Heavy Oil Booming

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Abstract

Heavy oil is usually viscous with a high specific gravity (near 1.000 g/cm^3) and can either sink, float, or remain neutrally buoyant and stay suspended in the water column when spilled. A number of factors can affect this behaviour and impact recovery efforts including water temperature, weathering, and emulsification over time. The containment of heavy oil presents a number of problems to spill responders because the oil may float near the surface without sufficient buoyancy to be properly contained by conventional booms. Specialized equipment is needed to help contain heavy oil. One option is the use of draft extensions made of netting material that would allow water to pass, but restrict the flow of heavy oil so that it can be collected using conventional or adapted equipment.

A number of experimental runs have been performed to compare the effectiveness of a boom modification. Specifically, the impact of different netting skirts on the containment abilities of the booming system under specific flow conditions has been assessed. This paper provides initial testing results to evaluate their containment abilities and their impact on restricting the flow of oil.

1 Introduction

Research over the past decade has led to the development of equipment designed to operate under fast flowing conditions (greater than 1 knot) (USCG, 2002). Secondary containment by sorbent booms and sweeps has been proposed as a means of collecting oil that has escaped primary containment (USCG, 2001). Testing of this response equipment has shown limited performance in their containment abilities unless they are configured properly (Cooper et al., 2005, Cooper and Velicogna, 2004, Schrader, et al., 1994, SAIC, 2003). Unfortunately spills of heavy oil in fast and slow moving water raises some unique technical challenges including logistical and operational problems not normally seen when dealing with spills of lighter oil. Density differences between the oil and water may allow for an increase in water washover, hampering detection and ultimately containment and recovery. Some recent spills have demonstrated that problems still exist with the containment of these spills because they do not behave in a traditional manner (Goodman, 2006). If the density difference is too small, oil may be affected by currents and drawn into the water column more easily which poses extreme challenges for recovery operations.

2 Background

SAIC Canada, under contract from Environment Canada's Emergencies Engineering Technologies Office (EETO), develops and performs studies to evaluate new and existing oil spill recovery and containment equipment in order to assist in the advancement of these technologies. A number of projects over the past few years has focussed on the recovery and pumping of heavy oils. The work has led to the development of modifications to equipment that has dramatically improved the collection and pumping capabilities of commonly stocked response skimmers in Canada. During these tests, problems were identified with heavy oils that had densities close to that of water. Portions of the oil would become entrained in the water column during flume tank testing and would be unrecoverable using traditional containment equipment on hand. Additional testing using sorbent booms to contain heavy oil also resulted in containment difficulties. It was proposed that alternate methods of containment, such as netting extensions on booms, be attempted to control or influence oil moving in the water column.

3 Testing Facility

Testing took place in a flume tank, located in a high-bay testing area managed by SAIC's Environmental Technology Program for Environment Canada. The flume tank is 9.14 m long, 3.05 m wide, and at the false floor has a working depth of 0.80 m. Twin variable speed drive units control propellers mounted beneath the false floor which is used to move water in a vertical racetrack orientation, generating currents within the flume tank. The tank was used in this series of tests with fresh water at an ambient temperature of 18 °C. This facility is located at Environment Canada's Environmental Technology and Science Centre in Ottawa.

4 Equipment Descriptions

4.1 Containment Boom

This series of testing included the use of 3 metre (10') sections of oil boom complete with 15 cm (6") diameter round polyethylene floatation members enclosed in the top pocket. The boom sections had detachable chain pockets held in place with Velcro as well as grommets with nuts and bolts every 30 cm (12") along the length of boom (see Figure 1). Mesh panels used in this initial set of tests were manufactured from nylon 3 metres (10') long by approximately 40 cm (16") high, with banding around all four sides, as shown in Figure 2. Velcro and grommets were installed along both 3 metre lengths to correspond to the boom described above. The mesh sizes used in this series of tests were 0.6 cm (1/4") square, 1.3 cm (1/2") square, 1.9 cm (3/4") square and 2.5 cm (1") square (see Figure 3 to Figure 6).

Figure 1 - Containment Boom

Figure 2 - Mesh Installed

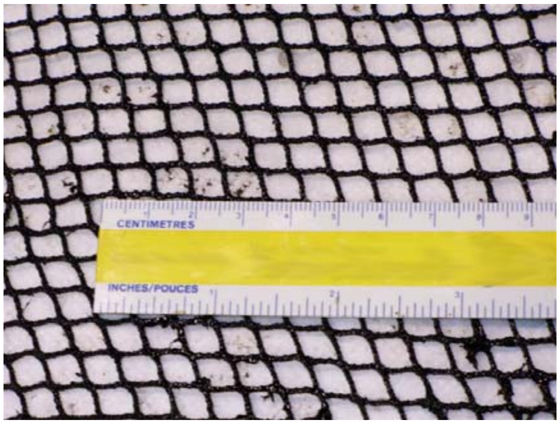

Figure 3 - 0.6 cm Mesh

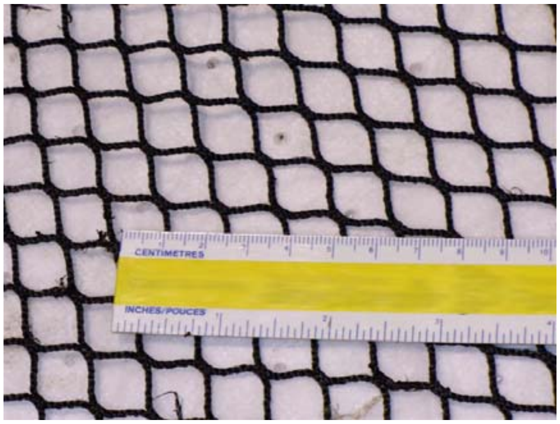

Figure 4 - 1.3 cm Mesh

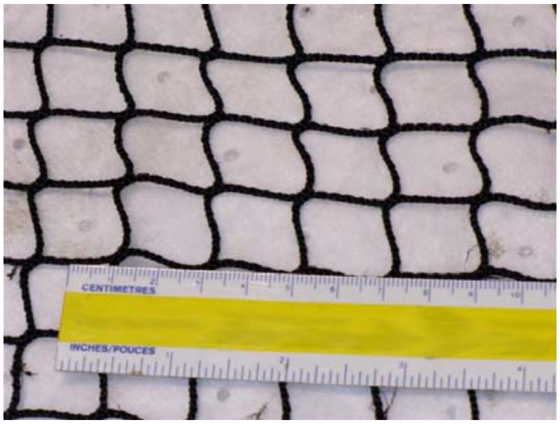

Figure 5 - 1.9 cm Mesh

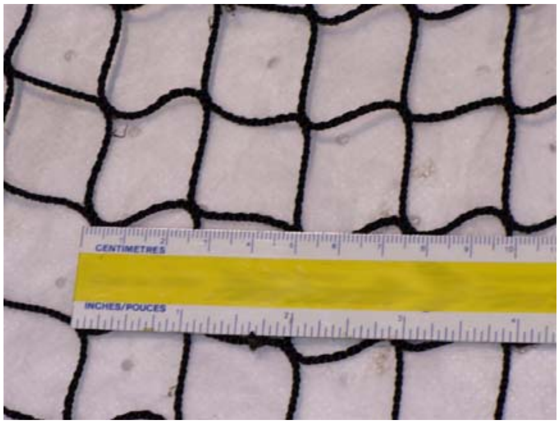

Figure 6 - 2.5 cm Mesh

4.2 Test Layout

The boom sections were placed across the width of the test tank approximately half way along the length of the tank. A moveable bridge was used as a measurement platform to anchor a portable flow meter for the determination of flow rates just in advance of the boom sections. The oil introduction point was located at one end in advance of the boom section so that the current would carry the oil into the boom, as indicated below in Figure 7.

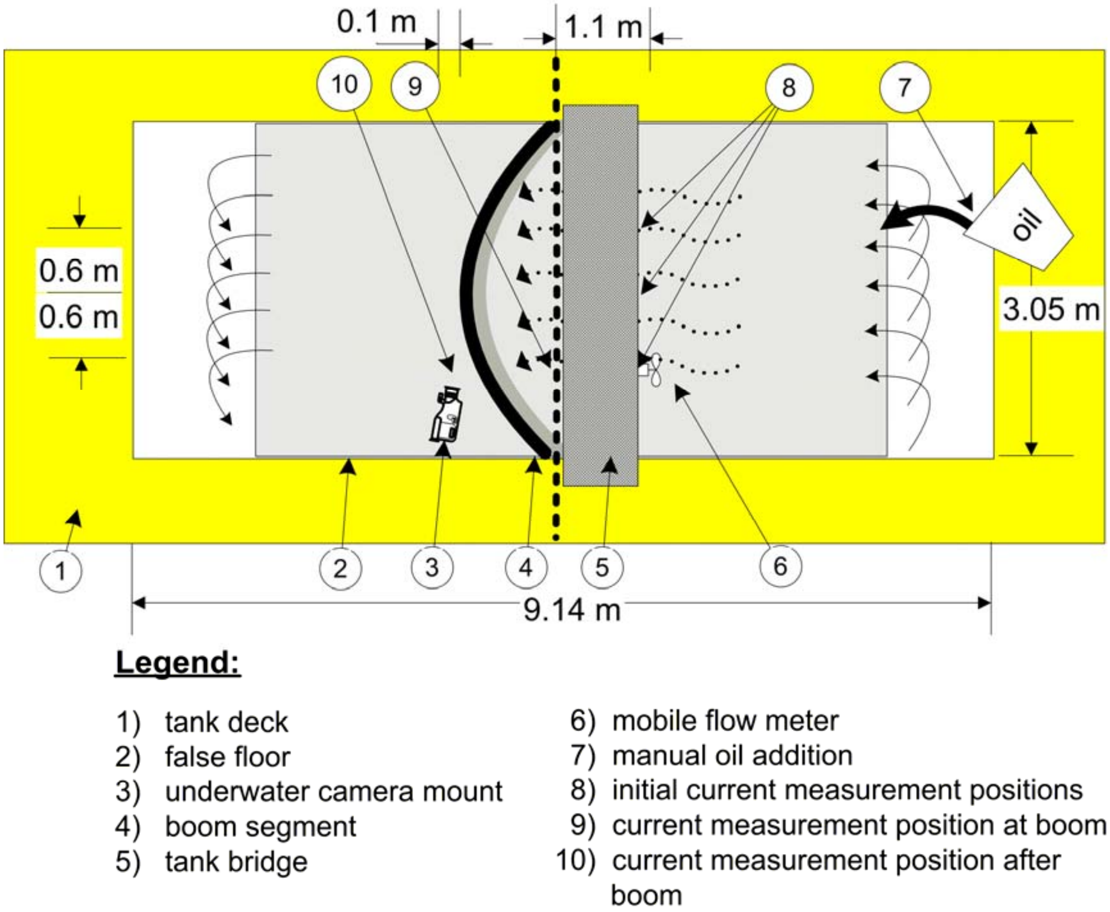

Figure 7 - Testing Layout

4.3 Test Oil

The oil used in this series of tests was a recovered bitumen product blended with bunker C resulting in a working viscosity of 105,000 cP (measured at 0.66 s^{-1}, 18 °C) and a bulk density of 0.999 g/cm^3 at 18°C. The density of the fresh water in the flume tank used during this set of tests closely matched the density of the oil. Lab scale pre-tests were conducted on the oil which was poured into beakers filled with water. Approximately 60% of the oil had a tendency to slowly float to the surface while the remainder either stayed in the water column or sank and pooled on the bottom over a period of 2 hours based upon visual observations. Ten litres, applied from a twenty litre bucket, was selected as the oil sample quantity for the test runs to provide a sufficient quantity to impact the booms while minimizing clean-up requirements between runs.

5 Test Protocol

The main goal of the testing was the determination of containment performance of different sized mesh skirts and to gauge their ability to control the flow of blobs of heavy oil. To that end, an experimental plan was developed and included the following tasks:

- Pre-test all mesh sizes in a range of currents (from 0.26 m/s or 0.5 knots to 0.77 m/s or 1.5 knots) to eliminate speeds that cause failures of the boom anchoring mechanism or failure of any boom component.
- Use the best practical speed based upon the results of the pre-test runs for subsequent runs with all mesh sizes. Record the behaviour of the mesh at the optimal flow rate.
- Add a ten litre oil sample over a period of 10 seconds to the tank at the beginning of each test run and record the behaviour at the surface and subsurface to determine retention times and failure modes of the mesh skirted booms.

5.1 General Test Procedures

The following procedures were used for the testing runs in this project:

- Install mesh size in boom to be used for test run.
- Ensure boom is securely attached to the anchoring apparatus using the 3 point contacts and mount the anchoring apparatus to the wall of the flume tank, leaving a 15 cm gap along each wall.
- Turn ventilation system to high in curtained area.
- Measure test quantity of oil.
- Start flow within test tank to required speed.
- Wait until a minimum of 10 minutes passed to ensure full flow has developed and steady state conditions are reached.
- Use a calibrated flow meter to determine the current in advance of and immediately after the installed boom for each mesh size when the tank is operated at a speed defined in the pre-test runs.
- Engage video recorders and ready camera.
- Signal start of oil sample addition.
- Monitor flow on the surface and within the water column to determine the behaviour of oil impacting the containment.
- Document the visual behaviour for each run.
- End recording.
- Clean tank surface and remove accessible sunken oil in preparation of subsequent runs.

Take pictures throughout the experiments to visually document the behaviour at the surface.

6 Testing Results and Discussion

6.1 Initial Testing

Initial test runs were performed to determine the best practical current that the set-up would hold, and that one might expect to attempt in recovery operations. The introduction of a mesh skirt provided less resistance to water flow and should be more stable in higher currents than a solid skirted boom. Initial test runs for each of the mesh sizes was performed with speeds starting at 0.26 m/s (0.5 knots), then climbing up to 0.77 m/s (1.5 knots). This testing allowed the behaviour of the mesh skirted booms to be monitored and determined if the system was capable of maintaining a containment configuration at the selected speeds. The boom with mesh skirt was able to maintain its shape for most of these runs but problems were encountered at the fastest speeds. Tests with the larger mesh sizes were successful, however, when the smallest size was used the boom anchoring system failed repeatedly after approximately 3 minutes into a series of test runs. It was felt that the relatively large surface area combined with the restricted flow through the mesh was simply causing too much force on the face of the boom at the higher speeds causing our anchoring system to fail at the bottom connection point. Based upon the results of the otherwise good results of the initial test runs and the maximum current that typical containment booms begin to lose containment (0.36 m/s or 0.7 knots) the initial speed of 0.51 m/s (approximately 1 knot) was selected as the target current for the next suite of tests.

6.2 Testing with 0.6 cm Mesh

Initial current measurements in advance of the boom showed a flow rate of 0.51 m/s (0.99 knots) in the middle of the channel, approximately 20 cm below the surface. Additional measurements were made 60 cm to the left and right of the centre (when facing in the direction of the current – towards the boom) at 20 cm below the surface and resulted in measurements of 0.48 m/s (0.93 knots) and 0.49 m/s (0.95 knots) (#8 in Test Layout, Figure 7). These measurements of the tank current remained consistent throughout the remainder of the test runs. Current measurements made at the boom (#9 in Test Layout, Figure 7) in line with the anchoring points perpendicular to the flow showed a flow rate of 0.42 m/s (0.82 knots), while measurements made directly behind the boom approximately 10 cm behind the apex (#10 in Test Layout, Figure 7) had a measurement of 0.40 m/s (0.78 knots).

The oil portion of the test run began with ten litres of the test oil being introduced in advance of the boom over a period of 10 seconds. The evaluation began as the bulk oil impacted the mesh boom (designated oil containment time t=0).

Oil impacted the mesh boom and was initially retained for a few seconds. Observations made at 1 second showed that the oil remained contained by the mesh. At 5 seconds the oil remained contained within the mesh, but at 10 seconds the oil had begun to migrate through the mesh (see Figure 8 through Figure 11) with wisps of oil shedding into the current. The quantity of oil loss started slowly but seemed to peak with gross losses occurring between the 19 second and the 25 second mark. By the 31 second mark most of the oil seemed to have passed through the mesh but was clinging to the back of the skirt. Oil losses diminished through the 40 second mark when most of the oil had been lost from the boom.

Figure 8 – 0.6 cm mesh Oil Impact

Figure 9 - 0.6 cm mesh 1 second

Figure 10 - 0.6 cm mesh 5 seconds

Figure 11 - 0.6 cm mesh 10 seconds

6.3 Testing with 1.3 cm Mesh

The initial current measurements in advance of the boom read approximately 1 knot as described in the previous run. The current measurement made at the boom for the 1.3 cm mesh was 0.43 m/s (0.84 knots), and a reading of 0.41 m/s (0.80 knots) was made directly behind the boom.

The oil test of this run began with ten litres of test oil being introduced in a manner similar to the previous run. Residual oil blobs that had sunken to the bottom of the flume tank in an inaccessible area remobilized during this run which complicated the data analysis but the video was clear enough to make determinations on the effectiveness of the boom in containing the fresh oil being added to the tank. When the bulk of the oil impacted the net the designated oil containment time was set as t=0.

Oil was initially contained by the mesh, but oil migration could be seen starting through the net as quickly as 3 seconds. Oil continued to migrate through the net and losses increased from the 5 second mark through the 9 second mark Gross losses are well underway by the 10 second mark (see Figure 12 through Figure 15) with most of the oil migrating through the mesh at 15 seconds after initial impact. Some oil is seen holding onto the downstream side of the mesh while wisps of oil continue to be shed in the current. Most of the oil is shed by the 21 second mark after initial impact.

Figure 12 - 1.3 cm mesh Oil Impact

Figure 13 - 1.3 cm mesh 1 second

Figure 14 - 1.3 cm mesh 5 seconds

Figure 15 - 1.3 cm mesh 10 seconds

6.4 Testing with 1.9 cm Mesh

The initial current measurements in advance of the boom read approximately 1 knot as described in the 0.6 cm Mesh run. The current measurement made at the boom for the 1.9 cm mesh was 0.46 m/s (0.89 knots), and a reading of 0.45 m/s (0.87 knots) was made directly behind the boom.

The oil test of this run began with ten litres of test oil being introduced into the current upstream from the boom in a manner similar to the previous two runs. As was performed in previous runs, oil containment time was set as t=0 upon the impact of the bulk oil on the mesh.

Shortly after impacting the mesh the oil starts to migrate through with some wisps of oil being shed as quickly as the 4 – 5 second mark. Losses increased at 5 seconds with gross losses starting at the 7 second mark. At 10 seconds major losses of oil continued (see Figure 16 through Figure 19) until the 12 - 13 seconds when most of the oil had migrated through the mesh. A moderate quantity remained attached to the fabric but most was shed by the 19 second mark.

Figure 16 - 1.9 cm mesh oil impact

Figure 17 - 1.9 cm mesh 1 second

Figure 18 - 1.9 cm mesh 5 seconds

Figure 19 - 1.9 cm mesh 10 seconds

6.5 Testing with 2.5 cm Mesh

The initial current measurements in advance of the boom for this final run read approximately 1 knot as described in the 0.6 cm Mesh run. The current measurement made at the boom for the 2.5 cm mesh was 0.48 m/s (0.93 knots), and a reading of 0.47 m/s (0.91 knots) was made directly behind the boom.

The final test run in this series was performed in a fashion similar to the previous three runs. Ten litres of oil was introduced in advance of the boom over a period of 10 seconds. The timing of the run was set to zero when the bulk of the oil impacted the containment boom.

Oil was seen to start migrating through the mesh shortly after contact. Within 3 seconds some wisps of oil could be detected from the impacts of smaller streams of oil. At 5 seconds shedding was pronounced. Most of the oil migrating through the mesh as gross losses by the 7 second mark. At 10 seconds the bulk of the oil was lost as shedding continued off of the mesh (see Figure 20 through Figure 23). Most of the oil was completely shed from the mesh within 12 seconds of contact.

Figure 20 - 2.5 cm mesh Oil Impact

Figure 21 - 2.5 cm mesh 1 second

Figure 22 - 2.5 cm mesh 5 seconds

Figure 23 - 2.5 cm mesh 10 seconds

6.6 Configuration Validation Testing with 0.6 cm Mesh

In a typical test run, the oil contacts perhaps 30% of the face of the mesh skirt. Although the boom was never secured to the floor, it did hang low during the previous four test runs. This validation test enabled a comparison to be made between the mesh skirted boom in the original configuration (covering most of the water column) and a modified installation that ensured a path for water to flow around the perimeter of the boom no matter how plugged with oil it became. The 0.6 cm mesh skirted boom was selected for this comparison test because it would suffer the greatest impact from constrictions in flow.

The boom was raised in this validation run so that the bottom of the skirt was no less than 15 cm from the tank floor. Gaps between the boom and flume tank wall along the sides at the anchoring points were maintained at 15 cm as in all previous runs.

The initial current measurements in advance of the boom for this validation run showed a flow rate of 0.51 m/s (0.99 knots) in the middle of the channel, with readings of 0.48 m/s (0.93 knots) being measured at points 60 cm to the left and right of centre (when facing in the direction of the current).

The current measurement made at the boom for the validation run was 0.44 m/s (0.86 knots), and a reading of 0.39 m/s (0.76 knots) was made directly behind the boom. All current measurements were taken at a standard depth of 20 cm.

Oil impacted the mesh boom and is initially retained. Part of the floating oil sample that is low in the water column passed through the unprotected region below the boom. The mesh initially retains the oil through the 10 second mark but shedding is seen to occur at the 25 second mark (see Figure 24 through Figure 27). Gross losses occur shortly thereafter with a bulk of the oil migrating through the mesh at the 40 second mark. Shedding off the back of the boom continues and most has been shed by the 60 second mark.

In this comparison, gross oil loss occurred at 31 seconds in the original configuration (original 0.6 cm mesh skirted boom run) and at 40 seconds for the validation run which is reasonably close given the differences in flow patterns within the flume tank. Shedding losses did occur at a longer interval during the validation test but this can be explained, at least partly, by the bottom of the boom causing a slight disruption in flow in the water column.

Figure 24 – Validation 0.6 cm mesh Oil Impact

Figure 25 – Validation 0.6 cm mesh 1 second

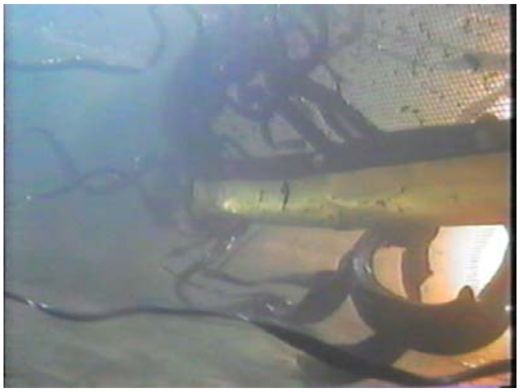

Figure 26 – Validation 0.6 cm mesh 5 seconds

Figure 27 – Validation 0.6 cm mesh 10 seconds

7 Conclusions and Recommendations

The larger mesh sized booms did temporarily impact the flow of oil but the oil then migrated through the mesh relatively quickly. The smaller two mesh sizes had a greater impact on slowing down the flow of oil, as one might expect. Problems encountered with anchoring the smallest mesh size indicate an increase in forces acting on the boom and may cause anchoring concerns if used to respond to actual spills in fast currents or if the boom is being towed.

None of the mesh skirted booms appreciably contained the oil. Their ability to slow the progress of the oil and affect the bulk oil in the water column does, however, demonstrate that this technique may have potential at controlling heavy oil under slower currents.

The results of this study have led to the development of the following recommendations:

1) Perform additional tests to determine possible containment or the residence time before initial and gross losses occurring using slower currents.
2) Perform additional tests using the two smaller mesh sizes along with a substrate for the oil to adhere to after impacting the mesh. This may consist of streamers or sheets of material leading off of the netting. A configuration of netting combined with adsorbent material would allow the netting to either be anchored and held stationary in the water column as oil flowed by, or in an advancing mode with the modified netting being dragged through the water column to collect the oil.
3) Compare any testing results using the above techniques with "typical" heavy oil sorbents such as pom-poms.
4) Oil viscosity will have a direct impact on the speed at which the oil will migrate through the mesh. Determine the time for first loss and gross loss for alternate oil viscosities.
5) Perform tests using a boom configuration that will allow a portion of the water to by-pass netting that becomes saturated with oil to lessen the forces driving the oil through the mesh. This can be accomplished in a number of ways including the installation of narrow panels of wider mesh.

8 References

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