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IMAROS 2

Summary report of WP4: Mechanical recovery

Deliverable D4.2

KYSTVERKET

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Disclaimer

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Executive summary

In the frame of the IMAROS 2 project, the work package 4 was dedicated to give recommendations to the applicability of different mechanical recovery systems based on the challenging behaviour of low sulphur fuel oils (LSFOs) and to get insights for operational guidelines related to sea operations. By involving the manufacturers of oil spill response equipment in the project, the objective was to promote development or modification of existing equipment in collaboration with selected manufacturers to be better prepared in case of a spill.

Manufacturers of oil spill response equipment were introduced to the challenges of recovering LSFOs in a Producers Involvement conference, whereafter interested companies could apply to qualify for participation in 3 separate mechanical recovery test trials with two VLSFOs (IM-27 and IM-28) and one ULSFO (IM-29) representing challenges for recovery in different ways. Trial periods 1 and 3 were conducted at the NCA test facilities, and indoor saltwater basin in Norway with all three LSFOs, in the fall of 2024 and the spring of 2025. Subsequent trial periods allowed for development of promising technologies and modifications on the equipment from one trial period to the next. Trial period 2 was conducted in ice conditions at XAMK's test facilities in Finland during the winter of 2025 using the IM-27 test oil, to evaluate recovery performance and oil behaviour in arctic conditions, as the strong temperature dependency of LSFOs and the presence of ice poses significant challenges for recovery.

In total, 11 different companies applied to participate in the trials where after a selection process conducted by the project consortium chose 5 different companies to be involved: Lamor, Desmi and Vikoma for the trial period 1 and 3 at NCA's test facilities, and New Naval and Lamor for the oil in ice tests in Finland. Koseq was chosen to an additional test trial at the end of the last trial period at the NCA test facility.

During the recovery trials in the fall of 2024, a study of measurements of oil components in air was conducted for the three LSFOs during recovery tests and when cleaning equipment, to assess the potential exposure of oil components in the working environment air. The results from the simplified occupational health survey showed that all the measured concentrations were below the respective current Norwegian occupational exposure limit values (OELs). For IM-27, IM-28 and IM-29, the concentrations of oil mist, oil vapours and the VOCs were below 10% of the current OELs.

Overall, the results from the mechanical recovery trials suggests that recovery equipment needs flexibility to be able to be prepared for an LSFO spill, due to LSFOs great variability in both chemical properties and behaviour at sea. The tested LSFOs exhibited poor flow properties, causing bridging and poor adhesion to skimmer brushes. The IM-28 and IM-29's high pour point caused the oil to form semi-solid slicks in the water. The oil thickness varied greatly within the slick with the highest thickness furthest away from the boom, thus changing the optimal attack point for efficient recovery.

During trial period 3, the modified skimmers demonstrated strong improvement in the recovery performance, with several successful measurements of recovery rates recorded. The test showed the need for skimmers to have the ability to actively manoeuvre into and

inside the oil slick to achieve effective recovery. Implementing thrusters on the skimmers proved to be essential for overcoming the poor flow properties of the test oils. In the hopper of skimmers, the poor flow properties have shown to be a challenge with regards to getting the oil down to the pump. Oil can stick on the sloped sides of the hopper, causing the pump to run dry. The test trials demonstrated that applying energy on the oil such as heating, mechanical movement or having the hopper and pump closer together can help the oil to slide down to the pump easier. Recovery of LSFO with poor flow properties showed to be even more challenging in sub-zero conditions with ice present. The trial period 2 showed that the IM-27 oil could be recovered in icy conditions, although its “short” properties combined with the presence of ice blocks created difficulties with oil inflow to both skimmer and pump. The use of hot water and steam improved oil flow to the pump and discharge hose but also led to an increase in free water uptake.

Due to the variability of LSFOs behaviour, it is recommended to have actively manoeuvrable skimmers with multiple configurations, such as interchangeable brushes, discs, or belts, as well as adjustable settings for immersion depth and operating speed. The challenge of this approach is that the equipment becomes more complex, which places greater demands on the operator. Work Package 4 provided significant insights into the challenges of recovering LSFOs and identified potential solutions through close collaboration with equipment manufacturers, leading to several new developments on mechanical recovery equipment.

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Introduction

In the IMAROS project, limited and poor performance of several oil skimmers was documented when testing mechanical recovery of LSFOs. Challenging oil behaviour caused poor inflow to the skimmers, due to properties such as solid or semi-solid oil slicks or lumps, low adhesion to oleophilic surfaces, or the oil having “short” properties where the oil would not continuously float towards the skimmer during recovery. Some LSFOs also caused difficulties with the oil flow from the skimmer’s hopper down to the pump.

The objective of work package 4 was to give recommendations to the applicability of different mechanical recovery systems based on the challenging behaviour of LSFOs experienced in the IMAROS project. By involving the mechanical recovery equipment manufacturers, the goal was to promote development or modification of existing equipment to be better prepared in case of a spill.

Manufacturers of recovery equipment were invited to participate in basin testing at NCA’s test facilities with their products. Additional tests were also performed in ice conditions in test facilities in Finland. Previous tests and analyses have shown that the behaviour of LSFOs is highly temperature dependent, and that recovery is particularly challenging in cold climate. Furthermore, recovery of oil from ice infested waters requires specific equipment adapted to low temperature and separation of oil from ice.

Manufacturers of oil spill response equipment were introduced to the challenges based on the results from IMAROS in a Producers involvement conference. Interested companies could apply to qualify for participation in the test trials. Subsequent trial periods allowed for improvements from one trial period to the next and facilitated development of promising technologies and possible modifications on existing equipment. Table 1 details the different tasks part of the work package.

Table 1: Details of the tasks of the WP4 of the project.

Work Package 4: Mechanical recovery			
Duration:	M1–M22	**Lead Beneficiary:**	**NCA**
Tasks	**Partners, location**	**Objectives**	
T4.1 - Manufacturer involvement and innovation	KBV, NCA, all - Malmö	Distribution of an open call to mechanical recovery equipment manufacturers to encourage involvement in the project for testing and possible development of their equipment on the LSFOs, addressing the challenges experienced in the IMAROS project. Host an information conference with interested manufacturers to present the challenges. Selection process of manufacturers to be involved in the next task.	

T4.2 - Mechanical recovery trial period 1	NCA - Horten test facility	Mechanical recovery tests at NCA's facilities. The manufacturers will be conducting the tests, supported by the project group. After the first test trials are conducted, the manufacturers get time to make modifications or new technologies to their equipment.
T4.3 - Mechanical recovery trial period 2	FBG, NCA - Kotka test facility	Mechanical recovery tests of LSFO in winter conditions i.e., oil in ice recovery tests to gain understanding of how the LSFO oil behaviour changes in sub-zero temperatures. The manufacturers will be conducting the tests, supported by the project group. The tests will utilize the same methodology that NCA uses in T4.2.
T4.4 - Mechanical recovery trial period 3	NCA - Horten test facility	Mechanical recovery tests at NCA's facilities with modified equipment. The manufacturers will be conducting the tests, supported by the project group.

Materials and Methods

T4.1 Manufacturer involvement and innovation

Producers involvement Conference

The Producers Involvement Conference took place in Malmö, Sweden, the 18th and 19th of April 2024 with additional attendance on-line. The aim of the conference was to share knowledge and challenges experienced in the first IMAROS project, to inform about the ongoing project IMAROS 2 and to invite recovery equipment producers to be involved in the planned mechanical recovery trials. A summary of the Producers Involvement Conference can be found in deliverable D4.1.

In total, there were approximately 40 participants. The main manufacturers of recovery equipment in Europe were present, most of them were in place in Malmö, and some participated on-line. Representatives of the following companies attended: Allmaritim, Desmi, Elastec, Foilex, Koseq, Lamor, New Naval, Nofi, Norlense, SpillTech and Vikoma. Representatives of the organizations that are project partners were also present, as well as associated partner OSRL.

NCA gave a presentation of findings and conclusions related to mechanical recovery of VLSFO and ULSFO in the IMAROS project. Significant challenges recovering some LSFOs were observed in the previous project. The attendees were also informed of the trials that would be conducted in both Horten and Kotka from autumn 2024 to spring 2025 and demonstrated what the test facilities look like. Selected equipment manufacturers would get the opportunity to test their equipment free of charge in the test facility in Norway and/or Finland and have access to three different LSFOs. The attended suppliers were also able to give a short presentation about their company and share their knowledge and experiences about challenges with mechanical recovery of LSFO. The manufactures showed great interest and they, as well as the responders, are keen to see innovations and development to find the right solution for recovery of this type of oils.

Selection of manufacturers to be involved in the project

After the Producers Involvement Conference, the project consortium received a total of eleven applications from equipment manufacturers with a great variability of solutions. All applications showed promising concepts with possible potential to combat, at least to some extent, the challenges with recovery of LSFOs.

The 11 applications came from businesses from 10 different countries, both inside and outside Europe. The applicants were from the companies Elastec, Technika, Desmi, Faltech, Vikoma, Allmaritim, Seinprotek, New Naval, Koseq, Lamor and Norlense.

Challenges concerning the inflow of VLSFO/ULSFO into the skimmers and from the hopper to the pumping solutions were emphasized in the presentations in Malmö. Although, the applicants suggested different concepts, the project consortium decided to focus mainly on this issue when selecting the applicants.

The project consortium evaluated the applications during workshop 2 in Billund, resulting in three companies being chosen for testing in Horten for trial period 1 and 3, and two companies for testing in Kotka for trial period 2. One additional company was invited to participate with a modified test procedure in Horten after trial period 3.

Companies chosen for mechanical recovery trial 1 and 3 at the NCA test facilities in Horten, Norway:

- Lamor Corporation Plc
- Vikoma International Ltd
- Desmi Ro-Clean AS
- In addition, Koseq BV was invited as an additional applicant to participate with an alternative test procedure after trial period 3.

Companies chosen for mechanical recovery trial 2 at the XAMK test facilities in Kotka, Finland:

- Lamor Corporation Plc (oil-in-ice concept)
- New Naval (oil-in-ice concept)

The chosen concepts fit within the frames and limitations described and demonstrated the best ability and plausibility to deliver according to the purpose and objectives of the project. The concepts were based on modifications of already proven technology. They also presented modifications and product developments addressing the specific issues with VLSFOs and ULSFOs presented at the conference in Malmö.

T4.2-4 Mechanical recovery trial period 1, 2 and 3

Mechanical recovery trial period 1

The NCA test facility located in Horten, Norway, consists of an indoor seawater basin where equipment can be tested in almost realistic surroundings by adding waves and current in the basin[1]. For trial period 1, Lamor, Desmi and Vikoma were invited to the NCA test facility in September and October of 2024, where each company got 2 weeks for testing their proposed technology on the three LSFOs. The first trial period allowed for experimentation and trying different approaches to determine what has the best potential for recovery of LSFOs with challenging behaviour. The experiences gained in the first trial period would determine what technology to go forward with in the final trial period.

For the test trials at the NCA test facility in Horten, Norway, the oils were emulsified to reach a water content of approximately 50 %. Each manufacturer tested on 2 cubic meters of each oil emulsion. The tests were performed with ambient temperatures, where the air temperature ranged between 12 and 17.5°C and the water temperature ranged between 14 and 15.5°C. The test configuration used were according to the NCAs test procedure for oil spill equipment, and four different test setups were conducted on the oils during the trial period to test the equipment in different conditions:

[1] https://www.kystverket.no/contentassets/47120f9d284743f387df5c47c3688a15/the-national-centre-for-testing-of-oil-spill-response-equipment--eng.pdf

Test setup 1: <u>Capacity test of oil emulsion in confined basin:</u>
Oil emulsion (approximately 50% water) and skimmer placed in a confined basin (4x4m). Capacity test of how much oil a skimmer can recover measured in m^3/h. The experiment is carried out with an oil thickness of 12.5 cm with 2000 litres of oil which corresponds to the skimmer always operating in oil emulsion. The goal is to recover 500 litres of oil for three similar repetitions to decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the potential free water to measure the true amount of oil emulsion recovered.

Test setup 2: <u>Capacity test of oil emulsion in confined basin with waves:</u>
Similar setup as test 1, in addition with waves.

Test setup 3: <u>Capacity test of oil emulsion in boom with current:</u>
Oil emulsion (approximately 50% water) and skimmer placed in the boom, with current simulating towing of boom. The speed of the current is approximately 0.6 knots. 2000 litres of oil emulsion is poured into the basin, and the goal is to recover 800 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.

Test setup 4: <u>Capacity test of oil emulsion in boom with current and waves:</u>
Similar setup as test 3, in addition with waves.

See Appendix 1 for details of NCAs test procedure, configurations, and test setups used for the mechanical recovery trials.

All three companies had promising approaches during the first trial period, but still significant room for improvement. An important part of the first trial period was to allow time for experimentation of different methods and technology to both determine what has the best potential for recovery of LSFOs with challenging behaviour, but also to verify which methods that does not have the desired effect on recovery. A lot of different methods were tried by the companies during the tests, such as removing floaters and surfaces in front of the skimmer head, mechanical cutting of solid oil slicks, putting thrusters on the skimmer, using jet stream or heating the oil in front of the skimmer to enhance flow, developing new types of brushes, changing placement of hopper and pump, mechanical movement or heating in the hopper, and water injection behind the pump. Some of the methods and technology showed little effect, but others were promising. Even though not all methods improved recovery, a lot of experience and knowledge was gained during the experimentation. The manufacturers underlined that the first trial period has given them significant new knowledge on how to handle LSFOs and useful experiences to improve their equipment. All three used the following six months to work on modifications and improvements before returning for retesting in April and May 2025.

Since trial period 1 was conducted as an experimental phase designed to facilitate open communication between the project group and the manufacturers, it was decided to keep the detailed descriptions of the technology and the oil recovery rate measurements from this trial period internal. A formal test report was instead prepared for trial period 3, featuring the finalized skimmer design and more comprehensive recovery measurements.

Mechanical recovery trial period 2

For trial period 2, the tests were performed at XAMK's outdoor test facility in Kotka, Finland. The test basin is an aluminium pool that was filled with freshwater and ice blocks mimicking a solid ice field that has a fairway broken in the sea. Ice coverage in the pool was approximately 80 %. Adding ice and cold temperatures, recovery of LSFOs is even more challenging than under the more temperate conditions of the trials in Horten. The test facility operates with ambient temperatures, and the measured air temperature was -4°C and the water temperature was 0°C during the tests. The facility made it possible to do mechanical recovery tests of LSFO in winter conditions to gain experience of possible challenges regarding recovery equipment of oil behaviour in sub-zero temperatures below the oil's pour point. One sample of fresh LSFO was used for trial period 2, sample IM-27. The oil sample was selected based on the initial information on its properties.

During week 7 in February 2025 Lamor and New Naval attended the trials in ice conditions in Kotka. The test procedure used in the trial is shown in appendix 2. A detailed description of the tested equipment is found in appendix 8 (*Test report from Lamor mechanical recovery trial period 2*) and appendix 11 (*Test report from New Naval mechanical recovery trial period 2*). Both manufacturers expressed that valuable experiences were gained during the trials, regarding the challenges of recovering LSFOs in cold and arctic conditions where ice is present.

Mechanical recovery trial period 3

The three companies Lamor, Desmi, and Vikoma, that attended trial period 1 at NCA's test facilities in the fall of 2024, came back to retest their modified equipment during April and May of 2025. At this time, the temperatures ranged between 12-14.5°C for water and 14-23°C for air. Based on the experiences gained during the first trial period, the test setups were slightly adjusted to better fit the use of the modified and more dynamic skimmers in the basin. Therefore, only test setups 3 and 4 were conducted during trial period 3:

Test setup 3: Capacity test of oil emulsion in boom with current:
Oil emulsion (approximately 50% water) and skimmer placed in the boom, with current simulating towing of boom. The speed of the current is approximately 0.6 knots. 2000 litres of oil emulsion is poured into the basin, and the goal is to recover 800 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.

Test setup 4: Capacity test of oil emulsion in boom with current and waves:
Similar setup as test 3, in addition with waves.

The companies had made improvements on their equipment based on the experiences during the first trial period and had made several modifications where the equipment was more prepared to tackle the challenges presented by the oils. A detailed description of the tested equipment is found in appendix 7 (*Test report from Lamor mechanical recovery trial period 3*), appendix 9 (*Test report from Desmi mechanical recovery trial period 3*) and appendix 10 (*Test report from Vikoma mechanical recovery trial period 3).* Oil recovery rate and free water uptake was measured and documented for all three skimmers and all three test oils.

One additional test trial with Koseq was conducted in June 2025 with a modified test procedure. This equipment is a high-capacity system, and to be able to test it larger volumes of oil were released. A detailed description of the tested equipment is found in appendix 12 (*Test report from Koseq additional mechanical recovery trial*). This test took place at the end of the last trial period in order to be able to re-use emulsion from all the previous trials. Oil recovery rate and free water uptake was measured and documented during the test.

The test oils

Ten cubic meters of the 3 large samples, 2 VLSFOs (IM-27 and IM-28) and one ULSFO (IM-29) were acquired for the mechanical recovery trials. Based on the trend analyses in this project and the first IMAROS project, the characteristics of these oils fit within range of the most used low sulphur fuel oils in Europe, as described in deliverable D2.3 (*Summary report of WP2 – Trends and samples*) and D3.1 (*Summary report of WP3 - Characterisation and Impacts*). The three oils also demonstrate some of the range in properties observed in LSFOs and represents challenges for recovery in different ways.

The oils were analysed at the laboratory of Sintef Ocean for the physical properties' viscosity, density, water content, and pour point, as can be seen in table 2. See appendix 4 and 5 for Sintef memo of the oil analyses conducted for the mechanical recovery trials. 51 samples of oil emulsion were taken in different stages during testing and analysed for viscosity, water content and density for selected samples. A list describing the samples of oil emulsion that were taken during testing in recovery trial period 1 and 3 is found in appendix 3.

Table 2: The oils physical properties (from Sintef Ocean). Viscosity measurements are from the temperature sweep.

IMAROS ID	Viscosity, temp sweep (cP)		Density (g/mL)		Water content	Pour point
	10 °C	50 °C	50 °C(measured)	15 °C(calculated)	(%)	(°C)
VLSFO IM-27	23104	282	0.931	0.954	0.1	12 (9, 24)*
VLSFO IM-28	36277	110	0.909	0.932	0.1	27 (21, 30)*
ULSFO IM-29	932	9.6	0.866	0.890	0.2	27 (15, 24)*

**For pour point, the first value is from the oil suppliers' certificate of analysis. The values in brackets are measured minimum and maximum pour point from Sintef and Cedre laboratories. Pour point measurements seems to be subjected to uncertainties and is described in more detail in deliverable D3.1 Summary report of WP3 – Characterisation and Impacts chapter 3.1.4.*

For the trials in Kotka VLSFO IM-27 was selected. Out of the three large samples, this is the sample with the lowest pour point (table 2). With a pour point of 12°C some degree of solidification of the slick was expected at low temperatures, still within a range possibly allowing mechanical recovery (not completely frozen solid).

Occupational Exposure

In addition to conducting mechanical recovery trials during the fall of 2024, a study of air measurements of oil components in air was conducted for the three LSFOs during recovery tests and when cleaning equipment. The aim of the study was to assess the potential exposure of oil components in the working environment air during the testing of oil skimmers in the basin with LSFOs, as a part of risk management.

A simplified occupational health survey was employed, where multiple measurements were performed to ensure that exposure to volatile organic compounds (VOC), oil mist, and oil vapours was under 10% of the current Norwegian occupational limit values (OELs). Samples were collected in the breathing zone of the workers and compared with stationary samples collected around the test pool. Oil vapours, oil mist, and volatile components such as benzene, toluene, ethylbenzene, xylene, and n-hexane were quantified. The summary report from the study is found in appendix 6.

Results and discussion

The complete test reports from the mechanical recovery trials for each of the manufacturer involved in the project is presented in Appendix 7-12. The main findings and experiences related to the testing of IM-27, IM-28 and IM-29 from the mechanical recovery trial periods are presented below.

Mechanical recovery of the VLSFO IM-27 oil

The IM-27 emulsion appeared relatively fluid, was dark in colour and did not produce a rainbow or metallic sheen on the water surface. The emulsion also remained stable during testing, however, during the tests small pockets of free water could be observed in the emulsion in the collecting tank, but it is not known if the emulsion partly separated or if it was free water from the recovery process that did not settle at the bottom of the collecting tank. Although the slick behaves relatively fluid, the oil exhibit some “short” properties, where the oil would not continuously float towards the skimmer during recovery, and a thin layer of water could be observed between the skimmer and the oil, hindering further recovery (figure 1).

Figure 1: Photo of water layer between skimmer and the IM-27 oil.

This challenge was evident during the mechanical recovery trial period 1 at the NCA test facility for the skimmers that floated stationary in the slick. Adding energy such as increased current or moving the skimmer within the slick, could assist recovery when this problem occurred.

For the tests performed at the NCA test facility during trial period 3, the equipment manufacturers had made modifications on their skimmers based on the challenges experienced during the trial period 1. All of the tested skimmers managed to recover the IM-

27 oil successfully, much due to the help of thruster movement. The thrusters enabled the skimmers to actively manoeuvre within the oil slick, preventing the formation of a water layer between the oil and the skimmer. Since the IM-27 oil emulsion was relatively fluid, no problems were observed with oil flow inside the hopper or pumping the oil through the discharge hose to the collection tank. There was also a relatively low free water uptake.

During oil-in-ice tests in Kotka, Finland, the fresh oil did not solidify, even with a water temperature of 0°C, well below the oil's pour point. Even though the oil stayed somewhat fluid in such cold conditions, there were challenges for the skimmers when recovering this oil in combination with ice. The short characteristics of the oil were also present, and ice blocks further enhanced the problem of getting in contact with the oil in between ice blocks. Barriers on the skimmer to stop ice from entering the skimmer also hindered oil reaching the skimmer. Some success was observed when operating the brush skimmers on low rotational speed in combination with using brushes with spacing between brush rows, allowing for relatively good oil adhesion. Hot water and steam improved the oil flow to the pump and discharge hose by making oil more fluid, but it also increased the free water uptake.

Mechanical recovery of the VLSFO IM-28 oil

The IM-28 emulsion was dark brown with minimal colour change during the recovery tests. The emulsion exhibited high viscosity and high pour point properties and created a semi-solid slick on the water surface. The slick remained too rigid to allow for significant oil thickening at the proximity of the boom even when increasing the water current. It could be observed that the oil tended to accumulate at the far edge of the slick, with greater thickness furthest away from the boom (figure 2) and began to roll from the forces of the water current. This slick behaviour differs from prior experiences with most conventional oils, where the greatest oil thickness is closest to the boom (apex), being the natural attack point for effective recovery.

Figure 2: Photo of the edge of the IM-28 oil slick, with high thickness furthest from the boom.

The semi-solid slick caused very poor flow properties into the skimmers and caused challenges for the skimmers during the first trial period. When operating the skimmer stationary, there was little to no flow of oil towards the skimmer, and bridging of the oil in front of the skimmer could be observed (figure 3). Oil bridging was also observed when the slick encounters an obstacle or constriction, and stayed stationary in front of the skimmer, even when increasing the water current to push the oil towards it.

Figure 3: Photo showing that the IM-28 oil is bridging in front of skimmer.

Although the IM-28 exhibited little to no flow properties and provided several challenges during the mechanical recovery trial period 1, the modified skimmers with installed thrusters was able to use the thrusters to manoeuvre from the “seaside” toward the oil slick, forcing the oil into the skimmer and allowing for good recovery during the recovery trial period 3. Compared to IM-27, recovery of IM-28 required much more active manoeuvring in the basin, as the skimmer constantly needed to pursue the oil and push it toward the skimmer brushes/brush bands. Modifications on brush traits, such as having large spacing between brush rows, also assisted in enhancing recovery. Furthermore, technologies such as dynamically adjusting the brush height or mechanically cut the slick into smaller pieces showed to help in the recovery of a semi-solid oil such as the IM-28.

In the hopper of the skimmers, this oil’s poor flow properties have shown to be a challenge regarding getting the oil down to the pump. Oil can stick on the sloped sides of the hopper, causing the pump to run dry. Applying energy on the oil such as heating, mechanical movement or having the hopper and pump closer together helped the oil to slide down to the pump easier. Even though the temperature of the oil during the recovery trials at the NCA test facility was below the oil’s pour point, it was observed that the IM-28 appeared to become less viscous and solid after being processed through discharge hoses. This can indicate that only small variations in temperature created by the added energy, has the potential to change its properties to some degree. Furthermore, the oil is shear thinning, meaning that also mechanical forces may change the viscosity of the oil substantially. But it should be noted that when the oil is collected in a storage tank, it is still likely to be challenging to get the oil out again without applying energy onto the oil such as heating or an internal pump.

Mechanical recovery of the ULSFO IM-29 oil

The IM-29 oil emulsion was light brown in colour and quite fluid when heated. The emulsion has a relatively low viscosity. However, upon pouring it into the basin, the oil became a semi-solid slick and at the same time it appeared to be extremely "short", easily fragmenting in the water (figure 4).

Figure 4: Photo of fragmentation/short properties of the IM-29 oil slick.

During the mechanical recovery trial period 1, the short and semi-solid properties caused several challenges for the skimmers to get hold of the oil, especially when operating the skimmer stationary in the water, as the oil in contact with the skimmer would easily break apart from the slick and the oil would bridge in front of the skimmer. It could be observed that the front edge of the oil slick thickened and began to roll from the forces of the water current, causing the slick to have a higher thickness furthest from the boom (figure 5). The emulsion also had a strong and unpleasant odour.

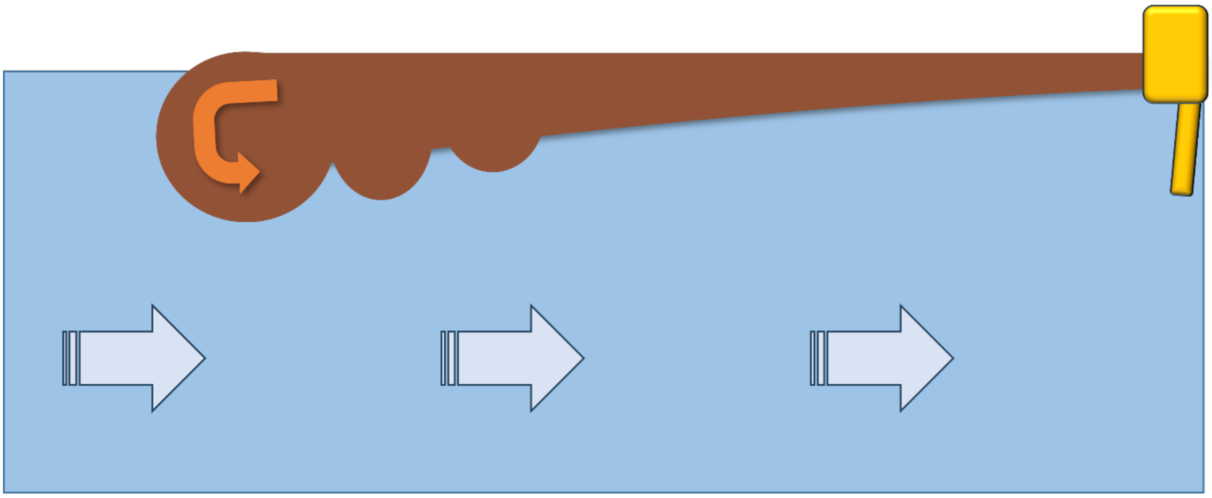

Figure 5: Illustration of how the oil slick has highest thickness furthest from the boom, due to rolling at the edge of the slick. Blue arrows indicate the direction of the current.

Even though the IM-29 exhibit both short and semi-solid properties, the modified skimmers tested in in trial period 3 managed to achieve good recovery when the skimmers with brushes/brush bands operated at low rotational speed in combination with using thrusters to push the skimmer towards the oil, which increased adhesion to the oil, while also keeping the free water uptake low. In contrast, higher rotational speed on the brushes introduces much more energy onto the oil surface, causing the oil in contact with the brushes to become highly fluid and slippery in addition to its already short characteristics. Hence, it was more efficient to operate the brushes at a lower speed.

Once inside the hopper, the oil flowed into the pump and through the discharge hoses without much difficulty. Adding energy onto the oil appears to change the oil's properties to become less solid and more fluid and slippery, as seen when processed through brushes or hoses.

Occupational exposure

The report from the study of air exposure conducted at the NCA test facility during the mechanical recovery trial period 1 is found in appendix 6. Overall, the results from the simplified occupational health survey showed that all the measured concentrations were below the respective current Norwegian occupational exposure limit values. For both IM-27, IM-28 and IM-29, the concentrations of oil mist, oil vapours and the VOCs from the tested oils were below 10% of the current Norwegian occupational limit values (OELs). The concentration of volatile compounds was below the detection limit, except for certain substances from IM-28 and IM-29 oils. The exposure index for the three oil samples was well below 10% of the OEL.

Conclusion

Both IMAROS projects have shown that LSFOs have a great variability in chemical characteristics and behaviour at sea. Several LSFOs have shown to have poor flow properties, causing bridging and poor adhesion to skimmer brushes and discs, which calls for skimmers to have the ability to actively manoeuvre into and inside the oil slick to recover the oil. Implementing thrusters on the skimmers proved essential for overcoming the poor flow properties exhibited by the test oils. Also, the oil thickness can vary greatly within the slick, and have highest thickness furthest away from the boom, thus changing the optimal point of attack for efficient recovery. In the hopper of skimmers, the poor flow properties have shown to be a challenge regarding getting the oil down to the pump. Oil can stick on the sloped sides of the hopper, causing the pump to run dry. Applying energy on the oil in form of heating, mechanical movement or having the hopper and pump closer together can help the oil to slide down to the pump easier. Recovery of LSFO with poor flow properties showed to be even more challenging in sub-zero conditions with ice present.

The mechanical recovery trials indicate that recovery equipment needs flexibility to be able to be prepared for an LSFO spill. Due to the variability in the behaviour of LSFOs, it is recommended to have actively manoeuvrable skimmers with multiple configurations, such as interchangeable brushes, discs, or belts, as well as adjustable settings for immersion depth and operating speed. The challenge of this approach is that the equipment becomes more complex, which places greater demands on the operator.

The work package 4 has resulted in valuable experiences both regarding the challenges with recovering LSFOs with problematic behaviour, but also possible solutions. By involving manufacturers of mechanical recovery equipment in the project and participation in the trials, we achieved great collaboration resulting in several new technologies and developments on equipment to combat the challenges.

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APPENDIX 1

Test procedure mechanical recovery Horten Test Facility

IMAROS 2 – WP4

Procedure for testing oil skimmers in the National Centre for Testing of Oil Spill Response Equipment

Norwegian Coastal Administration's Test Facility – Horten, Norway

Author(s): Norwegian Coastal Administration

Introduction and purpose

The test procedure describes how to approach testing oil skimmers in the National Centre for Oil spill response located in Horten, Norway. The test facility consists of an indoor saltwater basin where equipment can be tested in almost realistic surroundings by adding waves and current in the basin[1]. The basin makes it possible to test oil skimmers in full scale. The Centre also contains a laboratory where the water content, viscosity and density of the oil can be measured. Testing makes it possible to test oil skimmers under controlled conditions with almost realistic conditions, including waves and currents. The tests can be versatile and vary, possible tests are for example function testing, efficiency testing, testing of capacity and they all may give input for operational use.

The purpose of the procedure is to ensure quality and verifiability of the testing. However, it will be necessary to take experiment-specific considerations into account, depending on factors such as the purpose of the testing, the type of oil and the nature of the oil skimmer. Furthermore, the testing will contribute to evaluate the oils viscosity, thickness and so forth. The testing will also allow for discovery of weaknesses and strengths of the oil skimmer and uncover operational considerations.

The test done in the test centre will demonstrate how the oil skimmers function in a controlled environment. In an actual situation in the nature, several condition may influence the skimmers' function. This may be weather conditions, type of oil and other debris in the oil. The test in the test basin will never be able to recreate the environment accurately to the actual oil spill. The result of the test gives a solid basis for assessment but can't be uncritically transferred to real situations.

The approach of this procedure to test the oil skimmers capacity for recovering oil measured in m^3/h.

HSE in the test facility

Before start-up, risk factors must be highlighted by conducting a risk assessment or a Safe Job Analysis. Training shall be provided to internal personnel at the Norwegian Coastal Administration as well as external parties who use the test facilities. External parties who rent the test facility must complete the Self-declaration form – HSE in the test facilities.

The overview of which protective clothing is to be used in the test facilities is reviewed and everyone must always wear the required protective clothing.

When testing in new, unknown oil types, exposure measurements must be carried out to identify chemical health hazards. Exposure should not pose a danger to life and health.

The use of a respirator should be worn when; It is tested in new unknown oil types, exposure measurements so indicate, or when exposure measurements are in progress and results are not available. Respirators can also be used for discomfort with odours. See separate instructions.

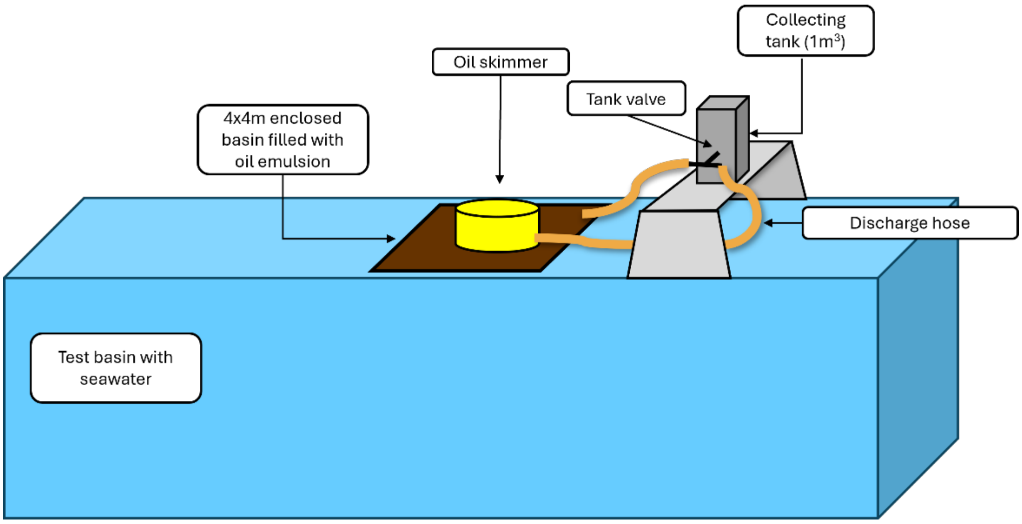
[1] https://www.kystverket.no/contentassets/47120f9d284743f387df5c47c3688a15/the-national-centre-for-testing-of-oil-spill-response-equipment--eng.pdf

Different configurations for testing

Mechanical recovery trial period 1

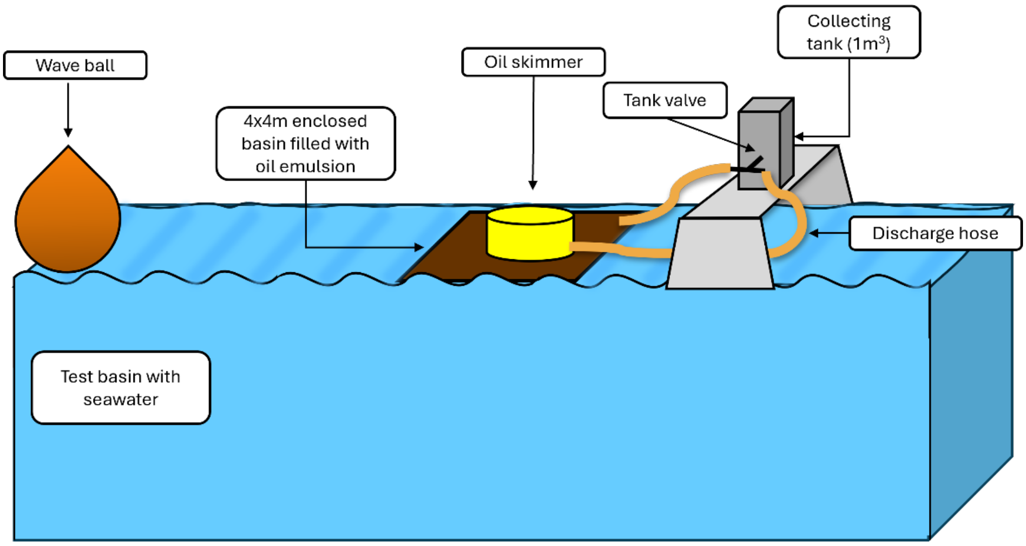
The test configurations used for the mechanical recovery trial period 1 in the IMAROS 2 project consisted of 4 different test setups:

Setup 1: Capacity test of oil emulsion in confined basin



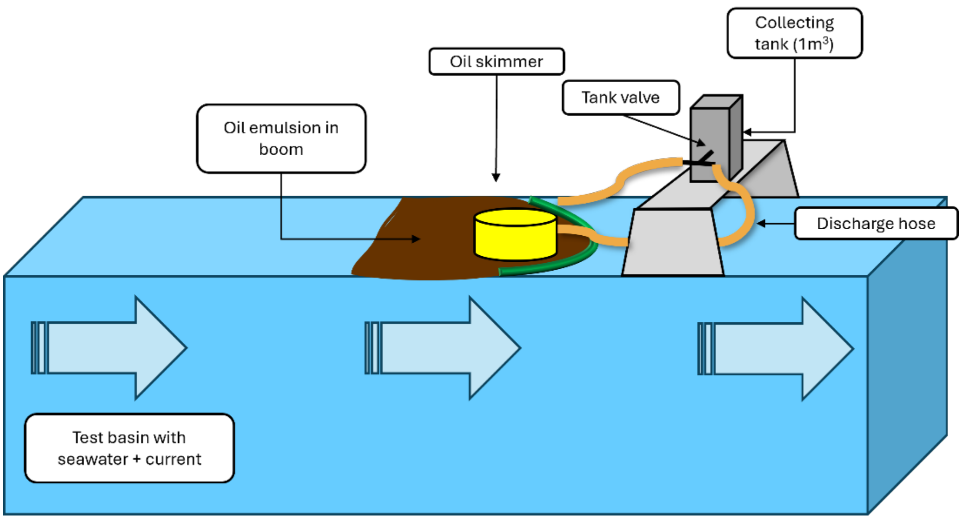
Oil emulsion (approximately 50% water) and skimmer placed in a confined basin (4x4m). Capacity test of how much oil a skimmer can recover measured in m^3/h. The experiment is carried out with an oil thickness of 12.5 cm with 2000 litres of oil which corresponds to the skimmer always operating in oil emulsion. The goal is to recover 500 litres of oil for three similar repetitions to decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the potential free water to measure the true amount of oil emulsion recovered.

Setup 2: Capacity test of oil emulsion in confined basin with waves



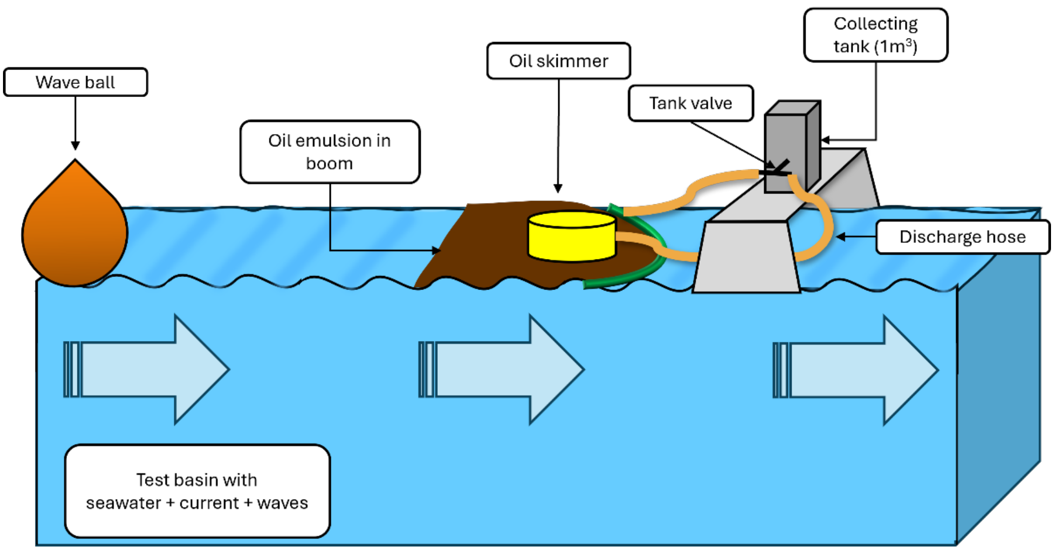
Similar setup as test 1, in addition with waves.

Setup 3: Capacity test of oil emulsion in boom with current



Oil emulsion (approximately 50% water) and skimmer placed in the boom, with current simulating towing of boom. The speed of the current is approximately 0.6 knots. 2000 litres of oil emulsion is poured into the basin, and the goal is to recover 800 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.

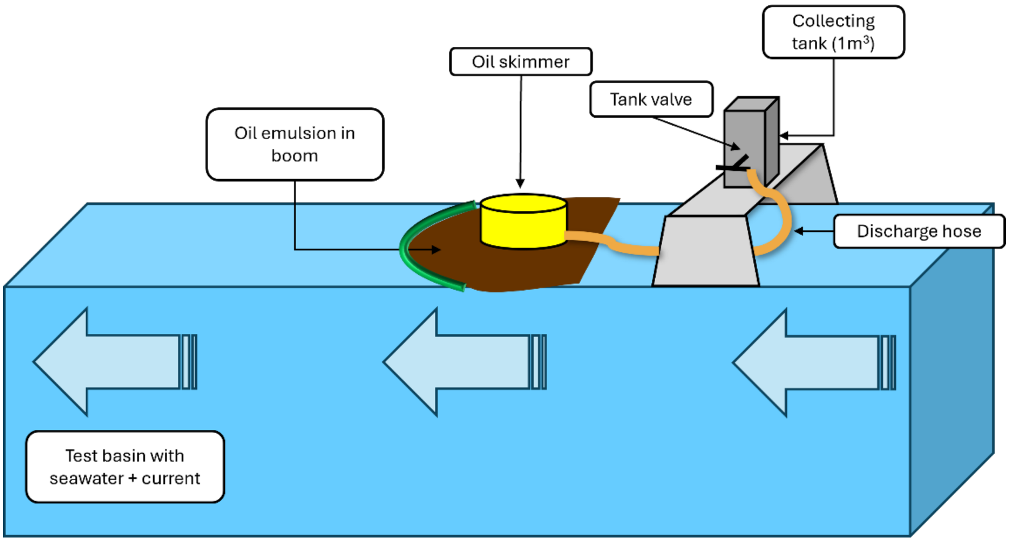
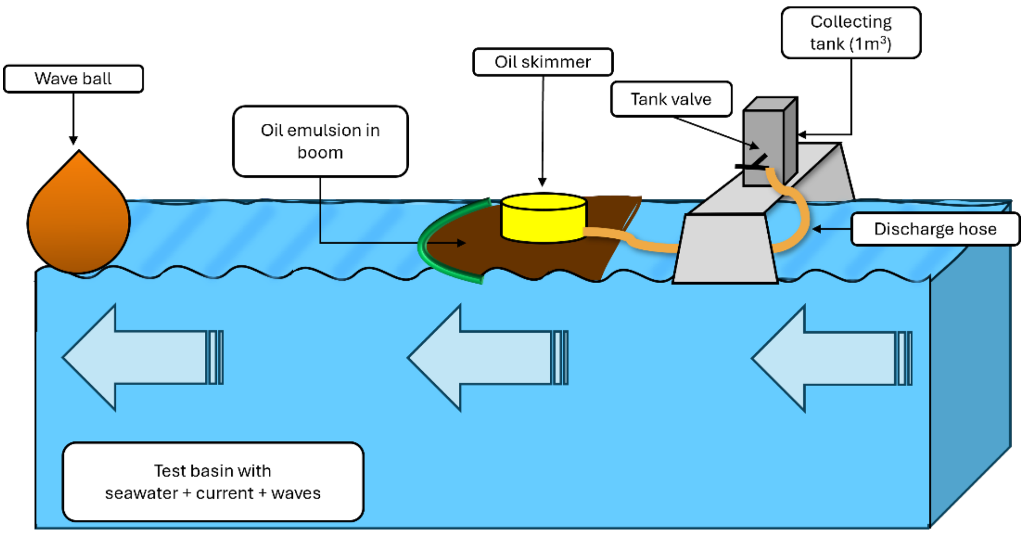
Setup 4: Capacity test of oil emulsion in boom with current and waves



Similar setup as test 3, in addition with waves.

Mechanical recovery trial period 3

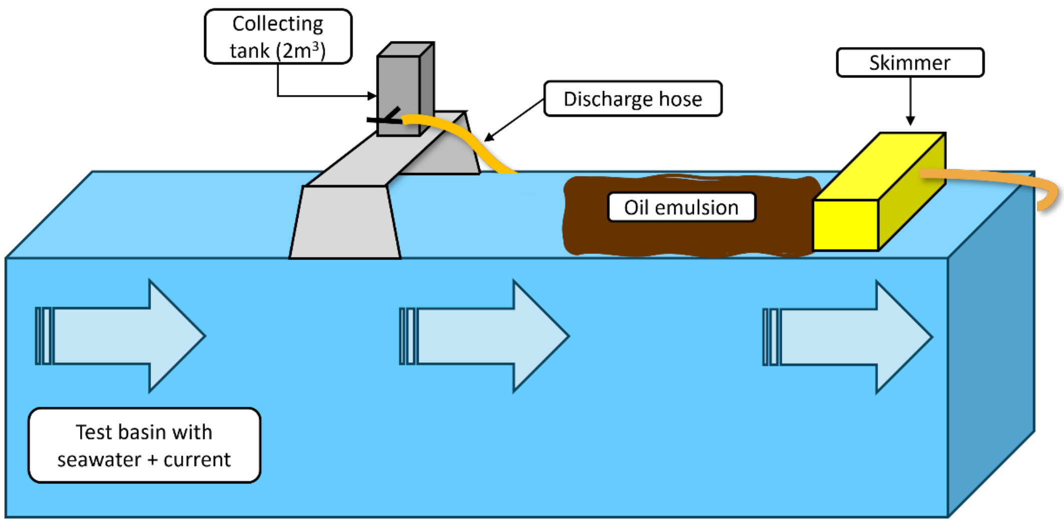
The mechanical recovery trial period 3 it was made a few adjustments to the configuration. Test setup 1 and 2 did not fit the use of dynamic skimmers and only test setup 3 and 4 was conducted. By adjusting the current to turn in the opposite direction allowed active skimmers to move more freely in the basin and within the oil slick. This adjustment also reduced possible issues with the discharge hose by always being without obstruction behind both skimmer and boom during test runs. The adjusted test setups for trial period 3 are as follows:

Setup 3: Capacity test of oil emulsion in boom with current
 Oil emulsion (approximately 50% water) and skimmer placed in the boom, with current simulating towing of boom. The speed of the current is approximately 0.6 knots. 2000 litres of oil emulsion is poured into the basin, and the goal is to recover 800 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.
Setup 4: Capacity test of oil emulsion in boom with current and waves
 Similar setup as test 3, in addition with waves.

Additional mechanical recovery trial

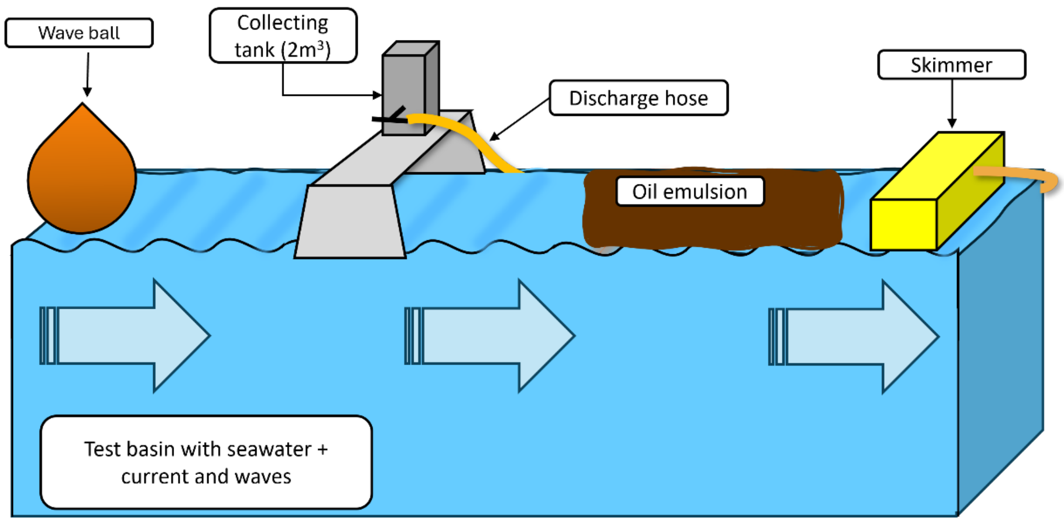
For the additional test with Koseq, it will be used a modified configuration. This equipment is a high-capacity system, and to be able to test it larger volumes of oil is needed. This test will re-use emulsion from the previous trials. The skimmer system is placed in one end of the test basin, and the oil is placed at the other end. With help of the current the slick will flow towards the skimmer. Due to the width of the skimmer system, no boom is required. The test setups for the modified configuration are as follows:

Setup 3: Capacity test of oil emulsion in boom with current



Oil emulsion (approximately 50% water) and skimmer system placed in the water, with current simulating towing of the sweeping arm system. The speed of the current is adjustable between 0.6-2 knots. 4000 litres of oil emulsion is poured into the basin, and the goal is to recover 1600 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.

Setup 4: Capacity test of oil emulsion in boom with current and waves



Similar setup as test 3, in addition with waves.

Operation of skimmer

Test 1 and 2: Optimize the skimmer towards recovering as much oil as possible, while minimizing recovery of water. Before starting the test run, the skimmer will be adjusted until optimal recovery is achieved.

Test 3 and 4: Optimize the skimmer to recover as much oil as possible, without considering that some water is also added. Before starting the test run, the skimmer will be adjusted until optimal recovery is achieved. After the test run, minimum 25 % of the supplied oil should remain in the boom.

Example
Example preparing for testing

Test Plan:
For each test, a test plan must be drawn up describing the purpose and planned implementation of the individual test. The test plan should also describe all configurations and settings, as well as include forms to document the results along the way. Special circumstances may necessitate deviations from the procedure described in this procedure. This must be justified and documented for the individual test.

Practical preparations made before conducting the test:
Make sure that the test facility and necessary equipment are prepared and functional.

- Filling oil in the basin
- Location of skimmer in the basin (float freely, optimize the system and more).
- Collecting tank with valves
- Measurements (thickness of the oil temperature oil/water)
- Current in the basin
- Wave program

Conducting testing
- Each test is conducted three times, (three separate runs). It is accepted that the three runs deviate a maximum of 20% from the average recovery rate. In the event of major deviations, the test must be carried out again.
- Each test is run with a minimum duration of 30 seconds or at least 400 litres must be recovered.
- The system should be in continuous stable operation throughout the test, (settings should not be changed along the way).
- The test ends by connecting in the by-pass valve and then shutting down the system.
- Metrics/readings of results:
    - Recovered volume is measured in the collecting tank.
    - Time duration recorded when desired volume for the test is collected.
    - Hydraulic pressure for generator and pump.
    - Let settle for as long as necessary to separate oil and water phase (15min)
    - Drain free water and measure remaining volume in the collection tank.
    - Calculate the oil recovery rate.

Sampling
For each test attempt, samples must be taken before and after the attempt. In order to provide representative samples, these must be taken from the basin, as close to the skimmer as possible, just before recording starts and in the collecting tank immediately after stopping recovery. Two parallel oil samples will be taken, one for analysis in the laboratory and one for storage.

Example

Setup of the oil recovery equipment

Hydraulic hoses

Hoses with different dimensions that are adapted to thematic couplings of type 7500 (3/4), 5000 (1/2) and 3800 (1/4) were used. Length of the hoses is approx. 15 meters. This was used for all the skimmers that were tested.

Power pack

The NCA's test facilities own fixed unit was used for running pumps and skimmers. The unit has a power of 90 kW, with variable pump.

Pressure/discharge hoses

The individual skimmer's original hose package was used:

Skimmer	Hoses
Drum skimmer	Discharge hose: 4'' 15 meters
Belt skimmer	Discharge hose: 4'' 15 meters
Adhesion band skimmer	Discharge spiro hose: 2'' 15 meters Pressure spiro hose: 2'' 15 meters
Brush skimmer	Discharge hose: 4'' 15 meters
Weir skimmer	Discharge hose: 2,5'' 15 meters

Test results

IM-XX: XXX SKIMMER

Purpose	Test 1 – oil emulsion in enclosed basin	Date	
Oil	VLSFO IM-XX		
Skimmer	XX skimmer		
Oil temperature	17˚C		
Air temperature	15.5˚C		
Water temperature	15.8˚C		
Salinity	1.03		
	Run 1	Run 2	Run 3
Total volume of oil in basin	3000 L	3000 L	3000 L
Oil thickness	18 cm	18 cm	18 cm
Volume of oil collected	480 L	450 L	490 L
Volume of free water collected	0 L	0 L	0 L
Time elapsed	04:45	02:10	02:02
Oil uptake rate	6 m^3/h	12.5 m^3/h	14.5 m^3/h
Oil sample	x		x
Deviation from procedure			

Example

Purpose	Test 3 - oil emulsion in boom with current		Date	
Oil	VLSFO IM-XX			
Skimmer	XX skimmer			
Oil temperature	19˚C			
Air temperature	15.7˚C			
Water temperature	15.7˚C			
Salinity	1.03˚C			
	Run 1	Run 2	Run 3	
Current	0.6 kn	0.6 kn	0.6 kn	
Total volume of oil emulsion in basin	2000 L	2000 L	2000 L	
Oil thickness	10 cm	10 cm	10 cm	
Volume of oil collected	691 L	674 L	690 L	
Volume of free water collected	109 L	126 L	110 L	
Time elapsed	02:52	02:33	01:46	
Oil uptake rate	14.5 m^3/h	15.8 m^3/h	23.5 m^3/h	
Oil sample	x		x	
Deviation from procedure				

APPENDIX 2

Test procedure mechanical recovery Kotka Test Facility

Procedure for IMAROS2 testing of oil skimmers in winter conditions (oil-in ice) in Kotka, Finland test facility on week 7/2025

version, 22 Jan 2025

Author(s): Finnish Border Guard

CONTENT

1 Introduction and Purpose

The purpose of the tests is to investigate capability of the oil skimmers in recovering low sulphur fuel oil (LSFO) from broken ice (oil in ice). The purpose of the procedure is to ensure quality and efficiency of the testing and to provide equal understanding to both producer company regarding the test setting.

The test conditions are mimicking solid ice field that has a fairway broken in the see. Ice coverage of the pool should be around 80 %.

2 Test facility and equipment

Tests are performed at XAMK's test facility in Sunilantie 10, Kotka, Finland. Test basin is an aluminium pool with the dimensions of 3m x 4m. The water depth of the basin will be 0,8-0,9 meters.

The producers selected to test their oil skimmer equipment will provide their own equipment including power packs, hydraulic connectors and steam hoses as well as discharge hoses. If needed for testing their equipment the producers will provide also excavator with a crane. The producers need to make sure that the discharge pipe and its hoses are warmed so that the recovered oil-water-ice mixture does not freeze in the discharge hose. Recovered oil mix will be transferred by producer's skimmer's pump to a heated IBC container provided by XAMK.

The test facility has fixed crane, that can be used. The crane loading capacity is 500 kg. Forklift or similar will be provided to help move the equipment. Also, a steam generator will be provided by FBG.

The test facility will provide the waste handling of used oil and the costs are covered by the IMAROS2 -project. The producers are responsible for cleaning their own equipment. If producers prefer that XAMK staff clean the equipment the producers need to order this work from the XAMK. The indicative cost for the cleaning is 100€/h. This needs to be agreed by making an agreement between the producer and XAMK.

LSFO will be provided by the IMAROS2 project. Preliminary information on the properties of the VLSFO: Kinematic viscosity at 50 ^{0}C 322 mm^2/s, Pour point 12 ^{0}C, Density at 15 ^{0}C 955,7 kg/m^3, Sulphur 0,387 mass %.

3 HSE

XAMK is responsible for the HSE, including providing the PPE for the manufacturer representatives. XAMK staff will brief all the participants on safety protocols.

4 Test protocol

Equipment producer will have access to the test pool during their two test days from 09:00 till 16:00.

- The other producer will not be allowed to access the test pool area during other producer's test period.
- The IMAROS2 project partner representatives will have access to the test pool area at any time during the test days.
- Access of any third-party representative who might ask permission from the IMAROS2 project to enter the test pool area during the tests is subject of approval by both the project representatives and the equipment producer.
- The technical pool personnel of XAMK is allowed to enter the test pool area during the tests.

The IMAROS2 project will take photos and record videos during the tests. The permission to publish recordings that show the used recovery equipment will be asked from the equipment producers. Equipment producers are allowed to utilise the photos and videos during their test day in their marketing material etc.

4.1 Practical preparations before conducting test

- Filling of water and ice in the basin
  - concentration of ice 80% to 90%
  - measuring the size of ice blocks is not needed
- Pouring the oil in the basin
  - 350-500 litres of oil per producer
- Location of skimmer in the basin
- Heated collecting IBC tank
- Measurements
  - temperature of oil, air, ice and water
- Thickness of the oil is calculated (pool surface area and oil volume) due to the fact that in broken ice oil thickness will vary

4.2 Conducting the test runs

- LAMOR will test Mon 10. Feb – Tue 11. Feb 2025
- New Naval will test Wed 12. Feb – Thu 13. Feb 2025
- Oil collection test runs are performed at least three times with the same oil, that is poured back from the collection tank to the basin after collection
- The equipment can be adjusted between the runs
- The runs do not need to be identical, i.e. the producers can adjust the time of the run as well as the positioning of the equipment in the pool.
- The test ends by connecting in the by-pass valve and then shutting down the system. Oil that is possibly remaining in the transfer hose of between the skimmer and collection tank will be moved to the collection tanks by XAMK technical personnel.

- The collection tank is let to settle for 30-60 minutes to separate the oil and water phases. The volume of collected oil is measured by measuring the oil layer thickness in the heated collection tank.

6 Test results

Purpose	Test of oil recovery in enclosed basin with ice blocks	Date	__.02.2025
Oil	VLSFO IM27		
Skimmer	New Naval / Lamor		
Salinity	0		
	Run 1	Run 2	Run 3
Oil temperature	30 ^{0}C, when poured	warm enough to be poured	warm enough to be poured
Air temperature at the beginning of the run			
Water temperature at the beginning of the run			
Total volume of oil in basin	250 litres	___ litres	___ litres
Calculated average oil thickness (not taking into account the ice)	2 cm	2 cm	2 cm
Measured oil thickness (range)	cm	cm	cm
Volume of oil collected	litres	litres	litres
Volume of water and ice collected	litres	litres	litres
Run's start time			
Run's end time			
Time elapsed (hh:min)			
Oil uptake rate	m^3/h	m^3/h	m^3/h
Deviation from procedure			

Run 1: oil from tank, temperature 30°C.

Run 2: oil recovered during the run 1 plus the amount remaining in the collection basin

Run 3: oil recovered during the run 2 plus the amount remaining in the collection basin

APPENDIX 3

List of analysed oil samples from mechanical recovery trial period 1 and 3

List of all analysed samples of oil emulsion taken during the mechanical recovery trials at NCA's Test Facility in Horten.

Sintef ID	NCA ID	Trial period	Company	Test setup	Description	Viscosity	Water content	Density
2024-8081	IM27-1D	1	Desmi	Test 1	In slick before test run	X	X	
2024-8077	IM27-1L	1	Lamor	Test 1	In slick before test run	X	X	X
2024-8078	IM27-1V	1	Vikoma	Test 1	In slick before test run	X	X	
2024-8082	IM27-4D	1	Desmi	Test 1	In collection tank after testing	X	X	
2024-7994	IM27-4L	1	Lamor	Test 1	In collection tank after testing	X	X	
2024-8079	IM27-4V	1	Vikoma	Test 1	In collection tank after testing	X	X	
2024-7993	IM27-10L	1	Lamor	Test 3	In collection tank after testing	X	X	
2024-8083	IM27-13D	1	Desmi	Test 4	In collection tank after testing	X	X	
2024-8080	IM27-13V	1	Vikoma	Test 4	In collection tank after testing	X	X	
2024-8086	IM28-1D	1	Desmi	Test 3	In slick before test run	X	X	X
2024-8084	IM28-1L	1	Lamor	Test 3	In slick before test run	X	X	
2024-7991	IM28-1V	1	Vikoma	Test 3	In slick before test run	X	X	
2024-7992	IM28-2L	1	Lamor	Test 4	In collection tank after testing	X	X	
2024-8085	IM28-4V	1	Vikoma	Test 4	In collection tank after testing	X	X	
2024-8087	IM28-7D	1	Desmi	Test 4	In collection tank after testing	X	X	
2024-8091	IM29-1D	1	Desmi	Test 3	In slick before test run	X	X	
2024-8088	IM29-1L	1	Lamor	Test 3	In slick before test run	X	X	
2024-8090	IM29-1V	1	Vikoma	Test 3	In slick before test run	X	X	X
2024-8089	IM29-2L	1	Lamor	Test 4	In collection tank after testing	X	X	
2024-7990	IM29-4V	1	Vikoma	Test 4	In collection tank after testing	X	X	
2024-8092	IM29-7D	1	Desmi	Test 4	In collection tank after testing	X	X	
2025-4852	IM27-2L25	3	Lamor	Test 3	In slick before test run	X	X	X
2025-4853	IM27-5L25	3	Lamor	Test 4	In collection tank after testing	X	X	
2025-4855	IM28-2L25	3	Lamor	Test 3	In slick before test run	X	X	
2025-4856	IM28-5L25	3	Lamor	Test 4	In collection tank after testing	X	X	
2025-4858	IM29-2L25	3	Lamor	Test 3	In slick before test run	X	X	
2025-4859	IM29-5L25	3	Lamor	Test 4	In collection tank after testing	X	X	
2025-4860	IM27-2D25	3	Desmi	Test 3	In slick before test run	X	X	
2025-4861	IM27-5D25	3	Desmi	Test 4	In collection tank after testing	X	X	
2025-4862	IM28-2D25	3	Desmi	Test 3	In slick before test run	X	X	X
2025-4863	IM28-5D25	3	Desmi	Test 4	In collection tank after testing	X	X	
2025-4864	IM29-2D25	3	Desmi	Test 3	In slick before test run	X	X	
2025-4865	IM29-5D25	3	Desmi	Test 4	In collection tank after testing	X	X	
2025-4866	IM27-2V25	3	Vikoma	Test 3	In slick before test run	X	X	
2025-4867	IM27-5V25	3	Vikoma	Test 4	In collection tank after testing	X	X	
2025-4868	IM28-2V25	3	Vikoma	Test 3	In slick before test run	X	X	
2025-4869	IM28-5V25	3	Vikoma	Test 4	In collection tank after testing	X	X	
2025-4870	IM29-2V25	3	Vikoma	Test 3	In slick before test run	X	X	X
2025-4871	IM29-5V25	3	Vikoma	Test 4	In collection tank after testing	X	X	
2025-4872	IM27-2K25	Add. trial	Koseq	Test 3	In slick before test run	X	X	
2025-4873	IM27-5K25	Add. trial	Koseq	Test 4	In collection tank after testing	X	X	
2025-4874	IM28-2K25	Add. trial	Koseq	Test 3	In slick before test run	X	X	
2025-4875	IM28-5K25	Add. trial	Koseq	Test 4	In collection tank after testing	X	X	
2025-4876	IM29-2K25	Add. trial	Koseq	Test 3	In slick before test run	X	X	
2025-4877	IM29-5K25	Add. trial	Koseq	Test 4	In collection tank after testing	X	X	
2025-4878	ULSFO-1L25	3	Lamor	Extra test	In slick before test run	X	X	
2025-4879	ULSFO-2L25	3	Lamor	Extra test	In collection tank after testing	X	X	
2025-4880	ULSFO-1D25	3	Desmi	Extra test	In slick before test run	X	X	
2025-4881	ULSFO-2D25	3	Desmi	Extra test	In collection tank after testing	X	X	
2025-4882	ULSFO-1V25	3	Vikoma	Extra test	In slick before test run	X	X	
2025-4883	ULSFO-2V25	3	Vikoma	Extra test	In collection tank after testing	X	X	

APPENDIX 4

Sintef Memo of oil analyses from mechanical recovery trial period 1

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Memo

IMAROS-2: Oil analyses from testing in Horten (revised)

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For your attention | Comments are invited | For your information | As agreed

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CLASSIFICATION
Internal

Background

As a part of IMAROS-2, SINTEF has measured oil properties (viscosity, density, and water content) in oils/emulsions from testing of skimmers in the Norwegian Coastal Administrations (NCA) facilities in Horten.

The oils used have previously been analysed and the measurements were reported in a SINTEF memo dated November 5, 2024, and are given in Table 1.

Table 1 The oils physical properties. Viscosity measurements are from the temperature sweep. For pour point, values in brackets are measured minimum and maximum pour point.

SINTEF ID	IM no.	Viscosity, temp sweep (cP)		Density (g/mL)		Water content	Pour point
		10 °C	50 °C	50 °C (measured)	15 °C (calculated)	(%)	(°C)
2024-5377	IM-27	23104	282	0.931	0.954	0.1	21 (9, 21)
2024-5378	IM-28	36277	110	0.909	0.932	0.1	30 (21, 27)
2024-5379	IM-29	932	9.6	0.866	0.890	0.2	21 (15, 24)

Oil samples

SINTEF received 21 samples on November 18, 2024. The samples SINTEF ID and the sample description given by NCA are shown in Table 2. The emulsion was broken in 5 of the samples when they arrived SINTEF.

Table 2 *SINTEF ID, sample description and an overview of the analyses performed on the samples. Samples with broken emulsion when arrival at SINTEF are indicated in the table.*

SINTEF ID	Sample description	Emulsion broken	Viscosity	Water content	Density
2024-8081	IM 27 - 1 D		x	x	
2024-8077	IM 27 - 1 L	x	x	x	x
2024-8078	IM 27 - 1 V		x	x	
2024-8082	IM 27 - 4 D	x	x	x	
2024-7994	IM 27 - 4 L	x	x	x	
2024-8079	IM 27 - 4 V		x	x	
2024-7993	IM 27 - 10 L	x	x	x	
2024-8083	IM 27 - 13 D	x	x	x	
2024-8080	IM 27 - 13 V		x	x	
2024-8086	IM 28 - 1 D		x	x	x
2024-8084	IM 28 - 1 L		x	x	
2024-7991	IM 28 - 1 V		x	x	
2024-7992	IM 28 - 2 L		x	x	
2024-8085	IM 28 - 4 V		x	x	
2024-8087	IM 28 - 7 D		x	x	
2024-8091	IM 29 - 1 D		x	x	
2024-8088	IM 29 - 1 L		x	x	
2024-8090	IM 29 - 1 V		x	x	x
2024-8089	IM 29 - 2 L		x	x	
2024-7990	IM 29 - 4 V		x	x	
2024-8092	IM 29 - 7 D		x	x	

Measurements

- Water content: Emulsion breaker was added to the emulsified oils, and the samples were kept at 60 °C over night to release the water. The difference between released water and remaining oil was used to calculate the water content in the emulsion.
- Density was measured in the water free oil at 50 °C and re-calculated to 15 °C (ASTM D1250-80). Then the water content was used to calculate the density in the original emulsion. Density was measured in three of the emulsions.
- The viscosity was measured at 10 °C at shear rate 10 and $100s^{-1}$.

Results

The results from the physical measurements of the samples are given in Table 3. In the column for comments, the visual observations done prior to measurements are summarized. No comments indicate "normal" emulsions.

Table 3 Physical measurements of the emulsified samples.

SINTEF ID	Sample ID from NCA	Broken emulsion/free water (mL)	Viscosity @10°C $10s^{-1}$ (mPa s)	Viscosity @10°C $100s^{-1}$ (mPa s)	Water content (w%)	Density (g/ml)	Comments to the samples when arrival SINTEF
2024-8081	IM 27 - 1 D		18917	4624	34		Droplets/small pockets with free water in the emulsion
2024-8077	IM 27 - 1 L	41	21242	4344	27	0.954	Droplets/small pockets with free water in the emulsion
2024-8078	IM 27 - 1 V		11765	2428	40		Droplets/small pockets with free water in the emulsion
2024-8082	IM 27 - 4 D	16	31271	3602	31		Little/no free water in emulsion
2024-7994	IM 27 - 4 L	27	15619	3922	42		Some droplets/small pockets with free water in the emulsion
2024-8079	IM 27 - 4 V		9998	2631	31		Droplets/small pockets with free water in the emulsion
2024-7993	IM 27 - 10 L	39	21835	5175	31		Free water in the bottom of the vial
2024-8083	IM 27 - 13 D	68	42548	10423	2		Free water in the bottom of the vial
2024-8080	IM 27 - 13 V		14449	3576	30		Droplets/small pockets with free water in the emulsion
2024-8086	IM 28 - 1 D		54959	334	61	0.932	Droplets/small pockets with free water in the emulsion
2024-8084	IM 28 - 1 L		47136	173	49		
2024-7991	IM 28 - 1 V		21386	1160	50		
2024-7992	IM 28 - 2 L		64734	1569	46		Some droplets/small pockets with free water in the emulsion
2024-8085	IM 28 - 4 V		42677	575	42		Droplets/small pockets with free water in the emulsion
2024-8087	IM 28 - 7 D		41581	2243	36		Droplets/small pockets with free water in the emulsion
2024-8091	IM 29 - 1 D		12173	2231	55		
2024-8088	IM 29 - 1 L		18492	3648	59		
2024-8090	IM 29 - 1 V		16007	3092	48		
2024-8089	IM 29 - 2 L		14636	2623	61		Some droplets/small pockets with free water in the emulsion
2024-7990	IM 29 - 4 V		12765	2647	54	0.892	
2024-8092	IM 29 - 7 D		17044	2450	54		

APPENDIX 5

Sintef Memo of oil analyses from mechanical recovery trial period 3

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Memo

IMAROS-2: Oil analyses from test period 2 in Horten

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For your attention | Comments are invited | For your information | As agreed

DISTRIBUTION
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PROJECT NO / FILE CODE	DATE	CLASSIFICATION
302008630-1	2025-09-29	Unrestricted

Background

As a part of IMAROS-2, SINTEF has measured oil properties (viscosity, density, and water content) in oils/emulsions from testing of skimmers in the Norwegian Coastal Administrations (NCA) facilities in Horten (test period 2).

The oils used have previously been analysed and the measurements were reported in a SINTEF memo dated November 5, 2024, and are given in Table 1.

Table 1 The oils physical properties. Viscosity measurements are from the temperature sweep. For pour point, values in brackets are measured minimum and maximum pour point.

SINTEF ID	IM no.	Viscosity, temp sweep (cP)		Density (g/mL)		Water content	Pour point
		10 °C	50 °C	50 °C (measured)	15 °C (calculated)	(%)	(°C)
2024-5377	IM-27	23104	282	0.931	0.954	0.1	21 (9, 21)
2024-5378	IM-28	36277	110	0.909	0.932	0.1	30 (21, 27)
2024-5379	IM-29	932	9.6	0.866	0.890	0.2	21 (15, 24)

Oil samples

SINTEF received 33 samples on September 5, 2025. The samples SINTEF ID and the sample description given by NCA are shown in Table 2. Skimmers from the four vendors Lamor, Desmi, Vikoma and Koseq were tested.

Table 2 SINTEF ID, sample description and an overview of the analyses performed on the samples. Samples with broken emulsion when arrival at SINTEF are indicated in the table.

SINTEF ID	KYV-ID	Test	Description	Viscosity	Water content	Density	GC/FID
2025-4851	IM27-1L25	Before test	Oil from IBC	X	X	X	X
2025-4852	IM27-2L25	Test 3	In boom before testing	X	X	X	
2025-4853	IM27-5L25	Test 4	In IBC after collection	X	X		
2025-4854	IM28-1L25	Before test	Oil from IBC	X	X	X	X
2025-4855	IM28-2L25	Test 3	In boom before testing	X	X		
2025-4856	IM28-5L25	Test 4	In IBC after collection	X	X		
2025-4857	IM29-1L25	Before test	Oil from IBC	X	X	X	X
2025-4858	IM29-2L25	Test 3	In boom before testing	X	X		
2025-4859	IM29-5L25	Test 4	In IBC after collection	X	X		
2025-4860	IM27-2D25	Test 3	In boom before testing	X	X		
2025-4861	IM27-5D25	Test 4	In IBC after collection	X	X		
2025-4862	IM28-2D25	Test 3	In boom before testing	X	X	X	
2025-4863	IM28-5D25	Test 4	In IBC after collection	X	X		
2025-4864	IM29-2D25	Test 3	In boom before testing	X	X		
2025-4865	IM29-5D25	Test 4	In IBC after collection	X	X		
2025-4866	IM27-2V25	Test 3	In boom before testing	X	X		
2025-4867	IM27-5V25	Test 4	In IBC after collection	X	X		
2025-4868	IM28-2V25	Test 3	In boom before testing	X	X		
2025-4869	IM28-5V25	Test 4	In IBC after collection	X	X		
2025-4870	IM29-2V25	Test 3	In boom before testing	X	X	X	
2025-4871	IM29-5V25	Test 4	In IBC after collection	X	X		
2025-4872	IM27-2K25	Test 3	In boom before testing	X	X		
2025-4873	IM27-5K25	Test 4	In IBC after collection	X	X		
2025-4874	IM28-2K25	Test 3	In boom before testing	X	X		
2025-4875	IM28-5K25	Test 4	In IBC after collection	X	X		
2025-4876	IM29-2K25	Test 3	In boom before testing	X	X		
2025-4877	IM29-5K25	Test 4	In IBC after collection	X	X		
2025-4878	ULSFO-1L25	Additional test	Before test start	X	X		X
2025-4879	ULSFO-2L25	Additional test	In IBC after collection	X	X		
2025-4880	ULSFO-1D25	Additional test	Before test start	X	X		
2025-4881	ULSFO-2D25	Additional test	In IBC after collection	X	X		
2025-4882	ULSFO-1V25	Additional test	Before test start	X	X		
2025-4883	ULSFO-2V25	Additional test	In IBC after collection	X	X		

Measurements

- GC screening analysis of the initial oils.
- Water content: Emulsion breaker was added to the emulsified oils, and the samples were kept at 60 °C over night to release the water. The emulsified IM-28 was harder to break, so these samples were added more emulsion breaker and kept at 70 °C one more night. The difference between released water and remaining oil was used to calculate the water content in the emulsion by assuming that the volume of the original emulsion was 100 mL using the following equation:

$$water\ content\ in\ original\ emulsion = ((100\ mL - free\ water) \times WC + free\ water)/(100\ mL) \times 100$$

- Density was measured in the water free oil at 50 °C and re-calculated to 15 °C (ASTM D1250-80).
- The viscosity was measured at 10 °C at shear rate 10 and 100s-^{1}.

Results

GC chromatograms of the oils are shown in Figure 1 to Figure 4.

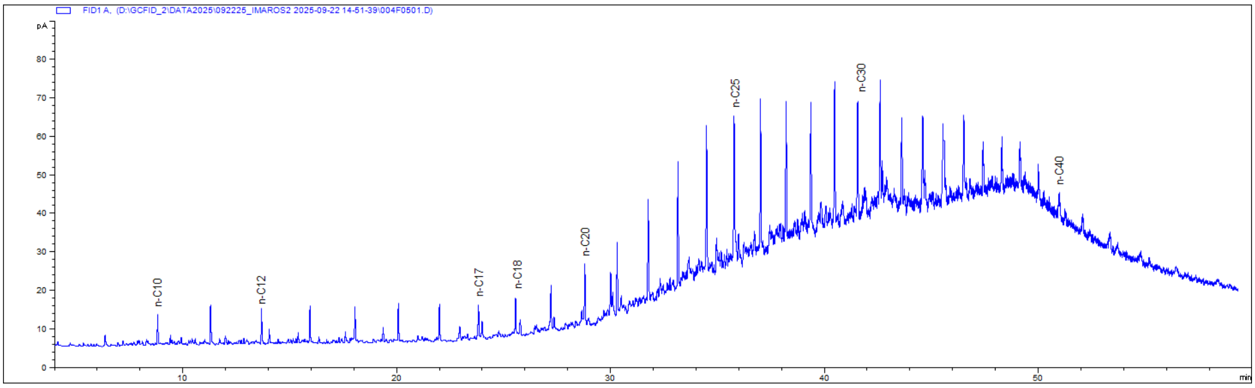

Figure 1 GC chromatogram of IM-27 1L25 (SINTEF ID 2025-4851)

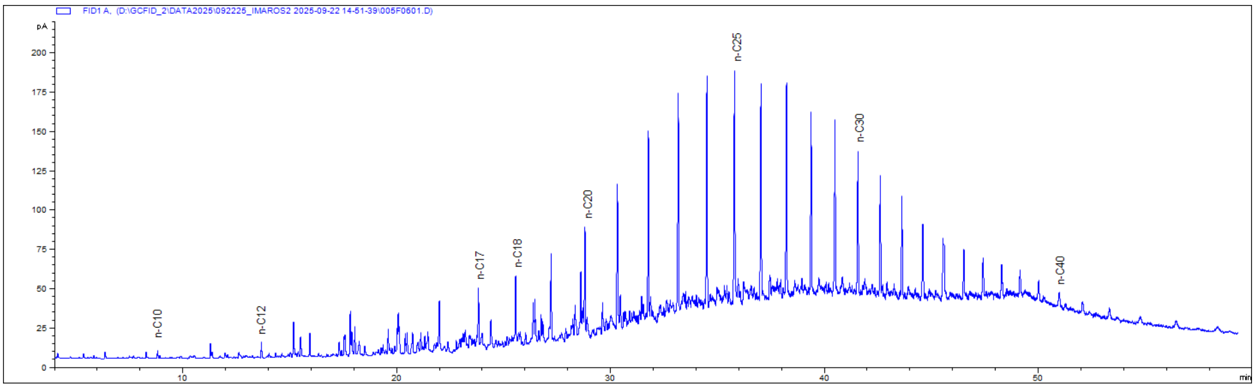

Figure 2 GC chromatogram of IM-28 1L25 (SINTEF ID 2025-4854)

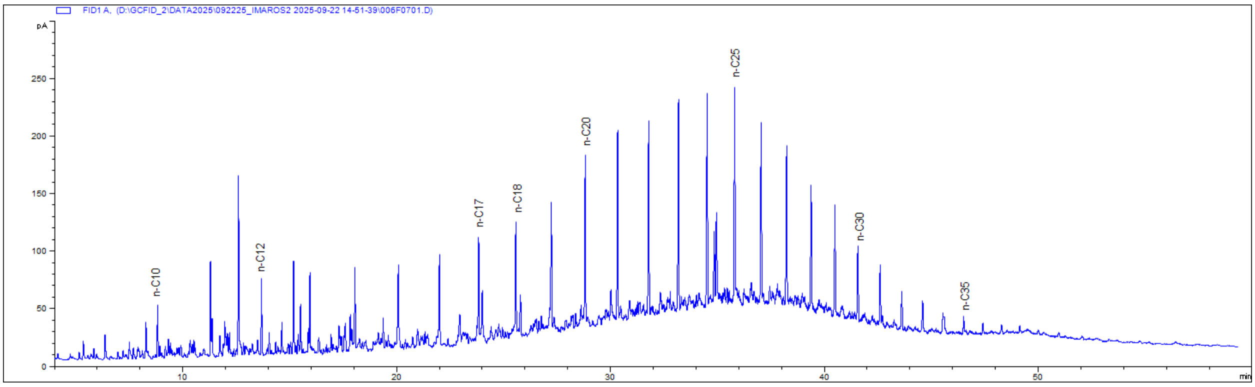

Figure 3 *GC chromatogram of IM-29 1L25 ((SINTEF ID 2025-4857)*

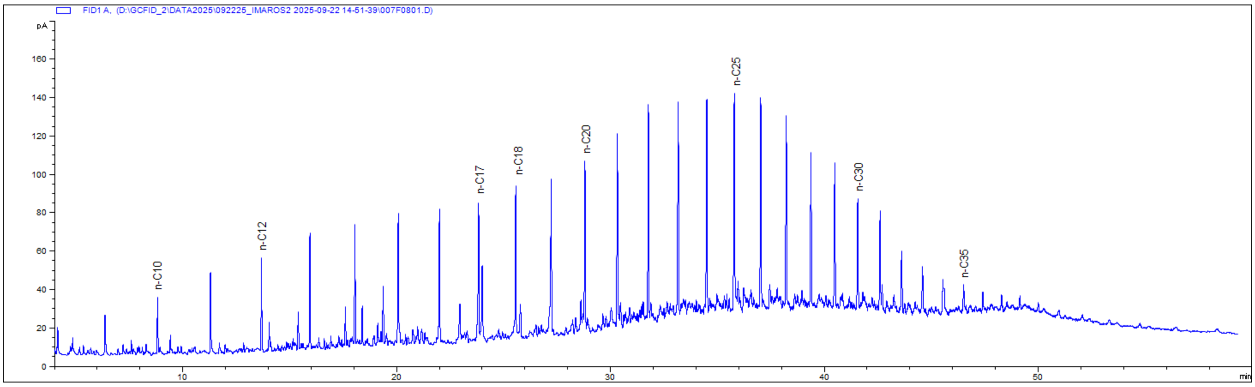

Figure 4 *GC chromatogram of ULSFO 1L25 (SINTEF ID 2025-4878)*

The results from the physical measurements of the samples are given in Table 3. In the column for comments, the visual observations done prior to measurements are summarized. No comments indicate “normal” emulsions.

Table 3 *Physical measurements of the oil samples. Yellow cells viscosity: Emulsion most likely broken during measurement. (*Calculated by assuming that the original emulsion contained 100 mL emulsion)*

SINTEF ID	KyV ID	Viscosity @10C 10s-1 (mPa s)	Viscosity @10C 100s-1 (mPa s)	Water cont. (WC) (v%)	Free water (ml)	WC in original emulsion* (v%)	Density in water free oil (g/mL)	Comments
2025-4851	IM27-1L25	34774	18149		0	0	0,9541	
2025-4852	IM27-2L25	17535	3601	37	10	44	0,9520	Pockets with free water
2025-4853	IM27-5L25	11280	1940	38	19	50		Pockets with free water
2025-4854	IM28-1L25	66196	14972	0	0	0	0,9320	
2025-4855	IM28-2L25	92222	3338	45	0	45		Some droplets of free water
2025-4856	IM28-5L25	49980	503	42	0	42		Some droplets of free water
2025-4857	IM29-1L25	11502	1100	0	0	0	0,8895	
2025-4858	IM29-2L25	19372	3318	51	0	51		Some droplets of free water

SINTEF ID	KyV ID	Viscosity @10C 10s-1 (mPa s)	Viscosity @10C 100s-1 (mPa s)	Water cont. (WC) (v%)	Free water (ml)	WC in original emulsion* (v%)	Density in water free oil (g/mL)	Comments
2025-4859	IM29-5L25	17992	1626	56	1	57		Some droplets of free water
2025-4860	IM27-2D25	23896	5032	25	24	43		Pockets with free water, free water in bottom
2025-4861	IM27-5D25	18281	2112	30	23	46		Pockets with free water, free water in bottom
2025-4862	IM28-2D25	80372	1558	44	1	44	0,9330	Some droplets of free water
2025-4863	IM28-5D25	69832	1014	40	0	40		Some droplets of free water
2025-4864	IM29-2D25	14954	2095	49	0	49		Some droplets of free water
2025-4865	IM29-5D25	11346	853	57	2	58		Some droplets of free water
2025-4866	IM27-2V25	15972	2624	29	25	47		Pockets with free water, free water in bottom
2025-4867	IM27-5V25	11324	4513	31	27	50		Pockets with free water, free water in bottom
2025-4868	IM28-2V25	70280	1357	44	0	44		
2025-4869	IM28-5V25	67887	234	38	0	38		Some droplets of free water
2025-4870	IM29-2V25	21470	2665	50	0	50	0,8917	
2025-4871	IM29-5V25	11253	261	57	2	58		Some droplets of free water
2025-4872	IM27-2K25	18259	3796	27	26	46		Pockets with free water, free water in bottom
2025-4873	IM27-5K25	16850	2263	32	22	47		Pockets with free water
2025-4874	IM28-2K25	32776	910	38	5	41		Som droplets/small pockets with free water
2025-4875	IM28-5K25	28512	895	33	3	35		Som droplets/small pockets with free water
2025-4876	IM29-2K25	13008	578	60	1	61		Some droplets of free water
2025-4877	IM29-5K25	9484	187	58	6	60		Som droplets/small pockets with free water
2025-4878	ULSFO-1L25	16906	4599	0	0	0		
2025-4879	ULSFO-2L25	65023	1696	7	0	7		
2025-4880	ULSFO-1D25	59760	7937	7	0	7		Some droplets of free water
2025-4881	ULSFO-2D25	49760	2881	20	0	20		Some droplets of free water
2025-4882	ULSFO-1V25	81621	9194	5	0	5		
2025-4883	ULSFO-2V25	31485	464	27	0	27		Some droplets of free water

APPENDIX 6

Report from the Occupational Exposure Study

IMAROS 2 – WP4

Assessing the potential exposure to oil components in air during recovery of three different low sulphur fuel oils

Norwegian title: Kartlegging av den potensielle eksponeringen for oljekomponenter i luft under opptak av tre ulike lavsvoveloljer

Author(s): Norwegian Coastal Administration

Summary

In the EU-funded project IMAROS 2, the potential exposure to oil components in air was determined during the recovery of three types of oil at the Norwegian Coastal Administration's test hall in Horten, Norway. The aim of this study is to assess the working environment air concerning oil components during oil recovery using various oil skimmers. This exposure assessment is utilised as a part of risk management.

In the investigation, a simplified occupational health survey was employed, where multiple measurements were performed to ensure that exposure to volatile organic compounds (VOC), oil mist, and oil vapours was under 10% of the current Norwegian occupational limit values (OELs). Samples were collected in the breathing zone of the workers and compared with stationary samples collected around the test pool. Oil vapours, oil mist, and volatile components such as benzene, toluene, ethylbenzene, xylene, and n-hexane were quantified.

The results indicate that the concentrations of oil mist, oil vapours and the VOCs from the tested oils were below 10% of the current OELs. The concentration of volatile compounds was below the detection limit, except for certain substances from IM28 and IM29 oils. The exposure index for the three oil samples was well below 10% of the OEL.

It was concluded that the exposure levels for all tested oil components were acceptable under the existing conditions. Although an unpleasant odour was reported from one of the oils, it was not considered harmful to health after evaluation. The project recommends no further follow-up unless changes occur that could potentially increase exposure.

Introduction

Background

In the EU-funded project IMAROS 2, the aim is to test how low-sulphur oil can be recovered when spilled at sea. The oil recovery tests will be conducted in a test pool, both indoors in a hall and outdoors in a pool with ice. The potential exposure during the recovery of the respective oils used in IMAROS 2 is not known, and therefore there is a need to evaluate this. The exposure assessment will be conducted during the tests inside the hall, as it is assumed to result in higher exposure compared to the recovery of oil outdoors in the test pool with ice.

In the IMAROS 1 project, the concentration of hydrocarbons in air was assessed during the testing of three low-sulphur oils and an MGO in the test hall in Horten. The results from the mapping indicated that the potential exposure to solvents in air (VOCs) and polycyclic aromatic hydrocarbons (PAHs) was low compared to the current Norwegian OELs (Bråtveit, Hollund, & Djurhuus, 2022). In IMAROS 2, the testing of oil recovery will also be conducted in the same test hall with different oils. Based on the safety data sheets and preliminary analyses of the oil, it is not expected that the new test oils will result in higher exposure than the oils tested in IMAROS 1. Considering the results from IMAROS 1 and the information regarding the new test oils, it was decided to carry out a simplified occupational health survey. A simplified occupational health survey involves 3-5 measurements within a similar exposed group (SEG), where the highest measured value (maximum value) is crucial in determining whether the exposure is acceptable—that is, below the current Norwegian OEL as described in the regulation on action and limit values appendix 1 (FOR-2024-05-15-785).

To determine which components of the workplace air should be sampled and analysed, oil samples were initially sent to the laboratory at the National Institute of Occupational Health (STAMI) for testing. The oils were suitable for the sampling method for oil vapour. Considering that oil recovery can mechanically generate oil mist, it was decided to include this in the sampling process. Note that oil mist is only expected to be present in measurable concentrations near areas where droplets are mechanically generated, such as during the cleaning of equipment used in the tests (e.g., oil skimmers and similar equipment). Solvents in air (BTEX and n-hexane) were also collected as these have relatively low limit values. PAHs were not measured because their concentrations are expected to be low. The measurements from IMAROS 1 indicated that the determined concentrations were around 1/1000 of the current OEL for naphthalene and biphenyl.

Objective

The objective of the study is to assess the exposure to oil components in the workplace air during the testing of various oil skimmers in the test pool. The results will be used as part of risk management.

The Norwegian occupational exposure limit values

The current Norwegian occupational limit values are provided in the regulation on action and limit values for physical and chemical factors in the work environment, as well as infection risk groups for biological factors. In this study, a simplified survey has been conducted. The assessment criteria for this survey are that the measured maximum value should be below 10% of the current OELs.

Chemical component:	**Occupational exposure limit value:**
Oilvapour:	50 mg/m^3
Oil mist:	1 mg/m^3
Benzene:	1 ppm
n-Hexsane:	20 ppm
Toluen:	25 ppm
Ethylbenzene:	5 ppm
Xylene (all isomers):	25 ppm

Methode

Sampling

In accordance with the Norwegian Labour Inspection Authority's guidelines on the assessment of chemical exposure in the working environment—Mapping and Assessment of Exposure to Chemicals (Norwegian Labour Inspection Authority, 2020)—samples have been taken in the breathing zone of test personnel working closest to the potential exposure. For comparison, stationary samples were also collected at the same location as during IMAROS 1 (Bråtveit, Hollund, & Djurhuus, 2022). Figure 1 is a sketch of the test pool, where stationary samples are marked with a cross. Shaded areas indicate where test personnel with sampling equipment have been located (around the pool, on the two bridges, by, the control panel, and in the laboratory and meeting room).

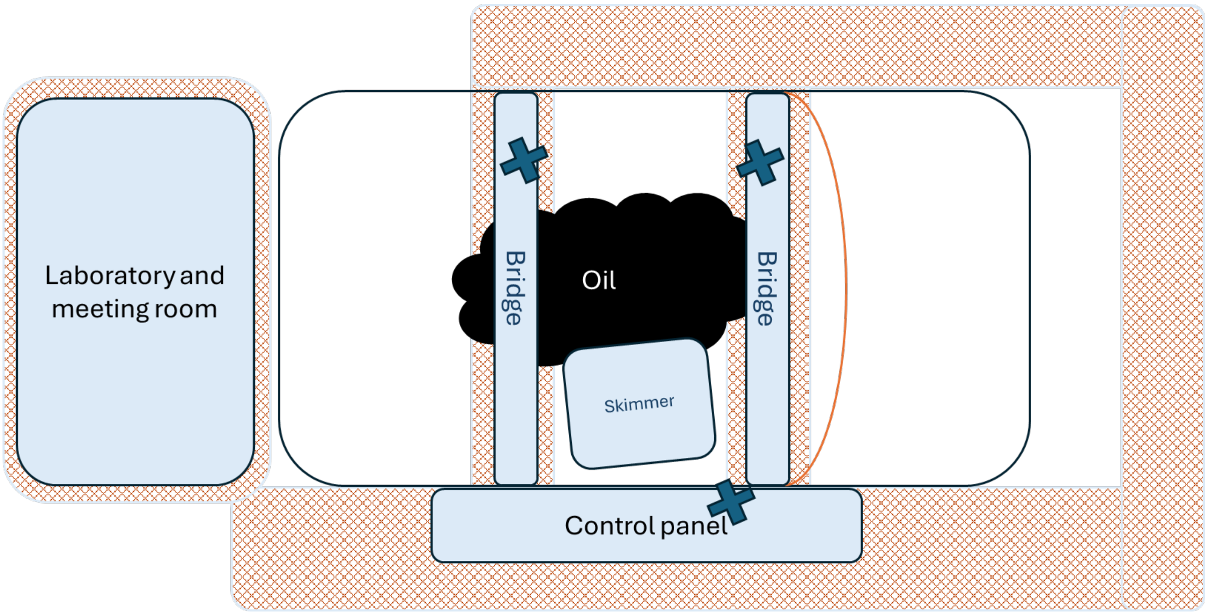

Figure 1: *Overview of the test area. Crosses indicate where the stationary samples were collected. The shaded area primarily shows where the test personnel operated when they were near the pool.*

In general, samples were collected throughout the entire test day (Table 1). A 37 mm total dust cassette with a glass fibre filter connected in series with an adsorbent tube (carbon tube) was used to collect oil mist/oil vapour. For this, a Casella Apex2 ATEX dust pump was connected and calibrated to 1.4 L/min before the start of sampling. The air flow rate was measured again at the end of sampling. The sampling cassettes were stored in a cool environment after they were exposed. Volatile organic compounds (VOCs) were collected passively in thermal desorption tubes with Tenax as the adsorbent.

Higher concentrations of contaminants in the workplace air were expected during cleaning compared to regular oil recovery. Therefore, it was decided to collect some short-term samples. The short-term samples were collected only during the washing operation, and only oil mist was collected according to the method described above.

Analysis

Reference oil was sent to the laboratory before sampling and analysed using gas chromatography with mass spectrometric detection (GC-MS) for information on the oil's composition. Oil mist was determined according to NIOSH method 5026 with Fourier transform infrared spectroscopy. Oil vapour was analysed with gas chromatography with flame ionisation detection in accordance with NIOSH method 1500. BTEX and n-hexane were analysed using thermal desorption and GC-MS detection. All samples were analysed at the National Institute of Occupational Health, Oslo - Norway.

Test Scheme

Three different oils were released into the test pool and collected using oil skimmers over three separate test days. Samples were collected in the breathing zone of workers in the test hall during the tests. Additionally, short-term samples were collected during cleaning. Table 1 provides an overview of the oils tested and the exposure times for the samples. For various reasons, some samples were not analysed—e.g. one of the samples fell into the oil during sampling, and one of the pumps ceased functioning during the sampling process.

Table 1: *Overview of test oil, date and sampling time*

IMAROS-ID	Oil type	Test date[a]	Median sampling time in minutes (min.-max.)		
			Personal	Stationary	Wash
IM-27	VLSFO	17.09.2024 (31.10.2024)	450 (na -450)	430 (430-430)	18
IM-28	VLSFO	19.09.2024 (01.11.2024)	440 (na-na)	440 (440-440)	32-34
IM-29	ULSFO	23.09.2024 (01.11.2024)	405 (285-411)	405 (na-405)	15

[a]Test date for short-term sampling in parentheses
[na] samples not analysed

Description of relevant test days

The skimmers were tested in accordance with the Norwegian Coastal Administration's "Procedures for Testing Oil Skimmers at the National Centre for Testing of Equipment for Oil Spill Response," and the following configurations were utilised:

<u>Test 1 - Capacity Test of Oil in Closed Pool:</u>

An oil emulsion (approximately 50% water) and a skimmer are placed in a closed pool (4x4 m). This is done to control the oil thickness and to allow for building up the desired oil thickness (12.5 cm with 2000 litres of oil). The capacity test measures how much oil a skimmer can recover and is expressed in m^3/h. The experiment is conducted with a thick layer of oil, ensuring that the skimmer is in the oil emulsion (at least 7.5 cm at the start and at least 5 cm at the end). The goal is to recover 500 litres of oil with three identical repetitions. The skimmer is optimised to recover as much oil as possible while minimising water intake. Before the test round begins, the skimmer will be adjusted to achieve optimal recovery.

<u>Test 2 - Capacity Test of Oil in Closed Pool with Waves:</u>
The same setup as Test 1, with the addition of waves.

<u>Test 3 - Capacity Test of Oil in Boom with Current:</u>
An oil emulsion (approximately 50% water) and a skimmer are placed in a boom, with a current simulating the towing of the boom. The current is used without the oil going beneath the boom, with a flow rate of approximately 0.2 knots. 2000 litres of oil emulsion are poured into the boom, and the goal is to recover 800 litres of oil in three identical repetitions. Optimise the skimmer to recover as much oil as possible, considering that some free water is also added. Before the test round begins, the skimmer will be adjusted for optimal recovery. After the test round, at least 25% of the oil should remain in the boom.

<u>Test 4 - Capacity Test of Oil in Boom with Current and Waves:</u>
The same setup as Test 3, with the addition of waves.

For all three exposure assessment days, tests were conducted both with and without waves. Table 2 shows which tests were performed on the various sampling days.

***Table 2**: Overview of Tests Conducted on the Three Different Sampling Days*

IMAROS-ID	Test before lunch break	Test after lunch break
IM-27	An oil emulsion of IM-27 was placed in a 4x4 m pool in the test basin, after which Test 1 and Test 2 were conducted.	The same oil was moved to float freely in the boom where Test 3 was conducted.
IM-28	An oil emulsion of IM-28 was poured into the test basin, and Test 3 was conducted.	Test 4
IM-29	An oil emulsion of IM-29 was poured into the test basin, and Tests 3 and 4 were conducted.	Test 3

Results

The results are presented for each chemical component to compare with the current Norwegian limit values. Measurements below the detection limit are not included in the figures. Concentrations for all samples and detection limits are provided in Appendix 1.

Oil mist

The figure below presents the concentration of oil mist measured in the workplace air for three individuals (P) working at the test pool, as well as samples taken at the three selected stations (S). Additionally, short-term samples taken during cleaning are presented. All samples are below 10% of the current limit value. Samples below the respective detection limits are not quantifiable and, therefore, not presented in the figure. This applies to samples taken during the cleaning of IM27 and IM29.

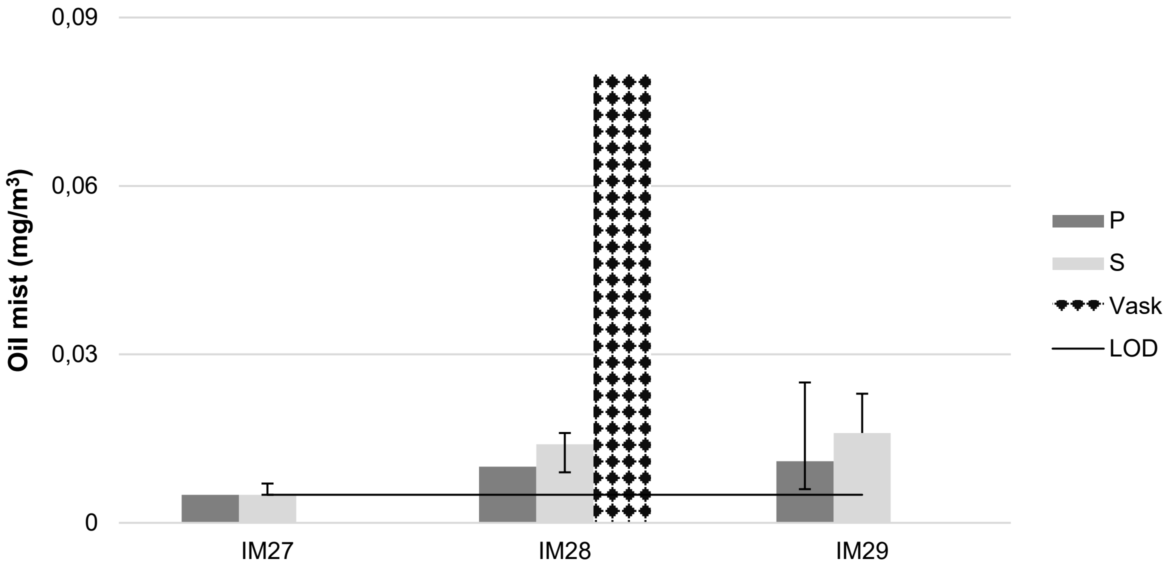

Figure 2: Median concentration of oil mist measured in personal (P) and stationary (S) samples during the recovery of three different oils. Short-term samples taken during cleaning is presented in dotted bar (Vask). The minimum and maximum concentrations are shown in the uncertainty bars. The detection limit (LOD) for long-term samples is indicated by the horizontal line (0.005 mg/m³). The LOD for cleaning IM27 and IM29 is 0.1 mg/m³. Samples with concentrations below the detection limit are not shown in the figure (this includes samples taken during the cleaning of IM27 and IM29).

Oil vapour

Concentrations of oil vapour in the workplace air of the test personnel and collected stationary in the test hall during the recovery of the three IMAROS 2 oils are shown in Figure 2. One of the samples from IM27 and two of the samples from IM28 are not analysed. All remaining samples are quantified, and the concentrations are below 10% of the current limit value.

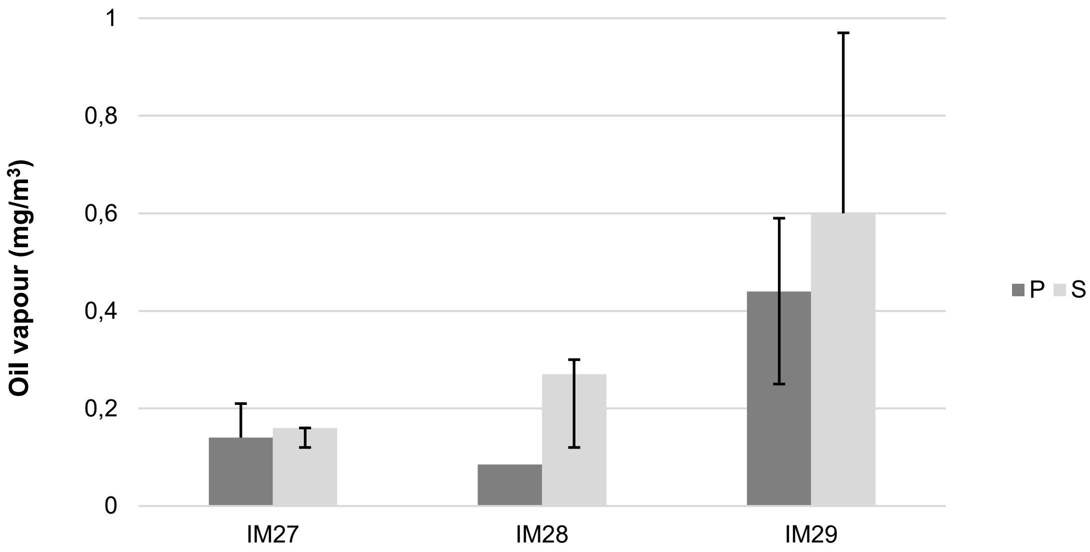

Figure 3: The median concentration of oil mist measured in personal (P) and stationary (S) samples during the testing of recovery with three different oils (IM27, IM28, and IM29). The minimum and maximum concentrations are shown in the uncertainty bars.

Volatile organic components

In general, the concentrations for BTEX (benzene, toluene, ethylbenzene, and xylene) are below the detection limit and are therefore not quantifiable. This applies to all samples taken during the recovery of IM27. Toluene is detected in samples from IM28 and IM29, with maximum concentrations of 0.01 ppm for IM28 and 0.1 ppm for IM29. For the IM29 samples, ethylbenzene is also detected in two stationary samples (maximum concentration of 0.02 ppm), m,p-xylene in all samples (highest determined concentration was 0.05 ppm), and o-xylene in four out of six samples (highest determined concentration was 0.02 ppm). All the determined concentrations are below the current Norwegian OEL.

Exposure index

In accordance with the Norwegian Labour Inspection Authority's guidelines, an exposure index has been calculated. The exposure index is used to quantify total exposure and is independent of the specific effects on the body. The exposure index is calculated using the following formula:

$$E_{index} = \frac{C_{(8\,hour)oil\,mist}}{GV_{olil\,mist}} + \frac{C_{(8\,hour)oil\,vapour}}{GV_{oil\,vapour}} + \left(\frac{C_{(8\,hour)toluene}}{GV_{toluene}}\right)^{a} + \left(\frac{C_{(8\,hour)xylene}}{GV_{xylene}}\right)^{b}$$

^{a}For IM28 og IM29. ^{b}For IM29. Under LOD for the remaining oils.

The exposure index is presented in Table 3, divided according to the three test oils.

Table 3: *Exposure index for the three different test oils*

Oil	IM27	IM28	IM29
E_{index}	0.01	0.01	0.02

E_{index} is assessed in the same manner as a substance with a limit value of 1, and with the same criteria as a simplified survey (10% of the limit value = 0.1).

Discussion

All measured concentrations are below the respective current Norwegian occupational exposure limit values. Compared to IMAROS 1 and considering the preliminary assessment of exposure per oil, this outcome is as expected. The hypothesis that exposure is higher during cleaning was confirmed for the IM28 oil. For the other two oils, the concentration of oil mist in the workplace air during cleaning was below the detection limit. It is noted that the detection limit during cleaning is higher because these are short-term samples. Nonetheless, it may still indicate that the concentration of oil mist in the workplace air during cleaning is higher than during regular oil recovery in the pool, yet still below the OEL for oil mist.

There was a report of one oil causing an unpleasant odour. None of the chemical components measured in this context can explain this, and it is most likely not harmful to health. However, it should be noted that headaches may occur if one experiences an unpleasant odour. Based on the measured concentrations and in consultation with The national institute of occupational health in Oslo, it was decided that no further follow-up with new measurements is necessary. Unpleasant odours often arise from other components in oil that have much higher OELs, such as amines. If symptoms such as eye/airway irritation and acute nausea occur, they should be reported and followed up.

Conclusion

Based on the criteria described in the simplified survey, the exposure is acceptable for each specific exposed group (SEG) if the measured maximum concentration is below 10% of the OEL. In this case, it means the concentration in the workplace air measured per test oil. The maximum values measured are below 10% of the OELs and the exposure is therefore considered acceptable. The same applies to the exposure index calculated for the measured components. A new assessment will be conducted if there are changes that could affect the exposure.

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Bråtveit, M., Hollund, B., & Djurhuus, R. (2022). *Air Measurements of Hydrocarbons Emitted from Oils During Testing of Skimmers at National Centre for Testing of Oil Spill Equipment.* Bergen: University of Bergen.

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Regulation on Action and Limit Values (FOR-2024-05-15-785). *Regulation on Action Values and Limit Values for Physical and Chemical Factors in the Working Environment as well as Infection Risk Groups for Biological Factors*. Retrieved from Lovdata: https://lovdata.no/dokument/SF/forskrift/2011-12-06-1358

Appendix A: Analysis results

Table 1A: Concentrations obtained from analysis report 000141 (date: 21.11.2024) and 00151 (date: 03.12.2024)

Oil	Sample ID	Personal(P) / stationary (S) /cleaning(V)	Sampling time (minutes)	Oil mist (mg/m^3)	Oil vapour (mg/m^3)	n-heksane (ppm)	Benzene (ppm)	Toluene (ppm)	Ethylbenzene (ppm)	m,p-Xylene (ppm)	o-Xylene (ppm)
IM27	OD-01	P	430	<0.005	0.21	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-02	P	430	0.005	0.14	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-03	P	430	na	na	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-04	S	430	0.007	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-05	S	430	<0.005	0.16	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-06	S	430	<0.005	0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OT-01	V	18	<0.1	na	na	na	na	na	na	na
	OT-02	V	18	<0.1	na	na	na	na	na	na	na
IM28	OD-07	P	375	Na	na	<0.02	<0.01	0.01	<0.01	<0.01	<0.01
	OD-08	P	440	0.010	0.085	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-09	P	440	na	na	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-10	S	440	0.009	0.12	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
	OD-11	S	440	0.014	0.27	<0.01	<0.01	0.01	<0.01	<0.01	<0.01
	OD-12	S	440	0.016	0.30	0.01	<0.01	0.01	<0.01	<0.01	<0.01
	OT-03	V	32	0.08	na	na	na	na	na	na	na
	OT-04	V	34	<0.07	na	na	na	na	na	na	na
IM29	OD-13	P	285	0.025	0.59	<0.02	<0.02	0.05	<0.02	0.04	<0.02
	OD-14	P	405	<0.005	0.25	<0.01	<0.01	0.02	<0.01	0.02	<0.01
	OD-15	P	411	0.011	0.44	<0.01	<0.01	0.02	<0.01	0.02	0.01
	OD-16	S	405	0.016	0.6	<0.01	<0.01	0.10	0.01	0.03	0.01
	OD-17	S	405	0.023	0.97	<0.01	<0.01	0.07	0.02	0.05	0.02
	OD-18	S	405	na	na	<0.01	<0.01	0.04	<0.01	0.03	0.01
	OT-05	V	15	<0.1	na	na	na	na	na	na	na

na = not analysed

APPENDIX 7

Test report from Lamor mechanical recovery trial period 3

IMAROS 2 – WP 4

Test report from Lamor mechanical recovery trial period 3

LAMOR - week 17, 2025

NCA Test Facilities – Horten, Norway

Author(s): Norwegian Coastal Administration

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Description of Horten test facility

The National Centre for Testing of Oil Spill Response Equipment, located in Horten, Norway, offers the opportunity to test oil skimmers under controlled yet highly realistic conditions. The test centre features an indoor saltwater basin with a dual-bottom design. Measuring 30 meters in length, 7 meters in width, and up to 4.5 meters in depth, the basin is equipped to simulate both currents and wave conditions. Figure 1 provides an illustration of the basin layout. Testing was conducted at water temperatures ranging from 12 to 12.5°C and air temperatures between 15 and 18°C.

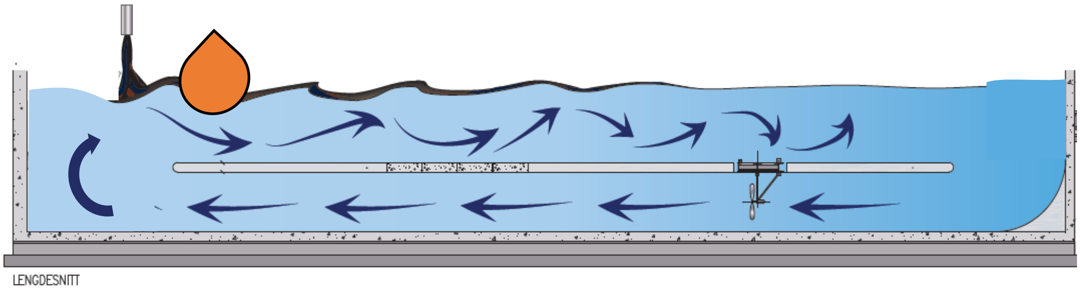

Figure 1: Illustration of the test basin with blue arrows indicating water current and a wave ball outlined with orange colour.

Test procedure

The skimmer was tested according to the NCA's "Procedure for testing oil skimmers in the National Centre for Testing of Oil Spill Response Equipment" with a configuration shown in figure 2. With the help of the current the oil slick flowed into the boom, where the skimmer was placed to enable recovery.

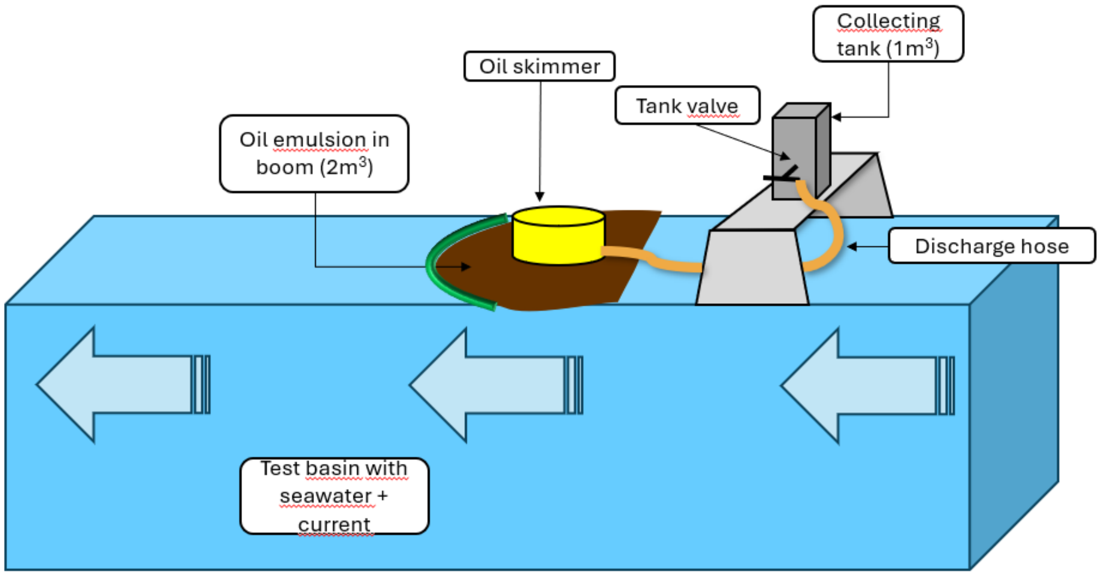

Figure 2: Illustration of the configuration used in the test basin.

The following test setups were conducted:

Test 3:	Capacity test of oil emulsion in boom with current: Oil emulsion (approximately 50% water) and skimmer placed in the boom, with current simulating towing of boom. The speed of the current is approximately 0.6 knots. 2000 litres of oil emulsion is poured into the basin, and the goal is to recover 800 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.
Test 4:	Capacity test of oil emulsion in boom with current and waves: Similar setup as test 3, in addition with waves.

For more details of the test procedure, see appendix 1.

The test oils

Table 1 shows the three test oils used in the recovery tests, with results of viscosity and pour point of the fresh oil samples, and the viscosity range of samples taken of the oil emulsion during testing. There were in total 6 samples taken during the tests at different stages to measure for water content in emulsion, viscosity, and density. The samples were analysed at the laboratory of Sintef Ocean. See appendix 4 and 5 for Sintef memo of the oil analyses conducted for the mechanical recovery trials. A list describing where and when the samples of emulsion were taken during testing in the recovery trial periods is found in appendix 3.

Table 1: some characteristics of the three oils used in the tests.

Imaros 2 ID	Oil type	Viscosity of fresh oil at 10°C ($10s^{-1}$)	Viscosity of emulsion at 10°C ($10s^{-1}$)	Pour point (°C)
IM-27	VLSFO	23,104	11,280 - 17,535	12 (9, 24)*
IM-28	VLSFO	36,277	49,980 - 92,222	27 (21, 30)*
IM-29	ULSFO	932	11,502 - 19,372	27 (15, 24)*

**For pour point, the first value is from the oil suppliers' certificate of analysis. The values in brackets are measured minimum and maximum pour point from Sintef and Cedre laboratories. Pour point measurements seems to be subjected to uncertainties and is described in more detail in deliverable D3.1 Summary report of WP3 – Characterisation and Impacts chapter 3.1.4.*

Description of the skimmer and additional equipment

Lamor provided a LAM 50 skimmer with installed thrusters, where the brush chain is complemented with a Feeder unit connected to the skimmer frame with the intention to enhance flow and transfer the oil onto the skimmer (see figure 3). The feeder is connected to the front side of the brush chain and works as an add-on unit to the already existing skimmer when encountering challenging LSFOs. Two different methods were developed to improve oil flow down toward the pump: traditional heating of the hopper, and the use of a mechanically operated pusher plate to move back and forth to assist oil movement. Additionally, a set of “cutting knives” were installed on the front sides of the Feeder to help break apart solid oil slicks, making the oil more accessible for the skimmer to recover.

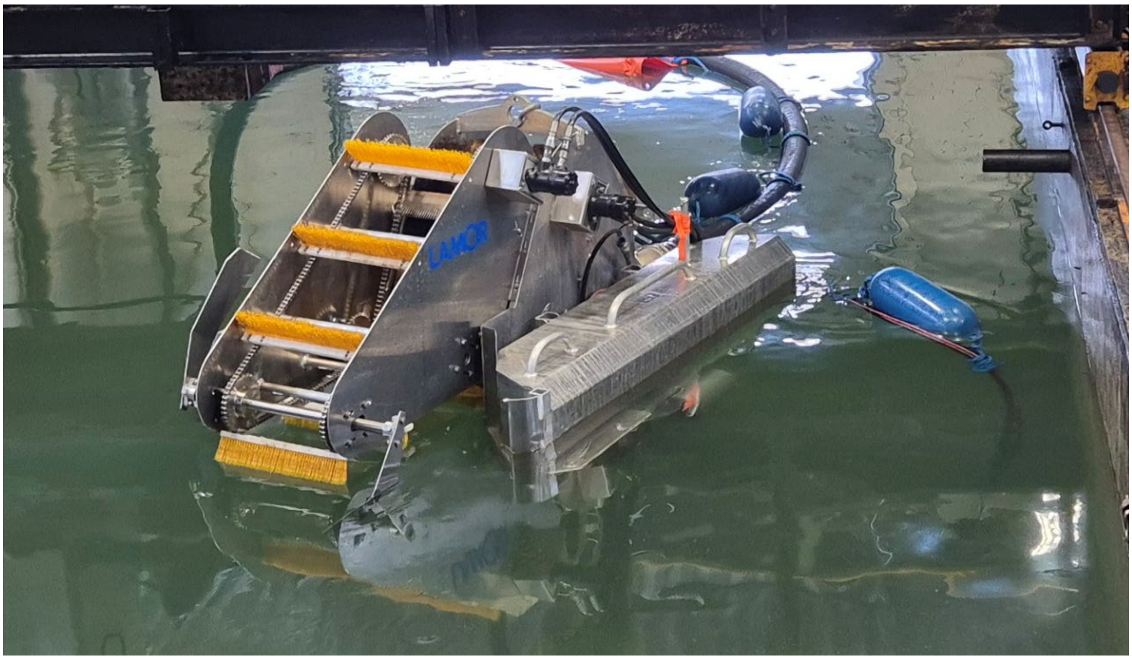

Figure 3: Photo of the LAMOR LAM 50 skimmer in the test basin with Feeder unit and additional equipment attached.

The pump was a GTA 50, type Archimedes screw pump with the following data:

- Work pressure: 210 bar.
- Viscosity max.: 1,000,000 mPas
- Capacity: 61 m^3/h
- Pressure max.: 14 bar.

Results

Table 2: overall results of best measured oil emulsion recovery rates for the tests conducted with the LAM50 skimmer and its attachments.

Oil	Skimmer	Hose	Additional equipment	Test no.	Oil recovery rate
IM-27	LAM50 with thrusters	4” spiral hose	Feeder	3	13.3 m^3/h
IM-27	LAM50 with thrusters	4” spiral hose	Feeder	4	17 m^3/h
IM-28	LAM50 with thrusters	4” spiral hose	Feeder, heating	3	16.9 m^3/h
IM-28	LAM50 with thrusters	4” spiral hose	Feeder, heating	4	23.9 m^3/h
IM-29	LAM50 with thrusters	4” spiral hose	Feeder, heating, pusher plate	3	9.6 m^3/h
IM-29	LAM50 with thrusters	4” spiral hose	Feeder, pusher plate	4	10 m^3/h

Recovery of the IM-27 (VLSFO)

Test setups 3 and 4 were used on this oil, with best results of 13.3 m^3/h and 17 m^3/h of oil recovery rates.

The skimmer performed well on the IM-27 oil, achieving good recovery rates with relatively low amounts of free water collected. The thrusters enabled the skimmer to actively manoeuvre within the oil slick, preventing oil bridging and minimizing the formation of a water layer between the oil and the skimmer, which can occur due to the short characteristics of the IM-27 oil. The pump delivered the oil to the collection tank without any problems. The Feeder unit which is in front of the skimmer body makes sure the skimmer has free access to the oil slick for collection and helped lifting the oil onto the brush chain of the LAM 50.

Figure 4: Photo of the Lamor LAM 50 skimmer with the feeder unit operating in the IM-27 oil.

Recovery of the IM-28 (VLSFO)

Test setups 3 and 4 were used on this oil, with best results of 16.9 m^3/h and 23.9 m^3/h of oil recovery rates.

Although the IM-28 exhibit little to no flow properties, the skimmer performed very well during recovery of this oil. Compared to IM-27, the IM-28 required more active manoeuvring in the basin, as the skimmer needed to pursue the oil and push it towards the Feeder. The thrusters enabled the skimmer to manoeuvre from the “seaside” toward the oil slick, allowing the Feeder access to oil and grab it effectively. Some manoeuvring challenges were observed, as some oil would stick to the sides and back of the skimmer.

Initially, the design of the hopper had some difficulties getting the oil down into the pump, but activating heating in the hopper resolved this issue, and later testing with the mechanically operated pusher plate in the hopper showed a similar positive effect. The “cutting knives” mounted on the sides of the Feeder proved valuable, as they were able to cut the slick into smaller patches, making it easier for the Feeder to capture and lift the oil onto the skimmers brush chain. Due to the Feeder’s design and interaction with the LAM brush chain, which provides mechanical assistance in lifting the oil all the way to the hopper, the brushes are less dependent on oleophilic adhesion for effective recovery.

When wave action was introduced in test setup 4, the slick was more compacted than in test setup 3. This resulted in a thicker oil layer and a smaller manoeuvring area, which overall yielded higher recovery rates.

Figure 5: Photo of the Lamor LAM 50 skimmer with the feeder unit operating in the IM-28 oil.

Recovery of the IM-29 (ULSFO)

Test setups 3 and 4 were used on this oil, with best results of 9.6 m^3/h and 10 m^3/h of oil recovery rates.

Even though the IM-29 exhibit both short and semi-solid properties, the skimmer achieved good recovery by actively using the thrusters to move in the slick in combination with the Feeder's ability to assist the LAM 50 by mechanically lift the oil all the way into the hopper. Once inside the hopper, the oil flowed into the pump and through the discharge hoses without difficulty. It appears that no heating is necessary to get this oil from the hopper down to the pump. The amount of free water collected was relatively low, although slightly higher than during recovery of IM-28. This could be related to more manoeuvring of the skimmer in the basin, as the fragmented oil slick caused the skimmer to operate occasionally in water while repositioning for more oil recovery. When operating the skimmer's pump and Feeder in combination with quite active thruster manoeuvring it can be challenging to coordinate all operations optimally. The cutting knives worked well to give the Feeder access to oil, while also creating some movement in front of the feeder brushes. When wave action was introduced in test setup 4, it gave similar recovery rates as in setup 3.

Figure 6: Photo of the Lamor LAM 50 skimmer with the feeder unit operating in the IM-29 oil.

Additional ULSFO test

One of the challenges when testing mechanical recovery in the previous IMAROS project, was that the IM-16 appeared as solid oil lumps in the test basin, making it difficult for the skimmers to both collect and pump the oil from the hopper. As neither the IM-27, IM-28 or the IM-29 had similar oil lump appearance, it was decided to use an ULSFO (see table 3 for chemical parameters) from NCA's stock that have shown in other earlier trials to appear as solid oil lumps, to do an additional test to determine if Lamor's skimmer, pump, and hose was able to recover a low sulphur oil which appears as separate oil lumps in water rather than a slick.

Table 3: chemical parameters of the chosen ULSFO used for the additional test.

ULSFO (NCA stock)	
Viscosity 10°C ($10s^{-1}$)	11500
Density kg/m^3	911.5
Pour point °C	18

1000 litres of fresh ULSFO were poured into the basin from a heated IBC container. The oil was dark in colour and appeared as semi-solid small oil lumps or bigger patches on the water surface. It was then left in the basin to allow to cool down to approximately 13 °C. The ULSFO did not seem to make as solid lumps as previously experienced in other trials, conducted at lower water temperatures. Due to the water temperature in the basin being 12.5 °C, it was not possible to cool down the oil to an even lower temperature.

The skimmer was then placed in the basin, attacking the oil from the "seaside", similarly setup as test setup 3, with the oil contained in the boom. Due to difficulties removing this oil from the collection tank, it was decided to pump the oil directly to an IBC container from the skimmer's discharge hose. Reliable recovery rates could therefore not be measured and is not included in the report.

The Feeder was able to collect the oil lumps and patches onto the brush chain by using the thrusters actively. When the oil got to the hopper there was initially some difficulties getting the oil to flow down to the pump. The heating and pusher plate in the hopper was turned on, resolving the issue. Neither the pump nor the discharge hose has any difficulties transferring the oil into the IBC container. Although this test could not accurately test recovery for particularly solid oil lumps, one could still see that a dynamic skimmer is necessary for recovering this oil as well. When there was no movement from the skimmer's thrusters, bridging of the oil appeared in front of the Feeder.

Conclusion

The tests demonstrated that Lamor's concept with the LAM 50 skimmer and its additional equipment has strong potential for recovering a range of low-sulphur fuel oils, successfully recovering all three test oils with good results.

The Feeder unit was effective at collecting oil of especially sticky/semi-solid properties to the brush chain, and into the hopper. The solutions for helping oil flow down to the pump by using heating or/and a mechanical pusher plate was well designed and worked as intended. Having the Feeder unit as an add-on to an already existing skimmer when encountering challenging LSFOs is a flexible solution to use when needed.

Using a dynamic skimmer with thrusters to actively manoeuvre in the oil slick, combined with the Feeder unit and other dynamic features such as heating/moving plate in the hopper provides much needed assistance for effective recovery of LSFOs with poor flow properties or short and semi-solid characteristics, but it also poses higher demands on the operator in the field, who must manage several controllers simultaneously, adding to the overall complexity of the operation.

In conclusion, the tests offered valuable insights into the challenges of recovering LSFOs, and the concept shows strong potential as part of a broader toolbox for addressing these oil types.

Appendix

Table with complete test results conducted at the Horten Test Facility for trial period 3.

Oil-ID	*Test setup*	*Rep.*	*Time*	*Litres total*	*Litres of oil*	*Litres of free water*	*% of free water*	*Oil recovery rate (m^3/h)*	*Skimmer and additional equipment*
IM-27	3	1	10:06	798	705,6	92,4	12 %	4,2	LAM50, Feeder, thruster
IM-27	3	2	3:00	840	663,6	176,4	21 %	13,3	LAM50, Feeder, thruster
IM-27	3	3	3:44	806,4	705,6	100,8	13 %	11,3	LAM50, Feeder, thruster
IM-27	3	4	3:18	798	705,6	92,4	12 %	12,8	LAM50, Feeder, thruster
IM-27	4	1	2:59	798	680,4	117,6	15 %	13,7	LAM50, Feeder, thruster
IM-27	4	2	2:22	798	672	126	16 %	17,0	LAM50, Feeder, thruster
IM-27	4	3	3:03	798	655,2	142,8	18 %	12,9	LAM50, Feeder, thruster
IM-28	3	1	2:37	806,4	739,2	67,2	8 %	16,9	LAM50, Feeder, thruster, heating
IM-28	3	2	3:10	806,4	781,2	25,2	3 %	14,8	LAM50, Feeder, thruster, heating
IM-28	3	3	2:53	814,8	747,6	67,2	8 %	15,6	LAM50, Feeder, thruster, pusher plate
IM-28	4	1	2:14	823,2	781,2	42	5 %	21,0	LAM50, Feeder, thruster, heating, pusher plate
IM-28	4	2	1:54	806,4	756	50,4	6 %	23,9	LAM50, Feeder, thruster, heating, pusher plate
IM-29	3	1	4:14	806,4	680,4	126	16 %	9,6	LAM50, Feeder, thruster, heating, pusher plate
IM-29	3	2	4:18	806,4	663,6	142,8	18 %	9,3	LAM50, Feeder, thruster, pusher plate
IM-29	4	1	3:54	798	646,8	151,2	19 %	10,0	LAM50, Feeder, thruster, pusher plate
IM-29	4	2	4:21	798	697,2	100,8	13 %	9,6	LAM50, Feeder, thruster, pusher plate

APPENDIX 8

Test report from Lamor mechanical recovery trial period 2

IMAROS 2 – WP4

Test report from Lamor mechanical recovery trial period 2 oil-in-ice

Lamor - week 7 - 2025

Author(s): Finnish Border Guard

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Description of Kotka test facility

Tests were performed at South-Eastern Finland University of Applied Sciences' (XAMK) test facility in Kotka, Finland, contracted by the Finnish Border Guard. The outdoor test basin is an aluminium pool with the dimensions of 3m x 4m. The water depth of the basin was 0.8-0.9 meters. There were blocks of ice mimicking solid ice field that has a fairway broken in the sea. The ice concentration was about 80 %.

During the test days, the water temperature was ranging between 0 to 2°C and air temperature was around -2.0°C.

Figure 1: Picture of the test basin.

Test procedure

The skimmer was tested according to the "Procedure for IMAROS 2 testing of oil skimmers in winter conditions (oil-in ice) in Kotka, Finland test facility on week 7/2025". Deviations from the protocol: Oil uptake rate was not measured, after first runs the oil was left at the pool overnight.

For more details of the test procedure, see appendix 2.

The test oil

LSFO (IM-27) was provided by the IMAROS2 project. The given information of the properties of the VLSFO: Kinematic viscosity at 50 °C 322 mm2/s, Pour point 12 °C, Density at 15 °C 955.7 kg/m3, Sulphur 0.387 mass %.

Observations of the IM-27 oil in cold conditions:

The oil poured into the basin was 35 °C and the air temperature was -2 °C during the first test day. The oil seemed to behave similar to traditional heavy fuel oil. Even after several hours the oil was still liquid and did not solidify. It was decided to leave the oil into the basin overnight to see how it behaves. The overnight temperature reached around -5 °C. In the morning there was more oil between the ice chunks, but the oil had not changed significantly overnight and still appeared relatively fluid.

Description of the skimmer and additional equipment

The Lamor LRB 150 is an oil recovery device intended for oil recovery from water surface either by being connected to excavator end, for example for pond cleaning or alternatively connected to a crane end, for example crane on vessel.

When connected to a crane, the oil recovery can be done overside of a vessel, either in open water or icy conditions. The actual LRB can be operated in several ways:

- using the oleophilic brush wheel for oil recovery and oil-water separation in combination with the integrated oil transfer pump for transferring recovered oil via hoses to tanks on vessel
- Alternatively, the brush wheel can be lifted up and «bucket» can be used as a «excavator-bucket» for «digging oil» in combination with the integrated oil pump for oil transferring the oil via hoses to vessel
- The bucket can be used without the oil transfer pump and simply as traditional «excavator bucket» and oil would be mechanically excavated and dumped into an open tank onboard vessel

Only the first option was used in the IMAROS 2 test. The other two option could be useful in recovery of ULSFO as well.

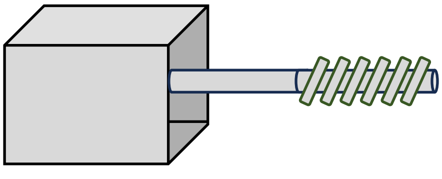
Main components of LRB is: brush wheel with scraper, bucket, screw for feeding pump, GTA pump, excavator and/or crane fixing arrangement, hydraulics control, remote control, heating arrangement.

Further, the LRB is available in different sizes from 40 to 250 (indicating bucket width).

Figure 2: Picture of the skimmer.

Results

<u>Recovery of the IM-27 (VLSFO)</u>
250 litres oil poured into the basin was 35 °C, air temperature was -2 °C. At the beginning of the first run, the oil temperature was 0-5 °C. The oil was collected only into the skimmer's scoop. The collected oil was returned to the basin after collection. The skimmer appeared to work ok, although it was difficult to know its true capacity due to only 250 litres of oil for the large bucket skimmer. It appeared that the pump was pumping a lot of oil, but there was a lot of air in the centre of the discharge hose. The screw struggled to transport the oil to the pump, even with the help from the heating loop. Inside the bucket there was a loop with hot water pipes, the generator showed temperatures of 75 °C, and returned with 45 °C.



The gap between the last screw and the pump housing: here the oil tumbles around like "bread dough" and will not enter the pump properly.

The oil left into the basin overnight was collected well. Some oil was not scraped off the brushes. The scraper was then adjusted to sit lower, which improved the scraping of the brushes after adjustment. A steam pipe was also used. Under the screw, there is a steam pipe leading to a compartment beneath the bucket. It was observed that oil/ice melted on the both the outside and inside of the bucket, which resulted in a significant amount of water inside the bucket.

The last run was done after adding 250 litres of oil into the basin. The scraper was reversed since the brushes were to be run in the opposite direction (upwards). A run was conducted with the brushes in the opposite direction, which worked okay but was not more effective, as the oil fell off along the way before reaching the scraper. Additionally, the way the brushes operated pushed the oil away from them. A significant amount of water also entered the scoop since the skimmer was operated deeper in the water surface than before. The brushes were about 30% below the water surface, which made it easier for the oil to adhere to the brushes compared to when they were positioned higher.

Conclusions and the way forward

In conclusion, this test confirmed that this kind of VLSFO, that mostly behaves like traditional heavy fuel oil. For this particular equipment, more difficult VLSFO would have been more challenging test oil.

APPENDIX 9

Test report from Desmi mechanical recovery trial period 3

IMAROS 2 – WP 4

Test report from Desmi mechanical recovery trial period 3

DESMI - week 19, 2025

NCA Test Facilities – Horten, Norway

Author(s): Norwegian Coastal Administration

KYSTVERKET

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Description of Horten test facility

The National Centre for Testing of Oil Spill Response Equipment, located in Horten, Norway, offers the opportunity to test oil skimmers under controlled yet highly realistic conditions. The test centre features an indoor saltwater basin with a dual-bottom design. Measuring 30 meters in length, 7 meters in width, and up to 4.5 meters in depth, the basin is equipped to simulate both currents and wave conditions. Figure 1 provides an illustration of the basin layout. Testing was conducted at water temperatures ranging from 14 to 14.5°C and air temperatures between 14 and 18°C.

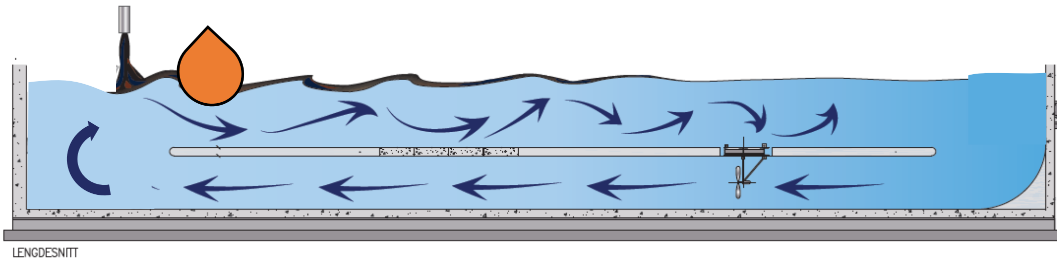

Figure 1: Illustration of the test basin with blue arrows indicating water current and a wave ball outlined with orange colour.

Test procedure

The skimmer was tested according to the NCA's "Procedure for testing oil skimmers in the National Centre for Testing of Oil Spill Response Equipment" with a configuration shown in figure 2. With the help of the current the oil slick flowed into the boom, where the skimmer was placed to enable recovery.

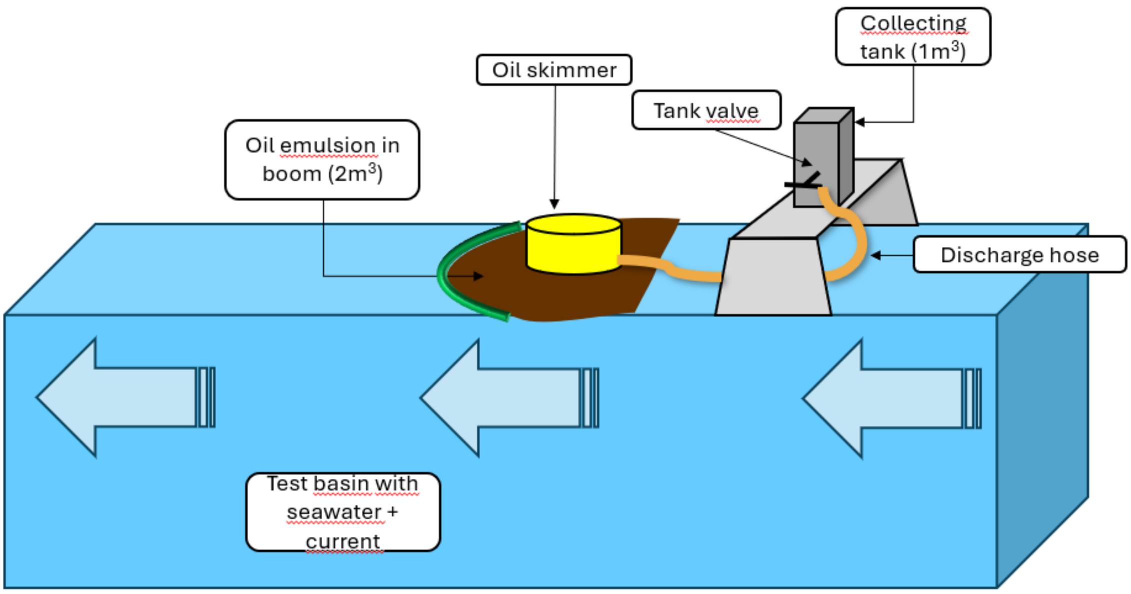

Figure 2: Illustration of the configuration used in the test basin.

The following test setups were conducted:

Test 3:	Capacity test of oil emulsion in boom with current: Oil emulsion (approximately 50% water) and skimmer placed in the boom, with current simulating towing of boom. The speed of the current is approximately 0.6 knots. 2000 litres of oil emulsion is poured into the basin, and the goal is to recover 800 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.
Test 4:	Capacity test of oil emulsion in boom with current and waves: Similar setup as test 3, in addition with waves.

For more details of the test procedure, see appendix 1.

The test oils

Table 1 shows the three test oils used in the recovery tests, with results of viscosity and pour point of the fresh oil samples, and the viscosity range of samples taken of the oil emulsion during testing. There were in total 6 samples taken during the tests at different stages to measure for water content in emulsion, viscosity, and density. The samples were analysed at the laboratory of Sintef Ocean. See appendix 4 and 5 for Sintef memo of the oil analyses conducted for the mechanical recovery trials. A list describing where and when the samples of emulsion were taken during testing in the recovery trial periods is found in appendix 3.

Table 1: some characteristics of the three oils used in the tests.

Imaros 2 ID	Oil type	Viscosity of fresh oil at 10°C ($10s^{-1}$)	Viscosity of emulsion at 10°C ($10s^{-1}$)	Pour point (°C)
IM-27	VLSFO	23,104	18,281 – 23,896	12 (9, 24)*
IM-28	VLSFO	36,277	69,832 – 80,372	27 (21, 30)*
IM-29	ULSFO	932	11,346 – 14,954	27 (15, 24)*

**For pour point, the first value is from the oil suppliers' certificate of analysis. The values in brackets are measured minimum and maximum pour point from Sintef and Cedre laboratories. Pour point measurements seems to be subjected to uncertainties and is described in more detail in deliverable D3.1 Summary report of WP3 – Characterisation and Impacts chapter 3.1.4.*

Description of the skimmer and additional equipment

Desmi provided a modified version of the Octopus In-Line skimmer with several features designed to recover challenging LSFOs (figure 3). A brush belt module with large openings between brush belts placed in front of integrated and adjustable floats, allows for minimal oil flow obstructions. The hopper edge is low in relation to the surface level, with steep walls designed to give minimal flow restrictions to the pump below. Thrusters are positioned relatively deep in the central position.

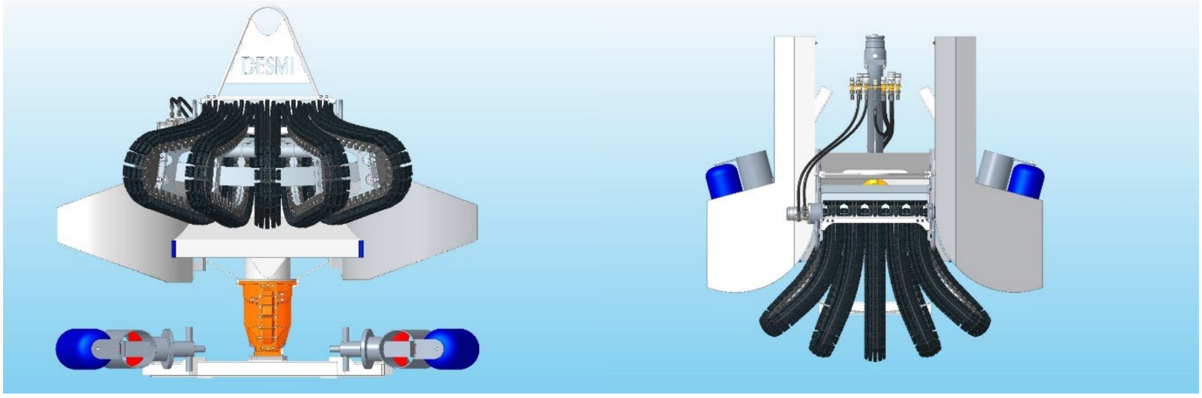

Figure 3: Illustration of the DESMI modified Octopus skimmer (from Desmi).

The pump was a DOP pump, type 200 with the following data:

- Work pressure: 210 bar (max. hydraulic requirement)
- Viscosity max.: >3,036,000 mPas
- Capacity: 66 m^3/h max
- Pressure max.: 13 bar

Results

Table 2: overall results of best measured oil emulsion recovery rates for the tests conducted with the modified DESMI Octopus skimmer.

Oil	Skimmer	Hose	Additional equipment	Test no.	Oil recovery rate
IM-27	Modified Octopus	4” flat hose	Thrusters	3	30.2 m^3/h
IM-27	Modified Octopus	4” flat hose	Thrusters	4	30.6 m^3/h
IM-28	Modified Octopus	4” flat hose	Thrusters	3	21.5 m^3/h
IM-28	Modified Octopus	4” flat hose	Thrusters	4	25.4 m^3/h
IM-29	Modified Octopus	4” flat hose	Thrusters	3	19.7 m^3/h
IM-29	Modified Octopus	4” flat hose	Thrusters	4	27.6 m^3/h

Recovery of the IM-27 (VLSFO)

Test setups 3 and 4 were conducted on this oil, with best results of 30.2 m^3/h and 30.6 m^3/h of oil recovery rate.

The skimmer performed well on the IM-27 oil, with good recovery rates both with and without wave action. The free water uptake was also relatively low. Even though the IM-27 oil has short properties, the movement from the thrusters helped the brushes to reach the oil. Additionally, since the brushes were positioned in front of the main body of the skimmer, they always had directly access to the oil. Furthermore, the specific design of the brush positioning, angled outwards on the sides, it was found to enhance oil recovery by providing a larger surface area and better access to the oil slick. These features may have had an impact in preventing the formation of a water layer between skimmer and oil. The pump and discharge hose effectively transported the oil to the collection tank without issues.

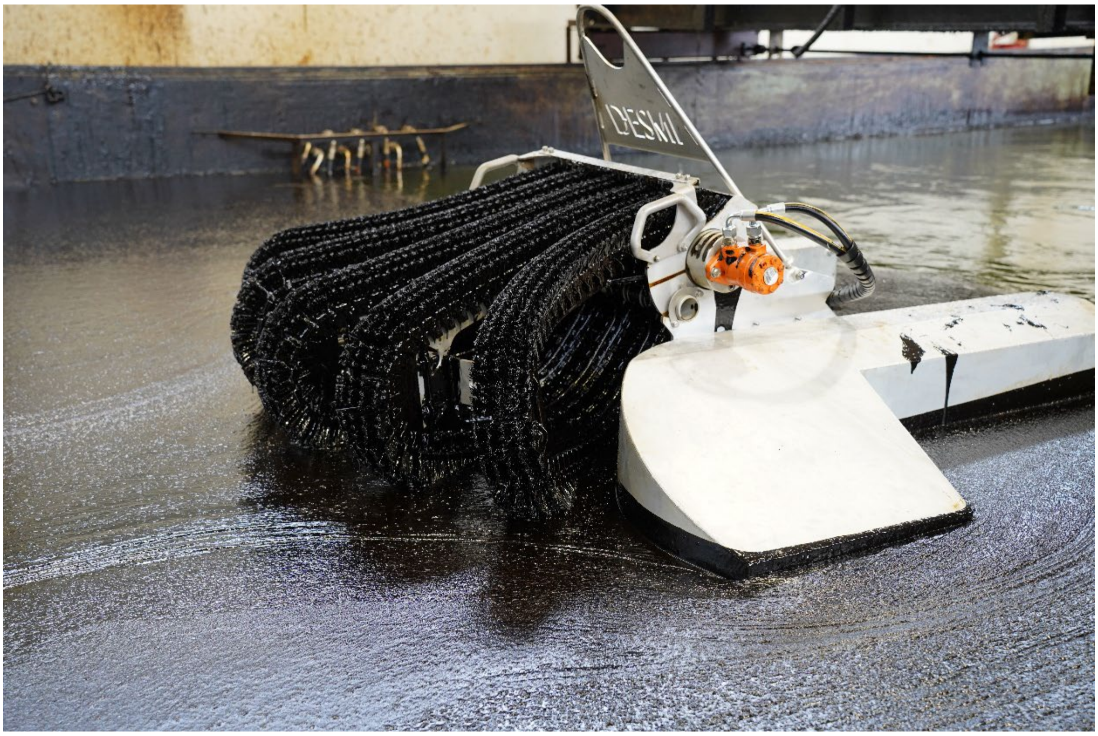

Figure 4: Photo of the DESMI modified Octopus skimmer operating in the IM-27 oil.

Recovery of the IM-28 (VLSFO)

Test procedures 3 and 4 were used on this oil, with best results of 21.5 m^3/h and 25.4 m^3/h of oil recovery rates.

Although the IM-28 exhibit little to no flow properties, the Octopus skimmer was able to use the thrusters to manoeuvre from the "seaside" toward the oil slick, forcing the oil onto the brushes, allowing for nice recovery. The brushes also occasionally dislodged and captured larger oil patches from the slick. It could be observed that some oil stuck to the back of the skimmer, making it hard to reach. The pump had no issues transporting oil from the hopper to the collection tank.

Compared to IM-27, the IM-28 recovery required more active manoeuvring in the basin, as the skimmer needed to pursue the oil and push it towards the brushes. While the thrusters provided much needed assistance for recovery, operating the skimmer in this type of oil poses higher demands on the operator in the field, who must manage the pump, brushes, and thrusters simultaneously, adding to the overall complexity of the operation.

Figure 5: Photo of the DESMI modified Octopus skimmer operating in the IM-28 oil.

Recovery of the IM-29 (ULSFO)

Test setups 3 and 4 were used on this oil, with best results of 19.7 and 27.6 m^3/h of oil recovery rates.

Even though the IM-29 exhibit both short and semi-solid properties, the skimmer achieved good recovery when the brushes operated at low rotational speed, which increased adhesion to the oil, while also keeping the free water uptake low. In contrast, higher rotational speed on the brushes introduces much more energy onto the oil surface, causing the oil in contact with the brushes to become highly fluid and slippery in addition to its already short characteristics. Hence, it is more efficient to operate the brushes at a lower speed.

Recovery rates improved further when wave action was introduced in the basin, as the resulting fragmentation of the slick into smaller patches allowed the brushes to capture oil more effectively as it detached from the main slick. Once inside the hopper, the oil flowed into the pump and through the discharge hoses without difficulty. However, it was observed that due to the spacing between the brush arms, some oil remained trapped in the gaps and was not collected into the hopper.

Figure 6: Photo of the DESMI modified Octopus skimmer operating in the IM-29 oil.

Additional ULSFO test

One of the challenges when testing mechanical recovery in the previous IMAROS project, was that the IM-16 appeared as solid oil lumps in the test basin, making it difficult for the skimmers to both collect and pump the oil from the hopper. As neither the IM-27, IM-28 or the IM-29 had similar oil lump appearance, it was decided to use an ULSFO (see table 3 for chemical parameters) from NCA's stock that have shown in other earlier trials to appear as solid oil lumps, to do an additional test to determine if Desmi's skimmer, pump, and hose was able to recover a low sulphur oil which appears as separate oil lumps in water rather than a slick.

Table 3: chemical parameters of the chosen ULSFO used for the additional test.

ULSFO (NCA stock)	
Viscosity 10°C ($10s^{-1}$)	11500
Density kg/m^3	911.5
Pour point °C	18

1000 litres of fresh ULSFO were poured into the basin from a heated IBC container. The oil was dark in colour and appeared as semi-solid small oil lumps or bigger patches on the water surface. It was then left in the basin to allow to cool down to approximately 15 °C. The ULSFO did not seem to make as solid lumps as previously experienced in other trials, conducted at lower water temperatures. Due to the water temperature in the basin being 14.5 °C, it was not possible to cool down the oil to an even lower temperature.

The skimmer was then placed in the basin, attacking the oil from the “seaside”, similarly setup as test setup 3, with the oil contained in the boom. Due to difficulties removing this oil from the collection tank, it was decided to pump the oil directly to an IBC container from the skimmer’s discharge hose. Reliable recovery rates could therefore not be measured and is not included in the report.

The skimmer was able to force the oil patches onto the brushes by using the thrusters actively. When there was no movement from the skimmer’s thrusters, bridging of the oil appeared in front of the brushes. Once the oil reached the hopper, it flowed down to the pump and delivered it through the discharge hose into the IBC container without problems. Although this test could not accurately test recovery for particularly solid oil lumps, one could still see that a dynamic skimmer is necessary for recovering this oil as well.

Conclusion

The tests demonstrated that the modified Octopus skimmer has strong potential for recovering a range of low-sulphur fuel oils, successfully recovering all three test oils with good results.

Both the hopper and pump solutions are well designed to recover the more challenging LSFOs with behaviour such as semisolid oils with sticky/poor flow properties. The brush scraper effectively directs oil almost directly into the pump, while the placement of the thrusters and floaters ensures high stability during operation and manoeuvring. The placement of the brush module at the front of the skimmer, combined with its wide working angle, provides unobstructed access and a large area for oil collection.

The tests also showed how the use of thrusters on the skimmer is very beneficial for being able to get hold of oils with poor flow properties or short and semi-solid characteristics. While the thrusters provided much needed assistance for recovery, operating the skimmer this way poses higher demands on the operator in the field, who must manage the pump, brushes, and thrusters simultaneously, adding to the overall complexity of the operation.

In conclusion, the tests offered valuable insights into the challenges of recovering LSFOs, and the concept shows strong potential as part of a broader toolbox for addressing these oil types.

Appendix

Table with complete test results conducted at the Horten Test Facility for trial period 3.

Oil-ID	*Test setup*	*Rep.*	*Time*	*Litres total*	*Litres of oil*	*Litres of free water*	*% of free water*	*Oil recovery rate (m^3/h)*	*Skimmer and additional equipment*
IM-27	3	1	1:44	806,4	739,2	67,2	8 %	25,6	Modified octopus, thrusters
IM-27	3	2	1:26	806,4	722,4	84	10 %	30,2	Modified octopus, thrusters
IM-27	4	1	1:46	806,4	739,2	67,2	8 %	25,1	Modified octopus, thrusters
IM-27	4	2	1:28	798	747,6	50,4	6 %	30,6	Modified octopus, thrusters
IM-28	3	1	2:57	806,4	546	260,4	32 %	11,1	Modified octopus, thrusters
IM-28	3	2	2:58	814,8	772,8	42	5 %	15,6	Modified octopus, thrusters
IM-28	3	3	2:01	806,4	722,4	84	10 %	21,5	Modified octopus, thrusters
IM-28	4	1	2:46	806,4	747,6	58,8	7 %	16,2	Modified octopus, thrusters
IM-28	4	2	2:52	806,4	772,8	33,6	4 %	16,2	Modified octopus, thrusters
IM-28	4	3	1:46	798	747,6	50,4	6 %	25,4	Modified octopus, thrusters
IM-29	3	1	4:15	798	739,2	58,8	7 %	10,4	Modified octopus, thrusters
IM-29	3	2	2:20	798	764,4	33,6	4 %	19,7	Modified octopus, thrusters
IM-29	3	3	2:29	806,4	781,2	25,2	3 %	18,9	Modified octopus, thrusters
IM-29	4	1	1:45	806,4	781,2	25,2	3 %	26,8	Modified octopus, thrusters
IM-29	4	2	1:43	806,4	789,6	16,8	2 %	27,6	Modified octopus, thrusters

APPENDIX 10

Test report from Vikoma mechanical recovery trial period 3

IMAROS 2 – WP4

Test report from Vikoma mechanical recovery trial period 3

VIKOMA – week 21, 2025

NCA Test Facilities – Horten, Norway

Author(s): Norwegian Coastal Administration

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Description of Horten test facility

The National Centre for Testing of Oil Spill Response Equipment, located in Horten, Norway, offers the opportunity to test oil skimmers under controlled yet highly realistic conditions. The test centre features an indoor saltwater basin with a dual-bottom design. Measuring 30 meters in length, 7 meters in width, and up to 4.5 meters in depth, the basin is equipped to simulate both currents and wave conditions. Figure 1 provides an illustration of the basin layout. Testing was conducted at water temperatures ranging from 14 to 14.5°C and air temperatures between 15 and 23°C.

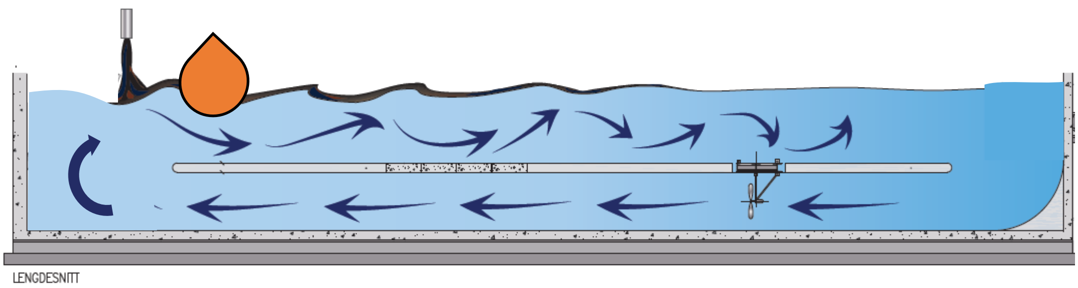

Figure 1: Illustration of the test basin with blue arrows indicating water current and a wave ball outlined with orange colour.

Test procedure

The skimmer was tested according to the NCA's "Procedure for testing oil skimmers in the National Centre for Testing of Oil Spill Response Equipment" with a configuration shown in figure 2. With the help of the current the oil slick flowed into the boom, where the skimmer was placed to enable recovery.

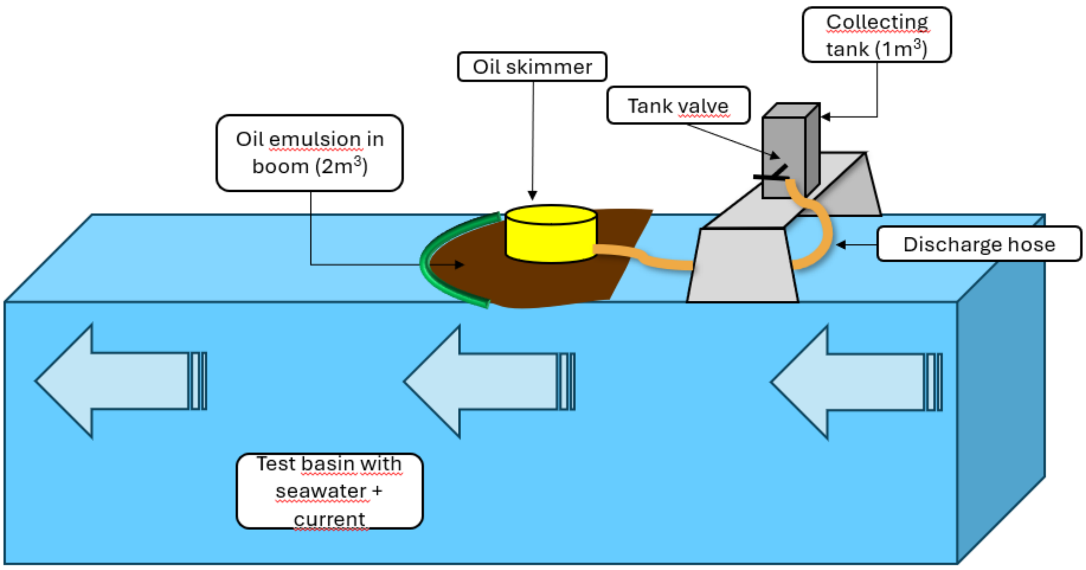

Figure 2: Illustration of the configuration used in the test basin.

The following test setups were conducted:

Test 3:	Capacity test of oil emulsion in boom with current: Oil emulsion (approximately 50% water) and skimmer placed in the boom, with current simulating towing of boom. The speed of the current is approximately 0.6 knots. 2000 litres of oil emulsion is poured into the basin, and the goal is to recover 800 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.
Test 4:	Capacity test of oil emulsion in boom with current and waves: Similar setup as test 3, in addition with waves.

For more details of the test procedure, see appendix 1.

The test oils

Table 1 shows the three test oils used in the recovery tests, with results of viscosity and pour point of the fresh oil samples, and the viscosity range of samples taken of the oil emulsion during testing. There were in total 6 samples taken during the tests at different stages to measure for water content in emulsion, viscosity, and density. The samples were analysed at the laboratory of Sintef Ocean. See appendix 4 and 5 for Sintef memo of the oil analyses conducted for the mechanical recovery trials. A list describing where and when the samples of emulsion were taken during testing in the recovery trial periods is found in appendix 3.

Table 1: some characteristics of the three oils used in the tests.

Imaros 2 ID	Oil type	Viscosity of fresh oil at 10°C ($10s^{-1}$)	Viscosity of emulsion at 10°C ($10s^{-1}$)	Pour point (°C)
IM-27	VLSFO	23,104	11,324 – 15,927	12 (9, 24)*
IM-28	VLSFO	36,277	67,887 – 70,280	27 (21, 30)*
IM-29	ULSFO	932	11,253 – 21,470	27 (15, 24)*

**For pour point, the first value is from the oil suppliers' certificate of analysis. The values in brackets are measured minimum and maximum pour point from Sintef and Cedre laboratories. Pour point measurements seems to be subjected to uncertainties and is described in more detail in deliverable D3.1 Summary report of WP3 – Characterisation and Impacts chapter 3.1.4.*

Description of the skimmer and additional equipment

Vikoma provided a modified Komara Star Disc/Brush skimmer with installed thrusters (figure 3). Vikoma have named the new skimmer Komara Omni. The skimmer's modular construction allows for easily changing skimmer modules depending on the type of oil recovery. Different types of skimmer module brush designs were developed: A Vikoma pattern "V Brush" and a straight pattern with larger spacing between the brush rows to allow for better adhesion and to get hold of oil with semi-solid and short characteristics. The skimmer is also modified to minimize forward facing surfaces and where the brush is always in direct contact with the oil to minimize bridging of oil with poor flow properties. In addition, Vikoma has developed a powered trim which gives the skimmer the ability to move the skimmer module up and down to suit for different oil depth.

Vikoma have informed us that Komara Omni will be offered with a wider range of recovery modules including star disc and plain oleophilic discs to provide greater flexibility in recovering different types of oil.

Figure 3: Photo of the Vikoma Komara Omni skimmer (from Vikoma).

The pump was a lobe pump, with the following data:

- Work pressure: 6.5 bar
- Viscosity max.: 1,000,000 mPas
- Capacity: 30 m^3/h
- Pressure max.: 8 bar

Results

Table 2: overall results of best measured oil emulsion recovery rates for the tests conducted with the Komara Omni skimmer.

Oil	Skimmer	Hose	Additional equipment	Test no.	Oil recovery rate
IM-27	Komara Omni	3'' spiral hose	Thrusters, powered trim, straight brush	3	27.8 m^3/h
IM-27	Komara Omni	3'' spiral hose	Thrusters, powered trim, V brush	4	31.3 m^3/h
IM-28	Komara Omni	3'' spiral hose	Thrusters, powered trim, V brush	3	12.8 m^3/h
IM-28	Komara Omni	3'' spiral hose	Thrusters, powered trim, V brush	4	15.3 m^3/h
IM-29	Komara Omni	3'' spiral hose	Thrusters, powered trim, V brush	3	15 m^3/h
IM-29	Komara Omni	3'' spiral hose	Thrusters, powered trim, V brush	4	33.9 m^3/h

Recovery of the IM-27 (VLSFO)

Test setups 3 and 4 were conducted on this oil, with best results of 27.8 and 31.3 m^3/h of oil recovery rate.

The skimmer performed well on the IM-27 oil and achieved very good recovery rates considering that the maximum capacity of the pump is 30 m^3/h. For this oil the recovery rates were so high that it could be considered increasing the pump capacity. The pump and the 3-inch discharge hose effectively transported the oil to the collection tank without issues, and the relatively small hose diameter also made the skimmer easier to manoeuvre for the operator.

Free water uptake was relatively low. The design of the V brush seems to give somewhat lower free water uptake than the straight brush and typical brushes, due to its concave pattern. The thrusters are powerful and working well to keep the skimmer active in the slick. The use of the powered trim adjusting the elevation of the skimmer, allowing it to adapt to varying oil layer thickness, proved to be a very effective and easy to use feature. While having more dynamic features makes for better recovery, it can make it more complex to handle for the operator in the field.

When wave action was introduced, recovery rates improved further. The skimmer remained stable in the water under these conditions, and free water uptake was further reduced, likely due to wave motion, which helped water to escape when the brush was working on the oil.

Figure 4: Photo of the Vikoma Komara Omni skimmer operating in the IM-27 oil.

Recovery of the IM-28 (VLSFO)

Test setups 3 and 4 were used on this oil, with best results of 12.8 m^3/h and 15.3 m^3/h of oil recovery rates.

Although the IM-28 exhibit little to no flow properties, the Komara Omni skimmer was able to use the thrusters to manoeuvre from the “seaside” toward the oil slick, forcing the oil onto the brushes, leading to efficient recovery. Compared to IM-27, recovery of IM-28 required more active manoeuvring in the basin, as the skimmer needed to pursue the oil and push it toward the brush. While the thrusters provided much needed assistance for recovery, in some experiments the powerful thrusters can cause some turbulence in the water, pushing parts of the slick further away from the skimmer, however this would be avoided with training/practice. The design of the hopper, pump, and 3-inch hose effectively transported the oil to the collection tank without issues. The powered trim feature proved particularly beneficial for this type of oil. By dynamically adjusting the skimmer height according to oil thickness, the operator could lower the brush module during forward motion in the slick to force oil onto the brush and raise it while manoeuvring in water to minimize brush contact with water and thereby reduce free water uptake.

When wave action was introduced in test setup 4, the slick was more compacted than in test setup 3. This resulted in a thicker oil layer and a smaller manoeuvring area, which overall yielded slightly higher recovery rates.


Figure 5: Photo of the Vikoma Komara Omni skimmer operating in the IM-28 oil.

Recovery of the IM-29 (ULSFO)

Test setups 3 and 4 were used on this oil, with best results of 15 m^3/h and 33.9 m^3/h of oil recovery rates.

The skimmer was very successful in recovering the IM-29. Even though the oil exhibits both short and semi-solid properties, the skimmer achieved good recovery by actively using the thrusters combined with rotating the V brush relatively slowly to get good adhesion to the oil, thereby transferring the oil to the hopper and pump very effectively, while keeping the free water uptake low. In contrast, higher rotational speed on the brushes introduces much more energy onto the oil surface, causing the oil in contact with the brushes to become highly fluid and slippery in addition to its already short characteristics. Hence, it is more efficient to operate the brush at a lower speed.

In test setup 4, where wave action was introduced, the recovery rate exceeded the pump's maximum capacity, reaching 33.9 m^3/h and overflowing of oil in the hopper as the pump could not remove oil quickly enough. This shows that the design of the skimmer with the V brush combined with thrusters and powered trim has strong potential for recovering this type of oil, particularly in dynamic conditions. The presence of wave action appears to assist in minimizing water uptake while allowing the skimmer to operate at steady pace in relatively high oil thickness.

Figure 6: Photo of the Vikoma Komara Omni skimmer operating in the IM-29 oil.

Additional ULSFO test

One of the challenges when testing mechanical recovery in the previous IMAROS project, was that the IM-16 appeared as solid oil lumps in the test basin, making it difficult for the skimmers to both collect and pump the oil from the hopper. As neither the IM-27, IM-28 or the IM-29 had similar oil lump appearance, it was decided to use an ULSFO (see table 3 for chemical parameters) from NCA's stock that have shown in other earlier trials to appear as solid oil lumps, to do an additional test to determine if Vikoma's skimmer, pump, and hose was able to recover a low sulphur oil which appears as separate oil lumps in water rather than a slick.

Table 3: chemical parameters of the chosen ULSFO used for the additional test.

ULSFO (NCA stock)	
Viscosity 10°C ($10s^{-1}$)	11500
Density kg/m^3	911.5
Pour point °C	18

1000 litres of fresh ULSFO were poured into the basin from a heated IBC container. The oil was dark in colour and appeared as semi-solid small oil lumps or bigger patches on the water surface. It was then left in the basin to allow to cool down to approximately 16 °C. The ULSFO did not seem to make as solid lumps as previously experienced in other trials, conducted at lower water temperatures. Due to the water temperature in the basin being 16 °C, it was not possible to cool down the oil to an even lower temperature.

The skimmer was then placed in the basin, attacking the oil from the "seaside", similarly setup as test setup 3, with the oil contained in the boom. Due to difficulties removing this oil from the collection tank, it was decided to pump the oil directly to an IBC container from the skimmer's discharge hose. Reliable recovery rates could therefore not be measured and is not included in the report.

The skimmer was able to force the oil lumps and patches onto the brush by using the thrusters actively. When the oil got to the hopper there was a steady flow down to the pump, that has no issues pumping it though the discharge hose and into the IBC container. Although this test could not accurately test recovery for particularly solid oil lumps, one could still see that a dynamic skimmer is necessary for recovering this oil as well. When there was no movement from the skimmer's thrusters, bridging of the oil appeared in front of the brush.

Conclusion

The tests demonstrated that Komara Omni (the modified Komara Star skimmer) has strong potential for recovering a range of low-sulphur fuel oils, successfully recovering all three test oils with good results.

The use of thrusters is very beneficial in being able to get hold of oils with poor flow properties or short and semi-solid characteristics, and the design of both the hopper and the pump was effective in transporting the oil to the collection tank.

The placement of the brush module unobstructed the front of the skimmer, combined with minimizing forward facing surfaces gives the skimmer access to oil at all times, and helps to avoid oil bridging. Earlier experiences with low-sulphur oils have shown that many LSFOs with poor flow properties lacks good adhesion to skimmer brushes, and Vikoma's V brush and straight brush where there is a gap between the brush rows helps mitigate this problem by allowing oil to collect in between the gaps, thereby not only relying on oleophilic adhesion in the brushes.

Using a dynamic skimmer that can actively manoeuvre in the oil slick, combined with other features such as the powered trim, provides much needed assistance of recovery, but it also poses higher demands on the operator in the field, who must manage several controllers simultaneously, adding to the overall complexity of the operation.

In conclusion, the tests offered valuable insights into the challenges of recovering LSFOs, and the concept shows strong potential as part of a broader toolbox for addressing these oil types.

Appendix

Table with complete test results conducted at the Horten Test Facility for trial period 3.

Oil-ID	*Test setup*	*Rep.*	*Time*	*Litres total*	*Litres of oil*	*Litres of free water*	*% of free water*	*Oil recovery rate (m^3/h)*	*Skimmer and additional equipment*
IM-27	3	1	2:10	848,4	764,4	84	10 %	21,2	Komara Omni, thruster, powered trim, straight brush
IM-27	3	2	3:32	798	655,2	142,8	18 %	11,1	Komara Omni, thruster, powered trim, straight brush
IM-27	3	3	1:35	806,4	672	134,4	17 %	25,5	Komara Omni, thruster, powered trim, straight brush
IM-27	3	4	1:27	814,8	672	142,8	18 %	27,8	Komara Omni, thruster, powered trim, straight brush
IM-27	4	1	1:54	806,4	722,4	84	10 %	22,8	Komara Omni, thruster, powered trim, V brush
IM-27	4	2	1:27	806,4	756	50,4	6 %	31,3	Komara Omni, thruster, powered trim, V brush
IM-28	3	1	9:24	806,4	730,8	75,6	9 %	4,7	Komara Omni, thruster, powered trim, V brush
IM-28	3	2	3:28	814,8	739,2	75,6	9 %	12,8	Komara Omni, thruster, powered trim, V brush
IM-28	3	3	4:46	806,4	630	176,4	22 %	7,9	Komara Omni, thruster, powered trim, straight brush
IM-28	3	4	4:58	823,2	739,2	84	10 %	8,9	Komara Omni, thruster, powered trim, V brush
IM-28	4	1	2:50	814,8	722,4	92,4	11 %	15,3	Komara Omni, thruster, powered trim, V brush
IM-28	4	2	3:00	806,4	705,6	100,8	13 %	14,1	Komara Omni, thruster, powered trim, V brush
IM-29	3	1	4:03	806,4	747,6	58,8	7 %	11,1	Komara Omni, thruster, powered trim, V brush
IM-29	3	2	2:53	798	722,4	75,6	9 %	15,0	Komara Omni, thruster, powered trim, V brush
IM-29	4	1	1:24	798	756	42	5 %	32,4	Komara Omni, thruster, powered trim, V brush
IM-29	4	2	1:22	798	772,8	25,2	3 %	33,9	Komara Omni, thruster, powered trim, V brush

APPENDIX 11

Test report from New Naval mechanical recovery trial period 2

IMAROS 2 - WP4

Test report from New Naval mechanical recovery trial period 2 oil-in-ice

New Naval - week 7 - 2025

Author(s): Finnish Border Guard

Description of Kotka test facility

Tests were performed at South-Eastern Finland University of Applied Sciences' (XAMK) test facility in Kotka, Finland, contracted by the Finnish Border Guard. The outdoor test basin is an aluminium pool with the dimensions of 3m x 4m. The water depth of the basin was 0.8-0.9 meters. There were blocks of ice mimicking solid ice field that has a fairway broken in the sea. The ice concentration was about 80 %.

During the test days, the water temperature was ranging between 0 to 2°C and air temperature was around -2.0°C.

Figure 1: Picture of the test basin.

Test procedure

The skimmer was tested according to the "Procedure for IMAROS 2 testing of oil skimmers in winter conditions (oil-in ice) in Kotka, Finland test facility on week 7/2025. Deviations from the protocol: Fresh heated oil was poured into the pool in the morning to the first day. Oil uptake rate was measured during day 2, but the oil in the pool was from previous days and no new oil was added.

For more details of the test procedure, see appendix 2.

The test oil

VLSFO (IM-27) was provided by the IMAROS 2 project. The given information of the properties of the VLSFO: Kinematic viscosity at 50 °C 322 mm2/s, Pour point 12 °C, Density at 15 °C 955.7 kg/m3, Sulphur 0.387 mass %.

Observations of the IM-27 oil in cold conditions:

The oil poured into the basin was 33 °C and the air temperature was -3 to -4 °C during the first test day. The oil seemed to behave similar to traditional heavy fuel oil. Even after several hours the oil was still liquid and did not solidify. It was decided to leave the oil into the basin overnight to see how it behaves. The overnight temperature reached around -5 °C. In the morning there was more oil between the ice chunks, but the oil had not changed significantly overnight and still appeared relatively fluid.

Description of the skimmer and additional equipment

The ScorSkim 30 is an oleophilic, free-floating skimmer designed for efficient oil spill recovery in a wide range of environments and scenarios. Its modular design allows for quick interchange between brush, disc, or drum recovery banks, depending on the viscosity and the type of target oil. Utilizing proven oleophilic technology, the system achieves oil recovery efficiency of up to 99%. Compact and easy to deploy, the ScorSkim 30 is well-suited for nearshore, harbour, and offshore operations.

It features an integrated on-board pump capable of recovery rates up to 54 m³/h. The skimmer is hydraulically driven, with low power requirements and quick couplings for seamless connection to a dedicated power pack. Constructed with durable, marine-grade aluminium, the system is highly resistant to oil, dispersants, and seawater. Two external floats provide enhanced stability and buoyancy. For operations in icy conditions, the skimmer is equipped with a front-facing ice-breaking grid and two steam injection circuits: one at the front and one at the pump's suction inlet to ensure continued performance in cold environments.

Figure 2: Picture of the skimmer.

Results

Recovery of the IM-27 (VLSFO)
250 litres of 33°C oil was poured into the basin; air temperature was -2 °C. There was already around 500 litres of oil from previous test days in the pool. At the beginning of the first run, the oil temperature was 0-5 °C.

General testing of the skimmer was performed during the first day. There were some issues with the skimmer that needed adjustments during the runs. Skimmer had some difficulties staying in level with the water, requiring several adjustments to the rear floats. Adjustment of the rear floats is necessary when the skimmer is deployed under varying conditions, including oil, water, or ice. This was also due to the large amount of ice in the basin. The skimmer did not have thrusters due to the dimensional constraints of the test tank and more specifically the depth. It had a front grid with large holes designed to stop ice, but this likely also blocked oil. Additionally, there was a debris grid over the pump, which also hindered oil flow into the pump. Eventually, the front grid was removed.

Initially, the skimmer was operated at a high speed. The brush managed to collect the oil in the immediate area where the skimmer was semi-submerged. However, the oil in the hopper drained very slowly towards the pump. The skimmer was equipped with steam/hot water pipes above the pump and in front of the front grid, directing heat toward the brushes. However, no significant effect was observed.

During day 2 three test runs were performed. The brushes did pick up the oil to the hopper quite nicely. If the hot water was on, a lot of water with the oil was collected to the collection tank. Once it was turned off, more oil than water was collected. The skimmer also had additional brush system that was introduced during the last test run. In this brush the bristles were cut to different lengths while in the original one the bristles were longer and cut to even length. This version performed equally well when compared to the first brush set.

Conclusions and the way forward

In conclusion, this test confirmed that this kind of VLSFO mostly behaves like traditional heavy fuel oil. For this particular equipment, more adjustments are needed to efficiently collect VLSFOs.

APPENDIX 12

Test report from Koseq additional mechanical recovery trial

IMAROS 2 - WP 4

Test report from Koseq additional mechanical recovery trial

KOSEQ - week 23 and 24, 2025

NCA Test Facilities – Horten, Norway

Author(s): Norwegian Coastal Administration

imaros2

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Description of Horten test facility

The National Centre for Testing of Oil Spill Response Equipment, located in Horten, Norway, offers the opportunity to test oil skimmers under controlled yet highly realistic conditions. The test centre features an indoor saltwater basin with a dual-bottom design. Measuring 30 meters in length, 7 meters in width, and up to 4.5 meters in depth, the basin is equipped to simulate both currents and wave conditions. Figure 1 provides an illustration of the basin layout. Testing was conducted at water temperatures ranging from 16.5 to 17°C and air temperatures between 18 and 22°C.

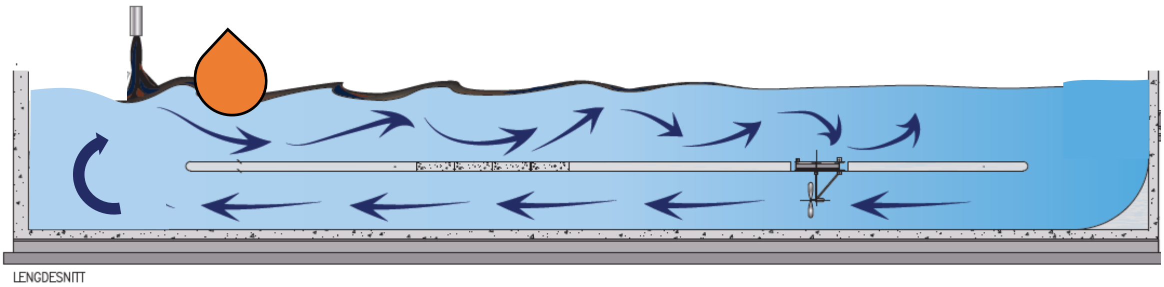

Figure 1: Illustration of the test basin with blue arrows indicating water current and a wave ball outlined with orange colour.

Test procedure

The skimmer was tested according to the NCA's "Procedure for testing oil skimmers in the National Centre for Testing of Oil Spill Response Equipment" with a modified configuration due to the large size of the skimmer system. The skimmer system was placed in one end of the test basin, and the oil was placed at the other end (figure 2). With help of the current the slick flowed towards the skimmer. Due to the width of the skimmer system, no boom was required.

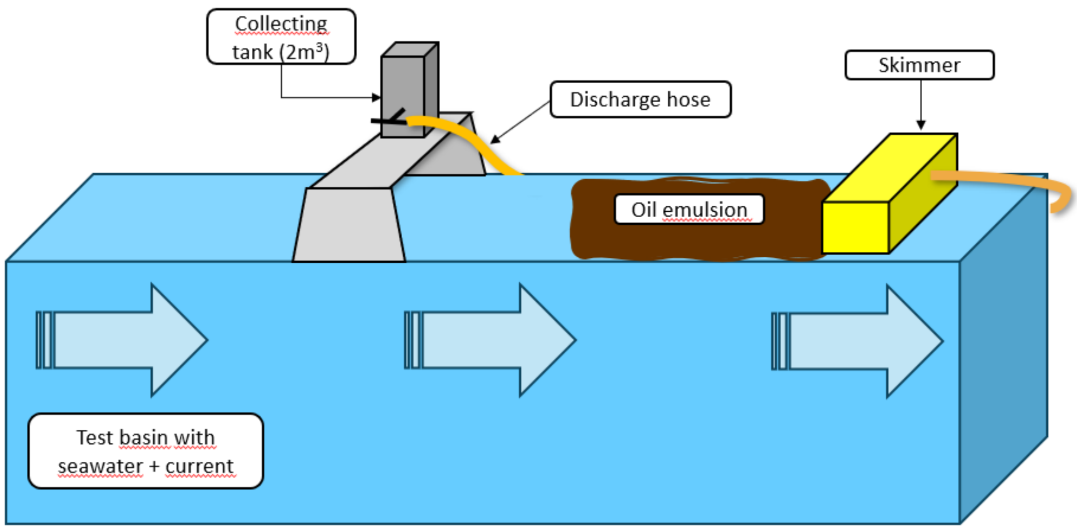

Figure 2: illustration of the modified configuration used for the recovery test.

The following test setups were conducted:

Test 3:	Capacity test of oil emulsion with current: Oil emulsion (approximately 50% water) and skimmer system placed in the water, with current simulating towing of the sweeping arm system. The speed of the current is adjustable between 0.6-2 knots. 4000 litres of oil emulsion is poured into the basin, and the goal is to recover 1600 litres of oil to the collecting tank. The best result of three similar repetitions will decide the recovery rate. After the test run, the oil in the collecting tank settles for 15 minutes, before draining the free water to measure the true amount of oil emulsion recovered.
Test 4:	Capacity test of oil emulsion with current and waves: Similar setup as test 3, in addition with waves.

For more details of the test procedure, see appendix 1.

The test oils

Table 1 shows the three test oils used in the recovery tests, with results of viscosity and pour point of the fresh oil samples, and the viscosity range of samples taken of the oil emulsion during testing. There were in total 6 samples taken during the tests at different stages to measure for water content in emulsion, viscosity, and density. The samples were analysed at the laboratory of Sintef Ocean. See appendix 4 and 5 for Sintef memo of the oil analyses conducted for the mechanical recovery trials. A list describing where and when the samples of emulsion were taken during testing in the recovery trial periods is found in appendix 3.

Table 1: Some characteristics of the three oils used in the tests.

Imaros 2 ID	Oil type	Viscosity of fresh oil at 10°C ($10s^{-1}$)	Viscosity of emulsion at 10°C ($10s^{-1}$)	Pour point (°C)
IM-27	VLSFO	23,104	16,850 - 18,259	12 (9, 24)*
IM-28	VLSFO	36,277	28,512 - 32,776	27 (21, 30)*
IM-29	ULSFO	932	9,484 - 13,008	27 (15, 24)*

**For pour point, the first value is from the oil suppliers' certificate of analysis. The values in brackets are measured minimum and maximum pour point from Sintef and Cedre laboratories. Pour point measurements seems to be subjected to uncertainties and is described in more detail in deliverable D3.1 Summary report of WP3 – Characterisation and Impacts chapter 3.1.4.*

Description of the skimmer and additional equipment

Koseq provided a modified version of the rigid Sweeping Arm weir skimmer system. Originally the equipment is 15 meters long, and to allow it to fit into the test basin, the bridge piece was removed, and the pontoons were fitted together. To customize the skimmer for recovery of challenging LSFOs, two Archimedes screws were attached in front of the existing weir skimmer, and the suction inlets were adapted to increase the inward flow to the pump and force the oil to the skimmer (figure 3).

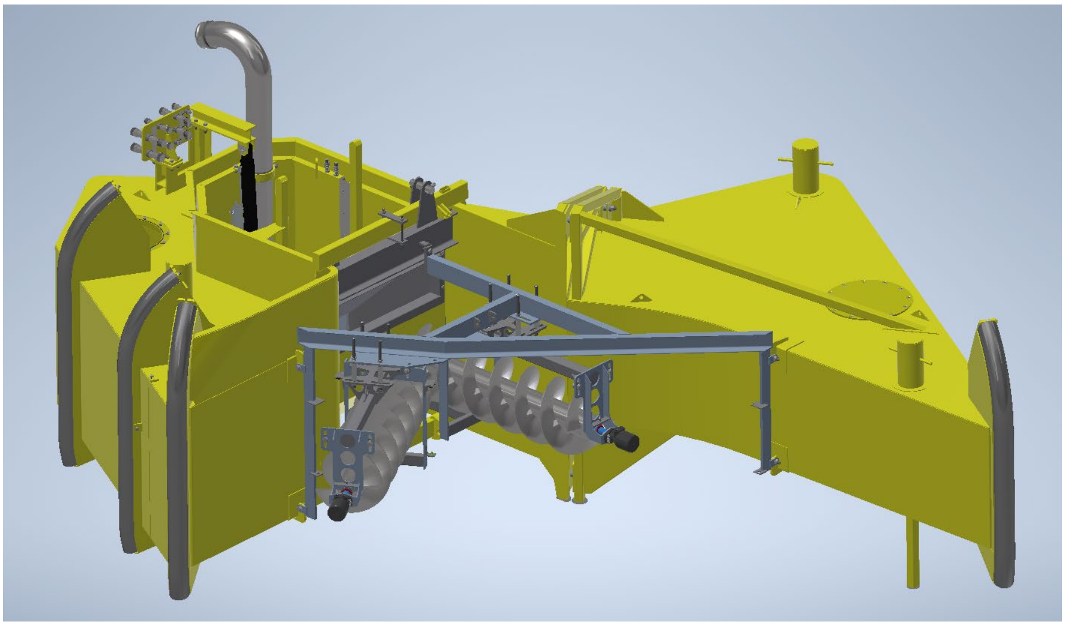

Figure 3: Illustration of the Koseq modified Sweeping arm weir skimmer system (from Koseq).

The pump was a Börger pump, type FL 1036 with the following data:

- Work pressure: 250 bar.
- Viscosity max: 200.000 mPas
- Capacity: 30-320 m^3/h
- Pressure max.: 5 bar.

Results

Table 2: overall results of best measured oil emulsion recovery rates for the tests conducted with the modified Sweeping arm skimmer system.

Oil	Skimmer	Hose	Add. equipment	Test no.	Oil recovery rate
IM-27	Sweeping arm	6” flat hose	Archimedes screws	3	37.1 m^3/h
IM-27	Sweeping arm	6” flat hose	Archimedes screws	4	38.8 m^3/h
IM-28	Sweeping arm	6” flat hose	Archimedes screws	3	No measurement
IM-28	Sweeping arm	6” flat hose	Archimedes screws	4	No measurement
IM-29	Sweeping arm	6” flat hose	Archimedes screws	3	14.8 m^3/h
IM-29	Sweeping arm	6” flat hose	Archimedes screws	4	20.9 m^3/h

Recovery of the IM-27 (VLSFO)

Test setups 3 and 4 were conducted on this oil, with results up to 38.8 m^3/h of oil recovery rate.

In general, the skimmer worked well on the IM-27 oil, although with significant water uptake. It is generally challenging to avoid a substantial water uptake when operating a weir skimmer in forward motion. Due to limitations in the test facility regarding supplied oil volume in the basin and the capacity of the collecting tank when testing such a large skimmer system, it is challenging to obtain reliable measurements. The high pump capacity resulted in short test runs and large margins of error. Despite these constraints, the skimmer successfully recovered IM-27 oil without major difficulties, the movement of the screws helped the oil flow towards the weir skimmer and went into the weir without problems. When introducing wave action, the added movement into the slick also appeared to help create inflow to the skimmer, which yielded somewhat higher recovery rates than when using only current.

It can be hypothesised that for this type of oil, the screws are not essential for recovery, as the relatively wide opening of the weir skimmer and continuous forward motion of the skimmer system helps force the oil flow into the skimmer. However, the system was only tested with the screws.

Figure 4: Photo of the Koseq modified Sweeping Arm weir skimmer operating in IM-27.

Recovery of the IM-28 (VLSFO)

Test setups 3 and 4 were used on this oil, but no recovery measurements were conducted because of several challenges for the skimmer with this oil type.

Due to the poor flow properties of IM-28, it was not possible to recover sufficient oil volume for quantitative measurements. Neither adjustments to current, velocity, nor variating the Archimedes screw rotating speed, had any notable effect of forcing the oil toward the weir skimmer. Even when the current was increased to 2 knots, the combined effect of current and screw action caused the oil to submerge beneath the skimmer rather than enter into it.

Given the challenging properties of IM-28, it is possible that a weir skimmer is not suitable for this type of oil. The oil's poor flow properties and semisolid characteristics prevents it from flowing into a weir, without some mechanical movement of forcing or feeding it actively into the pump. The screws themselves appeared to have little effect in feeding the oil to the skimmer. Instead, a bridging effect of the oil was observed in front of the screws, where the oil slick remained quite stationary and the screws eventually operated in only water without sufficient movement to force more oil towards it.

Wave action introduced some movement in the oil slick, occasionally breaking it apart slightly, but the bridging problem persisted, and the screws continued to have limited access to oil. As a result, no successful recovery could be achieved under these test conditions.

Figure 5: Photo of the Koseq modified Sweeping Arm weir skimmer operating in IM-28.

Recovery of the IM-29 (ULSFO)

Test setups 3 and 4 were used on this oil, with recovery rates ranging from 14.8 m^3/h for test 3 and 20.9 m^3/h for test 4.

Because of the properties of IM-29 with both being short and semi-solid, the skimmer also had some challenges with the recovery of this oil. The oil slick has little movement towards the skimmer despite operating the rotating screws at different speeds. The oil appears quite slippery when in contact with the screws and offered little adhesion to force it towards the skimmer. Increasing the current caused the oil to "roll" in the front of the slick, accumulating the oil thickness there, while keeping the thickness relatively low nearby the skimmer. In addition, it could also be observed a bridging effect in front of the screws, where the screws struggled to get contact with the oil and only operating in water.

Nevertheless, some oil did reach the weir skimmer, allowing for a relatively good recovery rate. Once collected in the weir skimmer, the pump had no problems with pumping the oil. When waves were introduced, the added energy created more movement in the slick, partly breaking it apart, allowing for more oil to be effectively fed toward the weir skimmer and recovered.

Figure 6: Photo of the Koseq modified Sweeping Arm weir skimmer operating in IM-29.

Conclusion

Conducting accurate tests with a skimmer with such high pump capacity proved challenging, given the limitations of the test facility and the skimmer’s potential for significant free water uptake. The constraints of collection methods and the limited size of the collecting tank in the test facility resulted in measurements with considerable uncertainty and margins of error.

The results suggests that this type of skimmer may struggle with recovery of low sulphur oils with poor flow properties combined with a sticky/semi-solid appearance, particularly when these oils present as solid slicks. However, the pump demonstrated no difficulties in pumping the recovered oils and the Archimedes screws appear to have a positive effect in assisting the recovery of especially short oils. In relation to the tests that where conducted, we cannot rule out that there are other configurations that will improve recovery of LSFOs with poor flow properties, such as the adapted suction inlet, modifications to the pump type or orientation, or removal of the screws. These configurations were not tested due to time constraints during the test trial.

In conclusion, the tests provided valuable insight into the challenges of recovering LSFOs and the concept hold promise to recover certain types of LSFOs as part of a broader toolbox.

Appendix

Table with complete test results conducted at the Horten Test Facility for additional trial with Koseq.

Oil-ID	*Test setup*	*Rep.*	*Time*	*Litres total*	*Litres of oil*	*Litres of free water*	*% of free water*	*Oil recovery rate (m^3/h)*	*Skimmer and additional equipment*
IM-27	3	1	0:51	1596,0	100,8	1596,0	94 %	7,1	Modified Sweeping Arm weir, Archimedes screws
IM-27	3	2	1:10	1528,8	638,4	1528,8	58 %	32,8	Modified Sweeping Arm weir, Archimedes screws
IM-27	3	3	2:41	1545,6	1008,0	1545,6	35 %	22,5	Modified Sweeping Arm weir, Archimedes screws
IM-27	3	4	1:15	1545,6	772,8	1545,6	50 %	37,1	Modified Sweeping Arm weir, Archimedes screws
IM-27	4	1	1:10	1495,2	621,6	1495,2	58 %	32,0	Modified Sweeping Arm weir, Archimedes screws
IM-27	4	2	1:57	1512,0	1260,0	1512,0	17 %	38,8	Modified Sweeping Arm weir, Archimedes screws
IM-28	3	1	-	-	-	-	-	-	Modified Sweeping Arm weir, Archimedes screws
IM-28	4	1	-	-	-	-	-	-	Modified Sweeping Arm weir, Archimedes screws
IM-29	3	1	4:34	1562,4	1125,6	1562,4	28 %	14,79	Modified Sweeping Arm weir, Archimedes screws
IM-29	4	1	3:20	1596,0	621,6	1596,0	61 %	11,19	Modified Sweeping Arm weir, Archimedes screws
IM-29	4	2	2:25	1646,4	840,0	1646,4	49 %	20,86	Modified Sweeping Arm weir, Archimedes screws