

# Summary report

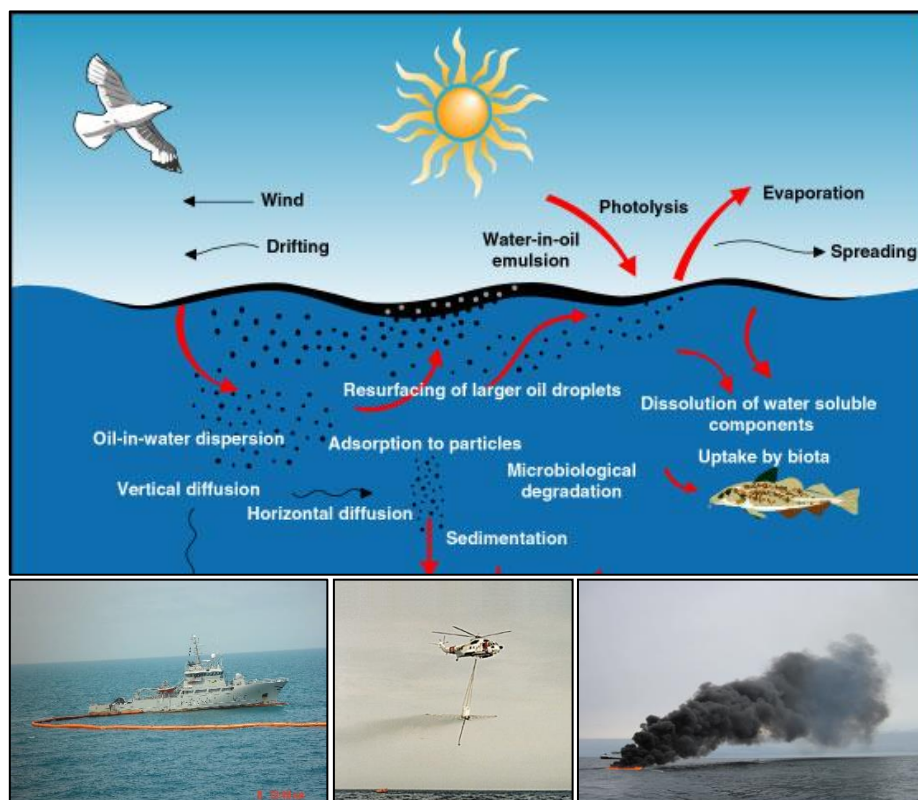
## Characterization of Low Sulfur Fuel Marine Fuel Oils (LSFO)

A new generation of marine fuel oils

### Author(s)

Per S. Daling

Kristin Rist Sørheim



SINTEF Ocean AS

Address:  
Postboks 4762 Torgarden  
NO-7465 Trondheim  
NORWAY

Switchboard: +47 46415000

Enterprise /VAT No:  
NO 937 357 370 MVA

# Summary report

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A new generation of marine fuel oils

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Kristin Rist Sørheim**CLIENT(S)**

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**ABSTRACT**

This is a summary report of the Multi-client project "Characterization of Low Sulfur Fuel Oils (LSFO) – A new generation of marine fuel oils" (2019-2020). The project has been funded by MPRI/Fisheries and Ocean-DFO Canada, ITOPF (R&D Award) and the Norwegian Coastal Administration (NCA).

In order to meet new requirements for lower sulfur oxides (SOx) emissions to the air, new generation of low sulfur marine fuel oil (LSFO) are now replacing the traditional Intermediate fuels and heavy fuel oils (like IFO 180 and IFO 380) with "Ultra Low Sulfur Oils" – ULSFO ( $S \leq 0.10$  % m/m), for use in the Sulfur Emission Control Area (SECA) in Europe and North America from 2015, and a Global Sulfur Cap regulation was implemented from 2020 with "Very Low Sulfur Oils" ( $S \leq 0.50$  %m/m). This project aims to provide responders better knowledge and preparedness for spills involving new generation of low sulfur residual marine fuel oil on the market today. The project included laboratory studies with focus on fate and behaviour, potential toxicity and with relevance to the effectiveness of different oil spill response options (use of dispersants and in-situ burning). Test methodologies was also subjected to an interlaboratory study and experiments performed both in Norway (SINTEF) and in Canada (SL Ross) on one of the tested oils.

The companies mentioned in this report provided samples for investigation of the fuel's characteristics when spilled in sea water to help with the development of an industry response strategy for a new generation of low-sulfur fuel oils. Many of the low-sulfur fuels being developed by the industry share similar compositions, so it is important to notice that the findings of this report are not unique to the fuel samples analysed. The results of this study are indicative of a new generation of marine fuel oil across the wider industry. Further laboratory analysis of low-sulfur fuel oils from other suppliers is needed to give a clearer understanding of the characteristics and behaviours of individual products.

**PREPARED BY**

Per S. Daling

**CHECKED BY**

Ivar Singsaas

**APPROVED BY**

Mimmi Throne-Holst

*This document has been approved according to SINTEF's approval procedure, and is digitally secured*

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## Preface

The Multi-client project "Characterization of Low Sulfur Fuel Oils (LSFO) – A new generation of marine fuel oils" has been a 1-year project (2019-2020) supported by a financial contribution from 1) Fisheries and Oceans Canada through its Multi-Partner Research Initiative (MPRI), 2) through the ITOPF R&D Award fund in 2019, and 3) by the Norwegian Coastal

Administration (NCA) as a part of their R&D strategic initiatives. This short report summarizes the background, key findings and results from this project presented in the main report (Sørheim *et al.*, 2020).

See also website:

[http://www.itopf.org/fileadmin/data/Documents/RDaward/Final\\_report\\_LSFO\\_Multipartner\\_3.1\\_.pdf](http://www.itopf.org/fileadmin/data/Documents/RDaward/Final_report_LSFO_Multipartner_3.1_.pdf)

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## Acknowledgements

The funding partners are acknowledged for financial support and constructive dialogue during the project. ITOPF has, through their extended connections worldwide assisted the project in getting two relevant samples of Very Low Sulfur Fuel Oils (VLSFO) from Chevron in Singapore and from the Shell refinery in the Netherland. The project team wants to acknowledge Chevron and Shell for their willingness to support and ship the oils for testing at SINTEF.

Furthermore, due to the challenge during the project period to get a relevant residual marine fuel oil from

Canada, an Ultra-Low Sulfur Fuel oil (ULSFO) from the Shell refinery was provided from the NCA. An aliquot of the ULSFO sample was further shipped to SL Ross in Canada for interlaboratory testing as a part of this project.

Finally, RelyOn Nutec (Trondheim, Norway) is acknowledged for use of facilities and assistance when conducting the ignitability (*in-situ* burning) experiments.



**KYSTVERKET**  
NORWEGIAN COASTAL ADMINISTRATION



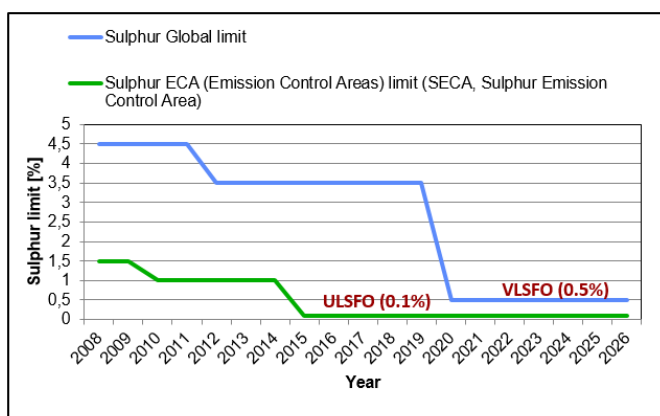
Fisheries and Oceans  
Canada



## 1 Introduction

The recent changes in IMO (International Maritime Organization) regulations concerning lower limits in sulfur content in marine fuel oils have resulted in a switch to new generations of low sulfur fuel oils, developed in order to meet the new requirements for lower atmospheric sulfur (SO<sub>x</sub>) emissions.

These new generation of low sulfur marine fuel oils (LSFO) called ultra-low sulfur fuel oils (ULSFO) with a sulfur content lower than 0.1% have been replacing traditional intermediate fuel oils and heavy fuel oils like IFO 180 and IFO 380 for use in the Sulfur Emission Control Area (SECA) in Europe and North America since 2015. Outside the designated emission control area, a new Global Sulfur Cap regulation was implemented from January 2020 for very low sulfur fuel oils (VLSFO) with sulfur content lower than 0.5% to the former sulfur limit of 3.5%.



As referred by IMO, this reduction of sulfur in marine fuel oils should have major health and environmental benefits for the world, particularly for populations living close to ports and coasts.

## 2 Objective

The main objective of the project has been to provide better documentation of the variability of the weathering properties and behaviour of new LSFOs when spilled under cold sea conditions.

This project has included laboratory studies on residual marine fuel oils that are now available on the market with focus on fate and behaviour, potential toxicity and

The present classification of Marine Fuels according ISO 8217, are grouped into:

1. Requirements for Marine Distillate Fuels
2. Requirements for Marine Residual Fuels

Oil spill response operations to incidents with marine fuels around the world have mainly had to deal with residual fuels (Heavy Fuel Oil (HFO) of various IFO-grades). Operative experiences from such incidents, together with the knowledge gained through laboratory characterization of the physical and chemical properties and weathering behaviour of different HFOs, have been crucial for environmental risk assessments and knowledge-based response to mitigate the effects under different environmental conditions (including arctic areas).

The ongoing upgrading among refineries worldwide to comply with the new sulfur requirements means that an increasing number of new marine fuel oil products are now entering the market. These new compliant LSFOs will likely span over a wide spectre within both heavy marine distillate fuels and residual fuels, that will not fit into a specific grade within the ISO classification.

Therefore, facing the 2020 Global Sulfur Cap and potential other regulations (e.g. arctic areas / cold climate regions), the new generation of marine fuel oils are expected to gain importance. The variation in their oil properties will be highly dependent on the feedstock (e.g. switch to sweeter crude oils) and the individual refineries' "recipes" in upgrading the different conversion processes (e.g. hydro-desulfurization, catalytic cracking, visbreaking) to reduce the amount sulfur and residual material.

with relevance to the effectiveness of different oil spill response options (use of dispersants and *in-situ* burning). Test methodologies were subjected to an interlaboratory comparison where experiments were performed both in Norway (SINTEF) and in Canada (SL Ross) on one of the fuel oils.

### 3 Selection of oils

Three different low sulfur residual fuel oils were selected for testing

- VLSFO from Chevron, Singapore
- VLSFO from Shell, The Netherlands
- ULSFO from Shell, The Netherlands

The purpose was to study the properties of representative marine residual fuel oils used primarily by vessels operating in European / Norwegian and Canadian waters. However, there was a limited access to residual fuel oils (VLSFO) in 2019 prior to the 2020 compliant Sulfur Cap. One sample of VLSFO was provided by Chevron in Singapore, and two different

fuel oils (VLSFO and ULSFO) were provided by Shell in Rotterdam (Netherlands). The fuel oils tested in this project showed a span in their physical-chemical properties based on available parameters given in Certificate of Analysis (COA).

For comparison, this report also includes results from previous studies of heavy fuel oils (HFO, NCA-project in 2013,) and Marine Gas Oil (MGO) / diesel oils, heavy distillates (HDME 50), Wide Range Gasoil (WRG) and a residual ULSFO, all SECA 2015 complying fuels (i.e.  $\leq 0.10\%$  S, in a NCA project in 2015-2017).

### 4 Physico-chemical properties and weathering of oil

When oil is spilled at sea it undergoes a number of chemical and physical changes. These processes are collectively termed weathering and determine the fate and behaviour of the oil as well as the effectiveness of oil spill response measures. The weathering processes vary over time depending on both the original composition of the spilled oil itself and the environmental conditions.

Laboratory characterization of chemical composition, physical properties of fresh and weathered oil residues were investigated on the three low sulfur residual fuel oils. The testing was performed at 2 °C representing cold climate or arctic conditions, and 13 °C reflecting typical summer seawater temperature in the North Sea. The test temperatures are also relevant for Canadian waters.

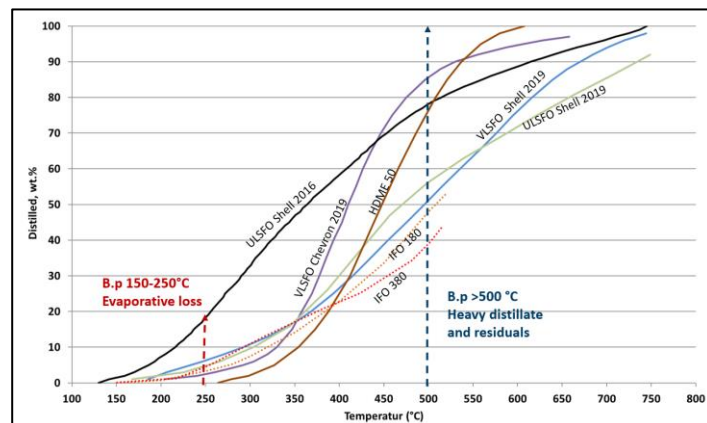
Experimental data was customized for use as input parameters to SINTEF's numerical Oil Weathering Model (OWM) to obtain reliable and robust weathering predictions of spill scenarios.

#### Evaporative loss and True Boiling Point (TBP)

A standardized laboratory evaporation methodology to produce topped residues with evaporative loss of volatile components with boiling points below 150, 200 and 250 °C, representing typically < 1 hour, <1 day, < 1-week weathering at sea, was prepared.

The residual fuel oils expressed very low evaporative loss in the range of 5-8 % for the 250°C+ topped residue for VLSFO Shell 2019 and ULSFO Shell 2019. The

VLSFO Chevron 2019 showed even a negligible evaporative loss (less than 2%), and the characterization were therefore conducted on the fresh oil, only (i.e. no evaporation). The TBP curves for the three LSFOs are compared with previous tested fuel oils are shown in figure below and show a wide span in the content heavy components with b.p. > 500 °C (i.e. > C<sub>36</sub>).

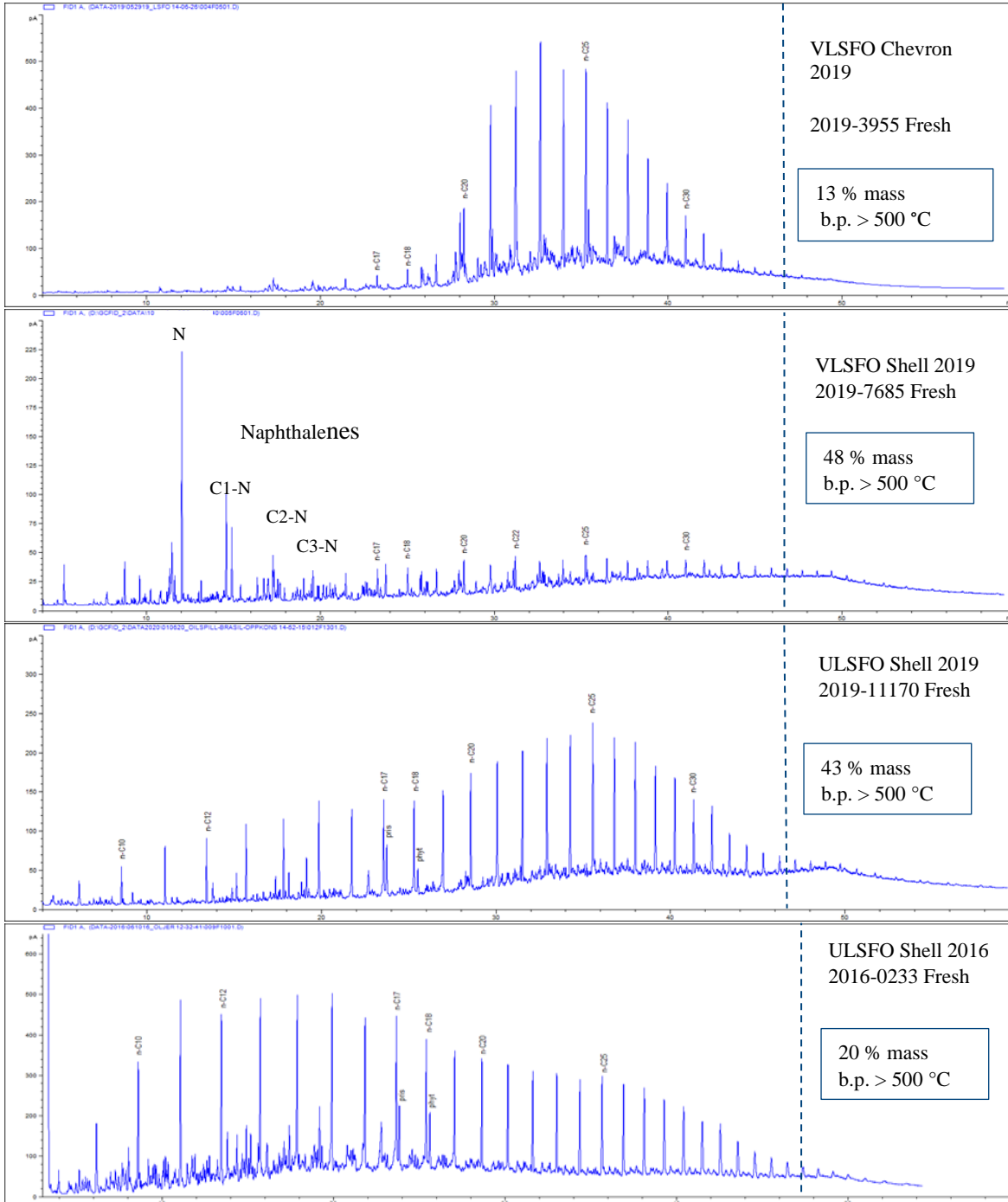


#### Hydrocarbon profile

The hydrocarbon profiles (C<sub>5</sub>-C<sub>36</sub>) by use of gas chromatogram coupled with flame ionization detector (GC-FID) are presented in gas-chromatograms, below. Compounds above 500°C are discriminated by this method, however this mass fraction can be estimated by the boiling point curve. The variation in the hydrocarbon profile of the less heavy components (<C<sub>36</sub>) seen in the gas-chromatograms below is reflecting variations in the physico-chemical properties. The VLSFO Chevron 2019 has paraffins (*n*-alkanes) in

the range of  $nC_{20}$  to  $nC_{30}$  with minor content of compounds lower than  $nC_{17}$  (boiling point 300 °C) that reflects the low evaporative loss. The VLSFO Shell 2019 has high peaks of naphthalenes relative to paraffins (paraffins are almost absent), however, this oil has a high content (48%) of heavy compounds are not

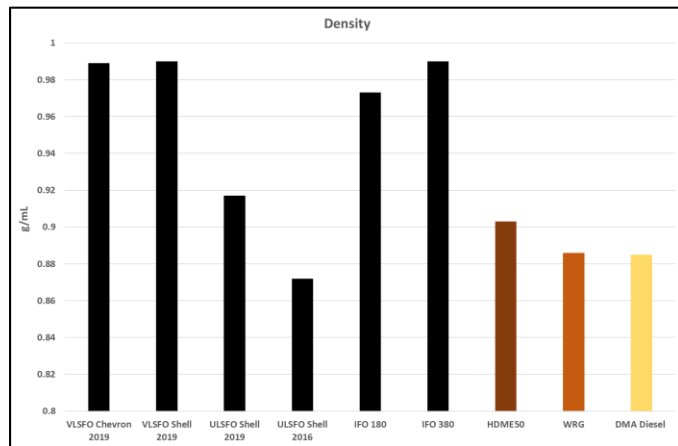
seen in the chromatogram. ULSFO Shell 2019 has a broad range of paraffins in the range of  $nC_9$ - $nC_{36}$  that reflects the high wax content from  $nC_{20}$  and has a significant higher content of heavier components compared to the 2016-batch of ULSFO from the same refinery.





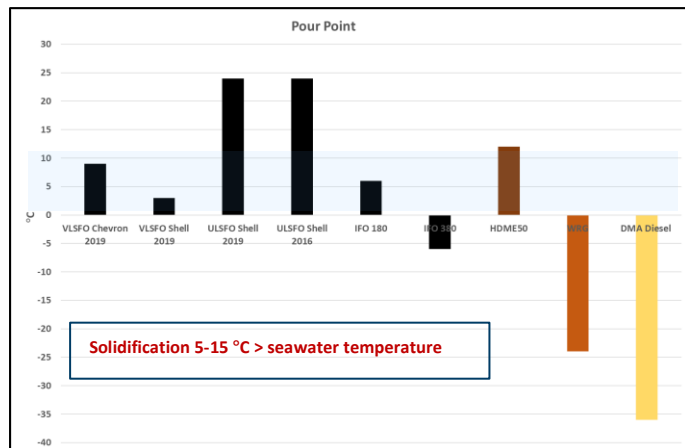
### Density

The densities of the fuel oils are in the range of 0.92-0.99 g/mL (15.5 °C). VLSFO Chevron 2019 and Shell 2019 are high density oils in the same range as IFO 180 and IFO 380 (> 0.97 g/mL). ULFSO Shell 2019 is in the same range as HDME50 with densities 0.90-0.92 g/mL.



### Pour Point

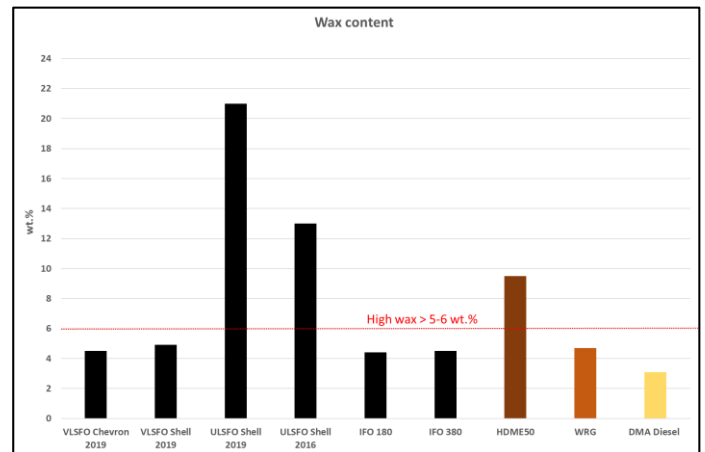
The pour point varies from +3 to +24 °C of the un-weathered (fresh oils). High pour points may imply solidification of oils at sea typically with pour points 5-15 °C above the seawater temperature. Here, ULFSO Shell 2019 expressed the highest pour point (+24 °C) among the oils.



The photo above shows solidified ULFSO at a room temperature of 20 °C.

### Asphaltene and wax

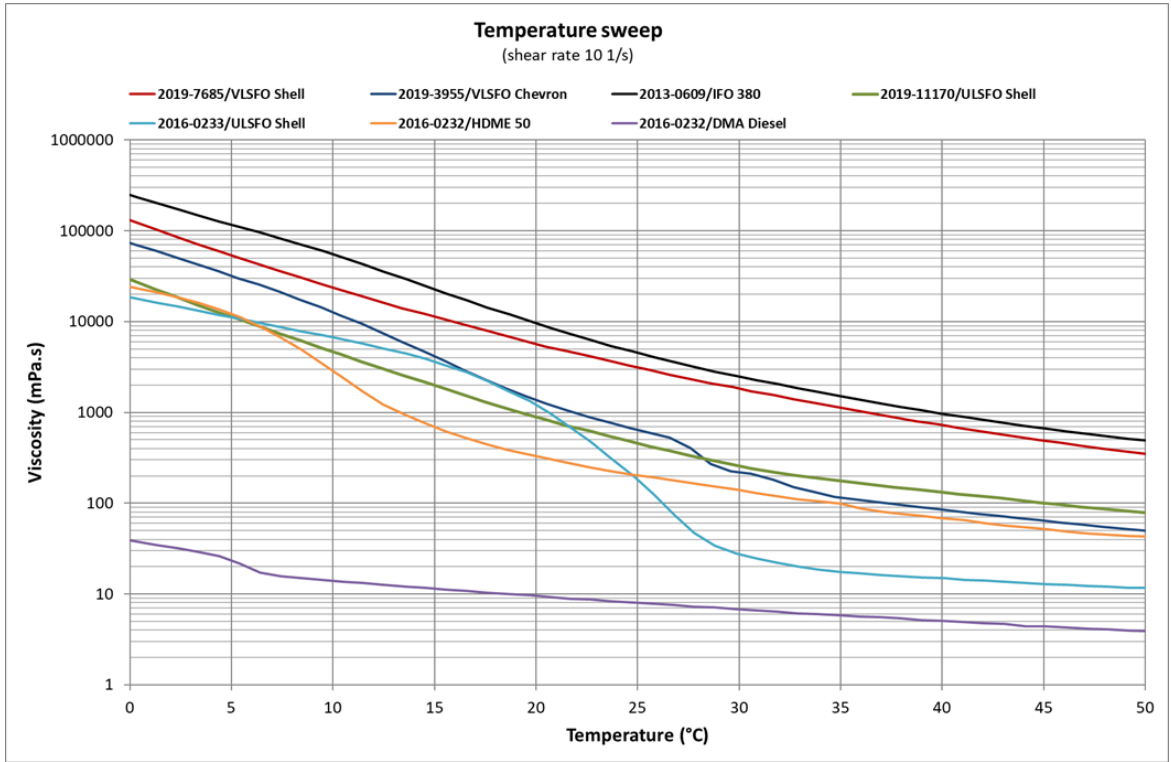
The ULFSO Shell 2019 expresses a high wax content (21%) and a low asphaltene content (0.14%). VLSFO Chevron 2019 and VLSFO Shell 2019 contain similar wax contents (~5%). Compared with the other tested fuel oils (<0.5%). VLSFO Shell 2019 has a high asphaltene content of 4.8%, which are in the same range at the IFO 180 /380.



### Viscosity

The viscosity expresses the flowability of the oils. A temperature-sweep from 50 to 0 °C was measured. Most of the oils express an increasing viscosity with decreasing temperature. VLSFO Shell 2019 showed similar viscosities as a heavy bunker fuel oil (IFO 380). The viscosity at 50 °C of VLSFO Shell 2019 was about 350 mPa.s. VLSFO Chevron 2019 and ULFSO Shell 2019 are both lower viscous oils (20-80 mPa.s at 50 °C), but their viscosities also increase more rapidly with decreasing temperatures influenced by the high pour

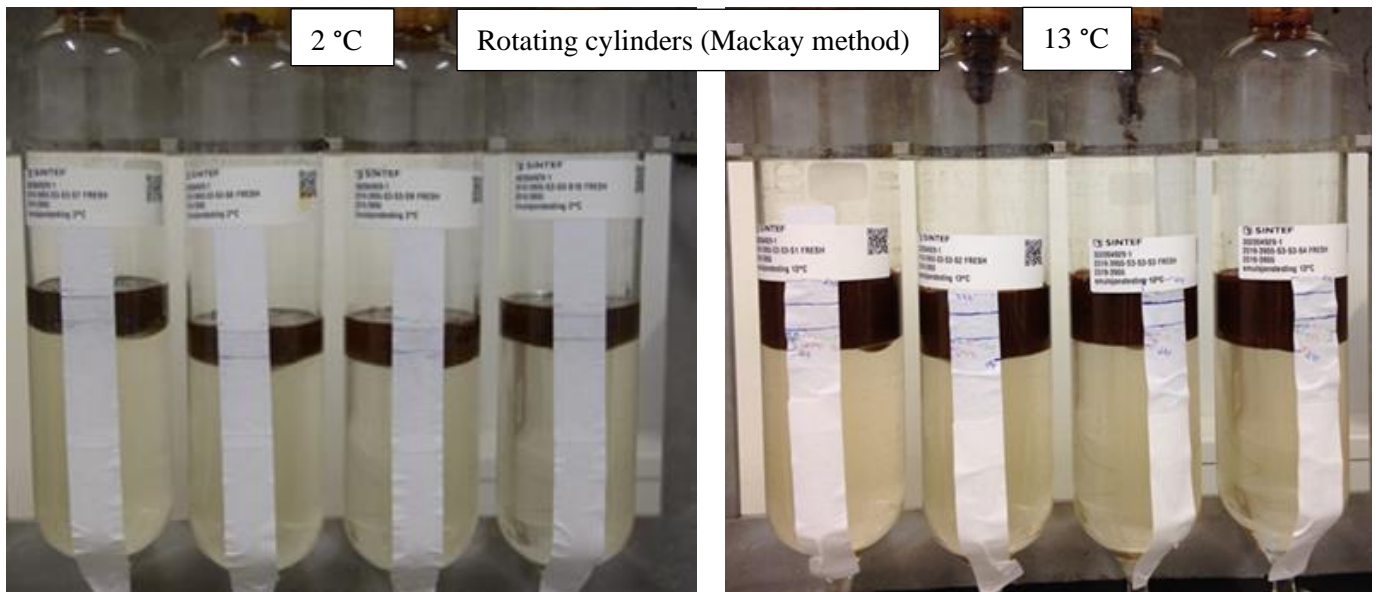
points. The low viscous DMA diesel has only a slight increase of the viscosities at cold temperatures



**Emulsifying properties**

The fuel oils incorporated seawater in the range of 50-67 vol.% at 13 °C (see picture below, example to the right). At 2 °C, the water uptake was in the range of 13-39 vol.% (see picture below, example to the left). The rate of water uptake was slow at both temperatures. The

non-weathered (fresh) oils expressed higher water uptake than the weathered residues at both temperatures. The emulsions formed were stable. Addition of emulsion breaker (Alcopol 60 O) did not break the emulsion to release incorporated water.



## 5 Oil weathering modelling

The experimental data generated in this project have been implemented into the SINTEF Oil Weathering Model (OWM). The OWM predicts weathering properties of oils with time at sea. OWM relates oil properties to a chosen set of input parameters such as release condition, oil type, oil film thickness, wind speed and sea temperature. Weathering predictions of oil properties at sea (e.g. evaporative loss, water

content, pour point emulsion viscosities, flash points, mass balance) are given in the main report. The predictions show the variability and similarities between the oils at different sea temperatures and wind speeds. The LSFOs from this project were also compared with predictions of marine fuel oils from previous projects.

## 6 Dispersibility and dispersant effectiveness

The purpose of dispersants is to enhance the natural dispersion of surface oil as small oil droplets into the water column. The laboratory testing of dispersants (dispersant to oil ratio, DOR 1:25) on the fuel oils, showed a reduced / low dispersibility effectiveness into small oil droplets. However, the dispersants have a potential to break up the oil slick into patches or larger lumps (at 13 °C), with use of the MNS (Mackay-Nadeau-Steelman) test.

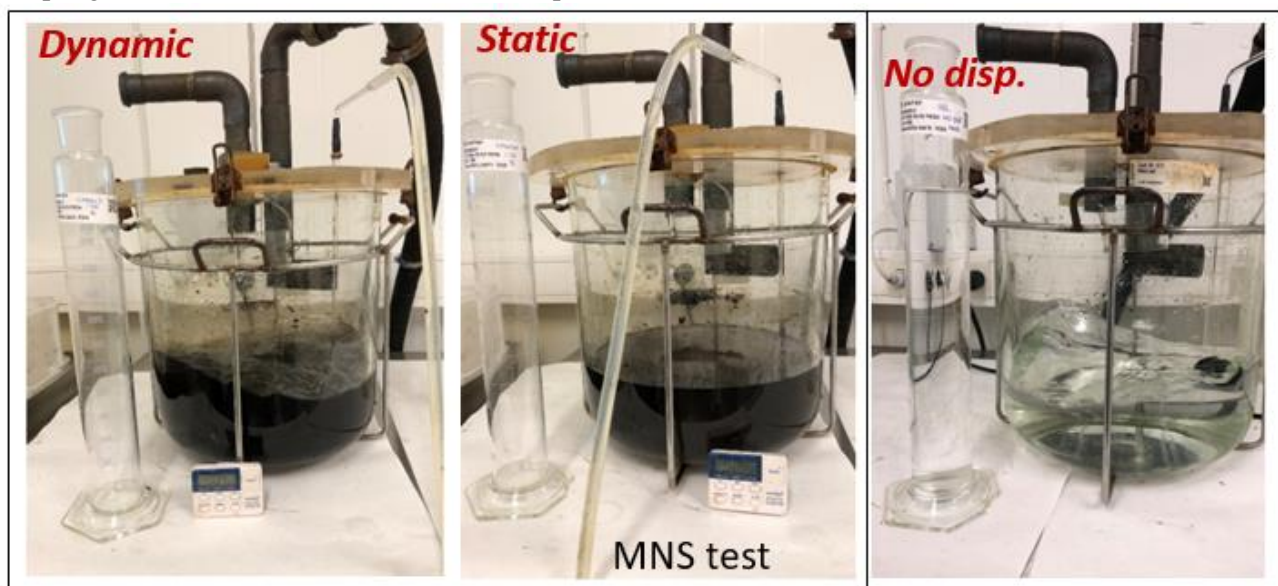
MNS reflects breaking waves conditions at sea (5-10 m/s wind speeds), shown here as dynamic sampling taken during the mixing period. Larger lumps formed after treatment of dispersants re-surfaced quickly when the wave energy was switch off (shown as static sampling). ULSFO Shell 2019 was less dispersible

compared to VLSFO Singapore and VLSFO Shell, mainly due to its high pour point.

At 2 °C, no effects after treatment of dispersants were observed for any of the oils. Similarly, no addition of dispersants also showed no effects on the surface slick (shown as no disp. in the figure below).

Overall, Corexit 9500A was found to be a slightly more efficient dispersant compared with OSR-52 and Dasic NS.

The low-energy testing (using the IFP dilution test), simulating non-breaking waves gave no effect.



## 7 Ignitability /In-situ burning

The ignitability i.e. the time needed to ignite the oils by using a "progressive" ignition strategy were tested in meso-scale trays (6 l oil on 70 L water). Non-emulsified oils were all ignitable, however, due to the low content of volatiles (light compounds) the oils needed prolonged time to be heated by an ignitor (gelled gasoline/diesel mixture) before the burn was totally spread on the oil layer.

ULSFO Shell 2019 was the easiest oil to ignite, with a heating time of 3 min. before the burn was spread to the surrounding oil. In contrast, VLSFO Shell 2019 needed

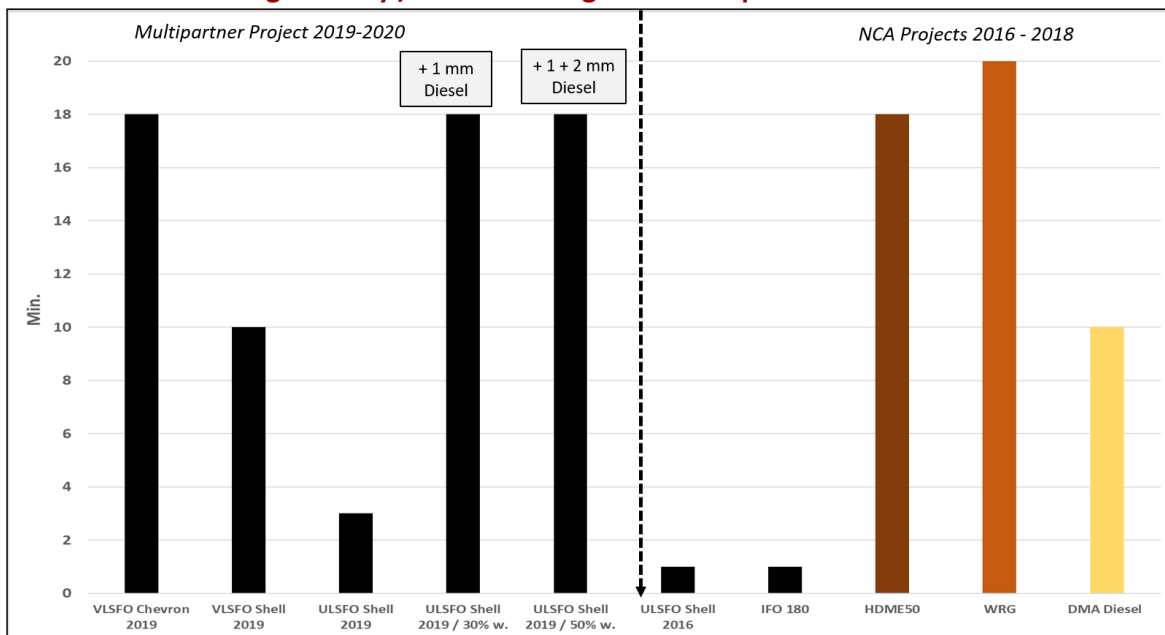
10 min. heating time and VLSFO Chevron 2019 18 min. before the burn totally covered the surface oil.

Emulsions (30 and 50 %) of ULSFO Shell 2019 were not possible to ignite by the ignitor without adding a layer of diesel as a primer (1 mm and 3 mm) on the top of the emulsified oil slick.

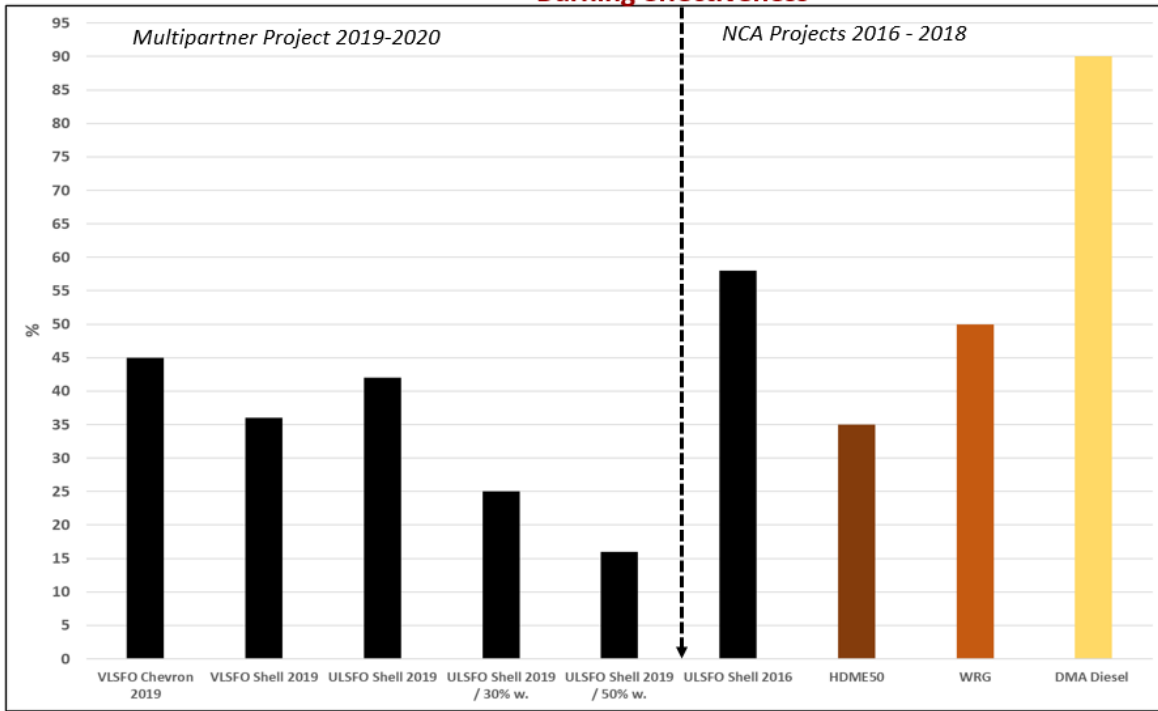
The burning effectiveness was 35-45 % for the non-emulsified oils, and 15-25 % for the emulsified oil (ULSFO Shell 2019). The burning effectiveness might be somewhat underestimated as the upper water layer beneath the burn gradually is heated and starts to boil and will promote termination of the burn.



**Ignitability / Time before ignitor burn spreads to oil surface**



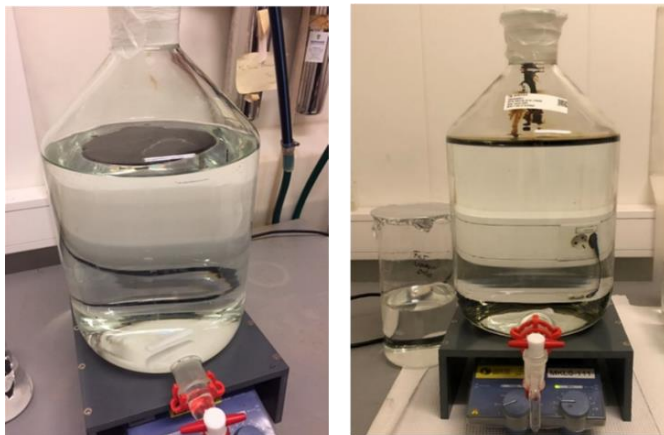
**Burning effectiveness**



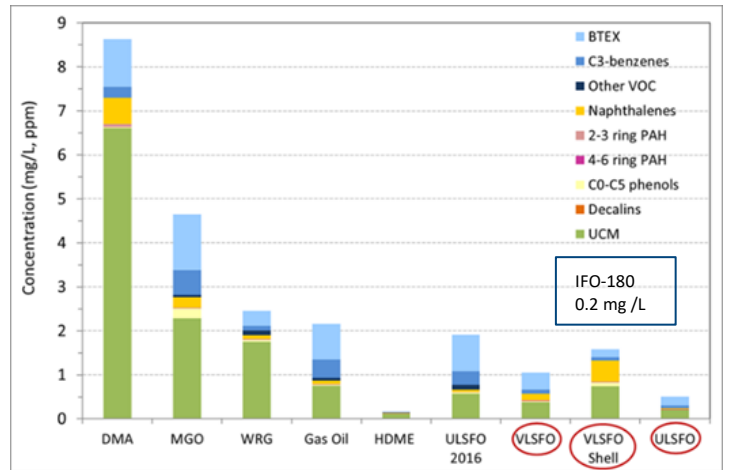
**8 Toxicity and chemistry of Water accommodated fractions (WAF)**

Water soluble fraction also called water accommodated fraction (WAF) were studied on the three fuel oils with emphasis on chemistry and acute toxicity. Low-energy WAFs solutions were prepared under controlled conditions following the guidelines established by the CROSERF forum, with an oil-to-water ratio of 1 to 40.

The total WAF concentrations of ULSFO and VLSFOs were in the lower range (< 2 mg/L) compared to marine distillates (4.5-8.5 mg/L; DMA diesel and MGO).



Two pelagic species representing primary producers were tested: The marine algae (*Skeletonema pseudocostatum*) and invertebrate (marine copepod *Calanus finmarchicus*).

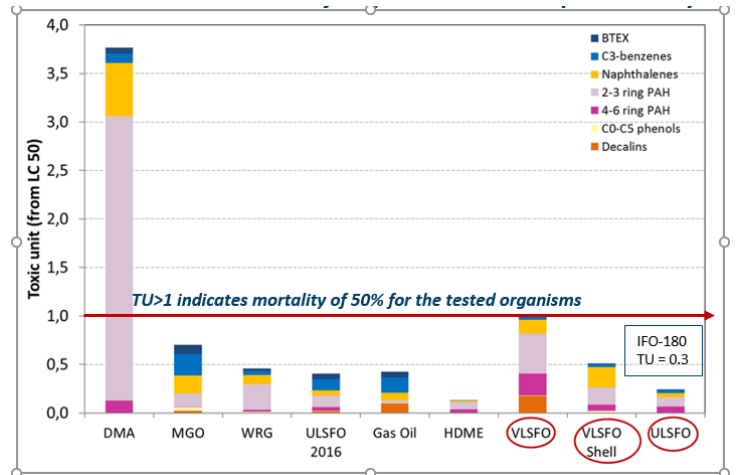


The theoretical Toxic Unit (TU) where computed based on the chemical composition of the WAFs. A TU > 1 for the total WAF implies more than 50% mortality on the test organisms. TUs for VLSFO Shell 2019 and ULSFO Shell 2019 were below 1 (0.51 and 0.24, respective). TU for VLSFO Chevron 2019 was 1.02,

indicating that the WAF could cause mortality > 50% of the test organisms.

However, the toxicities of the WAFs were low and are in the same range as other previous tested marine distillates fuels, except from a certain DMA diesel with a significant higher toxicity caused by its high contents of semi-soluble naphthalenes and polyaromatic hydrocarbons (PAHs).

The overall results from the relative and specific toxicities tests were also in accordance with the relative ranking of the TU values.

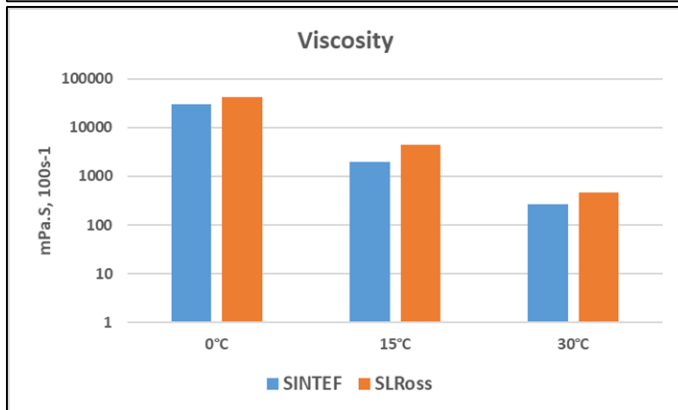
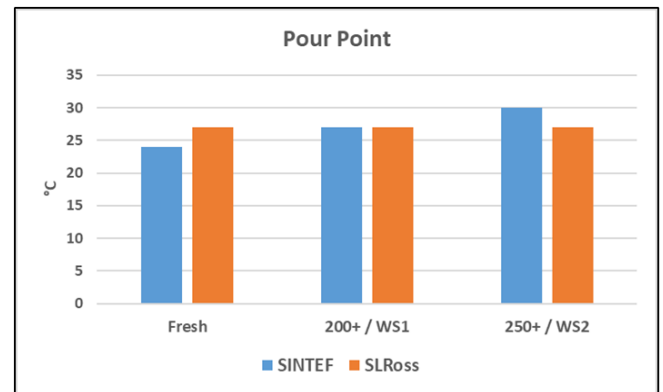


## 9 Interlaboratory comparison

### Physical-chemical properties

The interlaboratory comparison testing conducted at SINTEF and SL Ross Laboratories, performed on the ULSFO Shell 2019, showed acceptable results of the physical parameters for density, viscosity, pour points, and TBP. The procedures and methods used may differ since both laboratories used their standard protocols for

generating weathering data. Different weathering /evaporation procedures (i.e. distillation topping vs. oil in trays in wind tunnel) gave differences in the degree of evaporative loss, but also discrepancy in evaporation due to the high wax content and high pour-point oil for this specific oil.



### Emulsification

The discrepancy found on the emulsifying properties was related to variations in the experimental performance and procedures between the laboratories.

### Dispersibility

The dispersibility testing of ULSFO Shell 2019 was conducted by Baffled flask method (BTF) at SL Ross and by use of the MNS test at SINTEF. Corexit 9500A was used as dispersant. The tests indicated a low dispersible effectiveness on the fresh oil (<5%) at both laboratories.

### Ignitability /ISB

The experimental setup and test procedures for the ISB experiments are different at the two laboratories and may explain variance in the results of the burning efficiency. In both laboratories, the burn testing was conducted with a similar starting oil layer thickness on water of 1.7 cm (SINTEF) and 2.0 cm (SL Ross). However, the burn conditions at SINTEF using a tray with the oil layer on a "static" reservoir of water, is an attempt to simulate the burn of a "free" drifting oil slick. While the SL Ross test apparatus is more simulating a burn of oil when being towed in a boom behind a ship, and where the underlayer water is continuously replaced with cold water, that delay / avoid the water to boil. This gave a much longer burning time (e.g. 17 min. vs 6 min. in the SINTEF test) and give a higher burning efficiency (BE = 93% vs. 47% at SINTEF). It is also important to keep in mind, that these laboratory results must be considered as "relative" values, as these burns are conducted in a batch format, i.e. a larger starting volume of oil within the test cell should generate better

calculated efficiencies if the oil burns terminate at similar final residue slick thickness.

### Conclusion interlaboratory test

The ULSFO Shell 2019 was a challenging oil for interlaboratory calibration studies due to its extreme high pour point, solidifying properties and stickiness that may easily influence on the test results.

However, there has been a lot of lessons learned for both laboratories from this interlaboratory comparison study that form a good basis for further harmonization of laboratory test methodologies and standardization, including harmonized laboratory protocols for:

- Oil weathering (incl. evaporation, emulsification, photooxidation, etc.)
- In-situ burning testing (both ignitability and burning effectiveness)
- Dispersant effectiveness testing
- WAF / toxicity testing
- Implementation of experimental data into numerical models for oil weathering predictions

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## 10 Oil properties related to oil spill response

The companies mentioned in this report provided samples for investigation of the fuel's characteristics when spilled in sea water to help with the development of an industry response strategy for a new generation of low-sulfur fuel oils. Many of the low-sulfur fuels being developed by the industry share similar compositions, so it is important to note that the findings of this report are not unique to the fuel samples analysed. The results of this study are indicative of a new generation of marine fuel oil across the wider industry. Further laboratory analysis of low-sulfur fuel oils from other suppliers is needed to give a clearer understanding of the characteristics and behaviours of individual products.

In general, the oil weathering properties will influence the decision-making of response options (mechanical recovery, dispersant use and *in-situ* burning) in a spill situation. Studies so far have revealed that the new generation of low sulfur fuel oils may have oil properties that make them difficult to handle to mitigate the environmental impact in case of an oil spill:

- The effectiveness of using **dispersants** may be limited due to either high viscosities or high pour point

- The potential for use of **ISB** can be limited as the **ignitability** may be slow (i.e. extended ignition time) due to low contents of volatiles. Small amount of water uptake (emulsification) may prevent the oil to be ignited without use of significant amount of primers (e.g. diesel)
- The efficacy of **mechanical recovery** is dependent on the choice of skimmer system that force contact between the oil and the recovery unit. Oils with high pour points will likely need an "active", manoeuvrable skimmers (i.e. belt, drum, brushes) designated for solidified oils. Therefore, there is a need for more systematic testing and documentation of different skimmer concepts for such oils - particularly in cold water spill situations (ITOPF, Technical information paper)
- Behaviour when stranding on **shorelines**, e.g. adhesion to shoreline substrate or remobilization in acute and restoration phase. Shoreline clean-up techniques: washing with or without shoreline cleaning agents

### VLSFO Chevron 2019

- Mechanical recovery is expected to be an option both in cold climate areas and in higher

temperatures. The predicted viscosities are in the range of 10-60 000 mPa.s (2 °C) and 4000 to 40 000 mPa.s (15 °C)

- The use of dispersants proved to be ineffective at 2 °C, reflecting cold climate regions /arctic conditions. The oil has a potential for use of dispersants at higher temperatures (13 °C) to break up the surface slick into smaller patches. However, slick break-up requires energy in terms of either breaking waves (> 5 m/s wind speed) and/or artificial energy and high dispersant dosage. Larger oil droplets / lumps will easily re-surface.
- ISB is limited/reduced due to the low content of volatiles and high flashpoint (109 °C). By using the standard SINTEF ignition strategy, it took 18 min. before the burn from the gelled gasoline/diesel ignitor was spread to the surrounding oil. Due to the very long heating time needed for igniting the waterfree oil, tests on emulsified oil was not considered to be relevant.

#### **VLSFO Shell 2019**

- Mechanical recovery can be challenging due to the very high viscosities (risk for solidification) at 2 °C due to high viscosities 80 000 to 800 000 mPa.s. At higher temperatures, the viscosities are lower, but after 1 days of weathering e.g. at 10 m/s wind speed, the viscosity may reach 100 000 mPa.s.
- Use of dispersants is not an option at 2 °C, reflecting a cold climate /arctic conditions due to its high viscosities. At higher temperature (13 °C) the oil may have the potential (reduced) for dispersants to break up the slick but requires breaking waves conditions (> 5m/s wind

speeds) and /or additional artificial energy in addition to the dispersant. Larger oil droplets / lumps will easily re-surface

- ISB is limited /reduced on VLSFO Shell 2019 with a flashpoint of 100 °C. By using the standard SINTEF ignition strategy, it took 10 min. before the burn from the gelled gasoline/diesel ignitor mixture spread to the oil. Due to the very long heating time needed for igniting the waterfree oil, tests on emulsified oil was not considered to be relevant.

#### **ULSFO Shell 2019**

- The efficacy of mechanical recovery is dependent on the choice of skimmer system. At 2 °C, viscosities may surpass > 100 000 mPa.s. Due to the very high pour point, solidification at sea is a likely scenario. In a spill operation, this oil requires specific "active" skimmer systems designated for solidified oils (e.g. belt-skimmers, grabs).
- At 2 °C, ULSFO Shell 2019 was not found dispersible due to its high pour point and high viscosity. At 13 °C, adding dispersants showed low effectiveness. Overall, the use of dispersants is not recommended for ULSFO Shell 2019
- ISB have a potential on the non-emulsified oil. It took 3 min. before the burn was spread to the surrounding oil layer. Low potential for ISB for emulsified oil (need for using significant amount of diesel as a primer)



## 11 Conclusion and further recommendations

The low sulfur (residual) fuel oils tested in this project indicate a high degree of persistence on the sea surface. The oils have high viscosities and/or high pour points. Therefore, an oil spill response operation can even be more challenging than the previous traditional intermediately fuels oils (e.g. IFO 180 or IFO 380), particularly in cold water spill situations. Accordingly, for oil spill responders it is crucial to get a better overview and knowledge of the variability in the weathering processes, fate and behaviour and response capabilities of the new generation of low sulfur fuel oils.

The ongoing change among refineries to comply with the new sulfur regulations requires a demand for further characterization of the increasing numbers of such oils coming on the market. Further recommendations based on findings from this project are suggested:

- Small-volume samples of marine fuels (both distillate and residual fuels) from a larger number of refineries should be collected for a screening testing of simple oil parameters (e.g. TBP, density, pour point, gas-chromatography, viscosity and emulsifying properties at relevant sea temperatures)
- Based on such preliminary screening, a selection of oils should be followed up with a

more extensive oil weathering characterizations and meso-scale / basin testing of relevant response techniques (dispersants, ignitability/ISB, different skimmer concepts etc.), and shoreline adhesion and response techniques

- Further harmonization of test methodologies and test protocols among oil spill laboratories
- Gain a better knowledge of the differences in the chemical composition (e.g. key biomarkers and unresolved complexed mixture) between traditional marine fuels and the new generation of sulfur-compliant marine fuels (both distillates and residuals), by e.g. use of high-resolution analytical techniques
- A co-operation with the down-stream refinery industry would facilitate the possibility for formulating future marine LSFOs with a potential for reduced environmental impact of accidental spills (not only with respect to less air emission). This should involve improved oil spill response capabilities for residual LSFO, and lower toxic effect on marine organisms than today's marine fuel oil distillates

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