispersible





Based on pour point measurements of weathered, water-free oil residues.

Property: MASS BALANCE
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

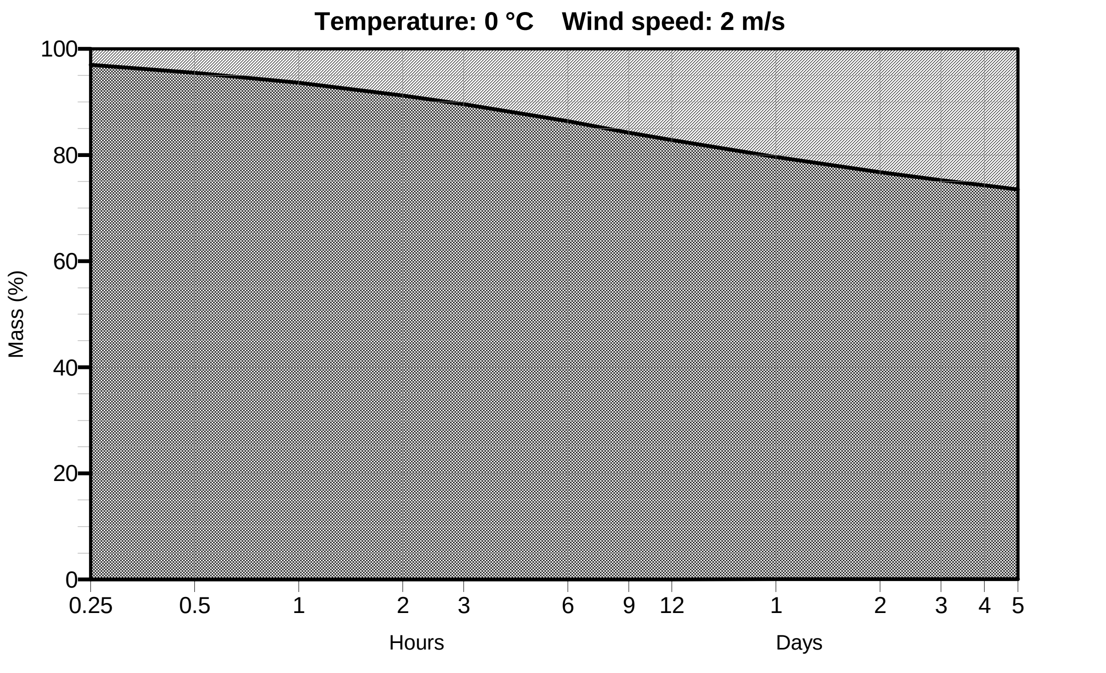
SINTEF

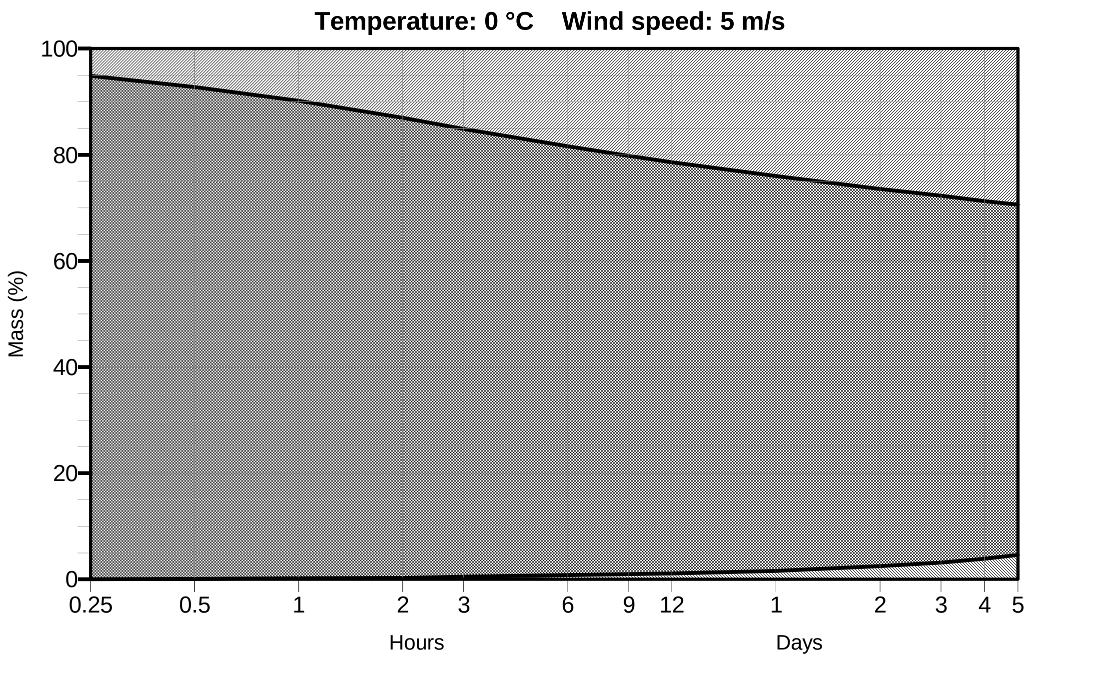
OWModel 3.2

Surface release - Terminal Oil film thickness: 1 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 21, 2008

Evaporated
Surface
Naturally dispersed





Property: MASS BALANCE
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

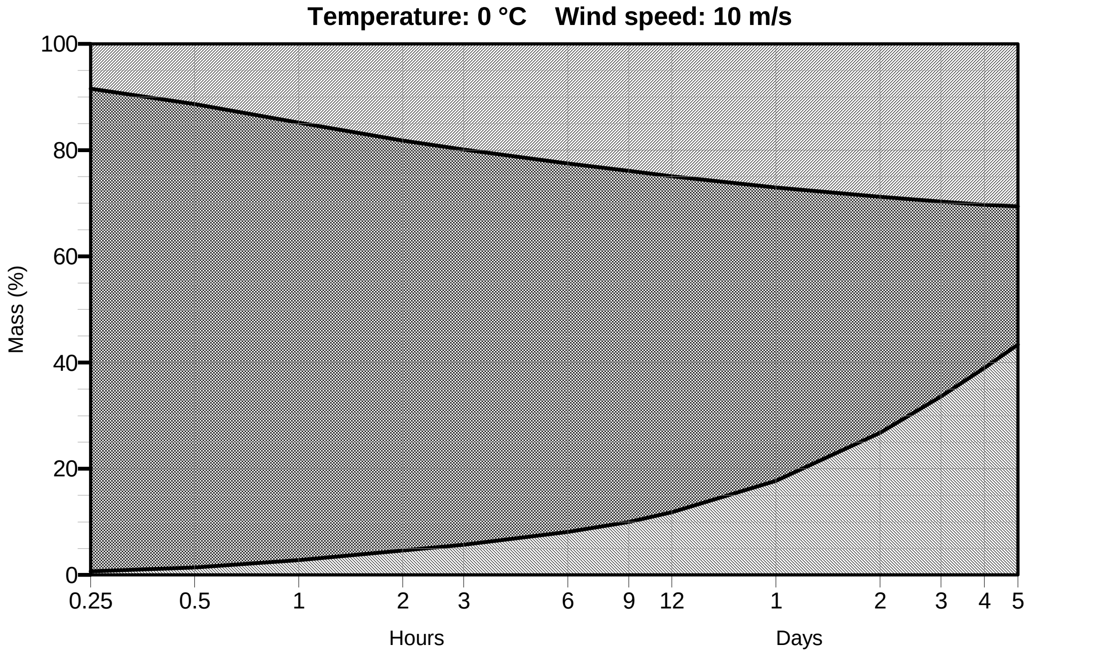
SINTEF

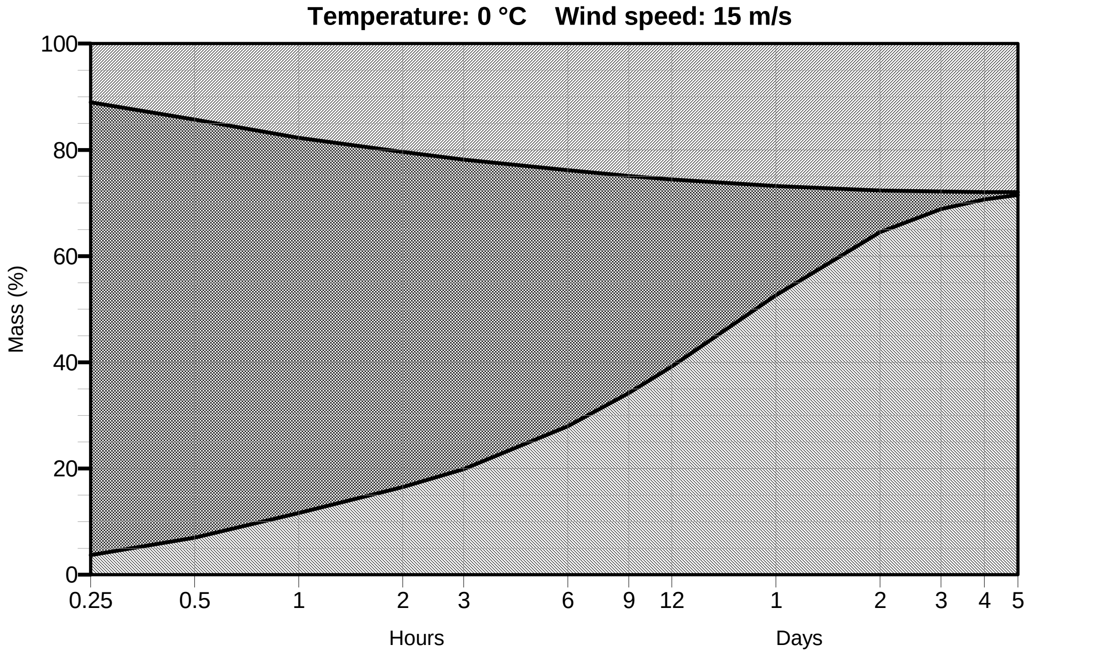
OWModel 3.2
© 2008

Surface release - Terminal Oil film thickness: 1 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 21, 2008

Evaporated
Surface
Naturally dispersed





Property: MASS BALANCE
Oil Type: RUSSIAN EXPORT CRUDE OIL
Description: REBCO - Project 800861 Kustbevakningen (EU-pro
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

SINTEF

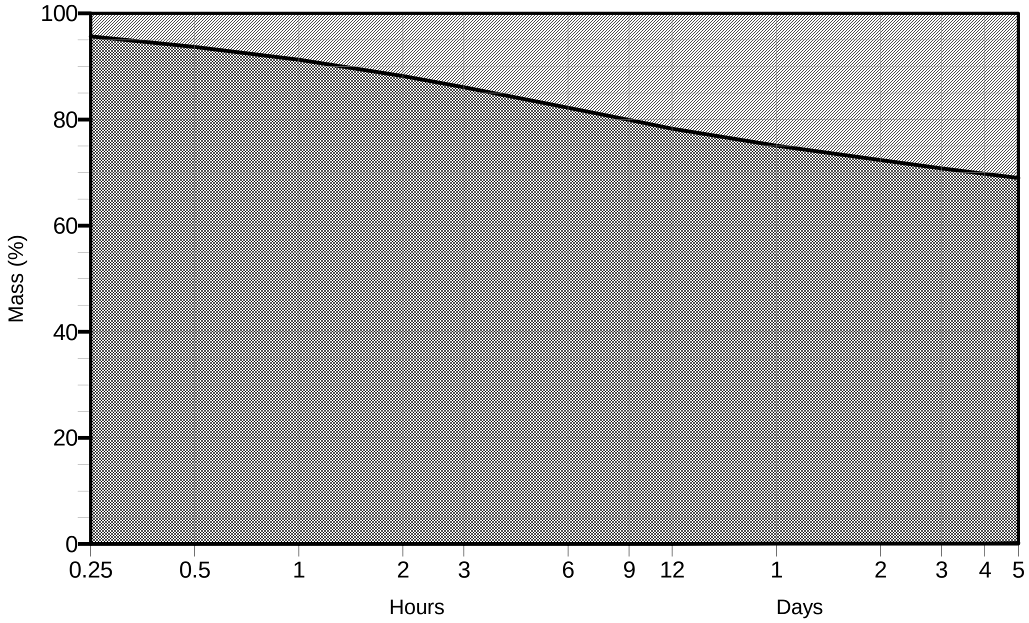
OWModel 3.2

Surface release - Terminal Oil film thickness: 1 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

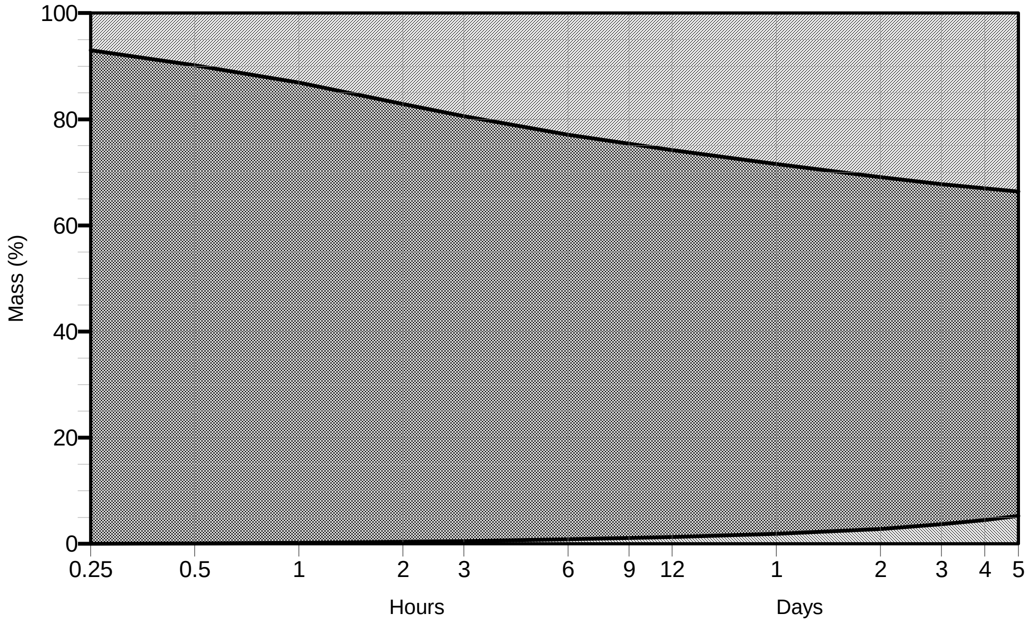
Pred. date: Oct. 21, 2008

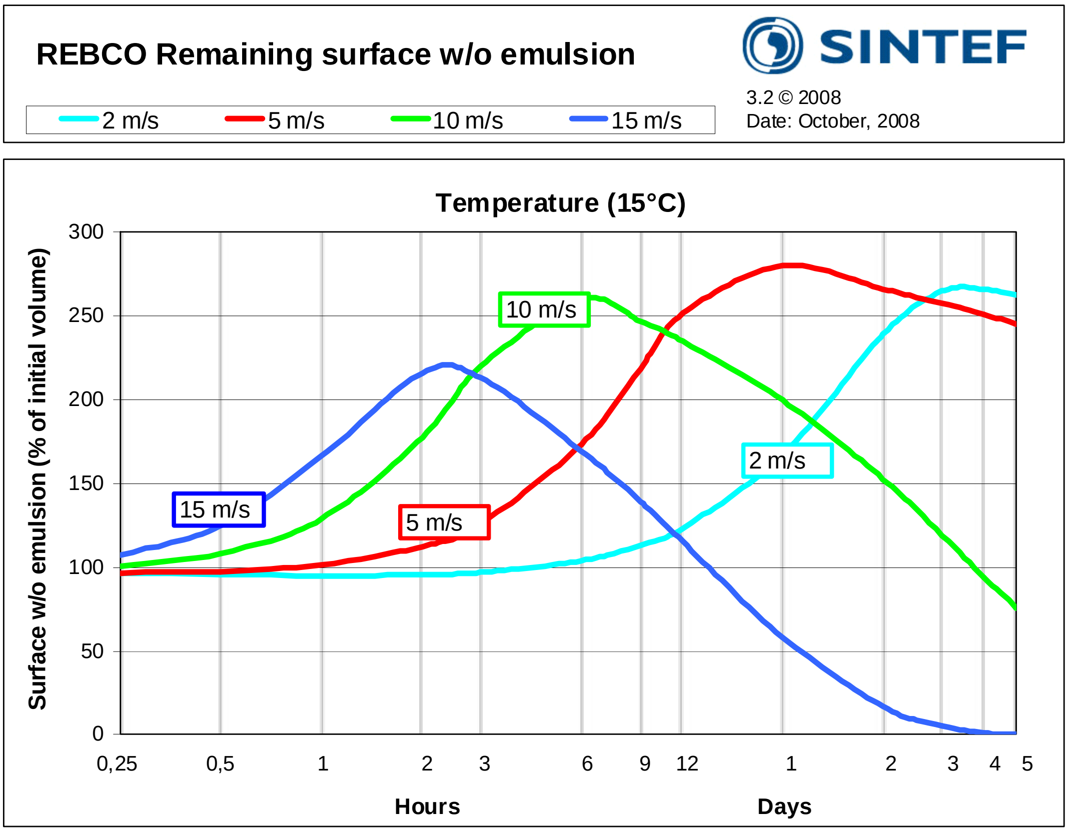
Evaporated
Surface
Naturally dispersed

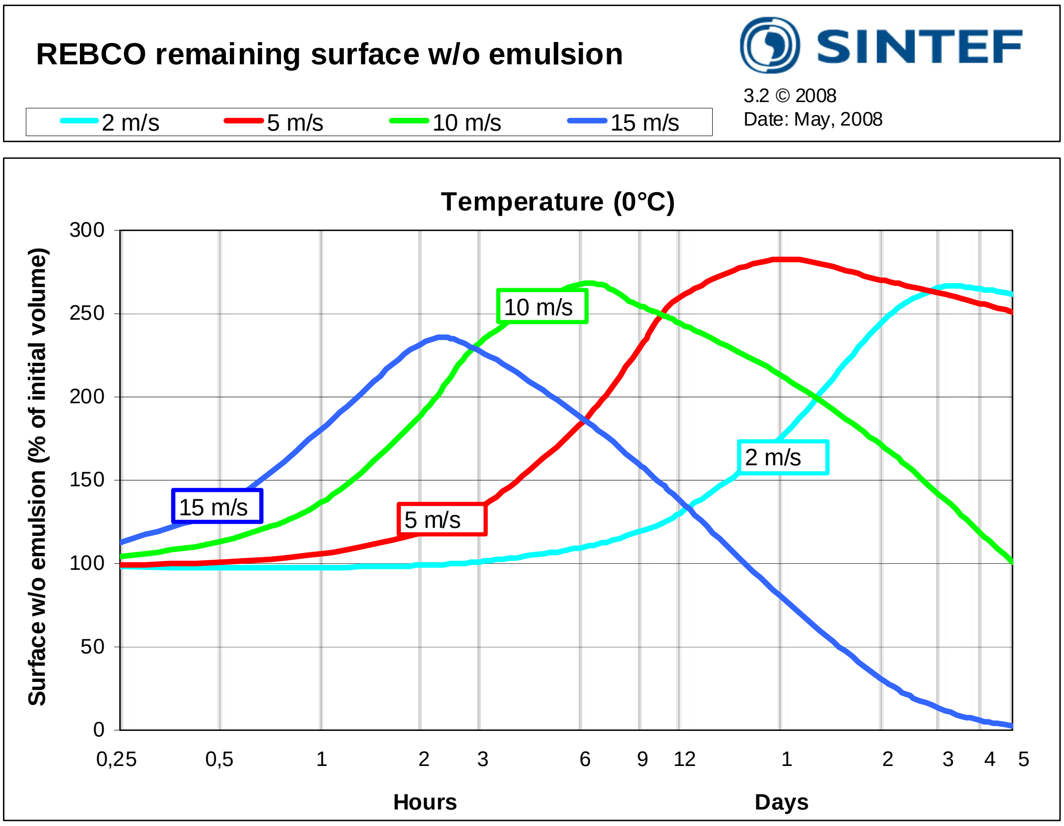
Temperature: 15 °C   Wind speed: 2 m/s



Temperature: 15 °C   Wind speed: 5 m/s




REBCO Remaining surface w/o emulsion
SINTEF
3.2 © 2008
Date: October, 2008
2 m/s
5 m/s
10 m/s
15 m/s
Temperature (15°C)
Surface w/o emulsion (% of initial volume)
0
50
100
150
200
250
300
0,25
0,5
1
2
3
6
9
12
1
2
3
4
5
Hours
Days


REBCO remaining surface w/o emulsion
SINTEF
3.2 © 2008
Date: May, 2008
2 m/s
5 m/s
10 m/s
15 m/s
Temperature (0°C)
Surface w/o emulsion (% of initial volume)
0
50
100
150
200
250
300
0,25
0,5
1
2
3
6
9
12
1
2
3
4
5
Hours
Days

8.6 Vysotsk IFO-380 bunker - prediction sheets

Property: EVAPORATIVE LOSS
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

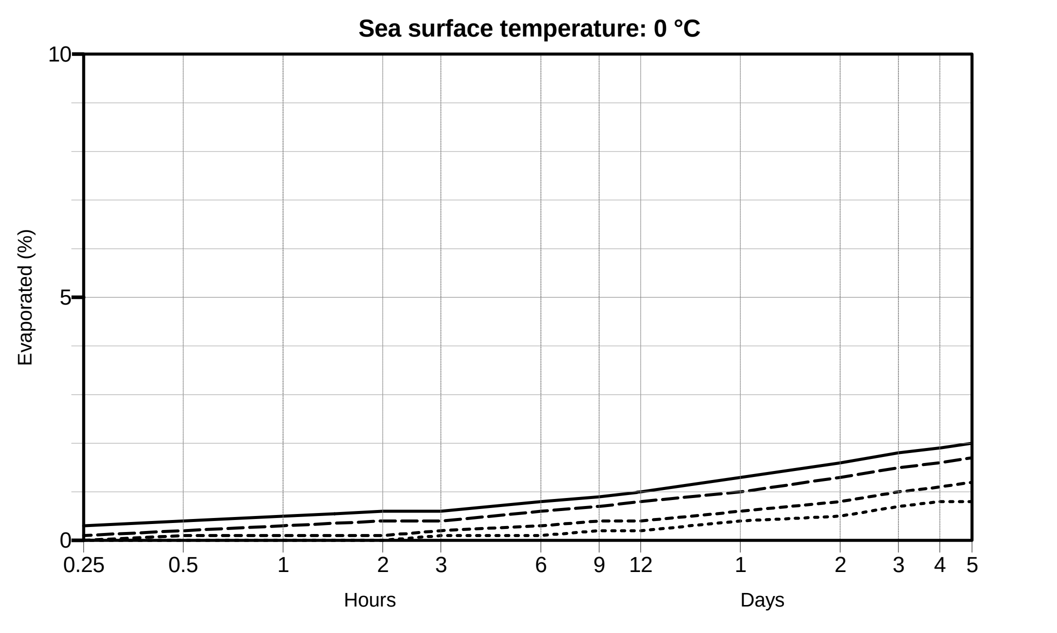
SINTEF

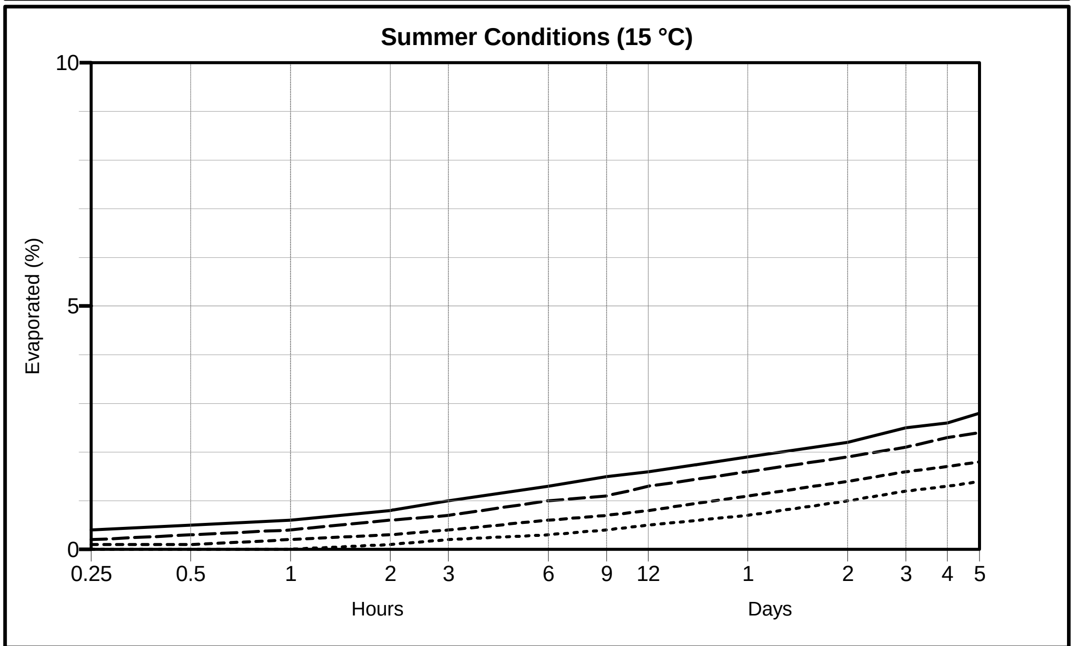
OWModel 3.2
© 2008

Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 14, 2008

- Wind Speed (m/s): 15
- Wind Speed (m/s): 10
- Wind Speed (m/s): 5
- Wind Speed (m/s): 2





Property: WATER CONTENT
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

SINTEF

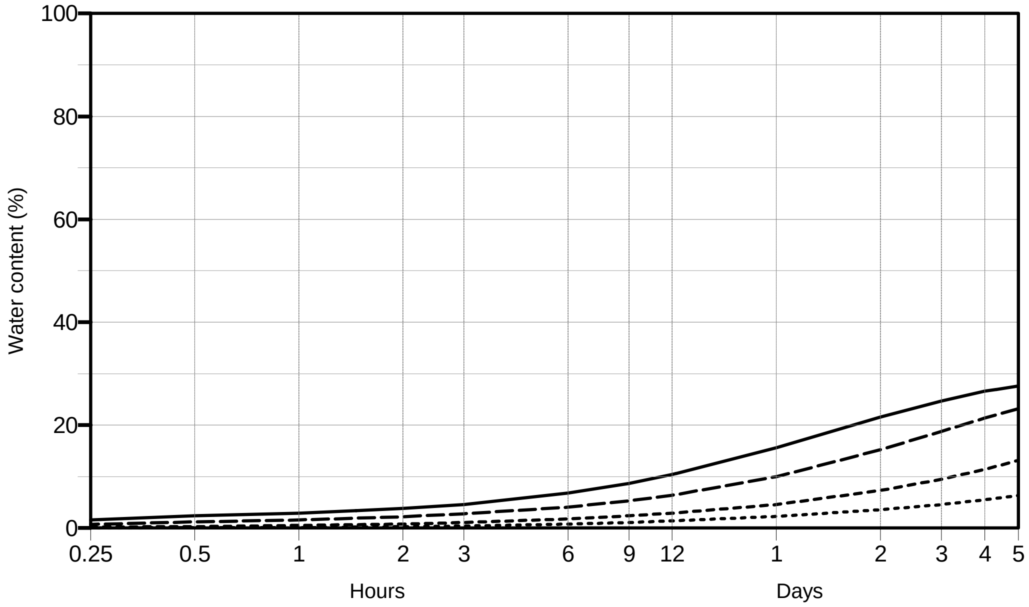
OWModel 3.2

Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

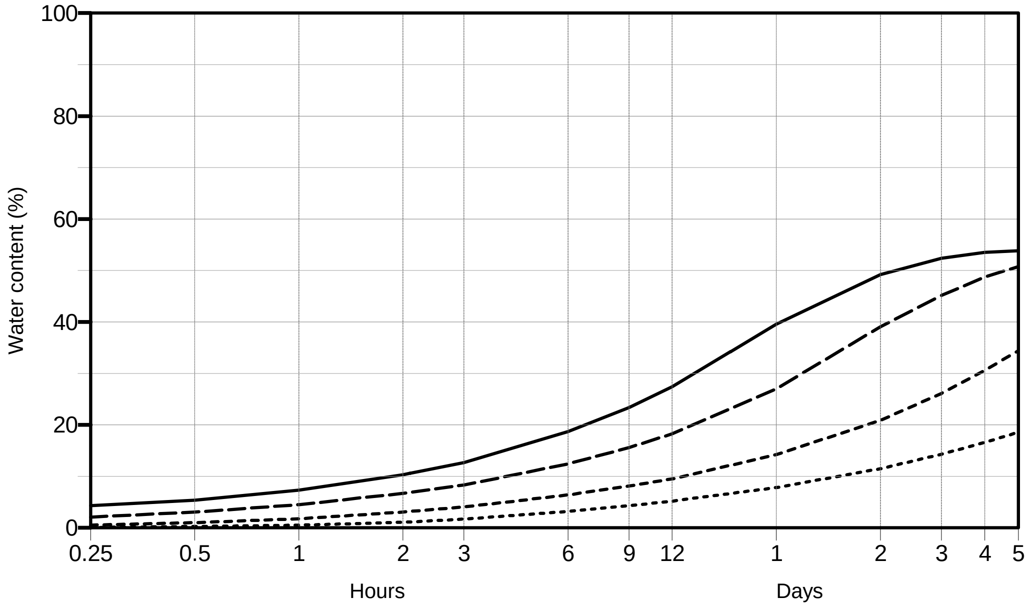
Pred. date: Oct. 14, 2008

- Wind Speed (m/s): 15
- Wind Speed (m/s): 10
- Wind Speed (m/s): 5
- Wind Speed (m/s): 2

Sea surface temperature: 0 °C



Summer Conditions (15 °C)



Property: VISCOSITY OF EMULSION
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

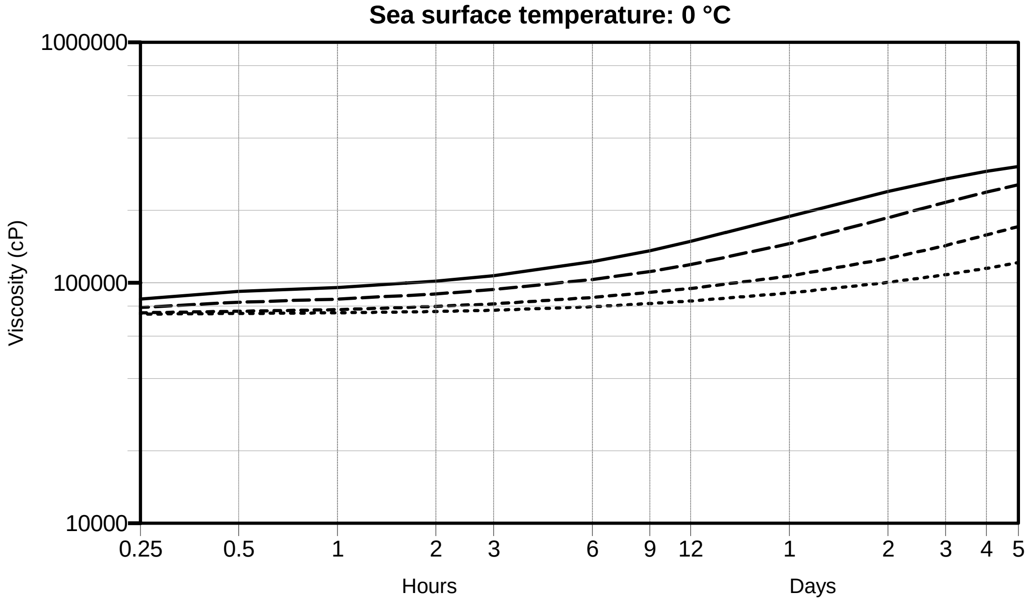
SINTEF

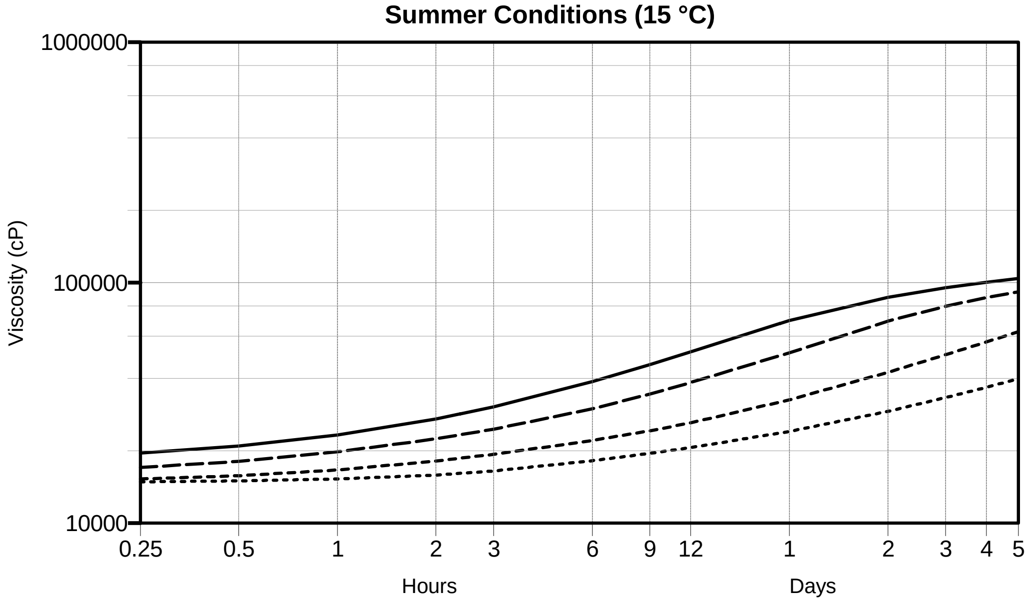
OWModel 3.2

Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 14, 2008

Wind Speed (m/s): 15
Wind Speed (m/s): 10
Wind Speed (m/s): 5
Wind Speed (m/s): 2





Based on viscosity measurements carried out at a shear rate of 10 reciprocal seconds.

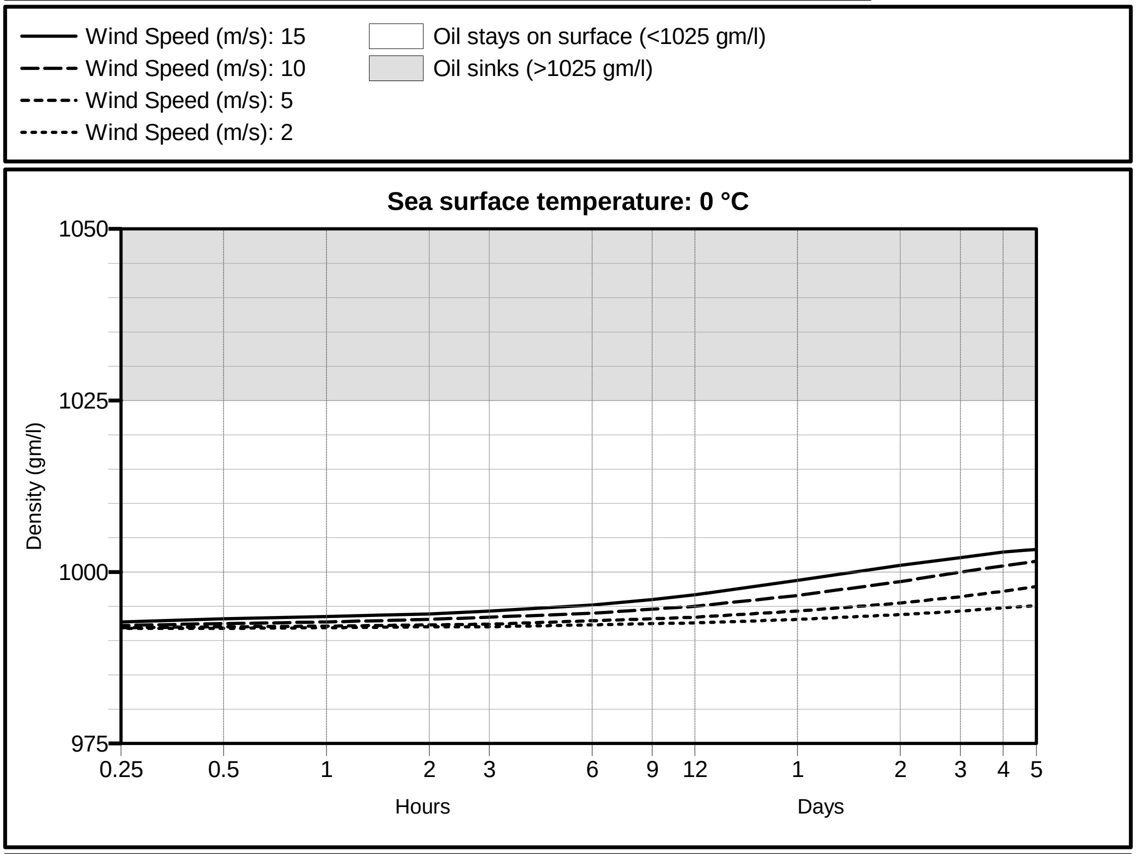
Property: DENSITY OF EMULSION
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

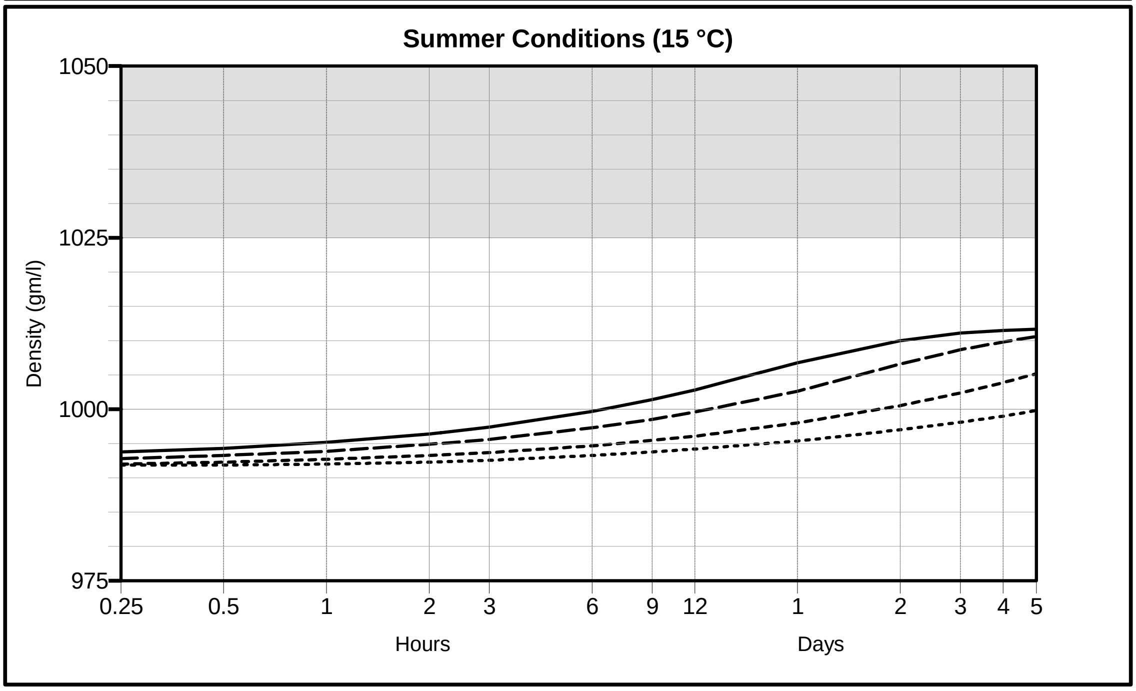
SINTEF

OWModel 3.2

Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 14, 2008





Property: POUR POINT FOR WATER-FREE OIL
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

SINTEF

OWModel 3.2

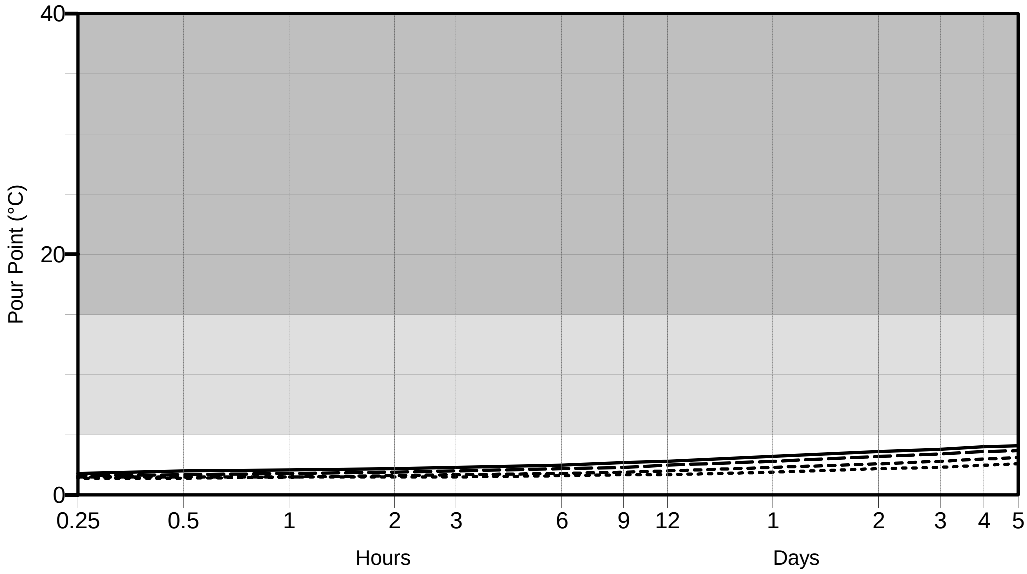
Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 14, 2008

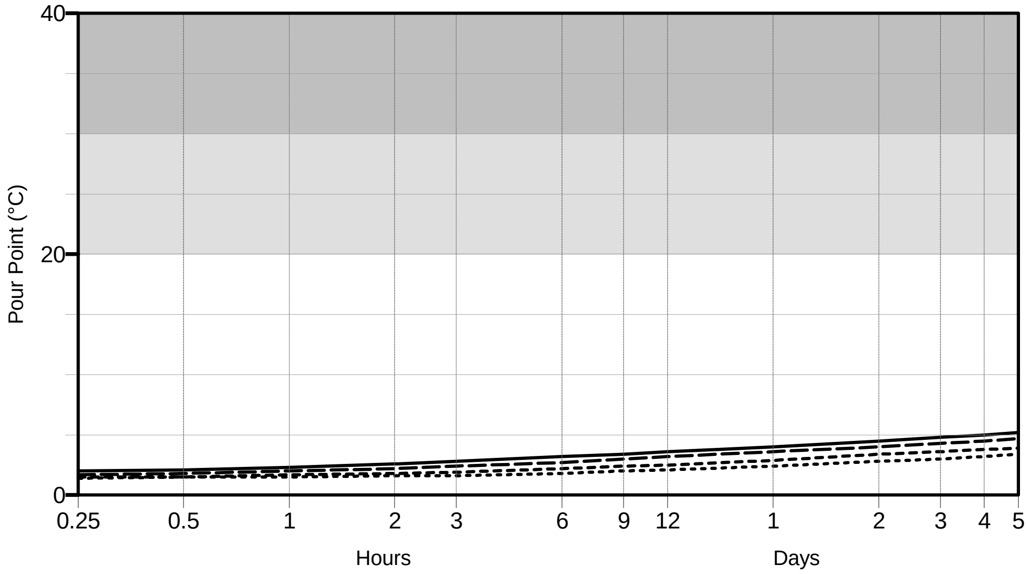
Wind Speed (m/s): 15
Wind Speed (m/s): 10
Wind Speed (m/s): 5
Wind Speed (m/s): 2

Chemically dispersible
Reduced chemical dispersibility
Poorly / slowly chemically dispersible

Sea surface temperature: 0 °C



Summer Conditions (15 °C)



Based on pour point measurements of weathered, water-free oil residues.

Property: MASS BALANCE
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Vysotsk, Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

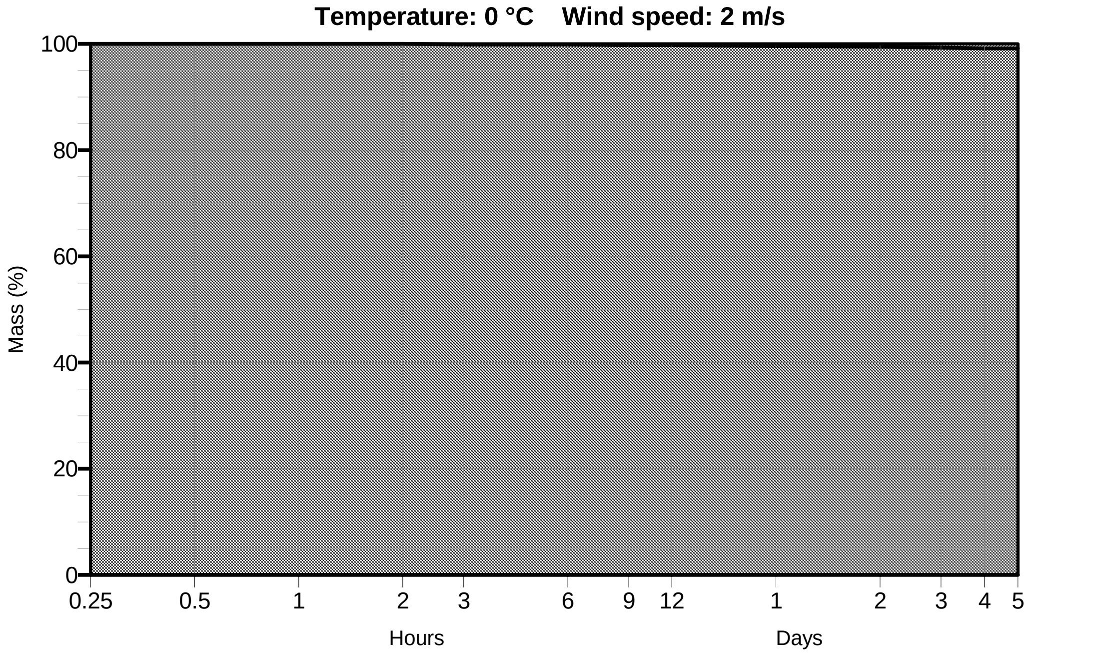
SINTEF

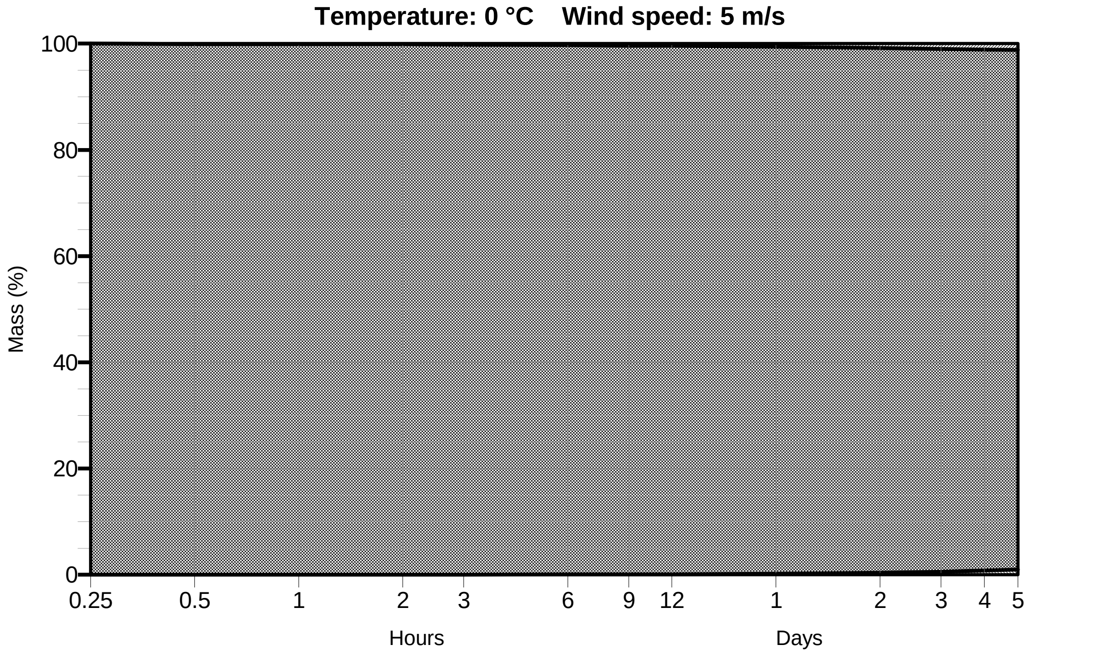
OWModel 3.2
© 2008

Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 21, 2008

Evaporated
Surface
Naturally dispersed





Property: MASS BALANCE
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Vysotsk, Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

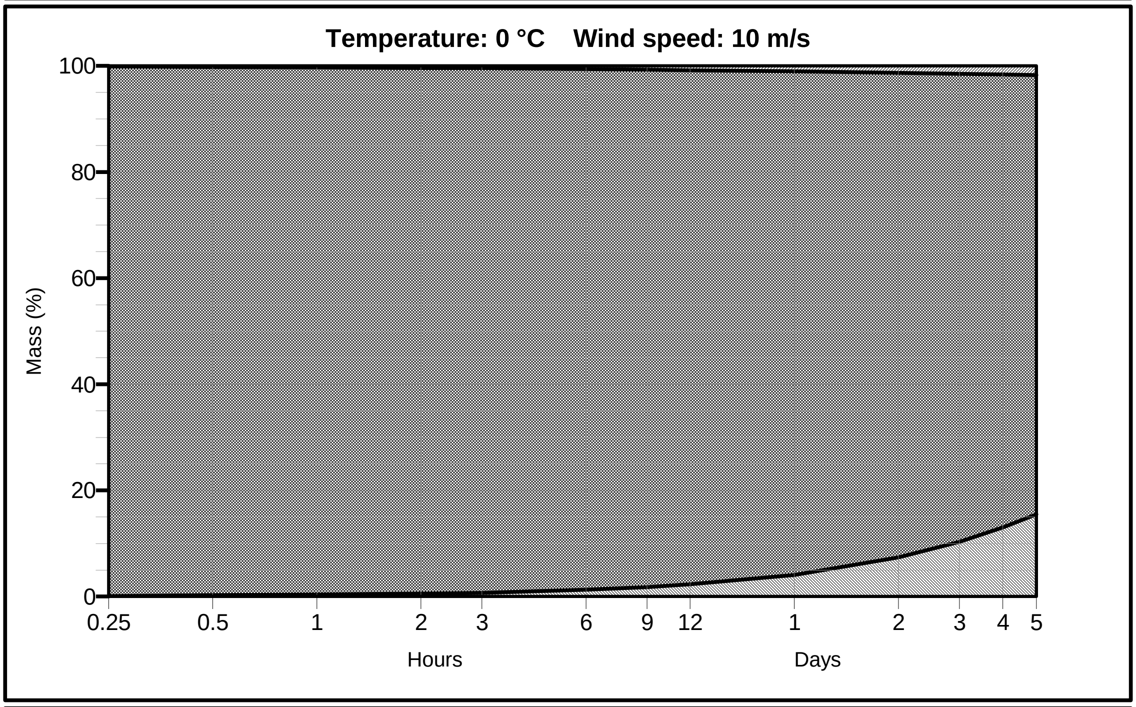
SINTEF

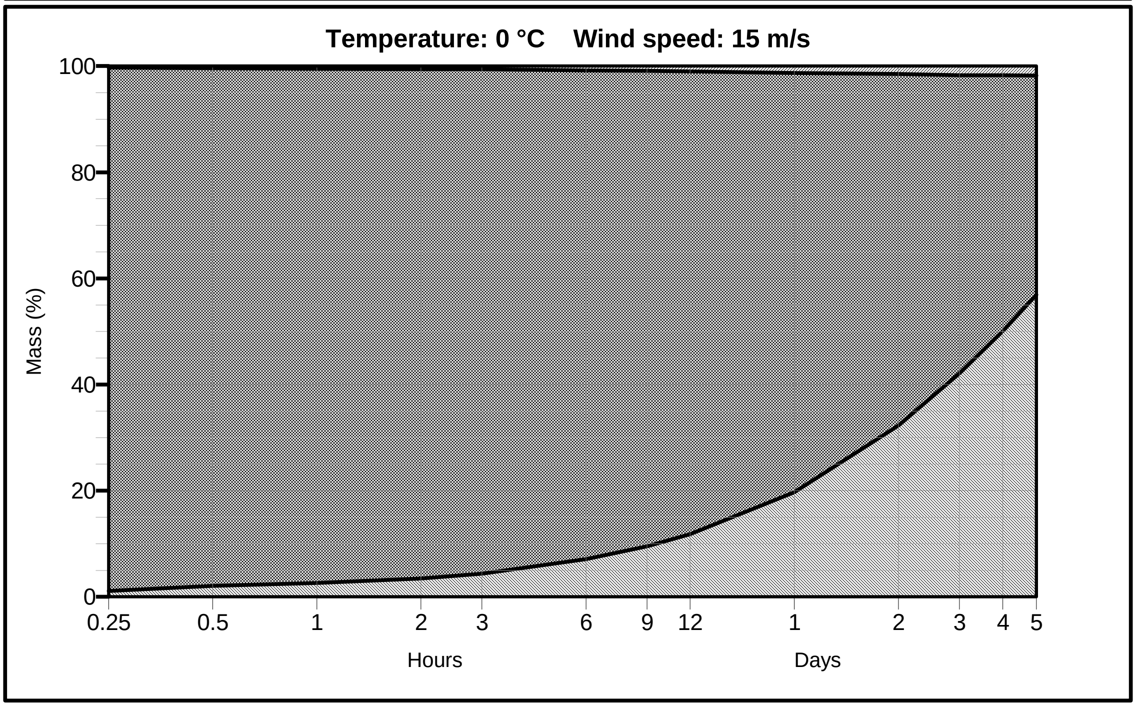
OWModel 3.2
© 2008

Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

Pred. date: Oct. 21, 2008

Evaporated
Surface
Naturally dispersed





Property: MASS BALANCE
Oil Type: IFO-380 RUSSIAN BUNKER FUEL
Description: Vysotsk, Kustbevakningen (SINTEF ID 2008-0106)
Data Source: SINTEF Applied Chemistry (2008), Weathering dat

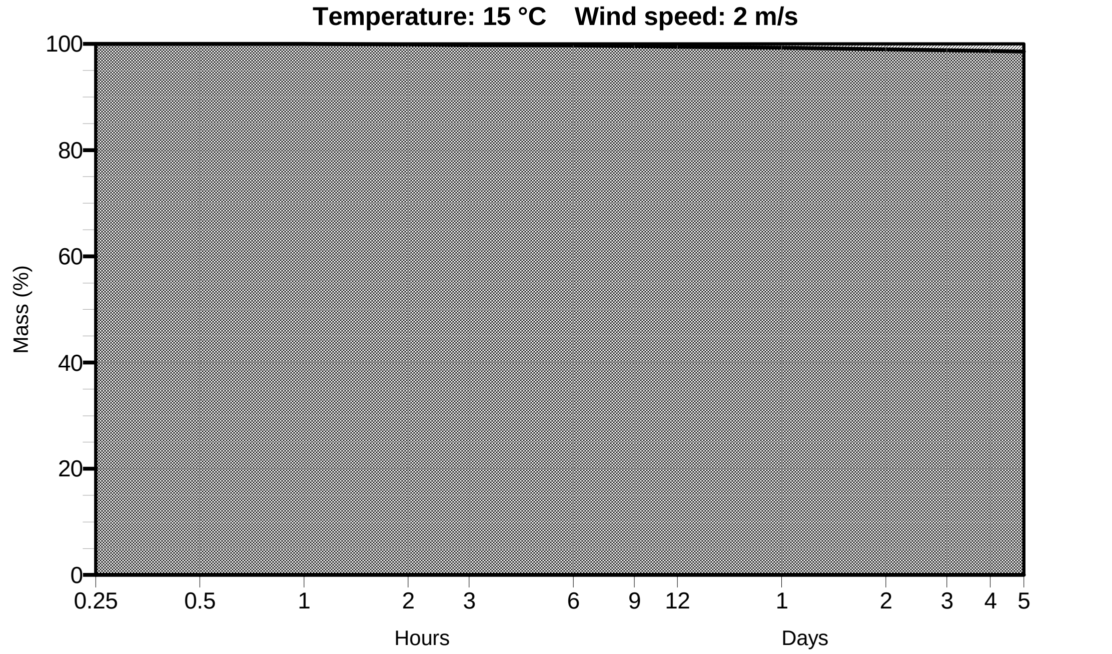
SINTEF

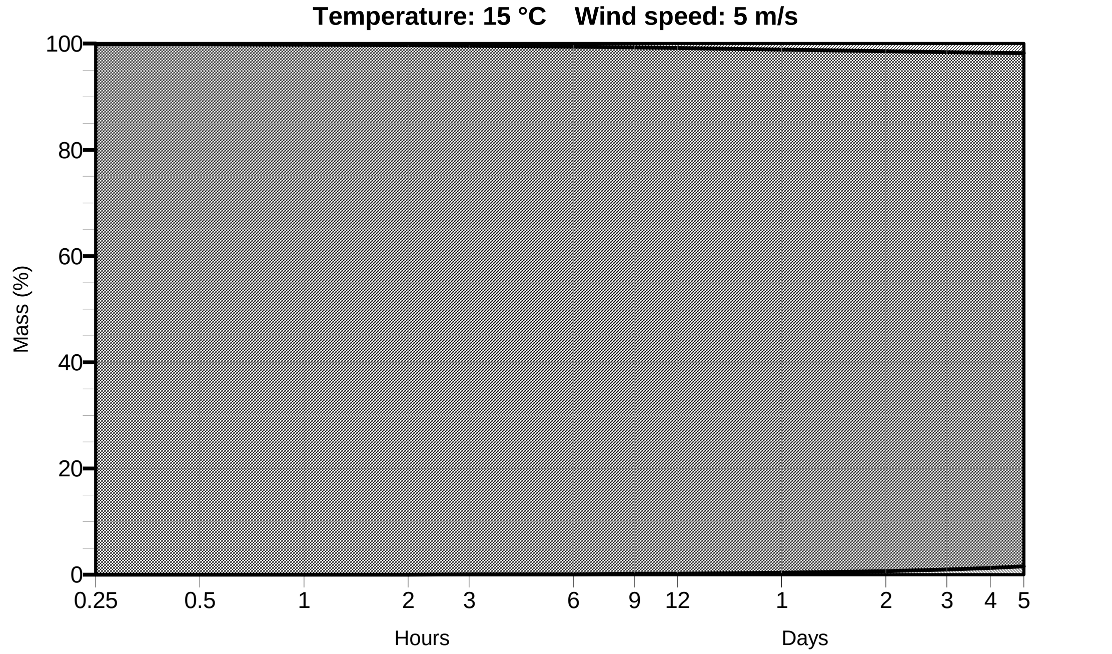
OWModel 3.2

Surface release - Terminal Oil film thickness: 2 mm
Release rate/duration: 1.39 metric tons/minute for 360 minute(s)

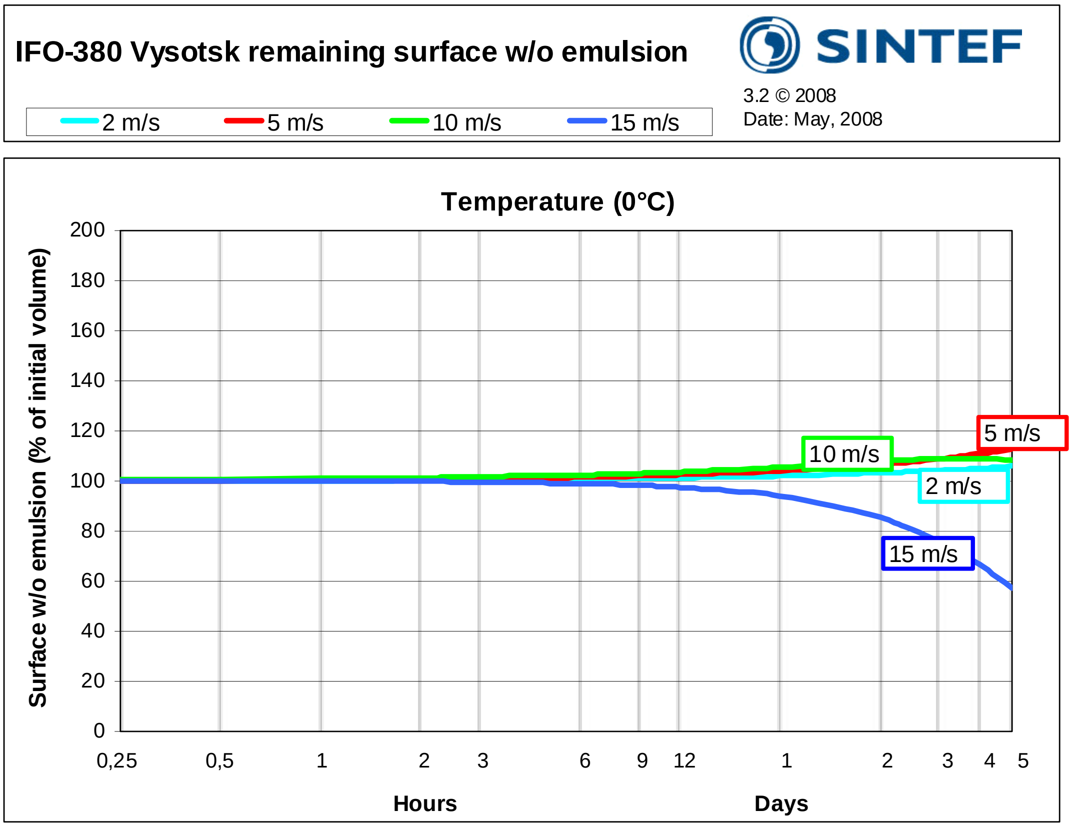
Pred. date: Oct. 21, 2008

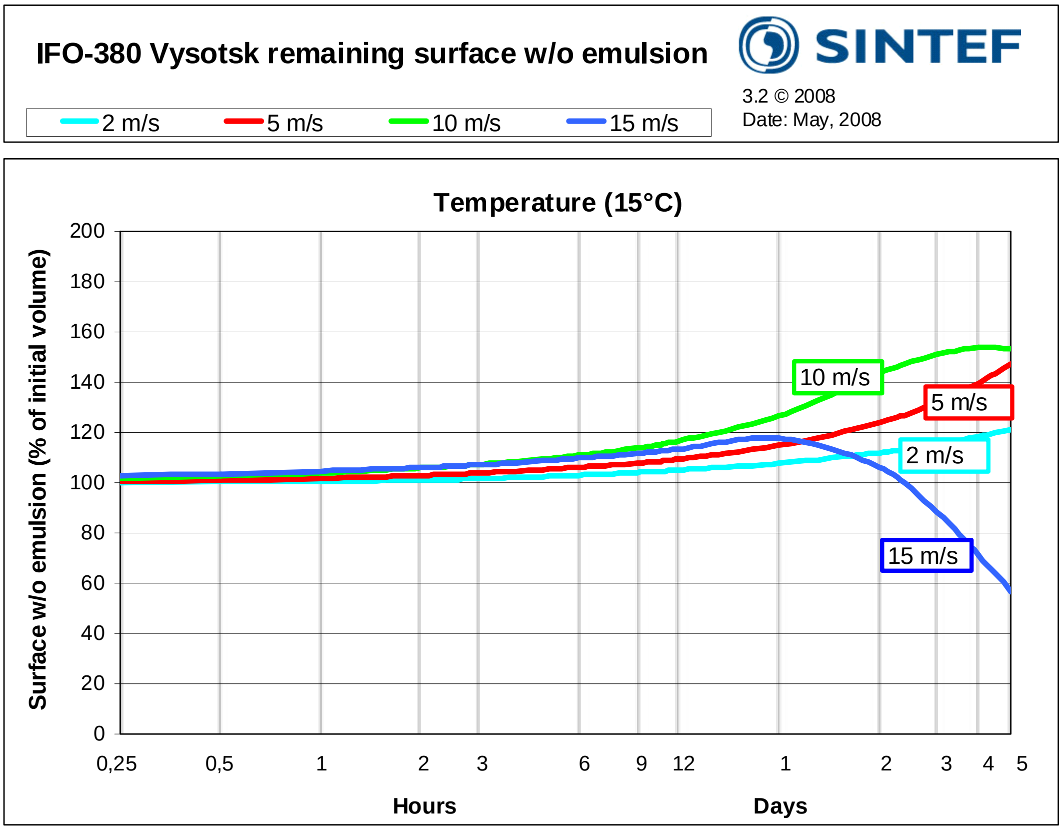
Evaporated
Surface
Naturally dispersed





Saknas temp 15 °C vind 10 och 15 m/s


IFO-380 Vysotsk remaining surface w/o emulsion
SINTEF
3.2 © 2008
Date: May, 2008
2 m/s
5 m/s
10 m/s
15 m/s
Temperature (0°C)
Surface w/o emulsion (% of initial volume)
200
180
160
140
120
100
80
60
40
20
0
0,25
0,5
1
2
3
6
9
12
1
2
3
4
5
Hours
Days
10 m/s
5 m/s
2 m/s
15 m/s


IFO-380 Vysotsk remaining surface w/o emulsion
SINTEF
3.2 © 2008
Date: May, 2008
2 m/s
5 m/s
10 m/s
15 m/s
Temperature (15°C)
Surface w/o emulsion (% of initial volume)
200
180
160
140
120
100
80
60
40
20
0
0,25
0,5
1
2
3
6
9
12
1
2
3
4
5
Hours
Days
10 m/s
5 m/s
2 m/s
15 m/s

8.7 SINTEF Oil Weathering Model (OWM) - the model and input

Laboratory data from weathered oil samples, generated in laboratories, form basis for input in models for prediction of the weathering behaviour of oils at different weather conditions.

The behaviour of spilled crude oils and refined oil products on the sea surface depends on the prevailing conditions (e.g. temperature, sea-state, current) and on chemical composition of the oil. Large variations in oil properties cause them to behave differently when spilled at sea. SINTEF OWM, schematically shown in Figure 4.1, relates oil properties to a chosen set of conditions (oil/emulsion film thickness, sea state and sea temperature) and predicts the changing rate of an oil's properties and behaviour on the sea surface (Aamo et al., 1993; Daling et al, 1997).

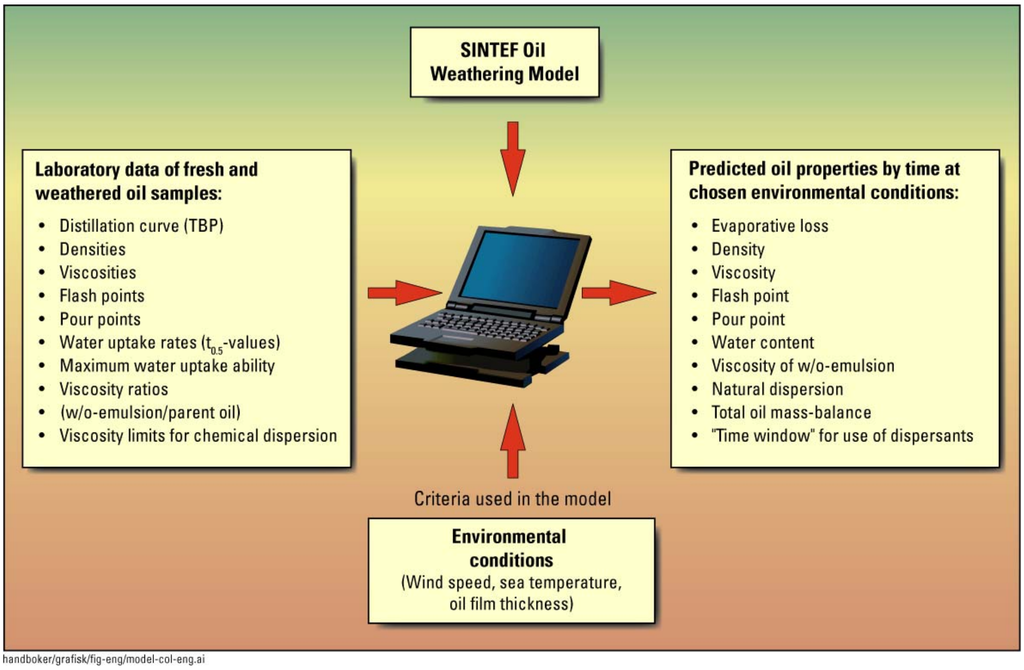


Figure 4.1 Schematic input data to SINTEF OWM and the predicted output oil properties.

The predictions obtained are a useful tool in Environmental Impact Assessment studies, contingency planning and Net Environmental Benefit Analyses (NEBA). The predictions in this report are presented over a time period of 15 minutes to 5 days after the oil spill has occurred. This covers potential spill situations where the response time is short (e.g. close to terminals) to offshore spills where the response time can be several days.

The validity of the predictions has in recent years been documented by correlation studies to field data from experimental oil spills (Daling and Strøm, 1999 and Moldestad et al., 2004).

SINTEF OWM's strength lies in the continuous evolution of empirical algorithms based on good data from experimental field trials performed for the last 15 years in Norway. The importance of having good experimental laboratory weathering data of the specific oil as input to the model is also a key element for obtaining reliable weathering predictions. Synthetic weathering data derived from crude assay data of the fresh oil give only tentative predictions, and with accuracy that is not satisfactory in connection to good contingency planning and as a reliable support for countermeasure decision making.

8.8 Input to SINTEFs Oil Weathering Model (OWM)

The experimental laboratory data used as input to the model, are found in Appendix B.

Geographical area: Baltic sea
Initial oil film thickness: 20 mm
Terminal oil film thickness: 1 mm for REBCO and 2 mm for Vysotsk IFO-380
Release rate 500 m^3 over 6 hours
Sea temperature: 15°C
Wind speed: 2 m/s, 5 m/s, 10 m/s and 15 m/s

A sensitivity study was performed at 3 different release rates (20 m^3 / 6 hours, 500 m^3 / 6 hours and 10 000 m^3 / 6 hours). There was no significant difference between the 20 m^3 and the 500 m^3 case, as shown in Figure 4.2 (the curves coincided).

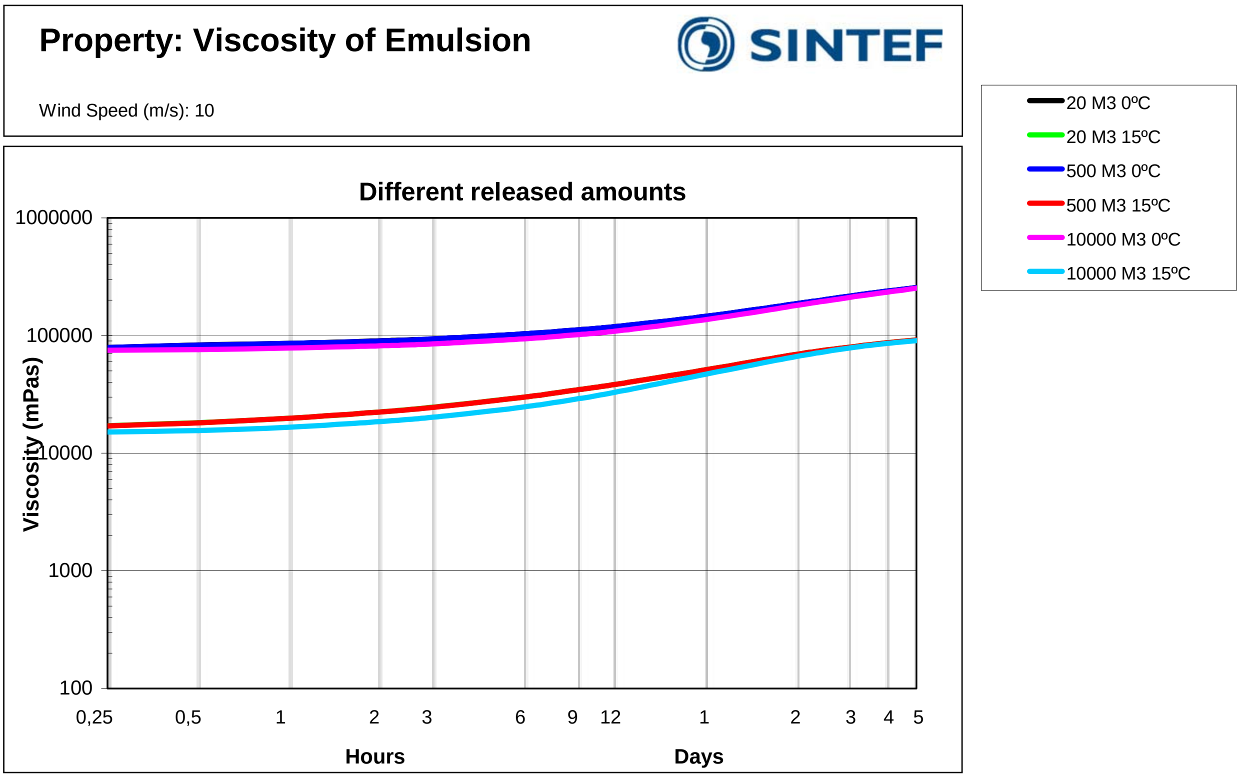


Figure 4.2: Sensitivity study for different release rates.

The relationship between the wind speed and the significant wave heights used in the prediction charts are shown in Table 4.1.

Table 4.1: Relationship between wind speed and significant wave height used in SINTEF OWM.

Wind speed [m/s]	Beaufort wind	Wind type	Wave height [m]
2	2	Light breeze	0,1-0,3
5	3	Gentle to moderate breeze	0,5-0,8
10	5	Fresh breeze	1,5-2,5
15	6-7	Strong breeze	3-4

The simulated properties for Russian Export Crude Oil (REBCO) and Vysotsk IFO-380 bunker oil at 0°C and 15°C are found in Appendix F and G, respectively.

8.9 Comparison of REBCO with other crude oil's behaviour at sea

The simulated weathering properties of the Russian Export Crude Oil is compared with other Russian crude oils analyzed at SINTEF the past years (from Belokamenka oil terminal in Murmansk area) and some selected North Sea crude oils (the waxy Norne, the asphaltenic Grane and the paraffinic Statfjord crudes).

The comparison is performed at 5ºC and a wind speed of 10 m/s.

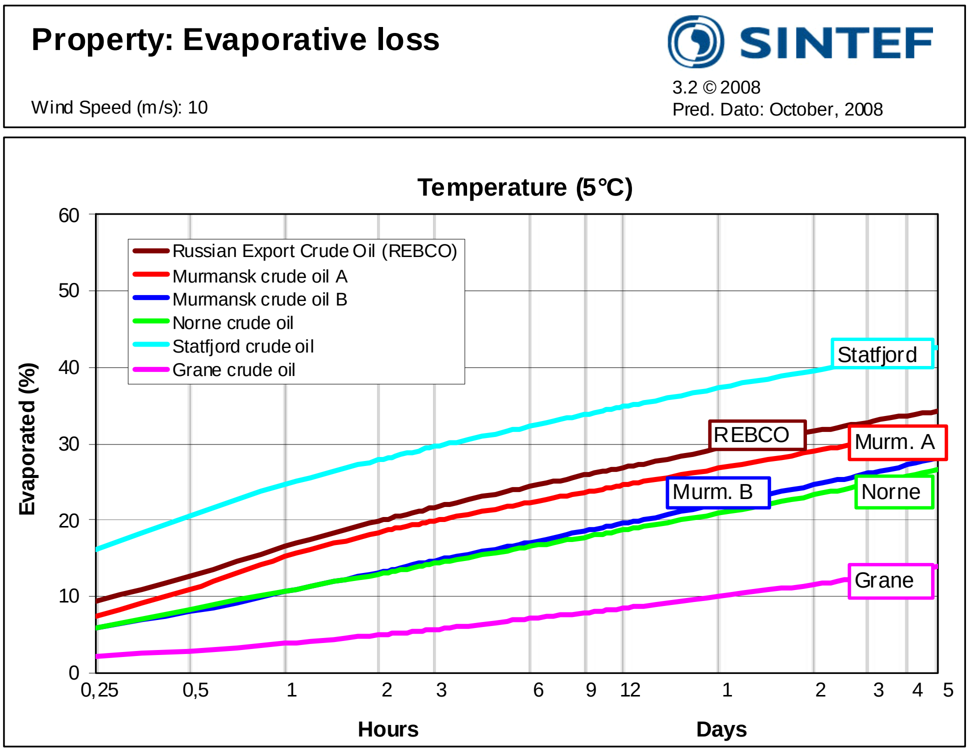


Figure 4.3: Evaporative loss of Russian and Norwegian crude oils.

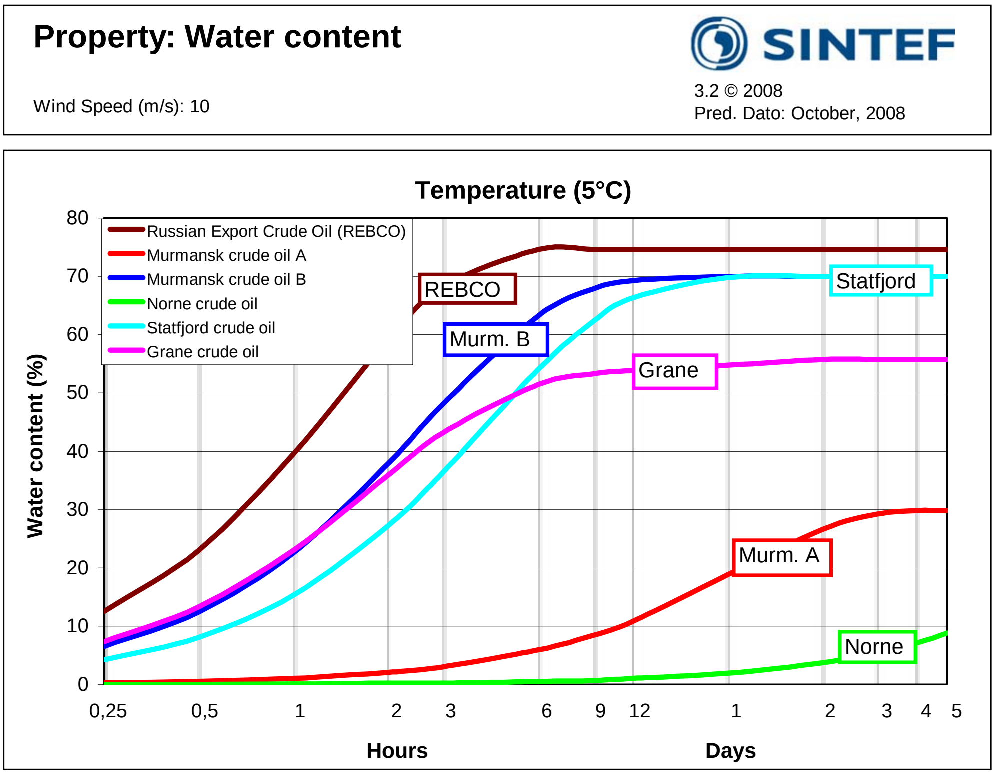


Figure 4.4: Water content of Russian and Norwegian crude oils.

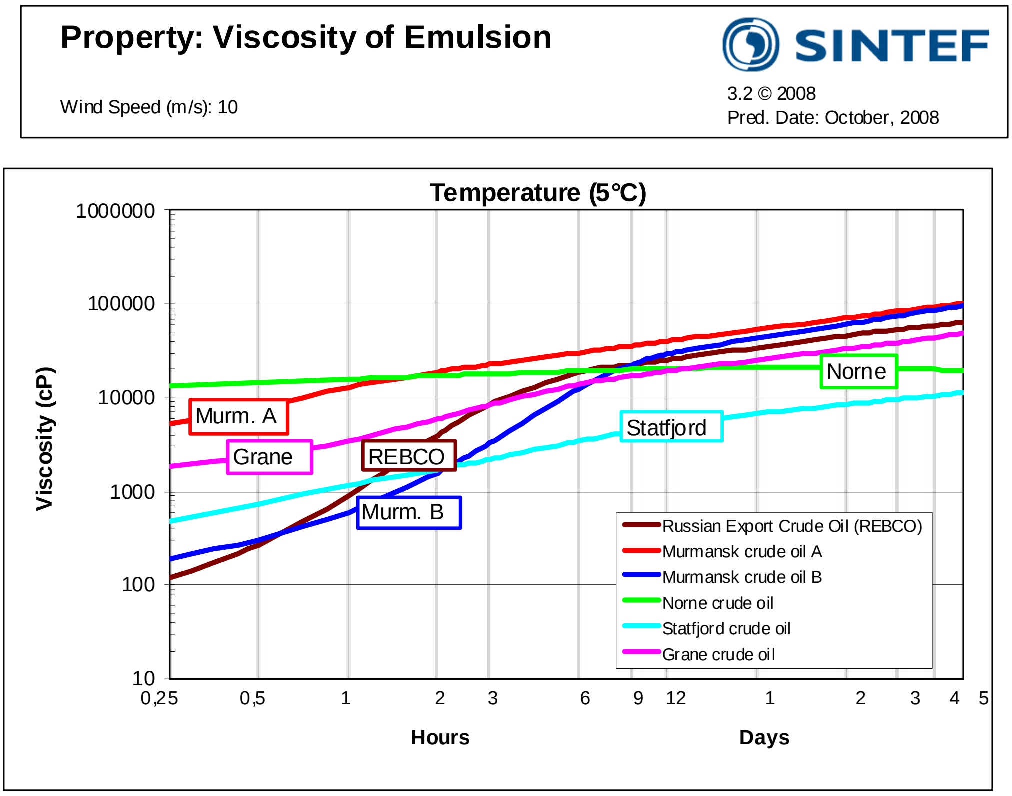


Figure 4.5: Viscosity of Russian and Norwegain crude oil w/o emulsions.

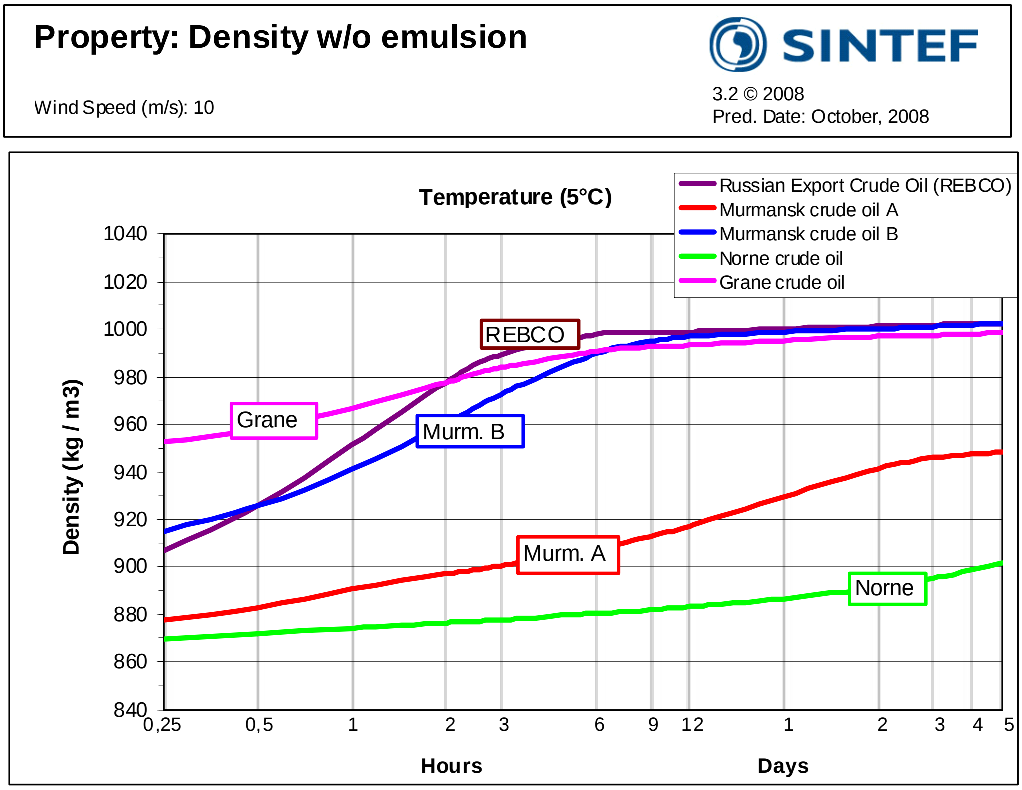


Figure 4.6: Density of Russian and Norwegian crude oil w/o emulsions.

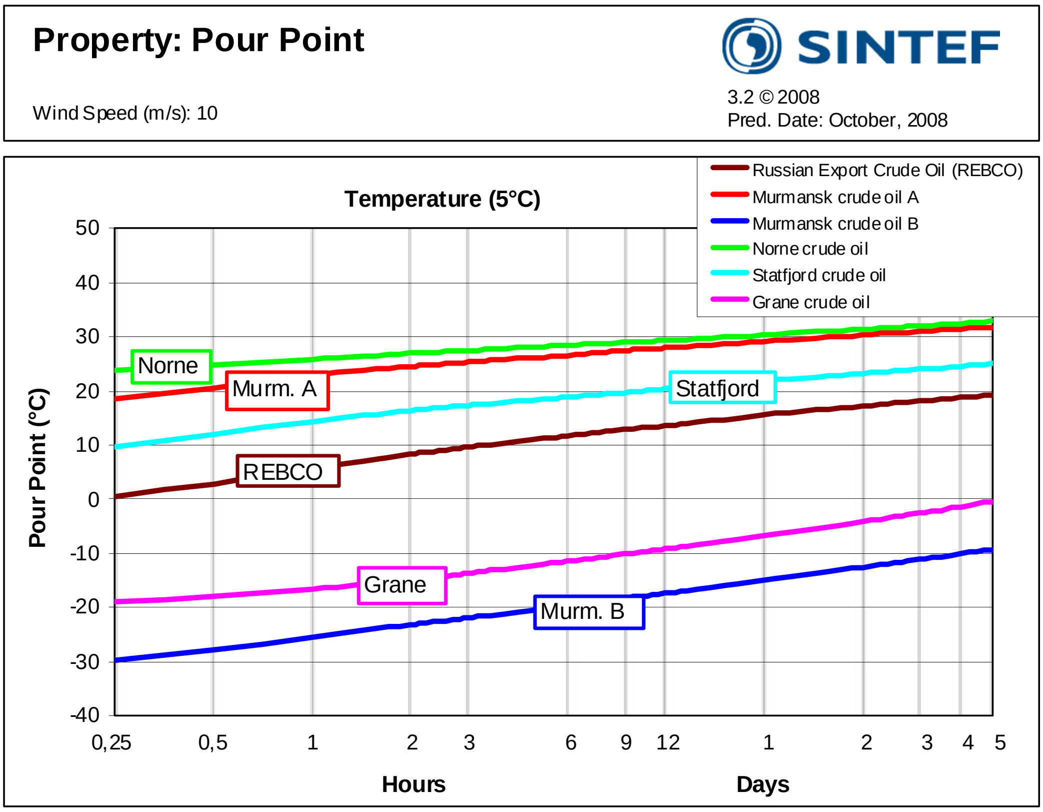


Figure 4.7: Pour point of Russian and other crude oils.

8.10 Comparison of Vysotsk IFO-380 with other bunker oil's behaviour at sea

The simulated weathering properties of Vysotsk IFO-380 bunker oil is compared with other relevant bunkers oils analyzed at SINTEF. The comparison is performed at 5ºC and a wind speed of 10 m/s.

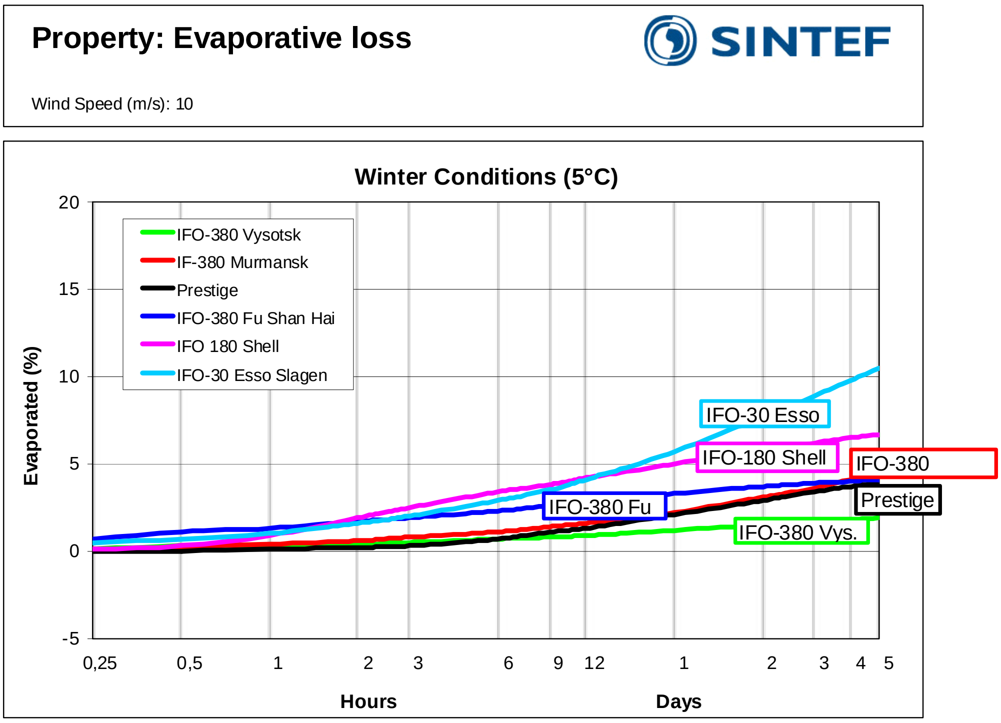


Figure 4.8: Evaporative loss of Vysotsk IF-380 and other bunker oils.

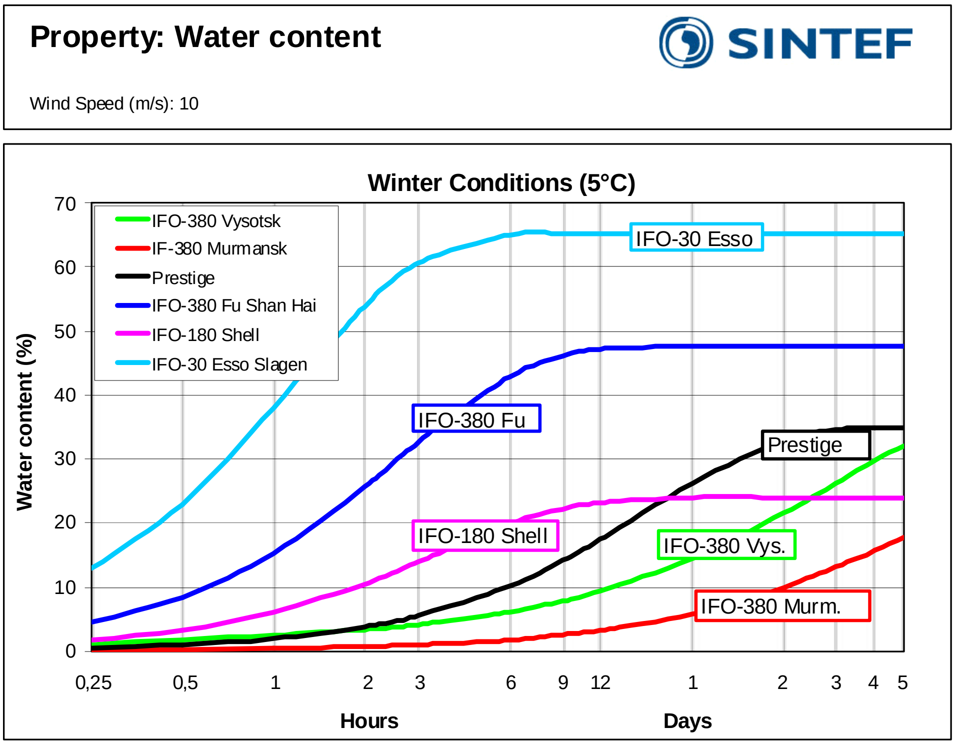


Figure 4.9: Water content of Vysotsk IF-380 and other bunker oil w/o emulsions.

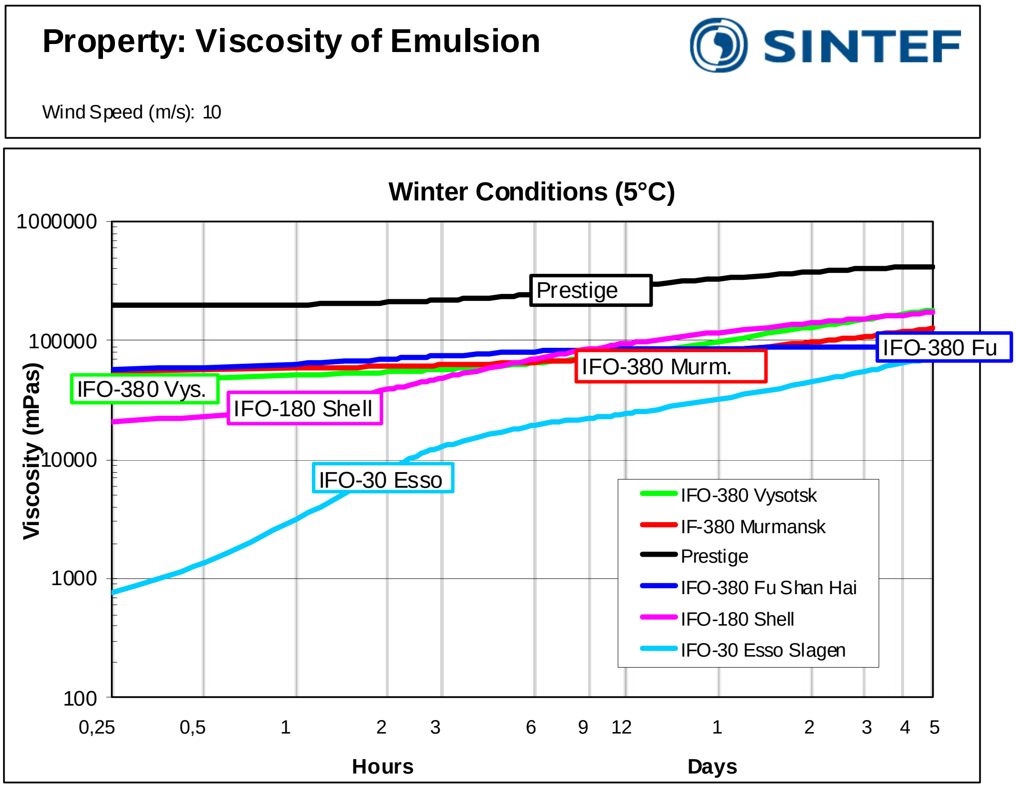


Figure 4.10: Viscosity of Vysotsk IF-380 and other bunker oil w/o emulsions.

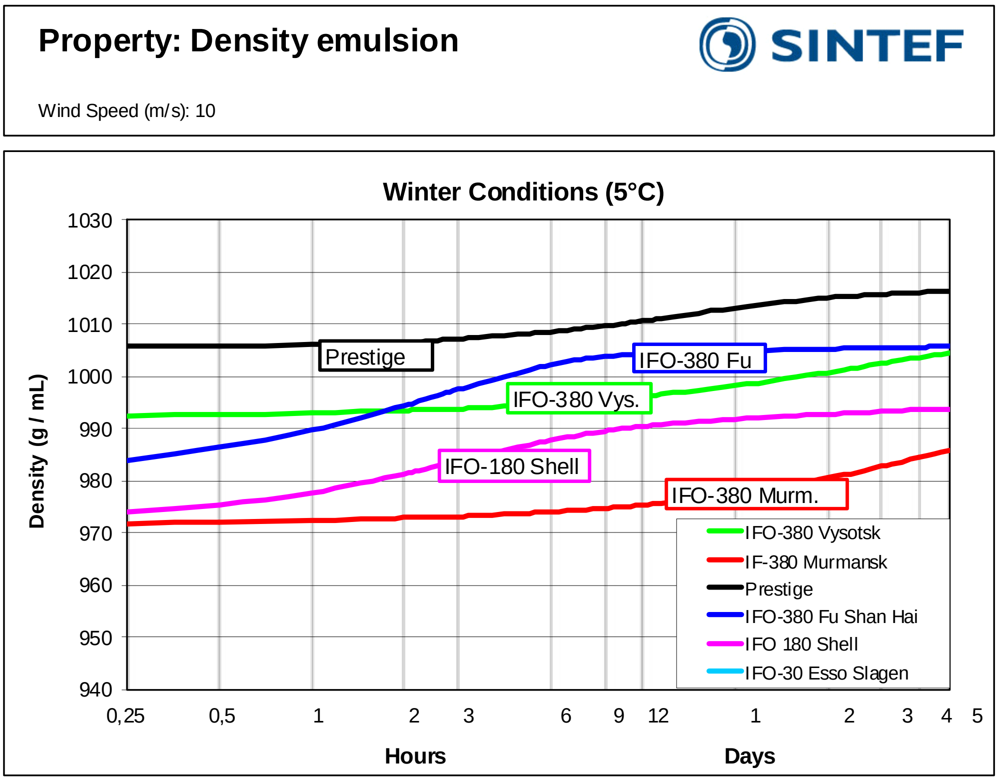


Figure 4.11: Density of Vysotsk IF-380 and other bunker oil w/o emulsions.

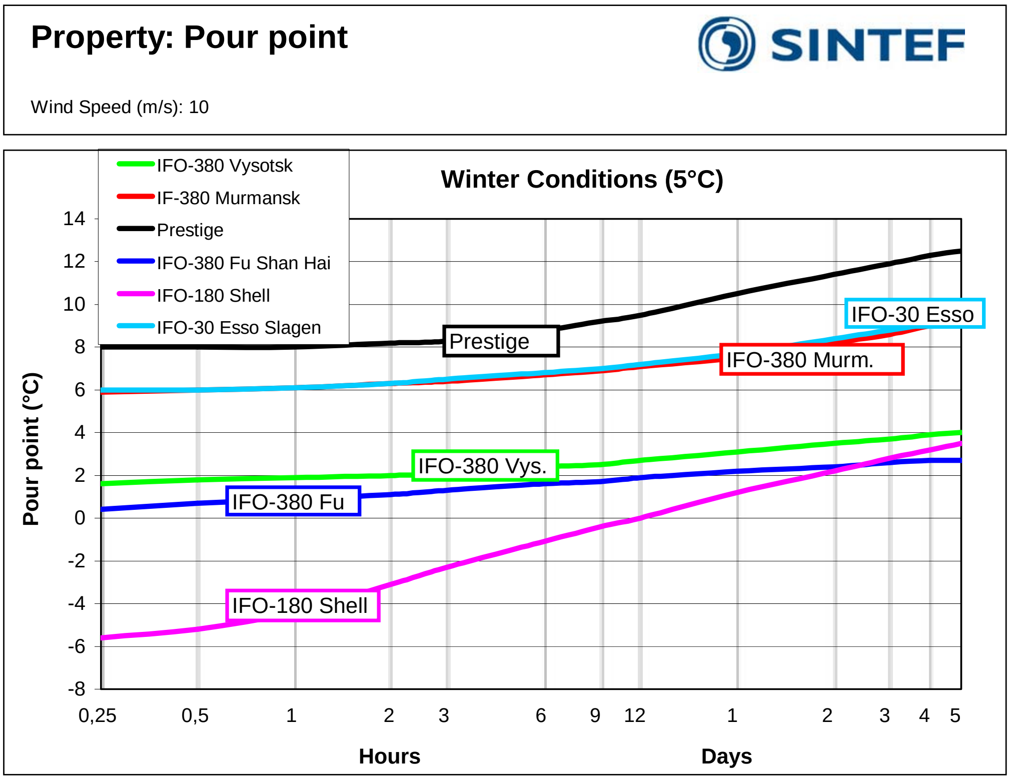


Figure 4.12: Pour point of Vysotsk IF-380 and other bunker oils.

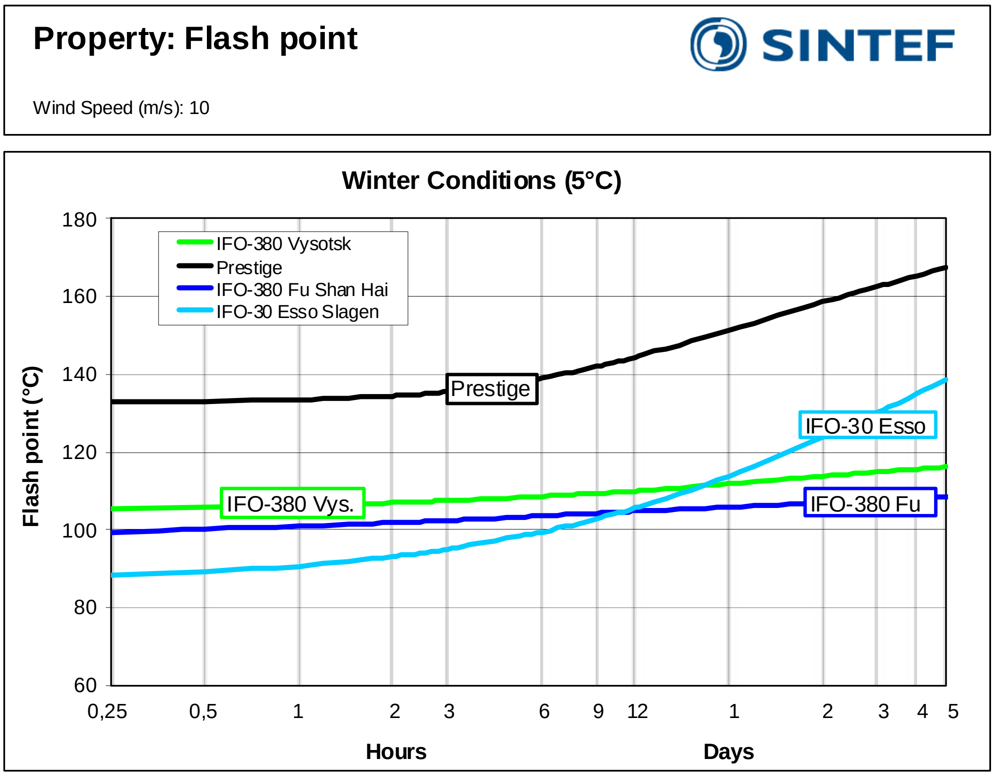


Figure 4.13: Flash point of Vysotsk IF-380 and other bunker oils.

Appendix 9 - Pre-analysis of “IFO-180” samples

SINTEF

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MEMO CONCERNS

Pre-analysis of “IFO-180” samples

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Janne L. Resby / Merete Moldestad (SINTEF)			X	

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PROJECT NO.	DATE	PERSON RESPONSIBLE / AUTHOR	NUMBER OF PAGES
800861	2008-03-13	Tove Strøm / Per S. Daling	67

Background and objective

SINTEF has now received three different shipments of HFO-samples in connection to the project **“Weathering properties and dispersability of one Russian Crude (REBCO) and one HFO Bunker fuel”.** This is due to wrong shipments of oils that has not been according to the sending specifications and requirements for the requested Intermediate Fuel 180 (IFO-180). The shipments are listed in Table 1.

Table 1; received samples

Shipment	Identification (SINTEF ID)		Date Received	Amount	Oil Requested	The samples were labelled
A	*	*	05.12.07	5 litres	IF-180	
B	6621-1767		19.12.07	26 x 1litres bottles	IF-180	as 1S, 1P, 7P……
C	6621-1783	2008-0049	12.08.08	3 x 10 litres cans	IF-180	1 of 3, 2 of 3, 3 of 3

**: not given an identification number at SINTEF*

The objective of this pre-study work presented in this memo was to check if the samples received were different.

Experimental work

The samples were homogenised as described below. Density, viscosity (temperature sweep), water content and Gas Chromatography (GC) were measured in the samples in shipment C. On samples in shipment B, only density was measured.

Pre-treatment / Homogenisation

- The samples were heated approx. 16 hours at 50°C (waterbath which was covered with plastic balls and aluminium foil to avoid water evaporation). The screwcaps were carefully loosened to avoid pressure building.
- The samples were carefully turned upside down by hand 20 times (to avoid air bubbles)
- A sample aliquote was transferred to a 50 mL beaker and kept at 50°C on an hot plate to keep the temperature while the sampling for the analyses

Density measurement Anton Paar

After homogenisation new syringe was used, and the instrument was cleaned, between each parallel (standard washing procedure).

Table 2; density sample from shipment B (only 4 spot samples of the total 26 sample)

Labelling (shipment B)	Density
1S	0,99892
1P	Impossible to measure
1P	0,98328
7P	0,98262

Table 3; density samples from shipment C

Labelling Samples	Parallel			
	1	2	3	Average
1 of 3	0,97969	0,97985		0,980
2 of 3	0,98846	0,98876	0,98862	0,989
3 of 3	1,00589	1,00528	1,00618	1,006

Water content measured by Karl Fischer

New Karl Fischer solution was used for each sample. Three parallels were analyzed, unless for sample 2 of 3, where 6 parallels were analyzed. The results are listed in Table 5.

Table 4; water content (wt%) of sample from shipment C)

Labelling Samples	Parallel						
	1	2	3	4	5	6	Average
1 of 3	0,321	0,393	0,250	-	-	-	0,32
2 of 3	0,464	0,535	0,393	-	-	-	0,46
3 of 3	0,785	1,035	1,249	0,785	0,607	0,607	0,84

Viscosity
The viscosity was measured as a temperature sweep from 50°C to 0°C (200 measurements in 100 minutes).

The results are shown in Figure 1 and table 5

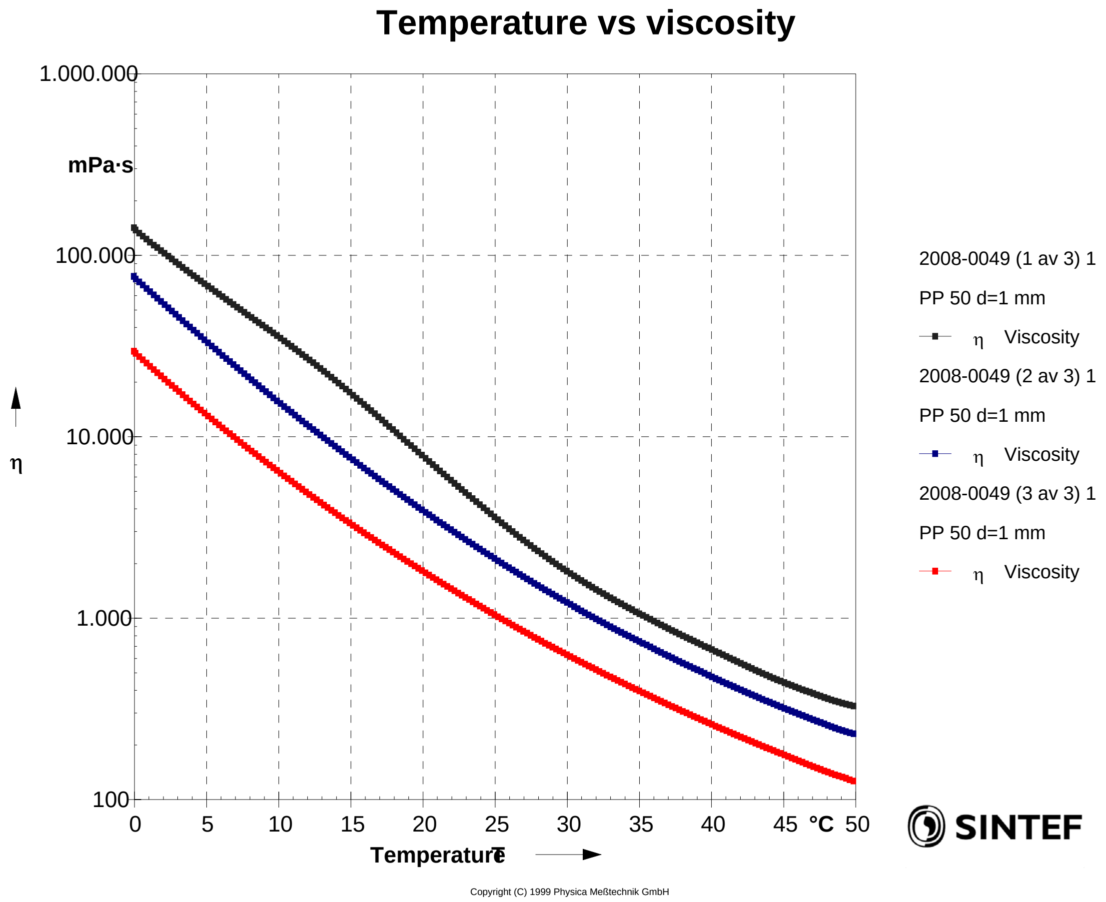
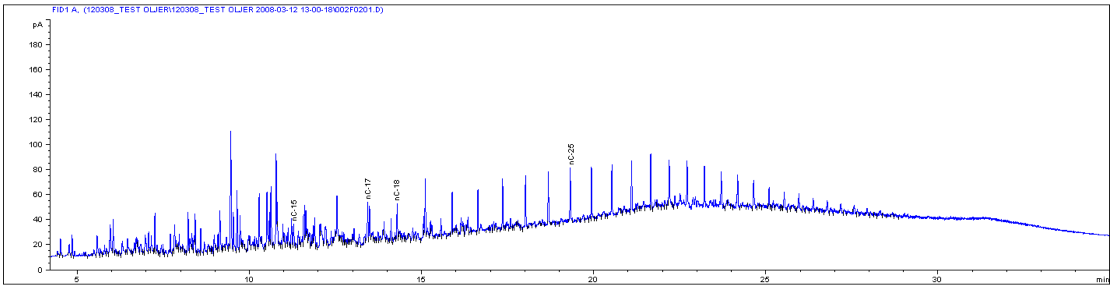


Figure 1; Temperature sweep shipment C

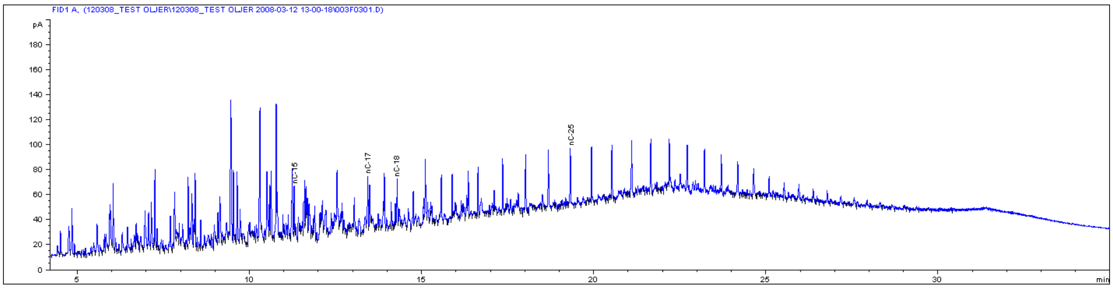
Table 6; Viscosity (mPas = cP) by temperature sweep samples in shipment C

Temperature	*sample 1 of 3*	*sample 2 of 3*	*sample 3 of 3*
[°C]	[mPa·s]	[mPa·s]	[mPa·s]
50	**328**	**230**	**127**
20	7.920	3.960	1.830
15	17.600	7.720	3.360
10	34.900	15.200	6.300
5	67.600	32.900	13.000
0	142.000	76.500	29.600

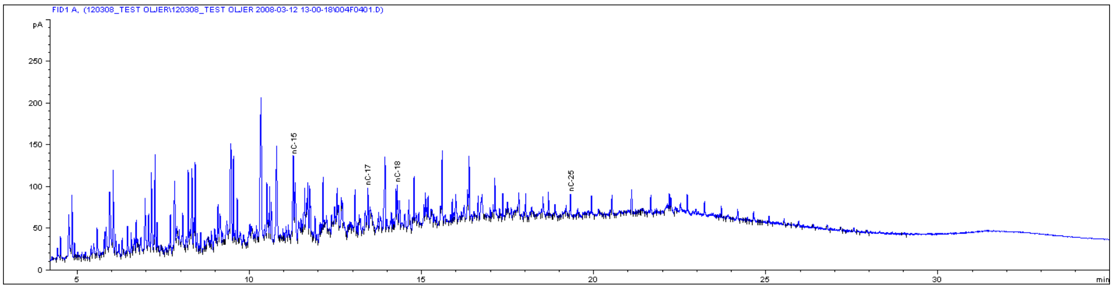
Gas Chromatogram (GC) of samples in shipment C



Sample 1 of 3: 2008-0049-1



Sample 2 of 3: 2008-0049-2



Sample 3 of 3: 2008-0049-3

Figure 2; GC chromatograms samples of shipment C.