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SNARE PERFORMANCE FOR SUNKEN AND SUBMERGED OIL DETECTION AND MONITORING

BY

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ABSTRACT - 687127

Most oil spill response strategies, tactics, and equipment are designed to address floating oil. Previous research and historic events have shown that spilled oil can suspend (i.e., submerged oil) or sink (i.e., sunken oil) as a function of the oil's density relative to that of the receiving waters. Processes such as wave action or current velocity, sediment entrainment, and oil weathering (e.g., evaporation) may change the buoyancy of floating oils causing them to submerge or sink. Non-floating oil is more difficult and expensive to detect and poses significant challenges for containment and cleanup. Many existing detection techniques for non-floating oils rely on oleophilic sorbents, such as snare, which are weighted depending upon the oil's location in the water column and then towed behind a vessel in designated transects. Currently, there is no quantitative method to relate the amount of oil collected by snare to the amount of oil encountered during towing. In addition, the dynamics and interactions of towed snare and oil remain largely unknown. To address these knowledge gaps, various components of snare performance have been evaluated since 2016 by the Coastal Response Research Center (CRRC) at the University of New Hampshire (UNH).

The research has evaluated: (1) the impacts of temperature, salinity, oil type, and tow velocity on adsorption and desorption of oil to snare, (2) snare dynamics and position in the water column as a function of tow velocity, (3) the impacts of material type and potential alternatives to snare (e.g., mosquito and fishing nets, plastic debris) for lesser developed countries (LDCs), and (4) the interaction of snare with sunken and submerged oil. The results determined: (1) adsorption of oil to snare was best for less viscous oils (No. 6 Fuel Oil) and lower water temperatures (5°C) and desorption was greatest at low temperatures (6°C) and low current velocities (< 1 knot), while salinity had no significant effect. (2) Tow depth for snare arrays decreased with increased velocity unless a vane was used. (3) Optimal spacing of snare on a chain is a function of tow and current velocity, and drag forces on the tow chain. (4) Snare alternatives with greatest potential for sunken oil detection in LDCs were nylon mosquito netting and plastic bags. The findings from this research improves understanding of the behavior of snare and how it interacts with sunken and submerged oil and can improve towing techniques used by oil spill responders, leading to more effective detection.

INTRODUCTION

When oil is spilled in the marine environment it either floats, sinks to the bottom of a water body, or becomes suspended in the water column. Oil may sink below the surface depending on oil characteristics (e.g., density, weathering), and environmental conditions (e.g., suspended sediment concentrations, density of water, current velocity). Any oil that sinks below the surface is known as submerged oil, and oil that sinks to the bed is referred to as sunken oil (CRRC, 2007). Submerged oil is difficult to locate and model due to poor visibility below the surface and the complexity of environmental conditions (e.g., water temperature, current velocity). Traditional oil recovery techniques (e.g., booms, mechanical recovery) designed for floating oils are ineffective for cleaning up non-floating oil. As a result, alternative methods and technologies (e.g., snare) are required to detect and recover non-floating oil.

Snare, an oleophilic, hydrophobic, polypropylene sorbent material, is a response technology that has been successfully used in non-floating oil spills (e.g., Athos I, T/B DBL-152) as a detection and monitoring tool. Compared to other detection and recovery techniques, snare is low cost, easily and rapidly deployable, can be stockpiled in advance of a spill, and is a United States Coast Guard (USCG) approved oil spill response tool (U.S. DOC et al., 2010). A single snare consists of an 8 oz. bundle of individual strands, or fronds, that are looped without loose ends. Snare is a versatile tool that can be used in different configurations depending on the spill conditions. Sentinels require multiple snare bundles attached equidistant along the length of a chain. The chain is tethered at the top to a surface buoy, extends the depth of the water column, and is anchored to the bottom. Snare-baited traps (i.e., snare bundles in crab or lobster pots) detect oil transport along the bottom in high-risk areas (e.g., fishing grounds). The most common configuration of snare is known as an arsenal; snare are tethered to a chain, a single snare equipped chain or multiple chains are then attached to a header bar and towed behind vessels to monitor transport of non-floating oil. Depending on their configuration, snare can be towed in transects in or near a potentially contaminated area at a speed of 2 to 5 knots (API, 2016). At certain points across the transect, the arsenal will be pulled out of the water and visually inspected for the presence/absence of oil as well as level of oiling (e.g., low, medium, high).

Few experiments have been conducted to characterize how well snare is able to capture and retain non-floating oils and what factors impact the movement and depth of snare arsenals in the water column. This research project was commissioned by a National Oceanic and Atmospheric Administration (NOAA) Scientific Support Coordinator and executed by students at the University of New Hampshire in partnership with the Coastal Response Research Center (CRRC); research was conducted in two phases during 2016-2018. The goal of this project was to improve detection and recovery techniques by understanding the factors that influence adsorption and desorption of oil to snare (e.g., temperature, salinity, oil type, tow velocity, number of snare and weight of towed arsenals).

Despite its effectiveness, technologies like snare may be expensive and time consuming to ship worldwide, making them impractical for typical response timeframes. Areas of highest concern are Least Developed Countries (LDCs) where there may be insufficient resources, response plans, and trained responders. A third phase of research was commissioned in 2018 by a marine biologist with NOAA’s Office of Response and Restoration (OR&R), who worked on oil spill response in LDCs and identified a need to improve low-tech, readily available response equipment in areas with limited spill response capabilities. The objective of the third research phase was to determine what materials might be locally available, inexpensive, and adequate at detecting and recovering non-floating oil (e.g., plastic shopping bags, fishing nets).

This paper includes a summary of all three projects (hereafter referred to as Phase 1, Phase 2 and Phase 3), discusses research methodology, synthesizes research results, applies findings to optimize snare operation, and compares potential sorbent alternatives to conventional snare.

RESEARCH OBJECTIVES

The objectives of this research were to: (1) evaluate the impacts of temperature, salinity, oil type, and tow velocity on adsorption and desorption of oil to snare, (2) observe and record snare dynamics and position in the water column as a function of tow velocity, (3) test impacts of material type and potential alternatives to snare for lesser developed countries, and (4) observe and record the interaction of snare with sunken oil. The summation of this research will inform responders deploying snare for oil detection and recovery during spills.

METHODS AND MATERIALS

Phase 1

Phase 1 included three experiments: 1) adsorption, 2) desorption, and 3) snare movement. The adsorption experiment was performed in a laboratory chemical hood and was completed by filling a large plastic tub with 3 inches of water at the desired salinity (i.e., 0, 35 ppt). A temperature controlled room was set to the desired temperature (i.e., 5, 20, 27 °C) and oil and water were stored until uniform temperature was achieved. The dry and wet mass of 15-inch segments of snare were recorded. Individual snare fronds were submerged in a small cup of water and 40 mL of fresh No. 6 Fuel Oil (specific gravity (SG) from 0.95 to > 1.03 as specified by the NOAA Scientific Support Team: Hazardous Materials Response and Assessment Division, viscosity $1.3*10^4$ cSt at 15 °C) or Alberta Bitumen (SG approximately 1, viscosity

10^5 cSt at 15 °C as specified by Gloekler et al., 2017) was gently added such that it remained on the surface of the water. The fronds were pulled out one at a time through the oil and allowed 3 minutes of drip time before the oiled mass of each frond was recorded. The test was repeated for each variable until the desired sample size was met.

The desorption experiment was completed in the UNH CRRC Annular Flume (Gloekler et al., 2017). The flume was filled with approximately 20 inches of freshwater at the desired temperature (i.e., 5, 38 °C). The adsorption experiment was repeated to saturate the fronds with No. 6 fuel oil. The annular flume motor was set to the desired velocity (i.e., 0, 1, 2 knots) and the frond was placed in water column for 15 minutes to simulate dragging behind a vessel. After 15 minutes, the frond was removed from the flume and the mass of the towed frond was measured. The process was repeated for each water temperature and salinity until the desired sample size was met.

The movement experiment was completed in the UNH Ocean Engineering Tow Tank (Durham, NH). A chain length, tethered to the tow carriage at the top, extended the entire depth of the tank, approximately 20 feet, and had a single snare bundle attached at the end. This configuration was towed at the desired velocity (i.e., 0 to 4 knots increasing in 0.5 knot increments) for the entire length of the tow tank, approximately 60 feet. During each tow, a subsurface viewing window allowed for visual observation of the snare configuration as it passed, and GoPro cameras were used to record and analyze the depth and diameter of the snare bundles using an *in-situ* scale bar. This process was repeated for each velocity (e.g., 0 to 4 knots) at a 0.5 knot step-wise interval. Lastly, two snare bundles were attached to the end of the chain at a measured distance (*Figure 1*). and towed using the same velocity range and interval to correlate tow velocity with depth of snare (e.g., on the bottom vs. in the water column).

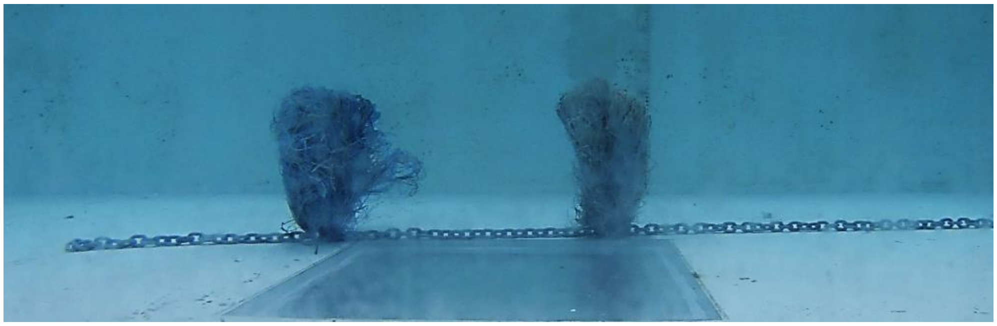

Figure 1: Two snare bundles attached to the end of the chain at 0 knots.

Phase 2

Phase 2 included three experiments: 1) adsorption, 2) desorption, and 3) a movement/chain dragging experiment. It was performed to supplement the data collected in Phase 1 and expand upon findings and applicability. Phase 2 tested the same temperatures as Phase 1 (i.e., 5, 20, 27 °C) and one additional salinity (i.e., 0, 15, 35 ppt). The procedure for the adsorption experiment was very similar to the one used in the Phase 1 experiment, with the only difference being that 16-inch snare segments were used instead of 15-inch ones.

The desorption experiment was completed in the UNH CRRC Annular Flume (Gloekler et al., 2017). The procedure for the desorption experiment was the same as Phase 1 but used Dilbit oil (SG < 0.94 as specified by NOAA (NOAA, 2019), viscosity 10^2 cSt at 15 °C (Witt O'Briens, 2013, POLARIS Applied Sciences, Inc., 2013) as specified to meet requisite pipeline tariff specifications (Transportation Research Board, 2013)). Phase 2 used the same temperatures (i.e., 5, 20, and 27 °C) and tow duration (15 minutes) but tested lower velocities (i.e., between 0 and 1 knot) due to limitations of the flume motors.

The chain dragging experiment was conducted in the UNH Chase Ocean Engineering Tow Tank, six configurations were analyzed: (1) one chain only, (2) one chain and one snare bundle, (3) one chain and multiple snare, (4) one chain and multiple snare with 10 lb weight, (5) two chains and multiple snare, (6) four braided chains and multiple snare. The procedure for this experiment was the same as Phase 1 and was repeated over the range of velocities (i.e., 0 to 4 knots in 0.5 knot increments) and for all configurations.

Phase 3

Phase 3 included a preliminary adsorption test and a flume-based adsorption test. These experiments differed greatly from Phases 1 and 2 in order to accommodate the different materials tested. The purpose of this test was not to establish the adsorption and movement behaviors of snare but instead to use snare as a control to test other potential sorbent materials. The preliminary adsorption test followed the American Society for Testing and Materials (ASTM) procedure F726-17: Standard Test Method for Sorbent Performance of Adsorbents for use on Crude Oil and Related Spills. The ASTM procedure calls for randomized triplicate tests for each material and final oil collected to be normalized by dry weight of the material. The materials tested in the preliminary adsorption test were polypropylene fishing net with large mesh size, nylon fishing net with large mesh size, nylon mosquito net with small mesh size, PET plastic soda bottle, polyethylene terephthalate (PET)/low density polyethylene (LDPE) plastic shopping bag, and conventional snare cut into strands. The snare for this experiment was sourced from a different manufacturer (ChemTex, Cumberland, RI) than that used in Phases 1 and 2 (Supply Pro Sorbents, LLC., Sugarland, TX). These materials allowed for comparison between the effects of surface area, material type, and structure.

This experiment took place in a chemical fume hood and a controlled temperature room. For this test, the oil was stored in a controlled temperature room until the desired temperature was reached (i.e., 23 ± 4 °C). Each adsorbent was cut into a square approximately 13x13 cm (the snare strands were cut into 13 cm strands and laid out side by side until a width of approximately 13 cm was reached). The test container was filled with fresh No. 6 oil to the specified depth (i.e., 2.5 cm) and the oil was mixed with the necessary amount of kaolinite clay (28.6% clay by weight) to make it sink in water (SG of 1.09, viscosity 4.5*10^4 cSt at 15 °C). The dry weight of the materials and their surface areas were measured and recorded, and the adsorbent sample was gently laid on the surface of the oil, covered, and stored in the controlled temperature room for 24 hours (± 30 minutes). After 24 hours, the material was removed in a vertical orientation along an edge and allowed to drain for 2 minutes (± 3 seconds). The mass was recorded following the drip time. This procedure was repeated for each material and the materials with the greatest oil collection by dry weight were selected for the next phase of testing per ASTM standards.

The purpose of the flume testing was to replicate potential *in-situ* conditions and determine how much oil could be collected by the materials. The flume tests were completed in the UNH CRRC Straight Flume (Durham, NH) using a motorized pulley system (*Figure 2*). Triplicate tests were used in order to be consistent with the preliminary adsorption test. The plastic bag and mosquito netting were cut into strips and bound together with trailing ends such that each material was constructed into a bundle similar to that of snare but without looped ends. Individual snare fronds were also cut to the same length and left with trailing ends. These bundles were smaller scale than conventional snare in order to fit inside the CRRC straight flume and avoid side-wall effects. The bundles were attached to fishing line and weighted with a small 4 oz fishing weight. Next, 100 grams of the No. 6 fuel oil and kaolinite clay mixture used for the adsorption test was injected into the bottom of the flume on laminated grid paper in fresh water at 19 °C. A dry weight and wet weight of the bundle was recorded, and they were placed at the end of the flume and dragged through the oil at the specified velocity (i.e., 1 or 2 knots). After each test, the bundle was allowed to drip for 30 seconds before it was weighed. The difference between the oiled wet weight and original wet weight was calculated to determine amount of oil collected. In order to be consistent with the preliminary tests, the results were normalized by dry weight. In the case of the flume test, normalizing by dry weight makes the most sense as this minimizes towing load for vessels while maximizing the sunken oil collected.

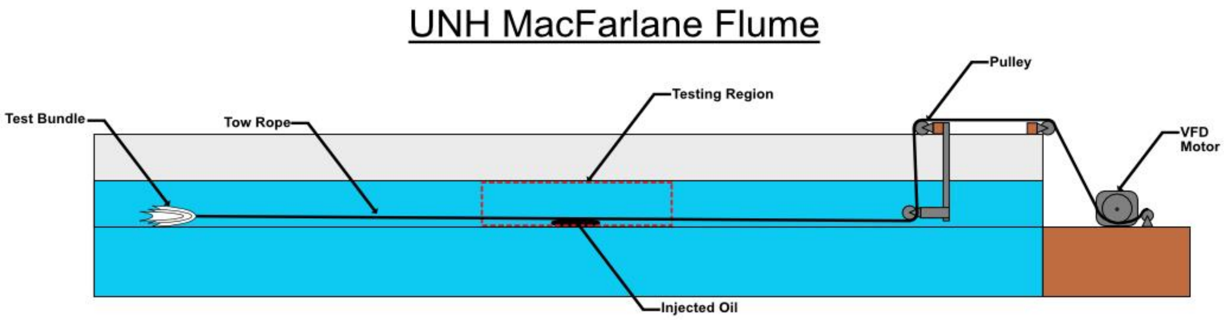

Figure 2: Diagram of pulley system in the CRRC straight flume.

RESULTS AND DISCUSSION

Phase 1

The adsorption experiment collected ten samples at two water salinities (0, 35 ppt), three temperatures (5, 20, 27 °C), and two oil types (No. 6 Fuel Oil or Alberta Bitumen). The experiment was run in a full factorial design, producing a 2x2x3 full factorial array. The data collection focused on amount of oil adsorbed to a frond which was determined by subtracting the wet weight of each frond from the mass of the oiled frond. Using JMP Pro software, a statistical model was designed using a full factorial experiment to study the effects of water temperature, salinity, and their combined effects on the adsorbency of the oil to snare. This method determined that the only significant parameter for No. 6 Fuel Oil adsorption to snare was temperature. More oil adsorbed to the snare in cold water than it did in warm water (*Figure 3*).

The water salinities tested were not a statistically significant parameter influencing oil adsorption to snare. For the Bitumen experiments, the most significant parameter was the interaction between salinity and temperature. This relationship was not linear and requires more testing and data to fully characterize the interaction. The most important outcome of the Bitumen trials was the determination that Bitumen does not have a strong affinity to snare and is more likely to adhere to itself than to the polypropylene snare material.

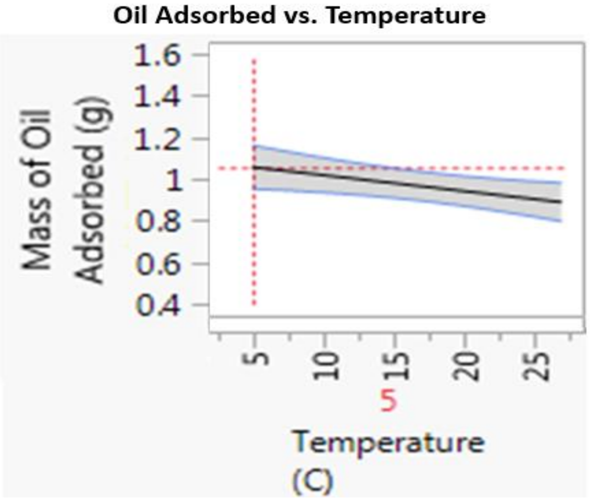

Figure 3: Oil adsorbed vs temperature for Number 6 Fuel Oil to snare.

For the desorption test, a percent loss of oil was calculated for the five experimental trials; trials were conducted at two water temperatures (5, 38 °C), and three water velocities (0, 1, 2 knots) using No. 6 Fuel Oil. The experiment was run in a full factorial design, producing a 2x3 full factorial array. A statistical model was designed using a full factorial experiment to analyze the influence of water temperature and velocity on desorption of No. 6 Fuel Oil. Water temperature and velocity both had a significant effect on desorption while the interaction between water temperature and velocity was not significant. As water velocity increased from 0 to 2 knots, the percent of oil desorbed decreased, and at higher temperature (e.g., 38 °C), the percent of oil desorbed decreased (*Figure 4*). A finding from this experiment was that more oil was lost at high temperatures and low velocities.

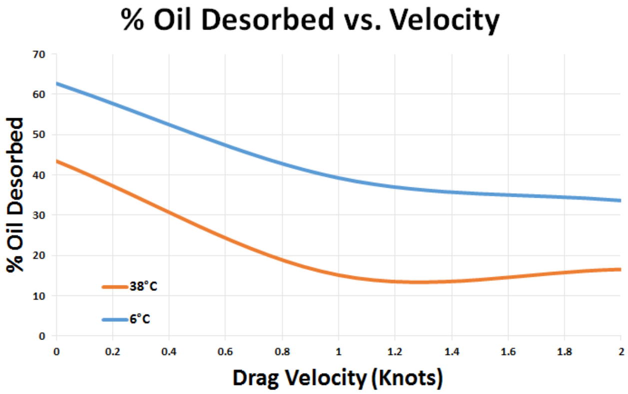

Figure 4: Percent oil desorbed vs velocity for Number 6 Fuel Oil and two water temperatures.

The snare movement experiment determined that the diameter of the snare cone decreases as velocity increases. Starting near 2.5 knots, the snare diameter only decreases approximately 5% more over a velocity increase of nearly 200%. This implies that there is an asymptote near 2.5 knots and the snare will not show significant decrease in diameter as velocity increases within the test range. In addition to measuring diameter, videos were taken to determine at what velocities the snare contacted the bottom of the tank. Between 0 and 1.5 knots, the snare bundles floated upwards and did not encounter the bottom. Between 1.5 and 2.5 knots, the snare bundles dragged along the bottom (*Figure 5*). At velocities greater than 3 knots, the snare and chain lifted off the bottom of the tank.

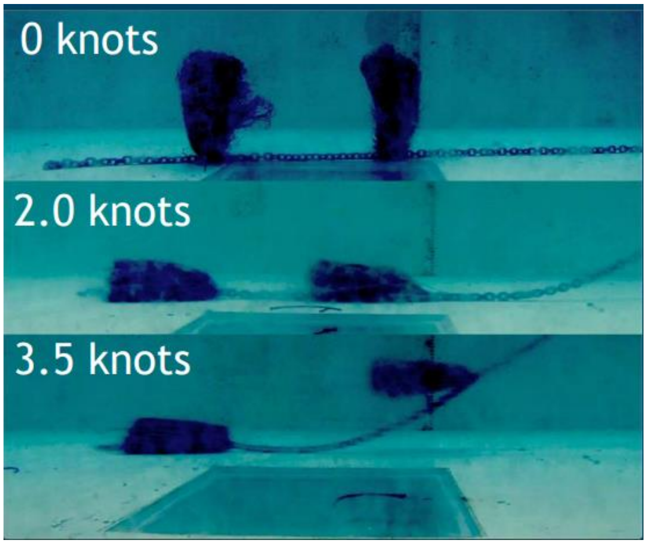

Figure 5: Snare movement with one chain and two snare bundles.

Phase 2

The adsorption experiment for Phase 2 compared the effect of oil type (Dilbit vs. Bitumen vs. No.6), temperature, and salinity with results found in Phase 1. The results showed approximately a 20% decrease in Dilbit adsorption over the temperature range tested (5 to 27 °C) with the adsorption decreasing as temperature increased (*Figure 6*). Salinity was not a significant factor for the adsorption of Dilbit to snare. These findings were consistent with those from the Phase 1 experiment.

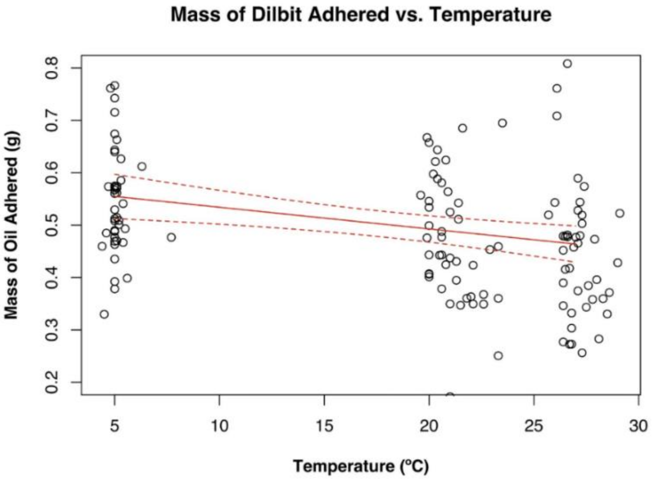

Figure 6: Mass of Dilbit adsorbed vs temperature.

The desorption experiment for Dilbit found no significant relationship between temperature, tow velocity, and desorption. Despite using a procedure very similar to that of Phase 1, the data indicated that the frond weight increased following the desorption experiment; results indicate that oil type influences the snare's performance. The authors speculate that increased frond weight may be due to the chemical properties of Dilbit, and the uptake of water at the oil:water interface. Further testing with Dilbit is required to confirm these results, and the influence of temperature and velocity on Dilbit desorption to snare.

The purpose of the chain dragging experiment was to expand on the findings from Phase 1 which established the relationship between bundle diameter and velocity as well as bottom contact and velocity for one chain with two snare. Phase 2 established a mathematical relationship between increasing velocity and the shape of the arsenal in profile. The towed chain with snare forms a half parabola shape, or a catenary, for which a shape parameter can be calculated. In addition, the variation in towing configurations were used to determine the drivers for shape change in the arsenal. Statistical analysis showed that the drag force on the snare is insignificant to the overall shape change and instead, the drag force on the chain is the main driver. The number of snares added in this test did not significantly impact the depth of the arsenal. The weighted systems were able to resist shape change better than the unweighted single chain but were still too shallow when dragged at velocities greater than 3 knots (*Figure 7*). Overall, it was determined that existing configurations are not as effective as they could be and that alternative configurations may improve snare contact with the bed and the ability to tow snare at a desired location within the water column.

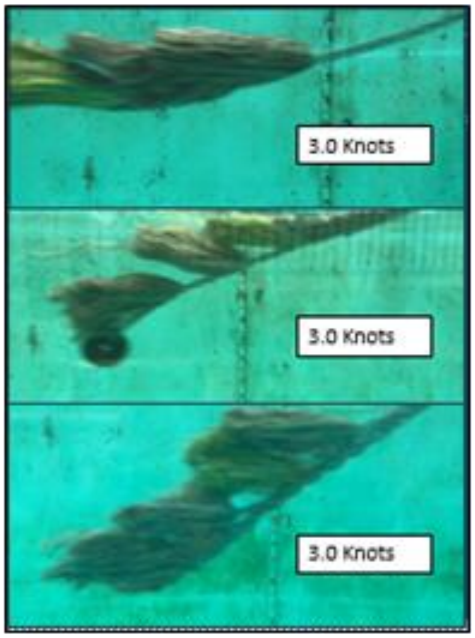

Figure 7: Weighted arsenal configurations at 3 knots.

Phase 3

The preliminary adsorption experiment tested five materials against snare fronds as a control. The purpose of this test was to determine relative ideal adsorbency for these materials when allowed complete contact with sunken No. 6 Fuel Oil. This test also served as a preliminary screening round for materials best suited for flume testing. A statistical model was developed in JMP to study their relative adsorbency. It was determined that the trials with the plastic bottle were too inconsistent and resulted in poor model fit due to unequal variances. In addition, the plastic bottles proved difficult to work with due to their rigidity and curvature. As a result, the plastic bottles were excluded from the JMP model and future experimentation. The new model with plastic bottles excluded had similar variances and clear differences among the means which allowed the materials with significantly different performance to be identified. The data normalized by dry weight showed that the mosquito netting adhered the most oil on a gram/gram basis (*Figure 8*). Plastic bags had similar performance. The other materials, snare, nylon fishing net, and polyester fishing net had significantly worse performance.

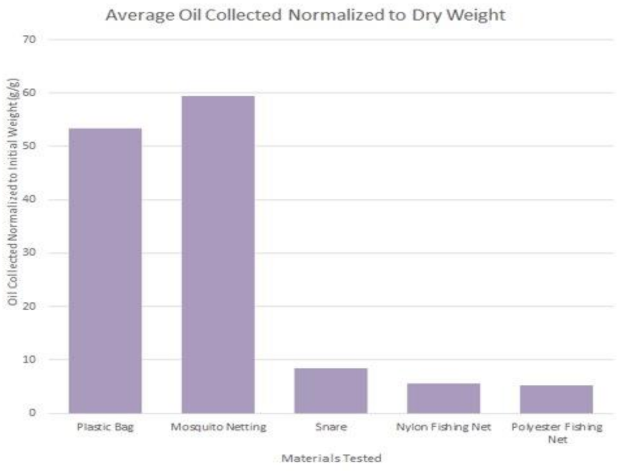

Figure 8: Average oil collected normalized to dry weight for Phase 3 preliminary adsorption tests.

The results from the adsorption experiment determined which materials would undergo further testing in the flume-based experiments. The materials, Plastic Bags and Mosquito Netting, had the highest oil absorbance capacity; these materials and conventional snare (*Figures 9a and 9b*) were used in this experiment.

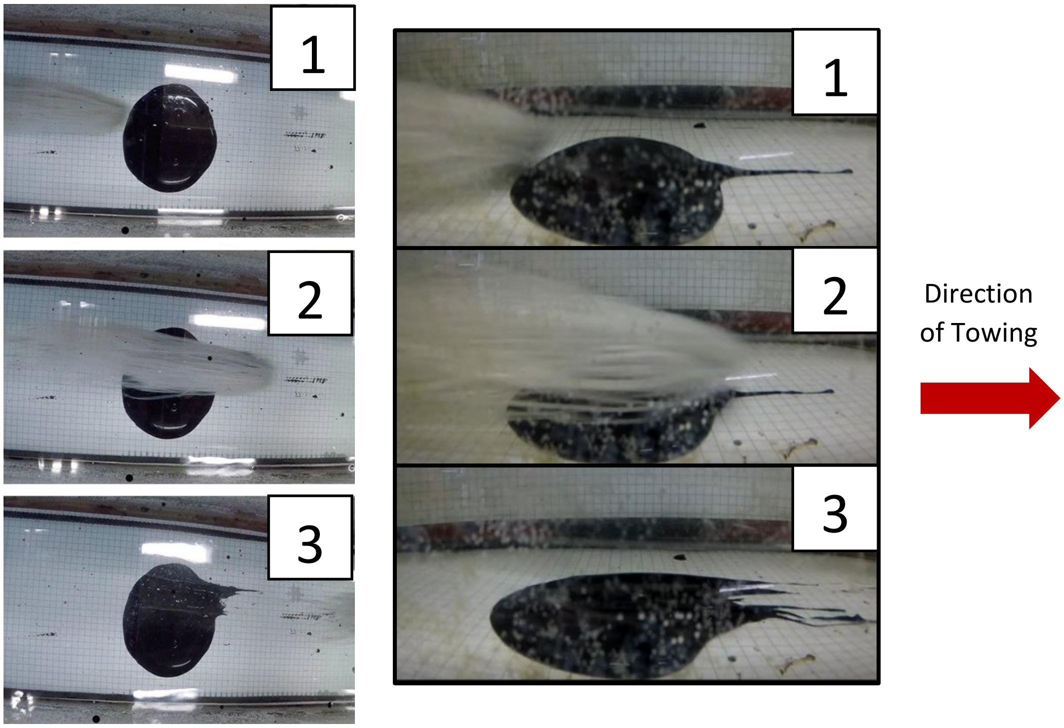

Figure 9a: (Left) Plan view of scaled down bundle of snare fronds dragged through 100 g of oil in the CRRC straight flume. Figure 9b: (Right) Longitudinal view of scaled down bundle of snare fronds dragged through 100 g of oil in the CRRC straight flume.

A similar statistical analysis as the one used for the preliminary adsorption experiment was used to analyze the flume adsorption experiment. The model created in JMP showed a slight lack of fit but was able to identify that the means were significantly different between materials. When normalized by initial dry weight of each material, the mosquito netting collected the most oil followed closely by plastic bags (*Figure 11*). Snare was the least effective material tested on a gram/gram basis by dry weight.

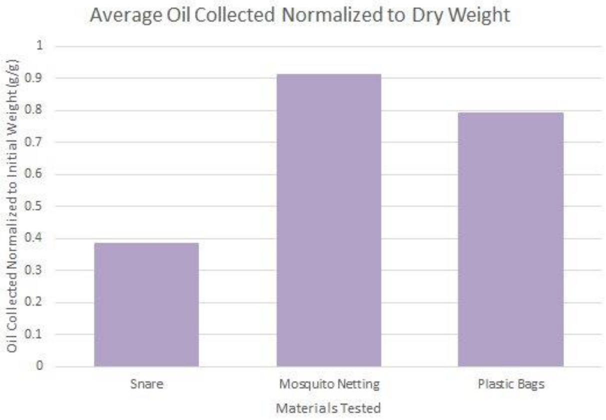

Figure 10: Average oil collected normalized by dry weight for the Phase 3 flume adsorption tests.

CONCLUSIONS

The outcomes of this project are directly relevant to informing response operations. Phases 1 and 2 provide a better understanding of what factors influence adsorption and desorption between snare and oil (e.g., temperature, salinity, velocity, oil type). This information will allow responders to determine if application of sorbents is appropriate for detection and recovery on a site-specific basis. In addition, the findings on snare dynamics and mobility can improve contact between snare and non-floating oils by allowing vessel operators to control the height in the water column by changing the velocity of towing, weight of chains, and number and configuration of towed snare. Finally, Phase 3 of this project presented potential alternative sorbent materials for use in locations where conventional snare is not readily available.

Summary of Findings

- Oil Type: Snare is more effective at adsorbing fresh Number 6 Fuel Oil and Dilbit than Bitumen because Bitumen's physical properties make it more likely to adhere to itself.
- Temperature: As temperature increases, snare captures less oil (i.e., snare has better performance in cold water).
- Salinity: No significant impact on adsorption for oil types tested.
- Velocity: Snare does not encounter a flat bed at velocities under 1.5 knots and chain lifts off the bed at velocities > 3 knots.
- Arsenal Setups: Previous systems need improvements for non-floating oil detection. Drag force on snare bundles does not drive shape change.
- Material Type: Nylon mosquito netting and PET plastic bags are potential alternative sorbents for sunken Number 6 Fuel Oil detection and recovery. Further research should be performed to determine true effectiveness at full scale.

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