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Report

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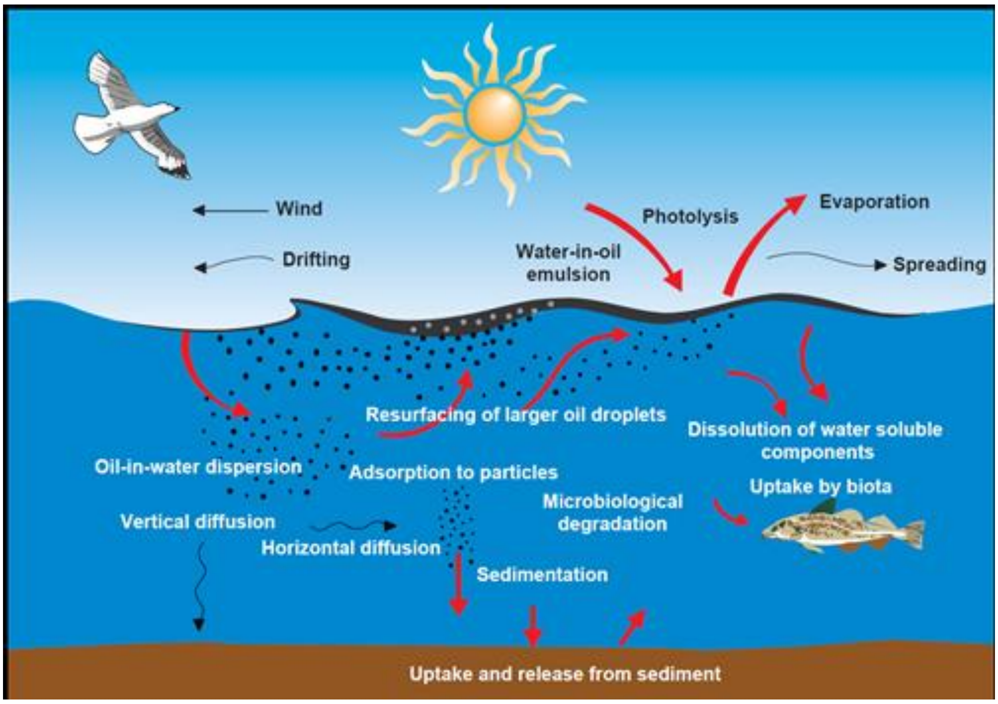

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ABSTRACT
A limited laboratory study of Rolvsnes crude oil has been conducted to compare the obtained weathering data with the existing properties of Edvard Grieg (previous Luno) crude oil, in addition to Solveig (previous Luno II) crude oil, from the neighbouring fields in the North Sea. Edvard Grieg has been used as a surrogate oil for Rolvsnes for environmental risk analysis and oil spill contingency. The laboratory study was performed at 13 °C).

The obtained weathering data for Rolvsnes were used in SINTEF Oil Weathering Model (OWM) for preliminary predictions for comparison with the previous predictions of Edvard Grieg and Solveig. Overall, the weathering properties of Rolvsnes are comparable with Edvard Grieg in addition to Solveig. However, Rolvsnes exhibits lower emulsion viscosities compared with Edvard Grieg and Solveig, and Rolvsnes will likely form lower emulsion viscosities if spilled at sea. The predicted emulsion viscosities of Edvard Grieg and Solveig can be considered as a conservative alternative for Rolvsnes.

Based on the very limited dispersion test on Rolvsnes, a viscosity limit for when the oil is considered as poorly dispersible was estimated and used for estimating time-window for operational use of dispersant. This should be verified with an extended test matrix for testing the dispersibility of Rolvsnes.

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SINTEF

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1 Introduction

New oil types, from heavy crude oil to light crude oils and condensates, are continuously coming into production worldwide, as well as on the Norwegian continental shelf. Due to large variations in different crude oils' physical and chemical properties, their behaviour and fate may vary greatly if spilled at sea. For example, the "Braer" accident at the Shetlands (1993) and the "Sea Empress" accident in Wales (1996) have demonstrated how different the fate and behaviour of the crude oils can be when spilled on the sea surface. For that reason, obtaining comprehensive knowledge about the expected behaviour of spilled oil at sea is of great importance. Moreover, the "Deepwater Horizon" incident in the Gulf of Mexico (2010) clearly showed how the effectiveness of the different response techniques changed as the oil weathered and emulsified on the sea surface over a time after the release. These past experiences and other incidents shape the knowledge base and the subsequent refinement of future operative strategies in terms of where, when, and how the mitigation methods should operate during a response operation.

According to the Norwegian Environment Agency and the Petroleum Safety Authority Norway (Ptil) regulations for petroleum activities (Aktivitetsforskriften §59), the characterization of oils with respect to their weathering properties and fate in the marine environment should be performed for all oils coming into production.

The scope of this project has been to assist Lundin Energy Norway AS to perform a limited weathering study including a small-scale laboratory testing at 13 °C on Rolvsnes crude oil and compare the obtained results to the previous weathering study of Edvard Grieg oil called Luno (Sørheim, 2010) to assess the similarities between these crude oils. Based on an evaluation, a recommendation is given if the weathering data for Rolvsnes and Edvard Grieg can be regarded as similar, or if a full standardized weathering and dispersibility study should be conducted to generate individual weathering data and predictions for the Rolvsnes crude oil. In addition, the weathering data of Rolvsnes were also compared with the Solveig crude oil previous Luno II (Hellstrøm and Johnsen, 2014) from the neighboring field.

Information about the Rolvsnes oil field is given below (see Figure 1-1).

16/1-12 (Rolvsnes) is a discovery in the central part of the North Sea (Utsira hight), south of the Edvard Grieg field.

The water depth is about 100 metres.
The discovery was proven in 2009, and subsequently delineated by well 16/1-25 S in 2015 and 16/1-28 S in 2018.

The reservoir contains oil in weathered and fractured granitic basement beneath a thin layer of Lower Cretaceous conglomerate.

Rolvsnes is planned to be developed as a subsea tie-back to the Edvard Grieg field.
The test production is planned to start in 2021.

Test production was started in 2021. The oil sample in this study was collected from this test production. Depending on the outcome of the test production and further work, a plan for development and operation (PDO) may be submitted in 2022.

Figure 1-1 https://www.norskpetroleum.no/en/facts/discoveries/161-12-edvard-grieg-sor/

2 Oil samples and methodology

SINTEF received (03.09.2021) 4*25 litres Jerry cans of Rolvsnes crude oil, block 16/1, well: 16/1-CA-1 H. (Figure 3-1). The shipment was registered in SINTEFs laboratory information management system (LIMS) and given the unique SINTEF ID: 2021-6498.

Figure 2-1 Rolvsnes crude oil (block 16/1, well: 16/1-CA-1 H) received at SINTEF.

The limited laboratory study of Rolvsnes included the following analysis parameters:

- Topping / distillation of the fresh oil into residues (200 and 250 °C+)
- Gas chromatographic (GC-FID) analysis of hydrocarbon distribution from nC_5-nC_{40}
- Density and viscosity of fresh oil and residues
- Pour point of fresh oil and residues
- Content by weight % of wax and asphaltenes
- Emulsification kinetics and maximum water uptake
- Emulsion viscosity and stability

The limited small-scale laboratory study was conducted at 13 °C . The results from the laboratory study are given in figures and tables in the chapter below. The analytical methodologies are further described in Appendix A.

2.1 Pre-handling of oils and HSE

In general, high-water content >2 vol. % is not beneficial for the topping /distillation step in the SINTEF laboratory due to a HSE (Health, Safety and Environmental) aspect. The oil samples (cans) were therefore checked for free-water and measured for water content in the oil phase by Karl-Fisher titration upon arrival. This step was needed prior to homogenization and analysis of chemical composition and physical properties related to oil weathering. The oil samples of Rolvsnes contained some free-water (400 mL) that was removed from one of the bottom of the cans to avoid free-water from being incorporated into the whole sample. In addition, the sample also had very high content of incorporated water in the bottom oil phase about 36 vol.% and about 1 vol. % in the upper layer, and it was therefore decided to pre-heat (70 °C) to remove released water prior to homogenization (2-3 litres of oil/water phase was removed). The final water content in the oil for further analysis was 1 vol.% after pre-handling, which was acceptable for the topping /distillation step in the laboratory.

2.2 Evaporation

The topping (distillation) procedure for evaporation is described in Stiver and Mackay (1984). Evaporation of the lighter compounds from the fresh oil was carried out as a simple one-step distillation to vapour temperatures of 200°C and 250°C, with an evaporation loss corresponding to approximately 0.5-1 day and 0.5-1 week of weathering on the sea surface. The residues are here referred to as 200°C+ and 250°C+, respective.

3 Physico-chemical characterization

3.1 Hydrocarbon distribution (GC-FID)

The hydrocarbon profiles of the fresh Rolvsnes crude oil were analysed by use of gas chromatography (GC) coupled with Flame Ionization Detector (FID). The hydrocarbon distribution of Rolvsnes was compared with Edvard Grieg and Solveig as shown in Figure 3-1.The fresh oil and the residues (200 and 250°C+) of Rolvsnes were also analyzed by use of GC-FID to verify the artificial evaporation (topping of the fresh oil), see gas chromatograms in Appendix B.

The gas chromatograms (Figure 3-1) show the n-alkanes as systematic narrow peaks. The first peaks in the chromatogram represent components with the lowest boiling points. Some of the more complex components, such as resins and naphthenes, are shown as a broad and poorly defined bump below the sharp peaks and are often described as the "Unresolved Complex Mixture" (UCM). Heavier compounds such as asphaltenes (> nC40) are not possible to analyze with this technique.

The hydrocarbon distribution (nC_5-nC_{40}) of Rolvsnes shows that this is a typically paraffinic crude oil and exhibits similarities with Edvard Grieg and Solveig. The oils are typically medium to light paraffinic crudes, with relatively high amount of the lightest compounds. The chromatograms also indicate medium amounts of wax/paraffinic compounds in the range of nC_{20}-nC_{30} for the oils in comparison.

Common screening parameters for oil spill identification, as well as for the degree of biodegradation, are the nC_{17}/Pristane and nC_{18}/Phytane ratios derived from the GC-FID analyses. The ratios of Rolvsnes, Edvard Grieg and Solveig given in Table 3-1. Rolvsnes and Solveig have most similarities based on the ratios, both exhibits relatively low nC_{17}/pristane ratios and high nC_{18}/Phytane ratios. The low nC_{17}/Pristane ratio particularly or Solveig can be explained by a biodegradation process in the reservoir.

Table 3-1 Ratios of nC_{17}/Pristane and nC_{18}/Phytane.

Oil name	nC_{17}/Pristane	nC_{18}/Phytane
Rolvsnes	1.2	2.0
Edvard Grieg	1.8	1.6
Solveig	1.0	1.8

**Ratios of 1 and higher typical for paraffinic oils*

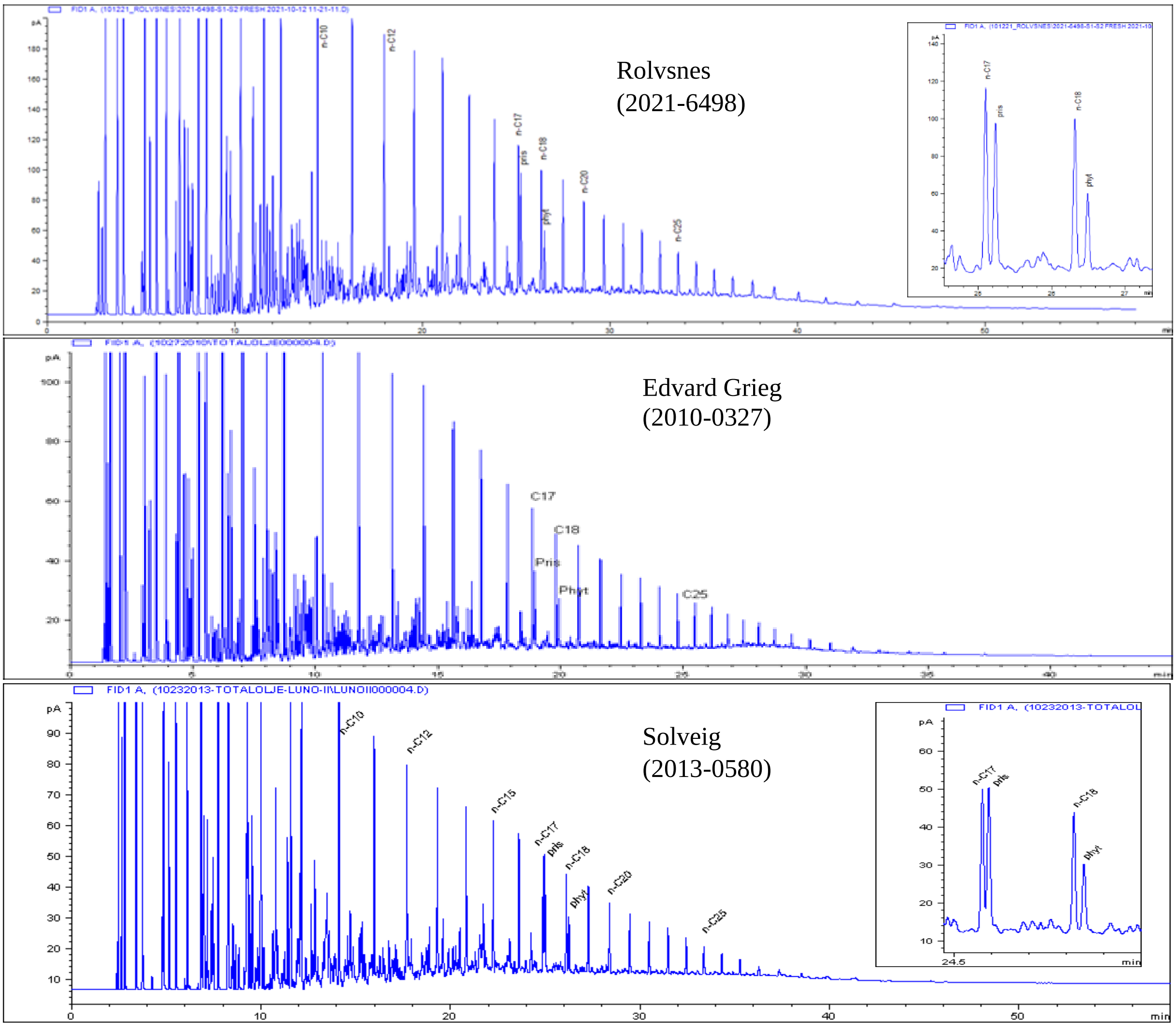

Figure 3-1 GC/FID chromatograms for the fresh oils of Rolvsnes, Edvard Grieg and Solveig.

3.2 Chemical and physical properties

Overall, there is many similarities between these crude oils. The content of asphaltenes and wax of Rolvsnes compared with Edvard Grieg and Solveig are given in Table 3-2. The asphaltenes and wax content are quite similar among these crude oils. The fresh crude oils contain a medium content of wax in the range of 2.7-3.9 wt.% , and asphaltenes in the range of 0.2-0.5 wt.%. The physical parameters of the fresh oils and residues of Rolvsnes, Edvard Grieg and Solveig are given in Table 3-3. Rolvsnes and Solveig have a slightly higher evaporative loss (5-7 vol. %) for the 250°C+ residue compared with Edvard Grieg. The densities and viscosities the fresh oils and residues are in the same range, with minor differences. The pour points of the fresh oil and residues of Rolvsnes are lower than Edvard Grieg and higher than Solveig.

Table 3-2 Asphaltenes and wax contents Rolvsnes compared with Edvard Grieg and Solveig.

Oil name	Residue	Asph. * (wt. %)	Wax (wt. %)
Rolvsnes	Fresh	0.4	3.6
	150°C+	-	-
	200°C+	0.5	5.2
	250°C+	0.6	6.3
Edvard Grieg	Fresh	0.2	3.9
	150°C+	0.2	4.8
	200°C+	0.3	5.4
	250°C+	0.3	6.0
Solveig	Fresh	0.5	2.7
	150°C+	0.6	3.4
	200°C+	0.7	3.9
	250°C+	0.8	4.4

**n-heptane (nC7) precipitation*
-: Not analyzed

Table 3-3 Physical parameters of Rolvsnes compared with Edvard Grieg and Solveig.

Oil name	Residue	Evap. (vol. %)	Residue (wt. %)	Density (g/mL)	Pour point (°C)	Visc. (mPa.s) 13°C ($10\ s^{-1}$)
Rolvsnes	Fresh	0	100	0.848	0	14
	150°C+	-	-	-	-	-
	200°C+	35	70	0.901	18	449
	250°C+	47	57	0.921	24	2505
Edvard Grieg	Fresh	0	100	0.850	6	30
	150°C+	22	82	0.883	15	207
	200°C+	32	72	0.897	21	1150
	250°C+	40	64	0.908	27	2350
Solveig	Fresh	0	100	0.851	-27	11
	150°C+	25	79	0.898	6	99
	200°C+	36	69	0.915	12	569
	250°C+	45	61	0.931	18	3165

-: Not analysed

The True Boiling Point curves (TBP) of Rolvsnes, Edvard Grieg and Solveig are shown in Figure 3-2. The TBPs reflect the evaporative loss of the 200 and 250°C+ residues given in Table 3-3, indicating the evaporative loss at sea. Overall, The TBPs show high similarity among these crude oils.

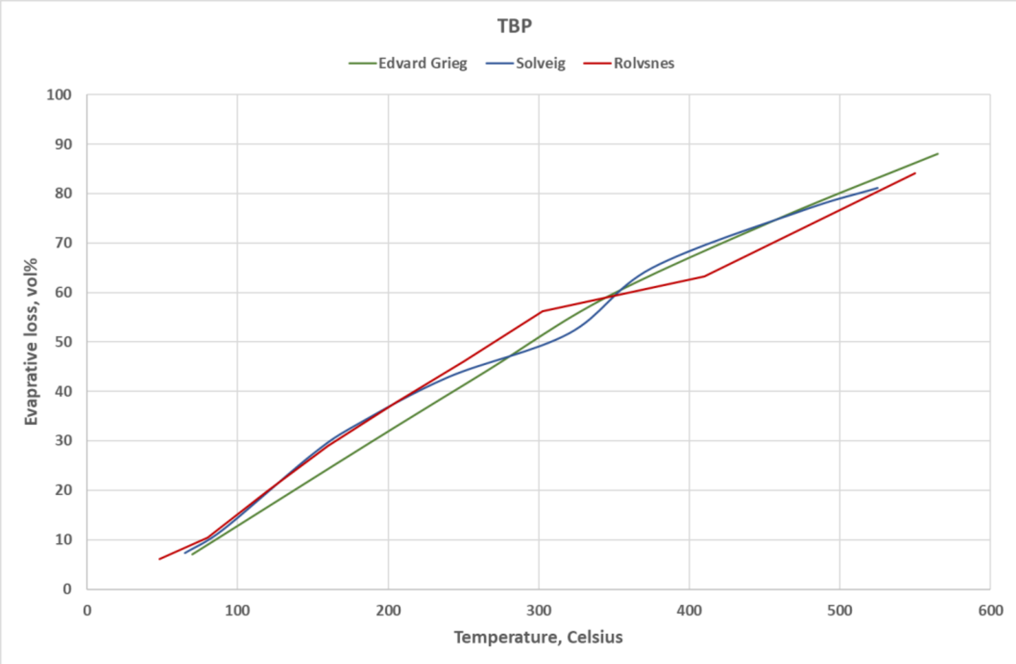

Figure 3-2 *TBP of Rolvsnes in comparison with Edvard Grieg and Solveig. TBP of Rolvsnes from mini-assay (Lundin).*

3.3 Emulsification, water uptake and emulsion viscosities

In general, emulsification is the mixing of seawater droplets into spilled oil at the water surface forming water-in-oil (w/o)emulsions. The emulsification of Rolvsnes was performed by use of rotating cylinders as described in Mackay and Zagorski, 1982, and Hokstad et al. 1993. Emulsions of the maximum water uptakes of 200 and 250°C+ residues after 24 hours rotation is shown in Figure 3-3.

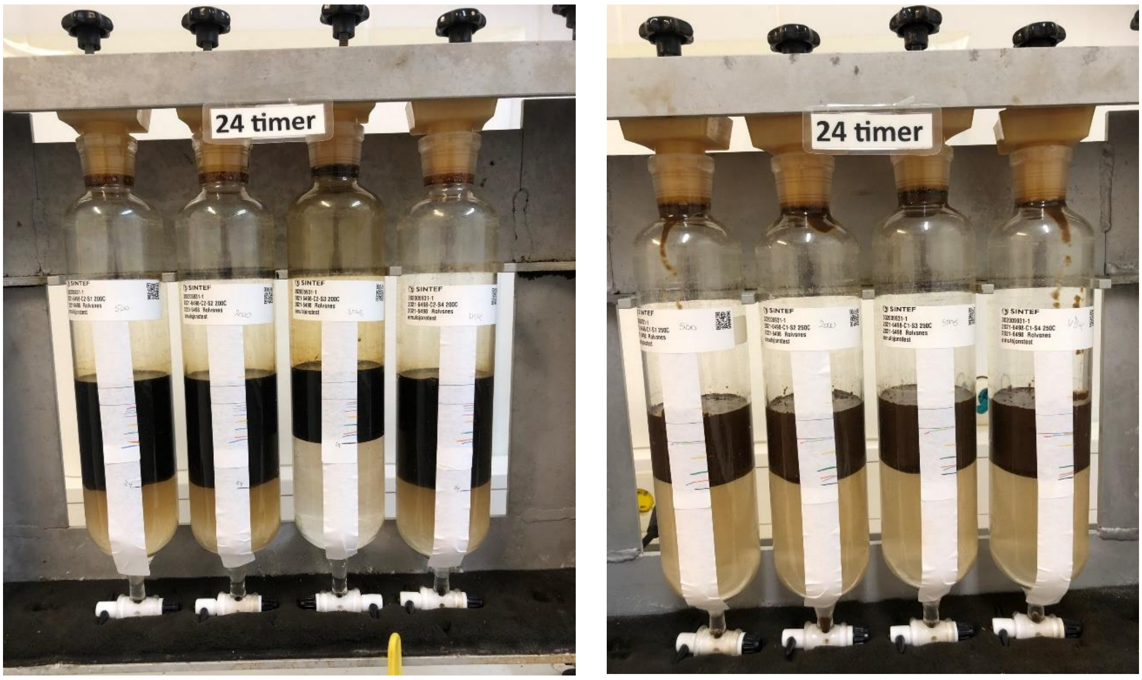

Figure 3-3 *Rotating cylinders of w/o-emulsions of Rolvsnes after 24 hours rotating time. Left: 200°C+ residue. Right: 250°C+ residue.*

The maximum water uptake (kinetics) for the water-in-oil (w/o) emulsion as a function of time is shown in Table 3-4 for the 200 and 250°C+ residue s. The $T_{1/2}$ values, which is derived from the tabulated data, is defined as the time needed to incorporate half the maximum water uptake. Table 3-5 shows the kinetics and maximum water uptake for Rolvsnes in comparison with Edvard Grieg and Solveig. The kinetics of 200 °C+ residue of Rolvsnes is most similar with Edvard Grieg, whist the 250°C+ residue of Rolvsnes is most similar with Solveig. The water-uptakes are in the same range within these crude oils, with minor differences.

Table 3-4 Water uptake of Rolvsnes at 13 °C.

Mixing time	200°C + (vol. % water)	250°C + (vol. % water)
Start	0	0
5 min	15	8
10 min	25	10
15 min	33	10
30 min	42	10
1 hour	53	47
2 hours	63	65
4 hours	68	70
6 hours	70	71
24 hours	81	73
$T_{1/2}$	0.51	0.84

Table 3-5 Comparison of kinetics ($T_{1/2}$) and maximum water (vol%) for Rolvsnes, Edvard Grieg and Solveig.

Oil	Residue	Kinetics $T_{1/2}$	Max. water (vol.%)
Rolvsnes	200°C+	0.51	81
	250°C+	0.84	73
Edvard Grieg	200°C+	0.55	80
	250°C+	0.25	76
Solveig	200°C+	0.29	80
	250°C+	0.93	71

Stability testing of the emulsion and the efficiency of the emulsion breaker (Aerosol OT-SE) of Rolvsnes are shown in Table 3-6 in comparison of Edvard Grieg and Solveig. Note: Alcopol 60 % was used as emulsion breaker for Edvard Grieg and Solveig. The different emulsion breakers are not expected to cause larger differences in effectivity. Rolvsnes, Edvard Grieg and Solveig form all stable w/o-emulsions and are partly broken adding the emulsion breaker. The main difference observed here was that the 200°C+ emulsion of Rolvsnes is almost totally broken adding 500 and 2000 ppm of emulsion breaker, compared to Edvard Grieg and Solveig.

Table 3-6 Stability of Rolvsnes, Edvard Grieg and Solveig for emulsions with no emulsion breaker, and effectiveness of emulsion breaker at 13 °C.

Residue	Emulsion breaker	Stability ratio* Rolvsnes	Stability ratio* Edvard Grieg	Stability ratio* Solveig
200ºC+	none	0.99	1.00	1.00
250ºC+	none	0.99	0.91	0.98
200ºC+	Emulsion breaker 500 ppm	0.07	0.32	0.61
250ºC+	Emulsion breaker 500 ppm	0.58	0.46	0.65
200ºC+	Emulsion breaker 2000 ppm	0.01	0.11	0.19
250ºC+	Emulsion breaker 2000 ppm	0.18	0.17	0.82

ppm: parts per million relative to oil fraction of emulsion.
**: Stability ratio of 0 implies a totally unstable emulsion after 24 hours settling.*
Stability ratio of 1 implies a totally stable emulsion.

The maximum water emulsion viscosities are shown in Table 3-7. Overall, the viscosities of Rolvsnes emulsions are lower compared with Edvard Grieg and Solveig. The 200°C+ emulsion of Rolvsnes is about 10-times lower than Edvard Grieg and Solveig. The viscosity of the 250°C+ emulsion is slightly lower for Rolvsnes the compared with Edvard Greig and Solveig.

Table 3-7 Maximum water emulsion viscosities of Rolvsnes compared with Edvard Grieg and Solveig.

Oil	Residue	Water content (vol. %)	Viscosity (mPa.s)	
			10 s^{-1}	100 s^{-1}
Rolvsnes	200°C+	85	2252	890
	250°C+	73	17199	-
Edvard Grieg	200°C+	80	23580	5310
	250°C+	76	21290	3550
Solveig	200°C+	80	23888	4094
	250°C+	71	24632	4208

3.4 Limited dispersion test

Edvard Grieg and Solveig have high viscosity limits for when these oils are considered as poorly/slow dispersible of 30 000 mPa.s. and 25 000 mPa.s, respective. It was suggested to perform a limited dispersion tests on selected 250°C+ emulsions of Rolvsnes. The tests were conducted with use of the high-energy MNS test (Mackay-Nadeau-Szeto) reflecting breaking waves conditions (> 5 m/s wind speed). Dasic Slickgone NS with a dosage to oil ratio (DOR) of 1:25 was applied to the emulsions. The criteria for when the oil/emulsion is considered as poorly dispersible is < 5% efficiency, based on the MNS test.

The results from the limited dispersion test of Rolvsnes are summarized in Table 3-8. The emulsion viscosities were in the range of 6777 – 17080 mPa.s, and the dispersant efficiency were low (0-11 %). Based on the results, a viscosity limit of 10 000 mPa.s was approximated for when the oil is considered as poorly dispersible (MNS effectiveness < 5 %). The estimated viscosity limit of Rolvsnes is lower compared with Edvard Grieg and Solveig. However, this should be verified with an extended matrix of other emulsions of Rolvsnes and may include the lower limit for when the oil is considered as good dispersible reflecting > 50 % dispersion efficiency based on the low-energy test (IFP).

Table 3-8 Dispersibility effectiveness on Rolvsnes (Dasic Slickgone NS, DOR 1:25).

Residue	Vol.%	Visc. $10s^{-1}$	Effectiveness % MNS-test
250°C+	50	6777	11
250°C+	75	17080	0 (no effect)
250°C+	73 (max. water)	16655	3

The estimated time-window of Rolvsnes is based on the preliminary oil weathering predictions given in Appendix C and described in chapter 4. Table 3-9 summarizes the estimated time-window for Rolvsnes compared with Edvard Grieg and Solveig at 2, 5, 10 and 15 m/s wind speeds at 15 °C. The estimated time-window for Rolvsnes is comparable with Edvard Grieg for operational use of dispersants.

Table 3-9 Estimated time-window for dispersant use of Rolvsnes compared with Edvard Grieg and Solveig.

Oil	Wind speed (m/s)	Time (days)	Wind speed (m/s)	Time (days)	Wind speed (m/s)	Time (days)	Wind speed (m/s)	Time (days)
Rolvsnes*	15	1 day	10	2 days	5	5 days	2	>5 days
Edvard Grieg	15	1 day	10	2 days	5	5 days	2	>5 days
Solveig	15	6 hours	10	12 hours	5	2 days	2	>5 days

**The predicted time-window is based on a tentative upper viscosity limit of 10 000 mPa.s*

4 SINTEF OWM predictions

Analytical data generated from the limited laboratory study of Rolvsnes was used as input to SINTEF Oil Weathering Model (OWM) to compare some relevant weathering properties (evaporative loss, water-uptake and emulsion viscosities) of Rolvsnes with the existing predictions of Edvard Grieg and Solveig (Figure 4-1 to Figure 4-3). The predictions for comparison are based on seawater temperature of 15 °C and wind speed of 10 m/s. In order to perform predictions of Rolvsnes, the lack of weathering data was approximated. The predictions for Rolvsnes must therefore be considered as preliminary and give an estimate of the weathering properties if spilled at sea.

Rolvsnes, Edvard Grieg and Solveig exhibit similarities of the evaporative loss and water-uptake (Figure 4-1 and Figure 4-2). However, the predicted emulsion viscosity of Rolvsnes is significant lower (from 2-3 hours weathering) than Edvard Grieg and Rolvsnes, as shown in Figure 4-3, and this is due to the lower measured emulsion viscosities of Rolvsnes compared with the other two oils.

The preliminary predictions of water-uptake, emulsion viscosity, and mass balances of Rolvsnes are given in Appendix C.

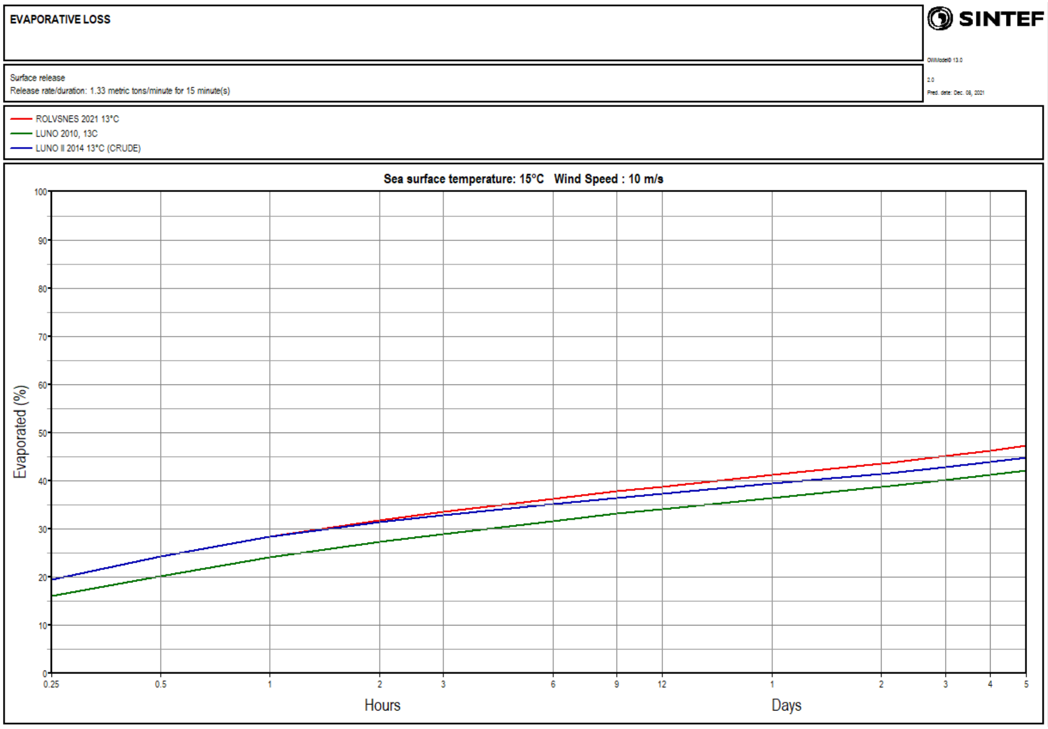

Figure 4-1 *Predicted evaporative loss at 15 °C and 10 m/s for Rolvsnes (preliminary) in comparison with Edvard Grieg (former Luno) and Solveig (former Luno II).*

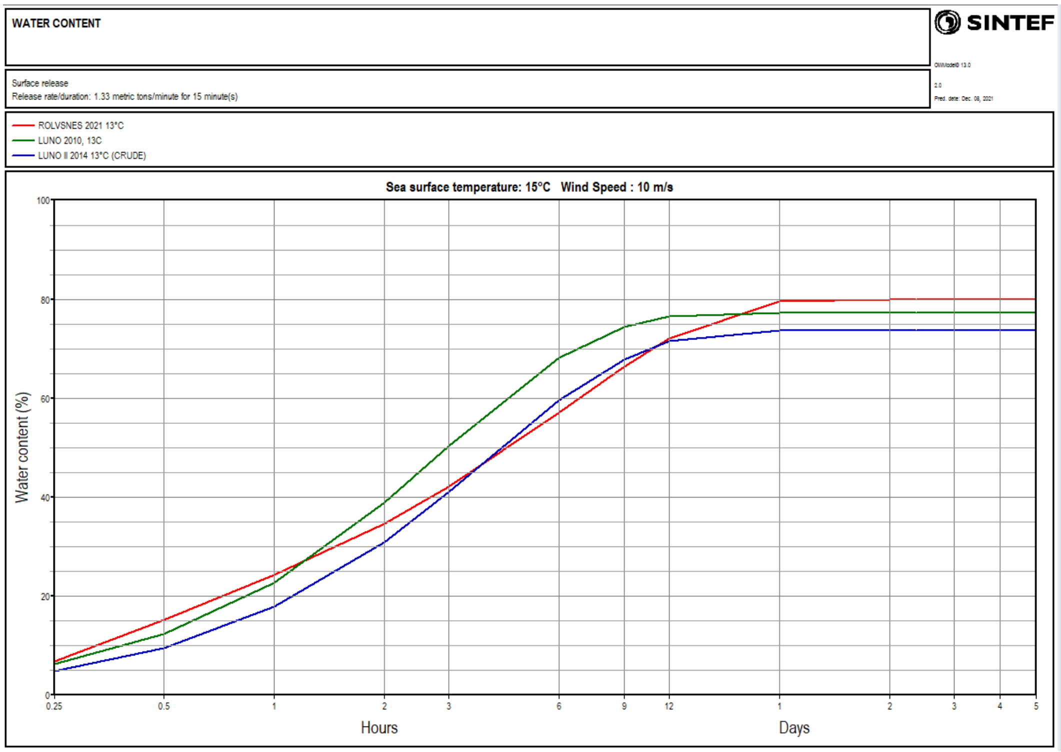

Figure 4-2 *Predicted water-uptake at 15 °C and 10 m/s for Rolvsnes (preliminary) in comparison with Edvard Grieg (former Luno) and Solveig (former Luno II).*

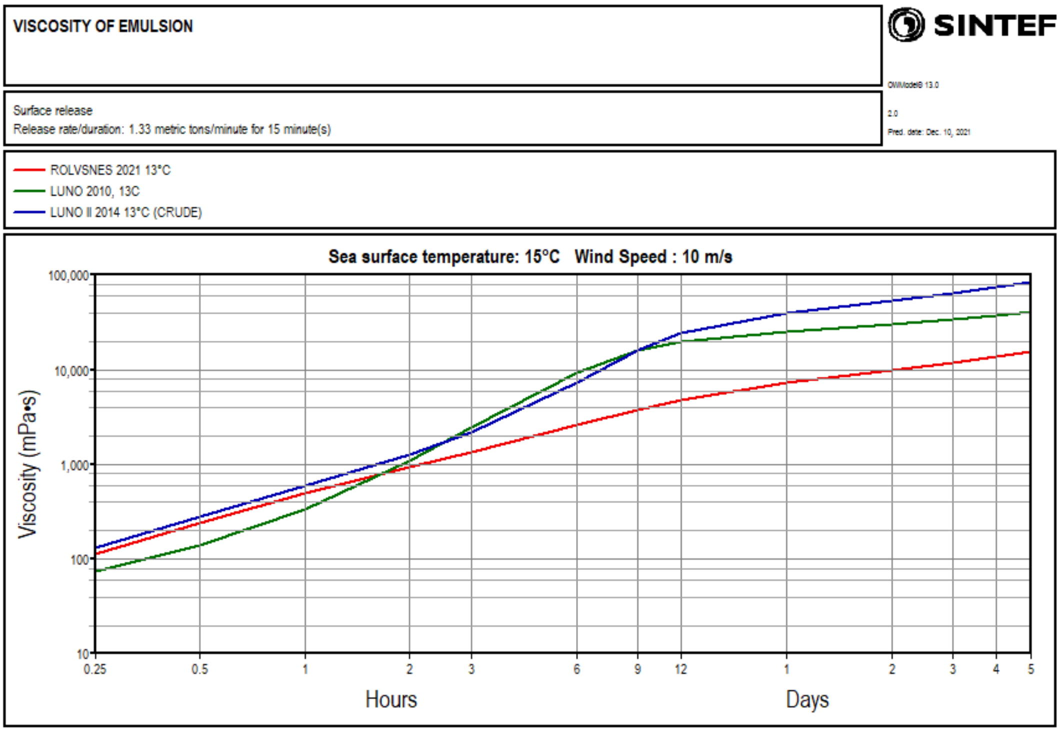

Figure 4-3 *Predicted emulsion viscosity at 15 °C and 10 m/s for Rolvsnes (preliminary) in comparison with Edvard Grieg (former Luno) and Solveig (former Luno II).*

5 Summary & conclusion

Rolvsnes is a paraffinic crude oil that exbibits similarity with Edvard Grieg and Solveig. Parameters as the wax and asphaltenes, density, evaporative loss, pour point, viscosity of the fresh oil and residue showed consistent data of Rolvsnes compared with Edvard Grieg and Solveig. The viscosity of maximum water 200°C+ emulsion of Rolvsnes were significant lower (10-times) than Edvard Grieg and Solveig, however the emulsion from 250 °C+ residue were in the same range as Edvard Grieg and Solveig. All these crude oils reached a relatively high comparable water-uptake (75-80 vol%) and formed stable emulsions that partly broke with application of emulsion breaker.

The limited dispersion test indicated a viscosity limit of 10 000 mPa.s ($10s^{-1}$) for when the Rolvsnes is considered poorly/slow dispersible, which is a lower limit compared with Edvard Grieg (30 000 mPa.s) and Solveig (25 000 mPa.s). However, the estimated time-window for operational use of dispersant seems to be comparable with Edvard Grieg, based on the preliminary predictions of emulsion viscosity as described below. The dispersibility of Rolvsnes should however be verified with extended test matrix.

The limited weathering data obtained from the Rolvsnes study were used as input to the SINTEF Oil Weathering Model (OWM). The lack of weathering data of Rolvsnes was approximated to perform tentative OWM predictions of selected weathering properties if spilled at sea. The preliminary weathering predictions of Rolvsnes were also compared with Edvard Grieg and Solveig for the evaporative loss, water-uptake and emulsion viscosity. The predictions for comparison are given as example of 15 °C and 10 m/s wind speed and indicate great similarities between these oils, except from the significant lower viscosity emulsion prediction of Rolvsnes.

Overall, based on this limited study, the weathering properties of Rolvsnes seems to be comparable with Edvard Grieg in addition to Solveig. However, Rolvsnes exhibits lower emulsion viscosities, particularly for the 200°C+ residue, compared with Edvard Grieg and Solveig, and Rolvsnes will likely form lower emulsion viscosities if spilled at sea. The predicted emulsion viscosities of Edvard Grieg and Solveig can be considered as conservative alternative for Rolvsnes.

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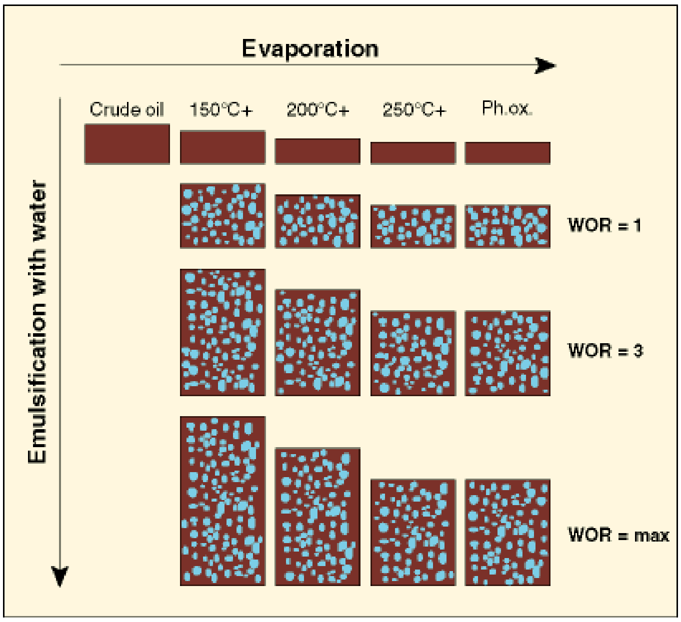
A Experimental setup

A.1Small-scale laboratory testing

To isolate and map the various weathering processes at sea, the crude oil was exposed to a systematic, stepwise procedure developed at SINTEF (Daling et al., 1990). The general procedure is illustrated in Figure A-1.



WOR: Water to Oil Ratio

WOR=1: 50 vol.% water

WOR=3: 75 vol.% water

WOR=max: the maximum water content

Figure A-1 Small-scale laboratory weathering flow chart of oil.

A.2Evaporation

The evaporation procedure is described in Stiver and Mackay (1984). Evaporation of the lighter compounds from the fresh oil is carried out as a simple one-step distillation to vapour temperatures of typically 150 °C, 200 °C and 250 °C, which resulted in oil residues with an evaporation loss corresponding to approximately 0.5-1-hour, 0.5-1 day and 0.5-1 week of weathering on the sea surface. The residues are referred to as 150°C+, 200°C+ and 250°C+, respectively.

A.3Physical and chemical analysis

The analytical methods used are given in Table A-1 and Table A-2.

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

Physical property	Analytical method	Instrument
Viscosity	McDonagh et al, 1995	Physica MCR 300
Density	ASTM method D4052-81	Anton Paar, DMA 4500
Pour point	ASTM method D97	-

Table A-1 Analytical methods used to determine the chemical properties.

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

Chemical characterization by GC-FID

The distribution of hydrocarbons (nC_5-nC_{40}) was analysed using a Gas Chromatograph coupled with a Flame Ionisation Detector (GC-FID). The Gas Chromatograph used was an Agilent 6890N with a 30m DB1column.

A.4Emulsification properties

The w/o emulsification studies were performed by the rotating cylinders method developed by Mackay and Zagorski (1982), which is described in detail by Hokstad et al.,1993. The method includes the measuring of the following parameters:

- Relative water uptake (kinetics)
- Maximum water uptake
- Stability of the emulsion
- Effectiveness of emulsion breaker

The principle of the rotating cylinders method is illustrated in Figure A-3. Oil (30 mL) and seawater (300 mL) are mixed and rotated with a rotation speed of 30 rpm in separating funnels (0.5 L). The emulsification kinetics is mapped by measuring the water content at fixed rotation times. The maximum water content is determined after 24 hours of rotation.

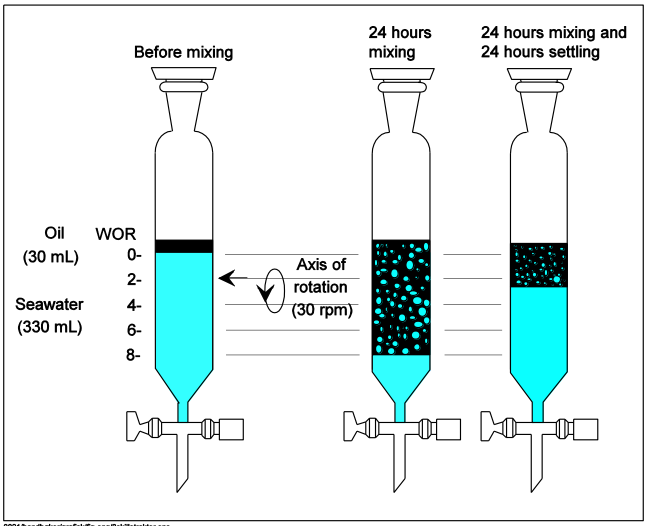


Figure A-3 Principle of the rotating cylinder method.

A.5Chemical dispersibility testing

There are several different tests for evaluating the effect of chemical dispersants. The energy input will differ in the different tests, and the obtained efficiency will be representative of different wave energies. At SINTEF, the IFP and MNS test is used in dispersibility testing. IFP and MNS test apparatus are shown in Figure A-4.

IFP (Institute Français du Pétrole test, Bocard *et al.*, 1984) is a low energy test estimated to represent low wave energies (2-5 m/s wind speed). A surge 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.

MNS (Mackay-Nadeau-Szeto test, Mackay and Szeto, 1980) is estimated to correspond to a medium to high sea state condition. The energy input in this system, applied by streaming air across the oil/water surface, produce a circular wave motion. The sample of the oily water is taken under dynamic conditions after a mixing period of 5 min.

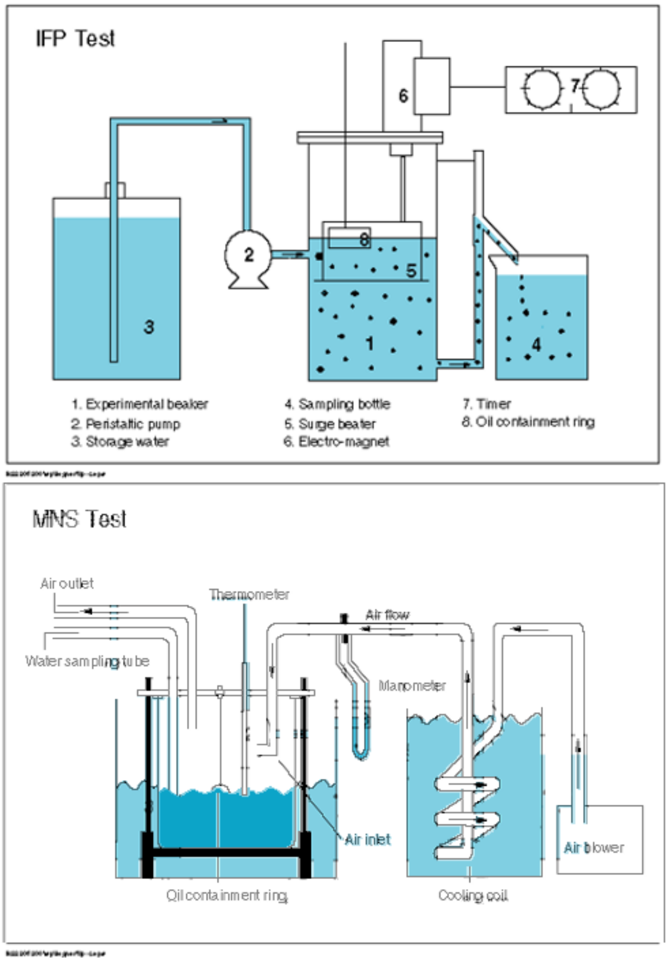


Figure A-4 *Laboratory apparatus for effectiveness testing of dispersants.*

B GC-FID chromatograms

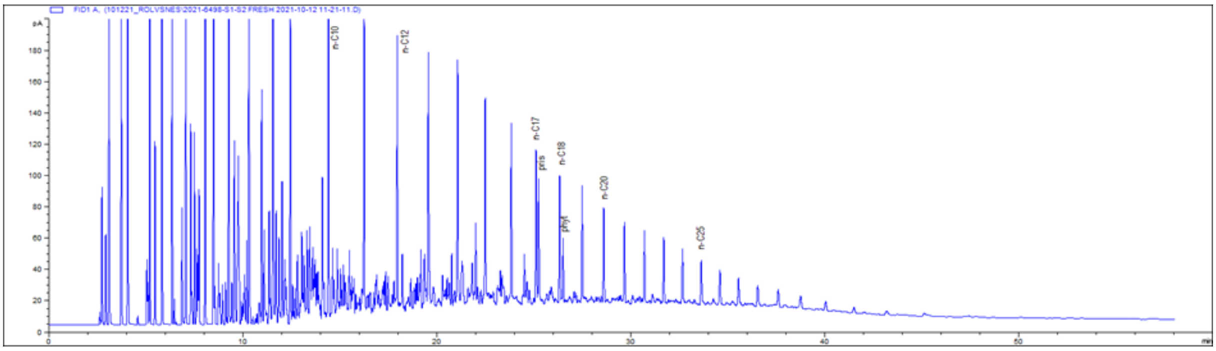


Figure B-1 GC-FID chromatogram of Rolvsnes fresh

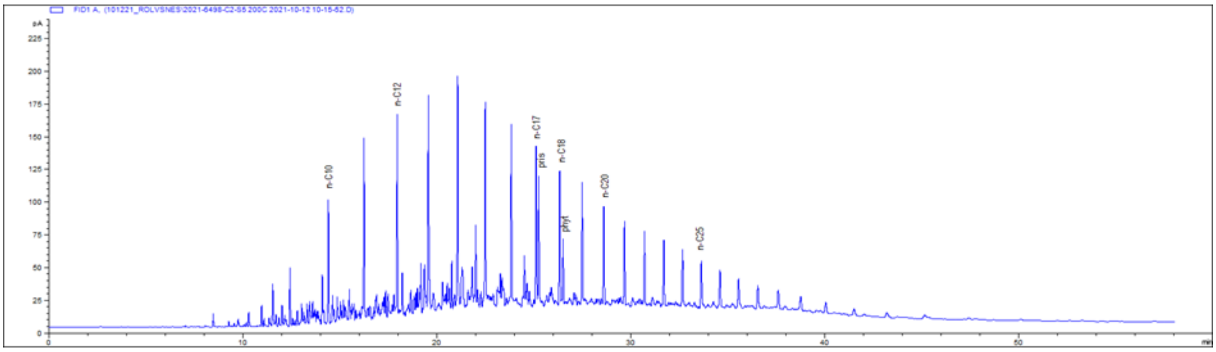


Figure B-2 GC-FID chromatogram of Rolvsnes, 200°C+

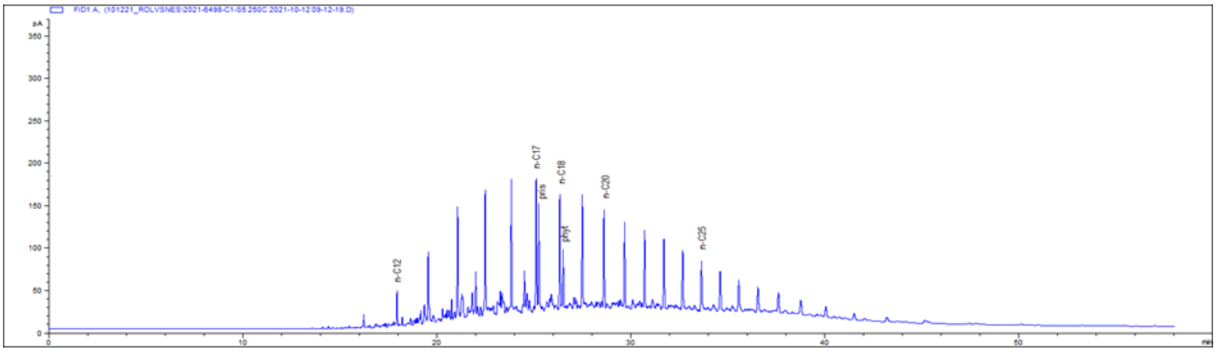
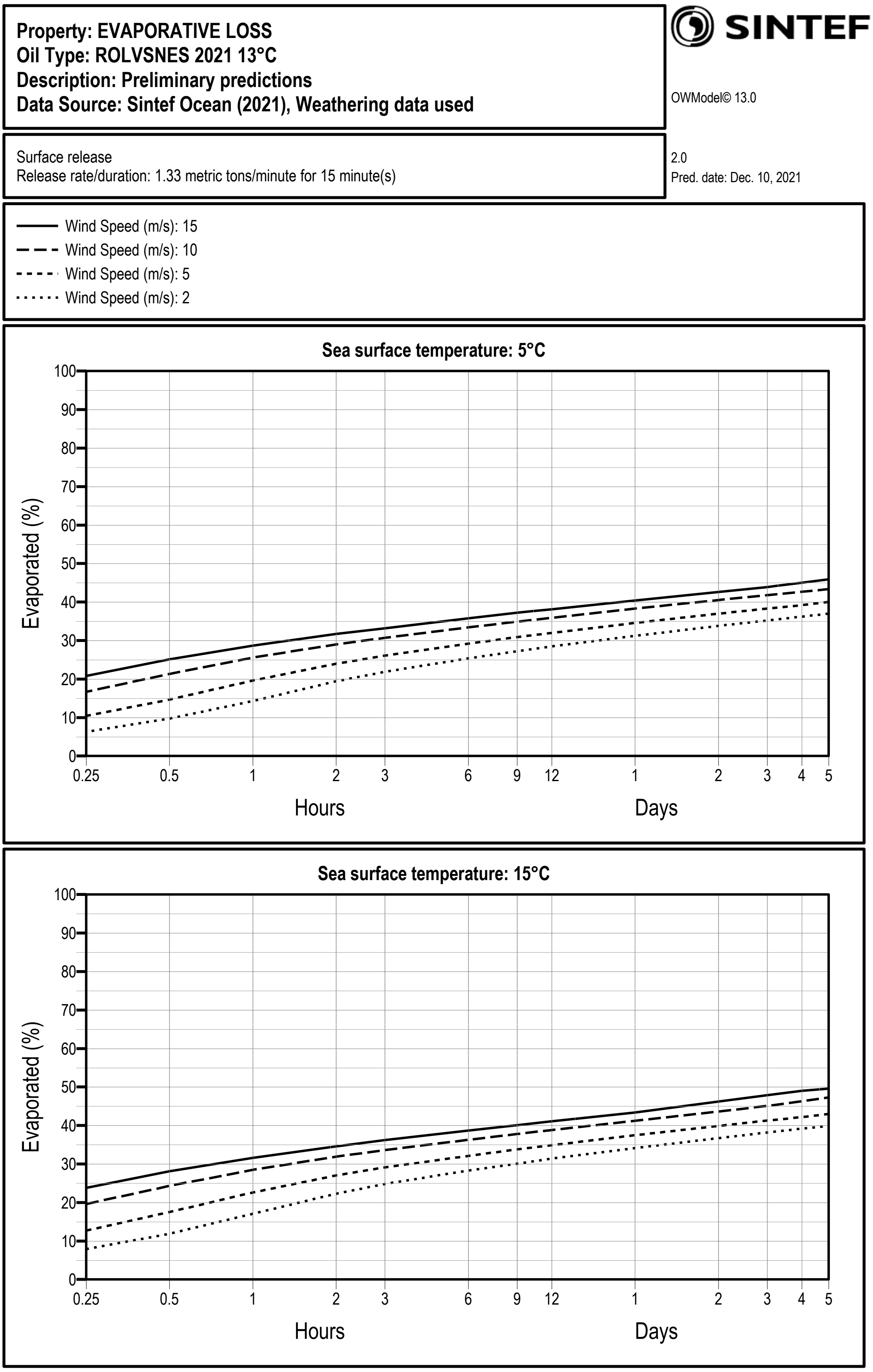
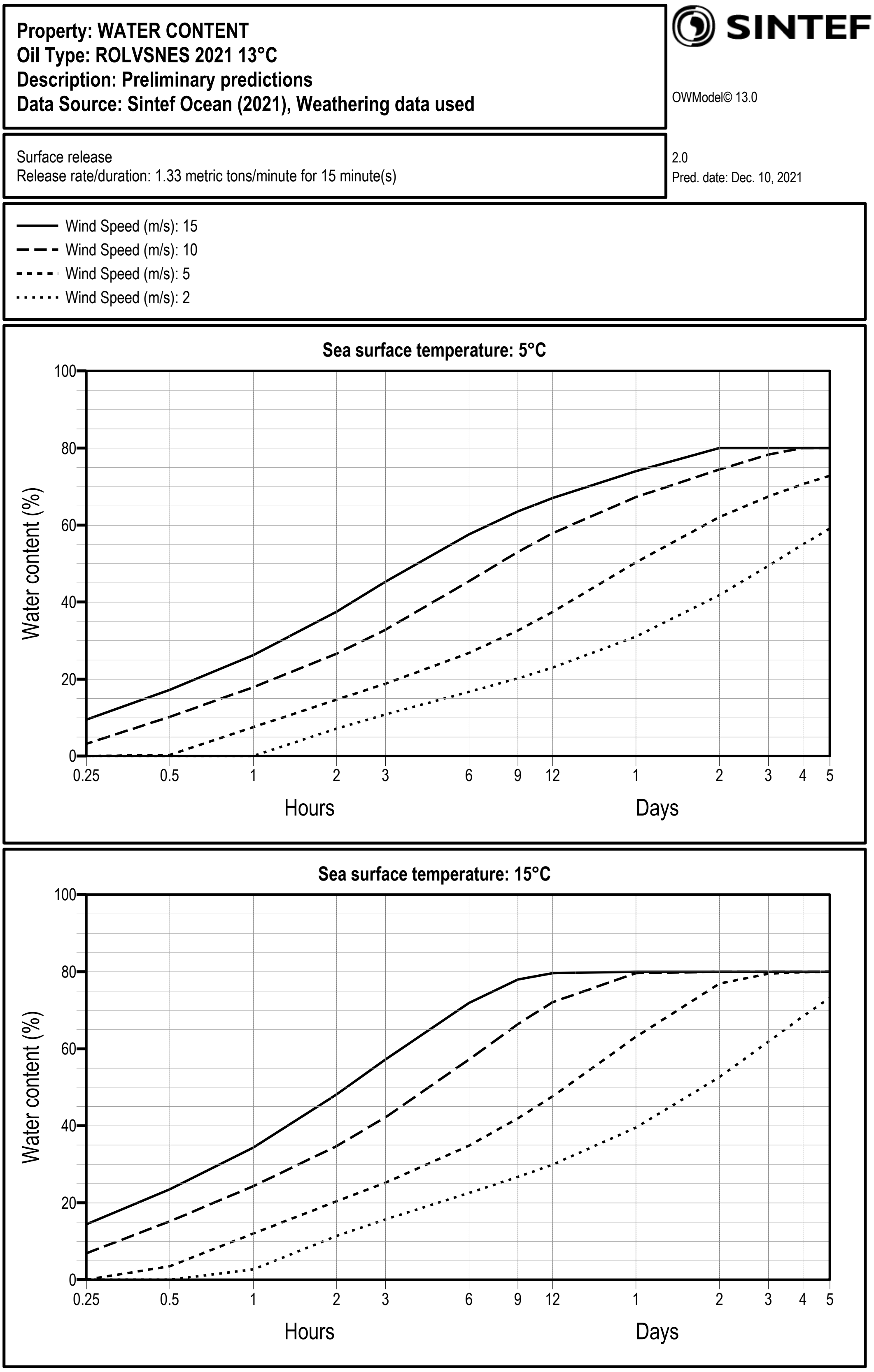


Figure B-3 GC-FID chromatogram of Rolvsnes, 250°C+

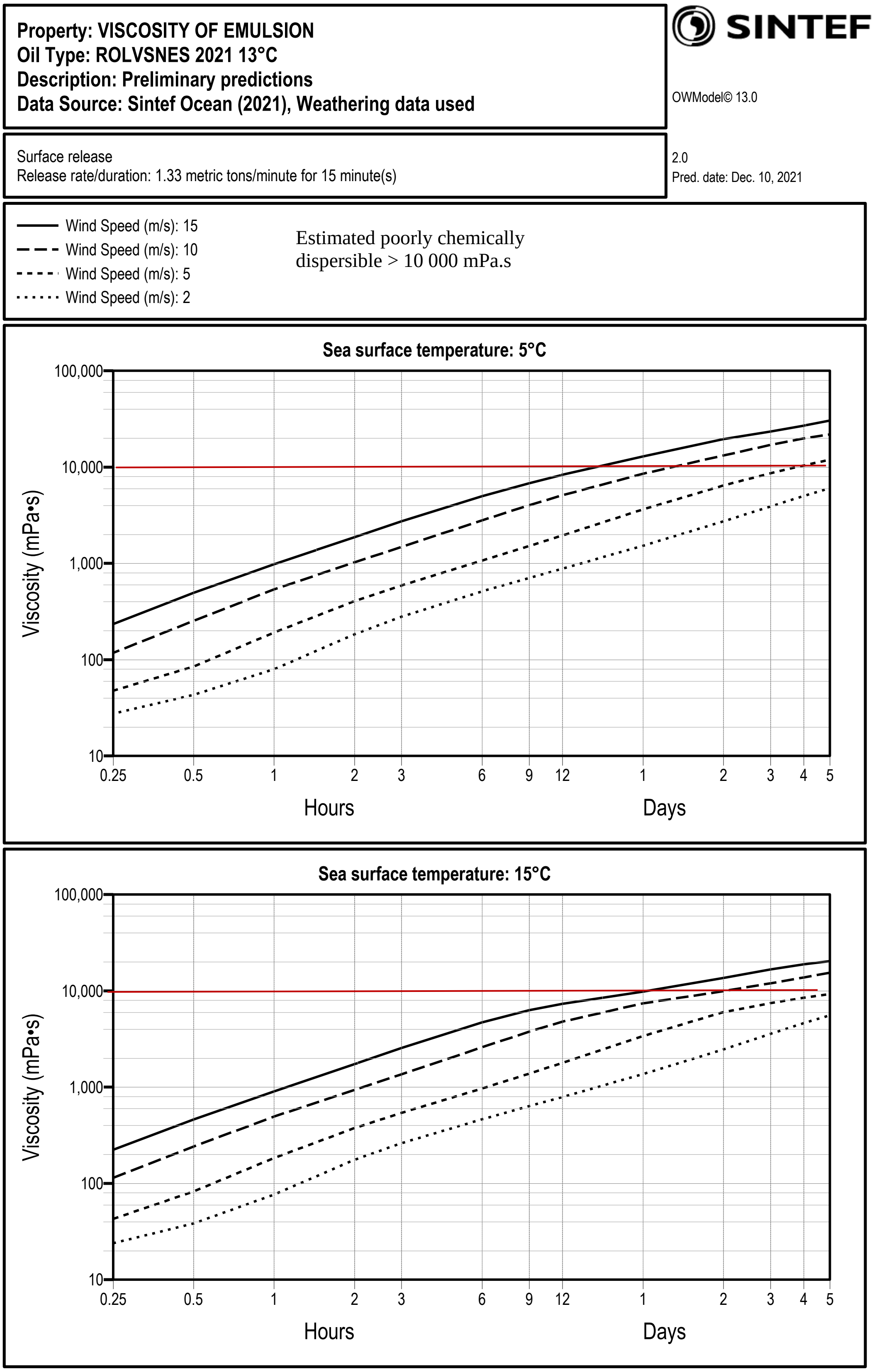
C Preliminary OWM predictions



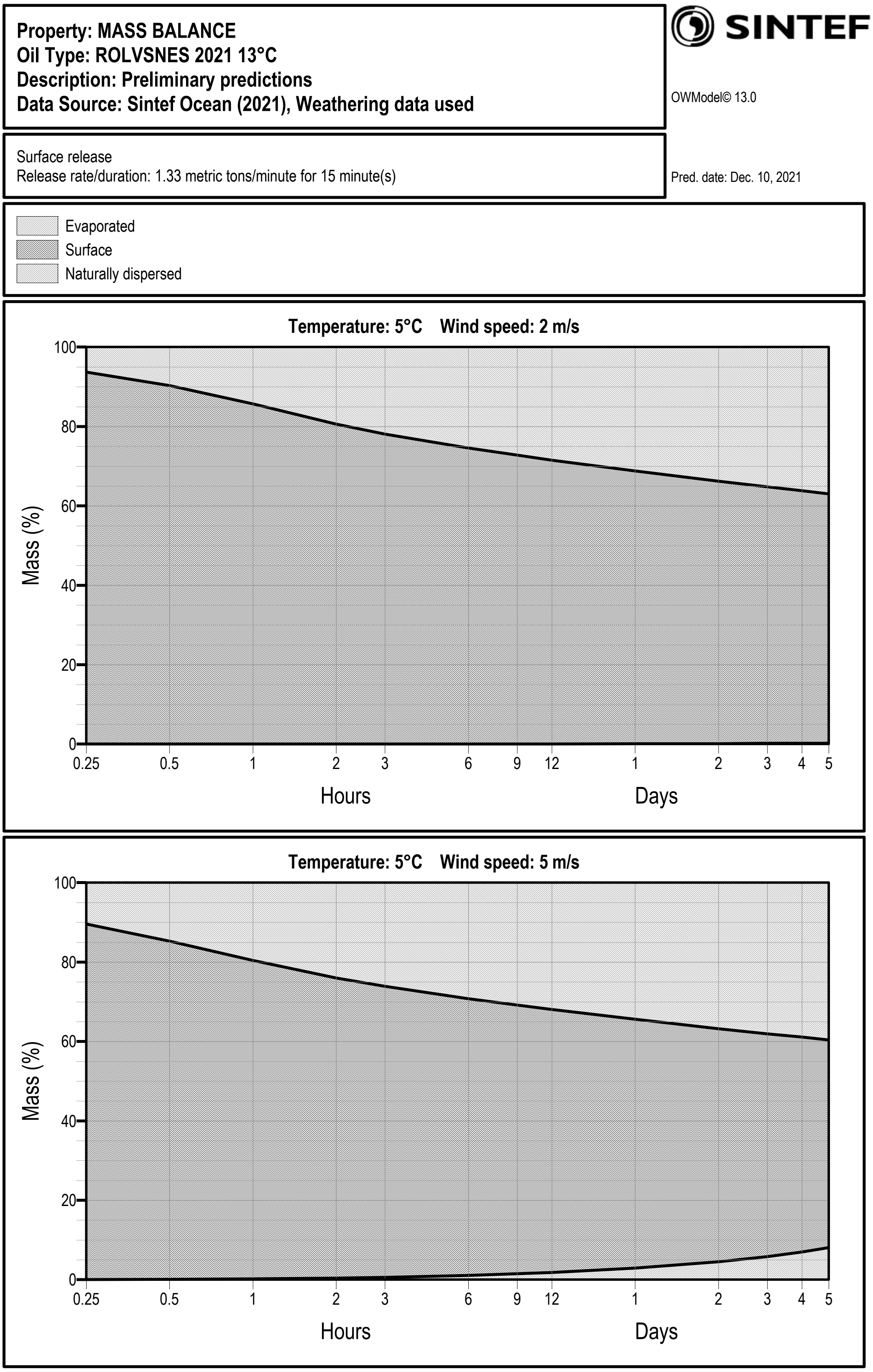
C-1 Preliminary prediction of evaporative loss of Rolvsnes.



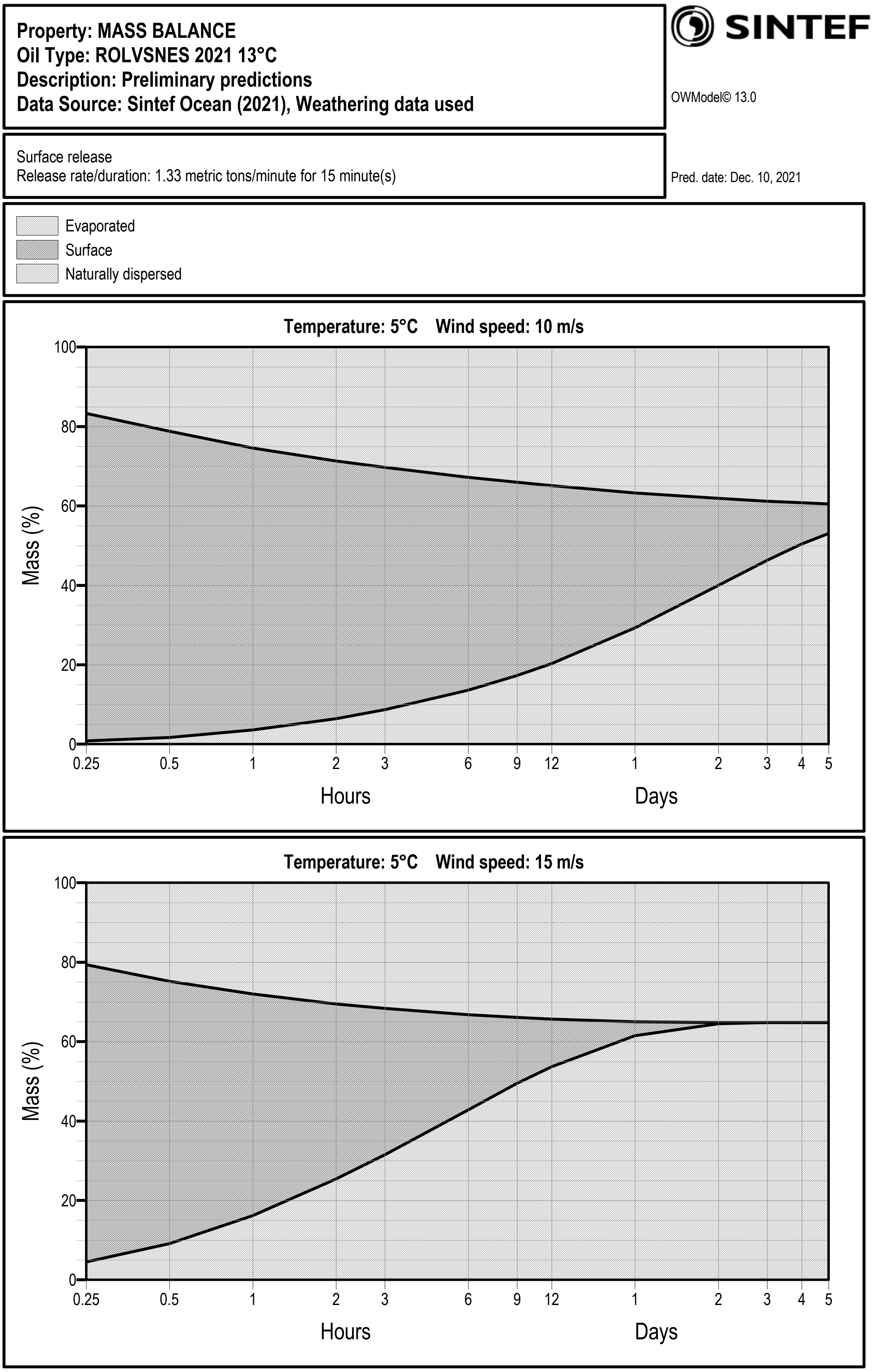
C-2 Preliminary prediction of water uptake of Rolvsnes.



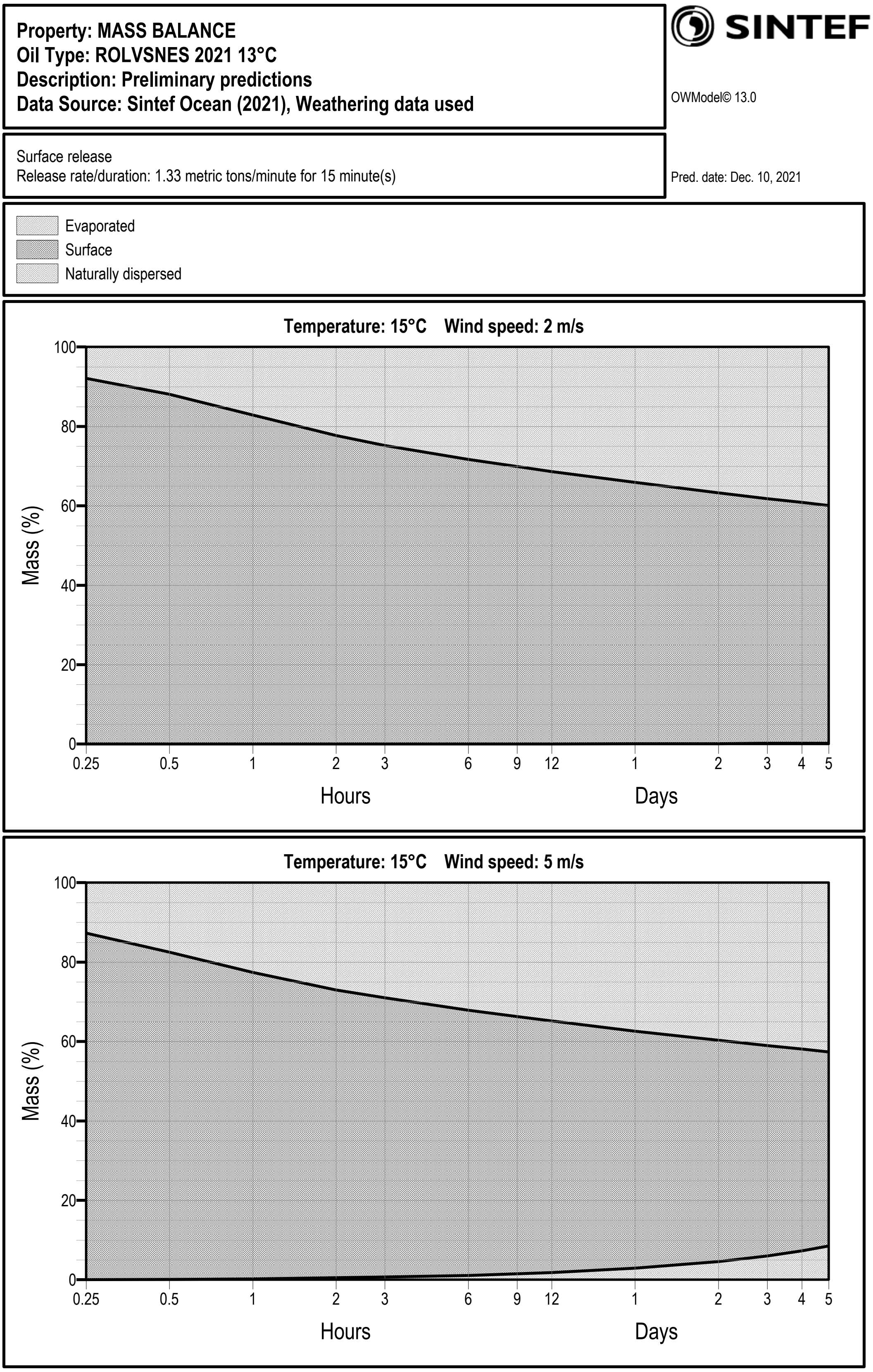
C-3 Preliminary prediction of emulsion viscosity of Rolvsnes.



C-4 Preliminary mass balances at 2 and 5 m/s of Rolvsnes at 5 °C.



C-5 Preliminary mass balances at 10 and 15 m/s of Rolvsnes at 5 °C.



C-6 Preliminary mass balances at 2 and 5 m/s of Rolvsnes at 15 °C.

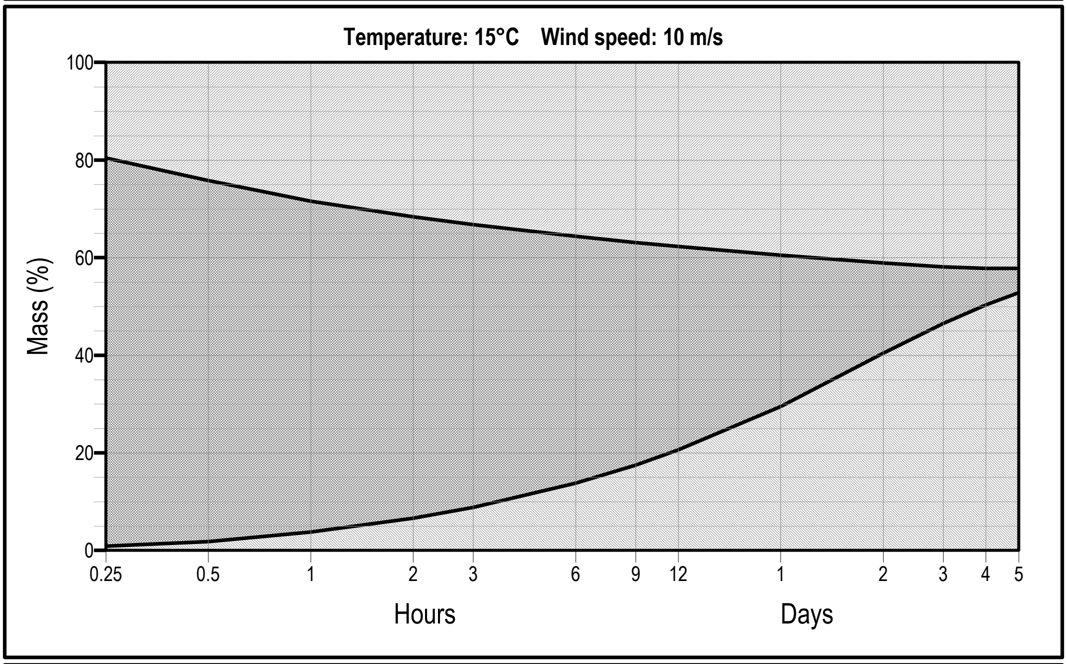
Property: MASS BALANCE
Oil Type: ROLVSNES 2021 13°C
Description: Preliminary predictions
Data Source: Sintef Ocean (2021), Weathering data used

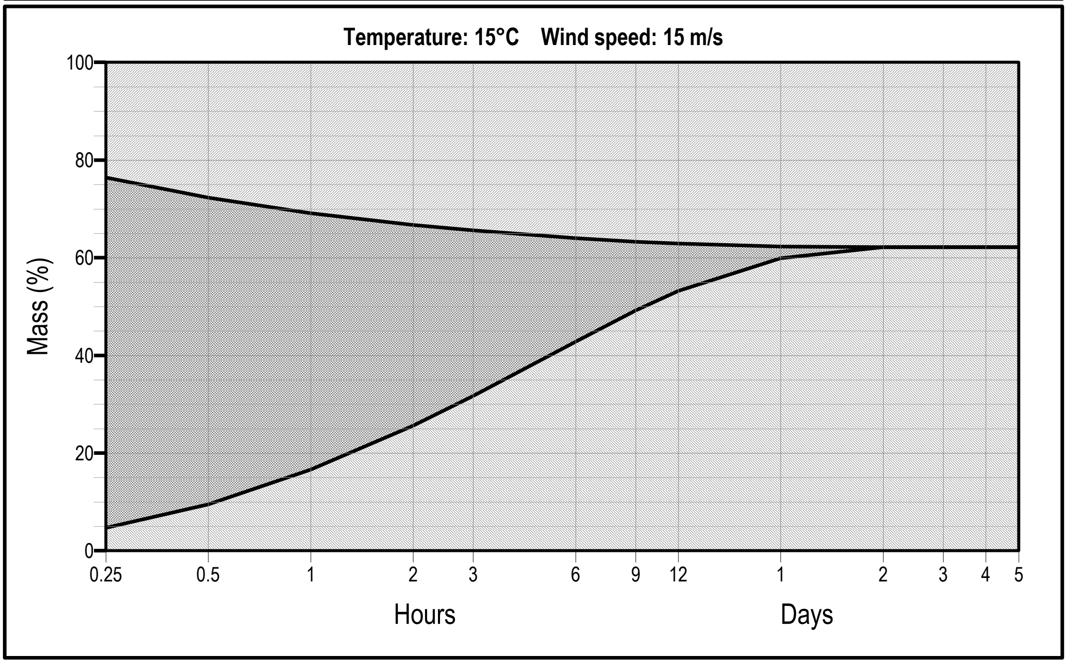
OWModel© 13.0

Surface release
Release rate/duration: 1.33 metric tons/minute for 15 minute(s)

Pred. date: Dec. 10, 2021

Evaporated
Surface
Naturally dispersed





C-7 Preliminary mass balances at 2 and 5 m/s of Rolvsnes at 15 °C.