TESTING OF THE LORI "STIFF BRUSH" SKIMMER SWEEP SYSTEM

by

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ABSTRACT

A LORI Side Collector system was purchased for the Canadian Coast Guard (CCG) and tested as a potential heavy oil recovery device for use in Canadian waters.

The LORI skimmer was quantitatively tested in an indoor wave tank using diesel, crude oil, emulsified crude and Bunker "A". The skimmer (consisting of one Side Collector Unit comprised of one brush pack containing two brush chains) was tested in 4°C water at current velocities ranging from 0.15 to 0.65 m/s, in calm water conditions and in waves of 5 to 7 cm high. The brush speed was varied between 6 and 30 cm/s. The skimmer was evaluated in terms of fluid recovery rate and oil recovery rate. The maximum capacity of the skimmer may not have been reached due to current velocity limitations of the tank. The effect of brush speed and oil encounter rate were determined. Skimmer performance increased with increasing oil viscosity. Higher current speeds and waves also enhanced recovery.

Following the tank trials, the system was installed on a 8.5 m Coast Guard sea truck and trials of the LORI Side Collector system were conducted on the St. Lawrence River in the vicinity of the CCG base in Prescott. These tests assessed the stability, manoeuvrability, sea keeping and operation of the system. Oil was not used in this section of the testing program, however the system was evaluated as to its ability to deal with debris and to direct an oil-substitute towards and into the skimmer entrance. In general the skimmer did not adversely hamper the manoeuvrability of the sea truck. The oil-substitute was satisfactorily recovered at velocities of up to 1.5 to 2 m/s.

DISCLAIMER

The contents of this report reflect the views of the contractor and not necessarily the official views of the Canadian Coast Guard.

INTRODUCTION

Recently, a new concept for recovering heavy oils and emulsions has been developed. This concept utilizes a sweep system in conjunction with stiff, cylindrical brushes mounted on an endless chain to move through the oil and remove it from the water's surface; oil is subsequently removed from the brushes by a specially designed "comb" that scrapes oil off the brush bristles. A brush pack consisting of softer bristles for the recovery of lighter oils has also been designed.

The concept shows promise as a heavy oil recovery device, an area requiring upgrading in the Canadian Coast Guard's oil spill response equipment stockpiles.

THE LORI SIDE COLLECTOR SYSTEM

The LORI Side Collector system, as designed by Oy LORI Ab of Finland and Hyde Products Inc. of Cleveland, Ohio and constructed by Navenco Marine Inc. in Montreal, consists of the above mentioned brush packs (consisting of two brush chains each) contained in removable recovery boxes mounted on the sides of a boat. Oil skimming booms extend on either side of the boat supported by jibs and lines. The basic principle of this system is the following: as the boat advances in the water, the side booms
collect and direct water and oil toward the skimmer entrance. The forward speed of the boat causes a pressure head between the intake and exit ports of the skimmer box effectively creating flow through the system. Oil and debris are recovered from the flow by the brushes while water is forced into the bottom and out the exit port of the skimmer box. The recovered material is removed from the brushes by specialized combs, then gravity fed to a collection station. The skimming system was designed to be removed when not in use, allowing the boat to attend to other tasks. The general layout of the skimmer system tested is shown in Figure 1. This skimmer system consisted of: two brush packs constructed for "over-the-side" use with two 17 cm diameter brush chains per pack recommended for use at relative velocities of up to 1.5 m/s; a gravity discharge system (i.e., no discharge pumps); power pack and hoses; and two side arms or jibs for dynamic skimming.

FIGURE 1: The LORI Side Collector system general arrangement
TEST PROGRAM

Testing of the LORI Side Collector system was conducted in two stages: first, flume tank tests were performed to evaluate the skimmer in terms of oil recovery rate and efficiency; and second, sea trials of the skimmer system installed on the sea truck were carried out. The results from these two stages will be discussed separately. Conclusions and recommendations from both stages are combined at the end of the paper.

Throughout both stages of this study, general construction and engineering standards were assessed. This considered: required maintenance and work load; the ease or difficulty of changing parts and servicing all components; problems encountered during installation and operation; as well as equipment reliability and operational problems encountered.

TANK TRIALS

GOALS

The goals of this portion of the test program were to:
1) measure the recovery rate of the skimmer at different current velocities and small wave heights;
2) determine the effect of oil viscosity and slick thickness on recovery rate;
3) determine the effect of brush speed on recovery and emulsification of recovered oil; and,
4) evaluate the overall operation of the skimmer with respect to movement of oil to the brushes, brush pick-up mechanism, water flow through skimmer, debris tolerance, ease of operation and noise.

TEST FACILITY, EQUIPMENT AND SET-UP

Test tank

The skimmer was tested at the S.L. Ross indoor wind/wave test tank in Ottawa (11 m long x 1.1 m high x 1.1 m wide). The variable speed wave paddle can generate standing or travelling waves from 1 to 25 cm high with a continuously variable period. A current generator capable of creating continuous currents of up to 0.65 m/s was installed in the tank for the purposes of this skimmer trial. The current generator consisted of a false floor fitted into the tank, roughly 30 cm above the bottom, and a propeller, installed in the tank at the opposite end from the wave maker. The propeller pushed water under the false floor causing it to recirculate back above the false floor where the skimmer inlet was located. The water temperature in the tank was approximately 4°C. The temperature of the oil, once added to the water ranged from 4 to 12°C depending on how long the oil had been in contact with the water.

Test oils

Three types of oil were tested, each conforming to ASTM standard F631-80, representing light, medium and heavy oils. In addition, water-in-oil emulsions ranging in water content from 40 to 75% were tested. The fresh oil's properties are indicated in the following table. The Hibernia C-90 crude is a waxy oil with a high pour point.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>Initial oil properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>OIL VISCOSITY TYPE</td>
<td>DENSITY (kg/m³)</td>
</tr>
</tbody>
</table>

Test set-up

Figure 2 shows the set-up for the skimmer testing at the S.L. Ross wave tank. With a maximum breadth of 75 cm and an operating draft of 48 cm, the LORI Side Collector Unit could have fit into the tank. However, it was not possible to fit a Sweep Arm system into the tank at the same time as the LORI Side Collector Unit; rather, the boom used to direct the oil and water to the skimmer's entrance was installed into the tank at an angle representing that achieved with the sweep arm jibs and the Side Collector Unit was connected to the outside of the tank. Ports were cut into the tank to permit unrestricted flow of water into and out of the skimmer. The maximum achievable water current in the tank was 0.6 to 0.7 m/s.

TEST METHODOLOGY

Test matrix

The following test parameters were varied in assessing the skimmer's capabilities.

- current velocities: 0.15, 0.25, 0.5, and 0.65 m/s
- brush speed: 6, 15 and 30 cm/s
- wave height: 0 and 5 to 7 cm

A total of 53 runs were performed. For each run, samples of the recovered oil were taken and analyzed for free water content, emulsified water content, and viscosity. The slick thickness or oil presentation rate, the recovery rate and the oil recovery efficiency were recorded for each run. As well, the throughput efficiency (a measure of the amount of oil lost past the entry and through the brushes) was visually estimated during testing.

Procedures

The following were the test procedures for the tank testing:

1. The LORI Side Collector Unit was fitted to the outside of the tank in such a way as to allow water from the tank to enter the skimmer unimpeded. The test tank was filled with cold water (approximately 4°C) to a height of 85 cm (55 cm above the false floor). Once the tank was filled, the boom used to direct the oil and water to the skimmer's entrance was placed into the tank.
FIGURE 2: Skimmer set-up in the flume test tank
2. The current and wave generators were turned on and adjusted to obtained the desired test conditions. Once the adjustments were completed, the skimmer power pack was turned on and the brushes started.

3. The test oil was then gently poured onto the water's surface using a spill plate. A volume, sufficient to create a slick of approximately 1 mm in thickness in the boomed area was used initially.

4. During the test, the recovered oil was recirculated back to the tank using a trough connected to the oil output end of the skimmer. A sample port was installed in the trough.

5. Once steady state was reached, sampling began.

6. Make-up oil was added as required to maintain or increase the presentation rate/slick thickness.

7. On completion of each run, the recovered oil was collected in a barrel for reuse or disposal. The power pack, wave and current generators were shut off and the tank prepared for the next run.

8. Steps 2 through 6 were repeated for each run.

9. At the end of each day the tank was drained and washed.

**Sampling and analysis**

The density and viscosity of the fresh oils used were determined prior to testing. For each run, samples of the recovered oil were taken periodically and analyzed for the following:

- free water
- emulsified water
- density * 
- viscosity * (using a Brookfield viscometer with a shear rate of 1 s⁻¹, generally)

* only if the oil properties appeared to be changing during the run

The following data was recorded during each run:

- current velocity
- wave height and period
- slick thickness/oil presentation rate
- fluid recovery rate, FRR (total volume of fluid recovered per unit time)
- oil recovery rate, ORR (volume of oil recovered per unit time)
- oil recovery efficiency (percentage of oil or emulsion in the recovered fluid)
- brush speed

The following visual observations were made during the testing:

- throughput efficiency (% of the oil presented to the skimmer that is lost past entry and brushes)
- first loss of oil past boom

**GENERAL OBSERVATIONS**

It was observed that oil initially recovered by the bristles at the lower end of the brush pack would gradually sink to the bottom of the bristle aggregate and drip through the brush pack onto the returning bristles below and be carried back to the entrance. While the initial capacity of the brush was high, much of the oil picked up at the skimmer's inlet drained back down into the well before it could reach the top of the brush pack and be recovered. This can be seen in Figure 3, where in the lower half of the brush pack, the bristles are more heavily coated than they are towards the top of the brush pack. The action of the skimmer brushes may contribute to emulsifying the oil, indicated by the rapid increases in recycled oil viscosity observed during the testing. The water content analysis performed on the collected samples confirmed this observation. The coarser stiff brushes sometimes "spit" oil ahead of the skimmer, particularly at the higher brush speed. It was therefore necessary to place a shield at the top of the skimmer ahead of the brushes to
prevent oiling of the surrounding area.

At low currents and high brush speed, with the encounter rates tested, oil was pushed away from the brushes as the brushes came up out of the water. It should be noted that this phenomenon is related to the current speed and was not observed at the higher current speeds of 0.5 and 0.65 m/s. This brush action also caused some dispersion of large oil droplets into the water and their subsequent loss through the skimmer water outlet; this was most pronounced at the high brush speed.

RESULTS

The results from the LORI Side Collector system tank testing are summarized in Table 2. The data collected during these runs has been plotted in Figures 4 through 9 to illustrate the composition of the recovered fluid. Figures 10 and 11 show the effect of viscosity on the fluid and oil recovery rates. It should be noted here that runs denoted as "crude" usually involved oil with emulsion water of less than 50%, whereas runs denoted as "emulsion" involved emulsions with greater than 50% water. It was difficult to test the skimmer with 100% water free oil during the crude oil run. This is because the oil emulsified quickly (within three to six runs) probably due to the skimmer action and recirculation of the oil back to the skimmer. Of greater importance is the performance of the skimmer as a function of the viscosity of the test oils.

In general, the LORI skimmer fluid recovery rate (FRR) and oil recovery rate (ORR) capabilities increased with increasing oil viscosity. With all test oils, recovery rates increased with increasing current velocities. High brush speeds at low current velocities usually resulted in higher free water recovery as much of the oil was pushed away from the brushes as the brushes came up out of the water. Lower brushes speeds were more effective at the lower currents. At the higher currents, higher brushes speeds could be successfully used. Small wave action generally enhanced skimmer performance, by increasing the contact area of exposed bristles to oil.

The light oil brush was more effective than the heavy oil brush in recovering fresh crude or emulsified crude oils with viscosities of less than 100,000 cP. This type of oil tended to drip through the coarser bristles of the heavy oil brush, resulting in lower recovery. For oil with a viscosity greater than 100,000 cP, the heavy oil brush was effective. Some overlap in viscosity ranges occurred in the test of the stiff brush, however the light oil brush was not tested on the highly viscous oils therefore a direct comparison could not be made. It is assumed that the light oil brushes, although likely capable of recovering the heavy oil, may not be stiff enough to withstand the weight and thickness of the heavier oil, and may also be more difficult to pass through the cleaning
FIGURE 3: Heavy oil brush recovering crude oil
   a) lower section
   b) upper section
comb and efficiently cleaned when saturated with a very heavy oil. Overall, recovery of emulsified crude oil and Bunker "A" by the LORI skimmer was better than for lower viscosity oils.

At current velocities of 0.5 m/s or higher, the highest free water content in the recovered fluid was 30%, with the average being 19%. Less than 10% free water was recovered over half of the time under the above mentioned conditions.

**Recovery of crude oil with the light oil brushes**

The results of the fresh crude oil runs recovered using the light oil brushes are presented in Figure 4. Fluid recovery rates and oil recovery rates of crude oil ranged from 0.228 to 0.864 m³/hr and from 0.212 to 0.726 m³/hr respectively. Recovery rates increased with increasing oil viscosity. When considering the total fluid recovery rate, a significantly higher percentage of oil was recovered at the higher current speed of 0.5 m/s than at the lower current speeds. At the lower current speed of 0.25 m/s, more free water was recovered. FRR and ORR were higher with the waves on than with the waves off.

Figure 5 shows the results from the analysis of recovered fluid during the skimming of emulsified crude with the light oil brushes. FRR and ORR ranged from 0.57 to 1.5 m³/hr and 0.50 to 1.42 m³/hr respectively. At the higher current velocity of 0.5 m/s, total fluid and oil recovery were higher with the wave maker off. At the lower current velocity of 0.25 m/s, the skimmer performed better without waves when the brush speed was 30 cm/s and roughly the same with or without waves at a brush speed of 15 cm/s.

During both emulsified and unemulsified crude oil runs, a low current/high brush speed combination resulted in oil being pushed away by the brushes and dispersed into the water in the well. This resulted in some oil escaping through the skimmer outlet. With this same current velocity but at the lower brush speed, very little oil escaped the skimmer and the throughput efficiency was roughly 99%.

**Recovery of crude oil with the heavy oil brush**

Results from these runs are shown in Figures 6 and 7. Fluid recovery rates ranged from 0.01 to 1.85 m³/hr, increasing with increasing viscosity. The oil/emulsion used in these runs ranged in viscosity from 58,000 to 580,000 cP. The heavy oil brush did not perform as well as the light oil brush on the unemulsified oil with viscosities under 100,000 cP. During run #28, at a current velocity of 0.45 m/s, a brush speed of 0.15 cm/s, and an oil viscosity of 40,000 cP and in calm water, a large amount of oil was seen escaping out the skimmer exit, which resulted in a lower throughput efficiency. The highest recovery rate (1.85 m³/hr) was achieved during run #38 with a brush speed of 0.30 cm/s, a current velocity of 0.5 m/s and with the wavemaker on. The oil had a viscosity of 795,000 cP. These results indicate that the stiff brush is better suited for very viscous or highly emulsified oils of over 100,000 cP.

It was observed, particularly during the emulsified crude oil runs, that although the brushes were completely saturated at the bottom of the skimmer inlet, by the time they reached the top, a significant amount of the oil had dripped through the bristles and onto the downward-travelling section of the brush.

**Recovery of Bunker "A" with the heavy oil brush**

Recovery rates of Bunker "A" were the highest of all the oils tested, ranging from 0.25 to 1.9 m³/hr. There was also a lower percentage of free water recovered during the Bunker "A" runs than during the crude oil runs. Small wave action significantly enhanced recovery rates of Bunker "A". The oil thickness at the skimmer inlet was at least 10 cm throughout these runs. During run #40, at a brush speed of 15 cm/s, a current velocity of 0.25 m/s, a viscosity of 47,000 cP and with the waves off, a minimal amount of oil was observed escaping out the skimmer exit. Under these same conditions but with the
wavemaker on, oil was lost under the boom. At low currents and high brush speeds some
dispersion of oil occurred at the skimmer inlet. The highest fluid and oil recovery rate
were achieved with a brush speed of 30 cm/s, a current velocity of 0.5 m/s and with waves
(runs 50 and 51). During run #48, the effect of current velocity was visually observed by
keeping the brush speed constant at 30 cm/s and varying the current speed from 0.25 to 0.5
m/s. At the lower current velocity, the brushes pushed the oil away. As the current was
gradually increased, the oil was pushed towards and collected by the brushes.

As a final test of the maximum recovery rate under optimum conditions, the
brushes were turned off and the entrance well closed off and filled to capacity with 175 L
of Bunker "A". At 13.5°C, the oil had a viscosity of 900,000 cP. The brushes were then
started up again and the recovery rate measured. At brush speeds of 15 cm/s and 30 cm/s
maximum short-duration recovery rates of 1.6 m³/hr and 4.4 m³/hr were achieved,
respectively.

Test results from 1986 acceptance trials by the Swedish Coast Guard (see the
report) showed a maximum oil recovery (with 5 brush chains) of 32 m³/hr of a heavy fuel
oil emulsion at a current of 1.25 m/s. This is equivalent to 12.5 m³/hr for a 2 brush chain
system. It is possible that the test conducted for this study did not reach the maximum
capability of the LORI system due to the upper current limit of 0.65 m/s in the test tank.

Recovery of diesel with the light oil brushes

The skimmer did not perform very well on diesel, demonstrating a maximum
recovery rate of 0.16 m³/hr. The breakdown of the recovered fluid is shown in Figure 9.
This skimmer is simply not suited for very light oil recovery. Diesel recovered by the
brushes dripped through the bristles and back into the bottom of the skimmer. At a current
speed of 0.45 m/s and brush speed of 30 cm/s although the diesel accumulated inside the
well, it was not picked up by the brushes. At this brush speed, the diesel tended to be
pushed away by the brushes.

During run #7, at a current speed of 0.3 m/s, a brush speed of 15 cm/s and with the
waves on, the recovery of diesel was negligible as most of the oil was observed to be
coming out the skimmer exit. The throughput efficiency was close to 0%.

General equipment performance

The LORI Side Collector system was easy to operate. Brush speed control was
simple, although it was necessary to use the lock-nut on the hydraulic control valves as
vibration from the engine would cause the valves to rotate. It was noted that the hydraulic
motor should be fitted with one male and one female quick connect to prevent the hoses
from being accidentally connected backwards. On-land manoeuvring and installation of
the system was somewhat cumbersome and required the use of two to three people and an
overhead crane.

Some problems were encountered with the diesel engine used to run the hydraulic
power pack. First of all, this particular diesel was very difficult to pull start, and should
be supplied with an electric start. The engine could not be started when the air temperature
was approximately 5°C. Once the engine had been running for some time (over one hour)
and was shut down, it was very difficult to start again. Often, pulling the rewinder resulted
in the engine running in reverse. This severely wrenched the hand and arm of the person
pulling the starter. After five days of testing, the rewinder broke while attempting to start
the diesel. The next day, after effecting repairs, the rewinder rope broke. The positioning
of the diesel engine inside the frame of the power pack led to two problems: the person
pulling the starter rope risked hitting their hand on the vertical frame support and safe
access to the fuel tank was restricted unless a funnel was used.

The hydraulic power pack was found to be particularly noisy. The sound level was
verified using a Bruel and Kjaer noisemeter (Type 4436). This diesel model produced a
maximum average noise level of 105 dB. One meter away from the power pack, the
average noise level was 101 dB. The acceptable level of noise without ear protection is 80 dB.

The general quality of construction of the skimmer was good; several cut metal edges required filing.

SEA TRIALS

GOALS

The goals of the sea trials test program were to:

1) assess the installation and removal of the units on a sea truck;
2) determine transit speeds that the sea truck was capable of in both a loaded and unloaded condition;
3) assess the deployment and retrieval of the system at a simulated spill site;
4) evaluate the stability, manoeuvrability and sea-keeping of the sea truck with the system deployed and in both a loaded and unloaded condition;
5) evaluate the Side Collector units' ability to recover oil, utilizing a non-polluting oil substitute as a flow visualization aid;
6) evaluate the Side Collector units' operation, including wave response, debris tolerance, noise, relative water levels, induced turbulence and water flow; and,
7) assess the general construction, engineering and safety aspects of the Side Collector unit as built and installed.

TEST METHODOLOGY

Procedures

The sea trials were conducted using the standards set out in ASTM F808-83 to the greatest extent possible. The following assessments were carried out:

1. **Installation and Removal**: The installation and removal of both Side Collectors c/w jibs and booms onto the sea truck was observed and timed; observations relating to ease of installation/removal, hazards, equipment required, problems, etc. were documented.

2. **Transit Speeds**: The best speed made between buoys one kilometre apart was measured. This test was repeated with the sea truck in an unloaded condition and with a ½-full and full portable tank on deck (filled with water) and while towing a ½-full and full storage bladder astern (filled with water). Tow-line loads were measured with a tensiometer. The stability and safety of the stowed Side Collector units and jib arms was assessed while in transit.

3. **Deployment and Retrieval of System**: The time required to deploy and retrieve (and stow for transit) the Side Collector system was measured several times. Observations regarding the ease of deployment and recovery and safety were made.

4. **Manoeuvrability**: The stability, manoeuvrability and sea keeping ability of the sea truck with the Side Collector system deployed was assessed with the sea truck in both unloaded and loaded conditions. This assessment involved measuring the maximum achievable speed; minimum speed at which steerage could be maintained; wave response and turning stability of the system.

5. **Collector Operation**: The ability of the jib, boom and collector to direct oil towards the recovery brushes was assessed by using an oil substitute. Small
apples were used to visualize the flow of oil towards and through the collector system. The ability of the apples to simulate oil behaviour was confirmed by towing some in the pocket of a boom deployed in a "U" configuration and determining the velocity at which they were entrained beneath the boom. The assessment involved determining collector failure velocity as well as observing any turbulence (i.e., vortices) generated by the system. Wave response and relative water levels were also assessed.

6. Recovery Operations: This assessment involved visual observations of water levels and turbulence inside the Side Collector as a function of forward speed and brush speed. As well, a variety of types of debris were dropped in front of the collector to assess its sensitivity to such items. The debris included polypropylene rope, lumber, plastic cans, sorbent pads and foam sponges (as specified in proposed amended ASTM standard F631-88).

Measurements

The following were measured during the trials.
PARAMETER | METHOD
--- | ---
Ambient Environmental Conditions | Digital thermometer
Air Temp/Water Temp | Portable weather station
Wind Speed/Direction | Hand-held current meter
Currents | Visual observation
Wave heights/period | Hand-held current meter; GPS (Global Positioning System); reference buoys
Vessel Velocity Relative to Water & Vessel Heading | metre sticks attached inside inlet and outside outflow of both Side Collectors
Skimmer Motion Relative to Waves | stopwatch
tow line tension | tensiometer
Mass of water in portable storage devices | timed flow of pumps

In addition, the tests were documented using videotape and 35mm photographs.

RESULTS AND DISCUSSION

Conditions on the St. Lawrence river over the three days of testing were relatively calm. Water temperatures were about 19°C, air temperature was 18 to 22°C, the current speed in the river averaged 0.55 m/s and the wave height was approximately 30 cm.

Installation and Removal

The time required for two people to uncrate and install the LORI Side Collector system (two side boxes, two jibs, two booms, two brush packs and the power pack) onto the CCG sea truck was one hour and twenty minutes. A boom truck with an overhead crane was used to lift the side boxes onto the boat and to assist in placing the brush packs into the skimmer boxes. Installation of the front diversionary booms and jib took four people 20 minutes. The diversionary boom system is intended to push the oil around the square bow of the sea truck and divert it towards the side collectors and skimmers. The installed skimmer system is shown in Figure 12.

Forty-five minutes were required, for four people assisted by a mobile crane, to dismantle the jibs and side collectors, remove them from the vessel and bring them up on dockside ready to be stowed away. The front diversion boom system took three people eight minutes to dismantle and stow on the dock.

Some of the bolt holes for the jib arm at both the boom end and at the gunwale end did not properly line up, therefore not all of the bolts could be inserted into place. It was noted that the jib and skimmer attachments as well as the hinges for the bow arm located on the sides of the boat should either be protected or, ideally, moved inboard to prevent them from being damaged while not in use. It was also felt that when the boat is being used for purposes other than skimming, attachments on the outside of the boat could be damaged, either while the boat is in use, or while at dockside when the boat bumps up against the dock. During installation, the hinges for the bow arm were knocked and bent.

Transit Speeds
The maximum transit speeds were measured with the skimmer side boxes raised out of the water and with the clevis pin resting in the upper support slot. The jibs and booms remained in the water during transit. This test was performed with the sea truck under various loading conditions: unloaded; with a partially loaded portable tank on deck; and, towing a storage bladder. The units remained fairly stable throughout transit; however, it was thought that a more secure locking mechanism should be used and that further stiffening was required at the point where the skimmer is supported during transit.

FIGURE 12: LORI Side Collector system installed on a 8.5 m sea truck
The following table gives the best speeds achieved under various loading conditions of the sea truck.

### Table 3
Best sea truck transit speeds

<table>
<thead>
<tr>
<th>Bladder (m³)</th>
<th>LOADING</th>
<th>Port-a-tank (m³)</th>
<th>BEST SPEED (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>empty</td>
<td>empty</td>
<td>2.25 †*</td>
<td></td>
</tr>
<tr>
<td>empty</td>
<td>empty</td>
<td>2.35 †</td>
<td></td>
</tr>
<tr>
<td>17.3</td>
<td>2.6</td>
<td>2.3 †</td>
<td></td>
</tr>
<tr>
<td>20.7</td>
<td>empty</td>
<td>2.5 †</td>
<td></td>
</tr>
<tr>
<td>empty</td>
<td>empty</td>
<td>5 ‡</td>
<td></td>
</tr>
</tbody>
</table>

* propeller size = 13¼"φ x 17", all others 13¼"φ x 15", twin 90 HP outboards
† Side Collector raised, jibs in water
‡ Side Collector raised, jibs stowed on board

Tow-line tension was also measured during this exercise. At a speed of 2.3 m/s with the sea truck pulling the bladder containing 17.3 m³ of water the tension averaged 680 kg with a maximum of 770 kg.

**Deployment and Retrieval of System**

The time required for two people to remove the boom and jib from the water for transport was 10 minutes. This was performed at dockside under calm water conditions. It was noted that, although the davits for raising and lowering the skimmers could be moved forward and used to raise the jib arms for stowing, once the jib arm was swung around towards the front of the boat and brought inboard the winch handle on the davit jammed against the skimmer outlet trough and could not be cranked to lower the jib arm. The jib arm obstructed the full range of motion. Four davits should be supplied (two forward and two aft) and these should be 30 cm higher than the two originally supplied. This is required in order to make full use of the davit during jib and boom removal. Otherwise, boom and jib removal must be performed at dockside as they are too heavy to manoeuvre by hand from inside the boat. The plastic covering the wire rope in the davit pulley caused the winch mechanism to jam. It would be advisable to replace this with uncoated wire.

**Manoeuvrability**

The stability and sea keeping of the sea truck with the Side Collector system deployed were good at all speeds tested. Maximum achievable skimming speeds were determined with the booms and skimmer deployed with the sea truck in unloaded and various loaded conditions. The following table shows the maximum achievable skimming speeds attained during these trials. The maximum achievable speed with the front bow deployed was 1.7 to 1.9 m/s, towing an empty bladder. The skimming speeds, indicated in Table 4, were achieved without the front boom system deployed.

A 360° turn with a radius of approximately 30 m (less than one tow length) was successfully completed while towing the bladder containing 11.5 m³ of water. Wave height was approximately 30 cm. The turn proceeded smoothly, except for a minor encounter with the bladder, and steerage was maintained throughout the exercise. Stability and manoeuvrability were not negatively affected. It was possible to manoeuvre the system at speeds as low as 0.25 m/s.
Table 4
Maximum achievable skimming speeds

<table>
<thead>
<tr>
<th>Bladder (m³)</th>
<th>LOADING Port-a-tank (m³)</th>
<th>BEST SPEED (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>empty</td>
<td>empty</td>
<td>1.6*</td>
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<tr>
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<tr>
<td>11.5</td>
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<td>1.4</td>
</tr>
<tr>
<td>11.5</td>
<td>1.4</td>
<td>1.25</td>
</tr>
<tr>
<td>11.5</td>
<td>2.6</td>
<td>1.45</td>
</tr>
<tr>
<td>17.3</td>
<td>2.6</td>
<td>1.5</td>
</tr>
</tbody>
</table>

* propeller size = 13¼"φ x 17", all others 13¼"φ x 15", twin 90 HP outboards

The wave response of the sea truck and skimmer system was good. At higher current speeds of 1.0 to 2.0 m/s, a significant amount of stress on the forward jib ropes was observed. These ropes should be replaced by a wire rope or cable system to ensure they are held in the proper position. Flexing of the side wall where the jibs connect to the boat was also observed when waves of over 30 cm were encountered. This attachment point should be reinforced. The booms followed waves of approximately 30 cm quite well. Occasionally, splashover occurred, but it was not too severe. The response to a wake with 60 to 90 cm swells, was also acceptable although some jerking of the skimmer and increased splashover was observed. The jerking and splashing was considerably less when travelling with the waves than when travelling into the waves. Waves from the side did not affect the skimmer as much as head-on waves.

At higher speeds, the tension created by the jib attachments caused the sides of the sea-truck to spread at the bow and take in water when the door was not closed. In order to enable operations of the sea truck with the bow ramp down, a support bar to brace the gunwales should be fitted at the bow.

Tensions in the line towing the bladder containing 11.5 m³ of water were measured at two velocities. At a current speed of 0.5 m/s, the tension was 115 kg, while at 1.5 m/s, a tension of 455 kg was measured.

Collector Operation

The ability of the jib, boom and collector system to direct oil toward the recovery brushes, as deployed on the barge was assessed using crab apples.

A water level height differential of 7 to 10 cm was measured between the inside of the boom and skimmer box and behind the boom when travelling at 1.4 to 1.5 m/s. Height differences of 15 to 21 cm were observed when travelling at 2.0 m/s. There was considerable turbulence in the skimmer box and inside the boom pocket at these current velocities. Vortex formation inside the skimmer box at velocities of 1.5 to 2.0 m/s was quite prevalent and could cause some oil to be drawn beneath the bushes. When boat speeds were reduced to 1.0 m/s, the level of turbulence dropped, although it did not disappear.

In general, apples thrown ahead of the side boom were collected in the pocket of the boom and directed into the skimmer. At 1.5 m/s, some of the apples entering the
skimmer inlet would get caught in the vortex created inside the skimmer box, however they did not seem to escape through the skimmer's water outlet. At velocities of above 2.0 m/s however, some of the apples were entrained and would reappear behind the booms. This was also noticed when debris and apples were thrown directly ahead of the skimmer. It was noted that apples and debris dropped directly beside the gunwale would occasional escape under the rubber seal between the collector and the side of the boat. This rubber seal should be extended downwards.

Skimming operations were also observed with the bow boom in place. This boom system was not found to be very effective. The front booms tended to plane due to insufficient tension in the bottom tension member, possibly caused by rotation of the bow float as a result of water pressure while under way. The purpose of these diversion booms would be to push the oil aside from the square bow and towards the side collectors, however at velocities of 1.5 to 2.0 m/s, oil would likely have been lost under the boom. Even at skimming speeds as low as 0.75 m/s, some of the apples were swept under these booms, while others were diverted back to the skimmer. At 1.5 m/s, the front boom was creating a considerable bow wave as the boat advanced. The front boom system did not appear very stable in waves. There was considerable rocking of the bow float. In larger waves (60 to 90 cm) this float completely submerged. Reinforcement of the bow connectors is recommended.

The collection boom was deployed in a "U" configuration in order to determine the velocity at which the apples were entrained beneath the boom (i.e. the first loss velocity of the boom). The vessel speed was gradually increased until loss of an apple beneath the boom was observed. This occurred at 0.75 to 1.0 m/s.

The point at which the boom is connected to the skimmer box requires some modification. The boom is connected to the skimmer by means of an I-channel, bolted to the boom, which is then inserted into a vertical slotted pipe welded to the side of the skimmer. This I-channel should be replaced with a T-channel. As built, the slightest load causes the connector to bind in the pipe, and the profile of the boom at the connector is incorrect and may induce boom failure at lower than design current speeds.

**Recovery Operations**

As it was not permitted to use a petroleum product in the St. Lawrence river, this test was conducted using the apples and various debris simulators. This was meant to complement the data collected during the tank testing of the skimmer in oil. Recovery operations were assessed by visually observing water levels and turbulence inside the skimmer as a function of forward speed and by examining the sensitivity of the brushes towards various types of debris presented to the skimmer (see Figure 13).

Debris, including polypropylene rope, lumber, plastic cans, sorbent pads and foam sponges, was dropped in front of the collector and observations made regarding the skimmer's ability to deal with such items. Most of the debris was collected by the booms and directed towards the skimmer inlet. Once inside the box, the water turbulence caused the debris to be pushed towards the brushes which then lifted the debris out of the water and up towards the top of the skimmer brushes. The smaller pieces of debris were recovered without any major problems. At times some of the smaller debris would become temporarily wedged between the brushes and the sides of the box. The larger pieces of wood (60 cm long) either wedged across the skimmer box preventing oil flow to the skimmer or, jammed roughly one foot up the brush pack, forming a bridge across the brushes, blocking subsequent recovery and causing other pieces of debris to remain stuck between the sides of the box and the brushes. These larger pieces were eventually pushed aside allowing the remaining debris to be recovered. At the higher brush speeds, some of the debris was flung over the top edge and back into the water. In the presence of oil, the debris will likely behave somewhat differently. Recovery of the debris is expected to be facilitated by the presence of oil, as the stickiness of the oil would cause the debris to adhere to the brushes. As well, the problem of the lighter pieces of debris being flung over the end of the skimmer may not be as pronounced once it is weighed down with oil. For
the most part, the skimmer was able to effectively deal with the debris it encountered; as well, the easy access to the skimmer facilitates clearing of debris.
FIGURE 13: Collection and retrieval of debris simulators
a) turbulence inside boom pocket
b) recovery of debris
CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Recovery rates for this skimmer system increase with increasing viscosity. Current velocities of at least 0.5 m/s (1.0 knot) are required for effective skimming, and wave action can increase recovery.

2. The maximum recovery rate of oil on water achieved within the limitations of the test tank program was 1.9 m³/hr at a current velocity of 0.5 m/s, a brush speed of 30 cm/s and in waves of 5 to 7 cm. The initial viscosity of the oil (Bunker "A") was 590,000 cP. When immersed in 900,000 cP Bunker a maximum recovery rate of 4.44 m³/hr was achieved at a brush speed of 30 cm/s.

3. The light oil brushes performed best on oils in the under 100,000 cP viscosity range, while the heavy oil brushes were more effective with oils in the over 100,000 cP range. Neither brush type was effective on oils with viscosities of less than 1000 cP.

4. During the sea trials, the LORI Side Collector showed good stability, manoeuvrability and seakeeping. The operation of the sea truck was not adversely affected by the skimming system. The maximum transit speed achieved was over 5 m/s. The fastest skimming speed achieved was 2.0 m/s.

5. The Side Collector was effective in containing and directing debris and the apples used for flow visualization, towards the skimmer inlet. The bow diversion booms, however, were not very effective at skimming velocities of over 0.75 m/s due to insufficient bottom tension in the boom. Recovery of most types of debris (except for 60 cm pieces of wood) was successful.

6. The LORI Side Collector system is suitable for upgrading the Canadian Coast Guard's heavy oil recovery capability.

RECOMMENDATIONS

1. The connections for the bow booms are not sturdy enough for this type of boat and should be reinforced. The connections for the jib arms should also be reinforced as flexing of the gunwales was observed.

2. All connections (bow booms, jib arms, and skimmers joints) should be protected or, ideally, moved to the interior of the boat as they are very susceptible to damage in their present configuration during day-to-day boat operations.

3. Plastic covered cable should not be used for the davit pulleys as the plastic can interfere with the mechanism. Uncovered cable would be more suitable.

4. The tow ropes attached from the jib arms to the bow should be replaced with a wire rope or cable for more secure and positive positioning of the jib arm.

5. Markers such as flags should be installed at on the floats of each jib arm in order to enable the boat driver to locate them while steering.

6. An electric start for the diesel engine on the power pack is highly recommended. Replacing this model with a quieter one, producing noise levels below that which require hearing protection, is also strongly recommended.

7. A bracing bar across the bow of the work boat is required for operation of the skimmer with the ramp bow down.

8. Four davits should be supplied with the skimmer. The front two (all four if
possible) need to be approximately one foot higher so that the side jibs and booms can be safely removed from the water with two people from inside the boat. One front davit will also be required to hold up the bow booms while in transit.

9. The hydraulic motor should be fitted with one female and one male quick connect to avoid accidentally connecting the hoses backwards.

10. The bow boom needs to be redesigned to overcome planing failure.

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