Development of a new fast water mop skimmer

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Contributing editors;
DeVitis, Kurt Hansen and Kathleen Nolan, "Development of Fast-Water Oil Spill Containment and Cleanup Equipment, " prepared for U.S. Coast Research and Development Center, Groton, CT, July 2001.

The USCG identified the limitation of current oil spill response devices when applied in fast currents. Considering the vast number of inland waterways in the USA the USCG embarked on a series of research projects to try and address the issue of recovering oil in fast flowing waters.

RO-CLEAN DESMI A/S was awarded an R&D project in late 1999 by the USCG Research and Development Center to develop and test a new lightweight ZRV rope mop skimmer (subsequently named “STREAM STRIPPER”.) The ZRV concept (Zero Relative Velocity) concept is well known and employed by several skimming devices. The useful feature of this system is the ability to work with higher currents and trash-laden oil. However existing craft that use the ZRV are large and expensive.

The new concept skimmer embraces brand new mechanical principals within proven technology. The objective is to develop a lightweight floating mop skimmer that can be towed at higher speeds than conventional skimmers or used in rivers. The prototype skimmer was tested at OHMSETT week of 10 July 2000. The results are found below in the report prepared by DeVitis, Kurt Hansen and Kathleen Nolan – reproduced by permission of Kurt Hansen, USCG R&D Center, Groton, CT

“Development of Fast-Water Oil Spill Containment and Cleanup Equipment, prepared for U.S. Coast Research and Development Center, Groton, CT, July 2001.”

General

The Zero Relative Velocity (ZRV) mop system is a well-proven method of recovering a variety of oils, with the capability of working in waves and able to handle debris. According to the manufacturer, no advancements have been made on lightweight towable ZRV units since the 1970’s. RO-CLEAN DESMI A/S and Hyde Products Inc. have combined efforts to design and fabricate a ZRV mop system, called the Stream Stripper, which was evaluated in this study. This system attempts to reduce the power requirements by using a paddle wheel as the best drive power source and also to improve the efficiency of the stripping mechanism.

Objective

The objective was to test the design capability of the new concept ZRV to determine if it could skim at higher speeds and to see if it has the same, if not greater, areal coverage than a conventional system with a funnel boom. The manufacturer hoped to obtain sufficient data to develop the paddle wheel design to support enough mops to cover the width of the paddle wheel. The other objectives included determining the mop drive requirements and the optimum length of mop in contact with the water surface.

Skimmer Description

The Stream Stripper was designed to be as light as possible so that it would ride over the waves (similar to a "Hoby Cat"- a sailing catamaran). The prototype mop skimmer was comprised of a 19 foot (5.8m) long lightweight catamaran that incorporated 13 oleophilic rope mops operating between the hulls. The use of these hulls should reduce the inertial mass of the system thus improving the towing and wave following characteristics. The mops were driven by a chain connected to a paddle wheel located at the stern of the catamaran. The paddle wheel was supplemented with a small hydraulic motor fitted to the drive pulleys in case it could not provide sufficient power to rotate the mops. The paddle wheel and hydraulic motor were used independently during this study. Figures 58 and 59, respectively, show a profile and frontal view of the Rope Mop skimmer. The mops were rotated by the drive pulleys mounted at the bow. The distance between the drive pulley and the return pulley was variable on the prototype to allow for adjustment in the mop tension.

Figure 58. Profile of Stream Stripper.

Figure 59. Frontal view of Stream Stripper.

The oil was recovered from the mop with a “stripper” mechanism which was mounted forward of the paddle wheel. This arrangement was chosen as a result of a series of laboratory tests. The oil was recovered into a tray which ran across the width of the catamaran located below the stripper and forward of the rear roller. The recovered oil tray was fitted with a three-inch male camlock coupling for a connection to an offload pump. The tray volume was calculated as 19.75 gallons. The mop skimmer was also equipped with ASTM boom connectors fitted at the leading edge of each hull and lifting points for an overhead crane. Figure 60 shows the rope mops passing through the stripper, the camlock connection and the collection tray.

Figure 60. Rope mops passing through the stripper, camlock connection, and collection tray.

Test Parameters

Initial testing was dedicated to evaluating the design and performance relationship between paddle wheel rpm and tow speed. Adjustments were made to the paddle wheel elevation relative to the water surface to maximize the drive power. The skimmer was towed at various speeds to qualitatively evaluate the capabilities of the paddlewheel as the power source. The relationship between the paddle wheel, mops, stripper, and drive pulleys was evaluated as a complete operating system.

Test Setup

Based on the preliminary drive system evaluation, the paddlewheel was positioned at its final adjustment to provide the highest power available. Oil recovery tests were performed while encountering Hydrocal 300 and Calsol 8240 test oil (see Appendix B for oil properties). During these oil recovery tests, tow speeds were incremented from 2 to 4 knots, and surface conditions included calm and harbor chop waves. Oil distribution was regulated to ensure 100 percent encounter with the rope mops and to provide an average slick thickness of 0.8 millimeters. Figure 61 illustrates the typical slick for most oil recovery tests. Figure 62 shows the slick concentration used during maximum recovery efficiency tests. These tests were designed to determine the highest percent of oil to water collectable by the mop system.

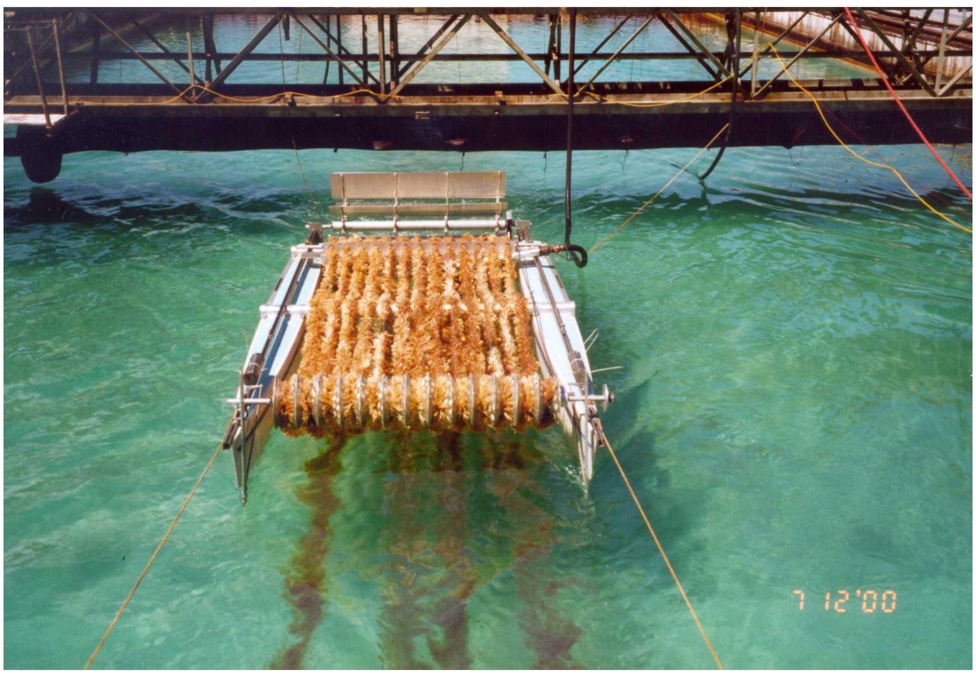

Figure 61. Typical slick for oil recovery tests.

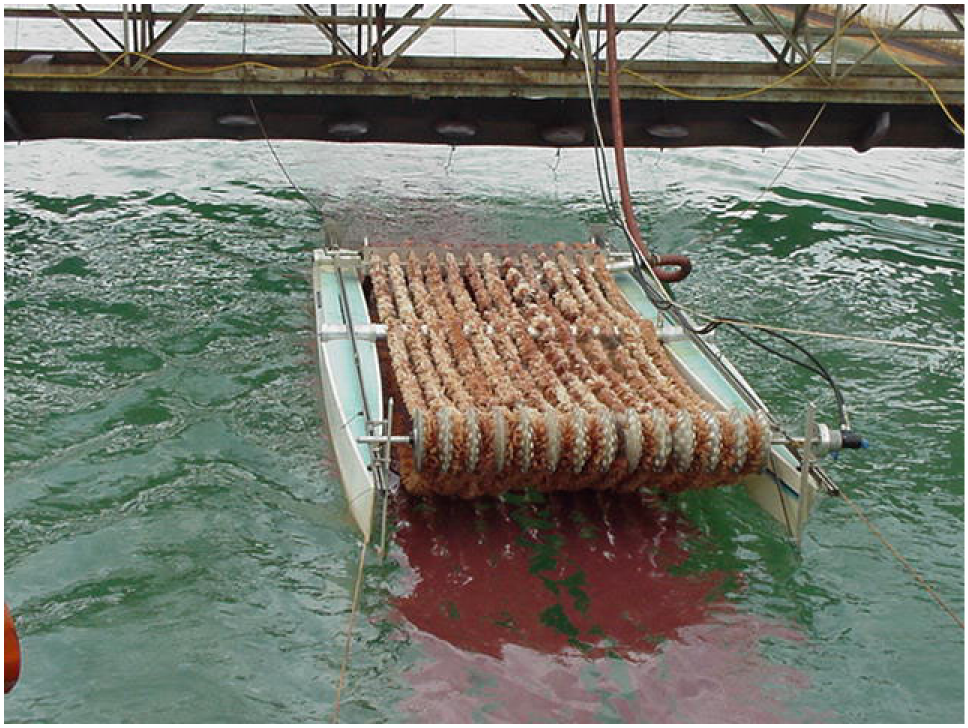

Figure 62. Typical slick used during recovery efficiency tests.

The skimming system was rigged within the Test Basin between the Main and Auxiliary bridges. The fluid collected from the skimming system was offloaded directly into the recovery tanks for measurements. Figure 63 shows the overall test setup including skimmer, pump and recovery tank locations. A 3-inch double diaphragm pump was provided by Ohmsett for offloading operations.

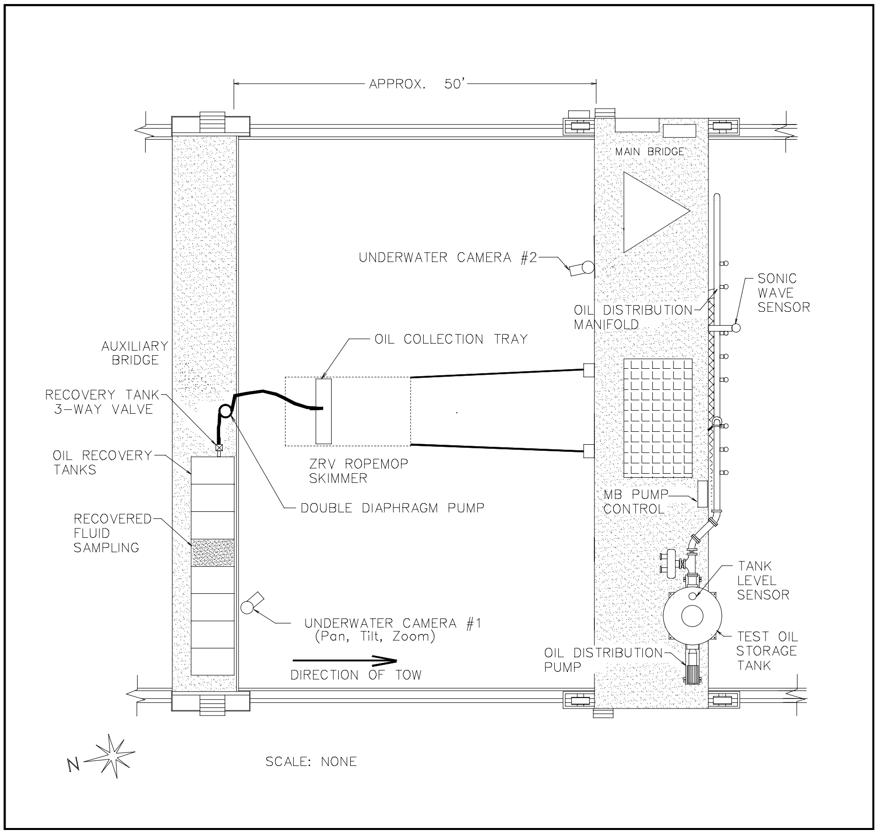

Figure 63. Stream Stripper, test setup.

Detailed Test Description

During this study, there were two primary test objectives to investigate. The first objective was to explore the capabilities of the paddlewheel as a power source for the rope mops. This was accomplished by increasing the tow speed of the Ohmsett Bridges until the paddle wheel provided power to the mop system. Adjustments were made to maximize the power available.

The second objective was to quantify the mop system's recovery performance. The primary measurements obtained to quantify performance were TE, Recovery Efficiency (RE), and Recovery Rate (RR). TE values were calculated as the percentage of oil collected versus the volume encountered. RE was determined by lab analysis of duplicate samples obtained from the discharge stream while operating at a steady state. RR was calculated as the actual volume of oil recovered for the contact time during the test (See Appendix F for detailed skimmer collection methods). Each test with oil was performed using the following procedure:

The source of spilled oil was the Ohmsett distribution manifold on the south side of the Main Bridge. The system travels south into the waves when they are being generated. The testing operation began by loading oil into the 1,500 gallon

Ohmsett Main Bridge storage tank. From this tank, the distribution pump delivered oil to the pneumatically operated distribution manifold. Wide T-bar style nozzles were used to aid in creating an evenly distributed oil slick. The test oil was distributed and controlled ensuring a 100 percent encounter rate.

With all test personnel in their assigned positions, the data collection computer and video cameras were started. The Main Bridge distribution pump was started and set for the predetermined pump rate in the circulate mode. The bridges and skimming system were then accelerated to the test tow speed. Once at speed, the oil distribution manifold was opened, creating the oil slick to be encountered. The start of actual encounter time was identified and then documented. An operator offloaded the skimming system collection tray, when appropriate, using an Ohmsett provided Viking double diaphragm pump. The recovered fluid was pumped directly to the Auxiliary Bridge recovery tanks for measurement and sampling.

Results

Initial testing evaluated the power capabilities of the Stream Stripper as the drive power source for the application, either being towed or moored in flowing water. The paddle wheel was adjusted to different elevations relative to the water level to optimize the available waterpower. The initial paddle wheel settings positioned the main paddle wheel shaft at 17 inches above the water line. The paddle wheel radius was 25-5/8 inches, positioning the paddles 8-5/8 inches into the water (this setting corresponded to the top location of available adjustment). Actual torque measurements were not obtained due to instrumentation costs and time restrictions. Power capabilities were evaluated (visually) by observing mop rotational speed, slippage between mop and pulleys, and by flow velocities at the paddles.

The skimmer was initially towed at increasing speeds until the paddles began to rotate and power the system and this occurred between 2.0 and 2.5 knots. While rotating at the slower speeds, the paddlewheel created a vertical bouncing action (approximately 3 inches) at the stern, due to the water force changing between paddles. Visually, it was apparent that the paddlewheel was not at full speed for the 2.5 and 3.0-knot runs relative to the water passing by it. The actual paddle speeds were measured at 3 and 4 knots to be at 8 and 13 revolutions per minute (rpm), respectively. The second setting evaluated was for the paddles at 9 1/2 inches into the water. The corresponding paddlewheel speeds for the 3 and 4-knot tows were 8.2 and 15.9 rpm, respectively. The third and final setting evaluated, placed the paddles at 11 5/8 inches into the water. This setting provided the highest rotational paddlewheel speeds and, visually, appeared to convert all the available waterpower into drive power. At 3, 4, and 5 knots, the corresponding rotational speeds were 9.0, 19.8, and 24.6 rpm respectively.

The 5-knot tow speed appeared to be limiting due to excessive slapping of the paddles into the water. At 5 knots the mops' speed measured 4.0 feet/second (ft/s), making it difficult for the rope mops to transition through the stripper. Oil recovery tests were performed with the paddlewheel positioned at the optimum setting of 11-5/8 inches in the water.

Tests 10 thru 24 were performed with Hydrocal 300 test oil in calm and harbor chop surface conditions, with the paddlewheel providing the power. During some of these tests, the oil recovery rate of the 13 mops was higher than the Ohmsett offload pump capacity and resulted in the collection trough overflowing. The collection trough was measured, and the capacity calculated as 19.75 gallons. Tests 12 and 14-15 (a double run) are considered the most valid data sets since minimal losses occurred from the collection well. Table 12 contains performance data obtained from tests 10-24. Omitted test numbers are due to aborted tests. Figure 64 graphically illustrates the data. Also observed was a reduction in mop speed between tests with oil versus no oil. At 3 knots without oil, the mop speed was measured at 1.3 ft/s; with oil the mop speed was .95 ft/s.

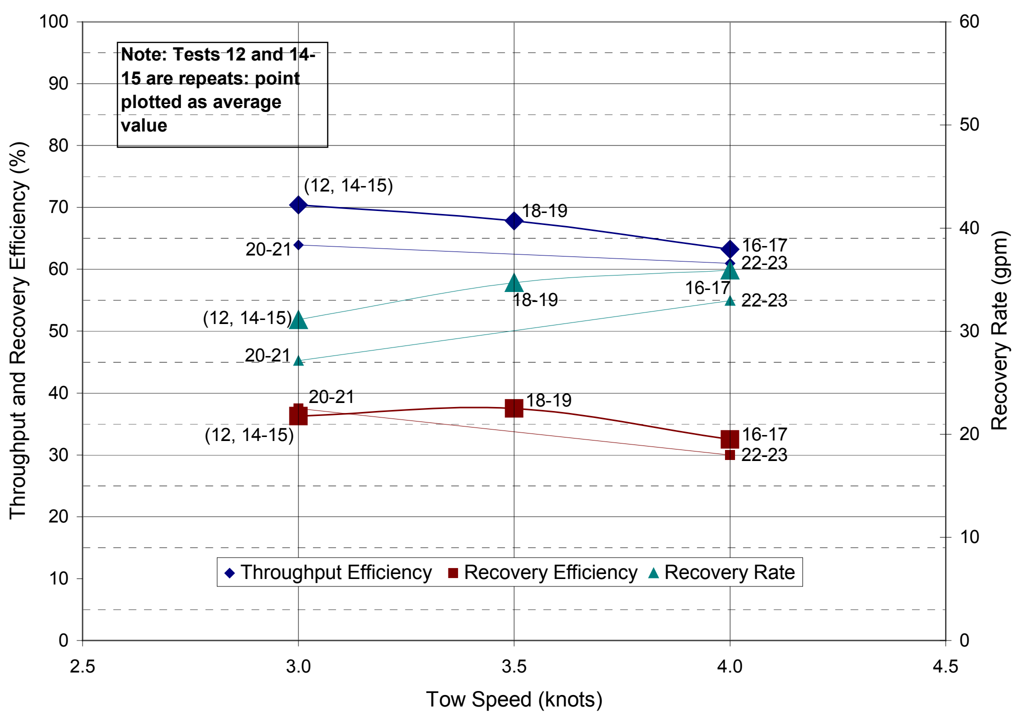

Figure 64. TE and RR performance data with paddle wheel.

Table 12. Performance data with paddle wheel.

Test Number	Tow Speed	Surface Condition	TE (%)	RE (%)	RR (gpm)
12	3	Calm	75	35	31
14-15	3	Calm	66	38	31
18-19	3.5	Calm	68	38	35
16-17	4	Calm	63	33	36
20-21	3	Harbor Chop	64	38	27
22-23	4	Harbor Chop	61	30	33
24 (Max RE)	3	Calm	21	35	16

The objective of test number 24 was to determine the maximum RE capabilities of the mop system. The mop encounter rate was 150 gpm (approximately 2.4 mm slick) compared to approximately 50 gpm (approximately 0.8 mm slick) for prior tests. The mop speed was measured as .74 ft/s; a reduction from .95 ft/s measured during earlier tests.

Beginning with test numbers 25-26, the mops were powered by a hydraulic motor mounted directly onto the front pulley shaft. Motor speed was preset at a control stand along with a hydraulic power supply. The tests evaluated recovery performance data while encountering Hydrocal 300 test oil in calm surface conditions at various mop speeds relative to the tow speeds. The results obtained for this test segment are presented in Table 13. As shown, the mop speeds ranged from 33 percent ZRV to 100 percent ZRV while being towed at 2.0 and 3.0 knots. Figure 65 graphically illustrates the TE values. Figure 66 illustrates the corresponding RE and RR values.

Table 13. Performance while motor driven (Hydrocal 300 test oil).

Test Number	Percent (%) ZRV	Tow Speed	TE (%)	RE (%)	RR (gpm)
25-26	33	3	67	30	28
27-28	50	3	79	30	35
29-30	75	3	69	15	30
32-33	100	3	70	10	29
34	33	2	100	53	30
35	50	2	57	45	19
36	75	2	79	10	23
37	100	2	82	20	27

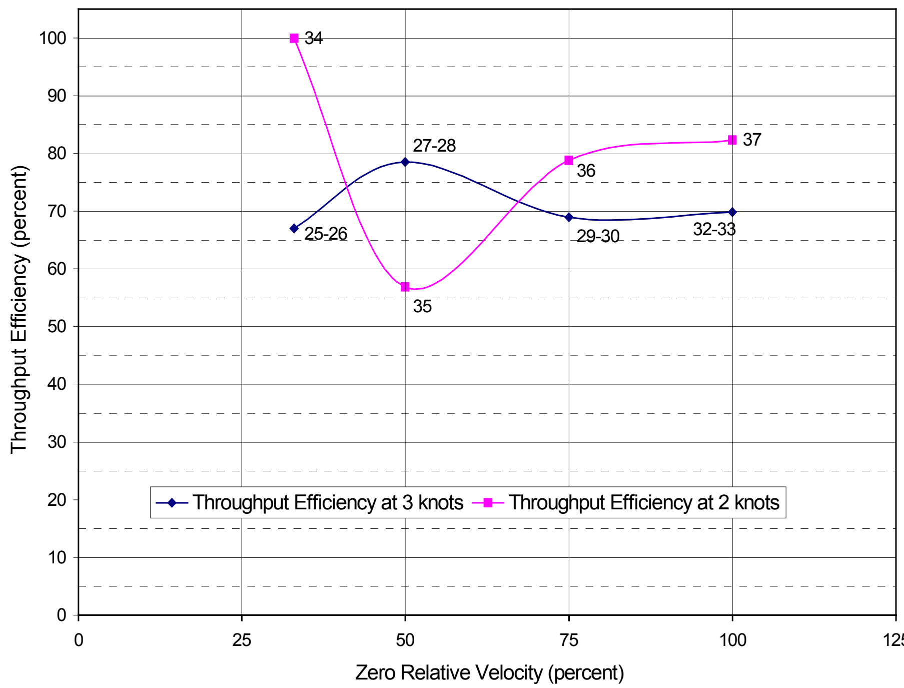

Figure 65. TE values for Stream Stripper.

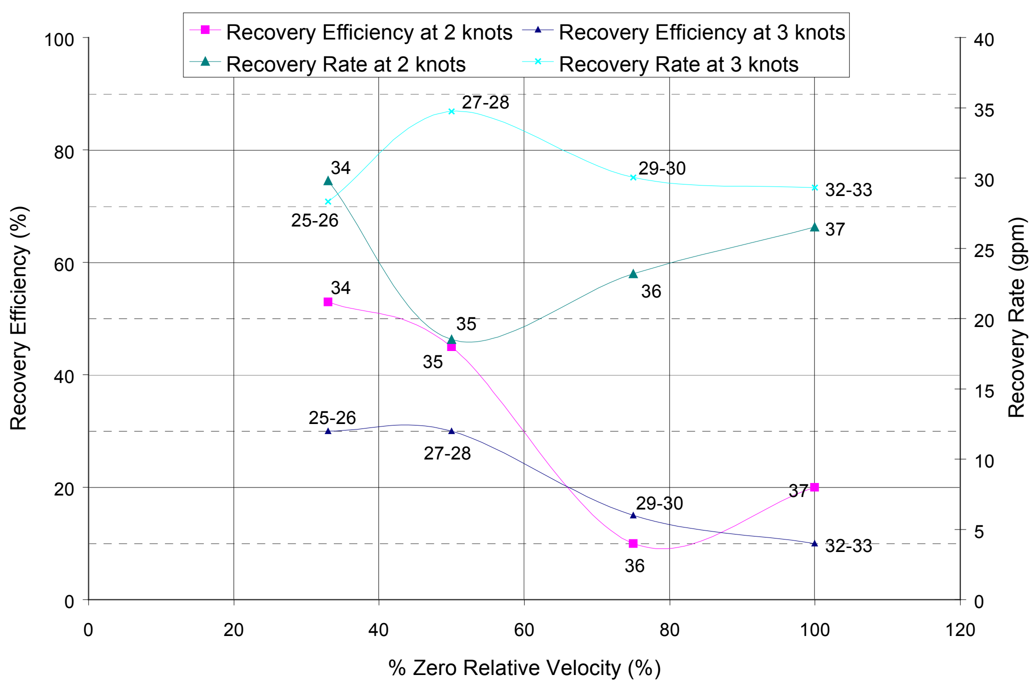

Figure 66. RE and RR values for rope mop ZRV.

A series of tests were performed with Calsol 8240 test oil in calm surface conditions with various mop speeds. This data is presented in Table 14.

Table 14. Performance Data Mop System while Motor Driven (Calsol 8940 test oil).

Test Number	% ZRV	Tow Speed	TE (%)	RE (%)	RR (gpm)
38-39	33	3	89	15	29
40-41	33	3	78	10	26
42-43	25	3	80	40	26
44 (Max RE)	10% (Actual)	3	19	63	31

Discussion of Results

The Stream Stripper design provided two options for powering the mop system; the aft mounted paddlewheel, and the forward pulley shaft hydraulic motor. Preliminary tests were performed to optimize the waterpower available to drive the thirteen rope mops. The highest mop system rotational speed was obtained with the paddles at 11-5/8 inches into the water. Rotational speeds of 8, 19, and 24 rpm were obtained at 3, 4, and 5 knots respectively, without oil present.

During oil recovery testing at 3 knots (5.1 ft/sec), it was observed that the rotational speed slowed down from 9 rpm to 7.4 rpm, or a mop speed of 1.3 ft/s to 1.1 ft/s. At 4 knots (6.7 ft/sec) there was also a drop in mop speed, from 2.7 ft/s to 2.3 ft/s. The drop in mop speed indicates additional power was required when the mops became oil soaked. Visually, when the mops were oiled, they appeared to swell. This added to the force required to pull each mop through its respective wringer.

Test numbers 24 and 44 (3 knot) were designed to determine the maximum recovery efficiency by creating an oil slick which was continuous and wide enough for the thirteen mops to consistently encounter oil throughout the test. The distribution rate for test 44 was 150 gpm (2.4 mm slick) compared to 50 gpm (0.8 mm slick) for test 24. The tests resulted in TE values of 35 percent and 19 percent, which was lower than all other tests. A decrease in mop speed was also observed, from 1.3 ft/s to .9 ft/s (Test 24) and .74 ft/s (Test 44). This drop in TE was clearly attributed to the decrease in mop speed.

Performance values using the paddlewheel as the power source were obtained at tow speeds of 3, 3.5, and 4 knots. Three knots was the minimal tow speed at which sufficient power was available to smoothly operate the mop system and four knots was the upper limit due to apparent slippage of the mops on the drive pulley. This may have been partly due to the uneven sections of the mops catching in the stripper. These uneven sections were caused by the mop strands slipping on the base rope and resulted in bare segments with a bunching of strands adjacent. The number of rope mops could have been reduced to improve the available power to load ratio, enabling the system to operate at slower speeds. TE values, shown in Figure 64, show only a slight decrease when encountering oil from 3 to 4 knots, an averaged value of 70 percent to 63 percent, respectively. RE values were relatively consistent throughout this portion of the test series. The average RE was 35 percent, maximum 37.5 percent and minimum 30.0 percent. The RE values indicate a consistent proportion of oil to water being adsorbed by the mops.

The second segment of testing with the hydraulic drive motor installed investigated the effects of varying the mop speed from 33 percent to 100 percent ZRV (percentage of Zero Relative Velocity) while advancing at 2.0 to 3.0 knots. Figure 65 graphically illustrates the TE achieved for each set of parameters. Test number 34, which was performed at 2 knots with a belt rotational speed of 33 percent ZRV achieved the highest TE, 100 percent. The corresponding RE was also the highest obtained using Hydrocal 300 test oil, 53 percent. The drop in TE performance between mop speeds of 33 percent to 50 percent ZRV (tests 34 and 35) does not indicate a clear trend. The TE results of test 35 may have been skewed lower due to oil losses at the collection trough. Oil losses did occur from the collection trough during the majority of tests. The 19.75-gallon trough filled rapidly, at which time the rear roller located above the trough acted as a drum skimmer pushing oil out causing additional losses. The quantity of oil loss was not measurable, but if completely collected, would significantly raise the TE and RR values. A adequate offload pump could have eliminated this condition.

Tests 38 thru 44 were performed using Calsol 8240 test oil. Earlier testing identified best TE performance with the mop speeds operating in the 33 percent ZRV range. Tests 38-39 and 40-41 were repeat tests that resulted in TE values of 89 percent and 79 percent. For Test 42-43, the rope mopes were operated at 25 percent ZRV, which did not appear to affect TE (80%), but did improve the RE from an averaged 13 percent (at 33% ZRV) to 40 percent indicating that a longer oil contact time is beneficial to RE.

The tests performed in this study have shown that passive power (derived from the paddle wheel design) is a feasible power source to operate a rope mop system. The optimum balance of power available and power required for a paddle wheel could be achieved through further studies. It was also determined that rope mops are effective in recovering a high percentage of encountered surface oil. RE results appeared to be dependent on the concentration of oil on the water surface. The highest RE (63%) was achieved during test 44 during which all the mops encountered surface oil.

As observed during Tests 24 and 44, the mop speed dropped from 1.1 for the standard TE test, to .95 and .74 ft/s respectively. This was due to the individual mops collecting more oil, enlarging the apparent mop size, and increasing the weight, thus increasing the power necessary during the wringing operation. In the case when the paddle wheel was driving the mops, insufficient power from the paddlewheel, causing the drive system to slow down. When hydraulically powered, the mop system also slowed down, but in this case, slippage occurred at the drive pulleys (front shaft). The skimmer needs enough forward motion to ensure that the mops wrap securely around the drive pulleys. The slipping at the drive pulley damaged the mops by bunching the strands on the base cord, resulting in a stalled stripper. This observation only contributes to the knowledge about the durability of the mops and their operating limitations.

SUMMARY

A series of tests have been completed that advances the development of systems that may help recovery of oil in fast currents. The data contained in this report should provide additional understanding to aid in responding to spills in fast water. This is especially true of the tension data collected on booms in fast water. An easy method to calculate tension loads has been determined that can be used for both stationary deployments and advancing skimmers. The throughput efficiency of the USCG HSS has been improved by the use of a baffle plate. The result is an increase of effective skimming at speeds up to four knots. Use of a baffle plate could also increase the performance of other inclined plane systems, especially the large number in the U.S. Navy inventory. Flow diverters have shown the ability to deflect oil up to 19 feet in fast currents. Their effectiveness and usefulness can be improved if their weight can be reduced and the leading edge can be redesigned to reduce their tendency to submerge at higher speeds. The sorbent sheet booms were evaluated and appeared to be effective in fast currents, especially for cleaning up sheens. Results from the Stream Stripper indicate that rope mop skimmers are a promising concept. The potential capabilities of paddle wheel power and an improved rope mop cleaning technique has been demonstrated. The data collected should prove useful for designers and builders to create improved rope mop skimmers.

The time and effort that occurred during this effort indicates the magnitude of designing, building and testing new equipment for any type of oil containment or recovery. Although most of the products tested here were prototypes, the data should be useful to responders who have similar equipment.