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Responding to Spills of Marine Distillate Fuels

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ABSTRACT: The current spill response capability in Finland is built to respond to oil spills caused by heavy fuel oils and the most transported oil cargoes. However, the implementation of the Sulphur Directive in 2015 changed the fuel profiles of the ships: prior to the new regulation ships operating in the Baltic Sea mainly used heavy fuel oil (HFO), whereas now ships use marine gas oil (MGO DMA) or marine diesel (MDO DMB) known as marine distillate fuels. This paper reviews the effectiveness of the current recovery techniques in responding to spills of marine distillate fuels based on the oil recovery field tests. The results indicate that conventional recovery techniques are only partially applicable to marine distillate fuels, which calls for a reassessment of the marine oil spill response capability and further research. The use and availability of low-carbon marine fuels will continue to increase as emission regulations become more stringent. This will require a continuous assessment of the oil recovery capabilities and the adaptation of spill response preparedness accordingly.

1 INTRODUCTION

The Gulf of Finland, in the northern part of the Baltic Sea, is one of the busiest sea areas in the world. The high traffic density has been identified as increasing the risk of a marine oil spill, which is why the Finnish authorities responsible for oil spill response in the region have persistently developed their response capacity. Under joint agreement between the Baltic Sea states, the preparedness is built upon mechanical recovery, and the use of dispersants or sinking agents is avoided, and in-situ-burning is applied only on a very discretionary basis. [1, 2.]

As the applicability of mechanical oil spill recovery technologies is substance-specific, development of equipment capability is based on the most likely oil spill scenarios. Until 2014, a potential oil spill was likely to have been caused by heavy fuel oils (HFO) and, accordingly, the authorities have been procuring equipment customized for these types of oils.

However, the implementation of the EU Sulphur Directive in 2015 significantly changed the fuel profiles of the ships operating in the Baltic Sea (Fig. 1). This raises the question of whether the achieved oil spill response capability is still valid.

This paper examines the impact of changes in fuel profiles on oil spill response performance, focusing on the oil recovery capability of the Finnish side of the Gulf of Finland. This paper examines the applicability of conventional oil recovery equipment for the recovery of marine distillate fuels. The term “conventional” is used here in reference to the equipment optimised for the collection of HFO in an aquatic environment. Marine distillate fuels refer to marine diesel oil (MDO DMB) and marine gas oil (MGO DMA). Marine gas oil consists exclusively of distillates, while marine diesel oil is a distillate fuel that may contain traces of residual oil.

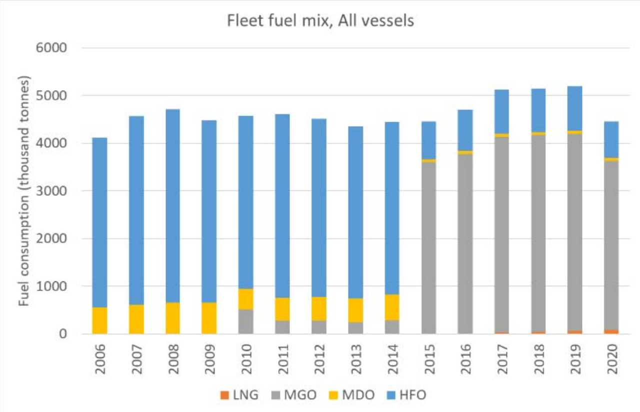

Figure 1. Estimated quantity of marine fuels used by ships operating in the Baltic Sea between 2006 and 2020. The uppermost part of each column shows the share of heavy fuel oil (HFO) and the lower parts establish the shares of distillate fuels (MDO, MGO) and LNG. [3]

No previous research has been conducted on the recoverability of marine distillate fuels and there are no incident case reports dealing with the response methods used. Previous studies have examined the environmental impact and toxicity of marine diesel oils, but none of them have addressed how they should be recovered. Instead, the challenges of responding to Low Sulphur Fuel Oils (LSFOs) have been increasingly studied following recent oil spills, such as the MV Wakashio grounding in Mauritius in 2020. However, the properties of these fuels differ from distillates to such an extent that the results are not directly applicable. It was therefore decided to carry out small-scale tests to demonstrate the recoverability of marine distillates and to see if more comprehensive research is needed.

This paper is structured as follows. First, the mechanical oil recovery methods used in the tests are presented, followed by the experimental tests, their set-up and results. Finally, the results are discussed in the light of general research on mechanical recovery of oil spills.

2 MEANS OF MECHANICAL OIL RECOVERY

Mechanical recovery is one of the methods to remove spilled oil from water. Mechanical removal is usually carried out by using skimmers, the most common of which are of oleophilic type. With oleophilic skimmers, oil recovery is based on oil adhering to an oleophilic surface of a rotating part of the skimmer, which can be in the form of a brush, drum or disc module. [4, 5, 6, 7, 8.] Disc skimmers are mainly available as portable units, but brush skimmers are available both as portable skimmers and as vessel-integrated recovery systems. These skimmers vary greatly in size and capacity, but the principle of the oil recovery is the same.

Oleophilic skimmers typically collect very little water compared to the amount of oil recovered. This means that their oil-to-water recovery ratio, also referred as recovery efficiency (RE), is generally high, although their suitability for different oil types varies depending on the skimmer design and the type of the oleophilic surface [7].

The surface is usually made of steel, aluminium, fabric or plastic, such as polypropylene and polyvinyl chloride [7, 8]. The adhesive surface is a critical factor in the oil recovery [9], as the surface material can affect the recovery rate by up to 20% [10]. In addition, the immersed area of the rotating surface affects the amount of water entrained: the larger the disc diameter, the greater the proportion of the adhesion surface rotating in the water under the oil layer [11]. This applies in reverse when the oil layer is or gets thin, which highlights the importance of using an oil boom to control the oil layer thickness: this leads to increased oil-wetted area of rotating surface replacing the equivalent water-wetted area [11] and results in higher oil recovery efficiency.

Adhesion also depends on the type of oil and its properties at the time of recovery [5, 6, 8]. These properties change over time as the oil weathers, requiring continuous evaluation of the skimmer performance during the operation. As oil weathers it becomes more viscous due to the evaporation of volatile compounds and, in some cases, the accumulation of water. This water accumulation is a process known as emulsification. [5, 7, 12.]

Increased viscosity enhances the oil recovery to some extent, after that it may become a limiting factor [10, 11, 12]. In addition to viscosity, oil emulsification can also reduce the effectiveness of oleophilic skimmers as the high percentage of water in the oil prevents the oil from adhering to the skimmer surface [6, 8, 13]. High viscosity or emulsification can further prevent oil from flowing towards the skimmer, requiring the oil to be pushed or the skimmer to be moved to provide continued recovery [6].

Despite these limitations, mechanical recovery has been identified as the main and most viable method in the Baltic Sea, as other response options may have adverse and unpredictable effects [1].

Sorbents are used as a secondary recovery technique to remove the remaining oil film after mechanical recovery. There are several types of sorbents, typically divided into oil-only and chemical-only products. They also vary in physical shape and size. Sorbents usually work by either absorption or adsorption [4, 5, 12, 14]. They are generally more effective on lighter than heavier oil products [12, 14] but there is limited research on their suitability for marine distillate fuels.

As no single recovery method is suitable for all situations [4, 6], it may be necessary to be able to use different recovery means and to select the most appropriate type of skimmer or sorbent for a given type of oil and operating conditions at the spill site, and to adapt the selection as necessary at each stage of the response operation as oil characteristics and conditions change over time [4, 5, 10]. However, keeping up-to-date knowledge of the appropriate methods is a challenge because of the rapid renewal and diversification of potential spill risk substances.

3 EXPERIMENTAL TESTS OF MECHANICAL RECOVERY OF DISTILLATE FUELS

The purpose of the tests was to examine the capability of the conventional skimmers to recover marine distillate fuels, and, by measuring the ratios of oil to water in the total amount of collected fluid, to compare recovery efficiencies of used skimmers. The tests were performed with marine diesel oil (MDO DMB) and Neste Light Fuel Oil (LFO) that is practically the same fuel as Neste Marine Gas Oil (MGO DMA) with common CAS number and Safety Data Sheet [15].

The experimental tests were carried out at the outdoor Oil Spill Response Testing Facility of the South-Eastern Finland University of Applied Sciences (Xamk) in Kotka. The test facility consists of a main basin with a diameter of 29 metres and a water depth of 2–3 metres, and several smaller test tanks. These tests were carried out in one of the smaller tanks of 12 square metres with a maximum water depth of one metre.

The tests were carried out during three days, the 17th, 24th and 28th of September 2022, at the average temperature of 17–23°C (See Table 1). The water used was fresh water, originally pumped from a nearby river, with a water temperature settled to the ambient temperature. The difference in salinity between the river water and the surface water of the Gulf of Finland brackish water was not expected to have a significant effect on the performance of the skimmers.

Table 1. Baseline data.

Experiment	Type of skimmer module	Test oil	Oil layer [mm]	Viscosity [mm²/s in 40˚C]	Density [kg/dm³ in 15˚C]	Temp. [˚C]	Date
1	Brush module	MDO DMB	10	2...11	≤0,9	22,5	17.8.22
2	Disc module	MDO DMB	10	2…11	≤0,9	22,5	17.8.22
3	Brush module	Light Fuel Oil	10	≤4,5	0,8…0,85	18,0	24.8.22
4	Disc module	Light Fuel Oil	10	≤4,5	0,8…0,85	23,0	24.8.22
5	Brush module	MDO DMB	10	2…11	≤0,9	17,0	26.8.22

All tests were performed using portable Minimax 12 skimmer frame with brush and disc modules, the electric-driven Power Pack LPP7.5VXE, hydraulic lines and hoses supplied from the manufacturer. This skimmer chosen is the most common skimmer type used by the Finnish rescue services.

An area was boomed at the surface of the water-filled test tank, in which the available oil volume formed a 10 mm layer of oil. The size of the area was defined taking into account that it would not restrict the operation of the skimmer. In the first tests (experiments 1 and 2) the skimmers were operated simultaneously (set-up presented in Fig. 2), but in subsequent tests, the skimmers were operated one after the other.

The recovered oil was transferred into two 300-litre IBC containers, the walls of which were transparent enough that the accumulation of fluids was visible from the outside. The recovery results of the skimmers were directed into separate storage containers for comparison (Fig. 3 and 4). Although estimating the liquid fractions from the tank column heights does not have a very high accuracy, it was considered appropriate and sufficient for the purpose.

Figure 2. Test tank setup used for skimmer performance experiments, with a brush skimmer on the left and a disc skimmer on the right. Photo: J. Halonen.

Figure 3. Recovered marine diesel oil (MDO DMB) and entrained water (free water and emulsion) separated by gravity in storage containers. On the left the recovery result of the brush skimmer and on the right the corresponding result of the disc skimmer. Photos: J. Halonen.

Figure 4. Recovered light fuel oil and entrained free water separated by gravity in storage containers. On the left the recovery result of the brush skimmer, on the right the corresponding result of the disc skimmer. Photos: J. Halonen.

As far as it was practical, the test protocol followed the general principles of Standard Test Method for Determining a Measured Nameplate Recovery Rate of Stationary Oil Skimmer Systems (F2709-18) of the ASTM International. The standard defines a criterion to quantify the performance of a stationary skimmer in ideal recovery conditions allowing a skimmer to operate at its maximum possible recovery rate [16]. Our test, in contrast, aimed to achieve realistic recovery efficiency values by mimicking authentic spill incident recovery conditions as much as possible. For this reason, the standard was applied when appropriate. For example, the initial oil layer thickness was set thinner (10 mm) than defined by the standard (>75 mm), and the layer thickness was allowed to decline as the recovery progressed.

The skimmers were tested according to the following procedure:

- A known amount of oil was added to the boomed area of the water-filled test tank. The volume was calculated to form a 10 mm thick oil layer. The thickness was measured.
- The skimmer was lifted into the tank and its free-floating position in the middle of the boomed area was secured with a rope.
- The rotation speed of the skimmer was optimised by the means of visual observation to minimise the volume of entrained free water. This means that the water content of the recovered fluid was assessed at the point where the adhered fluid is scraped by skimmer's plastic blade to a recovery sump. If the rotation speed is too high, water droplets start to appear in the fluid. As the thickness of the oil decreased and the amount of entrained water began to increase, the rotation speed was adjusted accordingly to achieve the optimum recovery result.
- When the skimmer could no longer take hold of the oil, the machines were stopped. The remaining oil was then absorbed by means of oil-only absorbents. The absorption capacity of the absorbents was observed, not measured.
- At the end of each test, the total volume of fluid (oil, water, water-in-oil emulsion) in the storage container was measured, and after the liquids were separated into their own phases, the proportion of each was assessed.

The main parameter examined was the oil recovery efficiency (RE). Recovery efficiency measures the selectivity of the skimmer, describing the ability of the skimmer to recover oil in preference to water. Recovery efficiency is expressed as the ratio of the quantity of the oil recovered to the total quantity of fluid (oil and water and their emulsion) collected [6, 16]:

$$RE = \frac{V_{oil}}{V_{total\ fluid}} \times 100$$

where
RE = recovery efficiency, %
V_{oil} = volume of oil recovered
$V_{total\ fluid}$ = volume of total fluid recovered

During the tests, the skimmers were operated as appropriate to avoid deliberate underperformance. As it is known, the oil recovery rate increases with the rotational speed up to some extent [11], but the recovery efficiency suffers: a higher rotational speed will cause a higher amount of free water to be entrained, particularly when the oil layer is relatively thin. High rotation speed will also emulsify the oil to a greater extent. [10.] Therefore, the rotation speed was continually adjusted to maintain optimal recovery. When the amount of oil in the test tank began to decrease, oil was diverted to the skimmer if it was found not to flow on its own. This assisted feeding of skimmer was carried out with the floor squeegees (Fig. 9).

After mechanical recovery, the rest of the oil was removed with absorbents. Their effectiveness was observed but not measured, as it was seen that the amount of oil remaining was not sufficient to achieve maximum absorption capacity.

At the end of each test, the total amount of recovered fluid was measured. The recovered fluid was let to separate into layers by gravity for one hour after which the proportions of oil, water-in-oil emulsion and free water was estimated. Hour was judged to be a suitable duration, as retention times generally considered adequate range from 15–30 minutes for light oils to 60 minutes for heavy oils [17]. The fluid was left to settle further in the containers from one day to one week but no significant changes in the degree of separation were observed [18].

3.1 *Impact of skimmer type on the composition of the recovered fluid*

The results of all five test experiments on the composition of the recovered fluids are shown in Figure 5. The composition indicates the recovery efficiency, i.e. the amount of oil recovered in relation to the total amount of recovered fluids.

A comparison of the collected fluids shows a clear difference between the skimmer types. Based on the results, the disc skimmer attained high recovery efficiency for both marine diesel oil and light fuel oil (87–92%). With the brush skimmer, the water entrainment was significant, resulting in low recovery efficiency (8–14%).

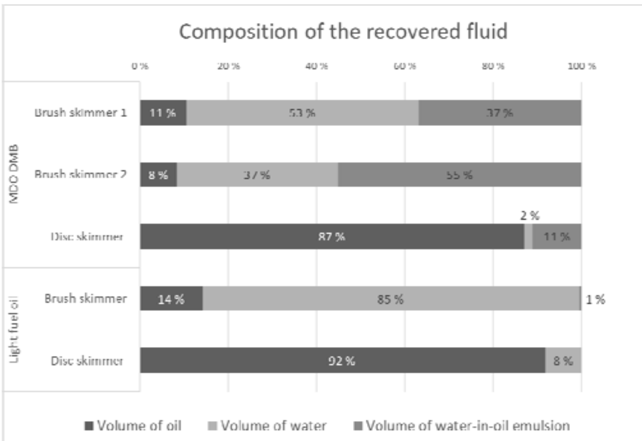

Figure 5. Composition of total recovered fluid grouped by oil type. Comparing recovery results of two skimmer types recovering two distillate fuels under equal recovery conditions. Tests at 17–23°C with the initial oil layer thickness of 10 millimetres. The total fluid includes the liquids recovered by the skimmers; the absorbed liquid is excluded.

When recovering MDO, the total water entrainment was +38% greater than in LFO recovery (Fig. 5), and the proportions of free water and emulsion were quite equal, 38% and 62% respectively (Fig. 6). Conversely, the water entrained in the recovery of LFO consisted almost entirely of free water. This occurred, because the LFO emulsion produced by the brush skimmer was not stable in nature but broke down, appearing as free water in the final recovery result.

The high water entrainment in the MDO recovery mainly reflects the low selectivity of the brush skimmer (Fig. 5). The disc skimmer also took up slightly more water when recovering MDO (13%) than when recovering LFO (8%), see Fig. 5. This is expected to be due to the higher emulsification tendency of MDO, as the water entrained was mainly in form of emulsion (Fig. 6). However, the difference between the amounts of free water and emulsion in the disc skimmer's recovery results is not very significant, and the actual quantities were very small (Fig. 7).

Figure 6 shows the composition of the total water entrainment divided into fractions of free water and emulsion. The amount of the recovered oil itself is excluded from this comparison.

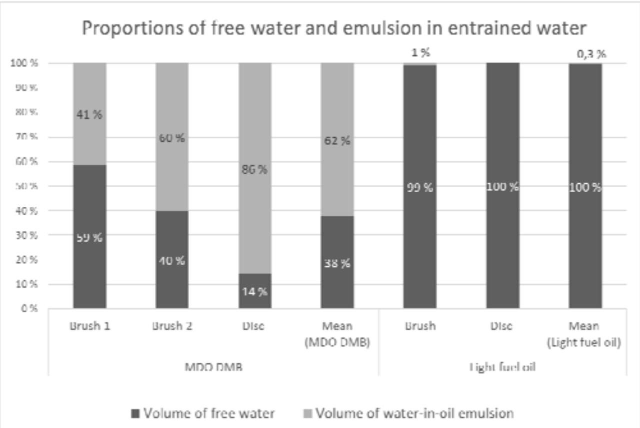

Figure 6. Distribution of total water entrainment into fractions of free water and emulsion, grouped by the oil type. Proportion of the oil itself is excluded. Last columns per oil type represent the average values.

3.2 *Impact of skimmer type on the total volume of the recovered fluid*

Water entrainment affected the total volume of recovered fluid and the skimmers differed considerably in producing this volume: using a brush skimmer, the total fluid volume increased by 480–540% (up to approximately six times the initial oil volume), while using a disc skimmer the total fluid volume increased by 5–6%, when all the collected fluids were taken into account. The total volumes of fluid relative to the amounts of oil initially spilt is presented in Fig. 7.

On average, entrained free water had a greater effect on the total volume of recovered fluid than emulsification (Fig. 5 and 7).

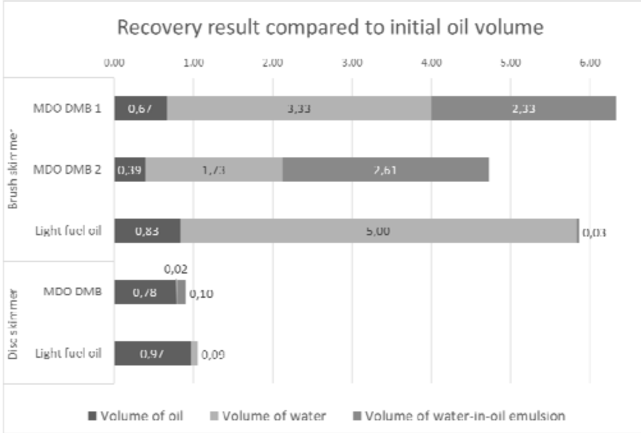

Figure 7. Total recovered fluid volume times the initial volume of oil discharged, grouped by skimmer type, and presenting the composition of the total fluid.

None of the skimmers achieved 100% oil removal, but the disc skimmer came very close by removing 97% of the light fuel oil. The brush skimmer also managed to remove 83% of the light fuel oil although the by-product was high proportions of excess water (Fig. 7).

With both types of oils, the disc skimmer left a thin oil film on the water surface. The oil remaining after the brush skimmer recovery was either a film (LFO) or a layer of water-in-oil emulsion (MDO).

3.3 *Impact of skimmer type on the emulsification*

The results regarding emulsion formation differ between the two types of skimmers. The disc skimmer produced no emulsion (0%) when recovering LFO, and 11% emulsion when recovering MDO. When the brush skimmer was used, the percentage of emulsions in the overall recovery result ranged from 37% to 55% for MDO but remained below 1% for LFO as the emulsion formed was largely broken down (Fig. 5).

As can be seen from Fig. 6, which shows the proportions of free and emulsified fractions in total water entrainment, emulsification occurred mainly during the MDO recovery. There was a clear difference between the oils tested: MDO had a much higher tendency to emulsify.

It was also observed that the movement of the rotating brushes alone generated energy sufficient for emulsification (Fig. 8) even though the rotation speed was kept minimal. Also with the LFO, the skimmer itself generated emulsion during the recovery, but it broke down very quickly (in minutes). It took much longer for MDO to settle, and the emulsion was still clearly present after a week.

Figure 8. Emulsion formation during a brush skimmer recovery. Skimmer with a brush module recovering marine

diesel oil (MDO DMB) on the left and light fuel oil on the right. Photos: J. Halonen and M. Kettunen.

In addition to the mixing caused by the rotating brushes, the entrained water passing through the pump and hoses may have contributed to the emulsification. It should therefore be noted that it was not possible to assess to what extent the emulsions were due to brushes and to what extent to other contributing factors such as pump-induced mixing and turbulence in the discharge hoses, or pressure pulses and the resulting splashing in the storage containers.

The disc skimmer produced the lowest volume of entrained water in terms of quantity. When the composition of the water entrainment in MDO recovery was compared (Fig. 6), it was found that a higher proportion of the water was in form of emulsion (86%) when using a disc skimmer than when using a brush skimmer (41%–60%), suggesting that the adhesive material of the discs may be more hydrophobic.

Both oils, in their original form, were drawn into the skimmer by the pull of the rotating unit, while the emulsified oils did not flow towards the skimmer without intervention.

Mechanical recovery was continued until the skimmers could no longer capture the oil. The remaining oils consisted of thin oil films or layers of emulsion depending on the type of oil and skimmer used. First, the oil was contained into a smaller area with an absorbent boom. If the absorbent boom was not sufficient to remove the oil, the remainder was absorbed with oil-only-sheets. The absorbent boom, as well as the sheets, were effective for LFO. However, they did not work well on the emulsified MDO. The oil only coated the surface of the absorbent boom and did not penetrate the material. The absorbent sheets turned out to be ineffective with the emulsion also. The capability of the sheets to remove the emulsified MDO was found to be based on adsorption rather than absorption.

4 DISCUSSION

The purpose of the experimental tests was to examine the capability of two most common types of conventional skimmers to recover marine distillate fuels. Recovery efficiency was evaluated by measuring the ratios of oil to the total amount of recovered fluid and comparing the proportions of emulsified and free water in the total water entrainment. The oils used were marine diesel oil (MDO DMB) and light fuel oil, which corresponds with marine gas oil (MGO DMA). In order to eliminate the variables introduced, the tests were conducted with the same skimmer frame in equal recovery conditions.

Although the number of tests carried out was rather limited, and the results may have been subject to some inaccuracy, as described earlier, the objective of assessing the need for further research was achieved. Some conclusions can also be drawn. The obtained results indicate that the skimmer type has a noticeable effect on the amount of entrained water as well as on the degree of emulsification, and hence on the total amount of recovered fluids.

4.1 *The impact of emulsification on recovery efficiency*

Emulsification is a process by which water droplets are dispersed into oil. Emulsification has an impact on the overall recovery operation as entraining water changes both density and viscosity of the oil, as well as causes the total volume of the fluid to increase [5, 7, 12]. Emulsification is usually associated with a weathering process and requires external mixing energy, such as wave action [4, 5, 7]. It was therefore interesting to note that, in the case of marine distillates, the rotation of the adhesion surface itself caused emulsification.

In the tests, emulsion formation on average had a smaller effect on the increased total volume of fluids than the amount of free water, but emulsification led to a reduction in recoverability. In particularly oleophilic skimmers are known to lose their efficiency if the oil emulsifies [6, 7, 13]. Although the brush skimmer was more problematic in terms of emulsification, and little to no emulsion was formed due to the disc skimmer, it is known that also the disc type becomes ineffective in situations where a water-in-oil emulsion has already formed. This is mainly because emulsions can be almost non-adhesive and, with high viscous emulsions, the discs are cutting through the emulsion instead of recovering it [5, 6]. Higher viscosity in general leads to a slower spreading rate and results in reduced access to the skimmer's adhesion surface [10].

The inefficiency of disc skimmers in recovering water-in-oil emulsions was also found in the field tests carried out in Norway. These tests used an emulsion made from fuels and an emulsifier mixed with seawater. Their further studies revealed that adding an emulsifier reduces the interfacial tension, which significantly decreases the adhesive properties of the emulsion. [8.] It is recognised however that also the emulsion itself has poor adhesion properties and is therefore difficult to recover with oleophilic skimmers [6, 7, 13]. On the other hand, according to Kystverket [19], the emulsion used in their tests adhered well to the adhesion surface but was hindered by a layer of water which appeared between the emulsion and the skimmer preventing continuous recovery.

Other studies [6, 19] support the finding that emulsions are less likely to move towards the skimmer causing discontinuous oil flow. Due to poor natural flow of the emulsions, feeding the skimmer needed to be assisted with floor squeegees (Fig. 9). It was found out later, that during the Kystverket's tests, almost a similar solution was applied, namely paddles [19]. It is possible that the assisted feeding may have contributed to the water-uptake, but the effect could not be distinguished nor measured.

Figure 9. Assistance is needed to feed emulsified oil onto the skimmer. Photo taken during a training session in which MDO DMB was recovered with Mimimax 25 skimmer and feeding was assisted with floor squeegees. Photo: J. Halonen.

The experience with assisted feeding and previous studies showed that although the recovery of emulsified oils is difficult it is not completely impossible but requires effort and time – in practice manual labour – but the problem of excess water remains unsolved. Emulsified oil can be recovered when it is physically pushed towards the skimmer or when there is a physical barrier against which the emulsion is driven. This challenge may only apply to stationary recovery, as in offshore operations, recovery vessel and its skimmer being in constant motion in relation to oil may force the oil onto the skimmer. [19.] It therefore seems that dynamic recovery systems would be preferable for recovering emulsion-prone oils, although further research is needed to ensure compatibility. In addition, the possibilities offered by decanting should be explored. However, decanting can only be applied to emulsions that break down in a relatively short time.

The emulsions formed in the tests were different in nature. Based on the categorization of Fingas and Fieldhouse [20], the emulsion formed with the MDO represented a stable or mesostable emulsion, and LFO formed an unstable oil-water mixture. Thus, the use of decanting seems a viable option to facilitate the on-site recovery for LFO only.

4.2 *The importance of skimmer type selection*

Both conventional skimmer types were capable of removing distillates from the water, but the recovery results varied. This means that, in the event of an incident, the removal of oil is possible with commonly available equipment, but different levels of intervention, storage capacity and time are needed to manage the quantities recovered to complete the response operation.

There are considerable differences between the skimmer results obtained in terms of efficiency and total fluid. Of the types of skimmers tested, the brush skimmer appeared to be less efficient. Further, the combination of the brush skimmer and MDO proved to be the least favourable in terms of emulsification due to the high volume and stable nature of the emulsion formed. This finding is significant in relation to the skimmers commonly available in Finland. Based on a small-scale survey carried out in March 2023 in the context of this study, 80% of all skimmers operated by the rescue services on the coast of the Gulf of Finland are of the brush type. More precisely, 65% of stationary skimmers are of the brush-type and the remaining 35% of the disc or weir type of skimmers, while 100% of the ship mounted recovery systems are of the brush type.

The recovery efficiency of the brush skimmer was relatively similar for both light fuel oil (LFO/MGO DMA) and marine diesel oil (MDO DMB). The use of the brush skimmers resulted in high total volume of the recovered fluid that reached its greatest value, six times the initial oil volume, during the MDO recovery. In addition to the high amount of entrained free water, the skimmer's tendency to produce an emulsion affected the total volumes recovered. Emulsification also affected the recovery itself, impairing the effective use of sorbents and requiring manual intervention. Consequently, emulsified oils seem more time-consuming to recover potentially delaying the recovery process and resulting in a prolonged impact time on the environment.

The total volume of fluid is an important factor as storage capacity is usually limited. Both temporary storage capacity onboard and adequate intermediate storing ashore can be potential bottlenecks for a timely and continuous spill response [12, 21]. The increase in the total fluid volume will also cause logistical concerns and raise the costs related to transport and disposal of recovered fluids [22].

Managing the total volume of recovered fluid is particularly important in the Gulf of Finland, where an oil spill is estimated to generate a relatively large amount of oily wastes due to the characteristics of the operating environment alone [23]. To prepare for this, the Finnish national recommendations [24] direct to scale the oil spill preparedness and storage capacity to 1.5 times the expected spill volume. Now that the risks associated with marine oil spills have changed to involve marine distillates, this would seem achievable only by using disc type of skimmers.

It should be noted that the recovery volumes of these tests may not be directly scalable to the size of an occurring spill event, since the thinner the oil layer becomes the greater the expected volume of entrained water [10]. In contrast to the tests, in an actual incident situation the recovery phase with a thin oil layer can be relatively short compared to the duration of the entire recovery operation. Furthermore, the effect of evaporation becomes more apparent in longer-term operations. On the other hand, the results obtained under controlled test-tank-conditions may not necessarily reflect the operating conditions at sea, as most skimmers operate at lower efficiency in moderate to heavy seas or in the presence of floating debris or ice.

Nevertheless, the test results give an indication of the significance of the skimmer type selection and the findings should be considered in contingency planning. Response plans will need to be updated more frequently in the future as the risk base for preparedness evolves and new substances posing a potential spill risk are introduced at an increasing pace. Contingency planning could be supported by the use of probabilistic models analysing response efficiency [see 21, 25, 26 and 27] by updating model parameters, such as variables related to recovery capabilities. As Parviainen et al. [28] point out, even though these models are currently instrumental tools that support predefined policies rather than exploring alternative response options, they could be applied more comprehensively. A systematic use of the models, supported by up-to-date values from the field tests, would facilitate both the assessment of the wider consequences of the selected measures and the regular evaluation required by Helcom of whether the operational capacity corresponds the total spill volumes expected [2].

The importance of the reassessments is underlined by the fact that although discharges of oil and other harmful substances into the Baltic Sea have decreased over the last 20 years, spills are still being detected and, more importantly, are increasingly caused by non-mineral substances [29]. Optimal recovery of these substances requires further research, as this study only considered commonly used marine fuels. Additionally, the scope of this paper was limited to the performance of stationary skimmers, focusing on two types of oleophilic skimmers typical for the Baltic Sea region. Further studies testing the characteristics of other types of skimmers as well as onboard recovery systems are therefore necessary and would benefit from being extended to cover not only a wider range of substances spilt but also the effects of recovery rates and potential decanting solutions.

5 CONCLUSIONS

This paper presented the oil spill response tests investigating the recovery of marine distillate fuels. The results indicate that conventional recovery equipment are only partially applicable to marine distillates and thus the capability to respond to marine oil spills needs to be reassessed and further research is needed.

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