Improved recovery of oil spills from water surfaces using tailored surfaces in oleophilic skimmers

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Abstract

The primary objective of this research was to perform a full-scale test of novel oleophilic drum recovery surfaces tailored for oil spill recovery, and to determine the relation between the operational parameters and oil recovery efficiency. There were a number of studies undertaken by the government and private companies in order to test the recovery efficiency of various skimmers (e.g. Foreman and Talley, 2002; Hvidbak, 2001; and Schwartz, 1979). These studies allowed to analyze the recovery efficiency of various skimmers, but did not evaluate or report the influence of the operational parameters such as spill thickness, surface pattern, ambient temperature, drum rotation speed, etc. on oil recovery efficiency. The skimmers tested in these studies had different configurations, dimensions, capacities and recovery modes; and in most cases several operational parameters were changed simultaneously during each test making it impossible to distinguish the effect of each variable separately. The current study specifically evaluated both design and operational parameters independently, thus providing key information on the influence of these parameters on the overall oil recovery efficiency.

To achieve the goals of this project, prototype interchangeable oleophilic skimmer drums covered with various polymeric materials were fabricated, installed in a standard skimmer

body and tested at the field scale in the Ohmsett facility test tank. The major test variables were:

- Oil type (Diesel, Endicott – Alaskan crude oil, and HydroCal 300 lubricant oil);
- Oil film thickness (10 mm, 25 mm and 50 mm);
- Drum rotation speed (30, 40 and 70 rpm);
- Air temperature (≈15ºC and ≈30ºC);
- Material of the drum surface (Aluminum, Polyethylene, Polypropylene, Neoprene, Hypalon);
- Drum surface pattern (smooth or grooved).

This study increased our understanding of the interactions between oil and the material of the recovery unit and identified operational conditions that will result in higher oil recovery efficiency. It was found that:

- The use of a proposed grooved pattern can increase the recovery efficiency by 100-200%. The grooved pattern was proven to be efficient even on Diesel, which is challenging to recover due to its low viscosity.
- The selection of the recovery surface material can increase the recovery efficiency by 20%.
- The recovery efficiency significantly depends on the type of petroleum product and is typically proportional to the oil's viscosity.
- In the case of light and medium viscosity oils, oil recovery efficiency was found to be inversely proportional to its temperature. Oil viscosity increases significantly when temperature decreases, leading to the withdrawal of a thicker oil film in every drum rotation.

- Oil slick thickness has a significant effect on the recovery efficiency. The decrease in spill thickness from 25 mm to 10 mm led to the 2-3 times lower recovery rates. The increase in film thickness from 25 to 50 mm did not increase the recovery rates. The amount of recovered free water was typically higher for a 10 mm slick than for a 25 or 50 mm slick.
- Drum rotation speed had a significant effect on the recovery efficiency. For the skimmer and drums tested, 40 revolutions per minute (RPM) appeared to be a nearly optimal rotation speed in most cases. Beyond 40 RPM, the drum would start to recover a significant amount of free water.

We expect a high level of interest for this research from manufacturers of oil spill recovery equipment since it will allow them to fabricate more efficient cleanup equipment without a significant increase in manufacturing costs. The use of more efficient technologies for oil spill recovery can reduce the time required for cleanup, response costs, and environmental damage.

Test Method

The field scale tests were carried out at the Ohmsett National Oil Spill Response Test Facility. Novel materials and surface patterns were used to retrofit the recovery drums on an existing skimmer at Ohmsett. These drums were installed in a standard skimmer body and used to recover an oil slick while monitoring major recovery parameters. The effect of each design or operational variable on oil recovery efficiency was evaluated.

Materials

Five materials (Aluminum, Polyethylene, Polypropylene, Neoprene, and Hypalon) were used to manufacture smooth drum surfaces. In addition, three drums had a groove pattern (30º angle, 1 inch deep) machined out of aluminum and coated with Neoprene and Hypalon. One aluminum drum was left uncoated. A scraper was made to match the grooved pattern. Figure 1 illustrates two grooved drums.

In order to eliminate the variables that could be introduced by using different skimming systems, a frame-type drum skimmer (Elastec Minimax) was used for all tests. This skimmer uses a drum that is rotated through the oil layer. The adhering oil is subsequently removed by a plastic blade to an onboard recovery sump.

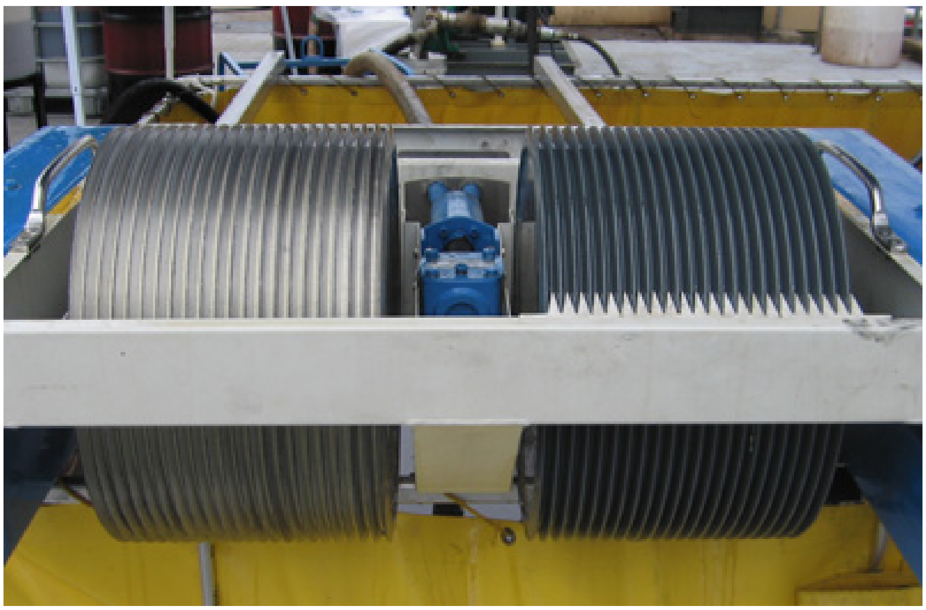

Figure 1. Grooved drums installed into a skimmer frame.

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Left - aluminum drum. Right – Neoprene-coated drum with matching scraper.

Test oils

Diesel, Endicott (an Alaskan crude oil), and HydroCal 300 (a lubricant oil) were used during the Ohmsett tests to study the effect of oil properties on the recovery efficiency. These oils have significantly different properties (Table 1), which allowed us to test the recovery surfaces on a wide range of possible recovery conditions. Diesel was only tested during the second test, at colder temperatures, since it was added later to the protocol.

Table 1. Properties of oils used in Ohmsett field tests

	Density at 15°C (g/ml)	Viscosity at 15°C (cP)	Asphaltenes %
Diesel	0.833	6	0
Endicott	0.915	84	4
HydroCal 300	0.906	340	0

Test Procedure

The tests at Ohmsett were carried out in two trips. The first trip was conducted in August of 2005, at the average ambient temperature of about 25-30ºC. The second trip was completed in October at an average ambient temperature of about 10-15ºC. The objective was to simulate oil spill under warm and cold water conditions, to determine the effect of temperature and oil viscosity on overall oil spill recovery efficiency. The experimental setup is presented in Figure 2.

During the tests, a skimmer assembly was secured in the center of the test tank located on the deck of the Ohmsett facility. Slick thickness was controlled to remain at a predetermined level throughout a given test. As the oil skimmer recovered oil from the test tank, additional oil was pumped from the oil reservoir at the same rate. In this way, real-time control of the slick thickness can be controlled to within ± 20%. Most runs during the first test trip were conducted for 5 minutes. Most runs during the second test trip were conducted for 3 minutes.

The drum rotation speed was controlled with the hydraulic system provided with the Elastec MiniMax system. Three rotation speeds (30, 40 and 70 rpm) were used for most of the tests. The first two speeds represented the regular operational conditions of a drum skimmer, with minimal free water skimming. The 70 rpm speed represented the maximum rotational speed that was achieved by this particular skimmer. At this speed, more oil was collected, but more free water was entrained by the skimmer, particularly for thinner oil slicks (10 mm). A higher rotational speed also emulsified the oil to a greater extent.

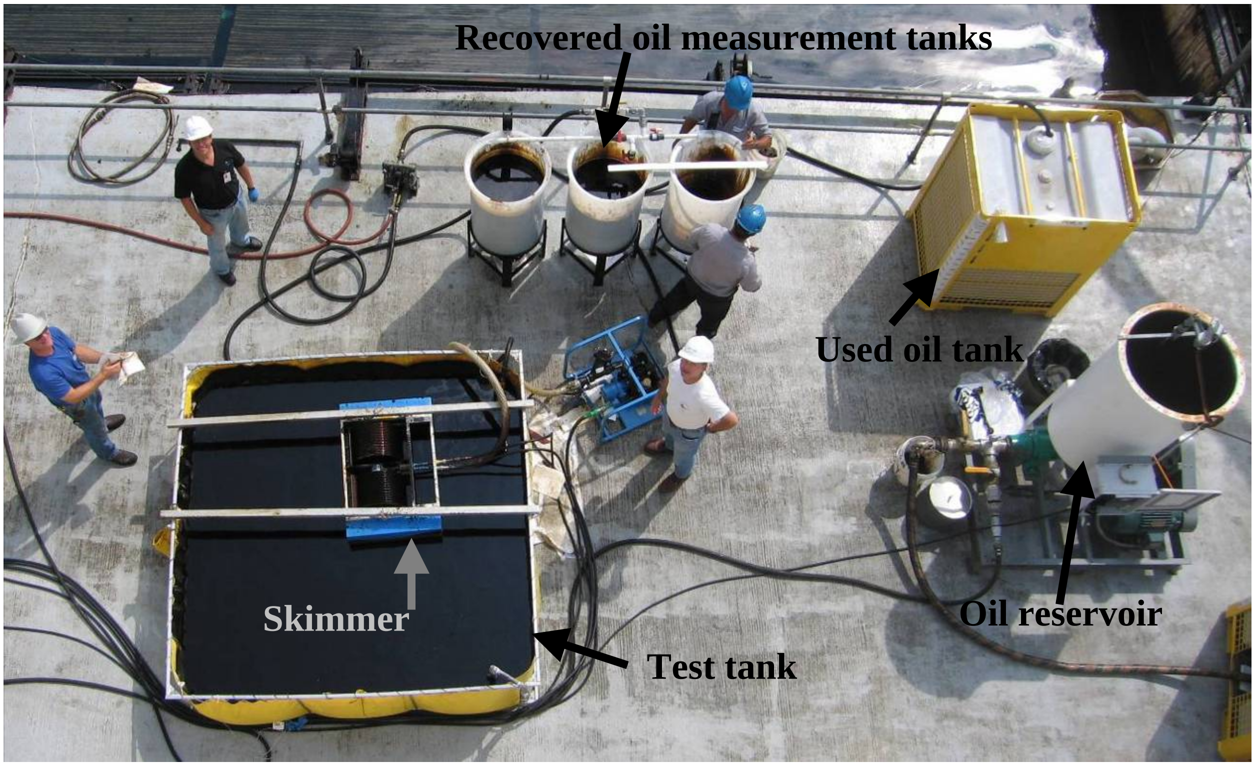

Figure 2. Test setup at Ohmsett.

At the end of each test run, the total amount of fluids (oil and water) was measured, the water was taken out from the bottom for several minutes until no more free water was evident, and the remaining oil or oil emulsion was measured again. A sample of the oil or oil emulsion was taken to measure the water content in the Ohmsett laboratory. This data, along with recovery time, were used to establish recovery rates and efficiency.

Test Results

The recovery efficiency of various skimmer drums tested with Endicott and HydroCal 300 (for an oil slick thickness of 25 mm) during the first phase of the experiments is presented in

Figures 3 and 4. The ambient temperature during the first test ranged from 25 to 30ºC. The oil recovery rates in gallons per minute (GPM) were estimated through the calculation of oil recovered per unit time. To determine this parameter, free and emulsified water in the recovered oil were subtracted from the volume of the total recovered product. These figures show that there is about a 20% difference in the recovery efficiency of smooth drums covered with various materials. The difference between smooth and grooved drums was much more significant. For both oils, grooved drums recovered more than 2 times more oil than smooth ones. A slight decrease in the recovery rates at 70 rpm can be explained by the higher amount of free water picked up by the drums, thereby decreasing the net amount of oil recovered.

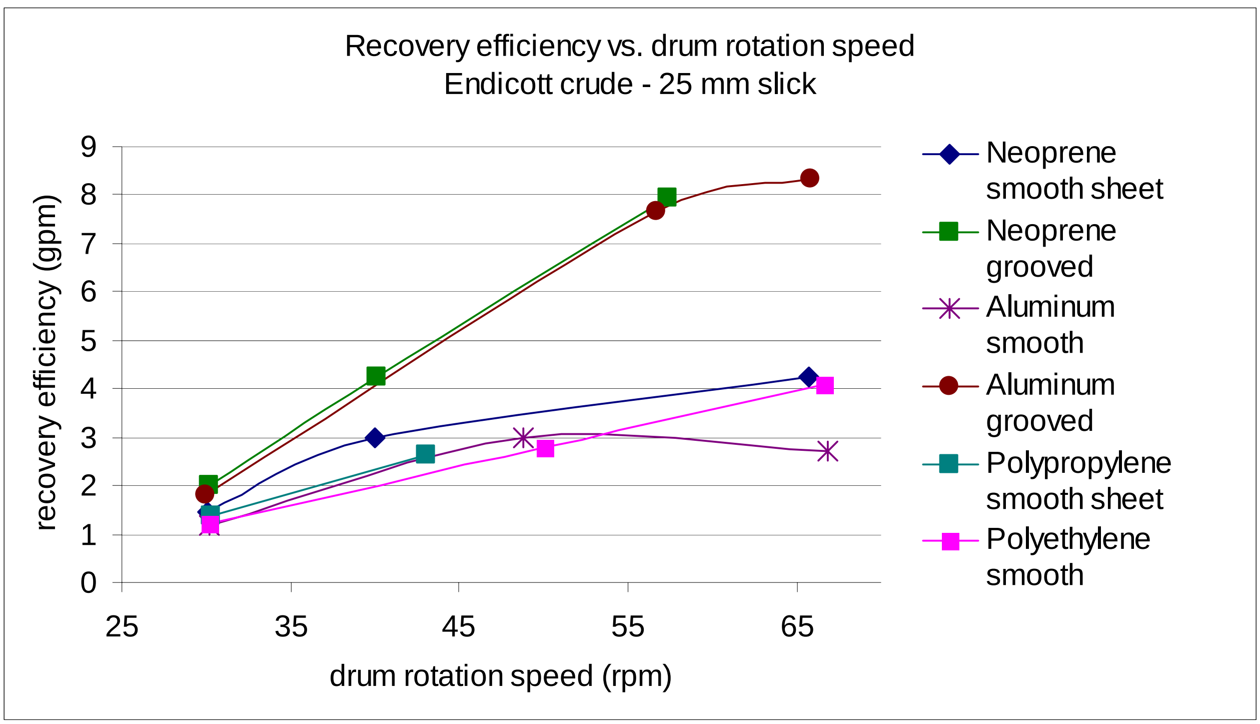

Figure 3. Recovery tests for Endicott crude oil at 25 mm oil thickness. Test at 25-30 ^{o}C.

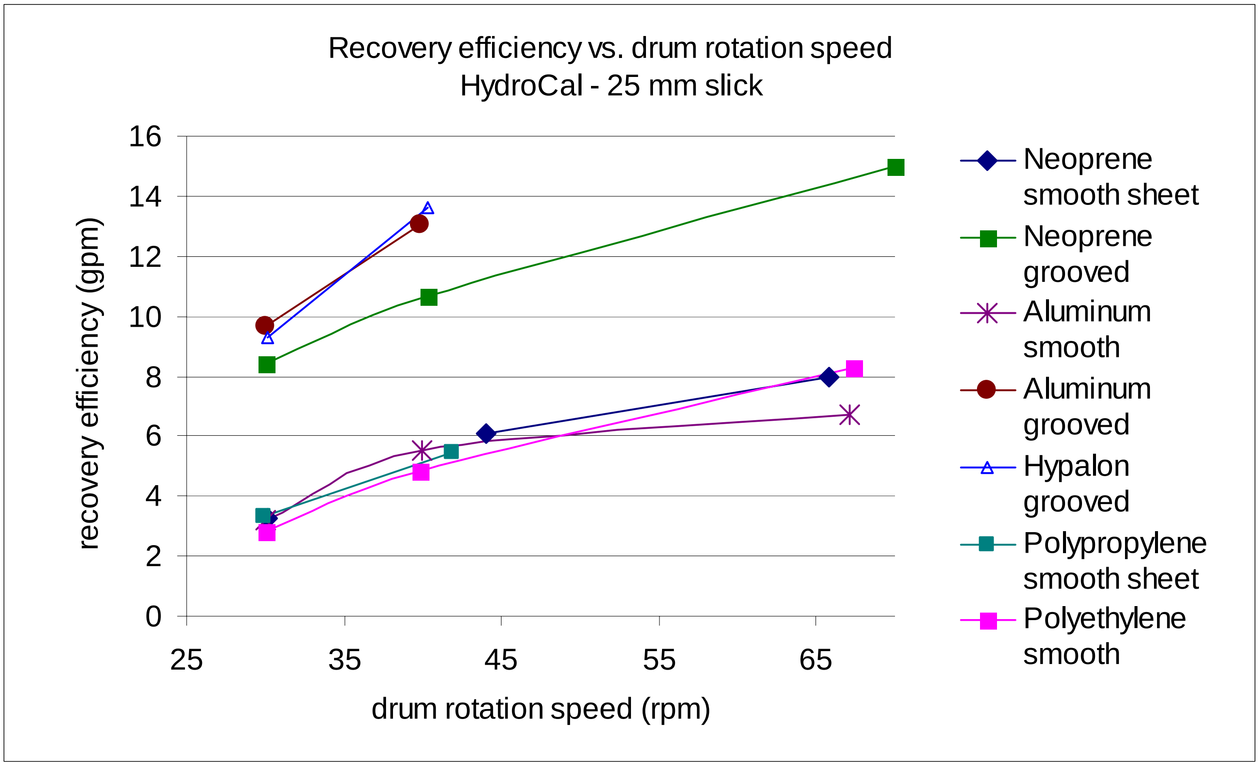

Figure 4. Recovery tests for HydroCal 300 at 25 mm oil thickness. Test at 25-30 ^{o}C.

At a 25 mm oil spill thickness, grooved drums recovered an amount of water that was comparable to the amount of water recovered by smooth drums. Some deviations in results might have been caused by the fact that some runs were performed with oil that was emulsified during the previous run. The water content of some recovered oils was as high as 8%. It was observed that HydroCal emulsified easily and had higher water content than Endicott oil, which influenced the overall recovery of free and emulsified water.

A comparison of the effects of oil type, oil spill thickness and drum surface pattern on the recovery efficiency is summarized in Figure 5. All presented data correspond to aluminum grooved and smooth drums. These data were collected during the first tests at the temperature between 25-30 ^{o}C. The decrease in film thickness of HydroCal oil thickness from 25 mm to 10 mm led to a significant decrease in the recovery efficiency. This was especially pronounced in the case of grooved drums. An increase of oil thickness from 25 mm to 50 mm did not increase the recovery rates. Although Figure 5 shows some decrease in the recovery efficiency at 50 mm, it was most likely caused by the fact that oil used for these tests was slightly emulsified and had an initial water content of about 6%. This reduced slightly the total oil recovered. When the grooved aluminum drum was tested with fresh HydroCal oil at 40 rpm and 50 mm, the result was similar to the recovery efficiency of the same drum at a 25 mm oil thickness. This data point is represented by the single red diamond in Figure 5.

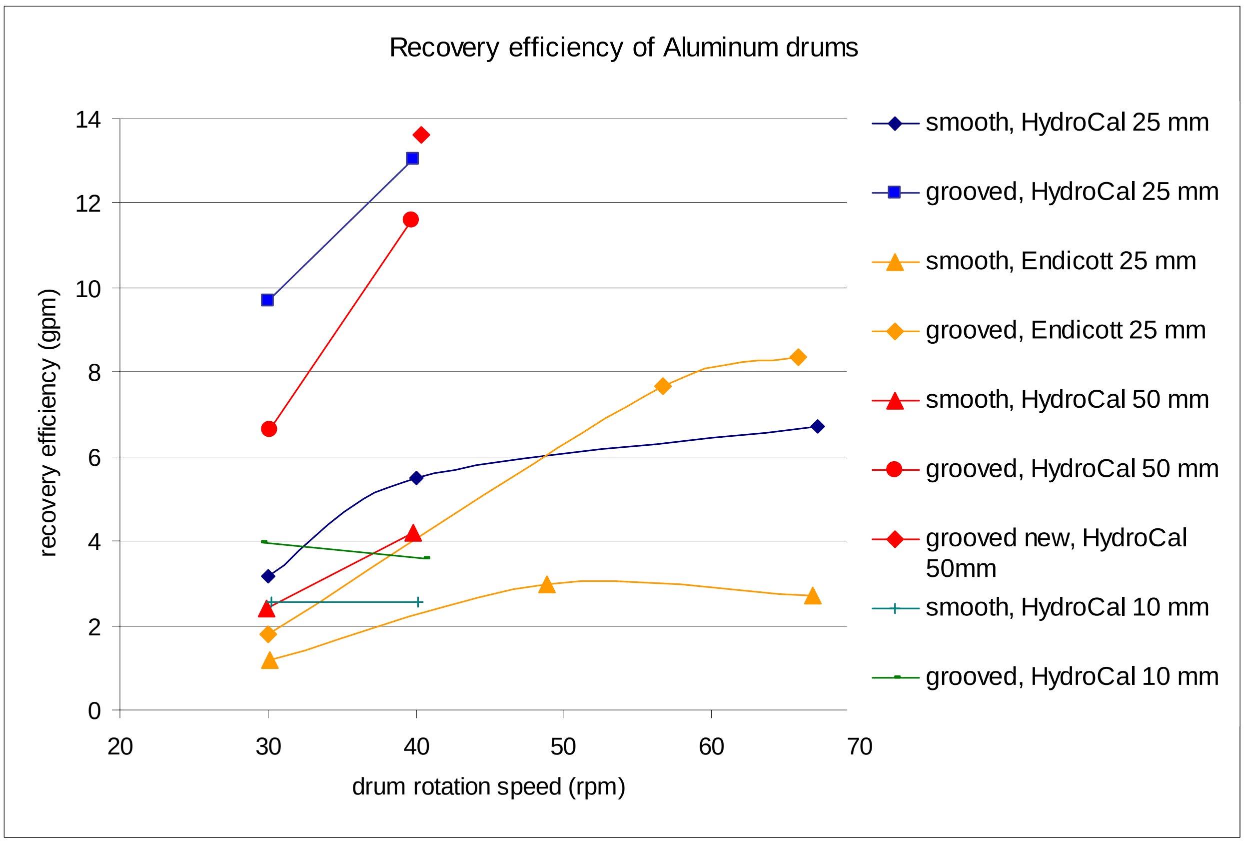

Figure 5. Recovery efficiency of aluminum drums. Test at 25-30 ^{o}C.

Figure 5 shows that the amount of oil recovered by the grooved drums was 2 to 3 times higher than the one recovered by the smooth drums. The oil type was also found to have a significant effect on the recovery efficiency, due mostly to the difference in viscosity.

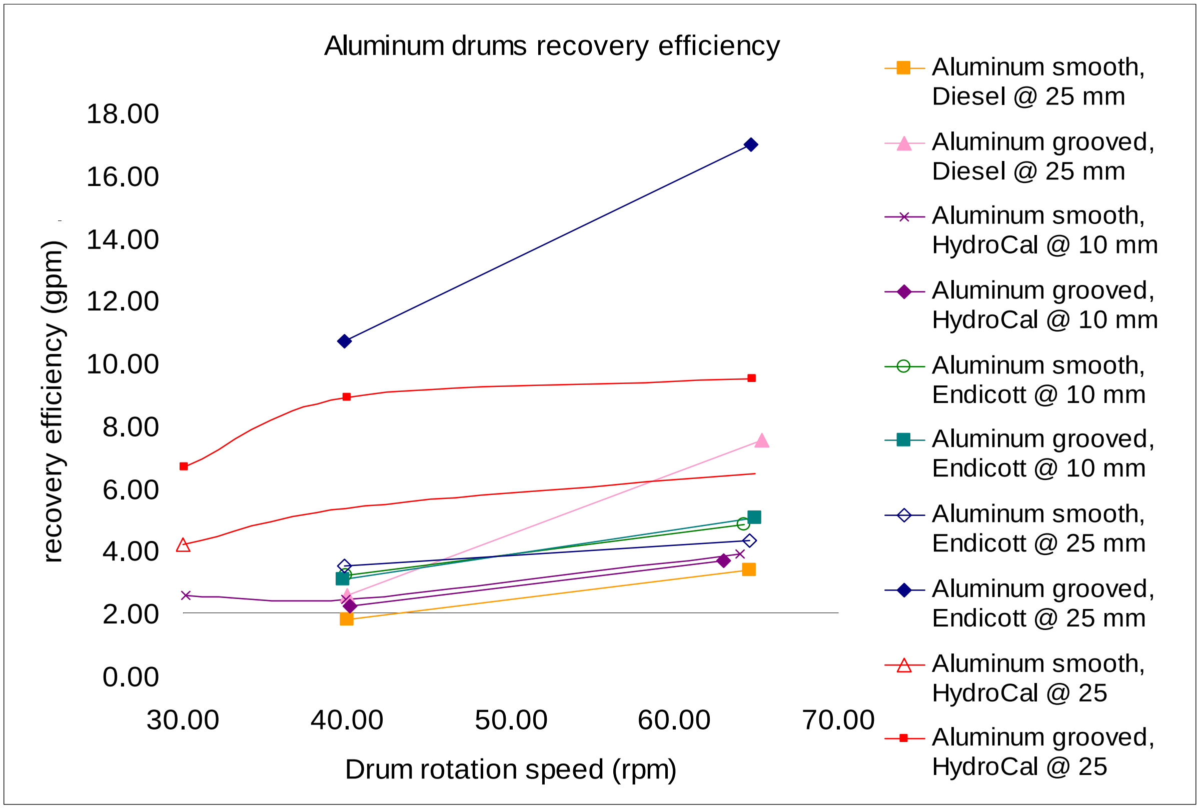

Figure 6. Recovery efficiency of Aluminum drums. Test at 10-15 ^{o}C.

The effects of the oil type, film thickness and drum surface pattern on the recovery efficiency observed during the second tests are summarized in Figure 6. For an oil spill thickness of 10 mm there was almost no difference between smooth and grooved drums. The surface pattern is much more effective for thicker oil slicks. At an oil thickness of 25 mm, the grooved pattern proved to be extremely efficient for Endicott oil and diesel, leading to 2-3 times higher recovery efficiency. Although the increase in recovery was less for the more viscous HydroCal oil, nevertheless the recovery efficiency increased by 50%. At 10 mm slick thickness, the recovery efficiency of HydroCal was lower than the one of Endicott. It might be explained by the increased viscosity of HydroCal at 10-15 ^{o}C. At such small slick thickness water comes into contact with the drum and the total contact area between oil and the drum is reduced. More viscous HydroCal was not able to spread as fast as Endicott did and had lower access to the drum leading to a higher amount of recovered free water thereby reducing the overall recovery efficiency.

The effect of temperature and oil spill thickness on the recovery efficiency is illustrated in Figure 7. At 10 mm oil thickness, temperature didn't have a significant effect on the recovery rates of smooth drums. During the second tests (at 10-15ºC, which for simplicity is denoted as 10 C on the graphic), grooved drums had recovery rates similar to smooth drums. The recovery rates of grooved drums during the Phase 1 tests (at 25-30ºC, which for simplicity is denoted as 25 C on the graphic), were significantly higher. Temperature change didn't have a significant effect on the recovery rates of smooth drums at 25mm. At a 25mm film thickness, grooved drums were considerably more efficient than the smooth drums, although their efficiency was higher at 25 ºC.

Figure 8 shows the effect of oil type and temperature on the recovery efficiency of aluminum drums. The decrease of temperature led to a slight increase of Endicott recovery rates by smooth drums, while it didn't have a major effect on the recovery rates of HydroCal. The decrease of temperature caused a test oils viscosity increase, which lead to a significant increase in the amount of recovered Endicott by grooved drums, while the recovery rates of HydroCal were somewhat reduced.

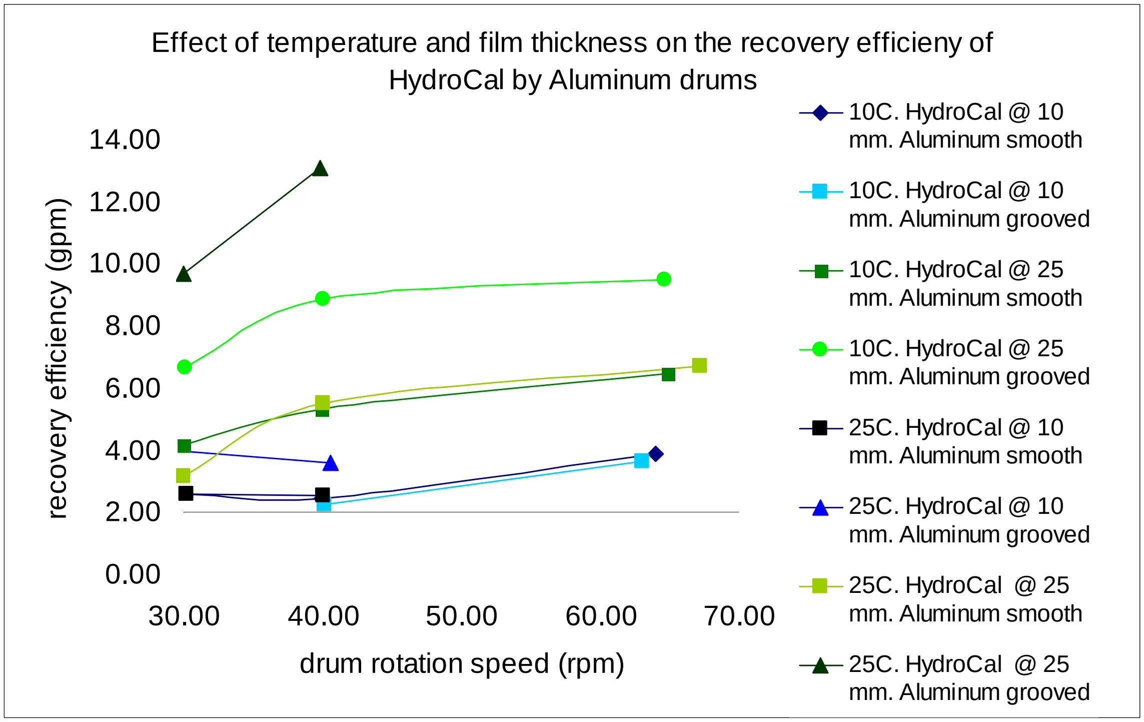

Figure 7. Effect of temperature and film thickness on the recovery efficiency of HydroCal by aluminum drums.

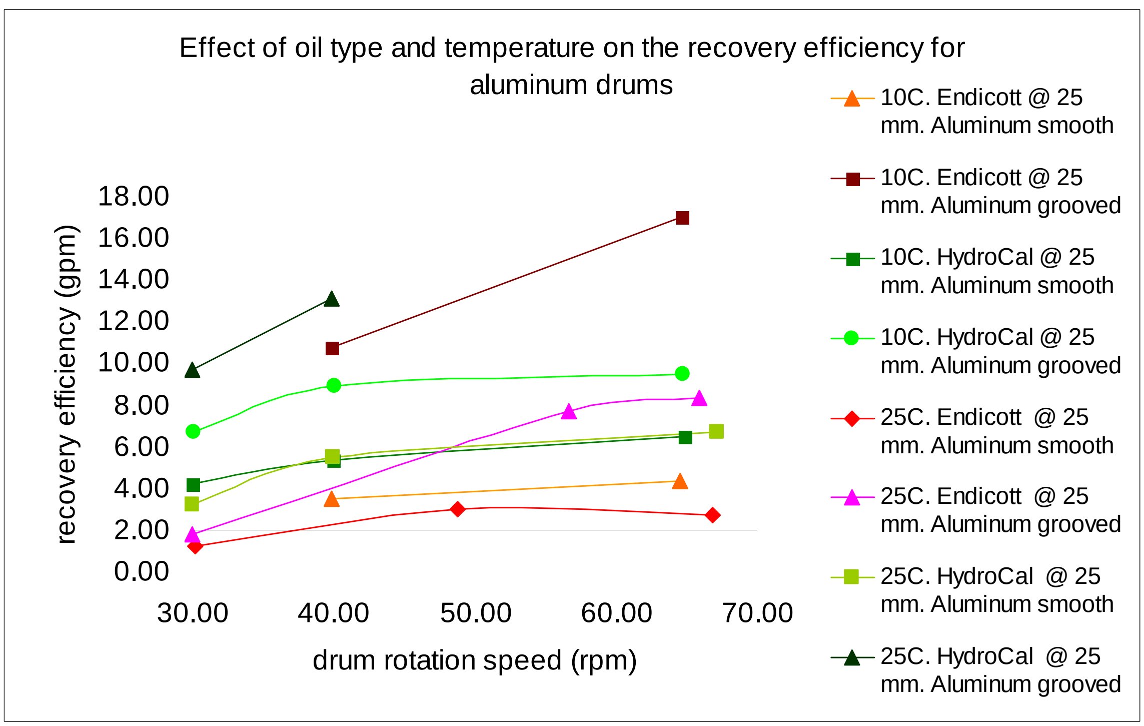

Figure 8. Effect of temperature and oil type on the recovery efficiency of aluminum drums.

Conclusions and recommendations

The field-scale tests confirmed the results of the laboratory experiments conducted during the previous phase of this project. It was found that

- The use of a grooved pattern can increase the recovery efficiency by 100-200%. The grooved pattern proved to be efficient even on such challenging oils as Diesel.
- The recovery efficiency of the grooved surface can be improved by tailoring groove dimensions to oil properties. Using more shallow and narrow groves for light diesel and fuel oil, and deeper and more open grooves for heavier oils may lead to even higher increase in the recovery efficiency.
- The selection of the recovery surface material can increase the recovery efficiency by 20%.
- The recovery efficiency significantly depends on the type of petroleum product and is typically proportional to its viscosity (when the oil is at a temperature above its pour point).
- Oil spill thickness has a significant effect on the recovery efficiency. The increase in oil thickness from 10 mm to 25 mm led to a 2-3 times higher recovery rates for grooved drums and 1.5-2 times higher recovery rates for smooth drums. The increase in oil thickness from 25 to 50 mm did not increase the recovery rates. The amount of recovered free water was typically higher for 10 mm oil thickness than for the 25 or 50 mm oil thicknesses.
- Temperature decrease was found to increase the recovery rates by increasing the viscosity of oil and allowing for a thicker slick to remain on the recovery surface after withdrawal. HydroCal recovered using a grooved surface was the only exception. As

temperature decreased, the viscosity of HydroCal reached a point where oil would not penetrate deep enough into the grooves, leading to a smaller amount of recovered oil.

- Drum rotation speed had a significant effect on the recovery efficiency. For the skimmer and a drum type tested, 40 rpm appeared to be a nearly optimal rotation speed in most cases. Beyond 40 rpm, the drum started to recover significant amounts of free water. It has to be noted, though, that free water was the only limiting factor. If a response team is not concerned with free water in the recovered product, the maximum rotation speed should be used to recover more oil.

Acknowledgements

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References

Foreman, M., Talley, J. Test and evaluation of advanced oil spill response equipment. Technical report TR-2209-ENV. Naval Facilities Engineering Service Center. 2002.

Hvidbak, F. Preparedness for Heavy Oil Spills, More Focus on Mechanical Feeder Skimmers. Proceedings of the International Oil Spill Conference, 2001.

Schwartz, S.H. Performance Tests of Four Selected Oil Spill Skimmers. Proceedings of the International Oil Spill Conference, 1979.