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Testing of Eight Oil skimmers in Three High Viscosity Emulsions at The Norwegian Coastal Administration Test Facility in Horten[1].

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Abstract

The results from performance testing of eight different oil skimmers in high viscosity water-in-oil emulsions in the test tank at the Norwegian Coastal Administration facility in Horten, Norway are presented. The eight skimmers were KLK 402, KLK 602, Foxtail 2-6, Uniskim Enviro Muliti 30, Foilex TDS 200, Desmi Terminator Beltskimmer, Lamor Minimax 40, and Frank Mohn HiWax 250.

The skimmers were tested in three high viscosity water/oil emulsions made by mixing seawater into heavy bunker oil by circulation pumping. The w/o-emulsions were saturated with water and stable during the test period. The average viscosities were 23,000, 58,000 and 145,000 cP as measured with a shear rate of 10 sec^{-1} and temperature of 13 ^{o}C. All the tested skimmers were functioning satisfactory according to their design criteria, and with few exceptions functioned well in the high viscosity emulsions. The measured recovery rate of emulsion varied from 0-24 m^3/hr. The total recovery rate, including free water varied from 0-37 m^3/hr. The tests were performed with and without harbour chops and with two different water currents in the test tank. The water content, the density, temperature, and the rheology of the test emulsions were measured during each test.

Introduction

The Norwegian Pollution Control Act sets the responsibilities for private, municipal and governmental oil spill response preparedness. In general the private industry is responsible for spills originating from own sources, the municipalities are responsible for minor spills within the municipalities borders and the government is responsible for larger spills, especially spills originating from unknown sources and vessels. The responsible authority on behalf of the government is The Norwegian Coastal Administration (NCA). The resources at hand for the NCA are 15 equipment depots located along the Norwegian coastline and at Svalbard, 9 Coast Guard vessels with oil spill response equipment, one ETV (Emergency Towing Vessel) and 4 NCA oil spill response vessels.

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[1] The paper does not necessarily recommend one skimmer or type of skimmer to be used for recovery of high viscosity emulsions. Users should always make their own thorough evaluations before selecting oil skimmers.

The NCA's interest in testing oil skimmers is not new. Since the early 1980's a test basin has been owned and operated by the government for the purpose of validating equipment before purchase, for own development of new equipment and for rent to manufacturers and researchers in their development of equipment. Over the years several different types of equipment have been developed, tested and verified using the test basin, e.g. the Foxtail skimmer, the Current Buster, the FraMo HiWax skimmer etc. Lately the DNV (Det Norske Veritas) certification programme for oil skimmers was developed and verified using the test basin (DNV, 2002).

As a result of the oil spills following the sinking of "Erika" and "Prestige", the NCA took the initiative to undertake a test program involving 7 representative types of skimmers that are currently part of the Norwegian oil spill response inventory, and that have a capability of recovering high viscosity oils. The main reason for the NCA interest in this was the general lack of knowledge and data regarding the use of skimmers in recovery of high viscosity oils coupled together with the increased focus on this subject in Europe following "Erika" and "Prestige".

Furthermore the problem with high viscosity oils and emulsions will be even more severe at low temperatures. E.g. in the case of weathered Prestige oil reaching viscosities of approx. 300 000 cP after 3 months at sea in 15 ^{0}C would at sea temperatures of 5 ^{o}C (typical Norwegian winter sea temperature) reach viscosities of close to 1 000 000 cP (Moldestad et al. 2003).

All the skimmers were taken from NCA depots and tested using own resources without the presence of the manufacturer. The main objective for the test programme was to verify the operational parameters set forth by the manufacturer, test the skimmers ability to recover high viscosity oils and to make a "fact sheet" for each skimmer. The following skimmers were tested:

- Foilex TDS 200 (Weir skimmer)
- Foxtail 2-6 (VAB skimmer)
- Desmi Terminator with band skimmer unit (Band skimmer)
- KLK 602 and 402 (Drum skimmer)
- Lamor Minimax 40 (Brush skimmer)
- Uniskim Enviro Multi 30 (Brush skimmer)
- Frank Mohn Transrec HiWax 250, - tested with manufacturer present.

The two original test emulsions were based on the emulsions described in the DNV certification programme as DNV oil class 5 and 6, having a viscosity of 20 000 and 50 000 cP (at shear rate $10s^{-1}$) (DNV, 2002). In addition a simulated "Prestige" emulsion was blended to a viscosity of 150 000 cP (at shear rate 10 s^{-1}). The test procedures were based on the DNV certification tests, but were modified by allowing re-circulation of the test emulsion to the test basin.

The Test Facility And Test Set-Up

The NCA test tank in Horten is 30 metres long and 7 metres wide. The test section is 28 metres long, 7 metres wide and the water depth is approximately 1.8 metres. Four propellers placed under a false bottom set up the water current in a continuous loop. A boom (Expandi 4300) with 0.5-m skirt is placed within the test section to contain the oil. The test set up in the tank is illustrated in Fig. 1.

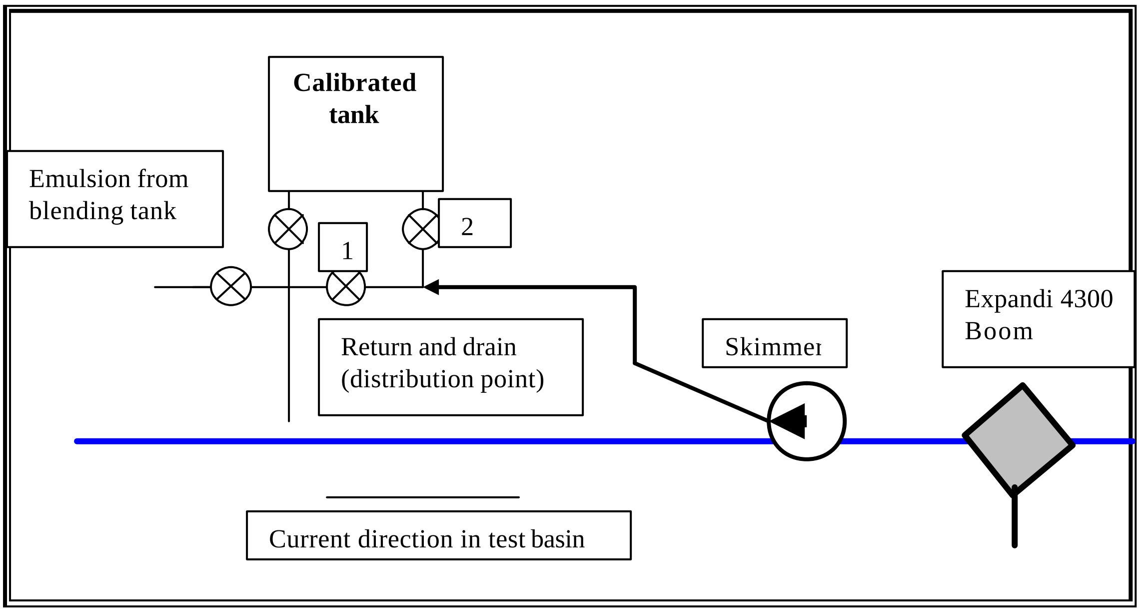

Figure 1. Illustration of the test set-up

The Tests

The main objective of the tests was to examine the different skimmers ability to recover high viscosity oils, and the tests were arranged mainly to measure the recovery rate of emulsion and free water. The skimmers were operated according to the specifications given by the manufacturer in the operational manuals. Some parameters, e.g. the rotational speed of drum, brush etc. and the current and wave conditions were varied during the tests, whereas the characteristics of the oil to be recovered, e.g. the viscosity was not.

The tests were based on the DNV procedure (DNV, 2002), but modified to allowing the re-circulation of the test fluid, use of a small sampling tank and using a modified slick-thickness control. Implications of these modifications are briefly discussed below. The actual test conditions are listed in Table 1.

The re-circulation of the emulsion means that the emulsion was pumped in a circle between the skimmer, located inside a boom in the test tank, and the points of oil/emulsion distribution to the test basin. By this modification the test emulsions were used over and over again during the tests. This modification, of course, demand that the characteristics of the emulsion does not change significantly during the test period, and was strictly monitored by measuring the water content and the viscosity of the test emulsion before and after each test. The emulsion was "saturated" with water, so that no more water could be mixed into the actual base oil. The reason for this is assumed to be that no more emulsifier is available in the system to make it stable. The rheology of a system like this will not change significantly even if continuously stirred by circulating from the test tank through the skimmer and back to the tank, as long as the temperature is not significantly changed. Water can be separated form the "water saturated emulsion" if high shear centrifugal pumps are used in the system. The amount of emulsified water and the rheology of the emulsion were measured during each test run.

The small, calibrated sampling tank was selected to have a size that did not significantly interfere with the total volume of the slick inside the boom in the test tank, and still be accurately enough the measure the flow rate and to separate the free water from the oily phase. It is believed that 10 seconds is enough to detect the recovered volume within 10% (+/- 0,005 m3) of the measured volume (50 l) of the sampling tank. The use of this sampling tank is a compromise between getting enough volume to get accurately enough rate measurements, to not interfere with the volume in the test system and get good settling when measuring the amount of recovered volume. The measurement system used during these tests are based on long-term experience with handling this type of high viscosity oily fluid and is assumed to be far more reliably than using flow meters and taking samples to detect free water.

The slick thickness was generally detected by measuring the size of the slick in the boom and divide with the known volume in the system. The reported slick thickness is an average of the total slick. This result was compared to the water current vs. thickness data in the test tank data published by DNV (DNV 2002). The estimated slick thickness was controled, especially for the lowest viscosity test emulsion, by cutting out a core of oil from the slick with a water sampler (cylinder, 0,6 m long with a diameter of 7,5 cm) measuring the volume of the "cut out" area of the slick directly. With high viscosity oil it was not possible to fill the water sampler and directly measure the slick thickness. Hence, by keeping the volume of oily fluid (using a relatively small sampling tank volume) and the water current constant in the test tank during the test, the slick thickness was controlled. Filling the sampling tank repeatedly for each test run ensured the accuracy of the measurement system, and the result is given as an average of the parallel test runs.

Oil Type No	Target viscosity (cP at 10 sek^{-1})	Viscosity range (cP at 10 sek^{-1})	Density range (g/cm^3)	Thickness of emulsion layer (mm)	Target current velocity (m/sec)	Length of oil slick inside the boom(m)	Comments
5	20.000	19.000-21.000	0,95-0,98	50	0,18	7	w/o-emulsion
6	50.000	40.000-60.000	0,96-0,99	100	-	-	w/o-emulsion
7	150.000	120.000 – 180.000	0,95-1,00	100	0,15-0,30	5-7	w/o-emulsion

Table 1. Overview of the target characteristics and test conditions for the three test series with different types of high viscosity water-in-oil emulsions.

The test layout is illustrated in figure 1. All pipes and hoses are either 4" or 5", depending on what is originally used internally in the skimmer and all valves are of the "butterfly" type. The test emulsions were released approx. 10 metres in front of the collecting boom, and pumped directly from the blending tank. During the tests the connection to the blending tank was closed, and in this way the emulsion was circulated from the skimmer to the release point in the test basin using the skimmer pump.

The Test Procedure

The test procedure for measuring the recovery rate by filling the calibrated tank was, with reference to fig. 1) to close valve 1 at the same time as valve 2 was opened. When the tank was almost close to full, valve 2 was closed and valve 1 opened. The tank level was measured, the filling time recorded and the recovery rate calculated. After 5 minutes settling time, the free water was drained out via the drainage valve. The level was once again measured and recorded, and the amount of free water and recovery rate of pure emulsion was calculated. The remaining emulsion was drained do the test basin, and the set up was ready for a new test run. For each test, three consecutive fillings were done for oil type 5 and 6. For oil type 7 only two consecutive fillings were done. Hence the presented results are the calculated average of either two or three fillings.

The Test Emulsions

The test emulsions were prepared using heavy bunker oil from the ExxonMobile refinery at Slagentangen, Norway as the base oil. Water from the test basin (seawater) was mixed into the base oil to form water in oil emulsion until the emulsion was saturated with water. The blending ratio between oil and water is given in table 2.

Base oil and water	Test emulsion		
	”No. 5” (vol%)	”No. 6” (vol%)	”No. 7” (vol%)
“Trinidad” (old test emulsion based on IF 240, containing 47 vol% emulsified water)	98	0	0
IF 240, from Exxon Slagentangen	0	21	0
IF 450, from Exxon Slagentangen	0	29	14
IF 670, from Exxon Slagentangen	0	0	51
Sea water from test basin	2	50	35

Table 2. Composition of the test emulsions.

Preparing The Test Emulsions

The preparation of the test emulsions was done in two stages. First a small sample was made to establish the right blending ratio between oils and water. Second the test emulsions were prepared and stored in a blending tank. This was done in a pump circulation loop as described by Gåseidnes (Gåseidnes, 1993), the circulation loop consisted of a mono pump and 4” hose with a total circuit length of 12 metres. The process of preparing the emulsion was by first mixing the base oils together and then injecting the seawater from the test basin. In this process it is important that the mixing pump is implying a kneading type of shear to achieve a gentle and slow mixing of the emulsion, to control (or limit) the shear rate and the turbulence during the mixing. The pump used was a mono-type (screw) pump giving the desired slow kneading effect. During circulation the water injection rate was 10% of the oily phase circulation rate, and the water was injected before the suction side of the pump. The quality of the emulsion was continuously checked during the preparation and when ready in the blending tank.

Sampling And Monitoring

Three samples were taken form each individual test of each skimmer. The samples were immediately brought to the laboratory in the test facility to measure the characteristics of the test emulsion for each test. The emulsified water content, rheology, and density were measured at the basin water temperature. The samples were stored at +4 ^{o}C until the test series of each test emulsion had been completed.

The water in the test tank is seawater taken form the fjord outside Horten. The density of the water was measured to 1.03 g/cm^3 at 15 ^{o}C by means of a 50-ml glass pycnometer.

Type of measurement	Method of measurements	Accuracy (+/-)
Current velocity in the tank (m/sec)	Measured with an OTT hand held propeller type of flow meter before each test	0,05
Initial amount of oil in the test system (m^3)	Sounding of the calibrated blending tank before and after transferring the emulsion.	0,1
Total amount of recovered fluid (m^3)	Manually sounding of the calibrated measurement tank (50 l)	0,005
Amount of emulsion and free water recovered (m^3)	Manually sounding of the measurement tank after 5 min settling, and draining of the water	0,008
Dimension of the oil slick contained in the test tank (m)	Visual observation with reference to marks alongside the boom.	1
Average thickness of the emulsion layer in the test tank (cm)	Calculated based on the total volume in the boom and the area coverage. Checked with sample taking for some tests.	2
Wave height (m)	Visual observation with references to marks on the walls of the test tank.	0,10
Density of the test emulsions (g/cm^3)	Measured by weighing a pycnometer of 50 ml at 20 ^{o}C	0,01
Viscosity (cP, 5 sek^{-1})	Measured from rheology curve taken with a Bohlin 88 viscosimeter	3000*
Viscosity (cP, 10 sek^{-1})	Measured from rheology curve taken with a Bohlin 88 viscosimeter	3000
Water content in the emulsion (vol%)	Solvent distillation with Xylol according to Dean & Starke	1
Temperature in the water (^{o}C)	Measured with a calibrated electronic thermometer	0,3
Temperature in the air (^{o}C)	Measured with a calibrated electronic thermometer	0,3

Table 3. Overview of measured parameters, measurement methods with accuracy. *) Variation in measurements over a complete test series.

The Tested Skimmers

This chapter gives a brief description of the 8 different skimmers that where tested. All skimmers are currently part of the Norwegian oil spill response preparedness, and were brought in from current equipment depots. A more detailed description of the skimmers is available through the manufacturers.

<u>The Foilex TDS 200</u> skimmer is equipped with a self-adjusting overflow weir. The skimmer is designed to handle all type of spills from light diesel fuel to heavy crude oil, and has a built-in Foilex twin disc positive displacement pump (Foilex, 1993). The skimmer is manufactured by Foilex AB in Sweden. This skimmer was tested in all three emulsions.

<u>The KLK 402 and 602</u> skimmer is a skimmer with two counter rotating drums with positive guides on the drum surface that lift and pressure auger the oil into a collection well placed above water level parallel with the drums. The skimmer is designed to work with

heavy oils. The 402 skimmer is not equipped with a built-in pump at the skimmer head, instead a freestanding Vogelsang rotating piston pump was used. The skimmer was not tested in emulsion No. 7 due to time constraint. The 602 skimmer is equipped both with a feeding screw in the collection well as well as a built-in Desmi DOP 250 positive displacement pump at the skimmer head. This skimmer was tested in all three emulsions. These skimmers are manufactured by H.Henriksen AS in Norway and marketed by Seagull Environment in Norway.

The Lamor Minimax 40 skimmer is a rotating brush skimmer. The brushes are placed on the outside of a rotating drum. The oil adheres to the brushes and is brought to a scraper and into a collection well, and is designed to work with a broad spectre of oils. This skimmer is not equipped with a built-in pump at the skimmer head. Instead a freestanding Vogelsang rotating piston pump was used. Due to pump cavitation the skimmer was not tested in oil type 7. The skimmer is manufactured by Lamor Corporation in Finland.

The Uniskim Enviro Muliti 30 skimmer is a rotating brush skimmer. The brushes are placed on the outside of a rotating drum. The oil adheres to the brushes and is brought to a scraper and into a collection well. The skimmer is designed to work with a broad spectre of oils. For use in cold and heavy oil the skimmer is equipped with hot water injection nozzles spraying the scraper area of the skimmer. The skimmer is equipped with a built-in Vogelsang rotating piston pump. Due to mechanical failure of the drum axis the skimmer was not tested in oil no 7. The skimmer is manufactured by Markleen Terra in Spain, and marketed by EnviroTeam AS in Norway.

The Foxtail 2-6 VAB skimmer is a vertical adhesion band skimmer. The skimmer consists of two 6" rope mops that circulate through a suspended skimmer head above the skimming area. When collecting oil, the oil adheres to the rope mops whereas the skimmer head functions as a wringer unit where the oil is squeezed out of the rope mops. The skimmer head is not equipped with a built-in pump, instead a free standing rotating piston pump is used. The skimmer is equipped with hot water injection in the skimmer head to facilitate the flow of oil to the pump. This skimmer was tested in all three emulsions, and the capacity of these types of skimmers is mainly depending on the number of rope mops used. The skimmer is manufactured by H.Henriksen AS in Norway.

The Desmi Terminator band skimmer unit is a Desmi Terminator weir skimmer with an attached belt skimmer unit. The belt unit can operate "both ways" and is equipped with thrusters to be moveable in the oil slick. The belt unit is designed to recover high viscosity oils that are unable to free-flow into the weir of the Terminator skimmer. The skimmer is equipped with a DOP-250 positive displacement pump. This skimmer was tested in all three emulsion, and is manufactured by Ro-Clean Desmi AS in Denmark.

The Frank Mohn TransRec 250 Hiwax skimmer consists of two counter rotating drums with attached shovels. It is originally designed for recovery of high wax content crude oils, but has proven its functionality on high viscosity emulsions as well. The skimmer is equipped with a built-in positive displacement pump and an annular water injection system for the transfer hose from the skimmer head. The skimmer is equipped with thrusters to be moveable in the oil slick. This skimmer was only tested in oil nr. 7, and is manufactured by Frank Mohn AS in Norway.

Measured Test Fluid Data

Viscosity

The viscosity was measured and Rheology curves were taken by means of a rotating viscosimeter (Bohlin 88) on samples of the settled test emulsion at the actual test basin water temperature during each individual test.

The rheology measurements were performed with increasing and retarding shear rates in the span from 3 sek^{-1} up to 100 sek^{-1}, if possible as water separation often was experienced at high shear rates. As the test fluids are non-Newtonian liquids, the viscosity has to be measured at least two different shear rates for the system to be specified. The results are reported in Table 4 as apparent viscosity at 10 sek^{-1}, which for some reason has been established as the standard for reporting oil spill viscosities. The given apparent viscosity is taken from the rheology curves.

Test emulsion No.	**Measured viscosity interval during the test series (cP at 10 sek^{-1} shear rate)**			**Comments**
	From	**To**	**Average**	
5	21.000	27.000	23.000	Temperature: 12,9 +/- 0,2 ^{o}C.
6	41.000	70.000	58.000	Temperature: 12,7 +/- 0,3 ^{o}C.
7	114.000	184.000	145.000	Temperature: 12,9 +/- 0,2 ^{o}C.

Table 4. Overview of the fluctuation of the physical condition of the test emulsions during the test series.

Emulsified water

Mixing with relative low shear between oil and water will very often result in stable water-in-oil emulsion if sufficient natural emulsifier exists in the system. Heavy fuel oils from the Exxon Refinery at Slagentangen were used as the base oil for the formation of the test emulsions. The fuel oil contains limited amount of emulsifiers and will generally be "saturated" with seawater in the range of 50 – 60 vol%.

The amount of emulsified water in the test emulsion was measured on samples taken from each individual test. The water content was measured by distillation with Xylol as solvent according to the Dean & Starke method. This is a laborious but accurate method to determine the water content. The results are given in Table 5 as the span of water content during each test series.

Test emulsion No.	**Variation of the emulsified water content during the test series (vol%)**			**Comments**
	From	**To**	**Average**	
5	52	60	56	Variation +/- 7%
6	36	50	43	Variation +/- 16%
7	38	50	44	Variation +/- 14%

Table 5. Overview of the variation in the emulsified water content of the test emulsions during the three test series.

Free water

The amount of free water recovered together with the emulsion was measured by sounding the calibrated 50-litre test tank before and after draining the settled water. The settling period was 5 min. The amount of recovered free water is connected to the type of skimmer, how it is constructed and used. Pumping the emulsion at high sear rates can also form some free water. The amount of free water recovered together with the emulsion is stated in Table 6, 7 and 8.

Skimmer Efficiency Data

In Table 6, 7 and 8 below the measured capacities are given for all the tested skimmers with the three high viscosity emulsions. The total recovery rate of fluid is given and the recovery rate of emulsion and free water is specified. The reported recovery rates are an average of the two best results with and without waves and for the three emulsions tested.

Skimmer	Capacity without waves (m^3/hr)			Capacity with waves (m^3/hr)		
	Total	**Emulsion**	**Water**	**Total**	**Emulsion**	**Water**
KLK 402	11	10	1	13	13	0
KLK 602	16	15	1	15	15	0
Desmi Terminator	4	4	0	2	0	2
Foxtail 2-6	4	3	1	4	4	0
Foilex	27	16	11	18	15	3
Lamor	1	1	0	2	2	0
Enviro Multi	7	6	1	8	7	1

Table 6. Average of the two best recovery rates for all tests with test emulsion no. 5.

Skimmer	Capacity without waves (m^3/hr)			Capacity with waves (m^3/hr)		
	Total	**Emulsion**	**Water**	**Total**	**Emulsion**	**Water**
KLK 402	15	15	0	12	12	0
KLK 602	19	19	0	19	19	0
Desmi Terminator	15	13	2	5	4	1
Foxtail 2-6	6	6	0	6	5	1
Foilex	26	20	6	26	26	0
Lamor	8	7	1	9	8	1
Enviro Multi	10	10	0	11	10	1

Tabell 7. Average of the two best recovery rates for all tests with test emulsion no. 6.

Skimmer	Capacity without waves (m³/hr)			Capacity with waves (m³/hr)			Comments
	Total	Emulsion	Water	Total	Emulsion	Water	
KLK 602	18	17	1	24	24	0	
Desmi Terminator	23	23	0	24	24	0	
Foxtail 2-6	6	4	2	8	6	2	
Foilex	18	14	4	19	16	3	
Lamor	0	0	0	0	0	0	The pump cavitates
FraMo HiWax	37	20	17	41	17	24	Recovery potential of this skimmer is too high for the test system.

Table 8. Average of the two best recovery rates for all tests with test emulsion no. 7.

Discussion of test and results

The large uncertainties, as listed in Table 3 in the rheology measurements, are a result of averaging over the total test period. The uncertainty is primarily connected to the change in the properties of the w/o-emulsion during the test. The experimental methodology used implies pumping the emulsion around in the test system during the test. The physical characteristics of the emulsion are constantly changing during this process. Generally the water content is slowly rising and the water droplet size distribution is getting smaller. Both processes generally enlarge the apparent viscosity. The water uptake is also changing the density of the emulsion and enlarging the volume of recoverable oil spill (emulsion) in the system. The recovery of the emulsion and associated free water is dependent on the thickness of the oil layer and the rheology of the emulsion.

To minimise the change in the properties of the emulsion during each test they were "saturated" by mixing with access water for at least three hours before the tests started. Generally water-in-oil emulsions based on Norwegian heavy fuel oil (Exxon Slagentangen Refinery) have equilibrium water content at about 50 +/-5 vol% if no emulsifier is added. The variation of rheology during each test was in the range of +/- 3000 cP, which equalise a maximum of +/- 13 %.

The reported capacity results is an average of three consecutive independent test runs, using the calibrated test tank to measure the recovered fluid for the test runs with test emulsion no. 5 and 6 and two consecutive runs for test emulsion no. 7. The variation of the measured capacities (total amount of fluid recovered, recovered emulsion and recovered free water) for the consecutive test runs is at most +/- 15 %.

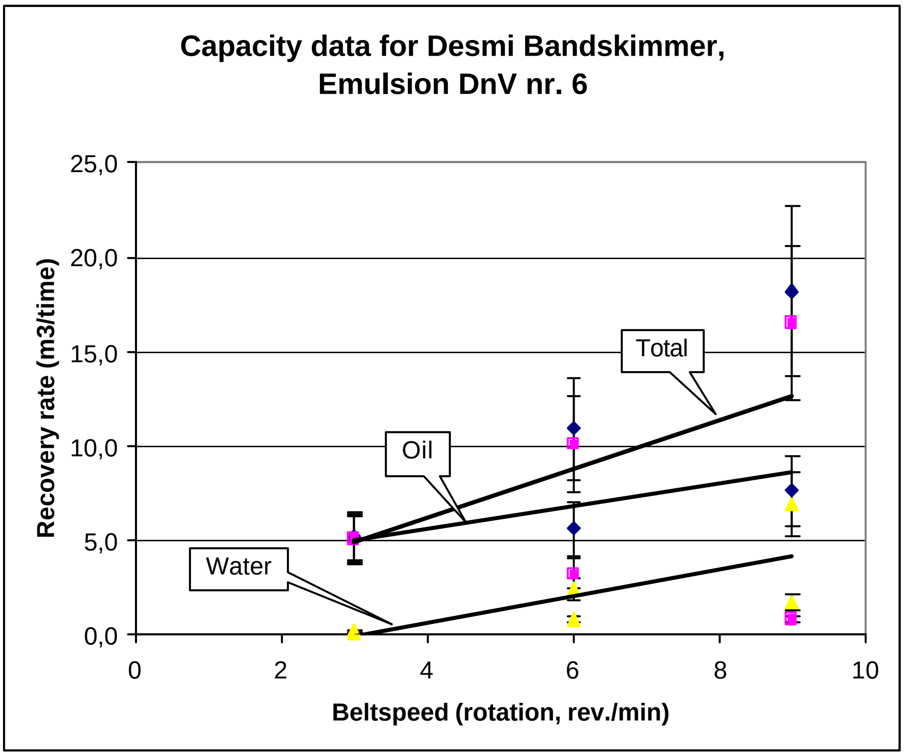

Figure 2. Recovery rate of emulsion, free water and total fluid vs. belt speed for the Desmi Terminator belt skimmer in test emulsion no. 6. The size of the bars in the diagram represents 25% uncertainty in the measured recovery rate.

To further check the reliability of the test results, two independent test series were performed with the same skimmer (Uniskim Enviro Multi 30) in the same test emulsion (test emulsion no. 6). The second test run was carried out 4 weeks after the first. Although the speed of the brush drum varied somewhat during these runs, the average recovery of emulsion was within +/- 25 % for all the individual tests in these test series.

Figure 2 is showing an example of the recovery rate for one of the tested skimmers in test emulsion no. 6. The bars in the graph represent 25% uncertainty, but the trends of the recovery rate vs. rotation speed of the belt is still quite clear.

Visual observation during the tests, shows that the most important factor for recovery seems to be the flow of emulsion up to the intake of the skimmer. The thickness of the emulsion layer, the stiffness of the emulsion and the relative velocity between the emulsion and the tank water normal to the skimmer intake, will give the flow of the emulsion towards the skimmer. The tested skimmers were placed inside a boom in the test tank with the intake against the water current. But some of the skimmers have intakes all around or at two sides of the skimmer, for these skimmers part of the intake capacity of the skimmer will be in the "shadow" and up against the boom wall.

The Frank Mohn HiWax 250 skimmer is a large recovery capacity skimmer. The recovery results obtained for this skimmer was clearly influenced by too small amount of emulsion in the test tank to ensure enough flow of emulsion towards the skimmer. Free water flowing through the oil slick was observed between the skimmer and the boom only a few seconds after the skimmer was started.

As a general trend, waves in the tank tend to lower the amount of free water recovered by the skimmers. The waves sheared the emulsion and with few exceptions facilitated the flow of emulsion towards the intake of the skimmer.

The Lamor Minimax 40 skimmer was not able to recover the high viscosity test emulsion no. 7. The reason for this was that the freestanding transfer pump was not capable of handling the emulsion, and was continuously cavitating. This problem can easily be overcome by changing the cargo pump.

The Desmi Terminator skimmer was run with the belt skimmer module in place. This belt unit functioned best with the two most viscous emulsions. With test emulsion no. 5 especially in waves, the emulsion was "pumped" away from the skimmer by its own heave response to the waves and a free water surface was formed near the intake of the belt.

The Foilex TDS 200 skimmer, which is a self-adjusting weir type skimmer, achieved remarkable good results. The recovery rate was high with all test emulsion, and the amount of free water low. Contrary to what could normally be expected from a weir skimmer, the amount of free water recovered was lower when the skimmer was operating in waves than when operating without waves. The increased recovery as a function of waves can probably be attributed to an increased slick thickness as a result of the wave pushing effect. Other explanations for this are probably the shearing effect and pumping of emulsion over the weir. Further, there is in no functioning wave dampening device at the end of test tank. This results in a very diffuse wave pattern in the test tank. We had practical difficulties with estimating the "pushing effect" of the waves in a specific direction but generally the wave action would push the oily phase to the skimmer randomly around the sink (i.e. all around the skimmer both in the current direction and in the shadow between the skimmer and the boom). This effect and the increased shearing of the stiff emulsion are assumed to be the main reason for the flow rate to increase with waves in the test tank.

The recovery rate of the Foxtail skimmer is connected to the number and size of adhesion bands used. The tested skimmer had two adhesion bands. Even this skimmer performed remarkable well in all test emulsions.

The water current in the test basin was held at approximately 0.35 m/sec. The largest relative velocity (perpendicular towards the skimmer entrance) a skimmer normally can be moved inside an oil slick without oil entrainment is approximately 0.54 m/sec (1 knot). In stiff emulsions experience shows that this speed limit can be 25% larger. In some of the tests, the skimmers were moved around inside the captured oil flake, but generally this resulted in variation in the test results within the 25% accuracy discussed above. Based on these considerations, the test results given must be regarded as minimum capacities.

Circular cuts were taken out from the emulsion flake inside the boom with a cylindrical sample taker to verify the calculated thickness. For the two thickest emulsions (No. 6 and 7) no good thickness measurements were achieved by this method. The thickness of the emulsion layer is estimated based on the calculated volume of emulsion in the test system and the visual observation of the filling of the boom (based on cm marks on the boom floaters) assuming equal thickness over the contained emulsion slick.

There is a need to develop a reliable measurement device to accurately monitor the thickness of the oil layer and the variation of the thickness towards a sink and inside the contained emulsion flake.

Impressions from other tests and actual oil recovery operations

Copenhagen agreement technical project group – recovery of high viscosity oils

The Copenhagen agreement is an agreement on cooperation in terms of oil spill response operations established between Denmark, Finland, Iceland, Sweden and Norway. As part of this agreement a technical project group was established to look into the problems assigned to recovery of high viscosity oils and oils infested with debris. The main part of this work was to arrange a workshop testing of three oil skimmers representative of the current inventory of the Nordic countries. During the workshop the KLK 602, Desmi Beltskimmer and Lamor OPC 4 skimmer were tested in an emulsion of approx. 100 000 cP (at shear rate 10 s^{-1}). The following general remarks are taken from the final report from the working group (Ly, 2003).

- The oil has to meet the active (moving) recovery parts of the skimmer before being obstructed by e.g. floats or grids. The active recovery parts of the skimmer may be either belt, drum, brush etc. If the oil does not meet this parts first, the flow of oil to the skimmer may be hampered and the recovery rate reduced significantly.
- During recovery of high viscosity oils, the skimmer should be able to manoeuvre towards the oil.
- To facilitate the recovery of oil infested with debris and garbage the pump intake should be equipped with solid cutting knives. An even better solution would be to remove the debris before the skimmer intake, however the challenge will be to do this without obstructing the flow of oil to the skimmer.
- The stability of the skimmer, and the wave following characteristics has to be good. This means that the skimmers should have sufficient reserve buoyancy built-in.
- The skimmers should be equipped with an annular water injection ring at the transfer pump outlet. This ring will create a thin annular shaped film of water between the transfer hose wall and the oil. The effects of this are a significant reduction in backpressure and/or the possibility to reduce the stress on the transfer pump. In all cases, an increase in the overall recovery rate from the skimmer will be obtained. Most skimmers can be equipped with such a system.

At-sea recovery operations following the “Prestige” accident.

Of the skimmers tested during this test program, two were taking part during the actual at-sea recovery operations following the sinking of “Prestige” in 2002. The Danish Coast Guard utilised the Desmi Terminator belt skimmer unit, and NOFO utilised the Frank Mohn Hiwax 350 skimmer. Both skimmers were used over a long period of time, and at the end of the recovery operations, the oil had weathered to a viscosity of approx 300 000 cP. According to our knowledge both of these skimmer units performed well during the recovery operations. Both skimmers are equipped with thrusters and annular water injection rings and for both systems it is our impression that these systems are vital to the success of recovering high viscosity oils and emulsions.

Conclusions

In general, all the tested skimmers functioned satisfactory. Both adhesion and weir types of skimmers were functioning well, and to some extend, surpassing what could be expected in terms of recovery rate. In most cases, the problems experienced with some of the skimmers can easily be overcome by minor modifications of the equipment.

The test facility of the Norwegian Coastal Administration at Horten is a good tool to test small and intermediate capacity high viscosity oil recovery skimmers. The FraMo HiWax skimmer has too large capacity to be accurately tested with at test set up as described during these tests. Allowing more emulsion in the test basin would make a modification that could have overcome these problems.

As a follow up of these tests, the NCA will use the reported test results together with earlier tests and information given by the manufacturers, to evaluate an indicative cost of recovering a standard volume of a high viscosity oil spill. This information, together with other knowledge, will be utilised in assessing high viscosity oil skimmers for future purchase. The detailed results will be further elaborated and used to develop a data sheet for each skimmer to inform on the optimum use of the skimmer in different recovery situations. The data sheets will follow the skimmer during actual spill recovery operations, and may hopefully contain important information for the equipment operator.

References

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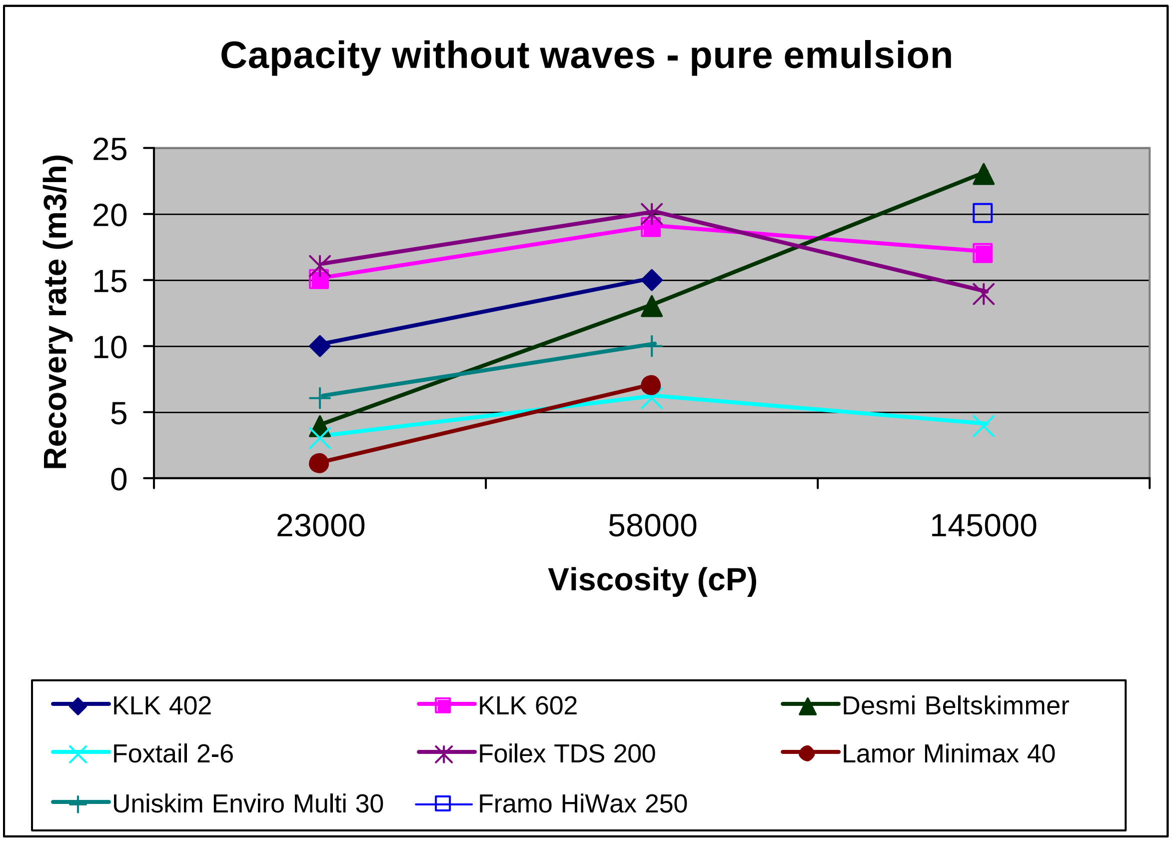

Figure 3. Recovery rate of pure emulsion vs. viscosity for all tested skimmers. No waves.

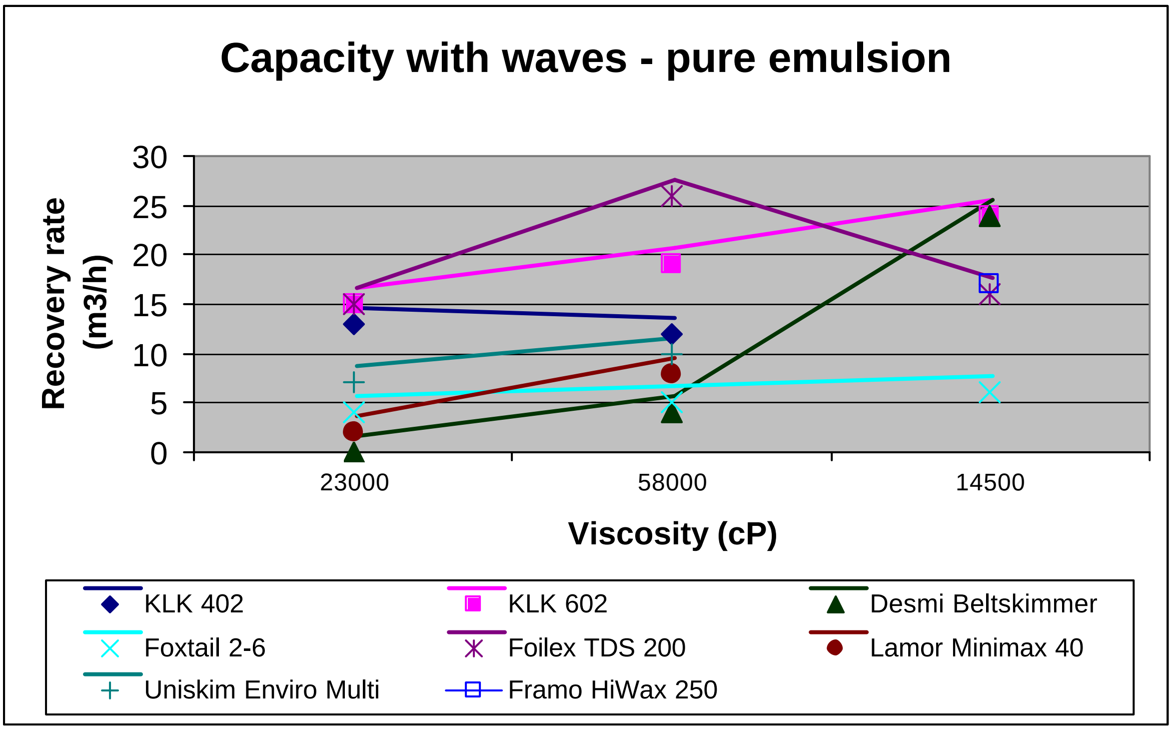

Figure 4. Recovery rate of pure emulsion vs. viscosity for all testet skimmers. 50 cm waves.