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Project Summary

Performance Testing of the DiPerna Sweeper

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The DiPerna Sweeper, a partial-vacuum oil skimmer, was tested in a 2-week test program conducted at the U.S. Environmental Protection Agency's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in Leonardo, New Jersey. Forty-three oil recovery tests were run. The object of the program was to establish a range of best performance for the skimmer under various environmental conditions in light and heavy oils.

The DiPerna Sweeper is a self-contained, floating oil skimmer that can operate in either a stationary or advancing mode. Its principle of operation is based upon drawing oil and water into a sealed container by creating a slight vacuum in the container. A floating weir serves as the inlet. The partial vacuum is created by pumping fluid from the sealed container. The container serves as an oil/water separator. Separate pumps draw water from the bottom of the vessel while others draw oil from the top.

The device was able to recover over 75% of the oil presented to it in calm water at tow speeds up to 2 kts. Performance decreased in waves. Modifications are suggested to improve such performance. The separator functioned well. In one case, the oil offloaded from the skimmer was 95% free of water.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The DiPerna Sweeper (Figure 1) was designed by James DiPerna and built by the Brewer Dry Dock Company,* both of Staten Island, New York. In April 1979, the skimmer, which can be transported on a common-carrier, flatbed tractor trailer, was moved from the shipyard to OHMSETT. The original gravity flow design was modified to a partial vacuum design at OHMSETT under the direction of Mr. DiPerna. The merits of the conversion were demonstrated using a small model built by Mr. DiPerna (Figure 2). The modifications did not affect the basic nonmixing oil/water collection principle. Other modifications suggested by Mr. DiPerna regarding removing the skimming head and altering the skimmer to allow the fluid to flow over a weir attached to the separator were not acted upon at this time.

On 14 May, the skimmer was lifted into the test tank where 43 oil recovery tests were run with light and heavy oils, which are described in Appendix B of the full report. On 25 May, the device was removed from the tank. All performance testing was conducted at

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Figure 1. *The DiPerna Sweeper being lifted into the test tank.*

OHMSETT by the operating contractor Mason & Hanger-Silas Mason Co., with the guidance of the U.S. EPA Project Officer.

Device Description

The original design of the DiPerna Sweeper consisted of a gravity-flow API oil/water separator mounted between two floatation chambers (Figure 2). A segregated floating head with an overflow weir, connected to the main portion of the skimmer by a 20-cm diameter hose, served as a fluid inlet (Figure 3). Oil and water were drawn into the skimmer over the weir by lowering the water level inside the device below the outside waterline. This was accomplished by pumping water from the bottom of the separator. Oil collected in the first compartment was routed to a rear compartment where it was offloaded by a small pump. The water was removed from the bottom of the separator in the second compartment. This design allowed the use of less than half of the separator volume since a good portion of the separator extended above the mean waterline. Modifications to seal the top of the separator from the atmosphere and reroute pump piping were carried out while the skimmer awaited testing at OHMSETT (Figure 4). The changes permit the use of the entire volume of the oil/water separator and simplify the offloading of collected oil.

With the top of the separator sealed, a partial vacuum is induced inside the separator by pumping air out from the top of the chamber. Fluid allowed over the inlet weir fills the evacuated area. Thus a flow of fluid over the weir can be maintained even though the fluid level inside the separator is above the waterline. Water is still removed from the lower rear of the separator, but the oil outlets are relocated to ports welded flush with the sealed deck. The design utilizes the entire volume of the oil/water separator with a minimum increase in vessel draft.

The segregated floating head was not modified from the original design. The design and concept of a light, wave-following skimming weir, which was separate from the main body of the skimmer, appeared sound and did not warrant change. The head was detached from the separator so it could follow waves, maintaining the weir at the desired depth. Swamping of the weir and sump by waves would be avoided if it performed as designed. The skimming head had not been previously tested in either a model or in full scale. Chambers and valves are incorporated into the head to permit ballasting with water.

The sweep width of the head is 1.2 m; the width of the weir is 0.5m. Directly behind the weir is a small sump that leads to the large hose connecting the head to the skimmer. Additional skimming heads can be attached to the skimmer with the use of small ports welded to the fluid inlet pipe. Because these heads can be used at a distance from the skimmer, oil can be collected from shallow areas or under piers while the main skimmer sits in deeper water.

Fluid is drawn into the skimmer by pumping water from the lower rear of the separator. It enters the separator chamber at the front directly beneath the deck. Unmixed oil is delivered to the top of the separator where it floats; the water seeks the lower level. In this manner, oil and water mixing is minimized. The residence time of the oil and water in the separator can be varied depending on the offloading pumping rate. The pumps used in the OHMSETT tests had a combined flow rate of about 120 m^3/hr. Residence time (190 sec) with all of the pumps operating appeared more than adequate.

A small, sealed deck house with plexiglass windows was placed on the skimmer with a pipe running from it through the deck to the keel of the separator. Water is drawn from the pipe producing fluid flow up the pipe. Windows allow the operator to see when oil is being drawn up the pipe and thus slow the water pump rate or to offload oil.

The vessel had an overall length of 5.5m, a beam of 2.9m, a draft of 1.7m, and a freeboard of 1m. The vessel weighed about 3000 kg.

Results

The DiPerna Sweeper proved to be a simple and effective design incorporating only pumps for oil recovery. The skimmer can be pushed, towed, or self-propelled during its oil collection operations. The force of the water from the pump discharge off the rear of the skimmer is enough to propel the device forward at about 0.25 to 0.5 kt. Such a forward speed may be suitable for tank testing but would not be practical for field use. The skimmer is chiefly designed to be attached to oil booms where winds and currents would drive oil to the skimming head; it is not intended for high-speed skimming.

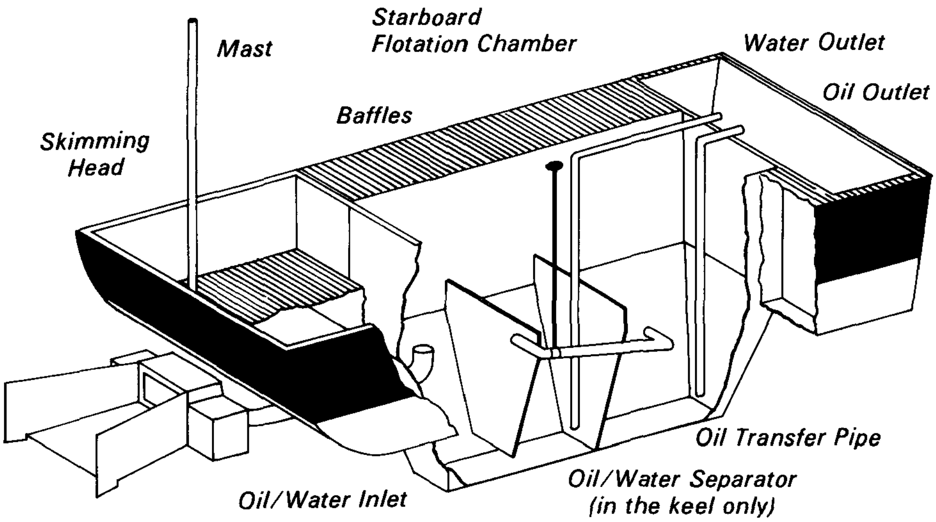

Figure 2. *Cutaway view of original DiPerna Sweeper design.*

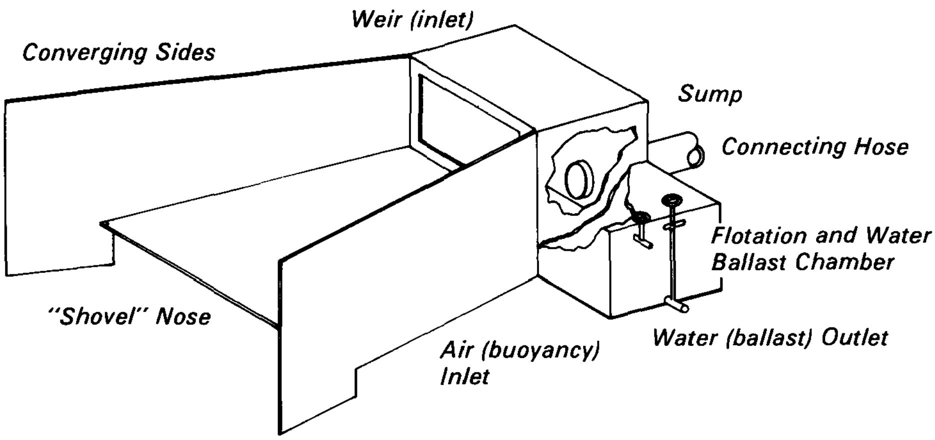

Figure 3. *Isometric view of the floating skimming head.*

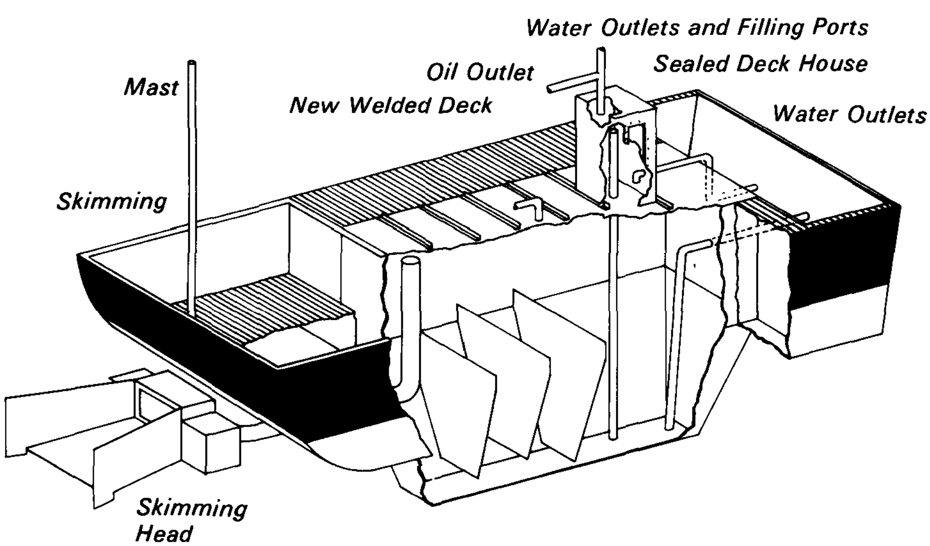

Figure 4. *Cutaway view of the modified DiPerna Sweeper.*

Floating Skimming Head

If the skimming head is to be retained, a major redesign is necessary. The shovel-nose design of the head caused many problems in the presence of waves. It acted as a damper to slow the inlet weir's wave response; it produced turbulence in the oil slick when it heaved above the waterline; it provided a spillway for the excess oil and water that was washed up to the weir but could not enter. As the oil and water ran down the nose, it mixed vigorously and pushed the oncoming oil slick away from the head. The best solution seemed to be a deeper weir cut in waves so the shovel nose would never rise high enough to cause problems. Under tow in both calm water and waves, the shovel nose acted as a diving plane causing the weir to sink below the calm-water setting and the head to pitch forward. The nose also caused problems with ballasting the skimming head. If the ballast water drained to the rear areas because of a rearward pitch of the head, the nose became a forward buoyancy chamber that maintained the head in the tilted position. SCUBA diver weights, guy wires, and a wire rope cable to a winch on the mast provided the ballast and kept the weir at the desired calm water setting for the tests. An unfortunate interference occurred, however because of the use of the guy ropes and the wire rope on the skimming head. When a wave trough was encountered, the ropes restricted the downward travel of the head causing a sudden stop. This prevented the weir from maintaining a constant depth and allowed water and oil to flow down off the nose onto the approaching oil slick. Without the ropes, however, the movements of the skimming head from side to side and pitching forward would have made oil collection much more difficult. The removal of the shovel nose from the skimming head and judicious placement of floatation and ballast should solve most of the above problems. A feature the skimming head lacks is a vertical plate to prevent waves from splashing over the head and, thus, losing oil. Finally, the weir tended to raise up above the waterline when the fluid in the head sump was pumped out and thus restricted flow over the weir. However, if the sump did not drain somewhat in between waves, the next wave would swamp the sump and oil would be washed away from the weir. A self-compensating weir lip or inlet valve could be built into the skimming head to prevent such starving of fluid flow.

Oil/Water Inlet Hose

The hose used in the tests was too heavy and too stiff to allow the skimming head to act independently of the main body of the skimmer. If the skimmer operator changed his location on the deck of the vessel, the slight tilt of the vessel would twist the hose and alter the attitude of the skimming head. The floatation of the skimming head is not enough to freely move the inlet hose in response to oncoming waves.

Oil/Water Separator

Converting the separator from gravity flow to partial vacuum made the additional separator volume available above the waterline. This accounted for 64% of the 6.3 m^3 total separator volume. Oil/water separation had to be enhanced by this change since the fluid residence time increased along with the volume. Only during wave tests using low viscosity oil did any oil reach the water discharge pump inlet, and then it was very little. This means that the water discharge capacity could be increased beyond that used in these tests without significantly affecting performance of the separator. Onboard storage capacity of collected oil was also increased by the modification. The changes also provided oil offloading ports on the deck that could be drawn from during a test to increase the mass flow rate through the skimmer. This was done by additional pumps placed on the skimmer.

Nonturbulent collection of oil and water was virtually unchanged by converting to a partial vacuum skimmer. The inlet pipe was extended to within 150 mm of the new decking to deliver the oil to the top of the collected fluid. This prevented the oil from having to rise up through the fluid inside the separator and perhaps be swept away with the water under the baffles to the water discharge pump inlet.

The vessel was stable and had a slow wave response because of the water-filled keel and the catamaran-like arrangement of the floatation chambers on both sides of the vessel.

Sealed Deck House

Purpose of the deck house was to determine when oil reached the inlet of the water discharge pipe located 100mm above the keel of the separator. This would be an indication that the vessel was either full of oil or that the water had been removed from beneath the oil and oil would be offloaded next. Since oil was offloaded from the ports welded flush with the deck and logistics prevented tests with enough oil to fill the skimmer, the deck house was not put to its designed use. It did, however, provide an excellent view of the amount of oil mixed with the water at the bottom of the skimmer. It also provided an additional port from which water could be drawn to increase the mass flow rate through the skimmer.

Oil and Water Offloading Pumps

The gasoline-driven pumps that arrived with the skimmer consisted of a diaphragm pump (7m^3/hr) for oil offloading and a centrifugal pump (70m^3/hr) for water discharge. Both pumps performed well until carburetor trouble forced the diaphragm pump out of service. With the increase in usable separator volume, the pump capacity could be increased without fear of drawing the collected oil out with the water. It was evident that an increase in mass flow rate over the weir could diminish the turbulence generated by the headwave and thus increase the skimmer's performance at higher tow speeds. To accomplish this, an air-driven double-diaphragm pump (32 m^3/hr) was placed onboard to offload oil from an exit port on deck and a gasoline centrifugal pump (16 m^3/hr) was placed onboard to discharge water drawn up into the sealed deck house. The resulting increase in mass flow rate produced an increase in performance in both calm water and in waves. The general absence of oil exiting with the discharged water would indicate the pump rate could be increased to about 225 m^3/hr without deleterious effects. This would give a fluid residence time of about 100 sec in the separator. Since the oil enters the separator only loosely mixed with the water, there should be enough time for the oil to stabilize at the top of the separator and not be drawn out with the discharged water.

Data Discussion

Recovery Efficiency (RE) was not recorded for each test because, less than halfway through the program, the oil was offloaded during the test rather than following it. During the test, offloading drew an uncontrollable amount of water with the oil; this lowered the RE of the device. Under such circumstances, comparing the RE's would not render useful conclusions as to the causes. The quantities of oil offloaded into the barrels gave representative values of RE if the barrel was not drained of much water before the sample was taken. This was the case in several tests in which the procedure was to offload the oil after completion of the test run. The values obtained were 86% for 0.5 kt, 91% for 0.75 kt, 91% for 1.0 kt, 89% for 1.25 kt, 88% for 1.5 kt, and 87% for 2.0 kt. These values should be considered below the capability of the skimmer since the amount of oil in the one full barrel represented 70% of the oil collected by the skimmer. As the oil was drawn from the skimmer, the oil layer inside decreased to where water was drawn out with the oil. This lowered the percentage of oil in the outlet stream and subsequently that in the barrel also.

There was not enough time in the test program to optimize device settings for every condition tested so the test results should not be considered the best performance possible by the skimmer. When time allowed, device settings were changed and tests were run under the same tank conditions.

Tow Speed

Increasing tow speed raised a head wave in front of the floating head and created turbulence by forcing more water to be channeled from the sweep width of the head (1.2 m) into the width of the weir (0.5 m). The tow speed at which performance would begin to decline should be predictable by comparing the flow over a rectangular weir (1.2 m wide) at different water depths over the weir to the tow speeds and pumping capacity of the skimmer. With the use of one pump, 70 m^3/hr of water could be discharged. A water depth of 4 cm is needed for a 70-m^3/hr flow. Bernoulli's equation predicts a 1.86-kt tow speed will produce a headwave of 4.5 cm. A decline in throughput efficiency (TE) and oil recovery rate (ORR) perfomance occurred between 1.5 and 2 kt. With the use of four pumps (125 m^3/hr), the point of decline should be about 2.2 kt. The data for TE versus tow speed in heavy oil and calm water show a significant decline in performance above 2 kt using four pumps. Extrapolation of these results suggest that a greater pumping capacity would result in better performance at higher tow speeds. As long as the current inside the skimmer is not large enough to entrain and sweep a good deal of oil to the water discharge inlet, performance will increase with pumping capacity.

Waves

TE and ORR were greatly decreased by the presence of waves. Below 0.75 kt in harbor chop waves, the oil was washed away from the skimming head by the wave reflection. Above 1 kt, TE performance declined to less than 50% in the harbor chop. This was because of the inability of the skimming head to respond well to the waves, which caused turbulence in front of the weir and allowed waves to splash over the head. ORR values leveled out and began declining at 1 kt in the harbor chop as compared with 1.5 kt in calm water.

Regular waves reduced skimming performance compared with that in harbor chop. The harbor chop condition varied the water level at the weir at a greater frequency than the regular waves. The skimmer head heaved only slightly during the harbor chop, but the waves slapped into and over the weir. In regular waves, the skimming head heaved a great deal and was often 180° out of phase with the oncoming waves. A great deal more turbulence was generated in front of the weir and more waves splashed over the skimming head and degraded the performance. A redesign of the skimming head and inlet hose should increase performance in waves at all tow speeds.

Oil Viscosity

Skimmer TE and ORR performance was superior in the high viscostiy oil. Driven by the turbulence created in front of the weir, the low viscosity oil tended to mix with the water and pass beneath the skimming head. Although the TE results were consistently lower in the low viscosity oil, the general trends in performance were very similar. Low viscosity oil reached the water discharge inlet during tests in waves whereas the high viscosity oil did not. The amount of oil discharged with the water was insignificant, but it points to a possible problem of discharging oil if the pumping capacity is increased.

Weir Depth

This variable was not investigated completely since the skimming head rose up in the water if the fluid in its sump was lowered very much. Generally, the weir was kept at about 60 to 70 mm deep in calm water. In wave tests, the weir depth varied a great deal because of the poor wave response capability of the skimming head. In wave tests, skimmer performance increased if the weir was set at a depth of about 100 or 120 mm before the start of the test. The lower setting further submerged the shovel nose of the skimming head and reduced its presence above the water's surface where it produced oil-entraining turbulence.

Slick Thickness

TE was not noticeably affected by the changes in slick thickness; however, ORR varied in direct proportion to the changes.

Recovery efficiency samples indicate the device is capable of consistently high values of RE.

Conclusions

The DiPerna Sweeper proved effective in recovering low and high viscosity oils at tow speeds up to 2 kt (Tables 1 and 2). Based on samples taken at the oil offloading pump outlet, the skimmer has the capability of collecting oil with less than 5% water. This is because the method draws oil and water into the skimmer without mixing them and offloads the oil from top of the collected fluid and the water from the bottom.

Best performance of the skimmer obtained during the 2-week test program is listed below (TE in percent; and ORR in m^3/hr). RE samples were not taken on every test and do not appear in the chart.

Discrete samples taken at the pump outlet resulted in RE values of 95.5% at 1 kt in calm water and 88% at 0.5 kt in the 0.3-m harbor chop.

The skimmer performed best in high viscosity oil in calm water. Waves caused drastic reductions in performance, and regular-wave, head seas resulted in the poorest performance.

The greater the number of pumps removing fluid from the skimmer, the better the device performed. Primary objective to improve performance was to get as much of the oil slick into the device as possible and not worry whether some oil was discharged out the stern with the water.

The shovel-nose design of the skimming head and its attachment to the main body of the device via a large stiff hose was not conducive to optimum wave following. Overall performance in waves could be substantially improved with the proper skimming head and inlet hose.

The main portion of the skimmer was stable and generally unresponsive to waves. This was due to the deep, water-filled keel and the floatation chambers on both sides of the vessel.

Recommendations

A redesign of the skimming head and inlet hose should be undertaken to improve wave response of the hose and head system, to improve the skimming head water ballasting system, to prevent wave splashover response and to prevent turbulence and headwave production while under tow in calm water and in waves.

The main portion of the skimmer should be outfitted with larger pumps than those tested. A pump with a capacity of about 200 m^3/hr should be used to remove the water from the bottom of the vessel, while a 50 m^3/hr positive displacement pump should be

	0.5 kt		*1.0 kt*		*1.5 kt*		*2.0 kt*		*2.5 kt*	
	TE	*ORR**	*TE*	*ORR*	*TE*	*ORR*	*TE*	*ORR*	*TE*	*ORR*
Calm water	*95.0*	*12.7*[+]	*96.2*	*26.3*[+]	*95.1*	*38.0*[+]	*75.3*	*40.2*	*33.2*	*22.1*
0.3m harbor chop	*44.1*	*5.3*	*72.8*	*19.4*	*46.4*	*18.5*	*27.3*	*14.6*	*ND*	*ND*
0.3m reg. wave	*ND*	*ND*	*38.3*	*10.0*	*23.5*	*9.4*	*21.1*	*11.3*	*21.0*	*14.0*

**ORR values are corrected to 12-mm-thick oil slicks by multiplying the measured ORR by 12 mm and dividing by the actual slick thickness.*
[+]One water discharge pump (70 m^3/hr) was used. All other tests used four pumps (125 m^3/hr total).

Table 1. *Test Results of the DiPerna Sweeper in High Viscosity Oil*

Test No.	Tow Speed (knots)	Waves (m x m)	Slick Thick (mm)	Weir Depth (cm)	TE (%)	ORR (m^3/hr)	Comments
SD 3	0.5	Calm	11.7	6.35	95.0	12.4	140 kg ballast on vessel, wts and ropes on head
1	0.5	Calm	12.4	6.35	91.3	12.6	Good test
2	0.5	Calm	12.4	6.35	93.7	12.9	No losses seen in underwater film footage
3	0.75	Calm	13.2	6.35	91.8	20.1	Ballast on skimmer raised to 340 kg
4	0.75	Calm	13.4	6.35	95.0	20.8	Good test, water discharge clean of oil
5	1.0	Calm	12.9	6.35	94.5	27.2	Small losses less than 1% at boom attachment points
6	1.0	Calm	12.8	7.62	84.3	24.1	Oil not hosed in at the end of the test, 95% RE at oil/water outlet
7	1.0	Calm	12.8	6.35	96.2	27.4	Good test
8	1.25	Calm	12.9	6.35	97.2	28.1	Oil shedding seen from the front
9	1.25	Calm	10.4	6.35	95.1	27.5	Same as test No. 8
10	1.50	Calm	9.4	6.35	95.1	29.8	Good test
11	0.5	0.3 m HC	11.9	varied	25.7	3.4	Wave reflection down nose of skimming head washed oil away, 88% RE at oil/water outlet
12	1.25	Calm	10.1	7.62	93.8	26.5	Good test
13	1.5	Calm	12.6	7.62	87.4	36.5	A good deal of entrainment from the skimming head
14	2.0	Calm	13.1	7.62	46.9	27.4	Entrainment much worse
15	2.0	Calm	12.8	6.35	55.9	31.8	Large oil losses seen due to shedding
16	2.5	Calm	12.2	6.35	23.4	15.9	Some oil escaped under the port boom
17	0.5	0.3 m HC	12.8	varied	30.7	4.4	Main skimmer and head out of phase due to waves, jerking action on head caused oil losses
18	2.0	Calm	8.7	6.35	34.3	13.3	New pump on skimmer failed in middle of test
19*	2.0	Calm	9.7	10.16	30.2	13.1	Four pumps used - lowered weir to gain flow
*Four pumps were used from this test on except for tests 24, 39, 40, 41, and 42.							
20	2.0	Calm	—	—	—	—	Aborted due to oil distribution pump failure
21	2.0	Calm	12.4	11.43	75.3	41.6	Good test
22	2.0	Calm	12.1	11.43	69.5	37.3	Skimming head rising and falling as it emptied and filled again
23	0.5	0.3 m HC	12.0	varied	44.1	5.3	Larger booms used to guide oil to the skimmer
24	0.75	0.3 m HC	11.7	varied	45.2	8.9	One pump used to compare results
25	0.75	0.3 m HC	12.0	varied	80.7	16.2	Turbulence caused by skimming head action, some oil reached the water discharge inlet
26	1.0	0.3 m HC	12.0	varied	72.8	19.4	86% RE determined from grab sample at oil/water outlet
27	1.5	0.3 m HC	12.5	varied	46.4	19.3	Skimmer head sump drained after each wave, good test
28	2.5	Calm	12.2	12.7	33.2	22.5	Good test, vortices in front of head caused losses
29	2.0	0.3 m HC	11.8	varied	27.3	14.4	Waves and oil splashed over skimming head
30	0.5	0.4x1.1.6	—	—	—	—	Aborted due to lack of oil entering skimming head

Table 1. *(Continued)*

Test No.	Tow Speed (knots)	Waves (m x m)	Slick Thick (mm)	Weir Depth (cm)	TE (%)	ORR (m^3/hr)	Comments
31	1:0	0.4x11.6	12.6	varied	38.3	10.5	Waves reflected from head washed on-coming oil slick away
32	1.5	0.4x11.6	12.5	varied	23.5	9.8	Same as test No. 31
33	2.0	0.4x11.6	12.5	varied	21.1	11.8	Air entered skimmer because the head drained completely at times
34	2.5	0.4x11.6	12.6	varied	21.0	14.7	Losses due to shedding more than splash-over, water discharge clean of oil

Table 2. *Test Results of the DiPerna Sweeper in Low Viscosity Oil*

Test No.	Tow Speed (knots)	Waves (m x m)	Slick Thick (mm)	Weir Depth (cm)	TE (%)	ORR (m^3/hr)	Comments
35	0.5	Calm	—	—	—	—	Test aborted due to obstruction in water jet nozzle which controlled the slick width
36	0.5	Calm	12.2	10.2	83.1	11.1	Water discharge lightly colored by oil
37	1.0	Calm	—	—	—	—	Aborted, water discharge pump ran out of gas
38	1.0	Calm	12.4	10.2	73.5	19.9	Vortices formed at boom attachment points, oil drawn underwater and lost
39	1.5	Calm	12.2	10.2	78.0	31.8	Smallest pump failed, three pumps in service
40	2.0	Calm	12.5	12.7	32.5	18.1	Three pumps in service, only 5 or 6% decrease in pumping rate of 4 pumps
41	2.5	Calm	12.3	11.4	8.3	5.7	Great deal of entrainment from skimming head
42	1.0	0.4x11.6	12.7	varied	7.2	2.0	Oil pushed away from head by reflection waves
43	1.0	0.4x11.6	—	—	—	—	Aborted due to break in oil boom tie line

used for offloading oil and removing air from the top of the skimmer.

The oil/water separator should be enlarged. A longer residence time and a more stable vessel would result if the lower portion of the oil/water separation compartment were extended beyond the center to the port and starboard sides to form a rectangular cross-section.

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The complete report, entitled "Performance Testing of the DiPerna Sweeper," (Order No. PB 82-109 174; Cost: $6.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
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