

Report

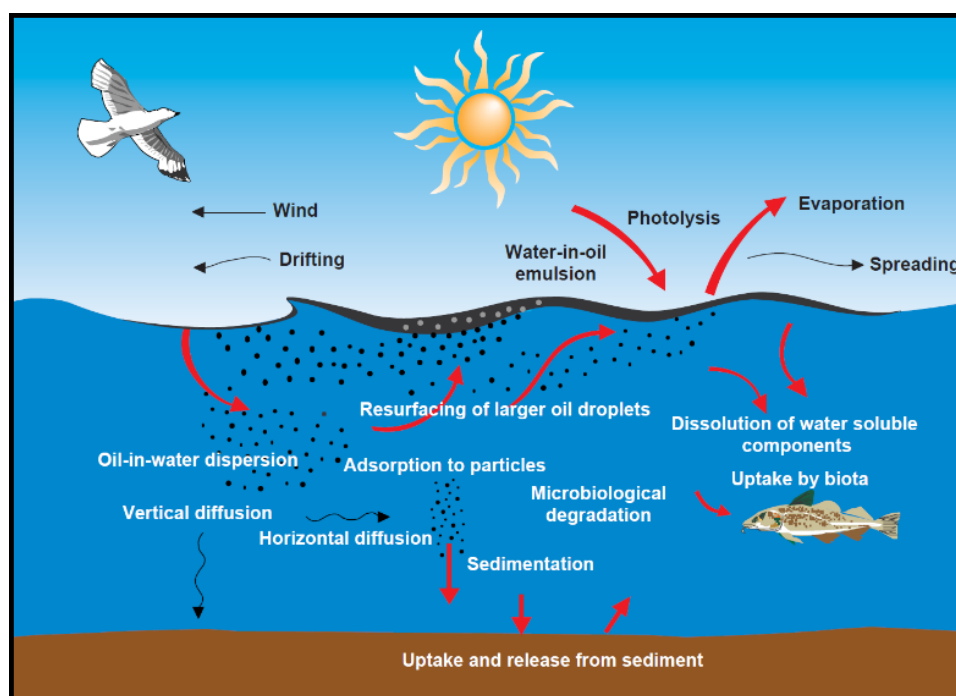
Aasta Hansteen blend– Weathering properties and behaviour at sea

In relation to oil spill response

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Report

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ABSTRACT

A weathering study has been conducted on Aasta Hansteen blend condensate. The study is based on a small-scale laboratory testing at 13 °C. The SINTEF Oil Weathering Model (OWM) was used to predict the weathering properties of the Aasta Hansteen blend condensate if spilled on the sea surface. The weathering properties were also discussed in relation to oil spill response.

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1 Executive summary

Spilled oils undergo changes when weathered on the sea surface. These changes affect oil behaviour and consequently oil spill countermeasures. Oil weathering varies over time and with different environmental conditions. Based on input from the experimental weathering data of the oil, the SINTEF Oil Weathering Model (OWM) is used to predict the properties of oil as it weathered over time. The lifetime of an oil spill at sea depends on the oil's composition, the release conditions (e.g. on the surface, underwater) and environmental conditions (temperature, wind, waves). Natural dispersion and evaporation are the main weathering processes that remove an oil spill from the sea surface. Evaporation of the lightest compounds increases the relative amount of wax and asphaltenes and changes the physical properties on the residual oil. This summary gives a brief overview of the main changes predicted for Aasta Hansteen blend condensate when weathered on the sea surface.

Aasta Hansteen blend is a partly biodegraded condensate with density of 0.823 g/mL. The condensate has low contents of asphaltenes (0.01 wt. %) and wax (0.07 wt. %). The pour points are low for the fresh oil and the residues (- 36 to - 6°C). Similar, the condensate also exhibits low viscosities (fresh oil and residues) ranging from 2 to 13 mPa.s measured at 13 °C (10s^{-1}). Based on its physico-chemical properties, it is not expected that Aasta Hansteen blend neither will emulsify nor solidify if spilled at sea. The predicted mass balances show that the condensate has short lifetime on the sea surface, particularly at high wind speeds, 6 to 2 hours, at 10 and 15 m/s due to high evaporative loss and natural dispersion/entrainment into the water column. At lower wind speeds (2-5 m/s), the oil/residue may remain for a longer time (> 2 days) on the surface.

Spilled oil on the sea surface assumes to reach the ambient water temperature within a short time period. The fire hazard, based on the volatile components from the oil, may be high if the flash point of the oil is below the sea temperature. For Aasta Hansteen blend, the flash point is predicted to exceed the sea temperature within the first 15 minutes at wind speeds (10-15 m/s), and within 0.5-1 hour at lower winds speeds (2-5 m/s). However, for larger release rates, the time for the flash point to exceed the sea temperature can be extended. Moreover, some storage tanks in vessels engaged in oil recovery operations may not be classified to carry liquids with flash points lower than 60 °C. Aasta Hansteen blend reaches this limit (60 °C) in approx. 5-9 hours after a spill at calm wind speed (2 m/s) at summer and winter conditions respective, and more rapidly at higher wind speeds.

Mechanical recovery is assumed not to be an optimal response method due to very low viscosities (< 20 mPa.s) that pronounce high risk for boom leakage for low viscous oils (lower than 1000 mPa.s). At low wind speeds low-viscous oils may be confined if the operational towing speed is low. In addition, mechanical recovery has in general low booming efficacy for thin oil films oil < 0.1-0.2 mm. However, in calm weather condition, after a surface (batch) release, mechanical recovery may have potential for Aasta Hansteen blend in an early phase before the oil has spread on the surface producing thin films.

It was not performed dispersibility testing on Aasta Hansteen blend due to its negligible water uptake. However, a simple test without application of dispersant by use of MNS (high energy test) indicated that the condensate has a high degree of natural dispersion producing small oil droplets (< 70-100 μm) that remained in the water phase upon stand still. The condensate is expected to have a rapid and vast spreading on the sea surface and produce thin oil films within relatively short time. Use of dispersants for film thicknesses < 0.1 mm are not considered to be optimal and efficient but may have a potential in the first hours in calm weather conditions, assuming film thicknesses > 0.1 mm, to enhance the natural dispersion.

Mechanical dispersion by use of high-capacity water flushing can be an option for thin oil films $< 0.2\text{-}0.3$ mm, in calm weather for low viscous oils such as Aasta Hansteen blend. A combination of mechanical dispersion and application of dispersants can be considered for film thicknesses larger than 0.3 mm.

Monitoring and remote sensing will in any case be important in an oil spill operation and can be evaluated as an acceptable and practical response option, particularly in increasing wind speeds ($> 5\text{m/s}$) for Aasta Hansteen blend.

2 Introduction

New oil types (from heavy crude oil to light crude oils and condensates) are continuously coming into production worldwide. 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 efficacy of the different response techniques changed as the oil weathered and emulsified on the sea surface over a long period. These past experiences 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. Appendix A describes the general physical and chemical properties and weathering processes of crude oils spilled on the sea surface.

SINTEF Ocean has performed a weathering study (refers to Aktivitetsforskriften § 59) on Aasta Hansteen blend based on a request from Equinor. The weathering study was conducted at 13 °C as agreed upon with the client. The obtained laboratory data were further used to predict the weathering properties of the condensate by use of the SINTEF Oil Weathering Model (OWM). Information about the Aasta Hansteen field is given in Figure 2-1, below.

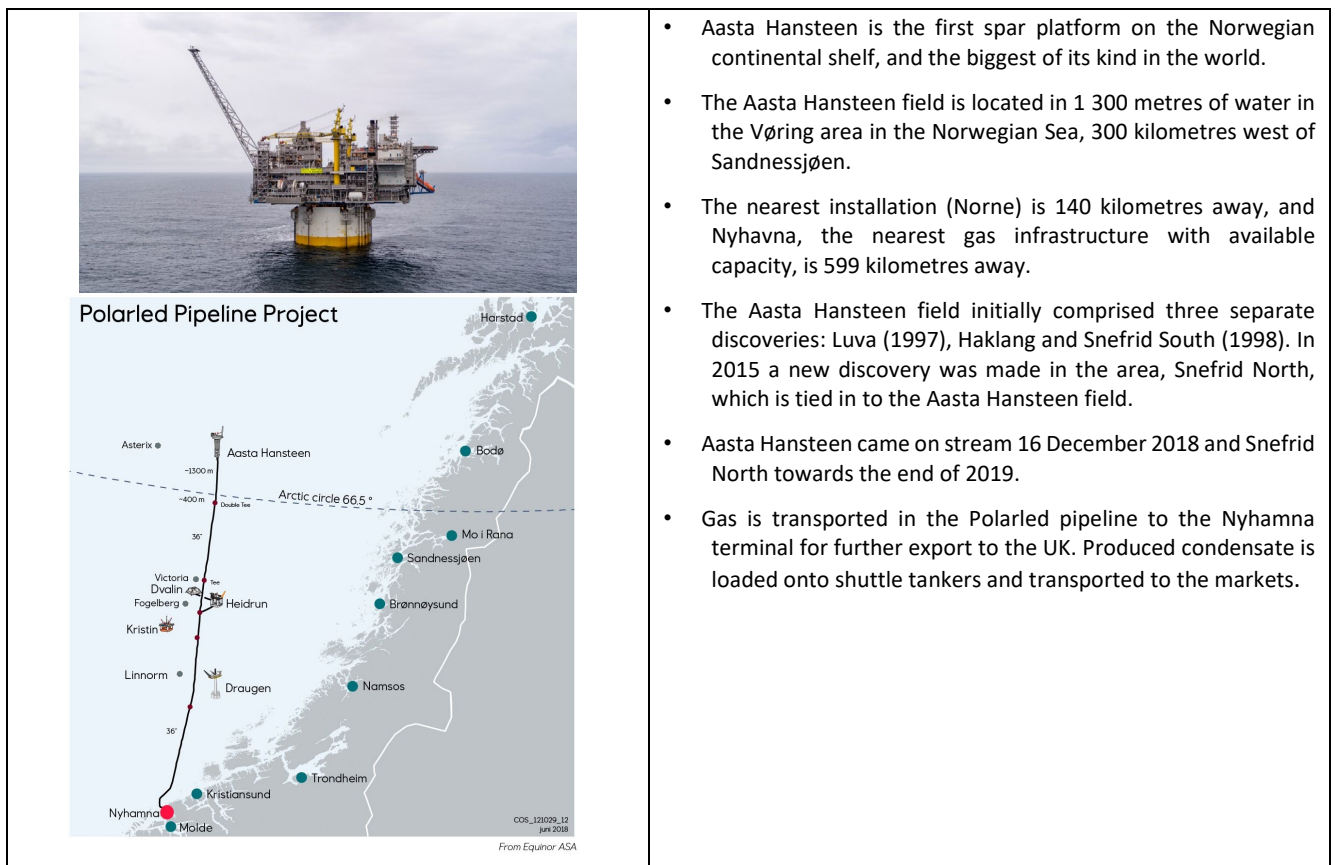


Figure 2-1

<https://www.equinor.com/en/what-we-do/norwegian-continental-shelf-platforms/aasta-hansteen.html>

3 Small-scale laboratory testing results

The methodology of small-scale testing is described in Appendix B. Physico-chemical parameters and weathering properties of Aasta Hansteen blend were compared with similar data of other Norwegian oils as listed in Table 3-1 (Kvitebjørn, Kristin, Skarv and Marulk). The oils in comparison were selected in agreement with Equinor. Kvitebjørn was tested for its weathering properties in 2009 and 2019, and the light condensate of Kvitebjørn 2019 was selected for comparison in this report due to its properties. Kristin (light crude oil), Skarv (condensate) and Marulk (condensate) are fields in the Norwegian Sea, as Aasta Hansteen.

Table 3-1 Oils compared with Aasta Hansteen blend*

Oil name	SINTEF ID	Report no	Reference
Kvitebjørn 2019	2019-1059	OC2019 A-097	Sørheim and Hellstrøm, 2019
Kristin	2006-0256	A 06221	Leirvik, 2006
Skarv	2013-0833	A 26022	Øksenvåg, 2014
Marulk	2014-0076	A 26367	Hellstrøm and Pettersen, 2014

*Aasta Hansteen blend was given the SINTEF ID 2019-10622

3.1 Gas chromatographic (GC-FID) characterization

The hydrocarbon profile of Aasta Hansteen blend was analysed by use of gas chromatography (GC) coupled with Flame Ionization detector (FID). Figure 3-1 illustrates the GC-FID output (i.e. gas chromatogram) of the fresh oil of Aasta Hansteen blend and its corresponding evaporated residues at three different degree of evaporative loss of volatiles at 150, 200 and 200°C+ (see Appendix B.2). The loss of low molecular weight (volatiles) compounds (shown towards the left of the chromatogram) at the three temperatures mimics that of natural weathering (evaporative loss at sea) and provides support for the artificial evaporation of the crude oil by use of distillation (topping) in the laboratory. The gas chromatograms 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 ($> nC_{40}$) are not possible to analyze with this technique.

Aasta Hansteen blend is a partly biodegradable condensate with a low nC_{17} /pristane ratio of 1.12 (Table 3-2), and has also a certain UCM (hump) as shown in the GC-chromatogram. The other oils in comparison were previously categorized as typically paraffinic oils/condensates (Figure 3-2). In addition, the relatively high density of Aasta Hansteen blend (0.823 g/mL) also indicates that the condensate contains heavy compounds (e.g. resins) that is typically for naphthenic /biodegraded oils. However, Aasta Hansteen blend also exhibits a high degree of light paraffins (*n*-alkanes) in the range of nC_5 - nC_{15} that reflects an insignificant content of wax/paraffins $> nC_{20}$.

Table 3-2 nC_{17} /Pristane and nC_{18} /Phytane ratios*

Oil name	nC_{17} /Pristane* *	nC_{18} /Phytane**
Aasta Hansteen blend	1.12	2.90
Kvitebjørn 2019	1.74	2.72
Kristin	1.91	2.56
Skarv	2.08	6.65
Marulk	1.45	3.84

Ratios > 2 typical for high paraffinic oils, ratios < 1 typical for biodegraded /naphthenic oil.

*The relation between *n*-alkanes and corresponding isoprenoids (pristane and phytane) are based on the peak heights from the GC-chromatograms

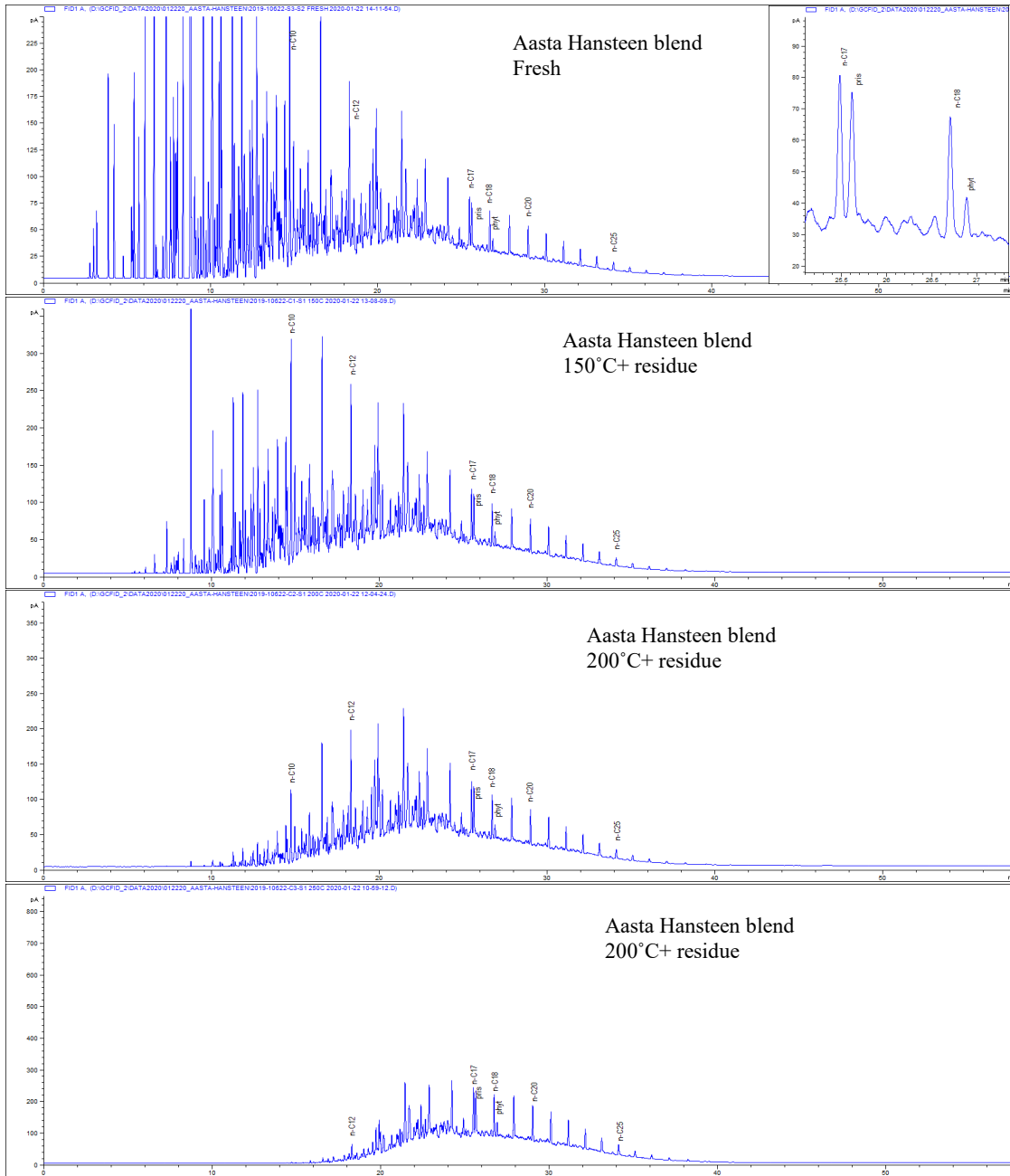


Figure 3-1 GC-FID chromatograms of fresh sample and evaporated residues of Aasta Hansteen blend, normalised on nC20

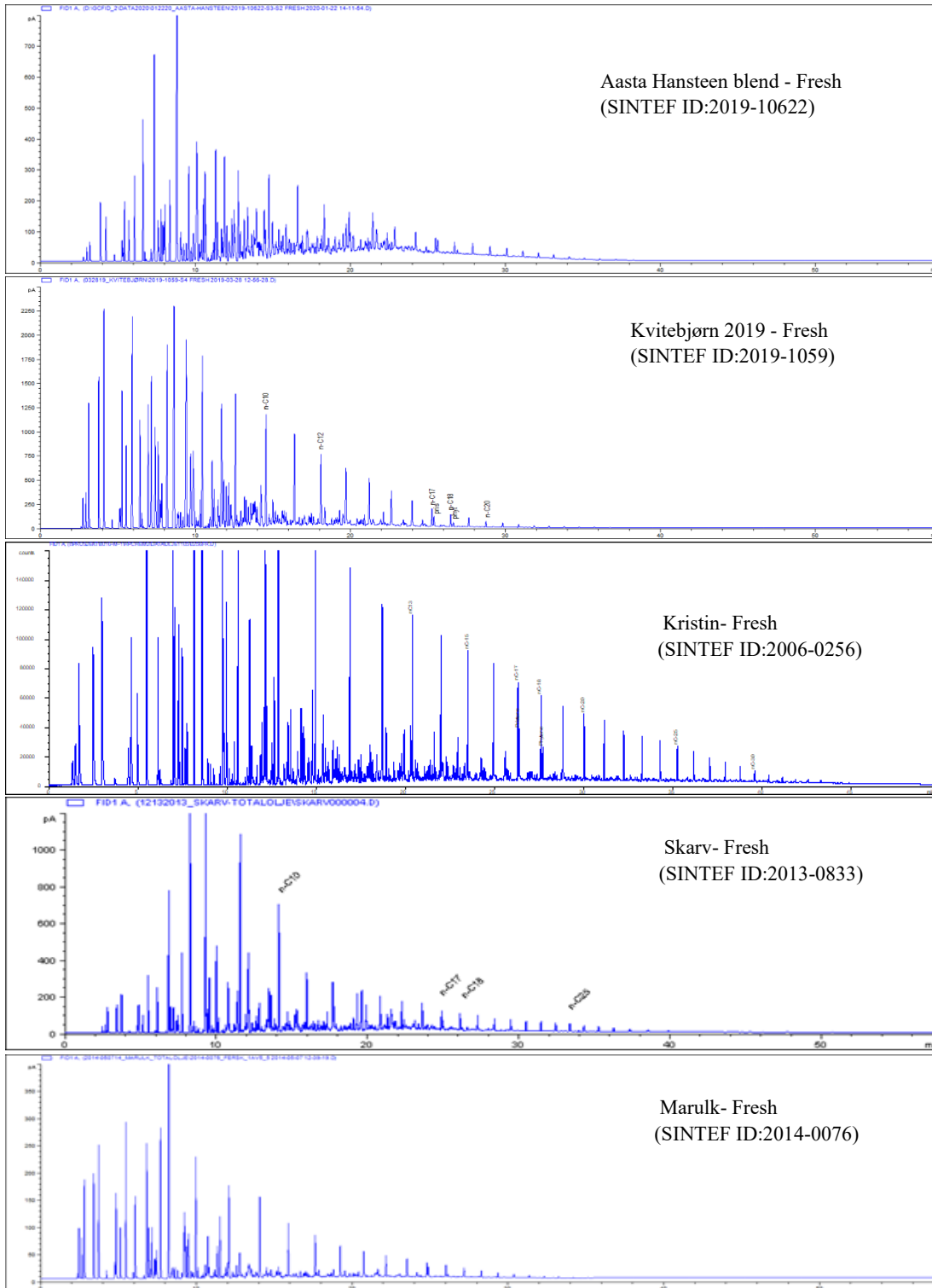


Figure 3-2 GC-FID chromatograms for fresh oils of Aasta Hansteen blend and other oils in comparison. The retention times differ between the chromatograms due to different temperature programs (relative comparison)

3.2 Chemical composition and physical properties

Asphaltenes and wax content of the fresh and weathered residues

The contents of asphaltene and wax for the fresh oil and weathered residues of Aasta Hansteen blend and the other oils for comparison are given in Table 3-3. Aasta Hansteen blend (fresh oil) has low contents of wax (0.07 wt.%) and asphaltenes (0.01 wt.%) and the condensate is comparable with Kvitebjørn 2019 and Marulk. Kristin and Skarv exhibit higher wax content (6.8 wt. % and 2.2 wt.% respective) but also have low asphaltenes as for the other oils in comparison.

Table 3-3 *Asphaltene ("hard") and wax content for different oils in comparison*

Oil type	Residue	Asph* (wt. %)	Wax (wt. %)
Aasta Hansteen blend	Fresh	0.01	0.07
	150°C+	0.02	0.10
	200°C+	0.02	0.14
	250°C+	0.04	0.24
Kvitebjørn 2019	Fresh	<0.01	0.14
	150°C+	0.01	0.39
	200°C+	0.02	0.80
	250°C+	0.05	1.91
Kristin	Fresh	0.02	6.8
	150°C+	0.03	9.7
	200°C+	0.04	12.0
	250°C+	0.05	15.0
Skarv	Fresh	0.01	2.2
	150°C+	0.02	3.1
	200°C+	0.03	4.5
	250°C+	0.04	6.6
Marulk	Fresh	<0.01	<0.01
	150°C+	0.01	0.01
	200°C+	0.01	0.01
	250°C+	0.02	0.02

**n*-heptane (*n*C₇) precipitation

Physical properties for the fresh and weathered residues

Figure 3-3 shows the fresh oil and the corresponding residues (150, 200 and 250°C+) of Aasta Hansteen blend. The fresh oil is light yellow (almost colourless), whilst the residues have darker colours upon evaporation. The 200 and 250°C+ residues exhibit a dark orange colour.

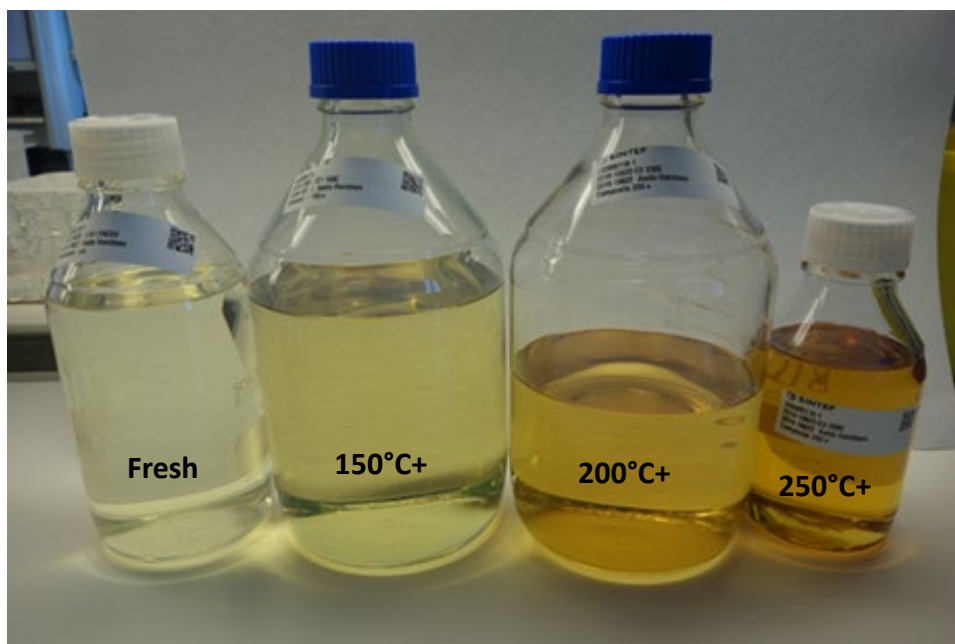


Figure 3-3 Aasta Hansteen blend from left to right: Fresh oil and residues (150, 200 and 250°C+)

The physical properties of Aasta Hansteen blend in comparison with Kvitebjørn 2019, Kristin, Skarv and Marulk are listed in Table 3-4. The evaporative loss of Aasta Hansteen blend is relatively high typically for condensates. Kvitebjørn 2019 is the lightest condensates and expresses the highest evaporative loss among the oils in comparison followed by Marulk, whilst Kristin (light crude oil) has the lowest evaporative loss among these oils. The density of Aasta Hansteen blend (0.823 g/mL) is comparable with Skarv (0.829 g/mL), whilst Kvitebjørn 2019 and Marulk exhibit the lowest densities (0.752 and 0.759 g/mL respective).

The pour points of Aasta Hansteen blend are very low and are in the range of <-36 to -6 °C. Low pour points are also measured on Kvitebjørn 2019 and Marulk, whilst Kristin and Skarv have significantly higher pour points particularly for the 250°C+ residue (+27 °C). High pour points reflect the higher wax content of Kristin and Skarv compared with the other oils. The viscosities of Aasta Hansteen blend are very low at 13 °C (2 to 14 mPa.s), similarly as for Kvitebjørn 2019 and Marulk. Kristin and Skarv show increasing viscosities of the residues that also reflects the increasing wax concentration by evaporation.

The true boiling point curves (TBP) of Aasta Hansteen blend, Kvitebjørn 2019, Kristin, Skarv and Marulk are shown in Figure 3-4. The TBP clearly show similarities of Aasta Hansteen blend and Skarv. Kvitebjørn 2019 is the lightest condensate flows by Marulk, whilst Kristin (light crude oil) has the lowest TBP among these oils.

Table 3-4 Physical properties of Aasta Hansteen blend, Kvitebjørn 2019, Kristin, Skarv and Marulk

Oil type	Residue	Evap. (vol. %)	Residue (wt. %)	Density (g/mL)	Flash point (°C)	Pour point (°C)	Visc. (mPa.s) 13°C (10 s ⁻¹)
Aasta Hansteen blend	Fresh	0	100	0.823	-	<-36	2
	150°C+	34	69	0.856	37	-27	3
	200°C+	55	49	0.878	75	-18	6
	250°C+	74	28	0.896	113	-6	14
Kvitebjørn 2019	Fresh	0	100	0.752	-	<-36	1
	150°C+	65	37	0.797	33	-24	2
	200°C+	84	18	0.816	72	-6	4
	250°C+	93	7.5	0.835	102	9	26
Kristin	Fresh	0	100	0.794	-	-39	2
	150°C+	33	70	0.831	36	0	26
	200°C+	47	57	0.846	72	12	539
	250°C+	58	45	0.860	114	27	7730
Skarv	Fresh	0	100	0.829	-	6	6
	150°C+	31	71	0.857	32	15	47
	200°C+	55	48	0.882	71	21	191
	250°C+	69	33	0.897	109	27	627
Marulk	Fresh	0	100	0.759	-	<-36	1
	150°C+	53	50	0.811	33	-12	3
	200°C+	69	34	0.829	62	0	5
	250°C+	80	22	0.842	104	6	9

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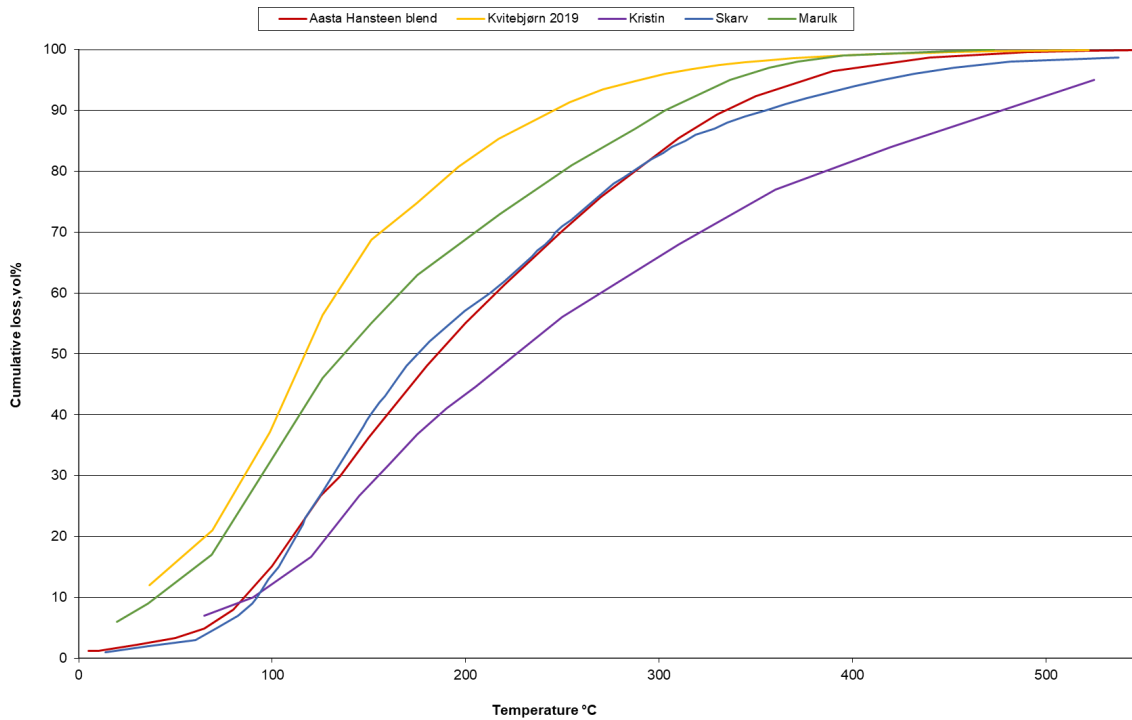


Figure 3-4 Distillation curves from SINTEF OWM for Aasta Hansteen blend, Kvitebjørn 2019, Kristin, Skarv and Marulk

3.3 Viscosity of fresh oil and water-free residues

The viscosity describes the oils ability to resist gradual deformation by increasing shear, where viscosities of so-called *Newtonian* oils remains constant independent on the applied shear rate (s^{-1}) at a given temperature. The opposite when shear is applied on so-called *non-Newtonian* oils the viscosity of such oils decreases. The dynamic viscosities (mPa.s) of Aasta Hansteen blend fresh oil and water-free residues are given in Table 3-5 with increasing shear rates (10, 100 and 1000 s^{-1}) at 13 °C. The fresh Aasta Hansteen blend oil and its residues exhibit *Newtonian* behaviour with very low viscosities.

Table 3-5 Viscosities of fresh oil and residues of Aasta Hansteen blend with increasing shear rate

Oil type	Residue	Visc. (mPa.s) 13°C (10 s ⁻¹)	Visc. (mPa.s) 13°C (100 s ⁻¹)	Visc. (mPa.s) 13°C (1000 s ⁻¹)
Aasta Hansteen blend	Fresh	2	2	2
	150°C+	3	3	3
	200°C+	6	6	6
	250°C+	13	13	14

3.4 Emulsifying properties

In general, emulsification is the mixing of seawater droplets into spilled oil at the water's surface (water-in-oil emulsion), forming a weathered oil residue that often tends to be relatively resistant to other weathering processes such as evaporation, and increases the total volume of oil due to the uptake of water into the oil.

Based upon the fact that Aasta Hansteen blend is a condensate with a negligible content of stabilizing components like the asphaltenes and very low content of wax, emulsification is not likely for this oil. However, a simple emulsification test on the 250°C+ residue was conducted to verify this assumption. No water uptake or emulsification was observed after 24 hours rotating time (30 mL oil/residue) and 300 mL seawater according to the standard procedure for maximum water uptake, as described in Hokstad et al., 1993. Testing at 13 °C.

3.5 Dispersibility

No standardized dispersibility testing was conducted on Aasta Hansteen blend due to no emulsification and the assumption that the oil easily will be naturally dispersed into the water column with wave actions. However, a simple dispersibility test for justification was performed on the 250°C+ residue, as described above (section 3.3), using the high energy MNS test (Mackay and Szeto, 1980). The MNS test reflects typically breaking waves conditions (> 5 m/s wind speed). Images from the test are shown in Figure 3-5. It was observed a high degree of natural dispersion of the 250°C+ residue in the breaking waves conditions. No re-surfaced oil/residue was visually observed after 5 min. stand still, i.e. after the wave energy was switched off, indicating formation of small oil droplets (< 70-100 µm) that remained in the water phase.

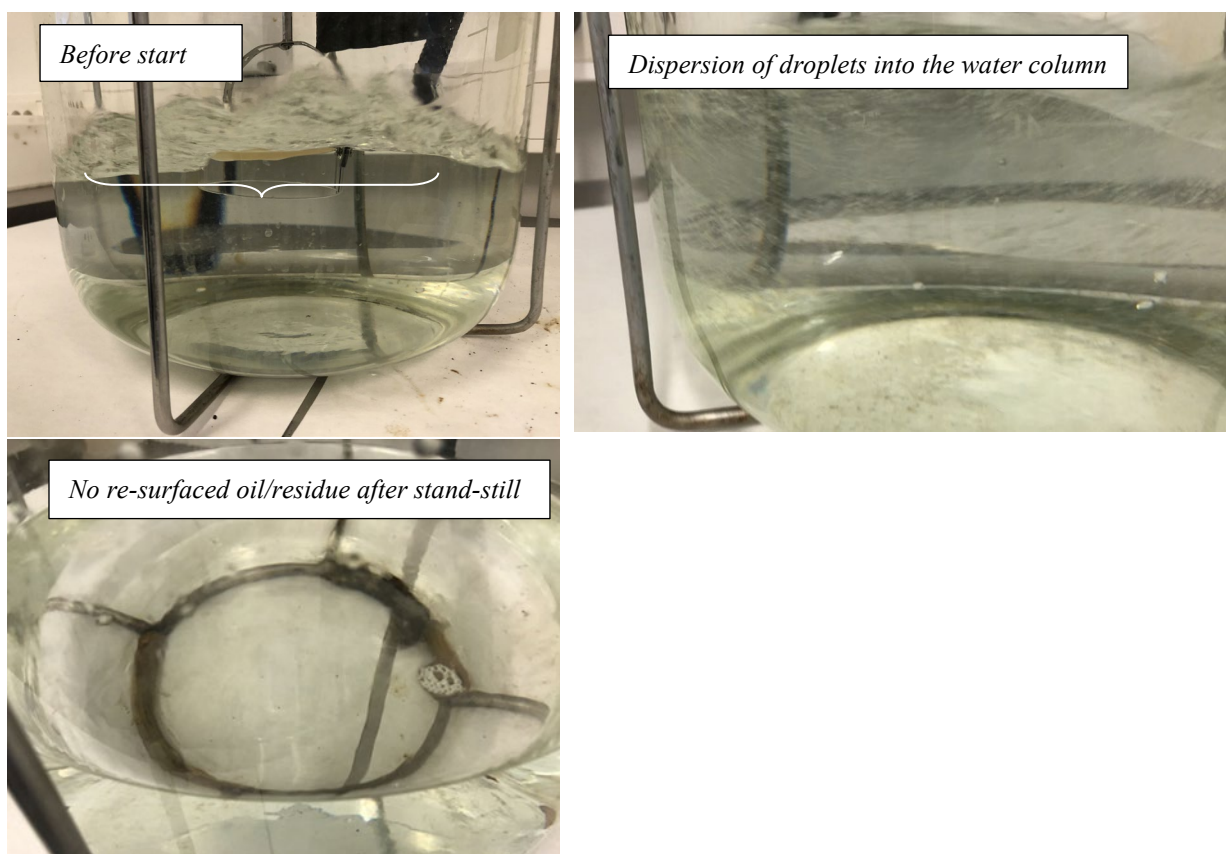


Figure 3-5 Dispersibility (naturally dispersion) of 250°C+ residue of Aasta Hansteen blend by use of MNS test.

4 Predictions with SINTEF Oil Weathering Model (OWM)

4.1 Description of SINTEF OWM

A systematic stepwise laboratory procedure developed at SINTEF (Daling et al., 1990) was used to isolate and map the various weathering processes that take place when oil is spilled on the sea surface. Laboratory study of Aasta Hansteen blend was conducted at 13 °C, and the analytical data were further used as input to the SINTEF Oil Weathering Model (OWM) (version 11.0.1). The experimental design for the study is described in Appendix B. The input data to the SINTEF OWM is given in Appendix C. The SINTEF OWM relates oil properties to a chosen set of conditions (oil/emulsion film thickness, wind speeds and sea temperature) and predicts the change rate of the oil's properties on the sea surface with time. The SINTEF OWM is schematically shown in Figure 4-1. The predictions obtained from the SINTEF OWM are useful tools in the oil spill contingency planning related to the expected behaviour of oil on the sea surface, and to evaluate the time window for operational response strategies in a spill operation. In this report, the presented predictions span a period from 15 minutes to 5 days after an oil spill has occurred. The SINTEF OWM is described in more detail in Johansen (1991), and in the user's guide for the model.

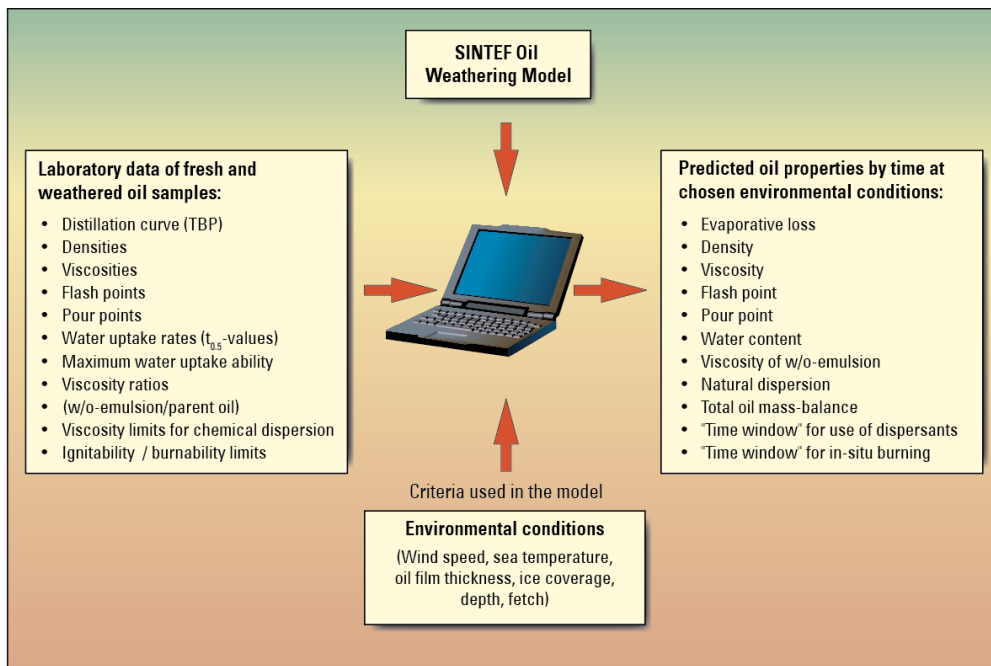


Figure 4-1 Schematic input data to the SINTEF OWM and the predicted output oil properties

Spill scenario

A standard surface release was used as a spill scenario (see section 4.2). The scenario chosen is not oil field specific but selected to give predictions of the expected weathering properties of the oil based on the experimental data and specified terminal oil film thickness. A standardized scenario will also more easily compare results of weathering properties with other oils.

Oil film thickness

Oils are categorized as condensate, emulsifying crude, low emulsifying crude, heavy bunker fuel or refined distillate. The categorization is also based on the experimental results obtained in the laboratory. The terminal film thicknesses vary among these categories based on experimental (field) experience. Aasta Hansteen blend is categorized as a condensate with a terminal oil film thicknesses of 0.05 mm.

Seawater temperature

The prevailing weather conditions greatly influence the weathering rate of oil on the sea surface. Due to the location of the oil field, the prediction seawater temperature chosen for Aasta Hansteen blend was 5 and 15 °C, reflecting typically winter and summer conditions.

Wind speed

The relationship between the wind speed and significant wave heights used in the prediction charts obtained from the SINTEF OWM are shown in Table 4-1.

Table 4-1 Relationship between wind speed and significant wave height used in the 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

4.2 Predictions of Aasta Hansteen blend

Input to the OWM

Oil type:	Condensate
Geographical area:	Norwegian Sea
Terminal oil film thickness:	0.05 mm
Release rate:	1.33 metric tonnes for 15 min, a total of 20 metric tonnes
Seawater temperature:	5 and 15 °C
Wind speed:	2 m/s, 5 m/s, 10 m/s and 15 m/s

Predicted properties

- Evaporative loss
- Viscosity
- Flash point
- Pour point
- Mass balance

The input data in OWM are based on the crude assay data for the fresh oil (distillation curve, wax, asph, density, viscosity and pour point), in addition to the generated weathering data for the evaporated residues. The

predictions are based on 5 days weathering independently if there is not predicted any remaining oil within shorter time. The predictions are shown to indicate the weathering properties in cases there are patches or oil left on the surface up to 5 days.

How to use the prediction charts: an example

If the oil has drifted on the sea surface, the following prediction charts could be used to determine the weathering properties of the oil/emulsion. Table 4-2 gives an example for the following scenario:

- Drifting time: 2 hours
- Seawater temperature: 15 °C
- Wind speed: 2, 5 and 10 m/s

Table 4-2 Example of weathering properties for Aasta Hansteen blend obtained from the OWM predictions after 2 hours of weathering at 2, 5 and 10 m/s wind speed

Weathering property	2 hours 15 °C 2 m/s	2 hours 15 °C 5 m/s	2 hours 15 °C 10 m/s
Evaporation, wt. %	31	41	52
Flash point, °C	37	54	74
Pour Point, °C	-25	-21	-17
Viscosity, mPa.s *	4	5	6
Mass balance / Oil on surface wt.%	70	57	18

**mPa.s = cP (mPa.s: SI-standard / cP: Industrial denotation)*

Property: EVAPORATIVE LOSS
 Oil Type: AASTA HANSTEEN BLEND
 Description:
 Data Source: Sintef Ocean (2020), Weathering data used

OWModell 11.0.1

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

2.0
 Pred. date: Apr. 26, 2020

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

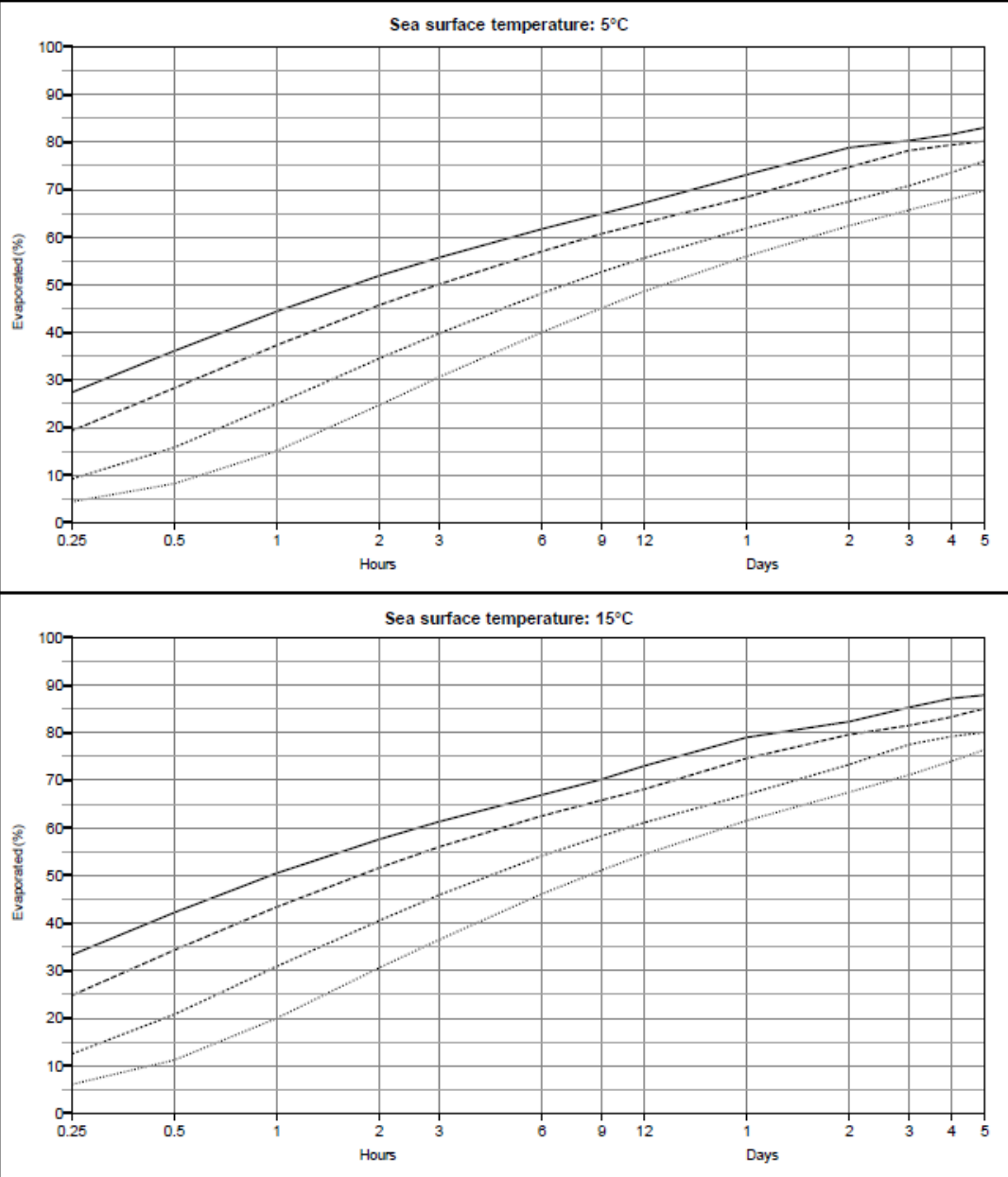


Figure 4-2 Evaporative loss of Aasta Hansteen blend predicted at sea temperatures of 5 and 15 °C

Property: VISCOSITY OF EMULSION
 Oil Type: AASTA HANSTEEN BLEND
 Description:
 Data Source: Sintef Ocean (2020), Weathering data used

OWModel© 11.0.1

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

2.0
 Pred. date: Apr. 26, 2020

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

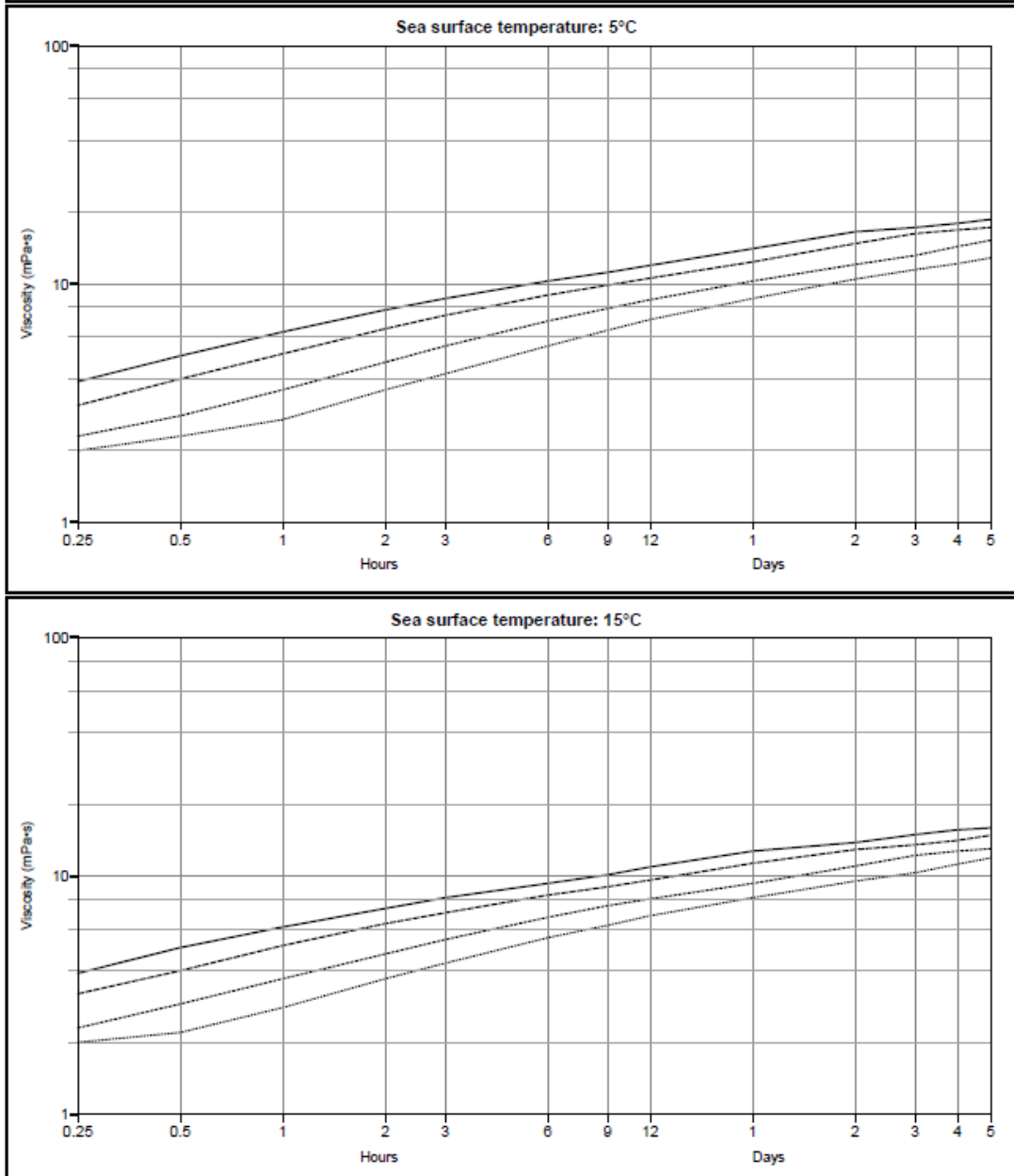


Figure 4-3 Viscosity of Aasta Hansteen blend predicted at sea temperatures of 5 and 15 °C, shear rate 10 s⁻¹

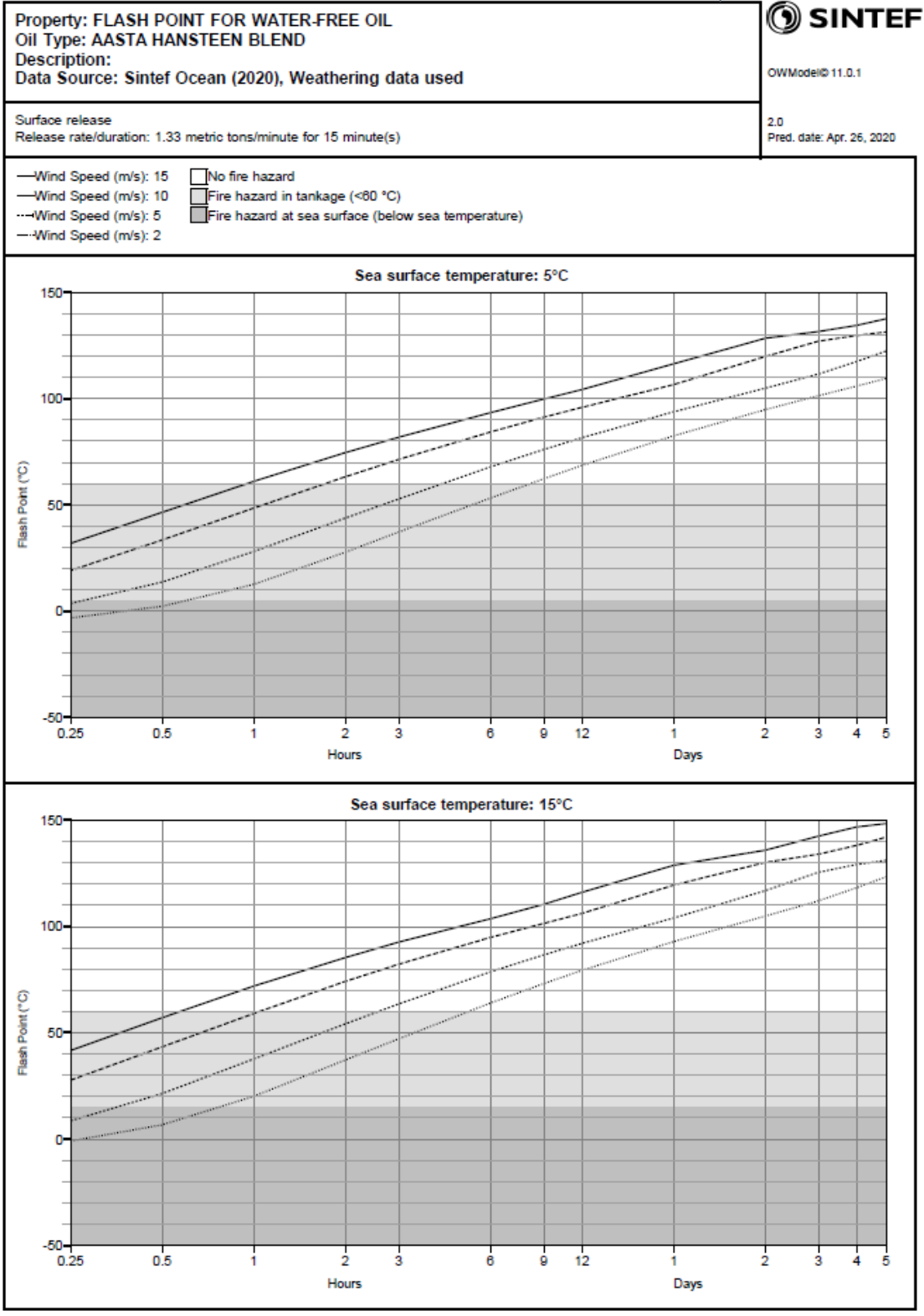


Figure 4-4 Flash point of Aasta Hansteen blend predicted at sea temperatures of 5 and 15 °C

Property: POUR POINT FOR WATER-FREE OIL
 Oil Type: AASTA HANSTEEN BLEND
 Description:
 Data Source: Sintef Ocean (2020), Weathering data used

OWModel© 11.0.1

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

2.0
 Pred. date: Apr. 26, 2020

- Wind Speed (m/s): 15 Chemically dispersible
- Wind Speed (m/s): 10 Reduced chemical dispersibility
- Wind Speed (m/s): 5 Poorly / slowly chemically dispersible
- Wind Speed (m/s): 2 Poorly / slowly chemically dispersible

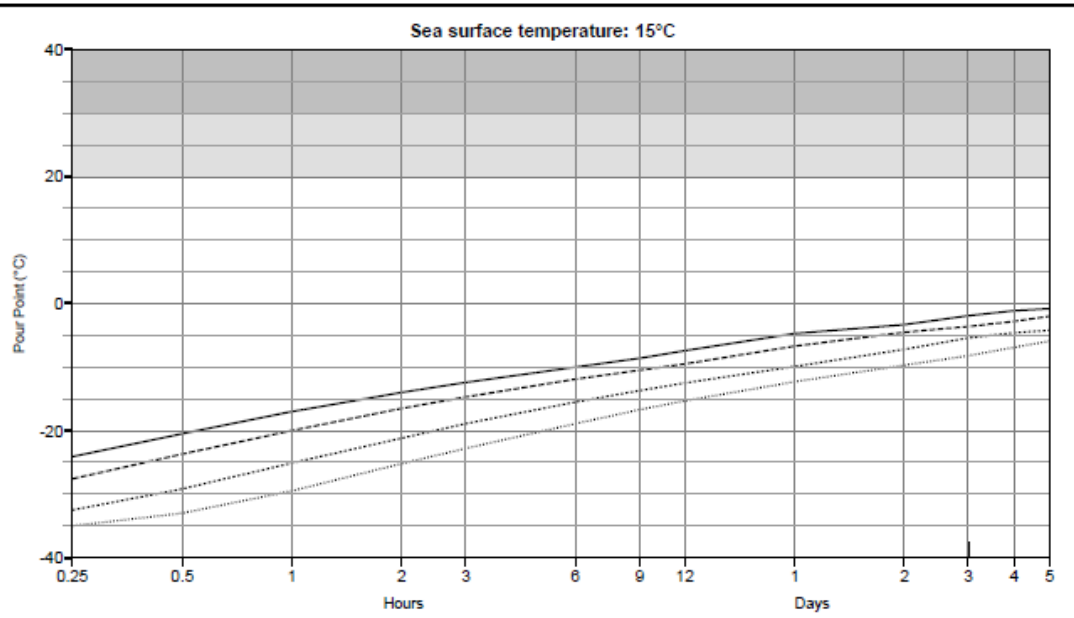
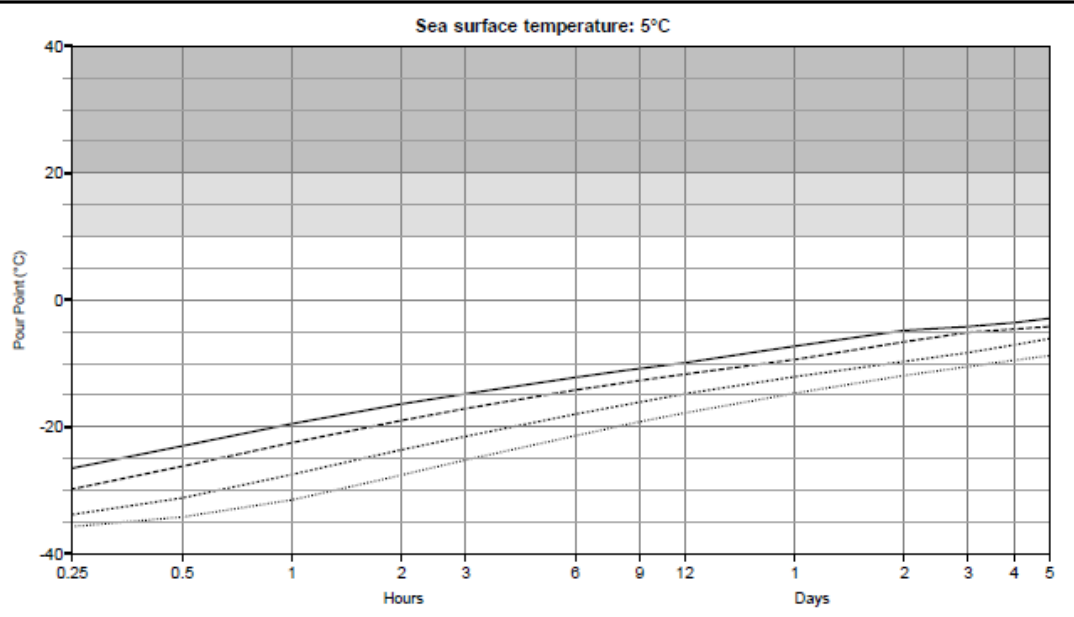


Figure 4-5 Pour point of Aasta Hansteen blend predicted at sea temperatures of 5 and 15 °C

Property: MASS BALANCE
 Oil Type: AASTA HANSTEEN BLEND
 Description:
 Data Source: Sintef Ocean (2020), Weathering data used

OWModel® 11.0.1

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

Pred. date: Apr 26, 2020

- /// Evaporated
- /// Surface
- /// Naturally dispersed

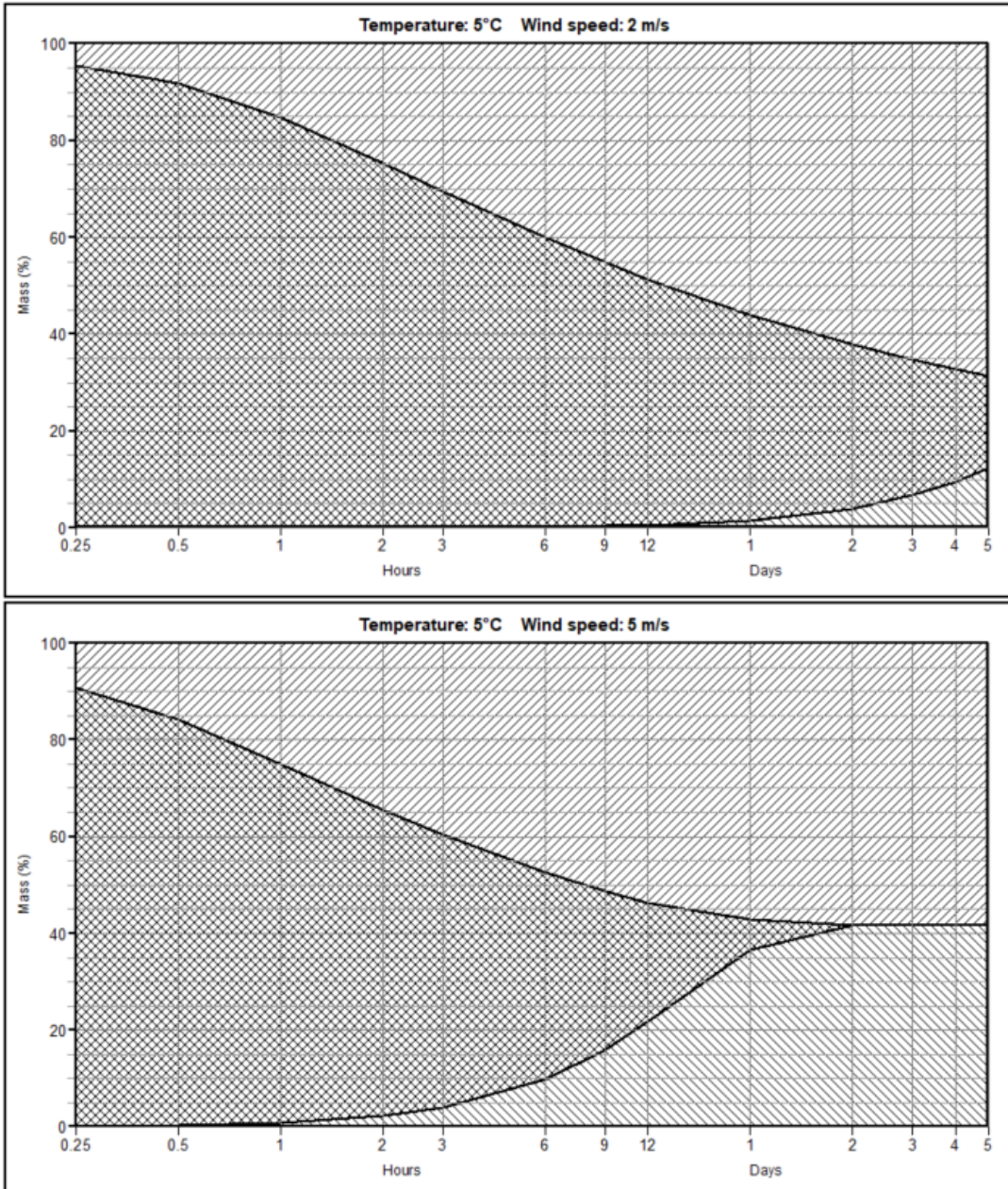


Figure 4-6 Predicted mass balance of Aasta Hansteen blend predicted 5 °C, wind speeds of 2 and 5 m/s

Property: MASS BALANCE
 Oil Type: AASTA HANSTEEN BLEND
 Description:
 Data Source: Sintef Ocean (2020), Weathering data used

OWModel® 11.0.1

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

Pred. date: Apr 26, 2020

- /// Evaporated
- /// Surface
- /// Naturally dispersed

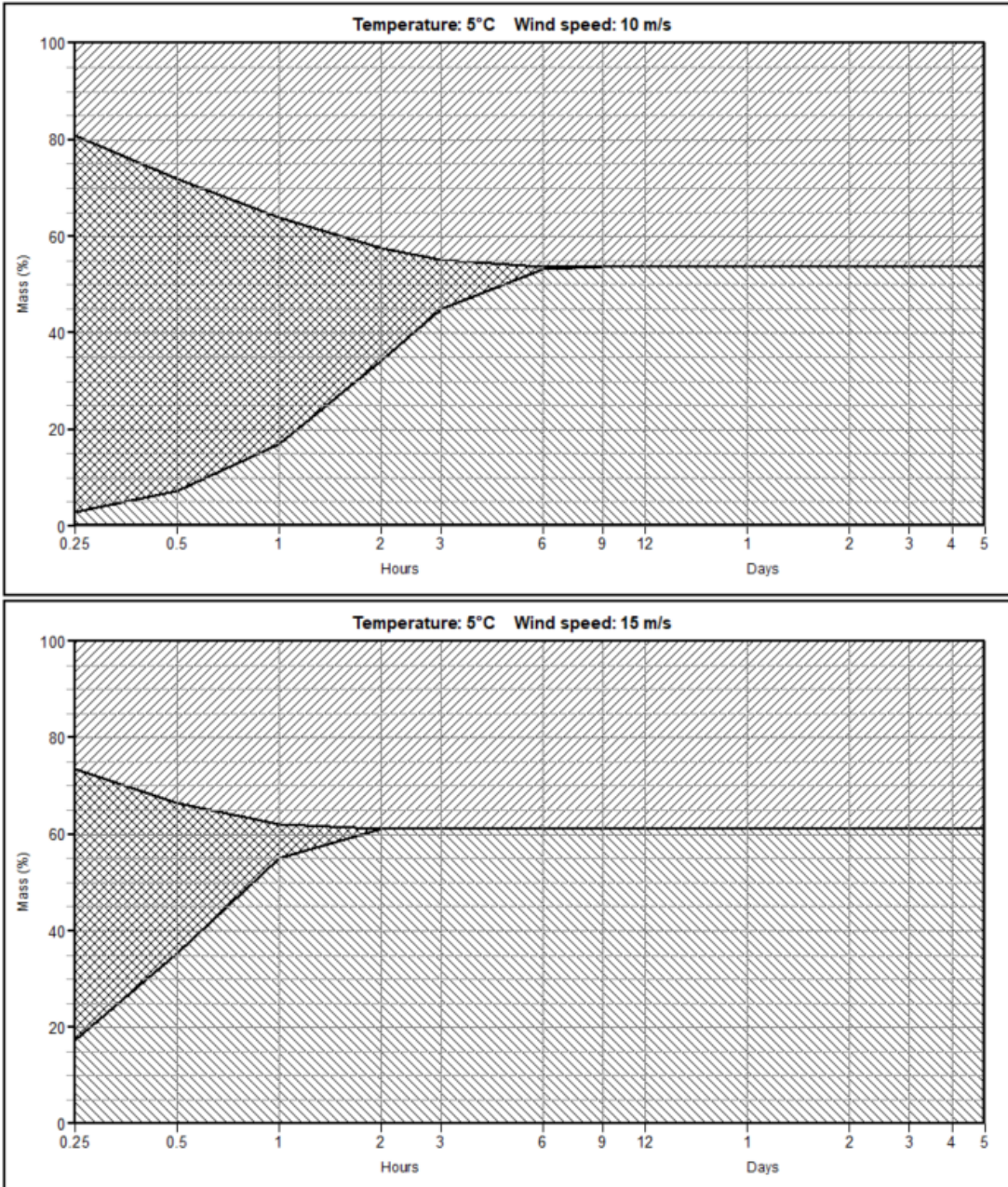


Figure 4-7 Predicted mass balance of Aasta Hansteen blend predicted 5 °C, wind speeds of 10 and 15 m/s

Property: MASS BALANCE
Oil Type: AASTA HANSTEEN BLEND
Description:
Data Source: Sintef Ocean (2020), Weathering data used

OWModel® 11.0.1

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

Pred. date: Apr 26, 2020

- /// Evaporated
- /// Surface
- /// Naturally dispersed

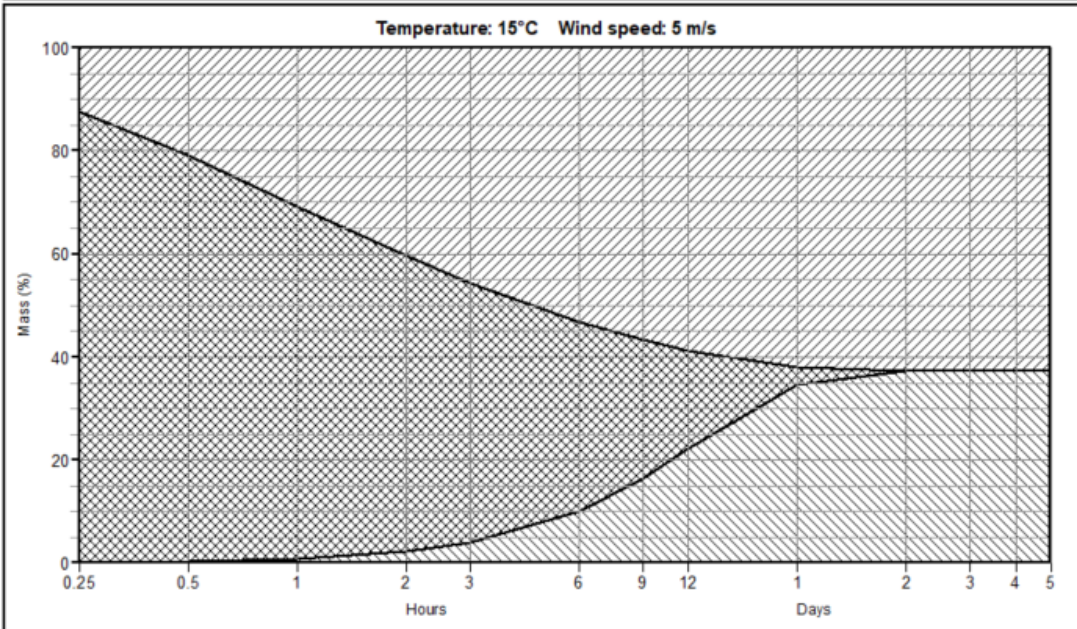
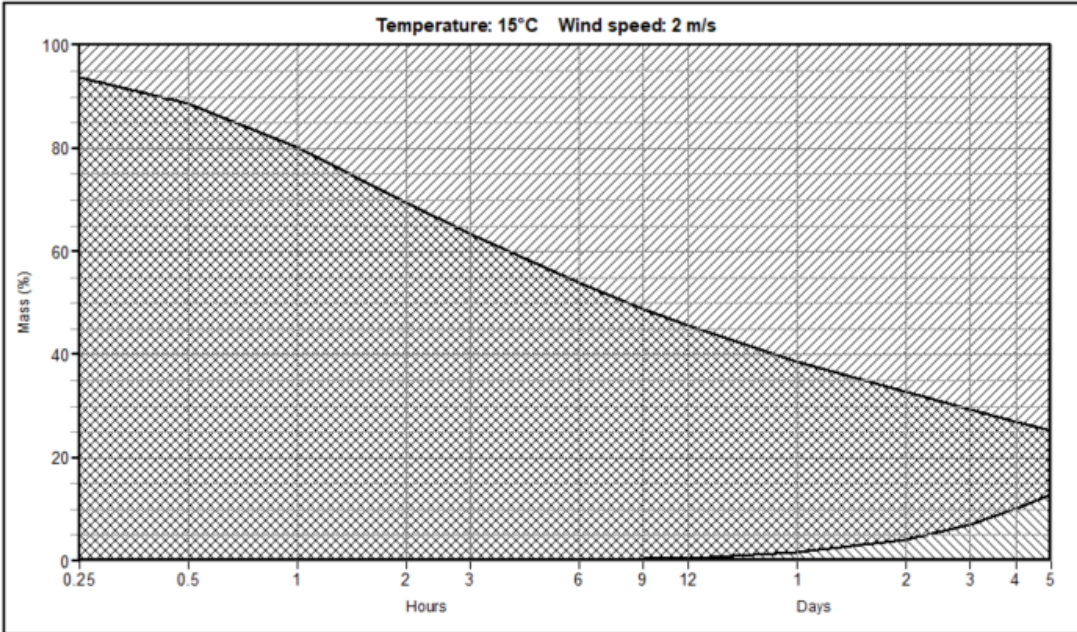


Figure 4-8 Predicted mass balance of Aasta Hansteen blend predicted 15 °C, wind speeds of 2 and 5 m/s

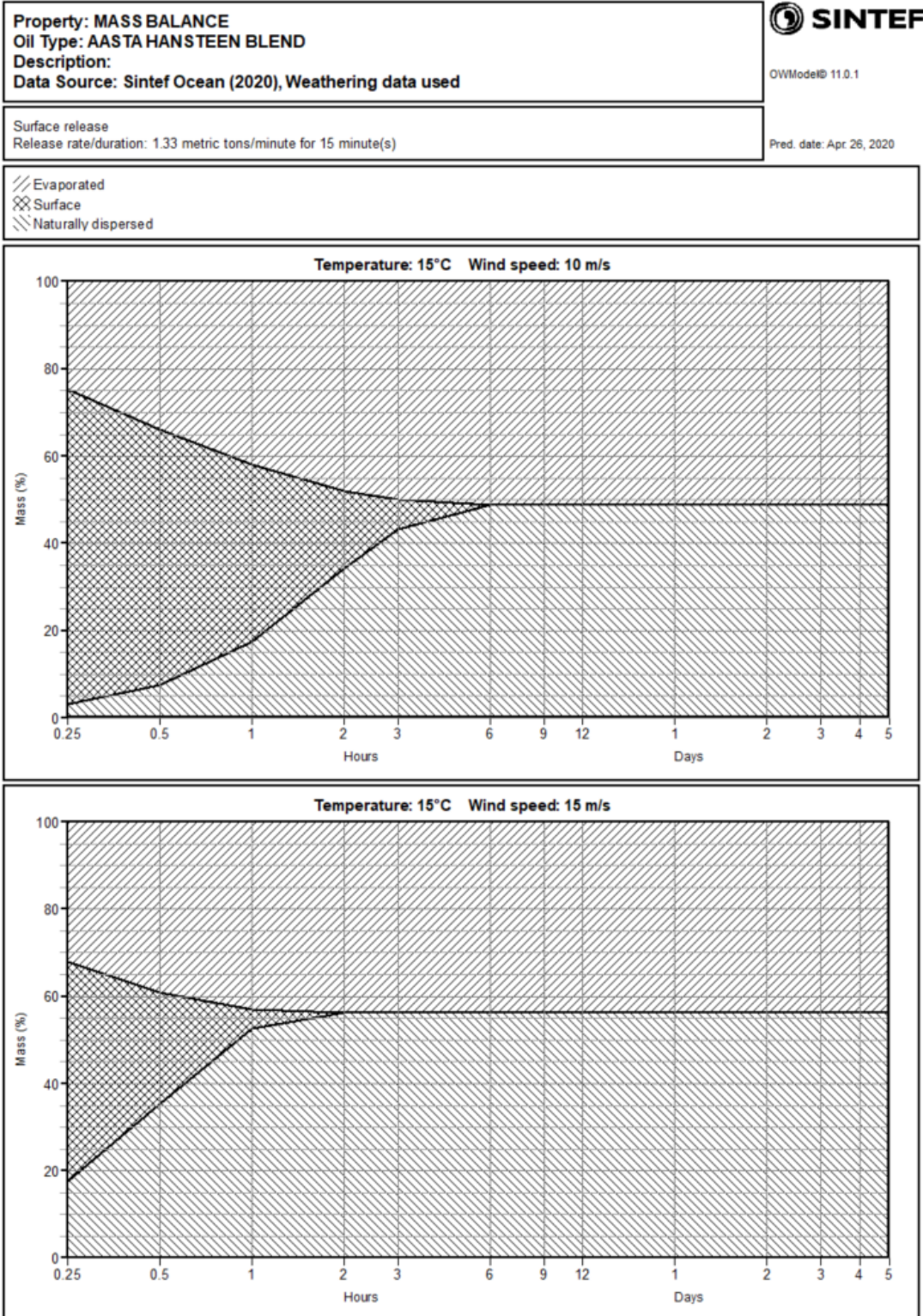


Figure 4-9 Predicted mass balance of Aasta Hansteen blend predicted 15 °C, wind speeds of 10 and 15 m/s

4.3 Find model oil

The "Find model oil" concept in SINTEF OWM correlates Crude Assay (CA) variables for the fresh oil to weathering behaviour to search for a surrogate or a model oil in the SINTEF oil database. The approach for comparing fresh oil properties identifying a model oil is based on calculating a parameter describing the *fit factor* (Table 4-3) (Brandvik et al., 2015) between the new oil and the characterised oil present in the oil database.

The concept uses the CA variables: viscosity, asphaltene and wax content, density, pour point and the evaporation slope to search in the oil the oil database to find the closest match among the oils with existing weathering data. The evaporation slope (volume% evaporated / °C) is calculated based on the true boiling point curve (TBP) close to the 50 – 250 °C range (corresponds typically up to 5 days of weathering).

Table 4-3 *Fit factors for Find model oil*

Fit factor	Description	Colour code
<0.25	Good fit	Green
0.26 -0.35	Reasonable fit	Yellow
>0.40	Unsatisfactory fit	Red

The CA variables of Aasta Hansteen blend were used as input in "Find model oil". The calculated fit to all the oils in the SINTEF database given as the 10 oils with the closest fit appears is shown in Figure 4-10. Aasta Hansteen blend showed only match with itself and no match with other oils/condensates from the latest version of the oil database.

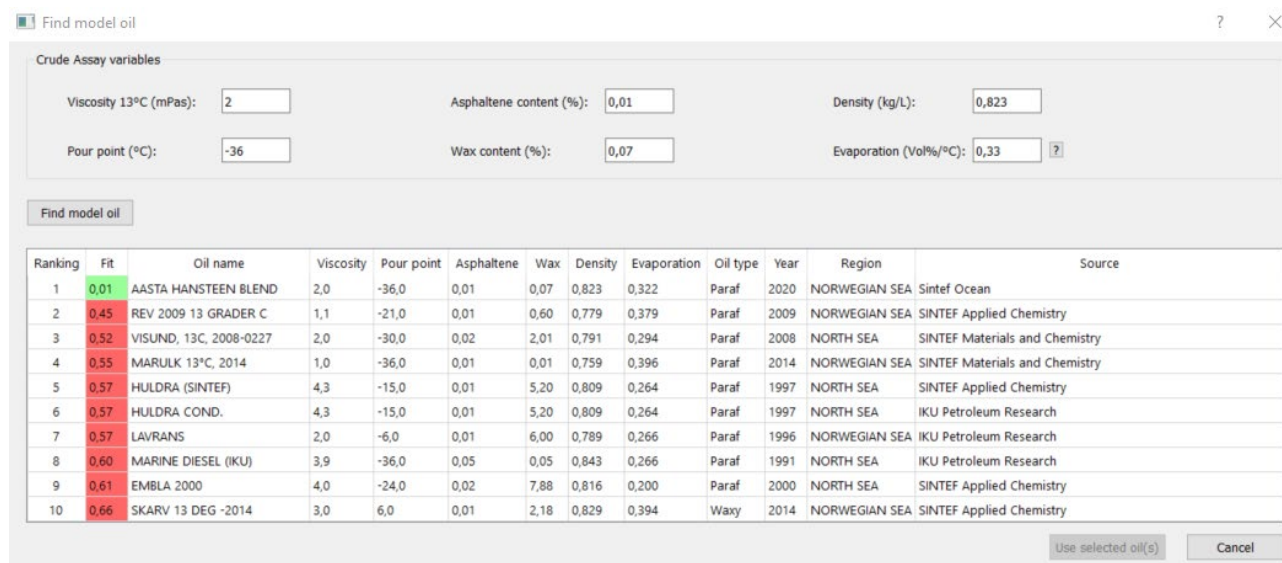


Figure 4-10 *The output crude assay data of Aasta Hansteen blend. No match (green value) with other oils/condensates from SINTEF oil database*

5 Comparison of OWM predictions

Weathering predictions of Aasta Hansteen blend were compared with predictions Kvitebjørn 2009, Kristin Skarv and Marulk. The presented comparisons given in the figures below are based on predictions at sea temperature of 15 °C and wind speed of 10 m/s.

5.1 Evaporative loss

Evaporation is one of the natural process that helps removing spilled oil from the sea surface. Aasta Hansteen blend and Skarv have similar evaporative loss as shown in Figure 5-1. Kvitebjørn 2019 has the highest evaporative loss (very light condensate) followed by Marulk. Kristin light crude oil has the lowest evaporative loss among these oils. The predictions of evaporative loss reflect the characteristics of the oils where the light condensate exhibits higher evaporative loss and have lower densities compared with light crude oils.

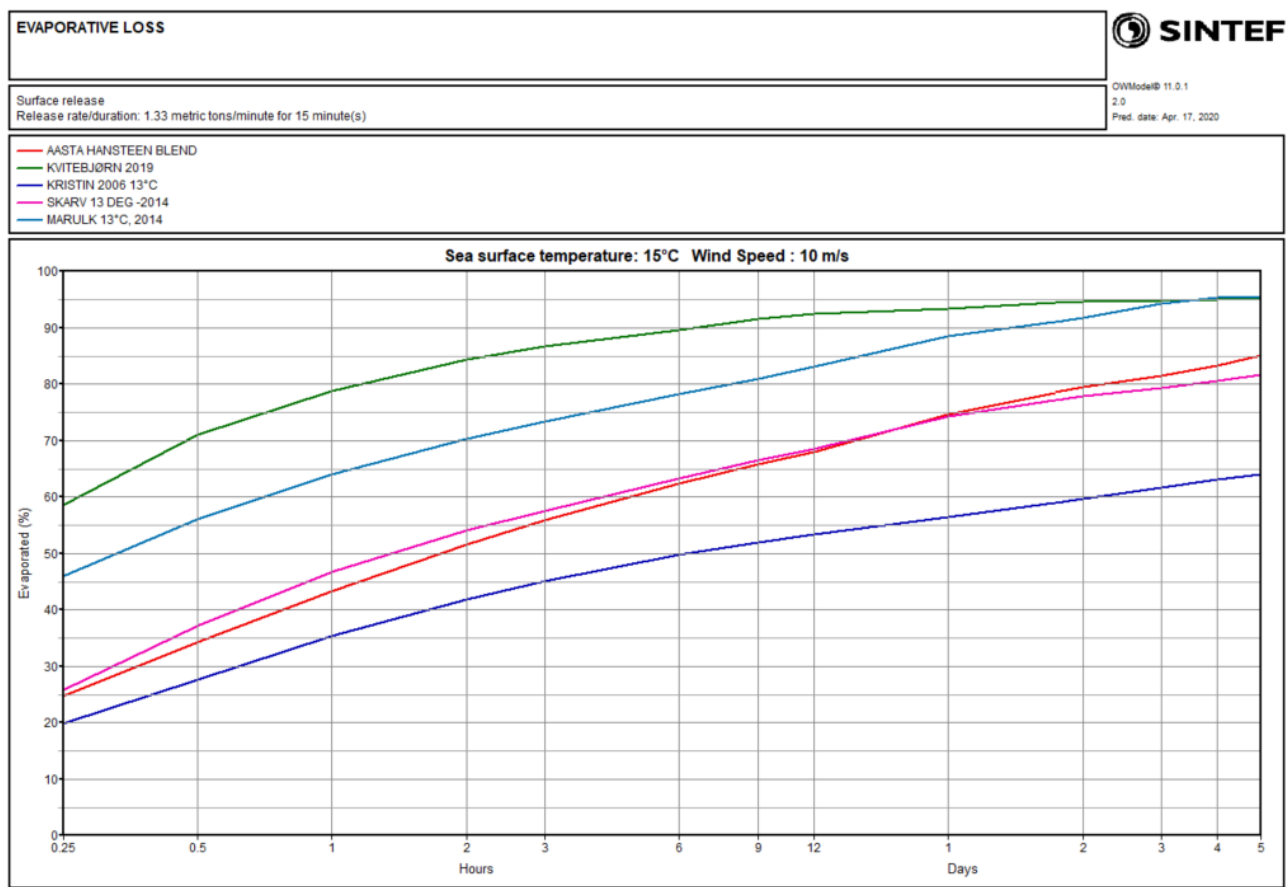


Figure 5-1 Predicted evaporative loss at 15 °C and 10 m/s for Aasta Hansteen blend compared with other oils

5.2 Flash point

When oil is spilled on the sea surface, the oil will be cooled to the ambient water temperature within a short period. The probability of fire will be high if the flash point of the oil is below the sea temperature. Fire hazard is dependent upon the amounts of volatile components in the oil and the potential for fire is usually over within the first few minutes of a spill due to the rapid evaporation of those components.

The flash points of Aasta Hansteen blend compared with the other oils are shown in Figure 5-2. The predictions show that only Kristin light crude oil is expected to pose a fire hazard 15 minutes after a spill, while the other condensates are above the set limit (15 °C) before this time point. Within 30 minutes after spill, Kristin is predicted to have a flash point above the fire hazard limit.

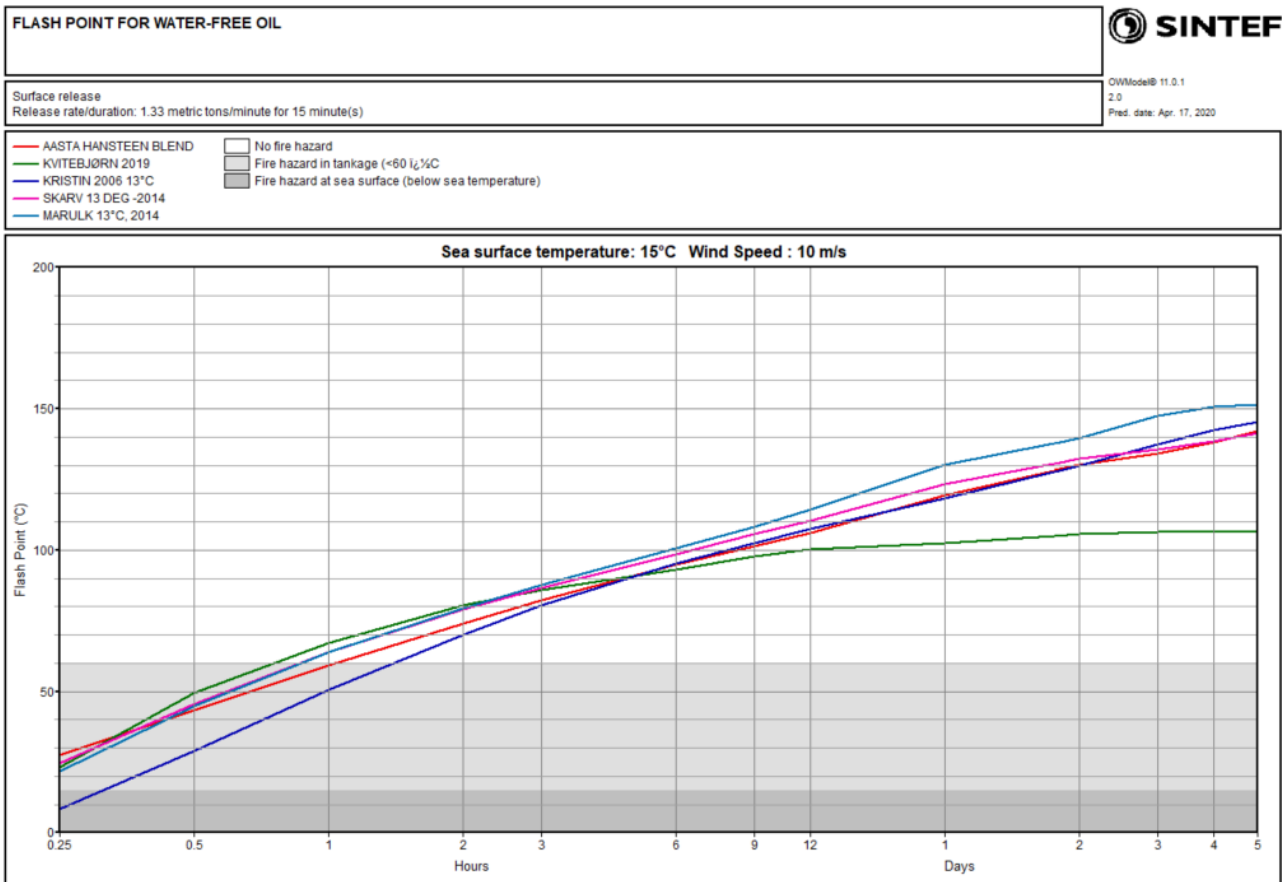


Figure 5-2 Predicted flash point at 15 °C and 10 m/s for Aasta Hansteen blend compared with other oils

5.3 Pour point

The pour point of Aasta Hansteen and the other oils for comparison are given in Figure 5-3. Aasta Hansteen blend expresses the lowest pour points followed by Kvitebjørn 2019 and Marulk. The low pour points reflect the low content of wax and will therefore not pose a challenge with solidification at sea. These condensates will also have a high degree of natural dispersion if spilled at sea. Kristin and Skarv have higher pour points development (higher wax content) with a potential to solidify if spilled at sea.

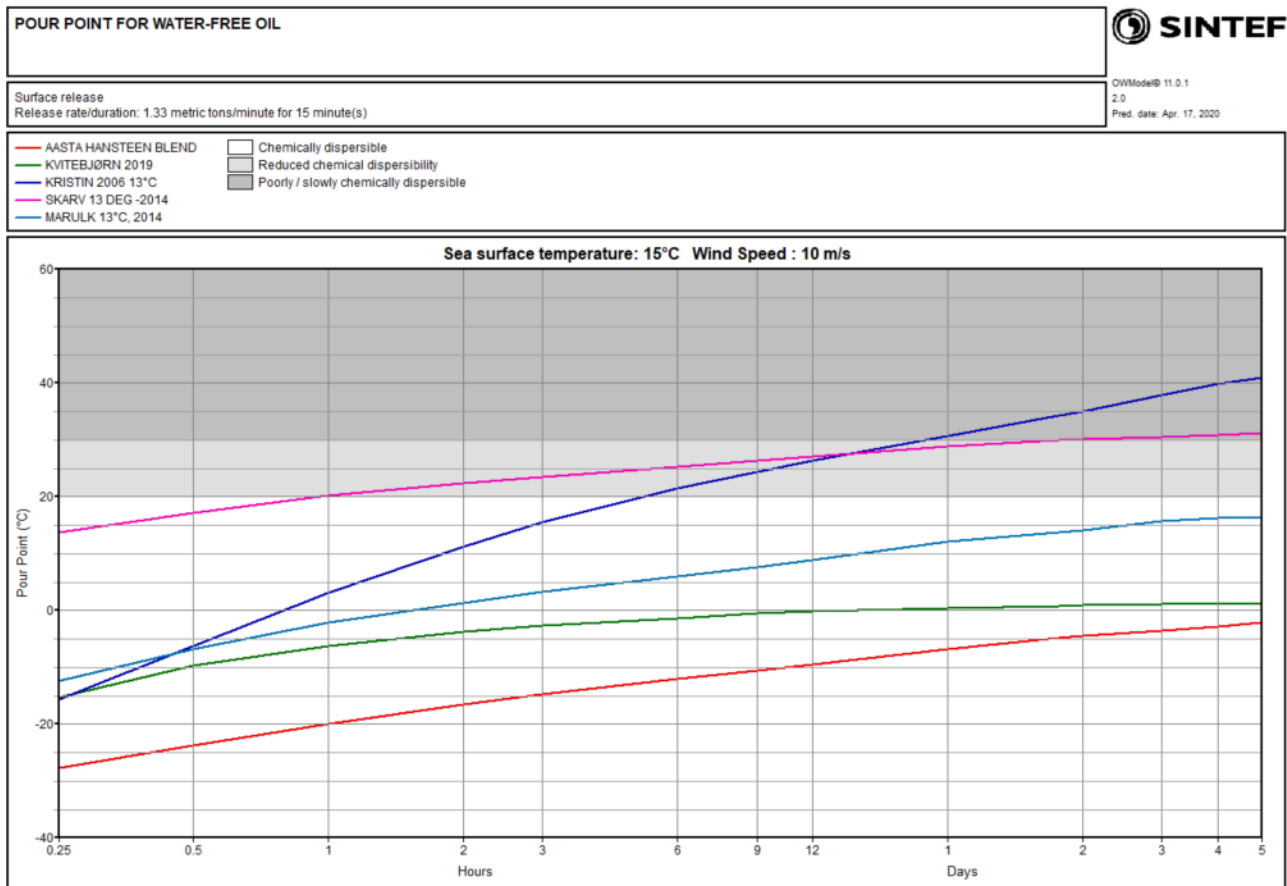


Figure 5-3 Predicted pour point at 15 °C and 10 m/s for Aasta Hansteen blend compared with other oils

5.4 Water content

The water uptake of the oils in comparison are shown in Figure 5-4. None of the condensates including Aasta Hansteen blend have emulsifying properties due to negligible water uptakes (water uptake is therefore not shown in the figure for Aasta Hansteen blend, Kvitebjørn 2019 and Marulk). Skarv produced unstable "emulsions" due to its wax content but was easily broken with applied energy from the laboratory testing. Therefore, Skarv is assumed to have very low water uptake at sea. However, Kristin light crude oil may reach a water content of 40-50 % predicted after 9 hours weathering time at sea.

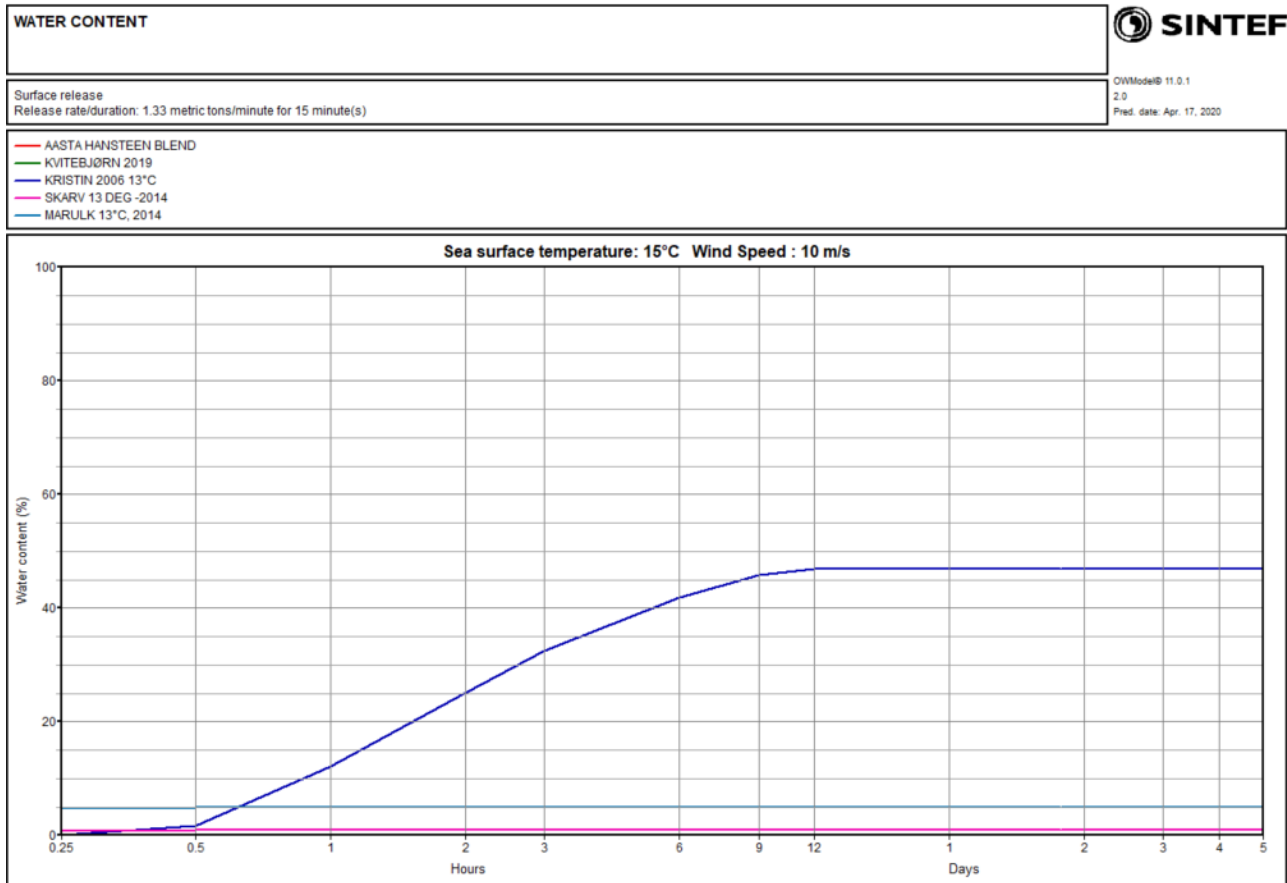


Figure 5-4 Predicted water content at 15 °C and 10 m/s for Aasta Hansteen blend compared with other oils.

5.5 Viscosity

Figure 5-5 shows the predicted (emulsion) viscosities of the oils in comparison. Aasta Hansteen blend, Kvitebjørn 2019 and Marulk have very low viscosities up to approx. 10 mPa.s. Kristin and Skarv exhibits higher viscosities, where the viscosities are predicted to increase gradually throughout 5 days of weathering. For mechanical recovery, low viscosities pose a risk for boom leakage (< 1000 mPa.s), and will influence on efficient confinement in a booming operation, see also section 6.

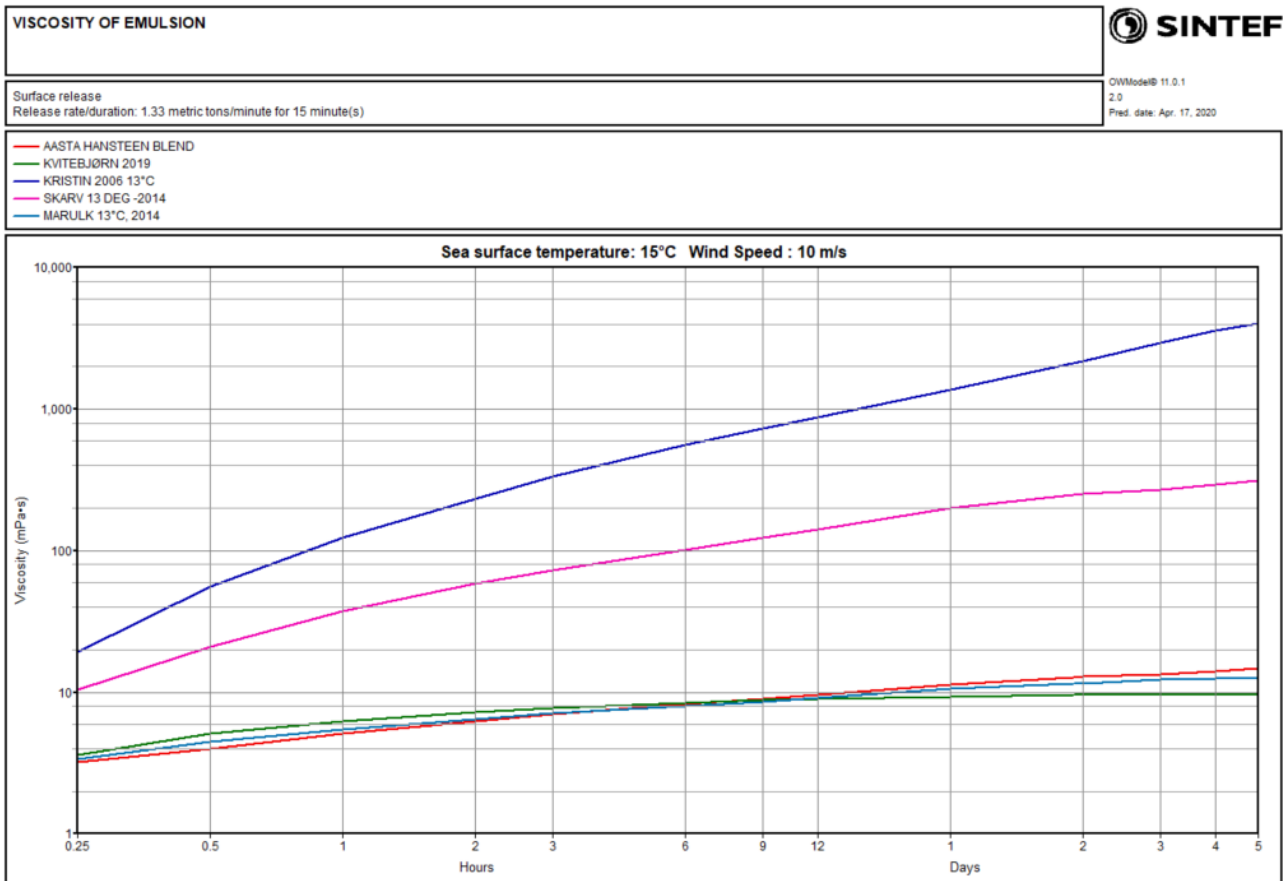


Figure 5-5 Predicted (emulsion) viscosity at 15 °C and 10 m/s for Aasta Hansteen blend compared with other oils

5.6 Surface oil

Due to evaporative loss and natural dispersion/entrainment, the amount oil (assumed no emulsification) on the sea surface will gradually be reduced. Figure 5-6 shows the predicted mass balance of remaining surface oil as a function of weathering. The light condensates Kvitebjørn 2019 and Marulk are predicted to be rapidly removed from the sea surface due to evaporation and natural dispersion within 2-3 hours, whilst Aasta Hansteen blend and Skarv have predicted lifetime of 6-9 hours. The emulsifying Kristin light crude oil is predicted to have a much longer lifetime on the sea surface being removed within 2 days.

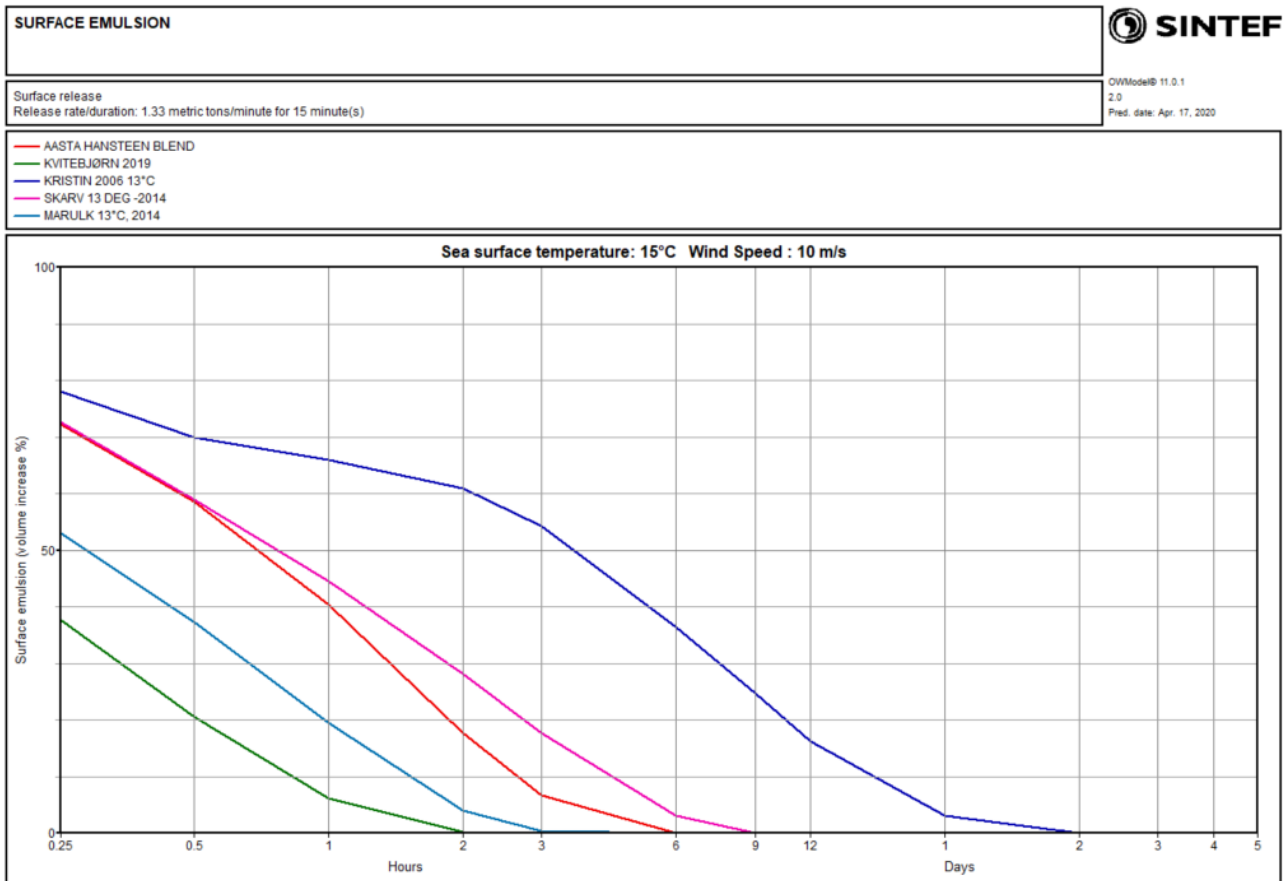


Figure 5-6 Predicted remaining surface oil at 15 °C and 10 m/s for Aasta Hansteen blend compared with other oils

6 Weathering properties of Aasta Hansteen blend when spilled at sea

The relative content of heavy oil components within a spilled oil increases due to weathering, and the physical and chemical properties of the oil will change over time. Knowledge about how the oil's properties change during weathering is therefore important in the management of oil spill response. Currently, mechanical recovery and the use of oil spill dispersants are the main oil spill response options at sea in the Norwegian sector, today. The potential of using water-flushing to disperse the oil is briefly discussed in this report.

6.1 Oil properties

Aasta Hansteen blend is a partly biodegraded condensate with a density of 0.823 g/mL, with very low contents of wax (0.07 wt. %) and asphaltenes (0.01 wt. %). The condensate has a relatively high evaporative loss and the weathering properties indicate that such oil will rapidly be spread on the sea surface to thin oil films (50 µm) and exhibits a low/negligible water uptake. Aasta Hansteen blend showed no emulsifying properties, and the physico-chemical properties are very similar to other non-emulsifying condensates such as e.g. Kvitebjørn 2019 and Marulk. The fresh oil and its 150, 200 and 250°C+ residues also exhibit very low viscosities ranging from 2-13 mPa.s at shear rate 10s⁻¹ (13 °C). The chromatographic characterization shows that Aasta Hansteen blend is a partly biodegraded oil but has also a high degree of light compounds as systematic peaks (*n*-alkanes; paraffins). In addition, the fresh condensate and residues have a low pour point of -36 °C (fresh oil) to -6 °C (250°C+ residue) with evaporation of the lightest compounds.

6.2 Flash point – Fire/explosion hazard

Flash point refers to the lowest temperature at which a fuel or oil can vaporize to form an ignitable mixture in the air. In case of an oil spill on the sea surface, the (heated) oil rapidly will be cooled to the ambient seawater temperature within a short period of time. The fire/explosion hazard will be at its greatest if the flash point of the spilled oil is below the seawater temperature

The flash points for Aasta Hansteen blend is expected to surpass the sea temperature within a few minutes at 5 and 15 °C, at wind speeds of 10 and 15 m/s predicted with the standardized surface release as shown in Figure 4-4. At calmer weather conditions (2 and 5 m/s) care should be taken during the first 0.5-1 hour. Moreover, the release rate may influence on the rate of evaporation, and for considerably larger (batch) release rates e.g. 100 times higher (8000 m³/h), the rate of evaporative loss is reduced as shown in Figure 6-1B. The time when the flash point has surpassed the sea temperature has now increased from 1 to 2.5 hours at 2 and 5 m/wind speeds.

Moreover, some vessels/storage tanks engaged in oil recovery operations may not be classified to carry liquids with flash points lower than 60 °C, e.g. towing vessels, smaller cargo or other vessels available in the emergency. This means that fuels or oils with the flash point less than 60 °C, are for those type of vessels not permitted as cargo. However, this limit is not considered as relevant for oil recovery vessels with A-class certification for transport of liquids (Class I/II, flashpoints < 60 °C), according to NFPA classification of Flammable and Combustible Liquids (<http://www.thetankshop.ca>). At low wind speed (2 m/s) this limit is reached within 4-5 hours (80 m³/h), shorter time for the higher wind speeds as shown in Figure 6-1 A. For a larger batch release rate (8000 m³/h) the flash point limit of 60 °C is stretched to >12 hours at 2 m/s wind speed (Figure 6-1 B).

As a general recommendation after an acute oil spill involving free gas (e.g. from a subsea release), a "safety" zone should be established early on and downwind from the spill site before response actions are initiated. 1-hour drifting time of slick (from the source) has e.g. been suggested in Norway before oil spill response

operations are initiated in open sea waters. Shorter waiting times have been predicted related to fire/explosion hazard related to the flash point. The following precautions should be taken:

- Prior to the initiation of spill response operations, an evaluation of fire/explosion hazard must always be conducted at the site
- Explosimeters should be utilized continuously and one should be aware of the possibility for varying release rates if "free" gas is involved

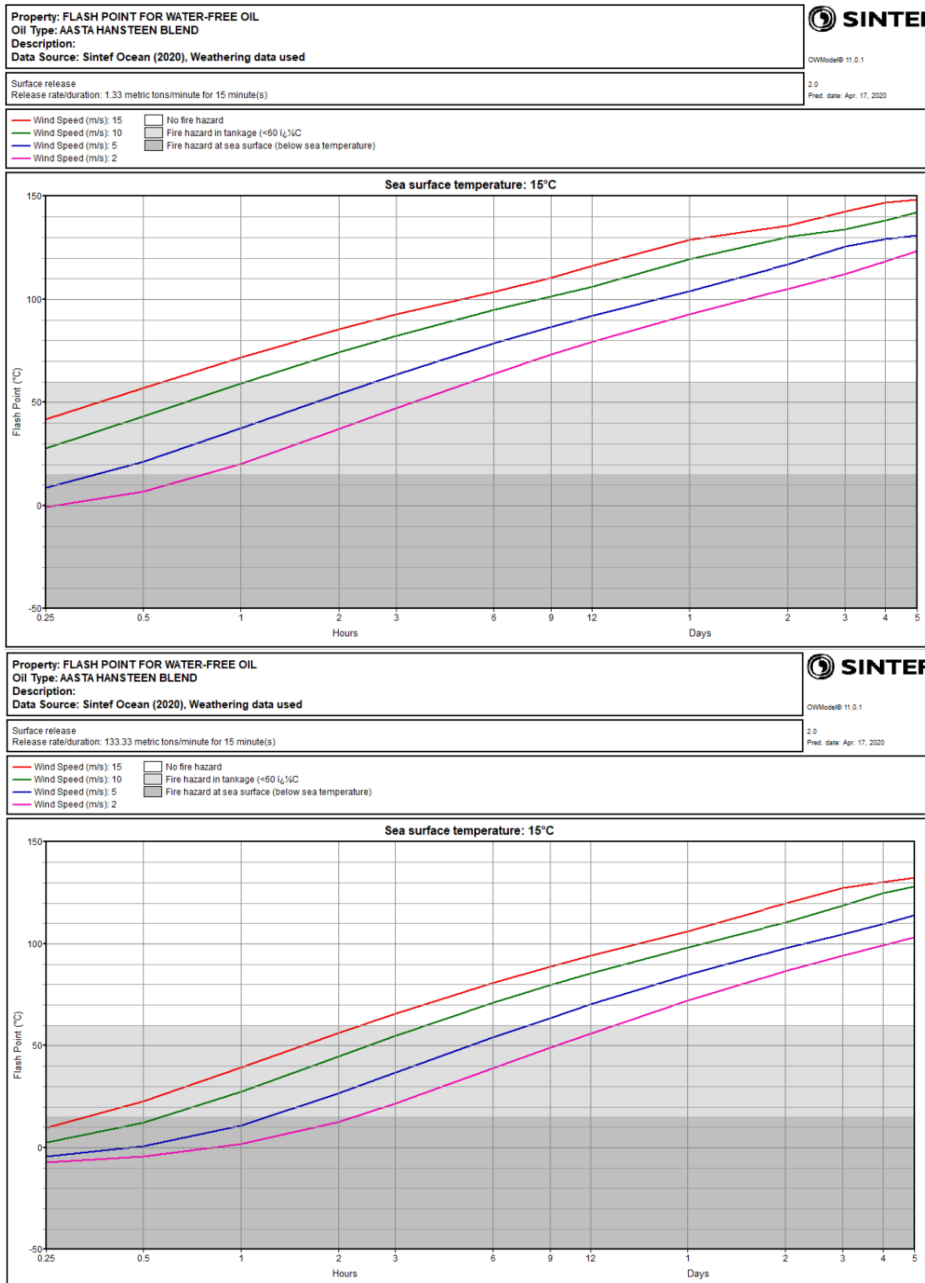


Figure 6-1 A (Above): Predicted flash points at different wind speeds for Aasta Hansteen blend at 15 °C (80 m³/h). B (Below): Predicted flash points at different wind speeds for Aasta Hansteen blend at 15 °C (8000 m³/h)

6.3 Solidification

Pour point depends on the oil’s wax content and the amounts of light components that can keep the wax components dissolved in the oil phase. In addition, high asphaltene content prevents precipitation and lattice formation and hence lowers the pour point. High pour points may prevent the dispersant to soak into the oil slick and influence the dispersant effectiveness and may reduce the potential for flowability towards weir skimmers. In cases when high viscosity of the oil/emulsion is not a limiting factor, high pour point may cause solidification (elastic properties) when oil is spilled on the sea surface. High pour point may therefore imply solidification on the sea surface immediately after the release, and this is pronounced when the pour point is typically 5-15 °C above sea temperature.

Aasta Hansteen blend exhibits low pour points and is not expected to pose any solidification (elastic properties) when weathered at sea at 5 and 15 °C within 5 days after a spill, see also the predictions in Figure 4-5.

6.4 Natural dispersion and evaporation

The lifetime of an oil spill at sea depends on the oil’s composition, the release conditions (e.g. on the surface, underwater) and environmental conditions (temperature, wind, waves). Natural dispersion and evaporation are the main weathering processes that remove an oil spill from the surface. Figure 6-2 shows the remaining surface oil over time for different wind speeds and temperatures for Aasta Hansteen blend. There is minor difference in lifetime between 5 and 15 °C for this condensate.

At high wind speed of 15 m/s, no oil remains on the sea surface after 2-hours weathering, but at calmer weather conditions 2-5 m/s wind speeds (no-breaking waves), the remaining surface oil is 15-20 %. The variation of remaining surface oil after a release is strongly dependent on the wind speeds and typically oils are more persistent on the sea surface with lower wind.

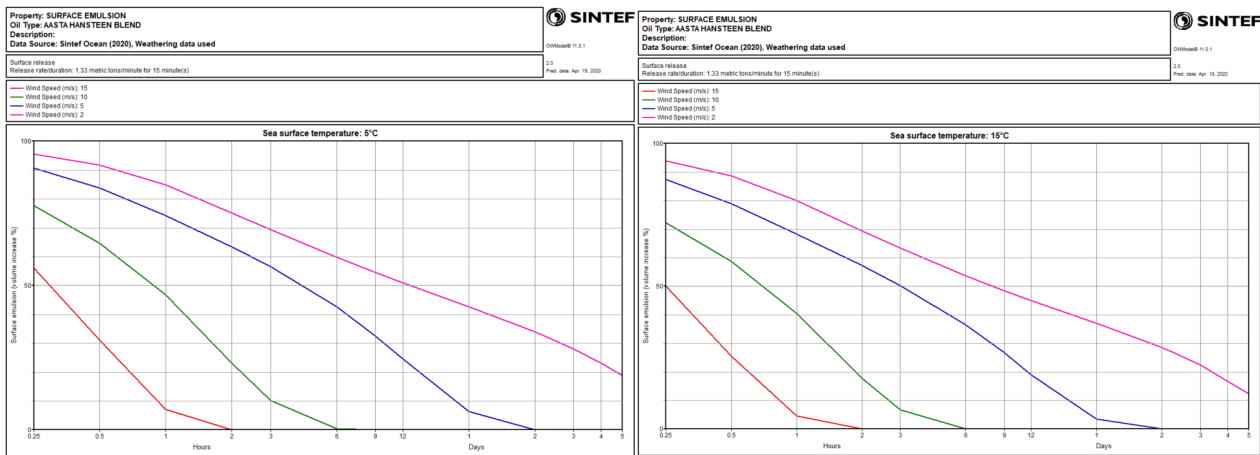


Figure 6-2 Remaining surface oil for Aasta Hansteen blend at 5 and 15 °C

6.5 Film thickness from surface release

Mechanical recovery requires normal minimum film thicknesses > 0.1-0.2 mm. Film thicknesses > 0.05-0.1 mm are considered for application of oil spill dispersants, as lower film thicknesses are likely to disperse naturally. However, other factors than film thickness should be considered when evaluate response options, as described in the next chapters. Figure 6-3 shows the predicted film thicknesses at different wind speeds.

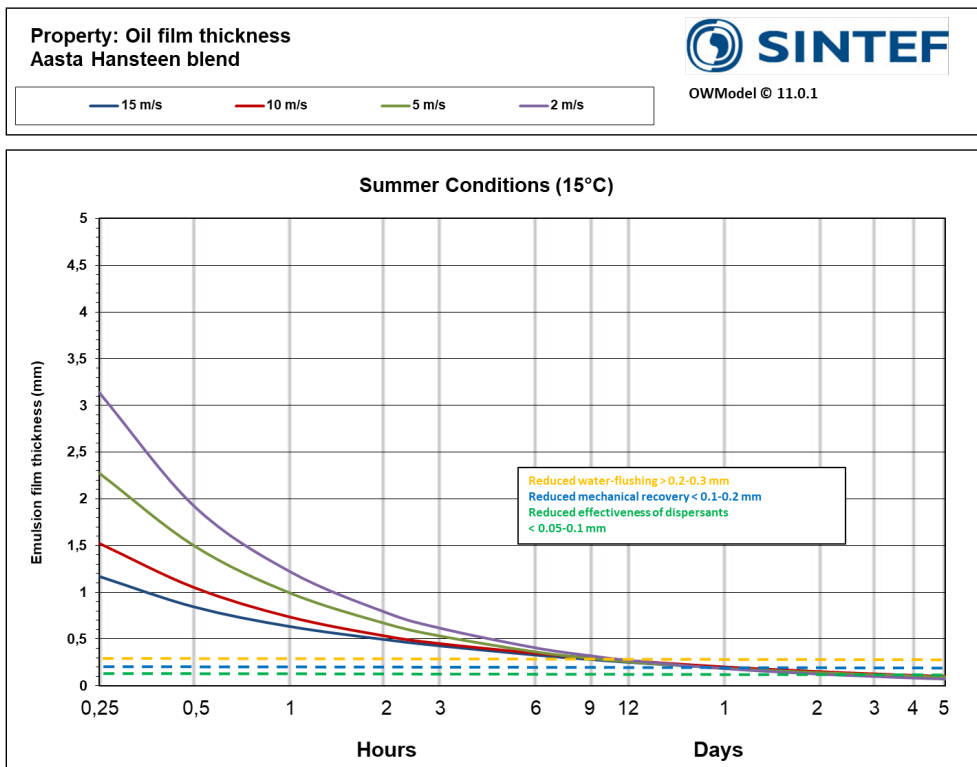


Figure 6-3 Predicted film thickness of Aasta Hansteen blend after 5 days of weathering (surface release)

6.6 Mechanical recovery by boom and skimmer

Experiences from Norwegian field trials with booms have demonstrated that the effectiveness of various mechanical clean-up operations may be reduced due to the high degree of leakage of the confined oil or emulsion from the oil spill boom.

The predicted mass balance indicates that Aasta Hansteen blend has short lifetime at sea particularly in high wind speeds, with a high degree of natural dispersion and high evaporative loss. In calm weather conditions mechanical recovery may have a potential close to release assuming film thicknesses > 0.1-0.2 mm. However, the remaining oil/residue on the sea surface has low viscosities around 10 mPa.s (no emulsification) and low pour point (no solidification). Aasta Hansteen blend is therefore assumed to have limited efficiency and low efficacy for containment for mechanical recovery due to considerable boom leakage with a limit of 1000 mPa.s (Norvik et al., 1992).

In addition, previous studies at SINTEF have shown that weir skimmers may reduce recovery rates (m^3/h) when skimming oils with viscosities in the range 15-20 000 mPa.s (Leirvik et al., 2001). Aasta Hansteen blend has viscosities far less than this limit and reduced skimmer efficiency would in any case not be an issue for this oil, see Figure 4-3.

6.7 Chemical dispersion

Dispersibility testing on Aasta Hansteen blend adding dispersants to the oil was not conducted in agreement with Equinor. High degree of natural dispersion and evaporative loss indicate that the lifetime at sea is short for Aasta Hansteen blend, particularly in high wind speeds (breaking waves > 5 m/s). Use of dispersants could reduce the lifetime at sea in non-breaking waves conditions (< 5 m/s). During a spill operation (batch release) use of dispersants may have a potential assuming that the thickness is higher than 0.1 mm to enhance the natural dispersion. It is expected low efficiency potential for low film thicknesses, as the dispersant droplets may fall through the oil phase into the sea water. In addition, applying dispersants assuming a very thin oil film < 0.05 -0.1 mm is not normally recommended due to high degree of herding.

6.8 Mechanical dispersion by high-capacity water flushing

Mechanical dispersion by high-capacity water flushing could have a potential for oil spill with thin (initial) film thickness up to 0.2 - 0.3 mm and viscosities < 150 - 300 mPa.s. In such cases, water flushing from high-capacity water flush boom and/or firefighting (Fi-Fi) systems could possibly break up the oil/residue into smaller droplets and enhance the dispersion into the water column. Water flushing could also be used in combination with application of dispersant in calm weather condition to enhance dispersant efficiency with use of artificial energy. This technology was tested in a full-scale trial (NOFO Oil-on-Water trial) in 2016 and described by Daling et al., 2017 and Sørheim et al., 2017 but is not implemented as a part of the oil spill response in Norway, today.

For Aasta Hansteen blend, water flushing could be an option after some hours from a batch release when the oil has been spread on the surface and produce thin films < 0.2 - 0.3 mm (see Figure 6-3).

6.9 Summary recommendation of response options

Aasta Hansteen blend condensate is not expected to form water-in-oil (w/o) emulsions if spilled at sea. The condensate will have a high degree of spreading on the sea surface that has a potential to reach thin film thicknesses (50 μm). In high wind speeds (breaking waves, 10-15 m/s) the condensate will also naturally be dispersed into the water column within few hours. In low wind speeds (non-breaking waves, 2-5 m/s) natural dispersion will be slower. However, the viscosity will be low for any remaining oil/residue on the sea surface, and the low pour points will not cause the oil/residue to solidify.

- Mechanical recovery:
 - The viscosity is low even at some days on the sea surface, and it is considered as too low for efficient confinement in a booming operation and pose a risk for boom leakage
 - Mechanical recovery may have a potential close to release assuming film thickness > 0.1 -0.2 mm in calm weather conditions
- Use of chemical dispersant:
 - Film thicknesses < 0.1 mm is too low for effective dispersant treatment
 - For a surface release dispersant may be possible in an early phase in calm weather conditions, if the thickness > 0.1 mm

- High-capacity water flushing (mechanical dispersion):
 - The predicted viscosity is well below 150-300 mPa.s which is the estimated upper limit for treatment of water flushing
 - The predicted film thickness is below 0.2-0.3 mm after some hours which is the upper limit for effective use of water flushing
 - Water flushing is therefore a possible option to be considered for the remaining oil/residue after some hours in calm weather conditions
 - Combination of water flushing and dispersant application in cases of film thicknesses > 0.3 mm
- Monitoring and remote sensing:
 - Short lifetime at sea is expected in increasing wind speeds (> 5 m/s) and monitoring and remote sensing can be evaluated as a satisfactory practical "response" option

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A The behaviour of oil on the sea surface

A.1 The chemical composition of crude oils and condensates

Crude oil is a complex mixture of thousands of chemical components. The relative compositions vary, giving rise to crude oils with different chemical and physical properties. The components found in crude oil are classified into two main chemical groups: hydrocarbons and non-hydrocarbons see Figure A-1.

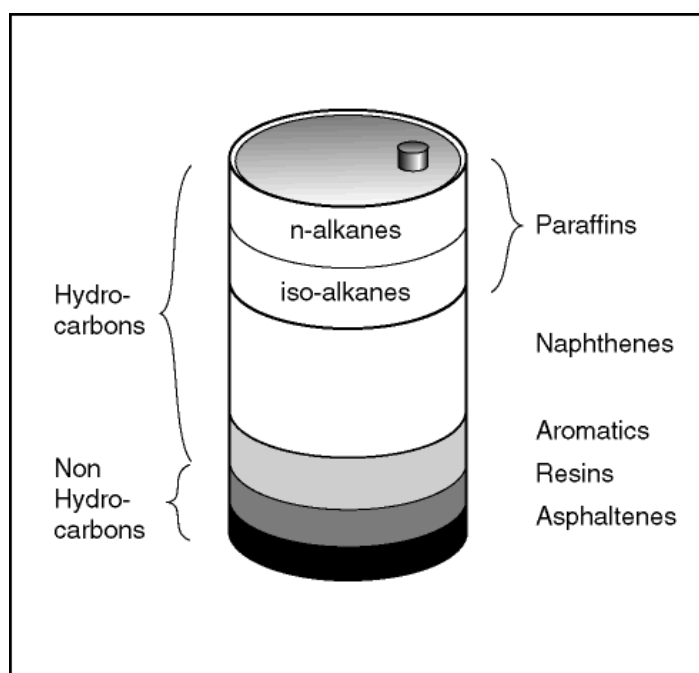


Figure A-1 The chemical composition of crude oils

A.1.1 Hydrocarbons

Most compounds in crude oils are hydrocarbons, which are composed of hydrogen (10-15 wt. %) and carbon (85-90 wt. %). These range from simple, volatile gases, such as methane with only one carbon atom to large, complex molecules with more than 100 carbon atoms. The hydrocarbons in crude oils include saturated and unsaturated molecules in linear, branched and cyclic configurations. Hydrocarbons are further classified into aliphatic and aromatic compounds. The two main groups of aliphatic compounds are paraffins and naphthenes.

Paraffins

Paraffins include *n*-alkane and *iso*-alkane aliphatic compounds. Waxes are an important subgroup of paraffins, containing more than 20 carbon atoms. The wax components of a crude oil will be present in a solution at elevated temperatures. At low temperatures, they may precipitate from the solution. These are principally *n*-alkanes. The wax content of crude oils can vary from 0.5 wt.% up to 40 or 50 wt.% in extreme cases, although the majority of the world's crude oils have a wax content of 2-15 wt.%.

Naphthenes

This group includes cycloalkanes containing one or more saturated rings. Each ring may have one or more paraffinic side chains, which are chiefly five- and six-membered rings.

Aromatics

Aromatics are a specific type of unsaturated cyclic hydrocarbons. Benzene, toluene and xylenes are examples of mono-ring aromatics, naphthalenes are di-ring aromatics and polycyclic aromatic hydrocarbons (PAH) contain three or more aromatic rings.

A.1.2 Non-hydrocarbons

In addition, hydrogen and carbon, some organic compounds in crude oils also contain small amounts of oxygen, nitrogen or sulphur, as well as some trace metals such as vanadium and nickel. These compounds are referred to as heteroatom organic compounds because they contain a heteroatom, which is any atom that is not carbon or hydrogen. The two most important groups of heteroatom organic compounds are resins and asphaltenes.

Resins

Compared to the hydrocarbons, resins are relatively polar and often have surface-active properties. Resins have molecular weights ranging from 700-1000. Carboxylic acids (naphthenic acids), sulphoxides and phenol-like compounds can be found in this group as well.

Asphaltenes

Asphaltenes are a complex group of poorly characterized chemical compounds that consist of condensed polycyclic aromatic compounds. They are large molecules with 6-20 aromatic rings and side chains (molecular weight 1,000-10,000). Asphaltenes may be classified as "hard" or "soft" based on the method of determination. Crude oils may contain up to 6 wt. % "hard" and 10 wt. % "soft" asphaltenes (Peregrino:13.4 wt.%)

A.2 Main oil categories – Related to weathering

Different oil types can have extremely different compositions, which impact their physical properties and effect their behaviour after a spill at sea.

Oils that are subject to weathering can roughly be divided into 3 main categories:

- Crude oils
- Light oils
- Condensates

Crude oils contain relatively more of the heavier components than light oils or condensates. Crude oils can be weathered in the laboratory to mimic natural weathering that occurs on the sea surface. The laboratory weathered crude oil identified as 250°C+ residue, corresponds to 0.5 to 1 week after a spill at sea, and contains less than 50% of its original volume due to evaporation. The heavier components allow the formation of stable water-in-oil (w/o) emulsions, which reduces oil spreading at the sea surface. The final (terminal) film thickness of a crude oil depends on the emulsion's physical properties, and will be in the order of 1 mm.

Light oils and crude oils are not specifically differentiated in reservoir terminology. However, it is suitable to deal with the light oils as a separate category when referencing weathering properties. Light oils have a high content of low molecular weight hydrocarbons. When subjected to laboratory weathering, the 250°C+ residue of light oils may lose 50-70% of their total volume due to evaporation. In contrast to condensates, which only contain light components, light oils contain a mixture of light and heavy components. These heavy components

may cause light crudes to emulsify in water, but these w/o emulsions are, however, very unstable. A light oil will spread less than a condensate, with a final film thickness of approximately 0.5 mm.

Condensates only contain low molecular weight hydrocarbons and are considered extremely volatile. Laboratory weathered condensates, such as the 250°C+ residue, typically lose more than 70% of their initial volume. Condensates do not contain components such as asphaltenes or heavier waxes and will not emulsify significant amounts of water. The spreading of condensates is relatively fast, and can result in a final film thickness of approximately 0.05 mm.

A.3 Physical properties of crude oils

The physical properties of specific oils are a result of their chemical composition. The most important physical properties in oil spill scenarios are discussed below.

Density

The density of a crude oil is dependent on the density of all of its components. The density of hydrocarbons increases with increasing molecular weight. Furthermore, paraffinic oils have lower density than those containing larger amounts of high molecular weight aromatics, such as naphthenic and asphaltenic oils. Specific gravity is defined as the oil density at 60°F (15.5°C) divided by water density at 60°F. In American literature, the density of the oil is often expressed as °API, where:

$$^{\circ}\text{API} = \frac{141.5}{\text{Specific gravity}} - 131.5$$

In the present study, the density of the oil is presented as specific gravity.

The density of fresh crude oils normally lies in the range 0.78 to 0.95 g/mL (50 to 10 °API).

A.3.1 Rheological properties

The viscosity of crude oils expresses its resistance to flow and is of special interest when pumping oil. **Absolute viscosity** (also known as dynamic viscosity) is a measure of internal resistance. In the SI system, absolute viscosity has units of N s/m², Pa s or kg/(m s), where 1 Pa s = 1 N s/m² = 1 kg/(m s). Absolute viscosity can also be expressed in the metric CGS (centimeter-gram-second) system as g/(cm s), dyne s/cm² or Poise, where 1 Poise = 1 dyne s/cm² = 1 g/(cm s) = 1/10 Pa s = 1/10 N s/m². https://www.engineeringtoolbox.com/dynamic-absolute-kinematic-viscosity-d_412.html The industry often uses centipoise, as the *Poise* is normally too large, 1 Poise = 100 cP and 1 cP = 0.001 N s/m². The viscosity of fresh crude oils can vary from less than 1 to more than 2000 mPa.s (cP) at ambient sea temperature. In comparison, water has an “absolute” viscosity of 1 cP and syrup's is 120 000 cP at 20°C.

Kinematic viscosity is absolute viscosity divided by density. 1 centistoke (cSt) = 1 cP / density. Because the density of weathered oils and emulsion are typically 0.9 – 1 g/mL, the units cSt and cP will often have similar values. Viscosity is temperature dependent. For liquids, the viscosity decreases with increasing temperatures. Viscous and waxy crude oils can exhibit non-Newtonian behaviour (viscosity varies with shear rate), especially close to, or below, their pour point. Water-in-oil (w/o) emulsions exhibits this non-Newtonian behaviour with shear thinning. In an oil spill situation, an emulsion may be liquid under turbulent conditions at sea, but can become much more viscous, or even semi-solid in calmer water conditions, or on beaches. Thus, the measurements of the viscosity of w/o-emulsions must be carried out under strictly controlled conditions (defined shear rates and thermal and mechanical history of the sample). At SINTEF, a shear rate of 10 s⁻¹ is routinely used for expressing viscosity data on w/o-emulsions.

The viscosity of an oil increases with evaporation since the heavier, more viscous components remain in the residue (Mackay et al., 1982). The difference in viscosity for crude oils is approximately 3 to 2000 mPa.s for fresh crude oils and several hundred/thousand mPa.s for their residues. Water-in-oil (w/o) emulsions are generally more viscous than the parent crude oil; this is illustrated in *Figure A-2*.

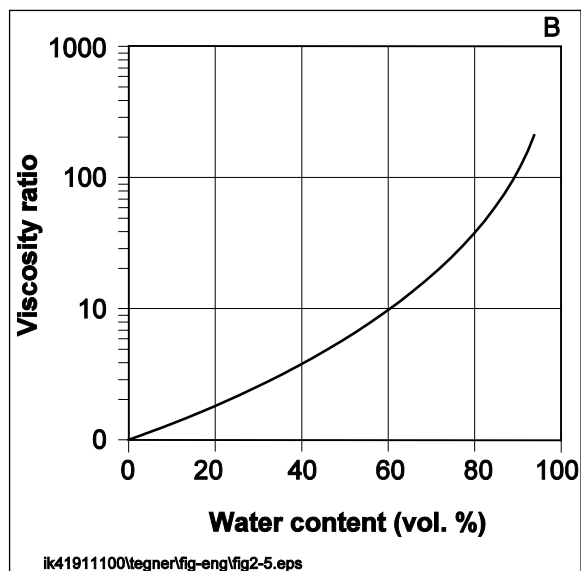


Figure A-2 Example of viscosity ratio as a function of water content

A.3.2 Pour point

The temperature at which oil ceases to flow when cooled without disturbance under standardized conditions in the laboratory is defined as the oil's pour point (ASTM-D97). The method accurately determines the temperature at which the oil become semi-solid under the specified laboratory conditions. Due to the movement at the sea surface, the oil may remain a liquid at sea at temperatures as low as 5 to 15°C lower than the pour point of the oil. The pour point of oil with high wax content will increase dramatically with evaporation as the lower weight molecules, which contribute to keeping the wax in solution, evaporate. The pour point for oils with high wax contents can reach 30°C, while low viscous naphthenic oils may have pour points as low as - 40°C. In an oil spill clean-up situation, the pour point provides essential information for when determining the efficiency of various skimmers, pumping rates and the use of dispersing agents.

A.3.3 Distillation curve

The distillation curve, which is obtained by measuring the vapour temperature as a function of the amount of oil distilled, shows the relative distribution of volatile and heavier components in the oil. The boiling point of a chemical component depends on its vapour pressure, which is a function of its molecular weight and chemical structure. Low molecular weight oil components have a higher vapour pressure, thus lower boiling points than higher molecular weight components of a similar type. Aromatic compounds boil at a higher temperature than paraffinic compounds of the same molecular weight, and *iso*-alkanes boil at a lower temperature than the equivalent *n*-alkanes. Hence, the distillation curve is an indicator of the relative amount of different chemical components, principally as a function of molecular weight, but also as determined by the chemical composition.

A.3.4 Flash point

The flash point is the lowest temperature at which the gas or vapour generated by the heating of oil will form an ignitable mixture in air. The flash point depends on the proportion of low molecular weight components. Fresh crude oils normally have a low flash point (from -40°C to 30°C). From a safety point of view, flash points are most significant at, or slightly above, the maximum temperature that may be encountered in storage or transport. The flash point is an approximate indicator of the relative fire and explosion hazard of oil.

Rule of thumb:

In the presence of an oil slick at sea, a fire and/or explosion hazard exists when the oil's flash point is close to or lower than the sea temperature.

Natural weathering processes such as evaporation and emulsion formation contribute to reducing the potential hazard by increasing the flash point. Thus, it will be a relatively short fire and/or explosion danger in the initial stages of oil spill. In the laboratory, the flash point is measured in a closed system with the components in the oil and gas equilibrated. In the field, however, the weather situation will influence the flammability of the air above the slick. The gas concentration will be high just above the oil film in calm weather and high temperatures, whereas the concentration will be low in cold and windy weather due to dilution and transport and a lower degree of evaporation.

A.4 The behaviour of crude oil spilled at sea

This chapter gives a general description of the main weathering processes when oil is spilled at sea. There are many natural processes that take place that change the volume and chemical properties of the oil. These natural processes are evaporation, water-in-oil (w/o) emulsification, oil-in-water (o/w) dispersion, spreading, sedimentation, oxidation and biodegradation. A common term for all these natural processes is weathering. The relative contribution of each process varies during the duration of the spill. The weathering of oil depends on the oil type (chemical and physical properties), the weather conditions (wind, waves, temperature and sunlight) and the properties of the seawater (salinity, temperature, bacterial flora, etc.). Figure A-3 illustrates the various weathering processes, and Figure A-4 shows their relative importance over time.

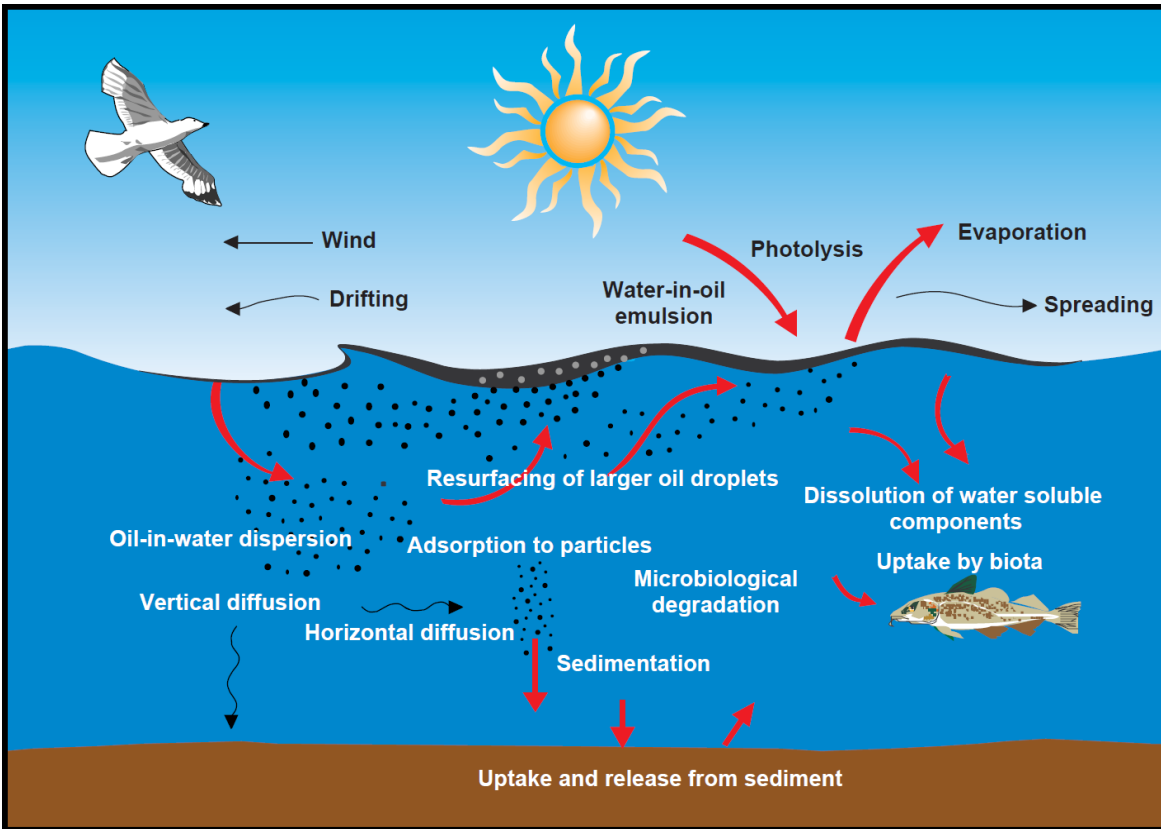


Figure A-3 Illustrating the weathering processes that take place when oil is spilled on the sea surface

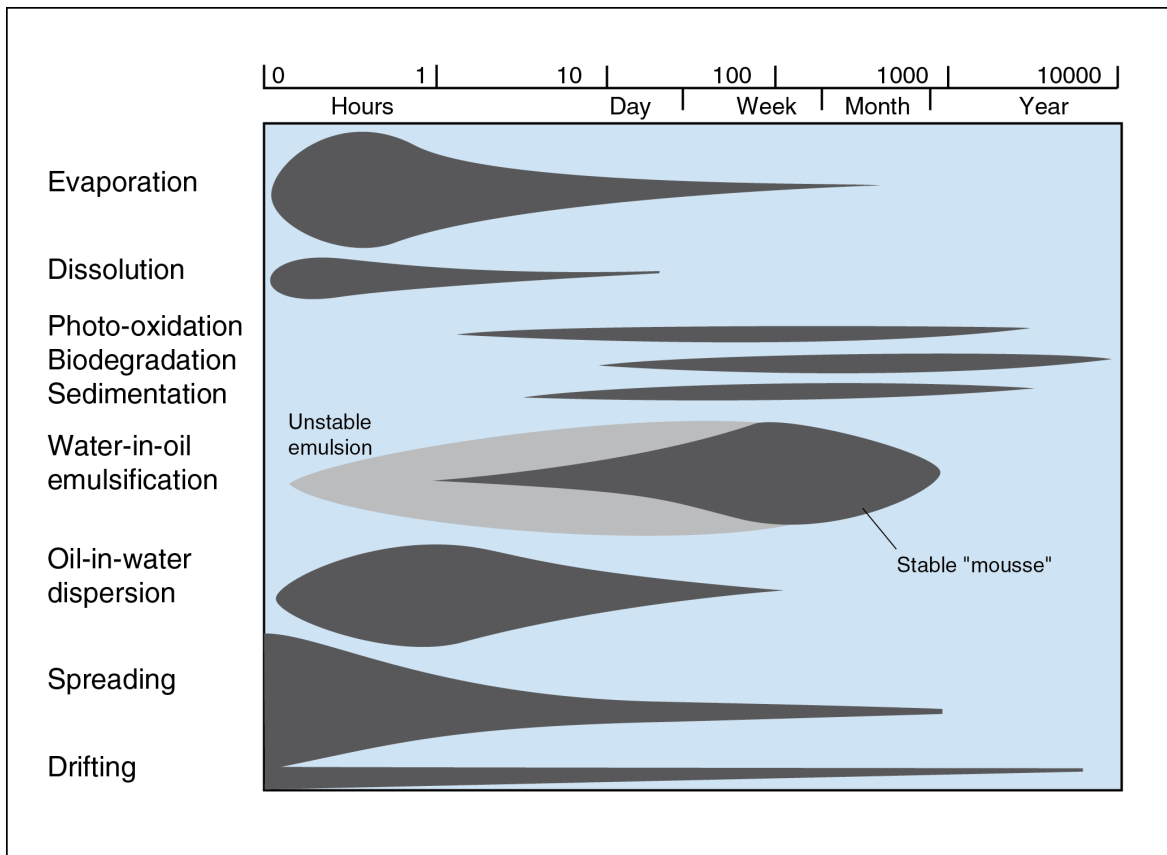


Figure A-4 Weathering processes' relative importance over time. Note: logarithmic scale

A.4.1 Evaporation

Evaporation is one of the natural processes that support the removal of spilled oil from the sea surface. The evaporation process starts immediately after the oil is spilled, and the evaporation rate decreases exponentially throughout the duration of the oil spill. The evaporated amount depends on the chemical composition of the oil in addition to the prevailing weather conditions, sea temperature and oil film thickness.

The rate of evaporation varies for different oil types. Light refinery products (e.g. gasoline and kerosene) may completely evaporate after a few hours/days on the sea surface. Condensates and lighter crude oils can lose 50% or more of their original volume during the first days after an oil spill. The most significant difference caused by evaporation is the loss of volatile and semi-volatile compounds, which increases the relative amounts of higher molecular weight compounds. With evaporations, the chemical and physical properties of the remaining oil will change. The density, viscosity, pour point and wax and asphaltene content, will all increase with increased evaporation.

A.4.2 Spreading

Oil spilled at sea will spread on the sea surface. Spreading is often the dominant process in the initial stages of an oil spill and decreases as the viscosity and density of the remaining oil increases. The spreading process is also reduced if the oil's pour point is 5-15°C below the sea temperature.

Oceanographic conditions (e.g. wind, waves and currents) affect the spreading process. The oil slick will be broken into "wind rows" aligned in the direction of the wind, see Figure A-5. The thickness of the oil slick varies, often differing by a factor of several thousand. Experience has shown that most of the total oil slick area consists of a thin film ($<1 \mu\text{m}$ oil thickness) that only contains 10% of the oil volume. Most of the oil volume ($\sim 90\%$) is in small patches of w/o emulsions with a film thickness of 1 to 5 mm, which often constitutes less than 10% of the total oil slick area.

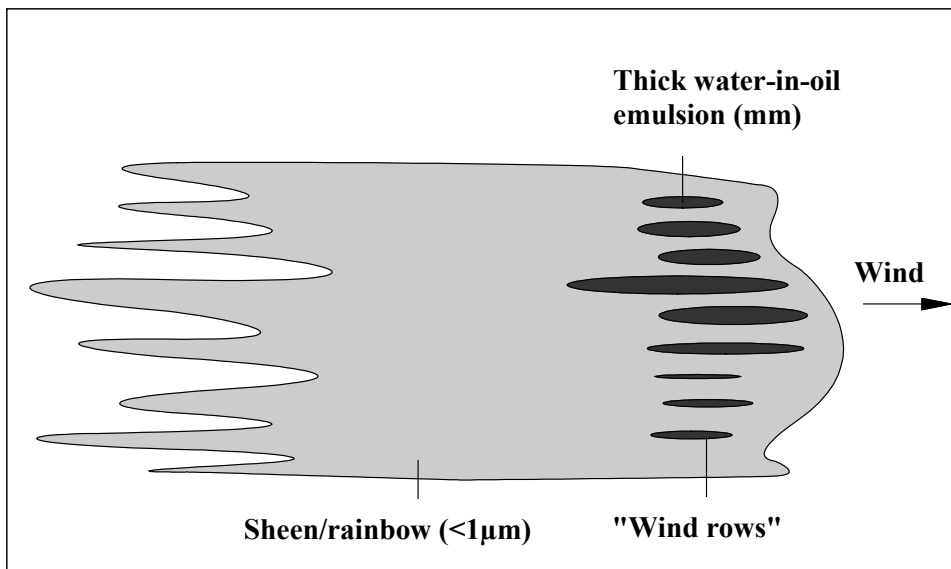


Figure A-5 The spreading of oil spilled on the sea surface and the distribution within the oil slick

A.4.3 Drift of an oil slick

The oil slick will drift as the weathering processes continue. The wind and current conditions cause the oil slick to drift, as illustrated in Figure A-6. Waves and wind create a current in the mass of water which amounts to approximately 3% of the wind speed at the sea surface. The influence of the wind decreases rapidly with the depth of the water below the surface. At 1 to 2 meters the current reduces to approximately 1% of the wind speed. This means that oil on the surface of the open sea, will move faster than the water below (e.g. Reed and Turner, 1991; Reed et al., 1994). In the absence of wind, the oil drift is governed by the prevailing (background) current.

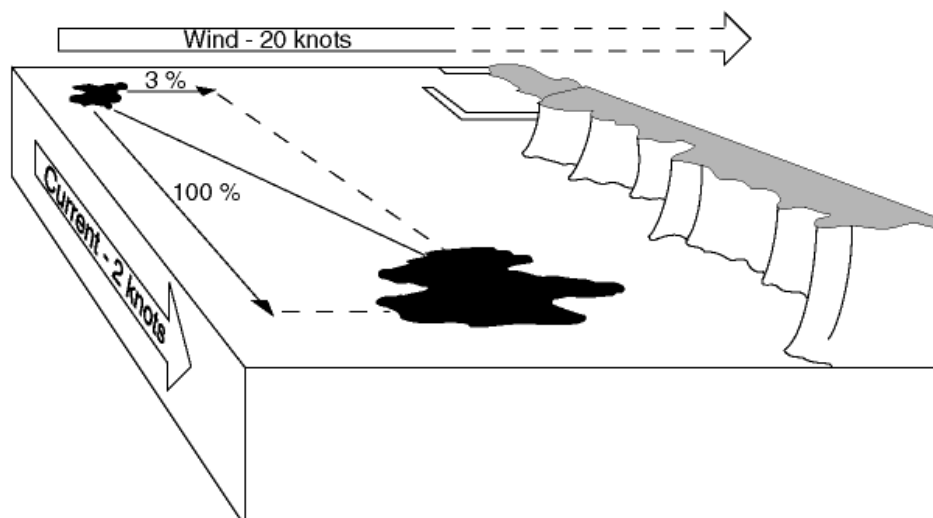


Figure A-6 An illustration showing how wind and current can influence the drifting of an oil slick

A.4.4 Water-in-oil (w/o) emulsion

The formation of water-in-oil emulsions significantly affects the behaviour and clean-up of oil spilled at sea. Because of emulsification, the total emulsion volume may increase to as much as six times the original spilled oil volume depending on the properties of the oil. The formation of w/o emulsions also contributes to keeping oil on the sea surface. A w/o emulsion normally has a higher viscosity than the parent crude oil, so the emulsification process will therefore retard/delay evaporation and the natural dispersion process.

The minimum criterion for the formation of w/o emulsions is the presence of breaking waves (i.e. a wind speed of >5 m/s). Nonetheless, a slow water uptake can also take place during calmer weather. Figure A-7 shows how wind speed influences the w/o formation rate.

Surface active compounds present in crude oil will promote the formation of w/o emulsions and contribute to stabilizing the emulsion. These components contain both hydrophilic and hydrophobic groups.

The maximum water uptake will vary for different crude oils. Tests performed at SINTEF have revealed that the maximum water uptake is independent of the prevailing weather conditions if the lower energy barrier for the formation of w/o emulsions is exceeded. The rate, however, depends highly on the weather conditions. In the laboratory, the $t_{1/2}$ -value is determined, which is the time in hours it takes before the oil has emulsified half of its maximum water content. The w/o emulsion formation rate depends on the oil's chemical composition, which varies for different oil types.

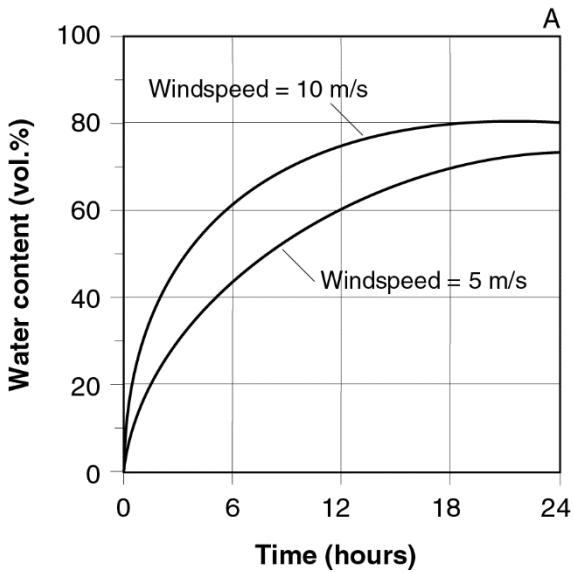


Figure A-7 Example of how weather conditions influence the w/o emulsion formation for typical oils

The stability of the w/o emulsion depends on the water droplet size, since not all water droplets in the emulsion are stable. Larger water droplets may be reduced in size by the flexing, stretching and compressing motion of the slick due to wave action, whereas the largest droplets may coalesce and be squeezed out of the w/o emulsion. After a certain period, the emulsion may only contain small water droplets with diameters of 1 to 10 μm , yielding a more stable emulsion.

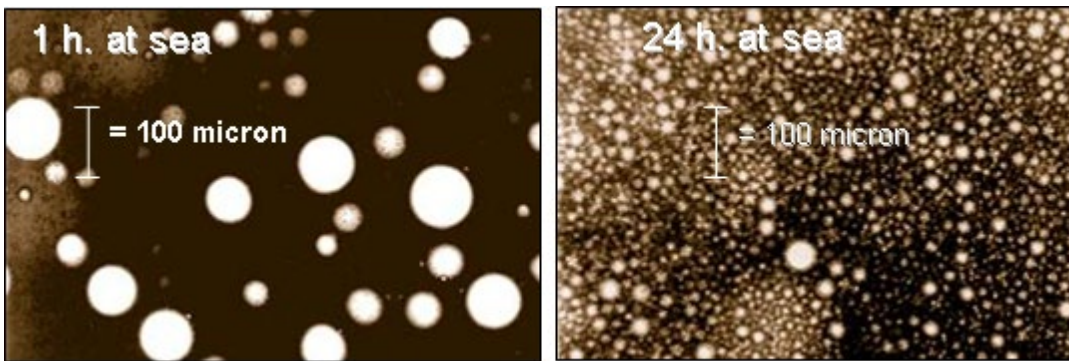


Figure A-8 Microscope pictures of w/o emulsion after (A) 1 h. and (B) 24 h. in a rotating cylinder

Thus, the formation of emulsions is the result of water retention by oil as an effect of both viscous and interfacial forces. The interfacial forces are the most important, and asphaltenes are largely responsible for this. Resins are similar compounds to asphaltenes and can stabilize an emulsion, but not to the same extent. Resins and asphaltenes have both hydrophobic and hydrophilic properties and will concentrate at the interface between the water and oil, thereby forming a layer that stabilizes the water droplets. The hydrophobic properties can lead to the concentration of wax along the water droplets, which further stabilizes the interfacial “skin” layer. The interfacial layer between the oil and water forms a physical barrier that hinders the coalescence of the water droplets and will stabilize the w/o emulsion. The stabilization of the water droplets by asphaltenes and wax is shown in Figure A-9.

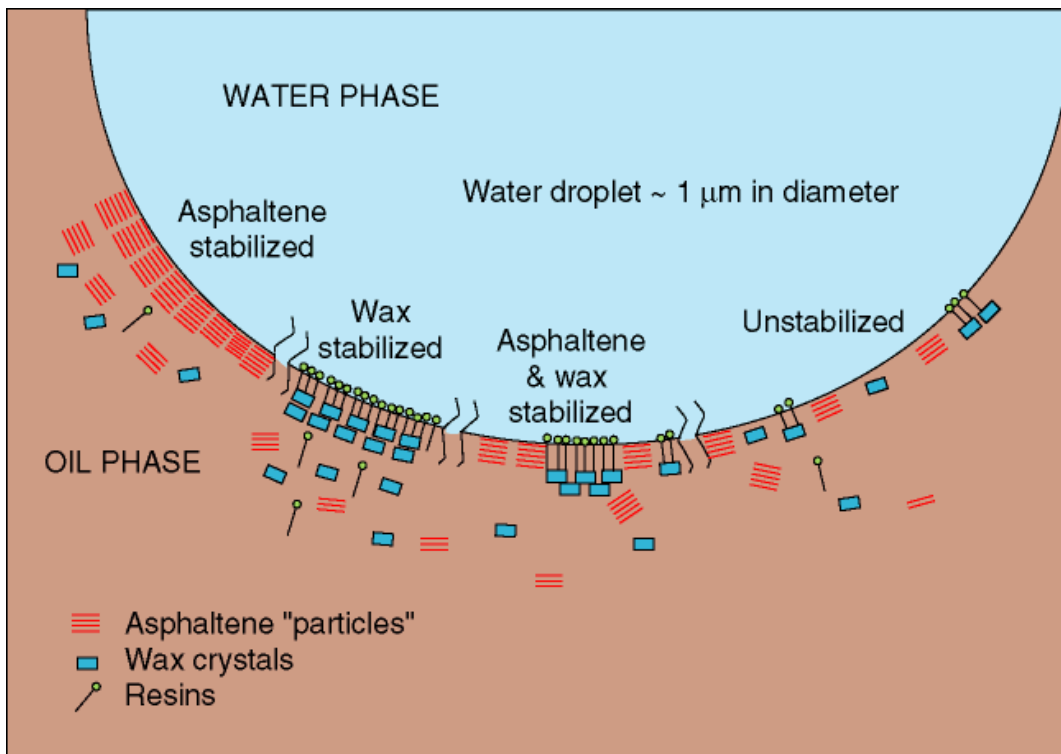


Figure A-9 Interfacial layer stabilized by wax and asphaltenes in w/o emulsion

Oils that contain large amounts of wax and small amounts of asphaltenes can form w/o emulsions stabilized by a continuous phase’s rheological strength (viscosity and elasticity) due to wax structure formed by precipitated wax. Wax stabilized emulsions are characterized by large water droplets and are fairly stable when stored, although they may break down when stress is applied and/or when the emulsion is heated to, e.g. 40-50°C.

Crude oil and sea water interfacial tension (IFT) plays a key role in the process of oil droplet formation. The need to understand and control droplet formation in dispersant system is extremely important. Addition of dispersants reduces the interfacial tension between oil and water that subsequently promotes the formation of a larger number of small oil droplets when surface waves entrain oil into the water column. These small submerged oil droplets are then subject to transport by subsurface currents and other natural removal processes, such as dissolution, volatilization from the water surface, biodegradation, and sedimentation resulting from interactions with suspended particulate material.

A.4.5 Oil-in-water (o/w) dispersion

Natural oil-in-water (o/w) dispersion will take place if there is sufficient energy on the sea surface, i.e. if there are breaking waves present. The waves will break the slick into small oil droplets (~1 μm - 1 mm in diameter), which are then mixed into the upper water column. The largest oil droplets will resurface and form a thin oil film (typically <50 μm). This thin oil film will be rapidly dispersed again by breaking waves as smaller droplets into the water column and will be available for rapid biodegradation.

The natural dispersion rate depends highly on oil type and can be one of the main processes that determine the lifetime of an oil slick on the sea surface. Natural o/w dispersion will gradually decrease with time since the evaporation of the lighter compounds will increase the viscosity of the remaining oil.

The purpose of applying chemical dispersing agents is to increase, or enhance, the natural dispersion rate. Dispersants reduce the interfacial tension between water and oil and thus promote natural o/w dispersion. When effective chemical dispersion is achieved, small oil droplets are formed, with typical diameters ranging from 5 to 100 µm. These are retained in the upper layers of the water column by the prevailing turbulence of wave action.

A.4.6 Water solubility

The water solubility of saturated hydrocarbons is generally very low, while lower molecular weight aromatic compounds are water-soluble to some extent; particularly aromatics, such as BTEX, 2-ring PAH and paraffin's up to C₇) have a potential to be dissolved in the water column (McAuliffe, 1987). Within the various types of hydrocarbons, the water solubility decreases from aromatics to naphthenes and from *iso*-alkanes to *n*-alkanes. In each series, the water solubility decreases with *increasing* molecular weight.

Evaporation and the release of oil components into the water mass are competitive processes since most of the water-soluble components are also volatile. The evaporation process is approximately 10 to 100 times faster than the release in the water column. The concentration of soluble oil components into the water column during an oil spill is quite low (< 1 mg/L), while the dissolution of oil components into the water column does not contribute to removing the oil from the sea surface. However, the water-soluble fraction is of great interest since it has a high bioavailability and thus the potential to cause acute toxic effects on marine organisms.

A.4.7 Photo-oxidation

Under the influence of sunlight, some of the oil components will slowly oxidize to resins and finally asphaltenes. The photo-oxidized components will stabilize the w/o emulsions and influence the oil's persistence on the sea surface. After a long period of weathering at sea, tar balls (mainly consisting of asphaltenes) may be formed. These tar balls break down very slowly, both at sea and on beaches.

A.4.8 Biodegradation

Seawater contains an abundance of microorganisms that can break down all types of oil components. Various microorganisms prefer specific oil components as their energy source. Bacteria prefer to degrade oil in contact with water and the rate of biodegradation depends on the water/oil interface area. The interface area increases as the oil is spread over the sea surface in a thin layer or by chemical or natural dispersion of oil into the water column. Important factors influencing the biodegradation rate are temperature, the concentration of available nutrients (i.e. nitrogen and phosphorus), oxygen, oil type and the degree of weathering. Low molecular compounds are degraded more rapidly than the high molecular weight/heavier compounds in the oil, thus giving the following order for biodegradation: straight-chain *n*-alkanes > branched *iso*-alkanes > cyclic alkanes > cyclic naphthenes > aromatics > resins > asphaltenes (Perry, 1984).

At sea, the formation of oil droplets by natural or chemical enhanced dispersion will increase the biodegradation rate in the water mass by 10 to >100 times compared to surface oil due to increased water/oil interfacial area. When immobilised on hydrophobic synthetic fabrics, *n*-alkanes biodegraded within 2-4 weeks at North Sea conditions (13°C; Brakstad and Lødeng, 2005). Some small PAHs dissolved in water can be degraded within a few days (Brakstad and Faksness, 2000), but high molecular-weight oil compounds

associated with particulate oil biodegrade more slowly and some very high molecular-weight compounds (equivalent to the heavy residues in crude oil that are used to make bitumen) may not biodegrade to any significant degree.

A.4.9 Sedimentation

Crude oil and oil residues rarely sink into the water mass since there are few oils that have a density higher than water, even after extreme weathering. Oil can sink by sticking to materials present in the water mass. W/o emulsions that have a higher density value (e.g. emulsified bunker fuel oils) can more easily stick to a material, particularly if coming to the shore, and can sink to the bottom if washed out again from the shore. In connection to sub-sea blowout at the sea bottom, it is assumed that some of the oil droplets generated in the plume may adsorb to suspended particles or encounter with the seabed sediment. This can cause some sedimentation of oil droplets to the seabed near the release. It is assumed that sub-sea dispersant treatment will reduce the potential for such sedimentation, due to lower adsorption /stickiness to sediment particles.

A.4.10 Deep water releases

Size distribution of the oil droplets formed during a subsurface release strongly influences the subsequent fate of the oil in the environment. Large droplets (typically larger than 5 mm) reach the surface after a couple of hours rise time from a depth of approximately 1000 m, while smaller droplets (down to 0.5 mm) may rise for up to a day before they will come to the surface. Fine droplets (below 100 microns) may stay in the water for weeks or even month before they eventually reach the surface. However, factors like vertical turbulence mixing in the water column, density stratification and cross flows will contribute to keep such fine small droplets submerged for even prolonged periods (Johansen et al., 2003). In case of deep-water releases, large droplets (mm range) will usually rise to the surface and form an oil layer with sufficient thickness to emulsify (form water-in-oil emulsions). This is usually caused by loss of buoyancy and more horizontal entrainment of the gas/oil/water plume due to dissolution of gas, possible hydrate formation, cross currents and density layers. However, large droplets (mm range) will leave the entrained plume and rise to the surface, illustrated in Figure A-10. This was observed both during the "DeepSpill" experiments in 2000 (Figure A-11) and the DWH oil spill in 2010 (Figure A-12). This emulsification will be dependent on oil properties and environmental conditions, such as temperature and sea state.

Thick surface oil slick

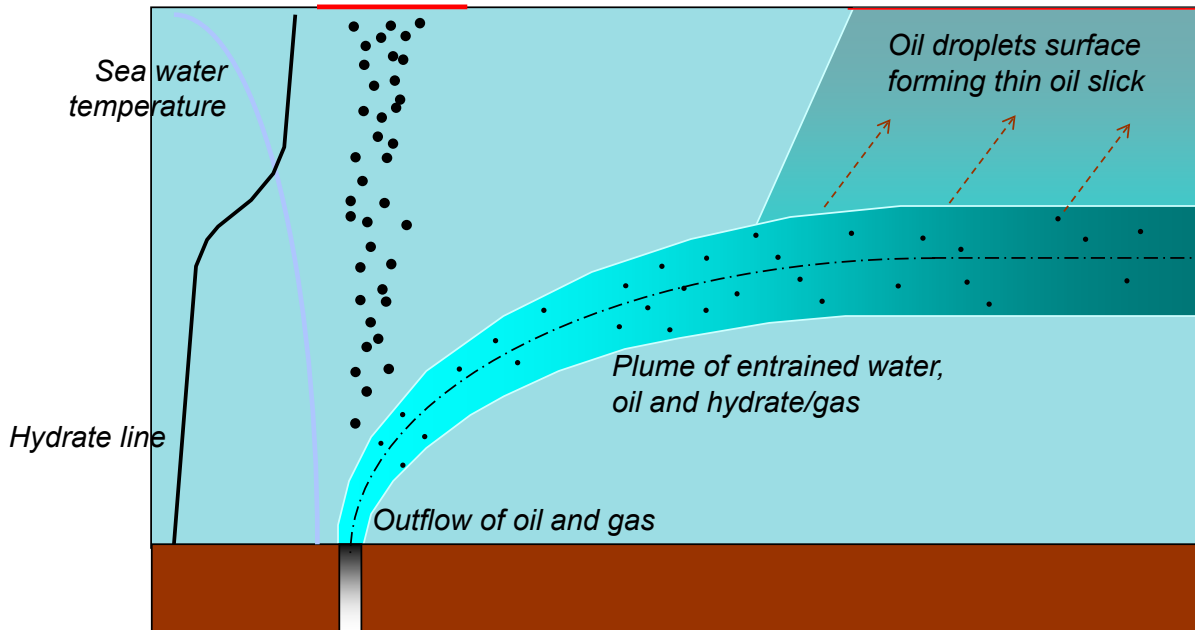


Figure A-10 Illustration of possible creation of thick surface oil slick ($> 200 \mu\text{m}$) from deep-water release of oil

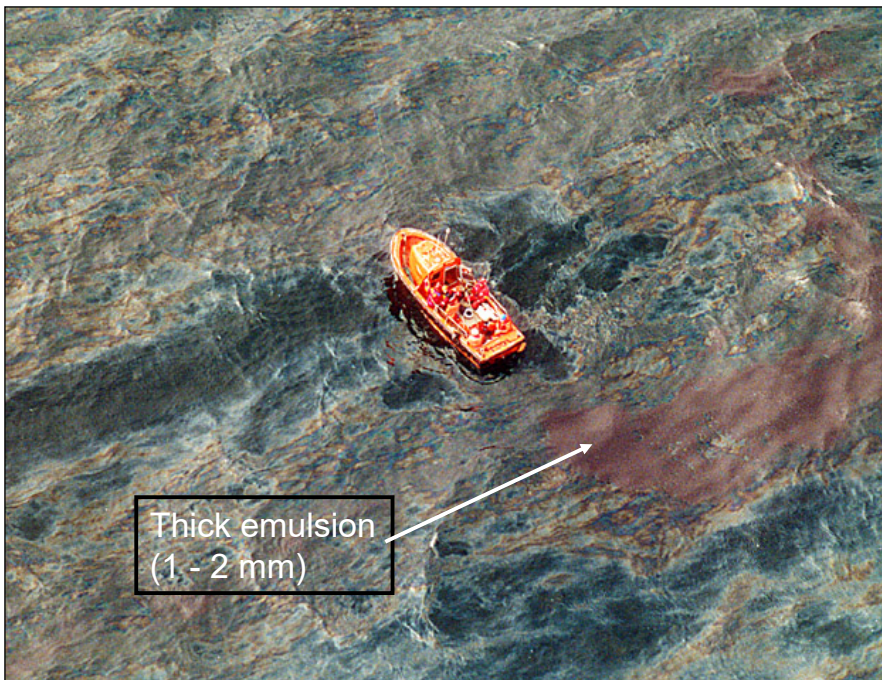


Figure A-11 Surface oil slick (initial thickness $> 200 \mu\text{m}$) from the experimental deep-water release "DeepSpill" in 2000. Surface oil is emulsifying similar to an oil slick from a surface batch release (from Leirvik et al., 2011)

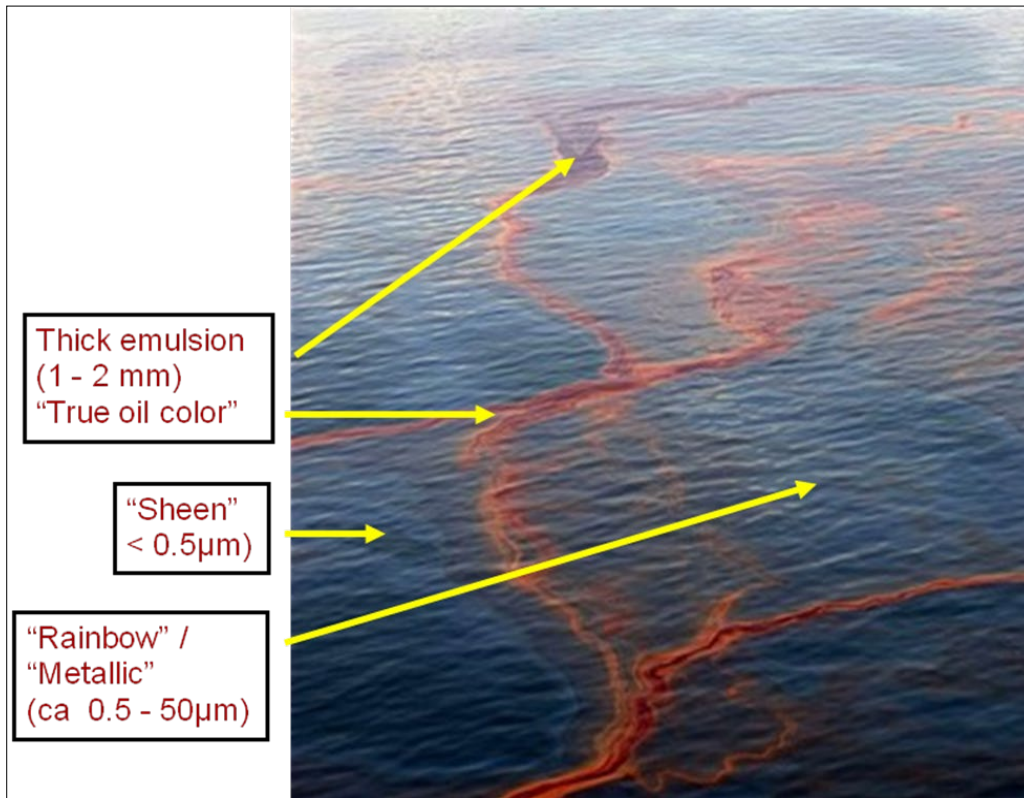


Figure A-12 Surface oil slick (initial thickness > 200 µm) from the DWH deep-water release. Surface oil is emulsifying like an oil slick from a surface batch release

A.4.11 Shallow releases

In case of a sub-surface release of oil and gas in shallower water (<500 meter) the buoyancy of the rising water/gas/oil plume is usually sufficient to reach the surface. The gas will be released to the atmosphere, while the large volumes of water will set up a horizontal current that will create a wide and thin surface oil slick (see Figure A-13, Figure A-14 and Rye et al., 1997). This surface oil slick could be too thin to emulsify (< 200 microns) and evaporation and natural dispersion will be the predominant weathering processes.

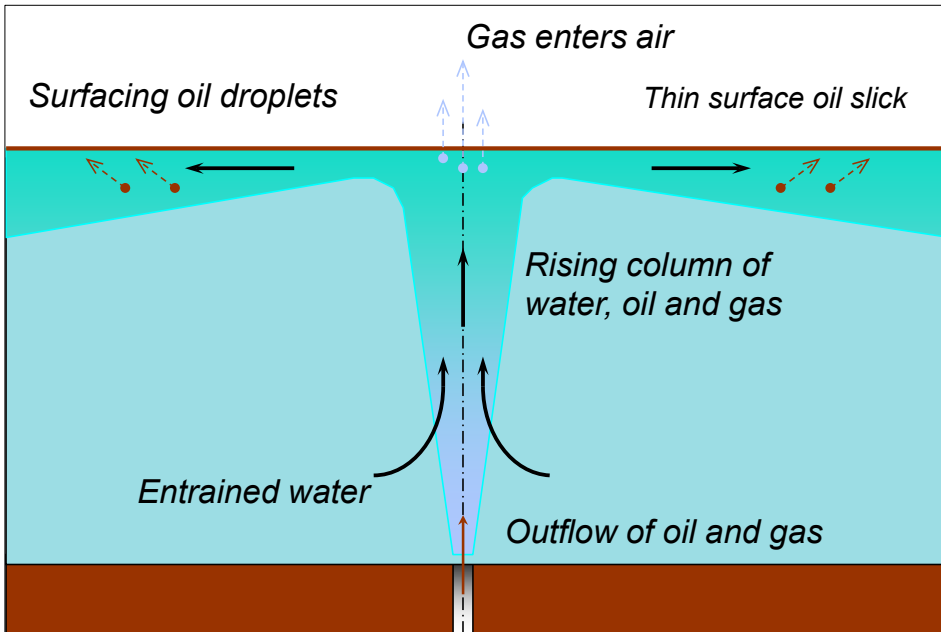


Figure A-13 Illustration of possible creation of thin surface oil slick ($< 200 \mu\text{m}$) from a shallow subsurface release ($< 500 \text{ m}$)

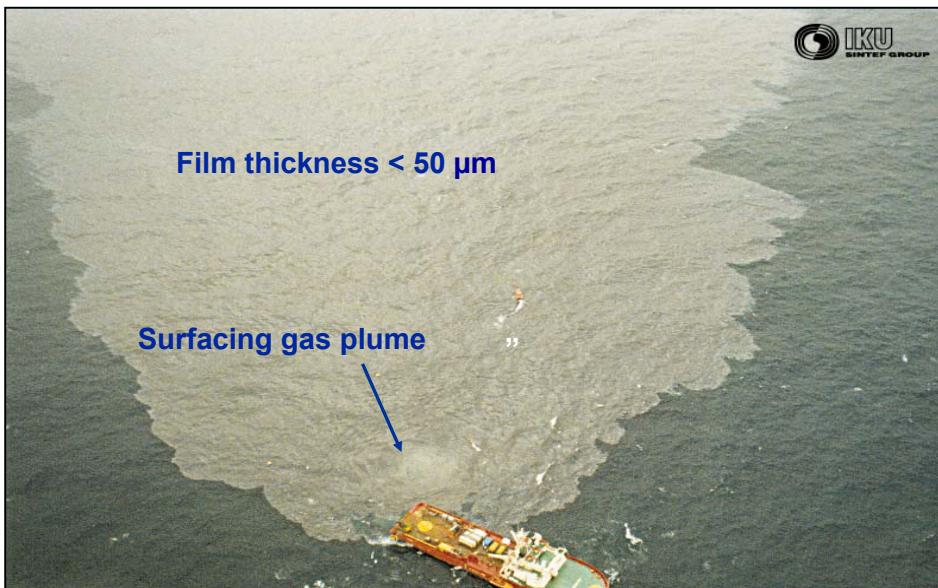


Figure A-14 Surface oil slick ($< 50 \mu\text{m}$) from experimental subsurface release at 106 m in 1996. The surface oil didn't emulsify and had a very limited lifetime (hours) due to the low film thickness and high rate of natural dispersion (even at $< 10 \text{ m/s}$ wind)

B Experimental setup

B.1 Oil samples and test temperature

3 x 20 Litres of Aasta Hansteen blend arrived at SINTEF Ocean AS 2019-12-12 (Figure B-1). The oil was given the unique SINTEF ID 2019-10622. The weathering study (small-scale) were performed at 13 °C.

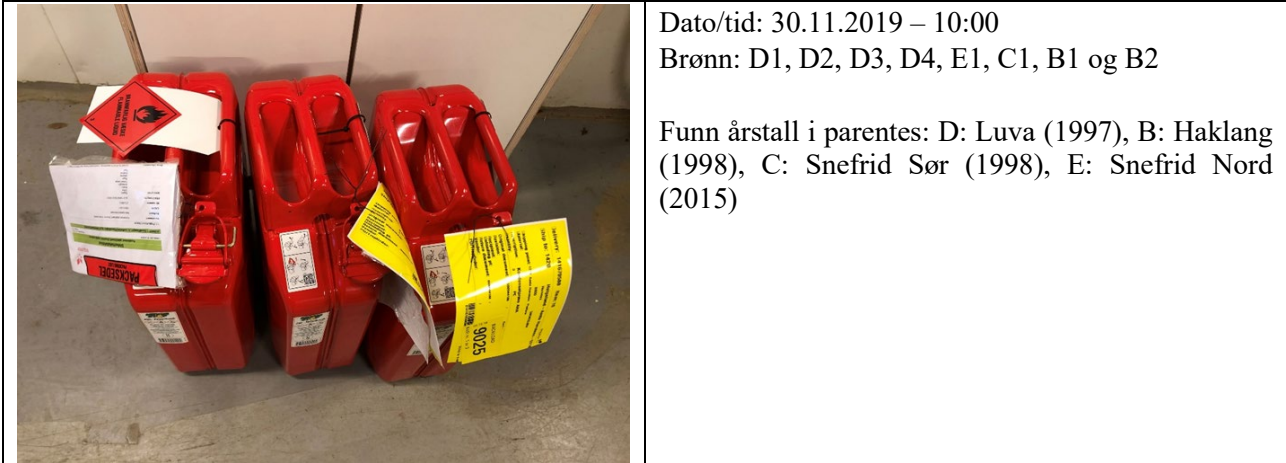
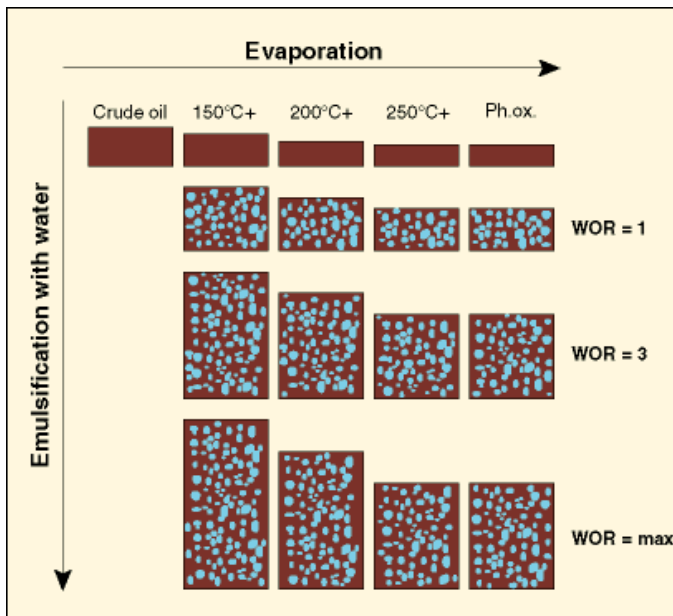


Figure B-1 3 x 20 Litres of Aasta Hansteen blend arrived at SINTEF Ocean

B.2 Small-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 B-2.



WOR: Water to Oil Ratio

WOR=1: 50 vol.% water

WOR=3: 75 vol.% water

WOR=max: the maximum water content

Figure B-2 Small-scale laboratory weathering flow chart of oil

B.2.1 Evaporation

The evaporation procedure used 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 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. These residues are referred to as 150°C+, 200°C+ and 250°C+, respectively.

B.2.2 Physical and chemical analysis

The viscosity, density, pour point and flashpoint of the fresh and water-free residues was analysed. In addition, wax content and "hard" asphaltene was measured for the 250°C+ residue. Viscosity for all the w/o emulsions was determined. The analytical methods used are given in Table B-1 and Table B-2.

Table B-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	-
Flash point	ASTM D 56-82	Pensky-Martens, PMP1, SUR

Table B-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 characterization by GC-FID and GC-MS

- The distribution of hydrocarbons (nC₅-nC₄₀) 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 DB1 column.
- The analysis and quantification of PAHs, phenols, and alkylated phenols (C₀-C₄) were completed using an Agilent 6890 Gas Chromatograph coupled with a, 5973 MSD detector (GC-MS) operating in SIM mode (Selected Ion Monitoring)

The volatile components were in the range of nC₅-nC₁₀ and were quantified by use of PT-GC-MS (Purge and Trap Gas chromatograph Mass Spectrometer operating in full-scan mode and using a modified version of the EPA 8260 analysis method).

C Input data to SINTEF Oil Weathering Model (OWM)

The laboratory data used as input to the SINTEF OWM for Aasta Hansteen blend is given in Table C-1 to C-3. The oil weathering predictions were based on the laboratory data at 13 °C.

Table C-1 Physical and chemical properties for Aasta Hansteen blend

Properties of fresh oil	Value
Density (g/mL)	0.823
Pour point (°C)	-36
Reference temperature (°C)	13
Viscosity at ref. temp. (mPa·s = cP) *	2
Flash point (°C)	-
Asphaltenes (wt. %)	0.01
Wax Content (wt. %)	0.07
Dispersible for visc. <	-
Not dispersible for visc. >	-

* Measured at shear rate 10 s⁻¹

Table C-2 True boiling point (TBP) curve for Aasta Hansteen blend

*TBP based on Crude Assay: Aasta Hansteen 2019 04

Temp. (°C)	Cumulative yield (vol. %) *
5	1.17
10	1.18
30	2.23
50	3.28
65	4.90
80	7.93
100	15.1
125	26.7
135	29.8
150	36.2
180	48.0
200	55.0
220	61.3
250	70.2
270	75.8
290	80.9
320	87.5
350	92.4
370	94.7
400	97.1
490	99.6
520	99.8
550	99.9

Table C-3 Lab weathering data for Aasta Hansteen blend, 13 °C

Properties	Fresh	150°C+	200°C+	250°C+
Boiling Point Temp. (°C)	-	182	234	286
Vol. Topped (%)	0	34	55	74
Weight Residue (wt. %)	100	69	49	28
Density (g/mL)	0.823	0.856	0.878	0.896
Pour point (°C)	-36	-27	-18	-6
Flash Point (°C)		37	75	113
*Viscosity of water-free residue (mPa.s = cP)	2	3	6	13
*Viscosity of 50% emulsion (mPa.s = cP)	-	-	-	-
*Viscosity of 75% emulsion (mPa.s = cP)	-	-	-	-
*Viscosity of max water (mPa.s = cP)	-	-	-	-
Max. water cont. (vol. %)	-	-	-	-
(T1/2) Halftime for water uptake (hrs)	-	-	-	-
Stability ratio	-	-	-	-

* Measured at shear rate 10 s^{-1}

- No data – not measured

D Chemical characterization (OSCAR oil profile)

The method for generating OSCAR oil profile is based on the quantification of semi-volatile organic hydrocarbons (SVOC) and volatile organic hydrocarbons (VOC) by GC-MS. The composition is divided into individual pseudo-component groups (OSCAR groups) representing the oil based on the TBP (True Boiling Point) and GC-MS analysis.

T

able D-1 *Chemical characterization ("oil profile") of Aasta Hansteen blend (fresh oil) from GC-MS analysis and TBP oil fraction*

SINTEF IC 2019-10622	Aasta Hansteen blend
1,600	1 C1-C4 gasses (dissolved in oil)
1,000	2 C5-saturates (n-/iso-/cyclo)
3,701	3 C6-saturates (n-/iso-/cyclo)
0,099	4 Benzene
6,500	5 C7-saturates (n-/iso-/cyclo)
0,770	6 C1-Benzene (Toluene) et. B
15,330	7 C8-saturates (n-/iso-/cyclo)
1,596	8 C2-Benzene (xylenes; using O-xylene)
8,214	9 C9-saturates (n-/iso-/cyclo)
1,690	10 C3-Benzene
7,500	11 C10-saturates (n-/iso-/cyclo)
0,135	12 C4 and C4 Benzenes
9,720	13 C11-C12 (total sat + aro)
0,045	14 Phenols (C0-C4 alkylated)
0,721	15 Naphthalenes 1 (C0-C1-alkylated)
11,679	16 C13-C14 (total sat + aro)
0,000	17 Unresolved Chromatographic Materials (UCM: C10 to C36) 0 0 0
0,000	37 metabolite 1
0,000	38 metabolite 2
0,924	18 Naphthalenes 2 (C2-C3-alkylated)
7,676	19 C15-C16 (total sat + aro)
0,423	20 PAH 1 (Medium soluble polyaromatic hydrocarbons (3 rings-non-alkylated; <4 rings))
6,777	21 C17-C18 (total sat + aro)
5,500	22 C19-C20 (total sat + aro)
5,097	23 C21-C25 (total sat + aro)
0,103	24 PAH 2 (Low soluble polyaromatic hydrocarbons (3 rings-alkylated; 4-5+ rings))
3,200	25 C25+ (total)

The SINTEF OSCAR model is a 3-dimensional Oil Spill Contingency And Response model system that calculates and records the distribution (as mass and concentrations) of contaminants on the water surface, on shore, in the water column and in sediments. The model allows multiple release sites, each with a specified beginning and end to the release. This allows time-variable releases at a given location, as well as throughout the study area. The model computes surface spreading, slick transport, entrainment into the water column, evaporation, emulsification and shore interactions to determine oil drift and fate at the surface. In the water column, horizontal and vertical transport by currents, dissolution, adsorption, settling and degradation are simulated. By modelling the fate of individual pseudo-components, changes in the oil composition due to evaporation, dissolution and degradation are accounted for. OSCAR may compute oil weathering from crude assay data, although the most reliable results are produced if the target oil has been through a standardized set of laboratory weathering procedures established by the SINTEF laboratories. Alternatively, the model may use oil-weathering properties from oils for which data already exist, selecting the oil in the oil database that most closely matches the composition of the oil of concern



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