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Heavy Oil Recovery Ohmsett Test Report

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Heavy Oil Recovery Ohmsett Test Report

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16. Abstract (MAXIMUM 200 WORDS) Facilities or vessels which store or transport heavy and/or sinking oils in U.S. waters must identify response organizations and strategies for responding to spills of these products, including identifying methods for assessing, containing, and recovering oil from subsurface environments. The U.S. Coast Guard (USCG) has acknowledged available technologies to accomplish these objectives are not readily available at this date. The objective of this project was to develop and test viable designs for systems which can detect and recover oil from subsurface environments. This is the second major report within this project, the first describing detection systems, that summarizes the results of a two-year effort to develop a recovery system. The USCG Research and Development Center developed specifications and awarded three contracts to design a complete detection and recovery system to Alion Science & Technology Corporation, Marine Pollution Control, and the Oil Stop Division of American Pollution Control. In 2011, these three companies were awarded options to build prototypes for testing. This report describes the designs of the three systems and results from prototype testing at the Ohmsett test facility in Leonardo, New Jersey. It also discusses the path forward for submerged oil detection, recovery, and decanting.					
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EXECUTIVE SUMMARY

The Oil Pollution Act of 1990 (OPA '90) requires facilities or vessels which store or transport Group V (heavy oils, sinking oils) in U.S. waters to identify response organizations and strategies for responding to spills of these products, including identifying methods for assessing, containing and recovering oil from subsurface environments. Current methods are inadequate to find and recover submerged oil, with responders having to reinvent the techniques on each occasion. The Coast Guard Research and Development Center (RDC) has embarked on a multi-year project to develop a complete approach for recovery of spills of submerged oils.

Three companies spent one year in designing separate systems to identify and recover oil that is sitting on the bottom. These companies then fabricated prototype systems able to be evaluated in the OHMSETT test facility. The three systems were:

- Alion developed a lightweight system using Remotely Operated Vehicles (ROVs). The ROVs may need more power and the pump intake nozzle may need to be smaller.
- Marine Pollution Control (MPC) designed a system based on a manned submersible. It can go deeper and stay longer than a diver, but may have high operational support requirements because the manned submersible may require a specialized support vessel.
- The Oil Stop Bottom Oil Recovery System (OSBORS) Group designed a bottom crawler system based on dredging technology. It could handle harsh wind/wave conditions; but may have high support requirements related to vessel transport and lift and lowering from the vessel and potential environmental impact because of its size and weight.

The systems provided different concepts for replacing the need for divers to work with pumps on the seafloor. They have unique capabilities but need more work to decrease amount of water/silt collected.

Field tests are tentatively scheduled for the summer of 2012 for the Alion and the OSBORS systems to evaluate aspects of the systems that were not addressed in the Ohmsett tests.

This project resulted in progress in the understanding of and capabilities for heavy/sunken oil spill response. However, there are areas that need further research:

- Detection
 - Determine full capabilities and limits of currently available sensors.
 - Improve data processing times and accuracies.
- Recovery
 - Lab tests to determine range of “pumpable” oil for the various types of pumps and nozzle arrangements, including maximum water depth at which the pumping system is able to function.
 - Cost-benefit analysis of the different types of delivery systems based on the location of the spill, including depth, bottom type, and available logistical support.
- Decanting
 - Develop detailed guidance and/or computational tools for decanting systems based on the conditions of the spill.



Heavy Oil Recovery Ohmsett Test Report

- Other Issues
 - Assessment of systems' effects on wildlife and the bottom environment.
 - Guidelines for conducting a cost-benefit analysis during actual spills.

Through this project, the USCG has taken a step forward in heavy oil detection and recovery capabilities. However, each spill will be different and the Federal On-scene Coordinator will need to determine what techniques to use.



TABLE OF CONTENTS

EXECUTIVE SUMMARY	v
LIST OF FIGURES	ix
LIST OF TABLES	x
LIST OF ACRONYMS AND ABBREVIATIONS	xi
1 INTRODUCTION.....	1
1.1 Objective	1
1.2 Background	1
1.3 Approach	2
1.3.1 Specifications and Performance Requirements	2
1.3.2 Phase I System Design.....	3
1.3.3 Phase II Prototype Development and Testing.....	3
2 SUBMERGED OIL RECOVERY SYSTEMS.....	3
2.1 Overview	3
2.1.1 Design	3
2.1.2 Testing.....	3
2.2 Alion Science & Technology Seagoing Adaptable Heavy Oil Recovery System (Sea Horse)	6
2.2.1 System Design	6
2.2.2 Ohmsett Test Procedure.....	9
2.2.3 System Performance	11
2.2.4 Lessons Learned.....	12
2.2.5 Path Forward.....	13
2.3 Marine Pollution Control	13
2.3.1 System Design	13
2.3.2 Ohmsett Test Procedure.....	17
2.3.3 System Performance	18
2.3.4 Lessons Learned.....	24
2.3.5 Path Forward.....	25
2.4 Oil Stop Bottom Oil Recovery System	25
2.4.1 System Design	25
2.4.2 Ohmsett Test Procedure.....	27
2.4.3 System Performance	29
2.4.4 Lessons Learned.....	31
2.4.5 Path Forward.....	32
2.5 Summary	32
2.5.1 Detection.....	32
2.5.2 Recovery	32
2.5.3 Decanting.....	32
3 CONCLUSION	34
3.1 Detection	34



TABLE OF CONTENTS (Continued)

3.2	Recovery.....	34
3.2.1	Delivery System.....	34
3.2.2	Targeting the Oil.....	34
3.2.3	Pumping System.....	35
3.3	Decanting.....	35
4	PATH FORWARD	35
5	RECOMMENDATIONS.....	35
5.1	Detection.....	36
5.2	Recovery.....	36
5.3	Decanting.....	36
5.4	Other Issues.....	36
6	REFERENCES.....	37
APPENDIX A. OHMSETT TEST FACILITY		A-1
APPENDIX B. OHMSETT SET-UP.....		B-1
APPENDIX C. ALION SYSTEM COMPONENTS.....		C-1
APPENDIX D. MPC SYSTEM COMPONENTS.....		D-1
APPENDIX E. OSBORS SYSTEM COMPONENTS.....		E-1
APPENDIX F. RECOMMENDATIONS FOR FEDERAL ON-SCENE COORDINATORS.....		F-1
APPENDIX G. USCG INTERNAL REFERENCES.....		G-1
APPENDIX H. VENDOR CONTACT INFORMATION.....		H-1



LIST OF FIGURES

Figure 1. Approximate bottom tray layout for Ohmsett	5
Figure 2. Ohmsett test trays, looking south.	6
Figure 3. Sea Lion II ROV.....	7
Figure 4. Lamor GTA A 20 pump.	8
Figure 5. Sea Horse design front view and during testing.....	8
Figure 6. Alion schematic of general purpose decanting system.....	9
Figure 7. Approximate bottom tray layout for Alion recovery tests.....	10
Figure 8. Configuration of trays for Alion sonar test.....	11
Figure 9. Alion oil recognition results at 2250 kHz.....	12
Figure 10. Design concept for FP sensors on submersible.	15
Figure 11. MPC recommended decanting system layout.	16
Figure 12. MPC recovery locations.	18
Figure 13. Detected oil patches with RESON radar.	19
Figure 14. EIC display showing oil detection at both FP sensors.	20
Figure 15. MPC test rig during evaluation.....	21
Figure 16. View of MPC test rig with articulated arm and nozzle.	22
Figure 17. MPC actual decanting layout.....	23
Figure 18. Pictures of MPC decanting system.....	24
Figure 19. OSBORS Sub-dredge.	25
Figure 20. OSBORS design decanting schematic.....	26
Figure 21. OSBORS pump mounted on excavator.	27
Figure 22. Approximate bottom tray layout for OSBORS recovery tests.	28
Figure 23. OSBORS actual decanting schematic.	30
Figure 24. Bag filter system and Baker phase separator.....	30
Figure B-1. Intended bottom tray layout for Ohmsett.	B-1
Figure B-2. Bottom tray layout for detection trays (7-10).....	B-2
Figure B-3. Bottom tray layout for recovery trays (1-6).	B-3
Figure B-4. Viscosity-temperature curve for oils.	B-4
Figure C-1. Sea Horse conceptual design for detection.....	C-1
Figure C-2. Sea Horse conceptual design for recovery.	C-2
Figure D-1. Representation of the general arrangement of the MPC system.	D-1
Figure D-2. MPC recommended decanting layout.	D-2
Figure E-1. OSBORS Sub-dredge.	E-1
Figure E-2. OSBORS decant and polish design.	E-2
Figure F-1. Recommended decanting system.....	F-7



LIST OF TABLES

Table 1. Ohmsett oil types. 4

Table 2. Ohmsett sand sizes. 4

Table 3. Alion test matrix. 9

Table 4. MPC test matrix. 17

Table 5. OSBORS test matrix. 28

Table 6. Specifications matrix. 33

Table B-1. Sand sizes. B-3

Table B-2. Ohmsett oil types. B-4

Table F-1. Advantages and disadvantages of submerged oil detection technologies. F-2

Table F-2. Advantages and disadvantages of submerged oil recovery delivery systems. F-4



LIST OF ACRONYMS AND ABBREVIATIONS

BAA	Broad Agency Announcement
BSEE	Bureau of Safety and Environmental Enforcement
cm	Centimeter (10^{-2} meters)
CONOPS	Concept of Operations
COTS	Commercial-off-the-shelf
cP	Centipoise
CRRC	Coastal Research and Response Center
cSt	Centistokes
EIC	EIC Laboratories, Inc.
FOSC	Federal On-scene Coordinator
FP	Fluorescence polarization
ft	Foot or feet
gpm	Gallons per minute
GPS	Global Positioning System
kHz	Kilohertz (1000 cycles/second)
kts	Knots
kW	Kilowatt
m	Meter or meters
m ³	Cubic meters
m ³ /hr	Cubic meters per hour
mm	Millimeter (10^{-3} meters)
MPC	Marine Pollution Control
nm	Nanometer (10^{-9} meters)
No.	Number
NRC	National Research Council
Ohmsett	Oil and Hazardous Material Simulated Environmental Test Tank, now called The National Oil Spill Response Test Facility
OPA 90	Oil Pollution Act of 1990
OSBORS	Oil Stop Bottom Oil Recovery System
PMT	Photomultiplier tube
POC	Proof-of-concept
PVC	Polyvinyl chloride
RDC	USCG Research and Development Center
RFI	Request for Information
ROV	Remotely Operated Vehicle
Sea Horse	Seagoing Adaptable Heavy Oil Recovery System
TMT	Tornado Motion Technologies
U.S.	United States
USCG	U.S. Coast Guard
VOO	Vessel of opportunity



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1 INTRODUCTION

Even though heavy (sinking) oils have historically accounted for a small percentage of spills, environmental and economic consequences resulting from a spill can be high. Heavy oils can sink and destroy shellfish and other marine life populations in addition to causing closure of water intakes at industrial facilities and power plants. The underwater environment poses major problems for spill response, including: poor visibility, difficulty in tracking oil spill movement, colder temperatures, inadequate containment methods and technologies, and problems with the equipments' interaction with water.

1.1 Objective

The objective of this project was to develop and test viable designs for systems which can detect and recover oil from subsurface environments up to 200 feet (ft) (61 meters (m)) in depth.

The purpose of the Ohmsett tests was to demonstrate the system's ability to effectively remove highly viscous submerged oil from a variety of simulated bottom conditions, and to receive, handle, and separate the high volume of materials generated from the operation.

1.2 Background

The Oil Pollution Act of 1990 (OPA 90) requires facilities or vessels which handle, store, or transport oils in U.S. waters to identify response organizations and strategies for responding to spills of these products, including identifying methods for assessing, containing, and recovering oil from subsurface environments. Existing systems are inadequate for heavy and sunken oil detection and recovery. Regardless of whether the oil is on the surface, neutrally buoyant in the water column, or on the bottom, its' recovery is difficult.

The National Academy of Science recognized this issue and developed a report that provided a baseline for responders (National Research Council (NRC), 1999). Since that report some progress has been made to identify successes and performance gaps (Coastal Research and Response Center (CRRC), 2007, Michel, 2008, and Rymell, 2009). In addition, a guideline for assessment and removal techniques is being developed by the International Maritime Organization (Chapman, 2011).

There are few submerged oil spills, so there is little incentive for industry to develop capabilities. Responses to recent submerged oil spills have shown responders have almost no capability in detection and recovery. In addition, Congress authorized the Department of Commerce and the Coast Guard to develop a submerged oil program (USC 2006). The U.S. Coast Guard (USCG) Research and Development Center (RDC) pursued this effort to develop these capabilities

Previous to recent USCG efforts, some research work had been done on detection of heavy oil. Laser fluorometers have been shown to have the capability to detect oil spills at night and to detect oil under the water surface, while in-situ fluorometers that detect hydrocarbons in the water column have also been developed. Finally, oil on the bottom has been located visually and with sonar. It is anticipated that a combination of sensors may be needed in order to search and confirm the location of oil.



Heavy Oil Recovery Ohmsett Test Report

The typical method of recovering oil on the bottom of the sea floor has been for a diver to take down a suction hose so that a pump can move the oil to the surface. For shallow spills the pump is located on a vessel or pier, and it discharges into some type of holding tank. For deeper oil, submersible pumps are attached to the diver's hose and intermediate pumps may be needed at the surface. The issues with this approach are lack of visibility and endurance for the diver, concerns about diver safety, and the large amount of water and sediment collected with the oil. In addition, the methods required for separation of the oil from the other components vary as the oil, sediment, and water temperature change.

The RDC heavy oil project began with a general Request for Information (RFI) in spring 2006. There were responses from 15 organizations, some of which addressed several topic areas. The range of costs indicated that the project would need to proceed in stages with detection issues addressed first. A Broad Agency Announcement (BAA) was released in summer of 2006 with proposals due in the fall. Two layers of specification were listed, one for immediate verification (proof-of-concept) and one for the second phase (prototype development). Four detection proof-of-concept devices were evaluated at Ohmsett between November 2007 and February 2008 (Hansen and Fitzpatrick, 2009). The next step was to address recovery issues.

1.3 Approach

The RDC developed specifications and released a BAA in June 2009 for a two-phased approach to heavy oil recovery. The Phase I System Design was expected to last 10-12 months. The Phase II Prototype Development was also expected to last 10-12 months with testing at Ohmsett in 2011.

1.3.1 Specifications and Performance Requirements

The main objective of these specifications was to define a fully integrated system that included detection, recovery, waste processing, and the release of clean water. The specifications were developed to address some of the major problems likely to be encountered, including lack of visibility, endurance of divers, and the need to handle a large amount of water and sediment along with the oil during the actual recovery. The BAA said the design concept should demonstrate as many of the following capabilities as possible:

1. Presence of heavy oil on the sea floor identified with 80 percent certainty.
2. Oil location geo-referenced to within 16.4 ft (5 m) in accuracy.
3. Minimal dispersion of oil or bottom material into the water column.
4. Provides real time data/feedback.
5. Provides recovery for all sea floor conditions (silty, rocky, and gravel bottom types; vegetation and shellfish-covered bottoms; and over flat and sloped areas and areas with rapid substrate changes).
6. Operates in fresh and sea water conditions equally well.
7. Operates in water depths of up to 200 ft (61 m).
8. Minimal maintenance requirements (easy to maintain and calibrate).
9. Easy to operate and requires minimal training.
10. Easily de-contaminated and durable.
11. Equipment operation not adversely affected by exposure to oil.
12. Operates in water currents at the surface of up to 1.5 knots (kts).
13. Deploys and operates in up to 5-ft (1.5-m) seas.
14. Operable during the day and night.
15. Sets up within 12 hours of arriving on site – special requirements shall be identified.



Heavy Oil Recovery Ohmsett Test Report

16. Viscosity – operates in the range of 2,000-100,000 centistokes (cSt).
17. Includes a decanting system that can handle the heavy oil and any oil that refloats in the recovery process.
18. Process to complete “polishing” the resultant water for disposal.
19. Minimal impacts to benthic resources that may be disturbed.

It was recognized that not all of the specifications could be evaluated during a test in a tank but could be described in the design documentation.

1.3.2 Phase I System Design

Three vendors were awarded contracts to develop designs to meet the specifications:

- Alion Science and Technology Corporation
- Marine Pollution Control (MPC)
- Oil Stop Division of American Pollution Control

The prime vendors teamed with other companies to provide additional expertise. Each vendor addressed the detection, recovery, and processing of the recovered material. Final Phase I reports were reviewed in November 2010. This current report describes the evaluation of the final designs that were reviewed in the Phase 1 report.

1.3.3 Phase II Prototype Development and Testing

Testing of design elements was conducted at the Ohmsett facility in Leonardo, NJ in November 2011. Details of the Ohmsett facility can be found in APPENDIX A. This report is based on the reports from the contractors (see References in Appendix G) and government observations.

Trays were laid on the bottom of the Ohmsett test tank and filled with two types of sand from ~1-4 inches (2-10 centimeters (cm)) in depth and three types of oil ranging in viscosities from about 15,000-140,000 centistokes (cSt) at thicknesses of 0.5-7 inches (~1-18 cm). Details of the test set-up can be found in Section 2.1 and APPENDIX B.

2 SUBMERGED OIL RECOVERY SYSTEMS

2.1 Overview

2.1.1 Design

The main design components for each system include detection, operation, and decanting and are described in the following Sections.

2.1.2 Testing

The purpose of the tests was to demonstrate the systems’ ability to effectively detect heavy oil on the sea floor, remove highly viscous submerged oil from a variety of simulated bottom conditions, and to receive, handle, and separate the high volume of materials generated from the operation.



Heavy Oil Recovery Ohmsett Test Report

For the Ohmsett tests, three types of highly viscous oil (see Table 1) were placed in submerged test trays on the bottom of the Ohmsett Tank. Each tray contained loose sand and various obstacles. Two types of sand were used – concrete and mason. Table 2 shows the particle size distribution for the two sand types. Note there is not much difference between the two sands, although the concrete sand is a little coarser.

Table 1. Ohmsett oil types.

Oil Type	Viscosity (cSt) (approximate)
Sundex	15,000
Tesoro/diesel (2.5 percent) mix	50,000
Tesoro	140,000

Table 2. Ohmsett sand sizes.

Sieve Size	Particle Size (mm) ¹	Concrete (#1) Percent Passing	Mason (#2) Percent Passing
3/8 inch	9.525	100	
#4	4.75	97.5	100
#8	2.38	92.7	97.1
#16	1.2	80.5	84.3
#30	0.599	54.3	58.6
#50	0.297	17.2	34.5
#100	0.152	2.3	7.3
#200	0.075	1.1	2.5

¹From [http://en.wikipedia.org/wiki/Mesh_\(scale\)](http://en.wikipedia.org/wiki/Mesh_(scale))

For the experiment 10 trays of width 8 ft (2.4 m) and length 20 ft (6.1 m) were positioned on the bottom of the Ohmsett test tank. The original tray design was a T-shaped geometry, with a thin rectangle of 4 trays pointing toward north, in the North Area, and 6 trays arranged in an almost square shape in the South Area (see Figure 1). Figure 2 shows the ten Ohmsett test trays in place.

The sediment in North Area is dominated by sand and contains long rectangular patches of sunken oil together with concrete blocks and stone piles. These trays were intended to be used primarily in the detection tests. In the South Area the sediment is dominated by oil and has a few patches of sand. These trays were intended to be used primarily in the recovery tests.

The original intent was to have all three vendors use the same configuration for testing. There are various reasons why this wasn't possible. The actual layout for each test is described with each vendor section.



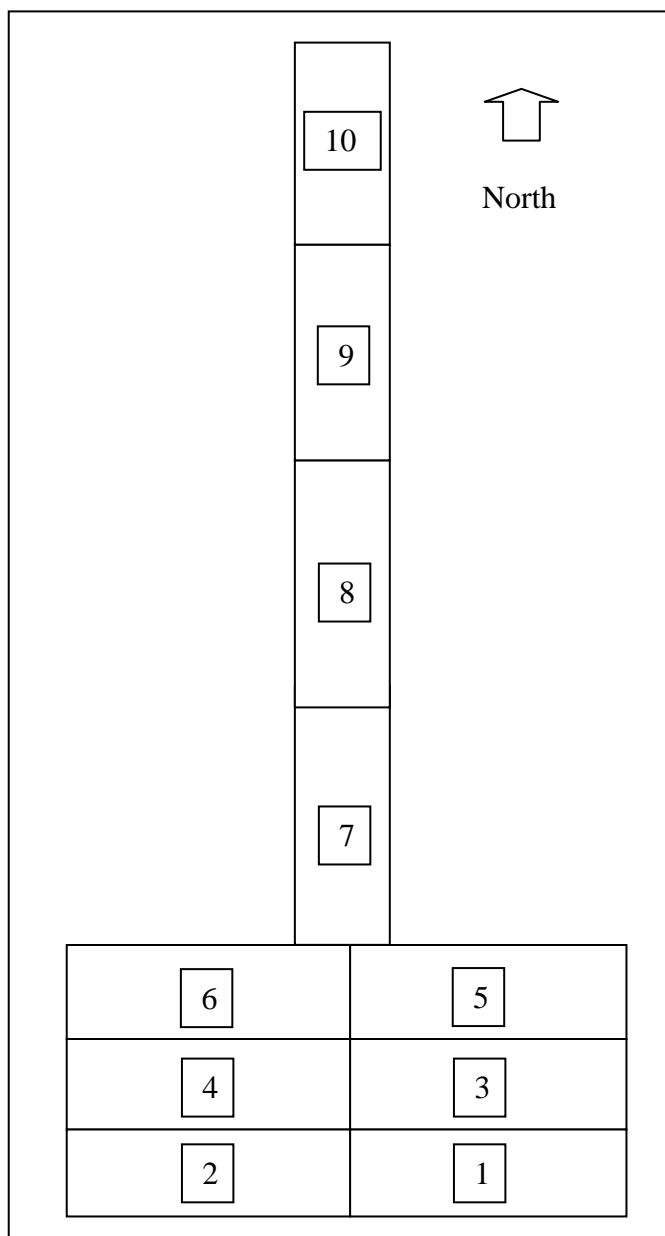


Figure 1. Approximate bottom tray layout for Ohmsett





Figure 2. Ohmsett test trays, looking south.

2.2 Alion Science & Technology Seagoing Adaptable Heavy Oil Recovery System (Sea Horse)

Alion designed a system based on small Remotely Operated Vehicles (ROVs) to fill the niche of a lightweight approach, called Sea Horse (SEagoing Adaptable Heavy Oil Recovery SystEm). The three major aspects considered crucial were: mobility, flexibility, and low cost. A single ROV is needed during the search and detection phase of the operation and then teamed with a second ROV for recovery operations.

2.2.1 System Design

The complete Sea Horse system consists of three major subsystems: detection, recovery, and decanting plus auxiliary equipment. Additional details of Alion's design, including a suggested Concept of Operations (CONOPS), can be found in APPENDIX C.

2.2.1.1 Detection

The detection system consists of the hull-mounted multi-beam sonar hardware, a single ROV (with cameras), the location system, and commercial-off-the-shelf (COTS) and custom software. A sonar system (preferably a multi-beam system) is temporarily mounted on a vessel of opportunity (VOO) for wide-area searching. The navigation system, plus Global Positioning System (GPS) receiver and a heading/roll/pitch sensor, is mounted on the VOO for geo-referencing the sonar data. A combination of COTS and custom-developed software is used to identify oil in the sonar imagery. As mentioned above, one of the ROVs in the recovery system can be used independently for underwater confirmation of oil or a total of three are needed for search and recovery to occur simultaneously.

In order to keep the system concept as flexible as possible, the system was not designed for a specific sonar. Sea Horse can use whatever sonar system happens to be available. This flexibility is enabled through the software selected, which provides a common user interface regardless of the hardware. Obviously, the detection performance will be a function of the specific sonar hardware selected. For the Phase II proof-of-concept Alion used the BlueView MB1350 and MB2250 systems (both multi-beam line scanners) for oil detection and the BlueView P900-130 (multi-beam field sonar) system for tracking the Sea Horse from the "decanting barge."



Heavy Oil Recovery Ohmsett Test Report

To retain overall system flexibility, Sea Horse has been designed to use a variety of hardware with resulting position accuracy again a function of specific hardware choices. The precise positioning system (GPS and roll/pitch/heading sensor) is mounted on the VOO and used to geo-reference the multi-beam sonar data. This allows the precise position of any sea bottom oil detected by the sonar to be determined during the detection phase. For the prototype testing, the positioning system consisted of a Trimble SPS-351 GPS receiver and an HMR 3000 compass.

2.2.1.2 Recovery

The recovery system consisted of an ROV-powered sled, the pump, the nozzle, and the hoses. The ROV selection was driven by four factors: weight, thrust, size, and cost. Of ten ROV systems considered, two systems stood out: JW Fisher's Sea Lion II and the Benthos Mini Rover. The Sea Lion II was selected for the Ohmsett tests (see Figure 3). Sea Horse used two ROVs mounted on a frame (see Figure 5).



Figure 3. Sea Lion II ROV.

The pump chosen for the Sea Horse test at Ohmsett was the Lamor model GT A 20 pump (see Figure 4). It is designed specifically for handling high viscosity materials and is in use for spill recovery. The Lamor pump is an Archimedes screw type of pump capable of creating some suction to supply the inlet side of the pump. However, it operates best as a flooded suction pump and is mounted on the ROV with a short nozzle.

This pump has a capacity of 88 gallons per minute (gpm) (20 cubic meters per hour (m^3/hr)).

The ROVs and pump were mounted on an aluminum framework. Buoyancy was added to maintain a level orientation for the system (see Figure 5 (left) for the conceptual design). The yellow cylinders on either side are the commercial ROVs. The pump is mounted on the frame in the middle. The red box over the pump is the flotation-for-buoyancy compensation. An example nozzle (black) is shown on the intake side connected to the pump by a short hose. This was replaced by two sections of white PVC pipe in the actual system. The discharge hose also has flotation strapped to it to keep the hose floating just off the sea floor. Figure 5 (right) shows the Sea Horse during testing.





Figure 4. Lamor GTA A 20 pump.

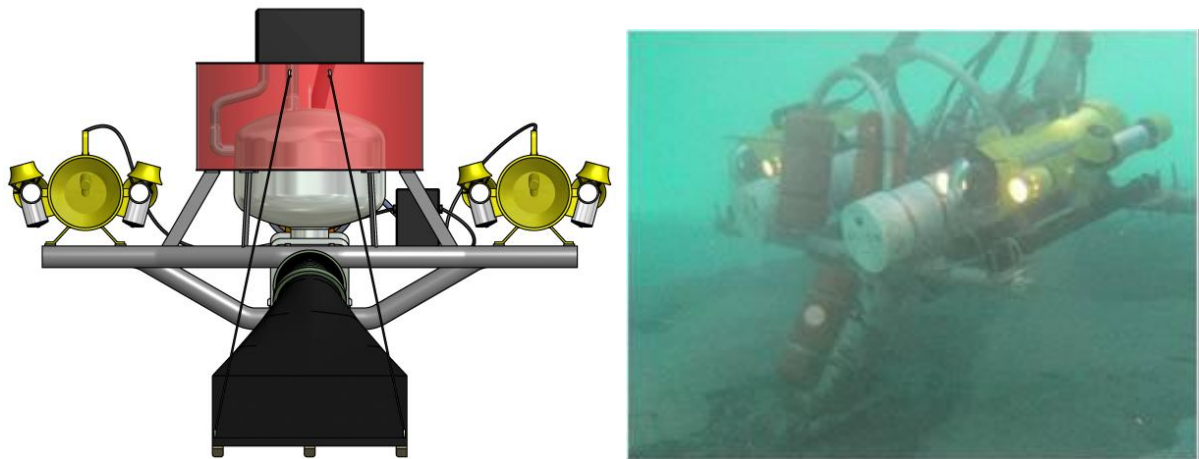


Figure 5. Sea Horse design front view and during testing.

2.2.1.3 Decanting

Alion acknowledged in their design document that the decanting system must be designed to handle heavy oils as well as a large load of sediment or sediment-loaded oil. This requires a multi-stage decanting system that can be mounted on a barge or on the shore. It would consist of a cascade of tanks acquired locally with the number of stages designed to suit a particular spill situation. The discharge of water and oil from the recovery system goes into a first stage (settling) tank; heavy materials settle, and water is decanted into a second tank using a submerged pump inlet. Skimmers and/or sorbent snares are placed on top of downstream tanks and the liquid cascades down into second and subsequent tanks. The “polishing” tank is filled with sorbent oil snares. Multiple lightweight devices with cyclic-acting pumps may allow uptake to be more efficient. The system is set up to be modular and can be configured to handle a variety of combinations of oil, water and sediment. This system (Figure 6) is conceptual and was not tested at Ohmsett.

Heavy Oil Recovery Ohmsett Test Report

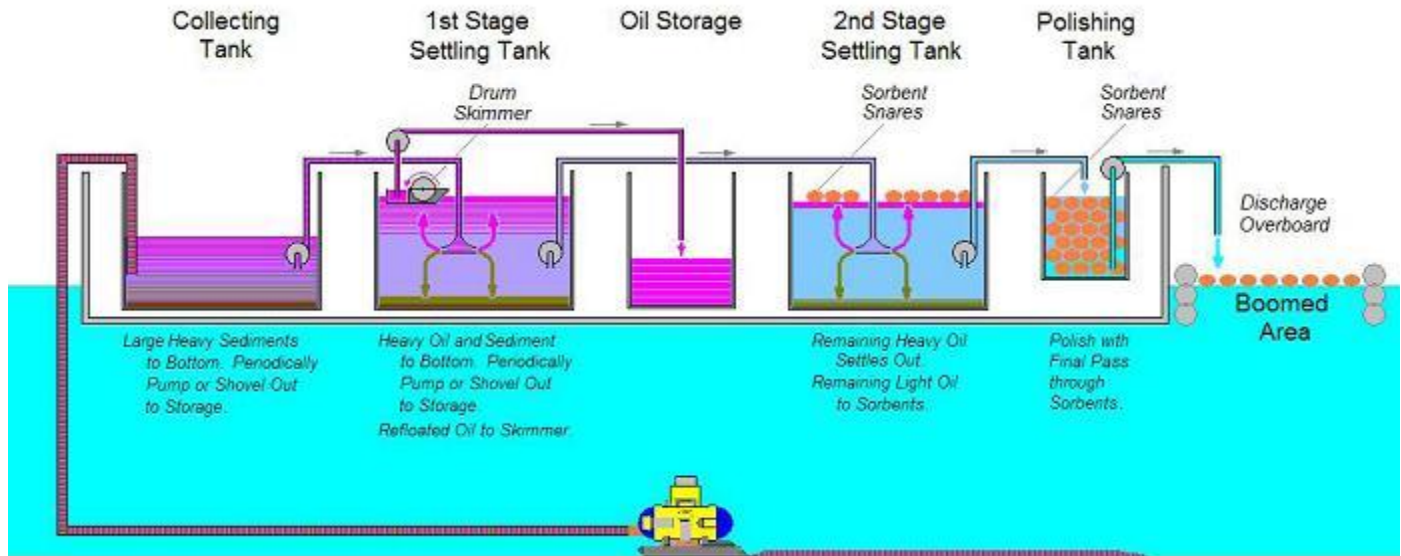


Figure 6. Alion schematic of general purpose decanting system.

2.2.2 Ohmsett Test Procedure

The Sea Horse is designed to be deployed from a vessel. The Ohmsett platform was used as a substitute. This was the first of the three systems tested, and the full tray configuration was not available. The configuration of the seven available trays used for recovery testing is shown in Figure 7. Table 3 gives Alion's test matrix. Alion detection tests were conducted after the other two systems were tested. Figure 8 shows the configuration for the detection tests.

Table 3. Alion test matrix.

Test Series	Title/Focus	Tray/Other
1	Pump test 1-3	7
2	Pump test 4	On surface ¹ – Sundex
3	Pump test 5	9
4	Pump test 6	10
5	Pump test 7	On surface ¹ - Tesoro/diesel
6	Sonar test	4, 5, 6, 8 (in-line configuration)

¹Note: On Surface: Nozzle placed in barrel of pure oil on Ohmsett deck



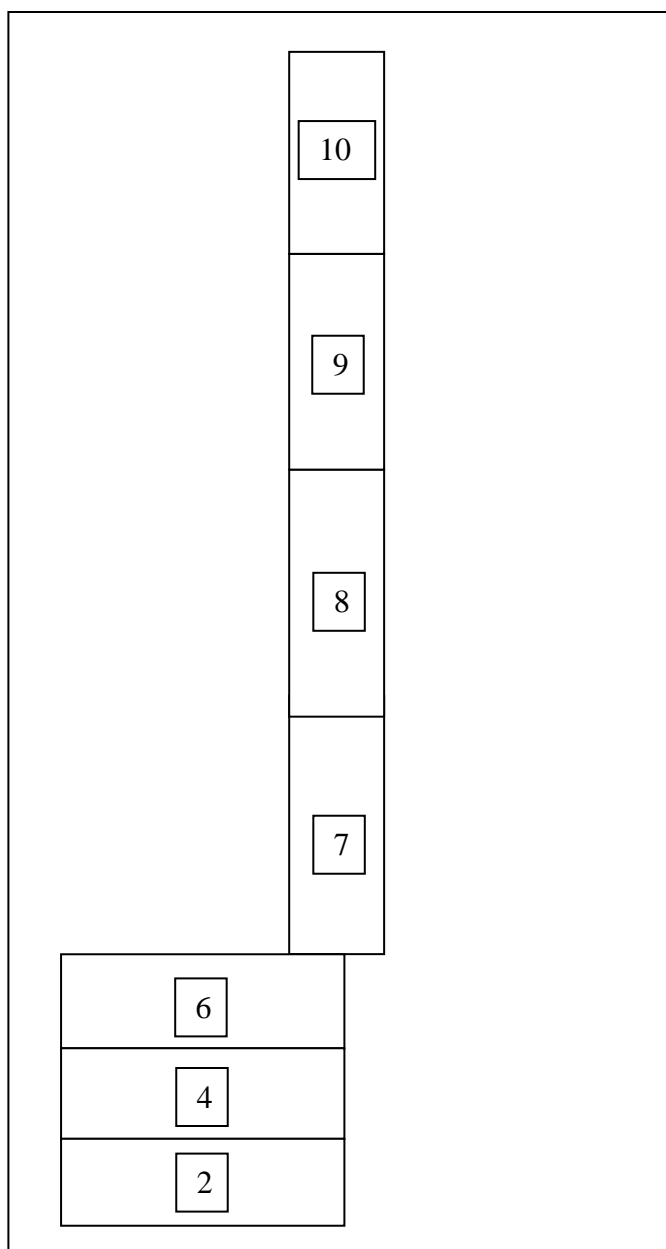


Figure 7. Approximate bottom tray layout for Alion recovery tests.

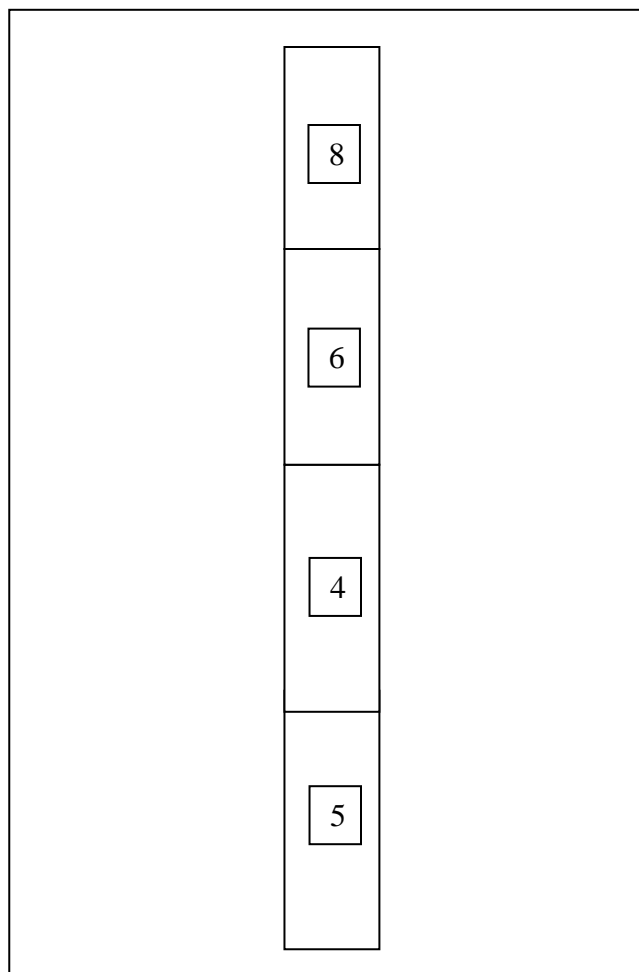


Figure 8. Configuration of trays for Alion sonar test.

2.2.3 System Performance

2.2.3.1 Heavy Oil Detection

Sonar data were collected at two different frequencies, 1350 kHz and 2250 kHz, and were separated as “north” or “south” to indicate the direction of the platform movement. Given the shallowness of the tank and the field of view (angle) of the BlueView sonar, four scans were necessary to cover the 8-foot (2.4-m) width of the trays. Both depth (bathymetric) and sonar return intensity values were collected. Figure 9 shows sample results from 2250 kHz.

After processing the detection data, Alion reported 83 percent of the oil was detected using the 1350 kHz sonar and 92 percent was detected using the 2250 kHz sonar. It should be noted that this assessment is based on percentage of total area detected; this may not be the best metric. The algorithms successfully identified all regions of oil; the difference was in identifying the same boundaries of the areas as compared to those selected in the (estimated) ground truth. The detection system was mounted on the platform. There is a very big difference, however, between detection at 6-8 ft (1.8-2.4 m) (depth of pool at Ohmsett) and detection at 200 ft (61 m). At greater depths, the beam spreads much more, but this greater coverage impacts resolution.



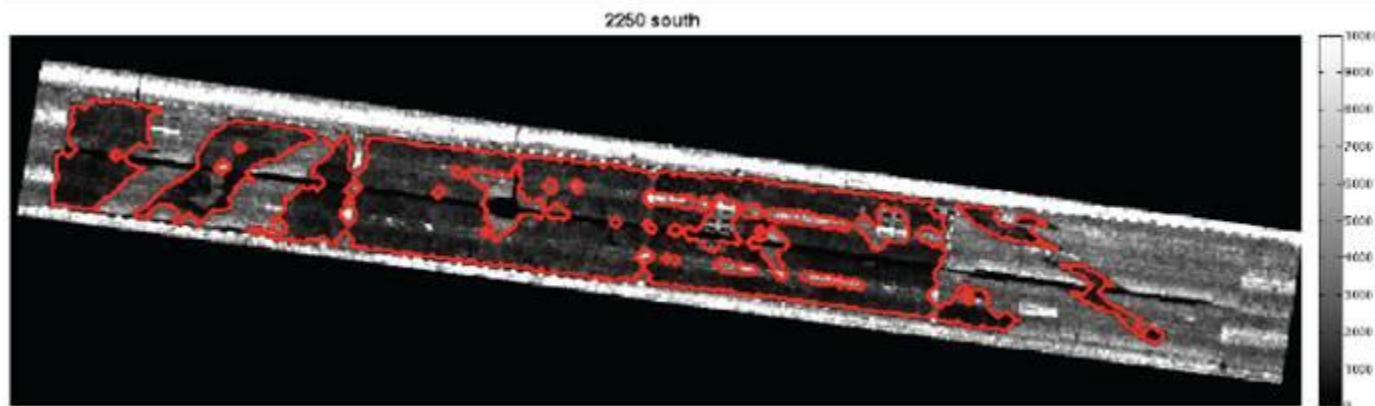


Figure 9. Alion oil recognition results at 2250 kHz.

2.2.3.2 Recovery

The system brought to testing weighed about 201 pounds (91 kilograms) when assembled; but any of the individual components could be handled by 1-2 people, so it meets the lightweight criteria. After some time in establishing neutral buoyancy, the recovery system was deployed into the oil.

Maneuverability and Control

Alion developed custom hardware and software to enable simultaneous control of both ROVs on the sled using a single control stick. This system worked well. Positioning of the Sea Horse to provide continuous movement of the nozzle through the sample materials for uninterrupted pumping was problematic because the thrusters on the ROVs were not powerful enough to move the nozzle through the sample material while the pump was running. Also, the system could only handle currents of less than 1.5 kts. This challenge could potentially be solved by replacing the Sea Lions with more powerful ROVs.

Oil Recovery Performance

In testing, the Lamor pump was able to successfully pump the ~15,000 cSt materials without difficulty. The pump was also able to pump the heavier ~50,000 cSt material through a short section of hose; but when trying to pump through the 50-ft (15-m) long, 4-inch (10 cm) diameter hose used with the Sea Horse, the material became plugged in the hose. The pump did not bog with the heavier material but the material would not move any further and only a small amount of water was able to pass around the plugged material in the hose. Only a small amount of oil was actually recovered. The pump was shown to easily handle these oils on the surface through a short hose, so possibly a smaller nozzle arrangement and smaller recovery hose along with the water injection may solve these problems.

2.2.3.3 Decanting

The designed decanting system was not demonstrated.

2.2.4 Lessons Learned

- Sea Horse had a problem with the oil covering and obscuring the forward and reverse camera view through the Plexiglas bubbles of the ROVs. The solution was to use the commercially available product, Rain-X, to coat the Plexiglas bubble lenses.
- To simulate operations in water currents, a drag test was performed by using the moving bridge platform at Ohmsett. At 1.25 kts the Sea Horse began to fall behind the moving bridge platform. In

order to achieve 1.5 kts, either additional horizontal thrusters would need to be added or a more powerful ROV system such as the Benthos MiniRover would be required. The MiniRover with about three times the thrust, was the recommended choice in the design phase, but was not purchased due to cost constraints.

- Testing conducted with Benthos MiniRover ROVs in place of the JW Fisher Sealion II ROVs would be beneficial to determine if the more powerful thrusters on the Benthos machine will improve maneuvering of the Sea Horse and improve movement of the nozzle during pumping. Alternatively, additional thrusters could be integrated into the Sea Lion-based system.
- One of the weaknesses with the current sled design is a lack of pitch control. The location of the ROVs and location of the thrusters on the Sea Lion ROVs provides good control over roll and yaw but no control over the pitch.
- The addition of attitude sensors (pitch/roll) to the Sea Horse would be beneficial to aid the operator in positioning the unit for optimum oil recovery performance. These could be easily added and integrated into the Sea Lion ROVs.
- A higher accuracy locating/positioning system is needed to increase the sonar data analysis performance.
- The pump was not able to move the more viscous oil through a long section of hose. One of Lamor's engineers said this problem should be overcome by using water injection. The addition of water injection should improve pumping capability by as much as 300 percent while the use of hot water for the water injection will improve the pumping capability even further. Note: water injection will add more water to the decanting process.
- The shape and size of the pump nozzle should be refined to be compatible with pump, hose configuration, and oil type.

2.2.5 Path Forward

Alion elements to be tested in the Phase III field test:

- Ability to be deployed and operate in up to 5-foot (1.5-m) seas.
- Detecting the presence of submerged oil (oil substitute) on the sea floor and identify the submerged oil with an 80 percent certainty (at depths greater than Ohmsett).
- Provide submerged oil location geo-referenced to within 16 ft (5 m) in overall accuracy.

2.3 Marine Pollution Control

Marine Pollution Control (MPC) developed a system composed of a manned submersible teamed with a recovery capability and additional sensors including an oil-discriminating sonar and fluorescence polarization (FP) sensor. Additional details of MPC's design, including a suggested CONOPS, can be found in APPENDIX D.

2.3.1 System Design

The MPC design uses a manned submersible connected to the surface by a robust, multipurpose marine umbilical system. The main advantages of this approach over divers are the ability of the submersible to stay down longer and deeper and the visibility that the clear sphere provides. The system is comprised of the following primary components:



Heavy Oil Recovery Ohmsett Test Report

- A vessel of opportunity (VOO) from which the operation will be conducted, of appropriate size and design to support an operation using the system (specified within the design but not a part of the design effort).
- A submerged oil pumping apparatus comprised of a hydraulically powered transfer pump integrated into an umbilical deployment and storage system capable of mobilization at the required depth of 200 ft (61 m).
- A manned submersible unit, outfitted with appropriate equipment to connect to the pumping apparatus at the terminating oil recovery skimmer head nozzle and capable of manipulating the equipment at the required depth of 200 ft (61 m). The manned submersible is also capable of deploying oil detection equipment to aid in the assessment and recovery of submerged oil masses, and navigational, communication, lighting, and video equipment to assist in that purpose. The company SEAMagine has a group of submersibles capable of depths up to 900 ft (275 m) that could work in this system.
- Oil detection equipment including oil discriminating sonar and FP sensors.
- A decanting system for processing the oil/water mixture that will be recovered via the pumping system during operations.

2.3.1.1 Detection

MPC's detection system used two sensors tested in connection with the previous portion of RDC's initiative to address the detection and recovery of submerged oil:

- Oil discriminating sonar technology from RESON A/S of Slangerup, Denmark, with offices in Goleta, CA.
- Fluorescence polarization (FP) from EIC Laboratories of Norwood, MA.

For this effort, RESON refined its technology and technological approach to improve the capacity of its systems (models Seabat 7125-SV and Seabat 7128-AUV) and align its use with MPC's solution for submerged oil recovery. The sonar units can be deployed either independently of the manned submersible to accomplish broad area survey capacity (the "downward looking" configuration), or can be mounted on a tilt and pan mechanism on the manned submersible to provide the pilot and operator with a real-time enhanced image of oil masses directly in front of them as they navigate in the subsurface environment.

The EIC equipment utilizes a laser system to affect a fluorescence polarization condition that can be used to detect the presence of oil in subsurface environments. Similar to the sonar system, the design provides a tilt and pan mechanism for deployment of the sensor in the area immediately in front of or below the cabin of the manned submersible. The direction and distance of the detection capability can be determined by the operator in the submarine, and a panel display will provide real-time data (the "forward looking" or "autofocus" configuration). Additionally, a second proposed application for this technology has been integrated into the recovery system by deploying a "fixed focus" FP into the skimmer head recovery nozzle (see Figure 10 for conceptual design). This sensor will detect oil within the fluid passing through the recovery system near the nozzle and will provide its data in real-time to the operator inside the cabin, thus providing another element to the feedback loop available to refine the oil recovery operations on site.



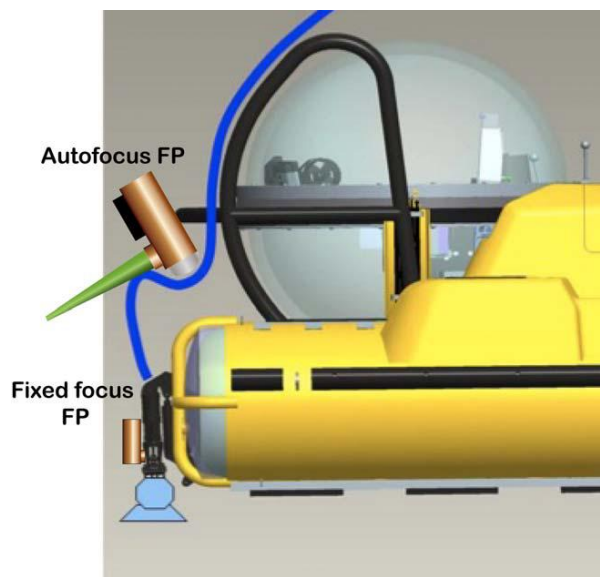


Figure 10. Design concept for FP sensors on submersible.

2.3.1.2 Recovery

MPC designed the recovery system, which includes a transfer pump, a vortex enhancer/debris chamber, and a skimmer head recovery nozzle. The function of the transfer pump is to provide the necessary suction and discharge flow to effectively draw in submerged oil at the nozzle and deliver it topside to the storage and decanting systems positioned on the VOO on the surface. The pump is mounted inside a custom-built carriage cage incorporated into the umbilical deployment system, and can accept a number of different pumps to increase operational variability of the system. All pumps selected thus far are of a centrifugal submersible design and are hydraulically powered.

Mounted on the intake of the transfer pump is a vortex enhancer/debris chamber; a cylindrical chamber with a port on its side to allow for connection of the suction hose. This device has two purposes that work in tandem to promote efficient oil recovery capacity. First, it acts to produce effective flow at the pump's intake and focus that flow through the suction hose leading to the skimmer head nozzle. Second, the chamber allows for larger solids that have entered the suction hose to fall out of the flow path to the bottom of the chamber, preventing unnecessary damage to the impeller of the pump. A removable, cone-shaped mesh screen is included inside the chamber to further enhance the system's ability to screen out damaging debris from the pump intake.

The skimmer head nozzle is deployed at the end of the suction hose and is designed to be held in the oil mass by the robotic arm of the manned submersible. The nozzle has multiple capabilities, including a heating capacity to assist in the recovery of thick, heavy oil and sensors and detection devices to provide feedback to the operator in the submarine's cabin. It has been designed to allow for adaption of other nozzle shapes, configurations, and enhancements by means of a cam-lock fitting connection (i.e., one skimmer head can be quickly removed and replaced with another in the field).

2.3.1.3 Decanting

The use of a pumping strategy for submerged oil recovery operations results in a significant, although manageable, amount of water accumulated during the recovery process. Although water intake may be

Heavy Oil Recovery Ohmsett Test Report

minimized through efficient skimmer nozzle design and operational techniques afforded the oil recovery operator in the manned submersible, significant amounts of water must be appropriately managed during the operations.

MPC has identified a number of appropriate technologies for oil/water separation and management, and has described a plan for developing a decanting process that is suitable for use with the system. Due to the wide range of different types of sinking oils, and their specific properties and behaviors, a decanting strategy with one set of equipment is not appropriate; some oils may require extensive decanting system equipment suites while others may separate for decanting purposes using a minimum of equipment. Figure 11 shows MPC's recommended decanting system design.

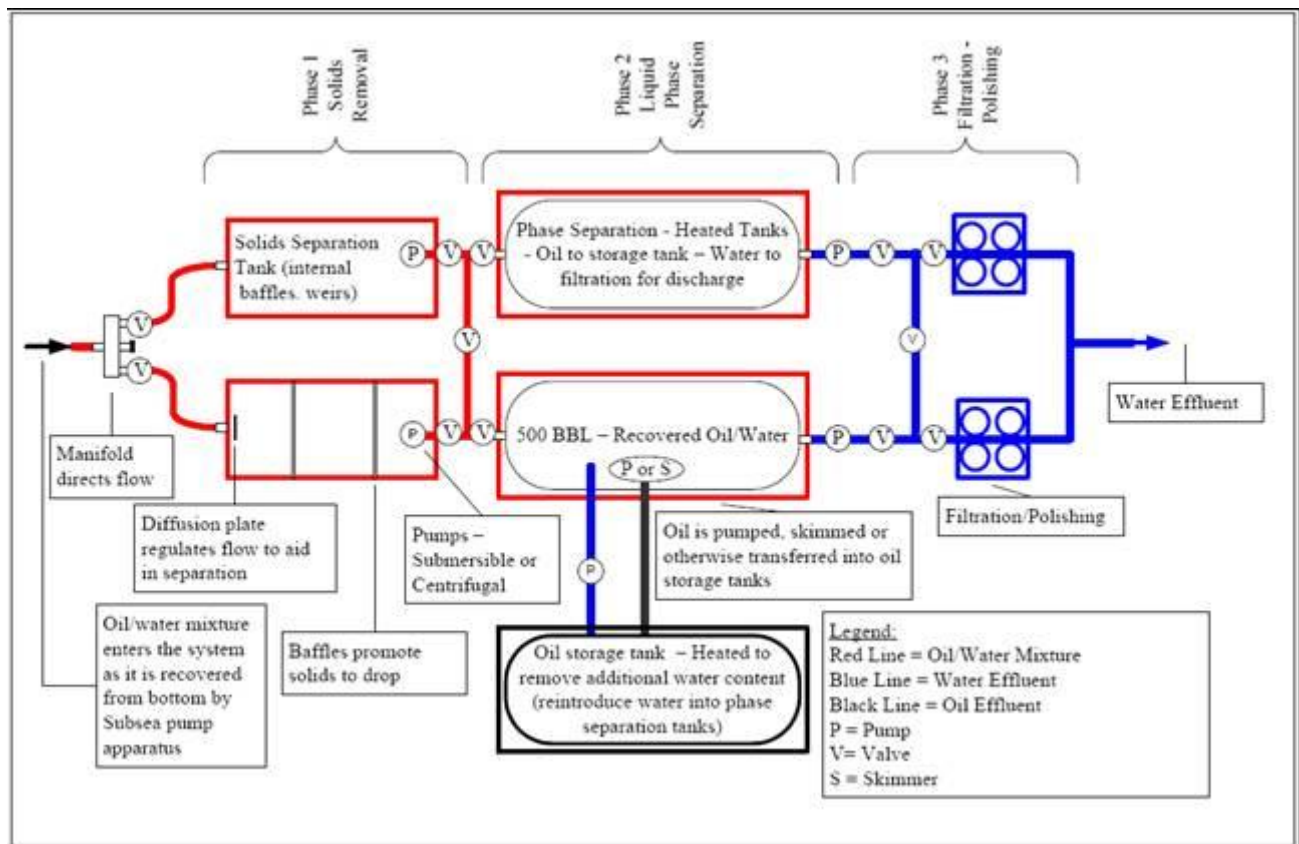


Figure 11. MPC recommended decanting system layout.

2.3.1.4 Design Concept Testing

The design concept, in prototype form, was field tested by MPC at two separate locations: Lake Travis, Texas in 2006 and Detroit, Michigan in 2007. In both of these cases, the submerged oil recovery pumping apparatus was connected to a manned submersible device and was used in operational configuration to recover simulated oil from the bottom of a water body. Additional field testing of the pumping apparatus was performed in 2010 to refine design ideas and guide further development of the system. In the future, MPC intends to perform additional field testing of the pumping and detection apparatus in diverse marine environments to extend the operational capacity of the design concept. This will include enhancement of the pump and debris control as well as the development of options for the separation process.



Heavy Oil Recovery Ohmsett Test Report

2.3.2 Ohmsett Test Procedure

The MPC tests at Ohmsett included proof-of-concept and baseline testing of the recovery and detection aspects of the system, as well as their deployment in conjunction with appropriate oil/water separation technologies to demonstrate overall system capacities. The configuration of the test trays and locations of tests is shown in Figure 12.

Since the Ohmsett tank was too shallow to deploy the submersible, a test rig was configured to represent the operational parts of the submarine including a heated nozzle, a robotic arm, a sonar, two FP sensors, and multiple video cameras and lights. A pump with a capacity of 2,200 gpm (500 m³/hr) mounted on a Vortex Enhancer to further control debris was hung from the main Ohmsett bridge. A full oil separation system was provided including two large tanks, a filter system, a heater to provide steam, and pumps with adjustable inlets that could take water from the tank without taking oil from the surface or the bottom.

MPC's test strategy focused on using the tests to investigate the capabilities of the individual technologies associated with the design concept, as well as to explore the capabilities of those technologies when functioning as an integrated system. Throughout the test process focus was placed on examining the technologies from the perspective of their eventual use in the field.

The prototype can be considered as five separate systems:

- MPC subsurface recovery system/pumping apparatus (including nozzle heating system);
- RESON oil-discriminating multi-beam sonar, deployed as a survey tool over trays 7-10 (Figure B-2) and as a forward-looking oil-discriminating display tool to guide the pilot/operator of the manned submersible (the "pilot/operator")
- EIC FP oil sensors, deployed as a forward looking oil detection tool for the pilot/operator and as an in-line sensor indicating the presence of oil within the suction hose of the recovery apparatus
- SEAmagine robotic arm and electro-hydraulic controls, pressure and temperature sensors, audio sensor for the pilot/operator, video cameras, and lighting
- MPC decanting system including storage and separation tanks, heating system, transfer systems for oil and water, and water filtration systems

Table 4 gives MPC's test matrix.

Table 4. MPC test matrix.

Test Series	Title/Focus	Tray/Other
1	Detection – RESON Sonar (see Figure B-2)	All
2	Detection – EIC FP (see Figure B-2)	All
3	Recovery – 11 positions (see Figure 12)	1, 2, 3, 5, 6
4	Decanting/filtration – 3 sequences	



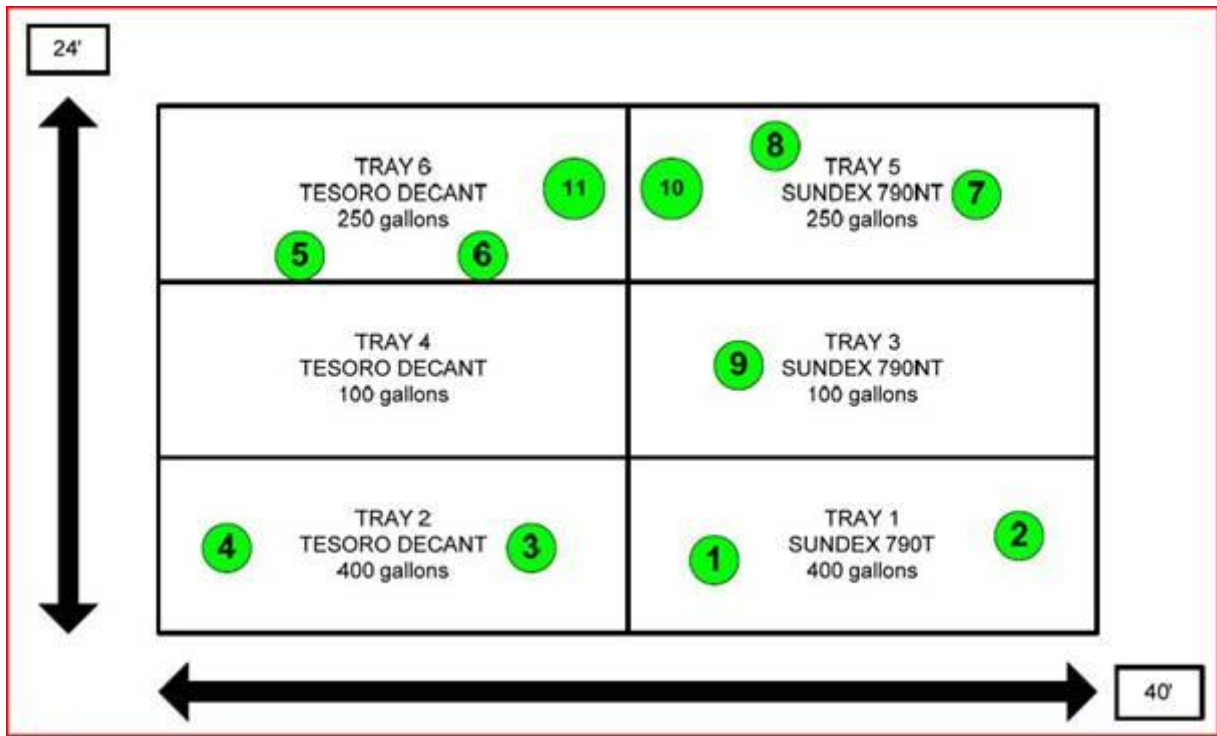


Figure 12. MPC recovery locations.

2.3.3 System Performance

2.3.3.1 Oil Detection

The RESON and EIC equipment functioned to locate and map the oil within trays 7-10, particularly when considered in tandem, with each detection device validating the results presented by the other. The first observation from the testing was that while the RESON equipment was clearly able to identify the shape and size of oil masses on the trays (Figure 13), it was the fact that the EIC sensor was able to simultaneously confirm that it was indeed oil (Figure 14) that provided the necessary level of confidence that would drive field operations.

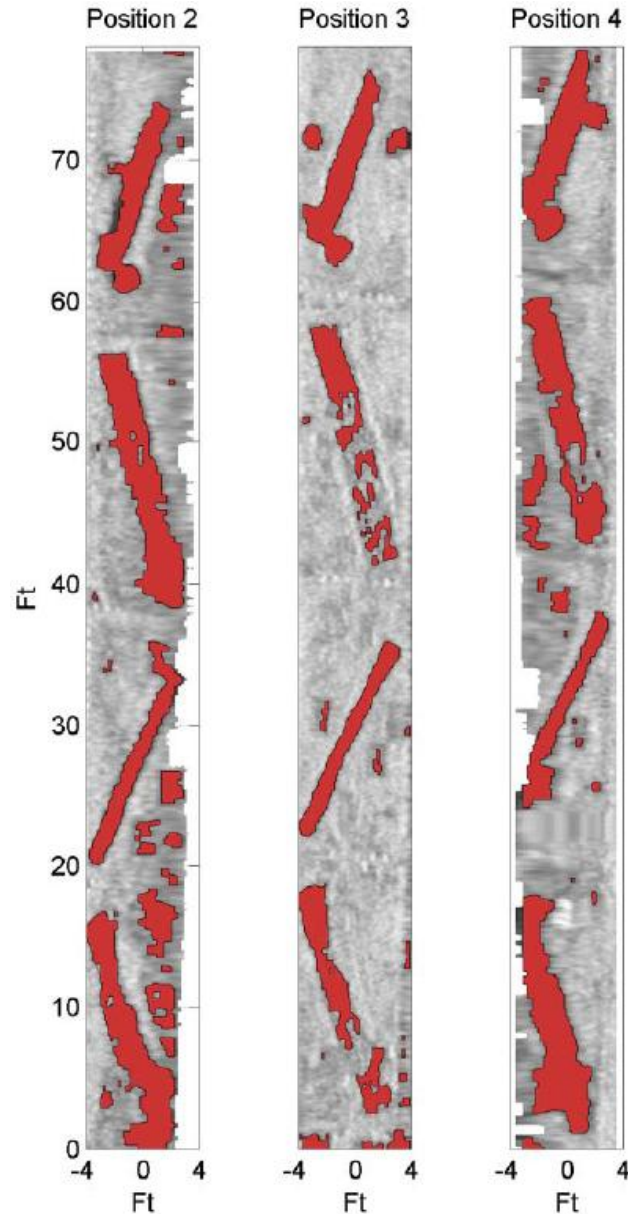


Figure 13. Detected oil patches with RESON sonar.

The RESON SeaBat 7125 downward-looking sonar has been applied for detection of heavy oil on the seabed. All acoustic data processed and presented here is acquired at 400 kHz for both the downward-looking and forward-looking sonars. Sunken oil has been detected with a certainty between 80 percent and 90 percent. The shapes of the areas can be extracted with a high degree of certainty. The false alarm rate is around 20 percent using the downward-looking system. Oil appeared to be seen using the forward-looking sonar but a strict analysis was not performed. The pilot of the submersible also has the use of an additional sonar mounted for navigation.

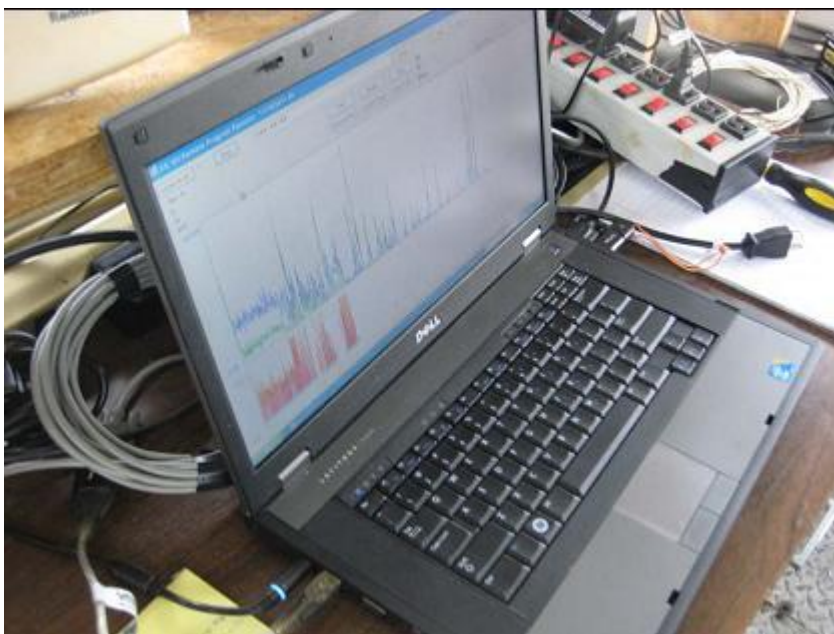


Figure 14. EIC display showing oil detection at both FP sensors.

The forward-looking capabilities of the SeaBat 7128 system are good. Images of the seabed contain high contrasts and a high amount of details. The oil detection software in the forward looking system still needs improvements and cannot be applied at this stage. The forward looking system does not work while oil is being removed as the MPC equipment uses steam at high pressures which has a damaging impact on sonar performance.

The FP technology is very specific to heavy oil detection since heavy oils are highly fluorescent and also exhibit strong fluorescence polarization due to their high viscosity. Thus, FP can be used to selectively differentiate heavy oil fluorescence from other fluorescing species in seawater, such as chlorophyll, that most likely will not show fluorescence polarization. The technology also works well in bright daylight conditions due to the fact that daylight is not polarized and also to the modulation scheme embedded in the detection electronics. The main limitation of the technique is detection in turbid or murky environments, where the suspended particulates in the water will scatter the laser excitation and thus significantly attenuate the FP signal. Thus, the FP instrument will have to be positioned as close as possible to the target area in turbid or murky environments.

The enhanced detection and observational technologies (including the oil detection equipment as well as the video systems and the auditory/pressure sensors) either did or would have provided important information that would guide and assist the pilot and operator in the submarine cabin. Extending the innate capacities of humans, who can process a broad range of information and react to it promptly and intelligently, is a prime feature of the MPC design concept (which places the human being at the very best vantage point to influence the operations).

2.3.3.2 Recovery

Eleven submerged oil recovery tests were performed at the Ohmsett test tank. These tests were restricted to two types of submerged test oils: Sundex 790NT (from trays 1, 3, and 5) and Tesoro oil (from trays 2 and 6). MPC did not perform recovery operations with the Tesoro Decant Oil cut with 2.5 percent diesel.



Heavy Oil Recovery Ohmsett Test Report

To ensure that the rig would not be compromised, the system was secured to the Ohmsett bridge and the nozzle was swung in an arc as the bridge was slowly moved over the test trays (see Figure 15 and Figure 16). The result was circular paths in the oil and sand. The system easily picked up the oil and also a large amount of sand and water, although these amounts were reduced as the nozzle opening and the power of the pump were reduced as the testing progressed. The efficiency of the system also improved as the testing went on as the operating procedures for communications to the pump operator and the bridge operator were refined. The reaction time was still significant while using radios to provide directions to the operator of the hydraulics located at a separate location about 30 ft (9.2 m) away from the camera screen.

The MPC submerged oil pumping apparatus was successful at transferring both types of oil, with the test results progressively improving throughout the sequence as techniques and equipment were adjusted on-site based on observations and discussion.



Figure 15. MPC test rig during evaluation.





Figure 16. View of MPC test rig with articulated arm and nozzle.

2.3.3.3 Decanting

MPC mobilized a suite of storage tanks, heating systems, filtration systems, and transfer pumps to store and decant the recovered oil/water/sediment mixture removed from the test tank. Figure 17 shows a schematic of the set-up and Figure 18 shows the filter (left) and heating elements inside tank (right). The equipment used was of a standard, “off-the-shelf” configuration, with the exception of a customized set of heating coils that was installed into the primary receiving tank. This approach was adopted by MPC to demonstrate the typical decanting equipment that is available for rent nationally to facilitate such operations. These tanks (and accessories) are highly adaptable, outfitted with top access points as well as bottom draw points and man ways, giving them a flexibility to adapt to different oil characteristics and evolving conditions.

While MPC was able to conduct a number of valid experiments relative to the decanting of the two oil types, the test format and facility hours limited the amount of data that could be derived. For example, test #1 concluded at dusk on November 12, with the tank containing 3,272 gallons (12.4 cubic meters (m^3)) of oil and water at the end of the day. Both the Sundex and Tesoro oils exhibited a pronounced tendency to sink to the bottom of the tank quickly, so MPC chose to allow the tank to settle naturally and at ambient temperature (as opposed to heating it using the boiler mobilized and set up on site).

In order to understand this process for purposes of developing a throughput process timeline (i.e., the time it takes the mixture to phase separate as compared to the system recovery rate and available storage capacity), it would have been advantageous to study the phase separation periodically overnight. This was not possible due to the inability to maintain crews on site and so, in this case, the tank was allowed to sit over a period of 41 hours. Examination of the tank showed pronounced phase separation between the oil (which sank to the bottom) and the water, which formed a middle layer with a very thin layer of oil (less than one-



Heavy Oil Recovery Ohmsett Test Report

eighth inch) on the surface. MPC then used an over-the-top pumping strategy to draw the layer of water out of the tank, pass it through a 5 micron oil-absorbent filter system, hold it in a secondary tank, and eventually replace it into the Ohmsett test tank with no noticeable sheen or otherwise detectable level of hydrocarbon present.

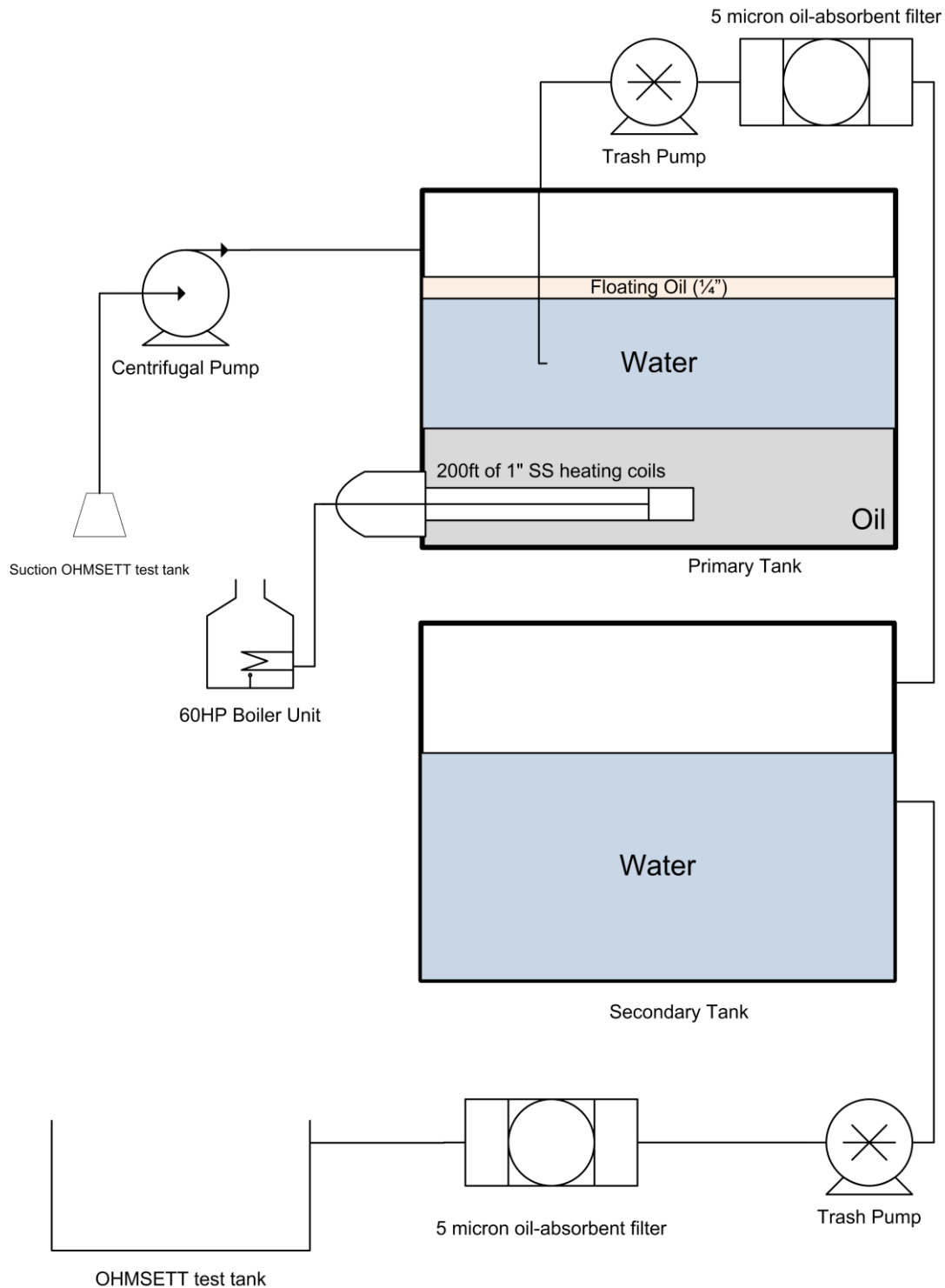


Figure 17. MPC actual decanting layout.





Figure 18. Pictures of MPC decanting system

(filter on left and heating elements inside tank at right).

This test showed that common equipment types (tanks, pumps, and filtration equipment) are available and versatile enough to be incorporated into an effective storage, decanting, and polishing system that would facilitate a submerged oil recovery operation.

2.3.4 Lessons Learned

- During the final oil recovery run the optical window of the fixed focus FP instrument became coated with oil, which resulted in a constant FP response even when no oil was being taken in. Upon disassembly a thick layer of oil was observed on the quartz window. Although the fixed focus FP instrument was positioned at a standoff distance (~4 inches (10 cm)) from the stream, the backpressure from the pump when the suction was stopped is enough to cause oil to splatter into the instrument window. A solution will be to increase the standoff distance and change the mounting angle of the instrument (45° angle) into the tube instead of the 90° angle used in the test may minimize the oil splatter.
- The RESON and EIC systems demonstrated valuable capabilities to guide operations, and the video and lighting systems proved of great worth as well.
- The tests indicated that enhancements to the pumping apparatus, including methods to prevent blowback through the hoses and decontamination of the skimmer head nozzle between pumping sequences, will be injected into the design process as MPC moves forward.
- The key to enhancing future operations ability to sustain the optimal recovery conditions for as long as possible is finding the best combination of pump flow rates, skimmer intake sizes, robotic arm and manned submersible movements, heat application, and methods for properly coordinating the mechanics of a given transfer sequence.
- The prototype test rig demonstrated the ability for the MPC equipment to operate above an area of contamination in the same manner as the submarine would, which hovers in place without the aid of downward thruster. Thus unnecessary disturbances to the benthic layer are reduced to the greatest extent.

Heavy Oil Recovery Ohmsett Test Report

- The two oil types selected for the tests seemed to exhibit characteristics that would suggest that the most appropriate process to promote phase separation would be to allow it to sink within the holding tanks at ambient temperatures. After witnessing how the oil/water/sediments mixture acted after holding times of 41 hours and 14 hours respectively, a clear water layer was derived that was easily filtered for discharge back into the Ohmsett tank. Attempts to filter the water layer after shorter holding times did not yield the same results (i.e., the filtered water exhibited discoloration and hydrocarbon odor), suggesting that either a longer holding time, additional procedures promoting phase separation, or a more aggressive filtration regime might be helpful.

2.3.5 Path Forward

Significant portions of the MPC Phase I design concept were validated during the Phase II prototype tests and no portion of the tests invalidated any critical element of the concept when considered separately or as part of a whole system. The experience at Ohmsett confirmed that the design concept is sound, and that, in fact, a number of system enhancements were clearly identified during the tests. A comprehensive test of all components would be useful.

2.4 Oil Stop Bottom Oil Recovery System

The Oil Stop Bottom Oil Recovery System (OSBORS) Group designed a specialized package of equipment to remove sunken oil and handle the recovered materials. The primary recovery device is the Sub-dredge, a remote-controlled pumping vehicle designed by Tornado Motion Technologies (TMT) (Figure 19). It relies on an external detection system for initial detection, but utilizes underwater cameras for recovery. The separation system consists of industry standard elements refined for this application. Additional details of the OSBORS design, including a suggested CONOPS, can be found in APPENDIX E.

2.4.1 System Design

2.4.1.1 Detection

The OSBORS design presumes the search and location of the submerged oil will be the function of a separate entity or organization.



Figure 19. OSBORS Sub-dredge.



Heavy Oil Recovery Ohmsett Test Report

2.4.1.2 Recovery

The key component of the entire system is the Sub-dredge, which was created to provide effective dredging with minimal turbidity and left-over residuals. The Sub-dredge is unmanned and controlled from the surface. It is self-propelled on the sea floor by hydraulically driven tracks. Its patented EDDY Pump incorporates a hydro-dynamically built casing along with a precision-engineered geometric rotor that operates at a minimum of 800 gpm (182 m³/hr). The most distinguishing feature of the Sub-dredge is its ability to adjust the depth of contaminant removal in millimeter (mm) increments. This minimizes the volume of clean materials removed with the contaminants, while minimizing turbidity and re-dispersal of contaminants.

2.4.1.3 Decanting

The goal of the Sub-dredge is to target the contaminants and minimize the amount of non-contaminated sediments brought to the surface, but an appreciable amount of water and sediment will be expected along with the recovered oil. Figure 20 shows OSBORS decanting design.

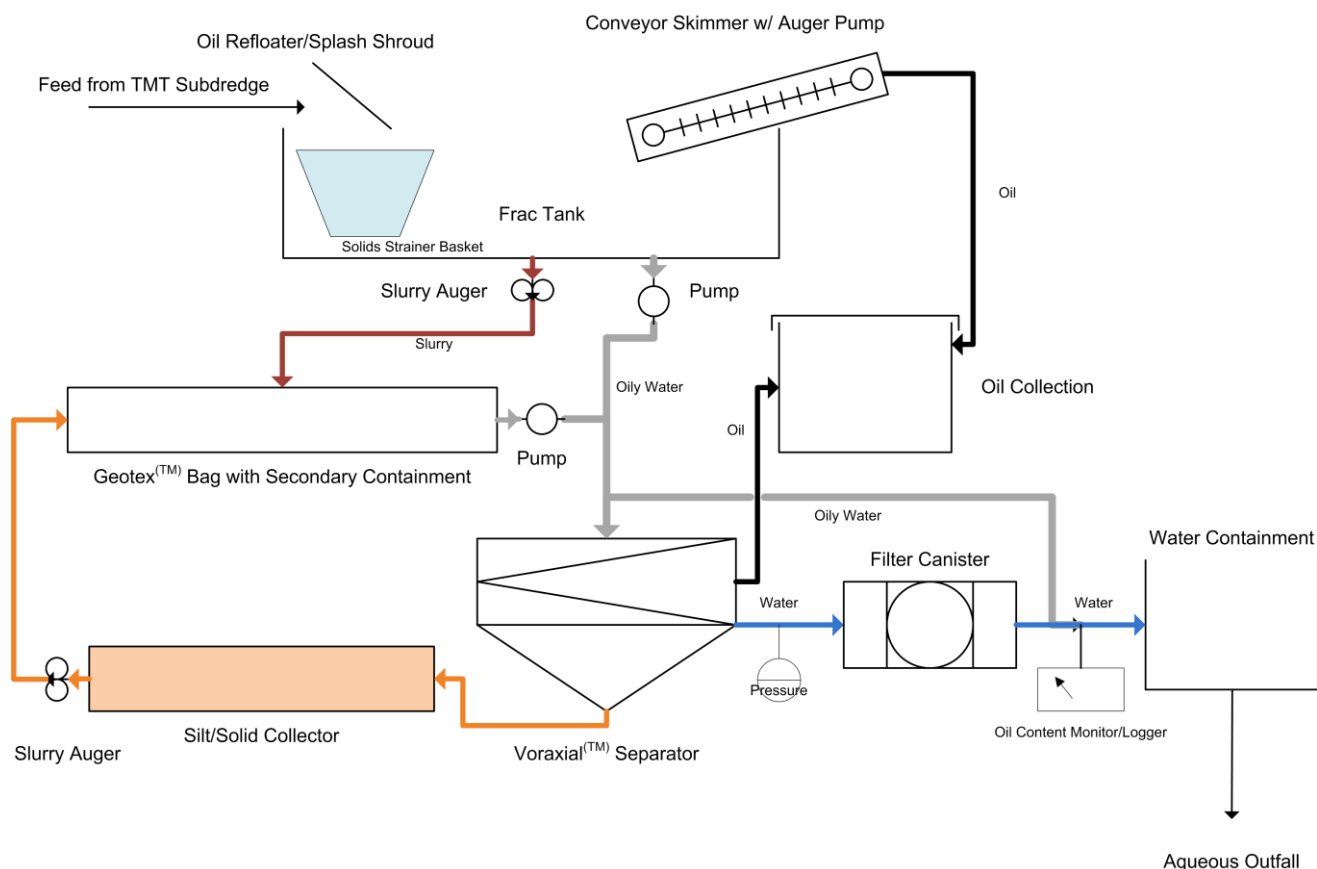


Figure 20. OSBORS design decanting schematic.

The primary reception tanks for the Sub-dredge's pumped materials will be mobile fractionation (Frac) tanks that are readily available throughout the coastal areas of the U.S. The first phase of separation is to refloat the oil for physical collection using a conveyor belt or rope mop oil skimmer. The open discharge is splashed into an inverted cone-shroud installed in the Frac tank. The second phase of separation is designed to be performed by the EVTN Voraxial® Separator, which is a patented, in-line, continuous-flow separator capable of pumping and simultaneously separating up to three components, such as oil, water, and solids.



Heavy Oil Recovery Ohmsett Test Report

The remaining wet solids are transferred from the Frac tank to the geo bags housed in the hopper barge(s) for dewatering. The resultant liquid from the dewatering should be sent through the Voraxial for a third phase of oil/water separation. The resultant water from the second and third phase separation processes should be analyzed for suitability to discharge in-situ.

2.4.1.4 Other Considerations

The most glaring challenge facing the OSBORS team was the size and weight of the Sub-Dredge. The prototype unit weighed almost 18,000 pounds (8,000 kilograms). Its heavy-duty tubular steel structure and the electric motor driven 8-inch (20 cm) EDDY pump were the main contributors to the weight factor.

The team agreed that the high volume of the 8-inch (20 cm) EDDY pump was not necessary as a lower volume pump did not necessarily reduce the recovery rate. A 4-inch (10 cm) EDDY pump could provide the same discharge head; therefore sizing down did not translate to a loss of effective speed of operation.

A pump to be powered with a hydraulic drive, powered from a surface mounted prime mover has been designed to replace the heavy electric motor on the dredge itself. With a smaller pump the size of steel tubing could be reduced to save more weight. The rubber track drives were widened to provide more stability and less incidence of sinking into softer silts. The addition of buoyancy compensation bags will further reduce the tendency to sink in softer silts.

2.4.2 Ohmsett Test Procedure

It is assumed the Ohmsett tank will simulate the general area reported to the OSBORS team where a concentration of submerged oil exists. From this information the Sub-dredge will be launched and use underwater cameras to pinpoint the oil prior to commencing pumping operations.

Since it was not practical to operate the large remote-controlled Sub-dredge in the Ohmsett tank, the EDDY pump was housed in a custom frame attached to the arm of a construction grade excavator and operated hydraulically (Figure 21). A mounted camera system and a closed-circuit monitor installed in the excavator cab allowed the operator to position the suction head and control the pump. In the excavator configuration, the system is proposed as a viable oil removal tool in water depths up to 49 ft (15 m).



Figure 21. OSBORS pump mounted on excavator.



Heavy Oil Recovery Ohmsett Test Report

The OSBORS Test Plan was based on addressing the specifications listed in Section 1.3.1. The test plan was set in five segments designed to gather information on each of the specifications as shown in Table 5. The tray configuration is shown in Figure 22.

Table 5. OSBORS test matrix.

Test Series	Title/Focus	Trays
1	Compatibility with Oil Detection Systems	
2	Oil Removal from Sea Floor	2, 7, 9, 10
3	Mobilization	
4	Maneuverability	
5	Top-side Materials Handling	

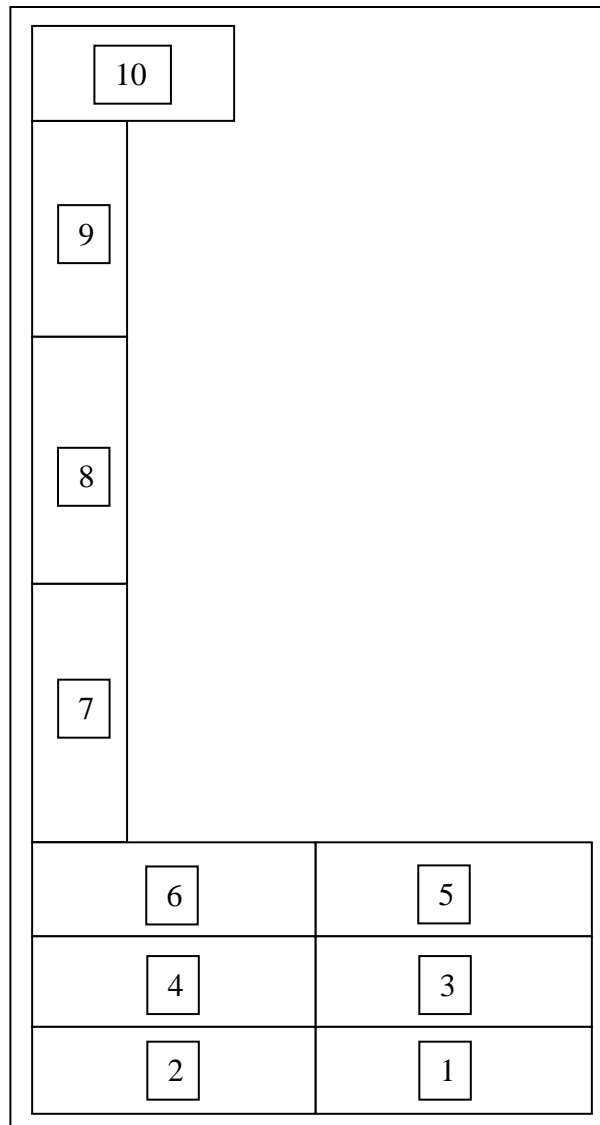


Figure 22. Approximate bottom tray layout for OSBORS recovery tests.



2.4.3 System Performance

2.4.3.1 Detection

The remote detection of oil was not tested, although the cameras used for recovery were. The system uses a high definition camera to locate, monitor, and record action at the head of the pump. The closed circuit video camera on the nose of the pump was activated to allow the operator and other viewers' visual confirmation of the location of the material to be removed. The camera also aided the operator in determining when to power on/power off the pump and the rate of removal on an instant basis. It also allowed determination of where the pump should be vertically and laterally in order to maximize removal efficiency, i.e., the most oil with the least solids and water. Finally, the videos provided a visual confirmation of the key results of the tests.

2.4.3.2 Recovery

Initially this system recovered oil with a large amount of water but refinements such as wheel removal and increased operator experience resulted in better output later in the testing period. Turbidity measurements were made by using a zone-grab sampler to obtain oil from near the pumping operations on the bottom and the results were consistently low. The system was able to effectively remove a majority of the oil from each tray in a matter of minutes. In one instance, the system removed approximately 90 percent of the oil in six minutes of pumping time.

Due to the unique tornadic suction created by the EDDY pump, no visible turbidity or dispersed oil was created near the pump during the tests. Analysis of collected samples confirmed that the pumping operation did not create turbidity or disturb oil into the water.

High viscosity oils were not a problem for the EDDY pump. As the EDDY pump is a dredging pump, and is designed to transfer up to 80 percent solids in slurry, it simply handled the high viscosity oil as if it were a solid. The volume of water being pumped also helped in the transport of the viscous oil through the piping and hoses.

Maneuverability of the unit was operator dependent, but only a minimum amount of training was required to make a new operator adequately skilled in the recovery technique to complete the tests. The recovery tests resulted in between 60 and 97 percent of the oil being recovered from each tray. A considerable volume of water was recovered in all cases. It was obvious to all observers that the entire volume of oil could have been removed from all trays if collection tank capacity had been larger.

2.4.3.3 Decanting

For the testing at Ohmsett, a full oil separation system was deployed that used a settling tank, mesh filter cloths, and surface skimmers, although some of the decanting components were scale models of those that would be used in the field. These were:

- Geotextile dewatering bags – The dewatering bags were a smaller version of what would be placed in hopper barges in the field. The materials used were the same and incorporated the same fill ports as the full-size model.
- Dewatering vessel – In the field, normally a floating hopper barge would be used to contain the solids dewatering bags and the resultant water. The test used a secondary containment pool made of coated fabric to simulate the barge.



Heavy Oil Recovery Ohmsett Test Report

- Liquid receptacles – For the test, smaller liquid receptacles were used to allow for volumetric measurements. These simulate larger, approved tanks that could be used to transport oily materials in the field.

Figure 23 shows a schematic of the actual system used by OSBORS at Ohmsett. Figure 24 shows the phase separator (right) and bag filter system (left). The recovered materials were pumped into phase separator type roll off containers to begin the separation of oil, water, and solids and to prepare the recovered water for treatment and subsequent in-situ discharge.

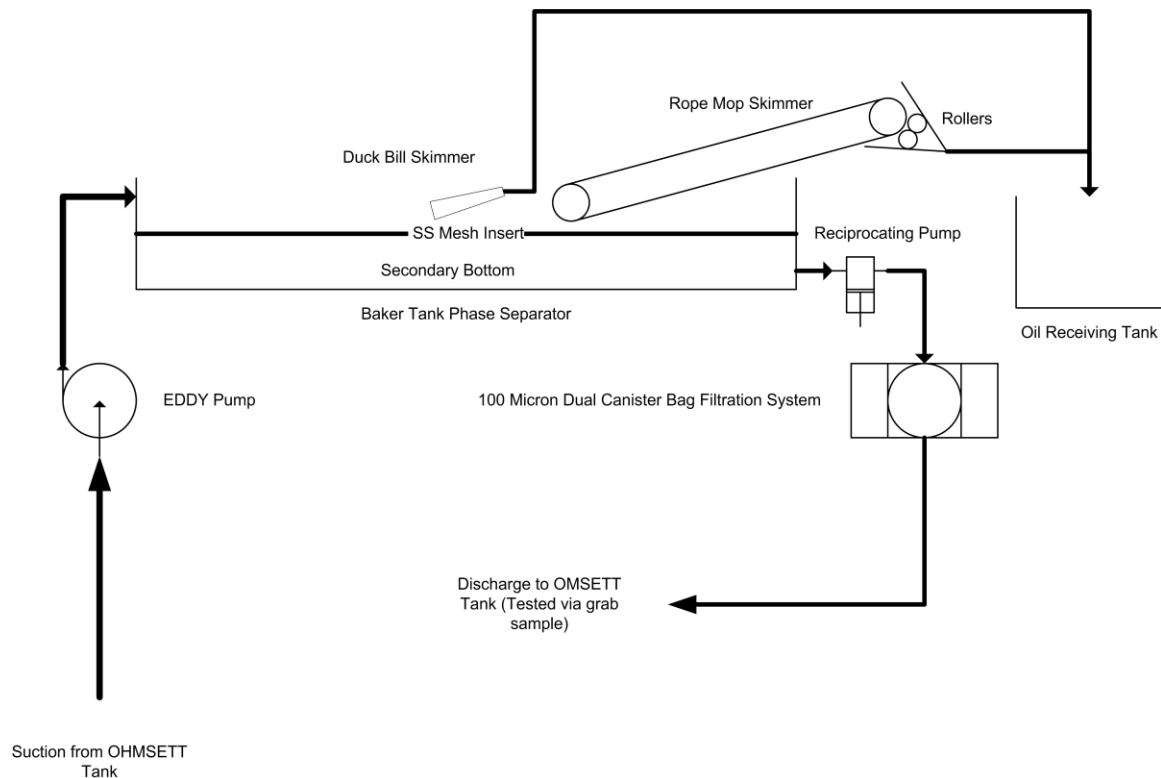


Figure 23. OSBORS actual decanting schematic.



Figure 24. Bag filter system and Baker phase separator.



Heavy Oil Recovery Ohmsett Test Report

Oil and water decanting and free oil removal from the storage tanks were not a total success, but enough knowledge was attained to demonstrate the viability of the system as it was designed for the tests. The main issue observed is that, due to the high volume of materials recovered by the pump, a more fluid and continuous decanting operation needs to be developed to allow for uninterrupted recovery pumping. Turbidity in dewatering was high because the fine masonry sand was smaller than the 100 micron filters could catch.

As expected, a large percentage of water, relative to oil and solids, was removed. Also, the collection tanks used for this test were essentially scale models of the ones that would be used in the field. Larger tanks can be easily adapted to handle large volumes of oily water by skimming the surface oil, filtering the water, and decanting it back to the water body.

2.4.4 Lessons Learned

- Two cameras are better than one. The operator suggested that if we had two wing cameras focused in on the pumping area, rather than one directly in line, that he could be more precise.
- Lighting will be necessary for real-world operations and should be wing mounted to avoid shadows. The contractor knew this going into the test. However, the clarity of the water in the Ohmsett tank did not require lighting.
- The support vessel for the OSBORS, whether in Sub-dredge or excavator mode, should have precision GPS instrumentation to target oil located by detection technology.
- A bottom sensing probe would be useful. A simple contact rod that would activate a light, or emit an audible sound, would aid the operator by providing a signal that he can engage the pump and target material. This would help reduce pumping of free water only.
- A one-way check valve should be installed at a suitable point in the flow line. When pumping ceased and the pump remained suspended, pointing down, materials still in the flow line would drain. This created unnecessary turbidity in the area and could also allow pumped oil to be released.
- During actual clean ups, it might be advisable to avoid objects such as coral, but track over larger objects such as stones and boulders.
- In excavator mode, careful observation and planning are required to avoid pinch points on the discharge hose.
- The phase separator is a valuable component. In a full scale operation, it does not have enough capacity to be the primary, initial material collection tank. If there were several set up side-by-side, they could be feasible, but the oil recovery operation would have to cease while discharge hoses were moved from a full tank to an empty tank.
- Full size (400-500 barrels) Frac tanks may be more suitable as the main collection tank. Materials could be transferred to the phase separator for intermittent treatment and preparation for water decanting and surface oil removal.
- The aeration created by the high energy of the discharge did aid in refloating a percentage of the oil. A suitable surface oil skimmer and collection system should be a permanent component of the top side treatment system.
- Open top tanks seem to afford more versatility than closed tanks. However, this may be an issue in permitting during field operations, particularly water-borne operations, so alternatives to open top tanks should be reviewed and planned for.
- A variety of filter sizes should be available. Most beach sands are larger than 100 micron, but the sands used in this test were obviously smaller than the mesh size, and hence, the solids were not adequately filtered for discharge.



2.4.5 Path Forward

In excavator mode, limitations of the system, as tested, included its reach and depth of water that the system could be used in. There are “long stick” excavators that will allow for operation in up to 50 ft (15 m) water depth. There is no reason to doubt the system will perform as demonstrated in deeper water. The footprint of the components can be operated from a standard deck barge or similar sized floating platform. Use of the EDDY pump with the remote controlled underwater Sub-Dredge will resolve most of the reach and depth questions. The Sub Dredge can operate and pump oil from 200 ft (61 m) depths and can range up to 350 ft (107 m) away from the umbilical terminal.

For the Phase III field test OSBORS plans to demonstrate the full system with crawler and pump arrangement. The company will pick the location and oil surrogate, possibly a semi-liquid clay they have had some experience with.

2.5 Summary

Three unique heavy oil recovery systems have been designed and elements of each of them tested at Ohmsett. All three systems have at least partially met many of the required specifications for detection and recovery of submerged oil (see Table 6). Since two of the systems were evaluated in a reduced configuration, some questions remain about some of the requirements; so they were given only partial credit. Funding only permitted about four days for the setup and testing of each and all could have used more time to refine their approaches. All improved their ability as the tests proceeded.

2.5.1 Detection

Alion and MPC successfully tested sensors for detecting and mapping the oil. Multi-beam sonar appears to be a useful tool for wide-area scanning, while FP is good for heavy oil identification.

2.5.2 Recovery

The three designs had different proposals for “pump delivery systems” to replace divers: ROVs, manned submersible, and Sub-dredge. Only one of these three systems, ROVs, was able to be tested at Ohmsett. MPC hung their recovery system from Ohmsett’s bridge and OSBORS used an excavator. In shallow water, the excavator may be considered an alternative pump delivery system.

Two of the three recovery systems, MPC and OSBORS, were able to successfully pump the high viscosity oil from the Ohmsett trays to decanting tanks due to the large pumps used. Alion’s system was unable to move the higher viscosity oils from the trays, but was able to move the two oils with lower viscosities between barrels on the surface.

Both MPC and OSBORS recovered a considerable amount of water and sediment with the oil, although it was not possible to exactly quantify the amount of oil versus water/sediment that was being recovered due to schedule practicalities and observational limitations.

2.5.3 Decanting

MPC and OSBORS tested decanting systems, which were partially successful in separating the oil from the water and sediments. When the water first enters the decanting system it is very forceful – this needs to be taken into account, especially if it is being fed into an open tank. One advantage of the high agitation is that some portion of the oil may be readily skimmed from the surface for further processing.



Heavy Oil Recovery Ohmsett Test Report

Table 6. Specifications matrix.

Specification	Alion	MPC	OSBORS
1. Presence of heavy oil on the sea floor identified with 80% certainty	Partial test – successful result	Tested – successful result	Not tested
2. Oil location geo-referenced to within 16 ft (5 m) in accuracy	Partial test – successful result	Partial test – successful result	Not tested
3. Minimal dispersion of oil or bottom material into the water column	Partial test – successful result	Partial test – successful result	Tested – successful result
4. Provides real time data/feedback	Tested – successful result	Tested – successful result	Tested (video during recovery) – successful result
5. Provides recovery for all sea floor conditions	Partial test – successful result	Partial test – successful result	Partial test – successful result
6. Operates in fresh and sea water conditions	Partial test – successful result	Partial test – successful result	Partial test – successful result
7. Operates in water depths of up to 200 ft (61 m)	Not tested		
8. Minimal maintenance requirements	Not tested		
9. Easy to operate and requires minimal training	Tested – partially successful result	Tested – partially successful result	Tested – partially successful result
10. Easily de-contaminated and durable	Tested – successful result	Tested – successful result	Tested – successful result
11. Equipment operation not adversely affected by exposure to oil	Tested – successful result	Tested – successful result	Tested – successful result
12. Operates in water currents at the surface of up to 1.5 kts	Tested – partially successful	Not tested	Not tested
13. Deploys and operates in up to 5-ft (1.5 m) seas	Not tested		
14. Operable during the day and night	Tested – successful result	Tested – partially successful result	Partial test (day) – successful result
15. Sets up within 12 hours of arriving on site	Partial test – successful result	Partial Test – successful result	Tested – successful result
16. Viscosity: Operates in the range of 2,000-100,000 cSt	Tested – partially successful	Tested – successful result	Tested – successful result
17. Includes a decanting system that can handle the heavy or refloating oil	Not tested	Tested – successful result	Tested – successful result
18. Process to complete “polishing” of the resultant water for disposal	Not tested	Tested – successful result	Tested – successful result
19. Minimal impacts to benthic resources	Tested – partially successful result	Tested – partially successful result	Tested – partially successful result



3 CONCLUSION

On many levels, submerged oil response operations represent a new threshold of endeavor for the spill response community. Solutions brought to bear on these spills in the past have been successful, but methodologies have been developed on the fly and technologies have been assembled on an ad-hoc basis. While the configurations for the systems discussed in this report are not exactly those expected to be used in the future, these tests have furthered the understanding of heavy/sunken oil response in a number of ways.

The components of any of the systems could be useful in combination if other scenarios are encountered. The development of these systems may not preclude the use of divers in some situations but may be substituted if the oil is deep (use manned submersible), in a surf zone (use crawler system) or if placing divers into the water is unsafe (use ROV). More guidance will be provided after the field tests in a final report later in 2012.

3.1 Detection

It should now be possible to detect and map oil on the sea floor and river beds. It may also be possible to use FP to detect oil in the water column. The limits of the abilities of the sensors still need to be tested in real-world conditions, including depth of water, visibility, and bottom conditions.

3.2 Recovery

3.2.1 Delivery System

One of the strong drivers for this project was to find an effective pump delivery system to replace divers. Of the three systems suggested, only one, ROVs, was able to be tested in the Ohmsett tank. The ROVs appear to be a reasonable delivery system for submerged oil recovery equipment, although refinements of the system designed by Alion are required for it to be fully successful.

The MPC manned submersible could not be tested at Ohmsett, but has been tested in the field by MPC and appears to be a successful way of delivering and running the recovery equipment. The OSBORS Sub-dredge is due to be field tested in the summer of 2012. The excavator used at Ohmsett may be a useful delivery system for shallow water.

3.2.2 Targeting the Oil

In situ visibility is critical for any system. In order to minimize the amount of water and sediments recovered, the nozzle of the pump must spend as much time as possible in contact with the oil. The best recovery rates at Ohmsett appeared to be when the pump operator could actually see the oil and target the nozzle accordingly. The clear water of the test tank permitted the operators to periodically check oil and/or system locations by looking over the side, which will probably not be an option for actual spills.

MPC and OSBORS would likely have more flexibility in the field than at Ohmsett to optimize their orientation with respect to the oil. Even in ideal conditions, it's possible that only 10-20 percent of the recovered material will be oil.



3.2.3 Pumping System

Two of the three pumps tested, MPC and OSBORS, were capable of pumping the highly viscous oil from a depth of 6-8 ft (1.8-2.4 m). These are very high capacity pumps that may be too powerful for other than very large spills. The limits of these pumps need to be identified. Oil properties, the amount of oil on the bottom and bottom type all need to be considered when selecting the optimal size of pump to minimize picking up water and silt and causing damage to the benthic community.

The key to enhancing future operations and sustaining the optimal recovery conditions for as long as possible is to determine the best combinations of pump flow rates, skimmer intake sizes, delivery system movements, and methods for properly coordinating the mechanics of a given transfer sequence.

3.3 Decanting

Submerged oil recovery operations result in a significant, although manageable, amount of water and sediment being accumulated during the recovery process. Separation of the oil-water-sediment mixture collected during underwater oil recovery can become a limiting factor in the operation and over-all throughput of the recovery system. The decanting system must be designed accordingly to handle these waste streams.

All of the vendors indicated that larger and possibly multiple collection tanks would be needed for a large spill. The size of the filter system varied from below 10 to 200 microns and this will also probably need to be adjusted for each spill. The use of multiple steps for separating oil is needed, especially since any sand sticking to the oil may not separate during pumping operations. There was discussion about whether other bottom types than loose sand would result in a similar volume of sediment. It is likely that since moving highly viscous oil sitting on the bottom requires high pump pressures, picking up the bottom material will most likely still be an issue. However, this needs to be tested in the field.

4 PATH FORWARD

There are limits to the information that can be gathered at a test facility. The choice of test media, including the oil types and the sediment types, should not necessarily be considered as representative of what is commonly transported or is to be encountered during response operations. A number of the original system specifications, such as operation in 5-ft (1.5 m) seas and 200 ft (61 m) depth, could not be tested at Ohmsett.

Field tests are tentatively scheduled for the summer of 2012 for the Alion and the OSBORS systems to evaluate aspects of the systems that were not addressed in the Ohmsett tests.

A separate RDC project has been initiated to study detection and mitigation for oil suspended in the water column.

5 RECOMMENDATIONS

This project resulted in progress in the understanding of and capabilities for heavy/sunken oil spill response, as discussed in Section 3. There are areas that need further research.



5.1 Detection

Determine full capabilities and limits of currently available sensors. Improve data processing times and accuracies. Recognize that broad-scale detection and focused recovery detection may require different tools.

5.2 Recovery

Lab tests are needed to determine range of “pumpable” oil for the various types of pumps and nozzle arrangements, including maximum water depth at which the pumping system is able to function. An approach for cost/benefit analysis of the different types of delivery systems based on the location of the spill, including depth, bottom type, and available logistical support should be developed. Performance of pumping systems if using water injection should be evaluated, especially when oil flow is intermittent.

5.3 Decanting

Develop detailed guidance and/or computational tools for decanting systems based on the conditions of the spill. Such tools would explicitly take account of oil and sediment characteristics as well as the volume flow rates desired for the recovery process. A possible area for further study is to determine whether the topography and sediment characteristics, along with those of the oil involved, can be systematized to permit a decanting system to be “tuned up” for a particular situation right at the beginning of the spill response, rather than by adapting the system mainly in response to observations that can be made with the decanting system already in operation.

5.4 Other Issues

Each spill will be different and the Federal On-scene Coordinator (FOSC) will need to determine what techniques to use. APPENDIX F provides some guidance for a FOSC responding to a spill of submerged oil. Additional guidelines are required for conducting a cost-benefit analysis during an actual spill.

An assessment of these systems’ effects on wildlife and the bottom environment is also needed. Use of sonar or laser may be limited by the presence of marine mammals or other endangered species. State and local organizations also need to be consulted for any underwater sensitive or archeological sites.



6 REFERENCES

Internal USCG RDC references, including vendor-specific design and test reports, are listed in APPENDIX G. Vendor contact information is provided in APPENDIX H.

Brown, C. E., Fingas, M. F., Gamble R. L., & Mysliski, G. E. (2002). The Remote Detection of Submerged Oil, *3rd R&D Forum on High Density Oil Spill Response*, International Maritime Organization, Brest, France, March 11-13.

Cabioc'h, F. (2002). Sunken Hydrocarbons and Chemical Products: Possible Responses and Available Methods, *3rd R&D Forum on High Density Oil Spill Response*, International Maritime Organization, Brest, France, March 11-13.

Chapman, N. (2011). *Operational Guidelines on Sunken and Submerged Oil Assessment and Removal Techniques*, International Maritime Organization (in press).

Coastal Research and Response Center (CRRC). (2007). *Submerged Oil – State of the Practice and Research Needs*, Durham, NH, December 12-13.

Deis, D.R., Tavel, N.G., Masciangioli, P., Villoria, C., Jones, M.A., Ortega, G.F., & Lee, G.R. (1997). Orimulsion Research and Testing and Open Water Containment and Recovery Trials, *Proceedings 1997 International Oil Spill Conference*, American Petroleum Institute, 9 pages.

Elliott, J. (2005). An Analysis of Underwater Oil Recovery Techniques 2005. *Proceedings 2005 International Oil Spill Conference*, American Petroleum Institute, 11 pages.

Fant, J.W. & Hansen, K.A. (2005). U.S. Coast Guard Oil Spill Remote Sensing: Preliminary Laser Fluorosensor Studies, *Proceedings of the Twenty-eighth Arctic Marine Oilspill Program Technical Seminar*, pp. 861-872. Environment Canada, Ottawa, ON.

Fant, J.W., & Hansen K.A. (2006). U.S. Coast Guard Laser Fluorosensor Testing, *Proceedings of the Twenty-ninth Arctic Marine Oilspill Program Technical Seminar*, pp. 951-964. Environment Canada, Ottawa, ON.

Hansen, K.A. (2009). Research Efforts for Detection and Recovery of Submerged Oils, *Proceeding of the 2009 Interspill Conference*, Marseille, France, May 12-14.

Hansen, K. & Fitzpatrick, M. (2009). *Heavy Oil Detection (Prototypes) – Report CG-D-08-09*, US Department of Homeland Security, June 2009.

Hansen, K., Guidroz, L., Hazel, B., & Hohnson, Dr. G.W. (2011). *Designing a Submerged Oil Recovery System*, International Oil Spill Conference, Portland, Oregon USA, May, 2011

Michel, J. (2006). *Assessment and Recovery of Submerged Oil: current State Analysis*, prepared for US Coast Guard Research and Development Center, June, 2006.

Michel, J. (2008). Spills of Non-Floating Oils – Evaluation of Response Technologies: *Proceedings 2008 International Oil Spill Conference*, American Petroleum Institute.



Heavy Oil Recovery Ohmsett Test Report

- National Research Council (NRC). (1999). *Spills of Non-Floating Oils, Risk and Response*. National Academy Press, Washington, D.C.
- Parthiot, F., E. Nanteuil, De, Merlin, F., Zerr, B., Guedes, Y., Lurtin, X., ... & R.K. Hansen. (2004). Sonar Detection and Monitoring of Sunken Heavy Fuel Oil on the Seafloor, *Proceedings of the Interspill 2004 Conference*, Trondheim, Norway, June 14-17.
- Parthiot, F. (2002), Monitoring of Sunken Fuel Oils, *3rd R&D Forum on High Density Oil Spill Response*, International Maritime Organization, March 11-13.
- Rymell, M. (2009). RP595, Sunken and submerged oils – behavior and response, *A Report for the Maritime and Coastguard Agency*, BMT Cordah Limited, February, 2009.
- United States Code (USC 2006), Title 33, Section 2672, “Submerged Oil Program,” July 11, 2006
http://uscode.regstoday.com/33USC_CHAPTER40.aspx#33USC2762
- Usher, D. (2008). *The Use of Manned Submersible Units to Accomplish Submerged Oil Recovery*, (pp. 1289-1291). International Oil Spill Conference, May, 2008.



APPENDIX A. OHMSETT TEST FACILITY

Ohmsett - The National Oil Spill Response Test Tank Facility (www.ohmsett.com) is the only facility where full-scale oil spill response equipment testing, research, and training can be conducted in a marine environment with oil under controlled environmental conditions (i.e., waves, temperature, oil types). The facility provides an environmentally safe place to conduct objective testing and to develop devices and techniques for the control of oil and hazardous material spills. Ohmsett's mission is to increase oil spill response capability through independent and objective performance testing of equipment, providing realistic training to response personnel, and improving technologies through research and development.

Ohmsett is located at the Naval Weapons Station Earle Waterfront in Leonardo, New Jersey (approximately one hour south of New York City). It is maintained and operated by the Department of Interior's Bureau of Safety and Environmental Enforcement (BSEE) through a contract with MAR, Incorporated of Rockville, Maryland. Ohmsett's above ground concrete test tank is one of the largest of its kind, measuring 203 m long by 20 m wide by 3.4 m deep. The tank is filled with 2.6 million gallons of crystal clear saltwater.

Ohmsett has a mechanically operated control bridge that spans the width of the tank and traverses the tank's length; two stand-alone work bridges can be stationary or rigidly attached to the mobile control bridge. The Ohmsett test tank allows testing of full-scale equipment. The tank's wave generator creates realistic sea environments, while state-of-the-art data collection and video systems record test results. The facility has proven to be ideal for testing equipment, evaluating acquisition options, and validating research findings.

Public and private sector entities are invited to contract the use of Ohmsett as a research center to test oil spill containment/clean-up equipment and techniques, to test new designs in response equipment, and to conduct training with actual oil spill response technologies.

Features & Capabilities

- A main towing bridge capable of towing test equipment at speeds up to 6.5 knots.
- An auxiliary bridge oil recovery system to quantify skimmer recovery rates.
- A wave generator capable of simulating regular waves up to one meter in height, as well as a simulated harbor chop.
- A movable, wave-damping artificial beach.
- An oil distribution and recovery system that can handle heavy, viscous oils and emulsions.
- A control tower with a fully-computerized 32-channel data collection system as well as above-and below-water video.
- A centrifuge system to recover and recycle test oil.
- Blending tanks with a water and oil distribution system to produce custom oil/water emulsions for testing.
- A filtration and oil/water separator system.
- An electrolytic chlorinator to control biological activity.
- Permanent and mobile storage tanks that can hold over 227,000 liters of test fluids.
- A vacuum bridge to clean the bottom of the tank.
- Staging and shop area for special fabrication.



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APPENDIX B. OHMSETT SET-UP

Figure B-1 shows the intended tray layout for the Ohmsett tests. Each tray measured 8 by 20 feet (2.4 by 6.1 meters). A base of sand and simulated obstacles, in the form of cinder blocks and stacks of flagstones created the “sea bottom” for the tests. Trays contained various amounts of sand, oil, and obstacles. There were two types of sand (Table B-1) and three types of oil (Table B-2), discussed below. A trail of oil in the top trays was intended to test detection/following capabilities (Figure B-2). Trays near the bottom of the figure are designed mostly to test recovery volume (Figure B-3).

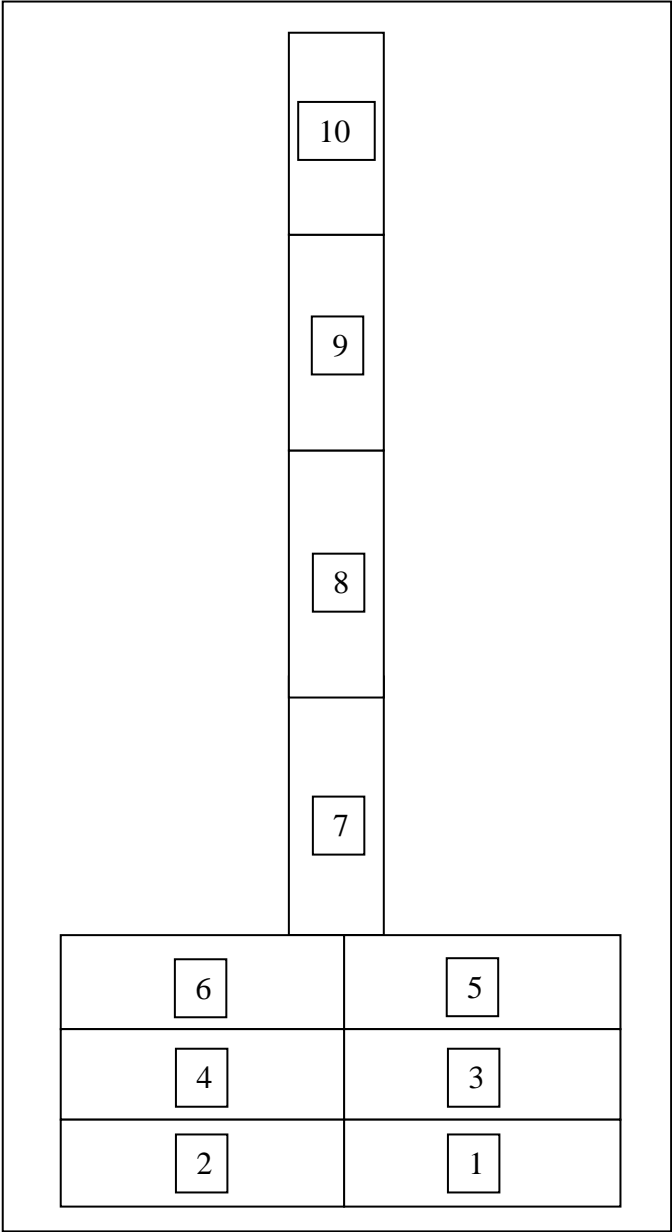


Figure B-1. Intended bottom tray layout for Ohmsett.

Heavy Oil Recovery Ohmsett Test Report

Tray 10

Concrete sand 9" thick
Oil: Tesoro w/diesel
Width 24 inches
Depth 6 inches to
0.5 inch
(60 gal)

Rocks nominally 12 inches
above oil except for
tray 8 which needs 2 feet

Tray 9

Mason sand 3" thick
Sundex oil
Width: 36 inches
Depth: 1 inch
(35 gal)

Tray 8

Concrete sand 9" thick
Oil: Tesoro w/diesel
Width 12 inches
Depth V- shape to
7 inches (80 gal)

Tray 7

Mason sand 6" thick
Sundex oil:
Width: 24 inches
Depth: 4 inches
(80 gal)

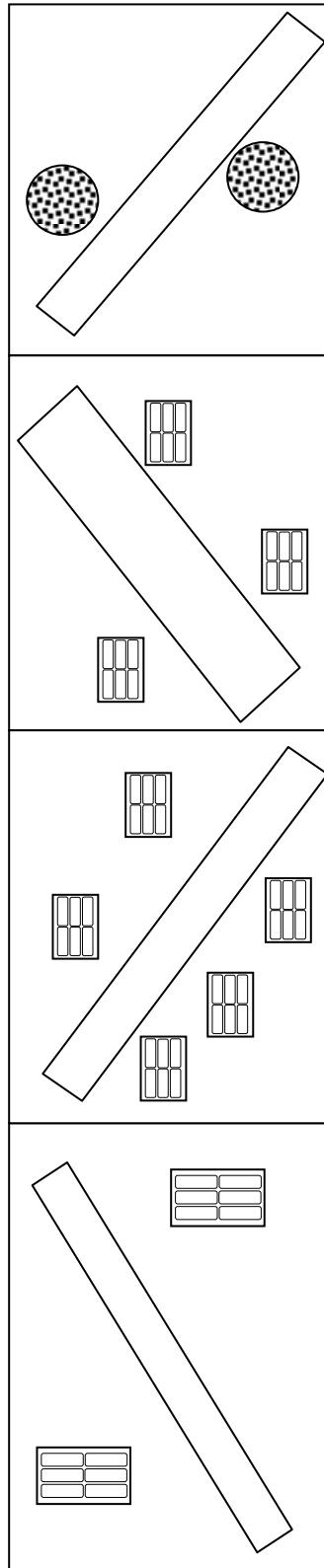


Figure B-2. Bottom tray layout for detection trays (7-10).



Heavy Oil Recovery Ohmsett Test Report

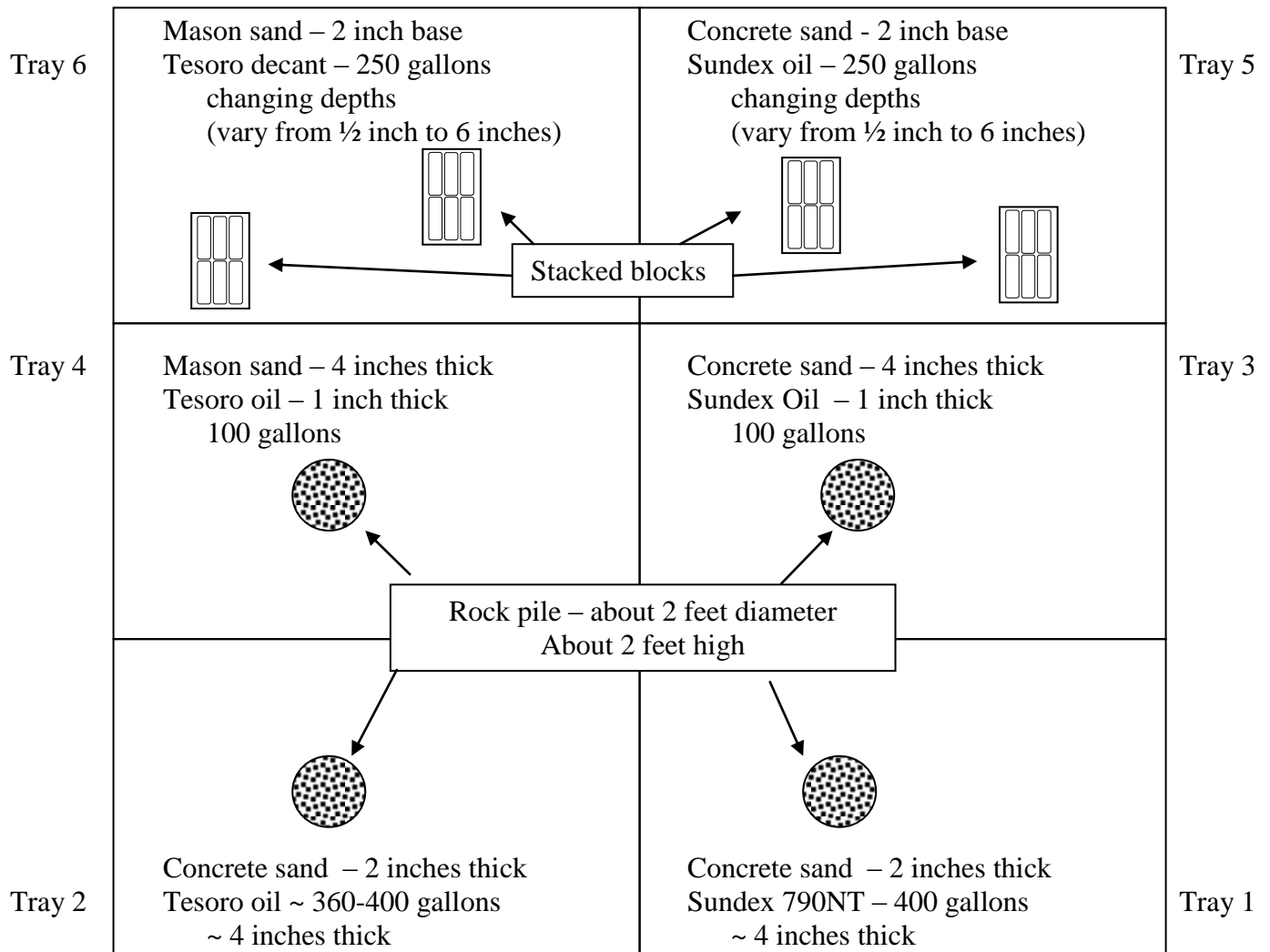


Figure B-3. Bottom tray layout for recovery trays (1-6).

Table B-1. Sand sizes.

Sieve Size	Particle Size (mm) ¹	Concrete (#1) Percent Passing	Mason (#2) Percent Passing
3/8"		100	
#4	4.75	97.5	100
#8	2.38	92.7	97.1
#16	1.2	80.5	84.3
#30	0.599	54.3	58.6
#50	0.297	17.2	34.5
#100	0.152	2.3	7.3
#200	0.075	1.1	2.5

From [http://en.wikipedia.org/wiki/Mesh_\(scale\)](http://en.wikipedia.org/wiki/Mesh_(scale))



Heavy Oil Recovery Ohmsett Test Report

Three types of heavy oil were used during the tests. Figure B-4 shows the viscosity-temperature curve for oils. The average water temperature during the testing period was $\sim 11^{\circ}\text{C}$, resulting in the approximate viscosities shown in Table B-2.

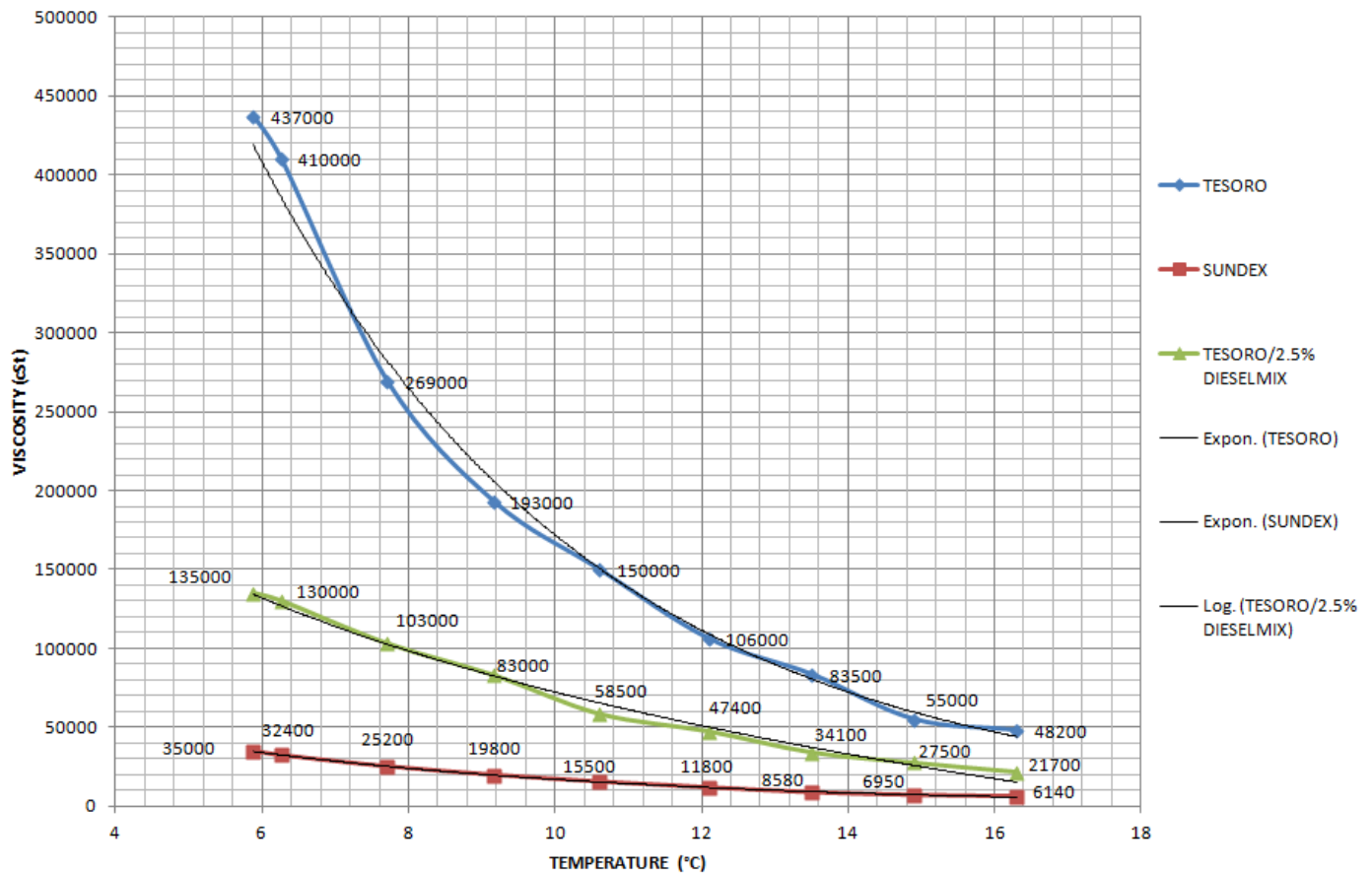


Figure B-4. Viscosity-temperature curve for oils.

Table B-2. Ohmsett oil types.

Oil Type	Viscosity (cSt) (approximate)
Sundex	15,000
Tesoro/diesel (2.5 percent) mix	50,000
Tesoro	140,000



APPENDIX C. ALION SYSTEM COMPONENTS

C.1 System Components

The complete Sea Horse system consists of three major subsystems: detection, recovery, and decanting, plus auxiliary equipment. The Sea Horse detection and recovery components are designed to operate on a vessel of opportunity (VOO) of 40-50 ft length that can maintain a fairly stable platform, provide around 300 ft² of deck space, and have adequate station-keeping capabilities. Decanting will require either a barge or shore set-up.

C.1.1 Detection

- Multi-beam sonar temporarily mounted on a VOO for wide-area searching.
- Navigation system (consisting of a Global Positioning System (GPS) receiver and a heading/roll/pitch sensor) mounted on the VOO for geo-referencing the sonar data.
- Combination of commercial-off-the-shelf (COTS) and custom software to identify oil in the sonar imagery.
- Inexpensive “mini” remotely operated vehicle (ROV) for underwater confirmation of oil (by high resolution sonar and video imagery).
- ROV-mounted multi-beam sonar to aid navigation and verification of oil in low-visibility conditions.

Figure C-1 shows a conceptual design of the Sea Horse during the detection phase.

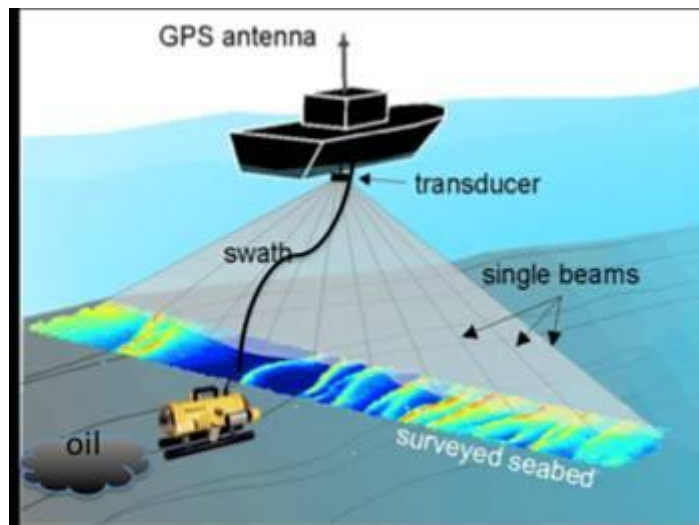


Figure C-1. Sea Horse conceptual design for detection.

C.1.2 Recovery

- Dual ROVs (as paired units) to propel bottom end of oil-recovery rig (to save costs the ROV used in the detection could be used as one of these).
- Multi-beam sonar temporarily mounted to the VOO to track ROV and help guide Sea Horse to the correct position.
- Positioning system mounted on the VOO to geo-referenced the multi-beam sonar data.

Heavy Oil Recovery Ohmsett Test Report

- Commercial air or hydraulic powered submersible liquid/debris pump.
- Variety of nozzles to suit conditions/materials.
- Lightweight hoses.

Figure C-2 shows a conceptual design of the Sea Horse during recovery operations.

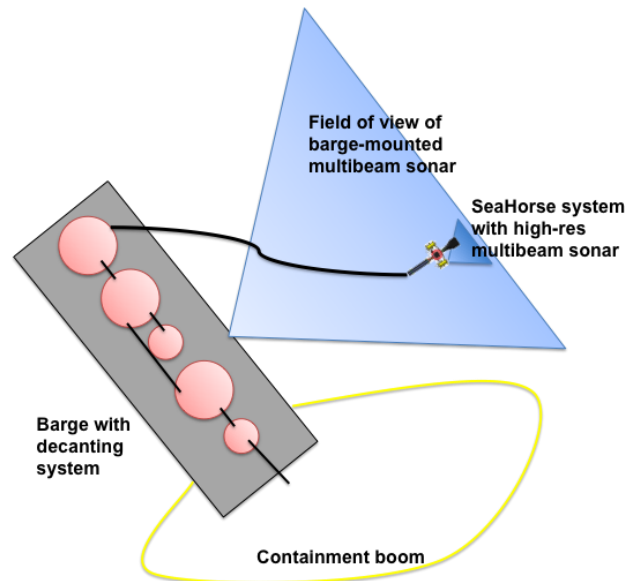


Figure C-2. Sea Horse conceptual design for recovery.

C.1.3 Decanting

- Barge for decanting system unless operating close enough to shore in which case the system can be set up on shore.
- Cascade of tanks acquired locally – number of stages to suit a particular spill situation and volume.
- Discharge of water and oil from ROV system(s) goes into a first stage (settling) tank, heavy materials settle, and water is decanted into a second tank using a submerged pump inlet.
- Skimmers and/or sorbent snares placed on top of downstream tanks (second tank and subsequent) of cascade.
- “Polishing” tank filled with sorbent oil snares.
- Potentially, multiple lightweight devices with cyclic-acting pumps may allow uptake to be more efficient (i.e., increased volume fraction of oil).

C.1.4 Auxiliary Equipment

- Commercial generators – acquired locally. A one-kilowatt (kW) generator is needed to power the single ROV, sonar system, and positioning system on the survey vessel. The decanting barge will need a larger 6-7 kW generator to handle the load from the Sea Horse (dual ROV) and sonar systems.
- Commercial air compressor or hydraulic power pack – either acquired locally or shipped in.



C.2 Equipment Specific to Ohmsett Test

Sea Horse used two JW Fisher Sea Lion-2 ROVs for frame propulsion, maneuvering, and underwater video monitoring .

Lamor GTA A 20 Archimedes Screw Pump - selected for this application because of its small size compared to other Archimedes screw pumps and Lamor's reputation for handling high viscosity materials in this type of application.

For the prototype demonstration at Ohmsett we tested the BlueView MB1350 and MB2250 systems (both multibeam line scanners) for oil detection and the BlueView P900-130 system (multibeam field) for tracking the Sea Horse from the "decanting barge."

C.3 Concept of Operations

Detection Phase: During the initial detection phase, the goal is to map out areas of submerged oil using a hull-mounted sonar system and a single ROV. This keeps the amount of material to be shipped to a minimum and a small vessel can be used making it easier to rent a vessel on-scene. When the software indicates a likely patch of submerged oil, the ROV is sent down to confirm this using video and high-resolution multi-beam sonar. The confirmed areas of oil are marked for immediate recovery because oil on the bottom of the sea floor can be highly mobile. Since the shipping and installation of these relatively small components are very quick and easy, this phase can commence within the 12-hour window. Detection operations can continue as needed.

Recovery Phase: Recovery of the oil requires a good deal more equipment to be on-scene and it is envisioned that most of this equipment would be sourced locally then assembled on-site. The barge can be anchored near the submerged oil patches, and the recovery phase can start. The same hull-mounted sonar used on the detection survey vessel is used on the barge to track Sea Horse and assist with guiding it to the located patches of submerged oil. Once all patches of oil within range are recovered, the barge is relocated to be near the next grouping of oil patches. The recovery operations can either use the detection confirmation ROV as part of Sea Horse or run detection in parallel with recovery operations using multiple ROVs and sonar systems.

There are two options for the recovery phase. The low cost option is to use the detection confirmation ROV as one of the Sea Horse sled ROVs. With this option, detection stops while recovery is being done. The second (higher cost) is to run detection in parallel with recovery operations; this requires an extra ROV. This option improves operational efficiency and allows for tracking the movement of submerged oil.

C.3.1 Surface Vessel Deployment

The Sea Horse system will be able to recover oil in open water locations aboard small to medium sized vessels. This feature allows engineers to isolate and extract oil in open water at depths up to 200 ft (61 m).

- Equipment shipped to site of oil spill and assembled
 - Fly-away system
 - Priority is sonar and ROV and control systems
 - Complete recovery and decanting gear can come later after survey has started



Heavy Oil Recovery Ohmsett Test Report

- Location of oil / Site mapping
 - Small survey vessel/work boat with multi-beam sonar added, also real-time detection software
 - Vessel covers large areas and identifies probable locations of oil – maps out extent of coverage
 - Single ROV with camera/sonar used to verify oil – results used to fine-tune detection software
- Recovery
 - Work boat (or party on board barge) maneuvers near oil location
 - Work boat or barge is secured in position with two anchors
 - Drops hose “anchor” and uses dual-ROV system within 30-50 ft (9-15 m) radius of the “anchor” to recover oil from all reachable locations
 - Relocates to next position and repeats
- Decanting
 - Barge has holding tanks and decanting gear
 - Decanting may occur on-shore for small spills

C.3.2 Near Shore Oil Spills in Harbors, Ports, and Marinas

The Sea Horse system will be able to recover oil from shore or near shore points to depths on the order of 150 ft (46 m). This shall be accomplished within the reach of the 200 ft (61 m) tether (additional lengths available). The tether allows the system to be deployed from beach, pier, dock, wharf or jetty.

- Equipment shipped to site of oil spill and assembled
 - Fly-away system
 - Priority is sonar and ROV and control systems
 - Complete recovery and decanting gear on shore
- Location of oil/Site mapping
 - Operate multi-beam sonar mounted to one ROV, also real-time detection software
 - Cover port area and identify probable locations of oil – maps out extent of spill and coverage
 - Use camera on ROV to verify oil location – results used to fine-tune detection software
- Recovery
 - Large vacuum systems deployed on pier, dock, wharf or jetty
 - Uses dual-ROV system within 164 ft (50 m) radius of set-in point to recover oil from all reachable locations
 - Relocates to next position and repeats
- Decanting
 - Vacuum and holding tanks and decanting gear on shore



APPENDIX D. MPC SYSTEM COMPONENTS

D.1 System Components

The system is comprised of the three primary subsystems: detection, recovery, and decanting. Auxiliary systems are required for deployment, support, communications, electrical and hydraulic power. The MPC system, without decanting and polishing components, requires 450 to 500 ft² of deck space on a stable platform vessel of opportunity (VOO). Decanting equipment footprint will be determined by spill size and spill characteristics. Figure D-1 shows a conceptual design of the detection and recovery components.

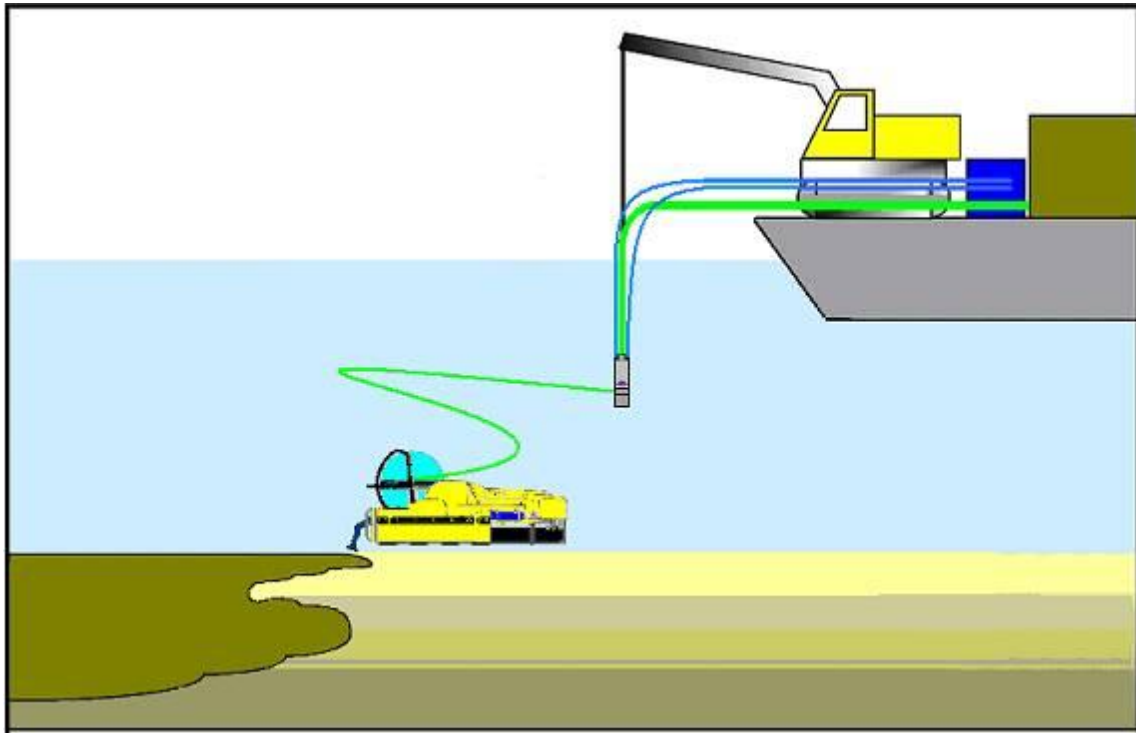


Figure D-1. Representation of the general arrangement of the MPC system.

D.1.1 Detection

- Oil discriminating sonar systems (downward looking/surveying mode and forward looking/navigation mode).
- Fluorescence polarization (FP) oil detection sensors (auto focus mode for forward looking operations and fixed focus mode for detection of oil within the suction recovery hose).
- A manned submersible capable of being un-tethered from the support vessel for search and assessment phases of recovery.

D.1.2 Recovery

- A manned submersible unit, outfitted with appropriate equipment to connect to the pumping apparatus at the terminating oil recovery skimmer head nozzle and capable of manipulating the equipment at the required depth of 200'. The manned submersible is also capable of deploying oil

Heavy Oil Recovery Ohmsett Test Report

detection equipment to aid in the assessment and recovery of submerged oil masses, and navigational, communication, lighting and video equipment to assist in that purpose.

- A hydraulically powered subsea robotic manipulator arm capable of deploying the skimmer head nozzle at depth.
- A pumping apparatus with heated skimmer head nozzle capable of transferring high viscosity submerged oil, driven by a KMA 333 hydraulic submersible pump and powered by a hydraulic power unit.
- A vortex enhancer/debris chamber is mounted on the intake of the transfer pump. This device acts to produce effective flow at the pump's intake and allows for larger solids to fall out of the flow path to the bottom of the chamber. Coupled with a cone-shaped mesh screen the system screens out potentially damaging debris from the pump intake.

D.1.3 Decanting

MPC identified a number of appropriate technologies for oil/water separation and management, and described a plan for developing a decanting process that is suitable for use with the system. Due to the wide range of different types of sinking oils, and their specific properties and behaviors, a decanting strategy with one set of equipment is not appropriate; some oils may require extensive decanting system equipment suites while others may separate for decanting purposes using a minimum of equipment. Figure D-2 shows MPC's recommended decanting design.

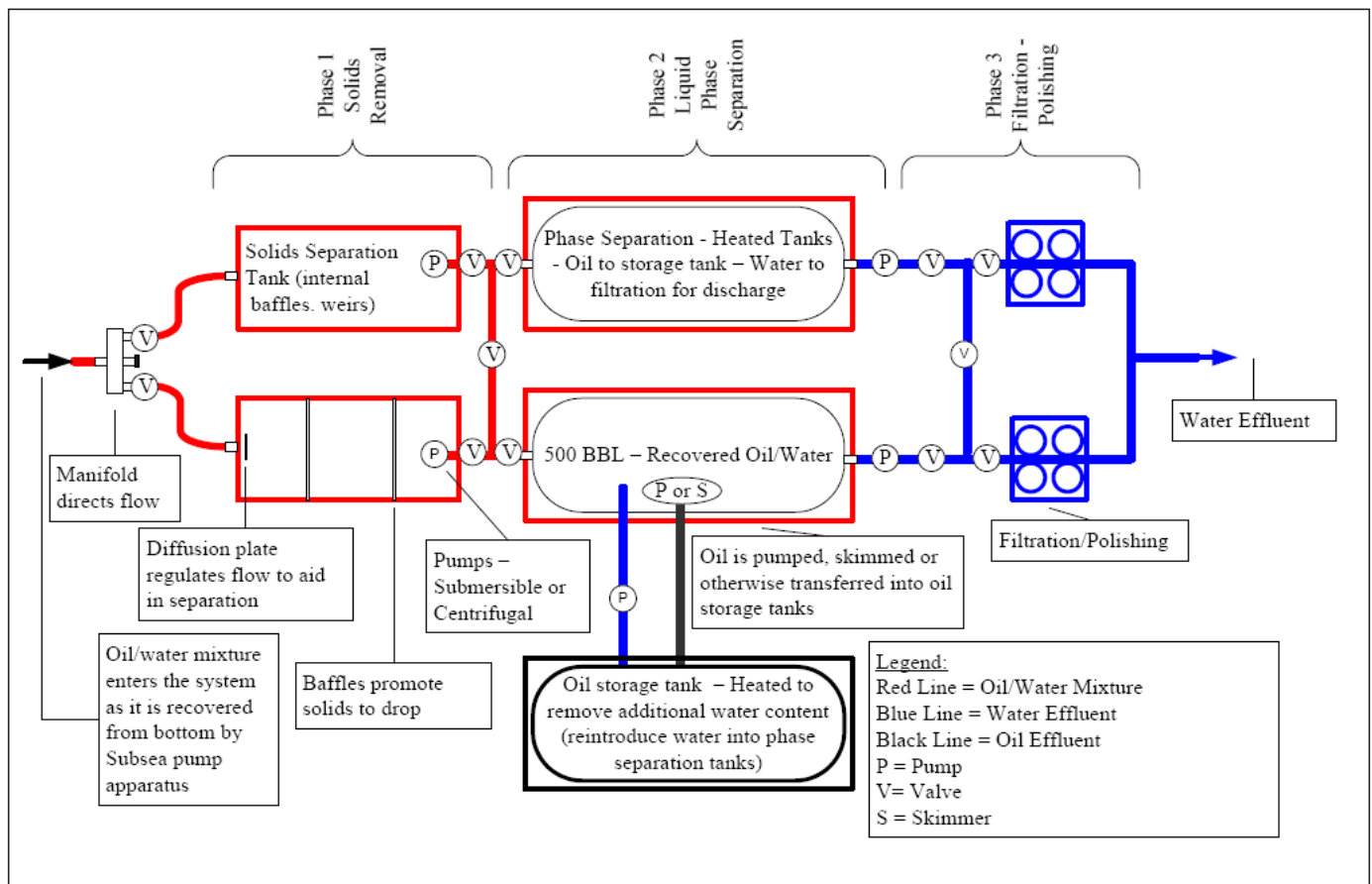


Figure D-2. MPC recommended decanting layout.



Heavy Oil Recovery Ohmsett Test Report

D.1.4 Auxiliary Equipment

The deployment system for the pumping apparatus (incorporating the transfer pump, vortex chamber, and skimmer nozzle) designed by Superior Energy Services Houston, TX, includes three skids and a power distribution and storage container. Specifically, the four packages which comprise this portion of the system are:

- Work Skid – Includes two reels capable of storing and deploying the umbilical and all associated hoses to provide transfer capabilities at depth. The work skid includes a rugged base structure and a winch and A-Frame (hydraulically powered) to facilitate launching and retrieval of the subsea pumping apparatus.
- Control Skid – Includes a fully enclosed work station for technicians monitoring the operations from the live data feeds and communications from the manned submersible and various other portions of the system. The work skid also features an extendable boom crane to assist in equipment deployment and some storage space for system components (pumps, tools, etc.).
- Hydraulics Skid – Includes three separate hydraulic power packs providing power to various hydraulic components in the system (i.e., pump, winch, crane, etc.).
- Power Distribution and Storage Container – Provides a dedicated weatherproof location for the electrical panels and associated equipment, as well as additional storage space for the system.
- A generator is specified for the unit, but not included as part of the system; they are readily available as rental units.

D.2 Equipment Specific to Ohmsett Test

Some components of the phase 1 design concept were not tested at the Ohmsett test facility during the phase 2 prototype testing due to the limited depth of the test tank at the Ohmsett facility (approximately 8 feet). The manned submersible, a central feature of Marine Pollution Control's (MPC) design concept, could not be deployed during the test.

Additionally, due to the relatively shallow depth of the tank, and in consideration of the costs associated with its development and production, the multi-purpose subsea umbilical system captured in the phase 1 design concept was not incorporated into the prototype design.

Specific components of the phase 1 design concept which were included within the phase 2 prototype design included:

- A pumping apparatus with heated skimmer head nozzle capable of transferring high viscosity submerged oil, driven by a KMA 333 hydraulic submersible pump and powered by a hydraulic power unit.
- A hydraulically powered subsea robotic manipulator arm capable of deploying the skimmer head nozzle at depth within the test tank.
- Oil discriminating sonar systems (downward looking/surveying mode and forward looking/navigation mode).
- Fluorescence polarization (FP) oil detection sensors (auto focus mode for forward looking operations and fixed focus mode for detection of oil within the suction recovery hose).
- A purpose built rig for deploying equipment within the test tank.



Heavy Oil Recovery Ohmsett Test Report

- Displays and controls associated with the devices mounted on the subsurface test rig.
- A suite of storage tanks, heating systems, filtration systems and transfer pumps to store and decant the recovered oil/water/sediment mixture removed from the test tank. The equipment utilized was of a standard, “off the shelf” configuration, with the exception of a customized set of heating coils that was installed into the primary receiving tank.

D.3 Concept of Operations

The submerged oil detection and recovery system will be deployed at the site of a submerged oil spill area using an appropriate vessel of opportunity (VOO) capable of supporting the mission components and holding station over the area where the oil mass is located, either by mooring in position or by other positioning methods. Selection of a VOO will be specific to the marine environment at the spill site. At a minimum, the VOO should have the necessary deck space and loading capacities to suit the oil recovery apparatus, the manned submersible, oil detection equipment, and the storage and decanting equipment. The VOO must also feature additional requisite logistic capabilities, such as a deployment crane apparatus to launch the manned submersible (the pumping apparatus includes its own deployment fixtures), as well as accommodations for crews. For inland operations a 100 x 35 ft (30.3 x 11 m) barge would suffice

Once the system has been deployed to the VOO and is brought into position over or near the spill site in an appropriate mooring strategy, the manned submersible can be deployed either connected to or independent of the oil recovery apparatus. In the independent deployment strategy, the manned submersible can operate in an assessment and survey mode, deploying its suite of oil detection equipment at the bottom to map the area and consistency of the spill to aid in rapid development of a strategy for initiating recovery capacity. If the oil mass is readily apparent, or following the assessment and survey phase, the submersible can be quickly connected to the pumping apparatus and will dive into position and begin recovery operations.

During oil recovery operations, the submersible can be operated in shifts of six hours or possibly longer, all the while holding station above the oil mass with the pilot and operator enclosed comfortably in a one-atmosphere cabin. The pilot and operator will be in constant communications with other technicians positioned topside, and the submarine position and conditions within the pumping apparatus will be displayed on monitors and recorded for later review or documentation of the response effort. In recovery deployment mode the manned submersible (with skimmer head nozzle attached) will have a unique ability to hover over the contaminated bottom area without disturbing the oil or the subsea sediments or vegetation; the recovery process should be both precise and unobtrusive to the environment. Oil recovery will be controlled by the operator while the pilot performs navigational tasks, and the operator will be afforded an auditory monitoring device at the skimmer head nozzle to assist in differentiating the quality and flow of the recovered material entering the pumping system.

A heated skimmer has been incorporated into the system, and the suction and transfer hoses comprising the transfer portion of the umbilical system will likewise be heated in order to aid in releasing oil into the system and ensuring that it flows smoothly through the hoses to the surface. Pumping flow will be controlled at the surface at the verbal direction of the operator in the manned submersible, and a bypass valve at the skimmer head nozzle will afford the ability to further control intake of water and oil. The operator will also have control of the angle of deployment and reach of the skimmer nozzle via a five-axis robotic arm mounted to the submarine.



Heavy Oil Recovery Ohmsett Test Report

During recovery operations, the transfer pump will be activated and oil and water will be drawn into the skimmer head nozzle and delivered through the transfer hose systems to the VOO positioned on the surface above. The recovered oil and water mixture transferred to the surface will be directed into a decanting and polishing system positioned on the VOO (established to suit the specific requirements of the oil type being recovered). The MPC design specifies a variety of pre-identified technologies, equipment types, and strategies for decanting operations (solids separation, heated phase separation, and filtration are all considered), with the ultimate objective of segregating the oil from the mixture and polishing the resulting water effluent for disposal on shore.

At the conclusion of a recovery work shift, the pumping operation will be suspended and the manned submersible will rise to the surface in a coordinated manner with the hose and umbilical system. Prior to surfacing the hose system will be flushed with water and isolated by means of a valve to eliminate the possibility of residual oil trapped in the hose being released into the environment during the process. At the surface the manned submersible will be appropriately tethered in position to the VOO, or can be raised to the deck of the ship for restocking of expendable materials or decontamination. Likewise the recovery system, including the umbilical deployment system and the inner casings of the transfer hoses, will be decontaminated on deck at the conclusion of a recovery sequence or operation or capped.



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APPENDIX E. OSBORS SYSTEM COMPONENTS

E.1 System Components

E.1.1 Detection

The OSBORS design presumes the search and location of the submerged oil will be the function of a separate entity or organization. The system uses a high definition camera to locate, monitor, and record action at the head of the pump. The closed circuit video camera on the nose of the pump is activated to allow the operator and other viewers' visual confirmation of the location of the material to be removed.

E.1.2 Recovery

The key component of the entire system is the Sub-Dredge (see Figure E-1). The Sub-Dredge was created to provide effective dredging with minimal turbidity and left-over residuals. The Sub-Dredge is un-manned and controlled safely from the surface and it is self-propelled on the sea floor by hydraulically driven tracks. Its patented EDDY Pump incorporates a hydro dynamically built casing, along with a precision-engineered geometric rotor that operates at a minimum of 800 gpm (182 m³/hr). It is about 20 feet long and weighs about 18,000 pounds. The conical shape of the rotating guard creates flat contact with the ground. Its capabilities enable it to pump at high production rates, to minimize over-dredging, and safely and precisely remove contaminated sediments and submerged oil.



Figure E-1. OSBORS Sub-dredge.

E.1.3 Decanting

The primary reception tanks for the Sub-dredge's pumped materials will be mobile fractionation (Frac) tanks that are readily available throughout the coastal areas of the U.S. Figure E-2 shows OSBORS decant and polish design.

- The first phase of separation is to try to refloat the oil by splashed into an inverted cone-shroud installed in the Frac tank for physical collection using a conveyor belt or rope mop oil skimmer.

Heavy Oil Recovery Ohmsett Test Report

- The second phase of separation is designed to be performed by the EVTN Voraxial® Separator, which is a patented, in-line, continuous-flow separator capable of pumping and simultaneously separating up to three components, such as oil, water, and solids.
- The remaining wet solids are transferred from the Frac tank to the geo bags housed in the hopper barge(s) for dewatering. The resultant liquid from the dewatering should be sent through the Voraxial for a third phase of oil/water separation. The resultant water from the second and third phase separation processes should be analyzed for suitability to discharge in-situ.

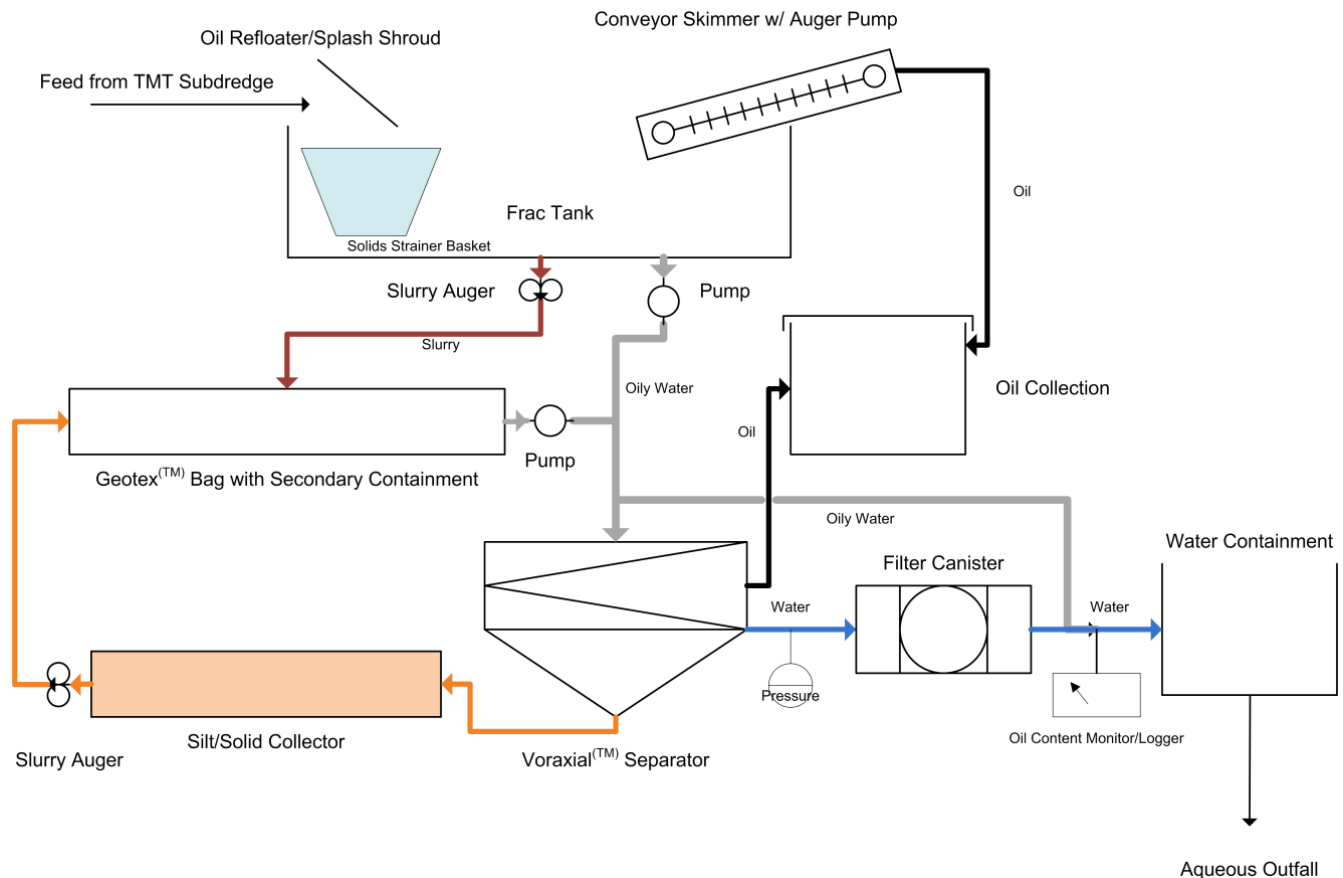


Figure E-2. OSBORS decant and polish design.

E.2 Equipment Specific to Ohmsett Test

Since it was not practical to operate the large remote-controlled Sub-dredge in the Ohmsett tank, the EDDY pump was housed in a custom frame attached to the arm of a construction grade excavator and operated hydraulically.

A mounted camera system and a closed-circuit monitor installed in the excavator cab allowed the operator to position the suction head and control the pump.

For the testing at Ohmsett, a full oil separation system was deployed that used a settling tank, mesh filter cloths, and surface skimmers, although some of the decanting components were scale models of those that would be used in the field.



Heavy Oil Recovery Ohmsett Test Report

Ohmsett Equipment List:

- EDDY Pump
- CAT 320DD Excavator
- Baker Phase Separator
- Adler Roll-Off Bulk Tank – Closed Top Mini-Frac Tank
- Baker – 3 Inch Duplex Bag filter
- Spate 75C Diaphragm Pump
- Model C-13e Mop Skimmer
- Turner Instruments 500D Portable Oil-in-Water Analyzer
- Hand held Turbidity Analyzer - 2100Q Turbidimeter
- Kronsberg High Definition Underwater Camera
- Secondary Containment Pools

E.3 Concept of Operations

It is assumed the response organization will report to the OSBORS team where a concentration of submerged oil exists. From this information the Sub-dredge will be launched and utilize its enhanced video capabilities to pinpoint the oil prior to commencing pumping operations. Using this method, the Sub-dredge can be effectively guided to within one meter of the presence of oil prior to commencing recovery operations, thereby reducing amount of water recovered.

The EDDY Pump can be attached to an Excavator, as it was during these tests, or mounted on the remote controlled Sub-dredge, and used to remove highly viscous submerged oil from the bottom of a lake or ocean. Support equipment (barge, crane, etc.) will depend on location of oil.



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APPENDIX F. RECOMMENDATIONS FOR FEDERAL ON-SCENE COORDINATORS

In responding to any oil spill, it is essential that the Federal On-scene Coordinator (FOSC) knows the location, area coverage, and characteristics of the oil to effectively deploy cleanup resources and protect environmentally sensitive areas. Spills of submerged oil pose special challenges during all phases of an emergency response.

- Submerged oils are difficult to detect and track.
- There are no proven containment methods for oil either suspended in the water column or deposited on the seafloor.
- Underwater recovery methods are complex, expensive, and inefficient. Submerged oil is often viscous, making it difficult to pump.
- Large volumes of water and/or sediment usually must be handled during recovery and disposal.
- Every submerged oil spill is a unique combination of conditions based on oil type and behavior, environmental setting, and physical processes.

F.1 Detection and Tracking of Sunken Oil

The appropriate method for detecting, tracking, and mapping oil deposited on the seabed depends on the water depth and clarity and environmental conditions. In general:

- **Visual and photobathymetric techniques** (e.g., multi-spectral photography) are restricted to water depths of 20 m or less and are suitable for both suspended and deposited oil.
- **Diver-based visual observations** can only be used in low-current and small wave areas with moderately clear water.
- **Acoustic techniques, video observations, water-column and bottom sampling, *in situ* detectors (including fluorescence sensors), and nets and trawls** typically have no depth restrictions except that the water must be deep enough for the instrument to be deployed and operated safely. They become more difficult to operate, however, as the current speed and wave height increase.

Measurements near the seabed become more challenging as the topographic relief of the bottom increases and the bottom surface becomes rougher. Fouling of instruments can be a serious issue.

F.1.1 Recommendations for Detection

The technology and approaches have not changed much since the National Research Council (NRC) report (Committee on Marine Transportation of Heavy Oils, National Research Council, 1999). Experiences during spills and research in the period since the report have contributed to better understanding of these techniques and approaches. Table F-1 (modified from Michel, 2006)) lists the advantages and disadvantages of a variety of submerged oil detection technologies.



Heavy Oil Recovery Ohmsett Test Report

Table F-1. Advantages and disadvantages of submerged oil detection technologies.

ADVANTAGES		DISADVANTAGES	
Visual			
<ul style="list-style-type: none">Can cover large areas quickly using standard resources available at spills		<ul style="list-style-type: none">Only effective in areas with high water claritySediment cover will prevent detection over timeGround truthing required	
Active Manual (V-SORS, Net Trawls)			
<ul style="list-style-type: none">Could detect both pooled and mobile oil moving above the bottomRelatively efficient in that large areas could be surveyedProvided spatial data on extent of submerged oilCan vary the length of the trawl to refine spatial extentCould be used in vessel traffic lanesGood positioning capability with onboard GPS and navigation system		<ul style="list-style-type: none">Time and labor intensive for deployment, inspection, and replacementSusceptible to snagging on the bottomCannot determine where along the trawl the oil occurredDifficult to calibrate the effectiveness of oil recoveryRequires a vessel with a boom/pulley and adequate deck space on the stern for handling, inspection, and replacementRequires use of white snare, which has to be special ordered	
Passive Manual (Snare Sentinels)			
<ul style="list-style-type: none">Provided spatial data on extent of submerged oilCould be used in vessel traffic lanesGood positioning capability with onboard GPS and navigation system		<ul style="list-style-type: none">Time and labor intensive for deployment, inspection, and replacementCannot determine when the oiling occurredDifficult to calibrate the effectiveness of oil recoveryRequires a vessel with a boom/pulley and adequate deck space on the stern for handling, inspection, and replacementRequires use of white snare, which has to be special ordered	
Side Scan Sonar			
<ul style="list-style-type: none">Good spatial coverageNot affected by poor visibilityGood visualization of large oil accumulations and other bottom features (e.g., debris piles, pipelines)		<ul style="list-style-type: none">Once the oil spreads out, has reduced success at oil identificationSlow turnaround (days) for useful product identificationNeeds validation of targets as oilLess accuracy in muddy substrates	
Multi-beam Sonar			
<ul style="list-style-type: none">Some systems can generate high-quality data with track linesGood locational accuracySoftware detection algorithms can increase search efficiency		<ul style="list-style-type: none">Data processing can be slowRequires extensive ground truthingRequires skilled operators	
Laser			
<ul style="list-style-type: none">Almost no false positivesCan use systems close to bottomData output easy to interpret		<ul style="list-style-type: none">Of limited use in turbid watersLimited availability	
Bottom Sampling			
<ul style="list-style-type: none">Can be effective in small areas for rapid definition of a known patch of oilLow tech optionHas been proven effective for certain spills		<ul style="list-style-type: none">Samples a very small area, which may not be representativeToo slow to be effective over a large areaDoes not indicate quantity of oil on bottom	



Heavy Oil Recovery Ohmsett Test Report

ADVANTAGES	DISADVANTAGES
Real-Time Mass Spectrometry	
<ul style="list-style-type: none">▪ Able to detect wide range of components▪ Able to provide real-time data	<ul style="list-style-type: none">▪ Droplets of oil or soluble oil must be in the water column▪ Oil on the bottom cannot be solid (as in low temperatures)

Additional considerations include:

1. Oil spill characteristics
 - a. Viscosity
 - b. Volume
 - c. Area of spill
 - d. Location
 - i. Trough/Flats/Canyon
 - ii. Distance from port
 - e. Depth
2. Environment
 - a. Benthic
 - b. Interactions – short/long term affects on the environment
 - c. Current
 - d. Effect of changing weather conditions
 - e. Temperature
 - f. Visibility
 - g. Debris
 - h. Bottom type
 - i. Topography
3. Methods
 - a. Detection – related to Visibility/Bottom Type/Debris
 - b. Delivery Method – related to Topography/Depth/Visibility/Environment
 - c. Decanting/Polishing/Storage – related to distance from port/debris/bottom type/weather effects
4. Logistics
 - a. Government Equipment Available
 - b. Leased Equipment Available
 - c. Backup equipment/spares availability
 - d. Time to get equipment on site
 - e. Transit time – personnel and equipment
 - f. Availability of skilled/trained operators/workers
 - g. Time to install/assemble equipment

F.2 Sunken Oil Recovery

The selection of containment and recovery methods is highly dependent on:

- Specific location and environmental conditions during the spill.
- Characteristics of the oil and its state of weathering and interaction with sediments.
- Availability of equipment, and logistical support for the cleanup operation.
- Potential environmental impacts of implementing these methods, particularly in sensitive benthic habitats.



Heavy Oil Recovery Ohmsett Test Report

The success of current methods varies greatly but is usually limited when the oil is widely distributed and/or the oil is mixed with sediments and water. In general, available methods are most successful when:

- Current speeds and wave conditions at the spill site are low.
- Oil is pumpable.
- The water is relatively shallow.
- The sunken oil is concentrated in natural collection areas.

F.2.1 Delivery Systems

Table F-2 lists the advantages and disadvantages of submerged oil recovery delivery systems.

Table F-2. Advantages and disadvantages of submerged oil recovery delivery systems.

ADVANTAGES	DISADVANTAGES
Manned Submersible	
<ul style="list-style-type: none">▪ Reduced physical interaction with the contaminated bottom▪ Increased visual access to bottom topography and areas of contamination▪ Reduced cross contamination and contaminant dispersal▪ Improved collection efficiency.▪ Lower risk and better “on oil” recovery time over divers	<ul style="list-style-type: none">▪ Cost▪ Reduced on oil recovery time due to returning to VOO to change out operators▪ Trained/Skilled operators required▪ Amount of deck space required
Unmanned Remotely Operated Vehicle (in water column)	
<ul style="list-style-type: none">▪ Increased visual access to the bottom topography and the contaminated bottom via remotely operated video▪ Reduced cross contamination and contaminant dispersal▪ Lower cost over manned submersible▪ Increased “on oil” recovery time – tethered vehicle does not have to be recovered to change out operators	<ul style="list-style-type: none">▪ Moderately high cost▪ Trained/Skilled operators required▪ Eyes on situ not as effective as manned submersible – less ability to adapt on site▪ If anchoring not possible, dynamic-positioning capable vessel needed
Unmanned Remotely Operated Vehicle (bottom tracking, crawlers)	
<ul style="list-style-type: none">▪ Increased visual access to the bottom topography and the contaminated bottom via remotely operated video▪ Lower cost over manned submersible▪ Increased “on oil” recovery time – tethered vehicle does not have to be recovered to change out operators	<ul style="list-style-type: none">▪ Moderately high cost▪ Trained/Skilled operators required▪ Eyes on situ not as effective as manned submersible – less ability to adapt on site▪ Bottom tracking submersible will have a greater impact on benthic and has a higher likelihood of contamination from oil▪ If anchoring not possible, dynamic-positioning capable vessel needed.
Divers	
<ul style="list-style-type: none">▪ Historically predominant method▪ Eyes on oil – diver can adapt to changing characteristics▪ Relatively low cost	<ul style="list-style-type: none">▪ Limited on spill recover time due to diver limits/fatigue▪ Diver and equipment contamination▪ Limitations on water depth



F.2.2 Pump and Vacuum Systems

Pump and Vacuum systems have historically been most successful for removing large volumes of sunken oil. They typically consist of a submersible pump/vacuum system, an oil-water separator, and a storage container. The systems can be mounted on trucks, on land, or on barges or ships. The suction head of the system can be controlled by a myriad of delivery modes including divers, remotely operated vehicles, and manned submersibles and may have an air or water injection system to assist in fluidizing and transporting the slurry. The pumped material is usually a mixture of water, oil, and oiled sediment. Highly viscous or solid oils are usually not pumpable and, hence, are not recoverable with this method. Some systems have added heating systems attached to the suction nozzle to lower oil viscosity and improve collection ability and efficiency.

The ability to adapt in situ by varying pump speeds/flow rates and adjusting or changing suction nozzles is highly advantageous to optimizing recovery efforts.

F.3 Decanting

Submerged oil pumping operations utilize water as a carrier device to transport oil while performing recovery, a necessary function that results in the accumulation of a large amount of water in the storage tanks. Inefficiencies in targeting the pump nozzle to the oil may result in an additional volume of water. Depending upon the nature of the oil, the benthic environment, and the efficiency of the pump and its nozzle, a large load of sediment or sediment-loaded oil may be unavoidably collected. Separation of the oil-water-sediment mixture collected during underwater oil recovery can become a limiting factor in the operation and over-all throughput of the recovery system. The decanting system must be designed accordingly to handle these waste streams. The system must also meet any Federal or local/state regulations and/or inspection before any water is pumped over the side.

The wide range of oil types and environmental conditions that could be encountered during submerged oil recovery operations requires a strategy for devising different types of decanting systems to suit different types of submerged oil spills, based on an inventory of components (tanks, heaters, pumps, filters) that could be drawn together using standard interfaces (compatible fittings, hoses, etc.). The attributes that must be considered for a decanting system intended especially for submerged oil recoveries are as follows:

- The ability to separate out sediment and other solids.
- The ability to separate oils of varying density and viscosity from either seawater or fresh water, including the ability to collect both the oil fraction that remains heavier than water, and the fraction that refloats during the process.
- The ability to configure the system appropriately for different types of recovered spill and on different recovery platforms.
- The ability to avoid or resist clogging due to suspended sediment or high-viscosity oil, or a combination of both, but without relying on uneconomically frequent or labor-intensive cleanouts or changes of strainers / filters; general ease of maintenance and low power requirements.
- Resistance to the chemical effects of different types and grades of recovered oil.
- The ability to operate satisfactorily under the anticipated motions of the recovery platform. Recovery platforms are nearly always platforms of opportunity and the range of ship motion environments is fairly broad even though the environment anticipated for recovery operations is usually modest



Heavy Oil Recovery Ohmsett Test Report

compared with rough weather for a seagoing ship. Settling and decanting can be quite sensitive even to modest platform motions, and can then become a bottleneck in the over-all system throughput.

- Security against the possibility of becoming a secondary spill source.
- Safety of personnel, system reliability, and low costs for acquisition and operation are considered highly important design criteria.

In situ oil on the sea floor may be either intrinsically denser than water, or it may be on the bottom because it adheres to or becomes mixed with sediment. When disturbed or agitated, whether by the natural environment or the recovery process, some fraction of the oil may refloat, while some fraction may remain heavy enough to settle out. In either case, the difference in density between water and oil may be small, so that settling proceeds rather slowly.

Multi-Stage Settling

For a variety of reasons, multi-stage decanting systems are often used. As one example, a four-stage decanting system was used in the Delaware River (Athos) submerged oil recovery. Most of the oil refloats. On that site a series of three 4,000 gallon fractionation tanks were used for decanting the oil. The first tank was used for collection and the second and third for settling. An oleophilic drum skimmer was placed on the top of the second tank to recover oil for transfer to storage. Sorbent snares were placed on top of the third tank to recover any remaining residual oil. Finally, water was pumped from the third 4,000 gallon tank through a 350 gallon polishing tank filled with sorbent oil snares, and then discharged into a boomed area alongside the work barge, with additional sorbent snares floated in it.

When a significant fraction of the oil is intrinsically denser than water, or adheres more strongly to the sediments with which it was in contact then settling will result in material on the bottom of each tank. For this reason, floating skimmers and floating sorbent snares on the top will not be able to concentrate or capture all of the oil. A general-purpose system must include a way to remove heavier oil and sediments from the tank bottoms, as well as refloats from the tops. Submersible pumps can be suspended at a variable depth within each tank in a cascade, discharging into the next stage. By appropriately setting the depth of the intake, the pump can be used to transfer water to the next stage of the settling cascade, or to transfer oil to a storage tank.

The processing at each stage may be conducted either continuously or in batches, depending on:

- The size and depth of the tank.
- The amount of flow disturbance at the inlet.
- The number of parallel processes available.
- The relationship between desired processing rate and available settling rate.

As mentioned above, this quantity varies with density difference, the volume ratio (water and oil) taken up in the collection process, and the amount of remixing taking place due to platform motions.

If the system is set up as a modular system then the critical stage can be duplicated and the bottleneck relieved. For example, if a large quantity of oil is refloats at the first stage, then the number of oleophilic skimmers in the first stage tank(s) can be increased. By contrast, if less of the oil is refloats, then the collecting tank(s) would tend to become more “bottom heavy” and would require more frequent clean-out of the bottoms. This could be accommodated by shifting one or more tanks into the collecting role, so that the available settling area is increased at that point in the process, and the amount of surface skimming reduced.



Heavy Oil Recovery Ohmsett Test Report

The depth setting on the intakes of the pumps transferring effluent from one stage to the next can also be adjusted to accommodate different volumes of refloated oil.

Figure F-1 shows a recommended decanting system design using the following stages.

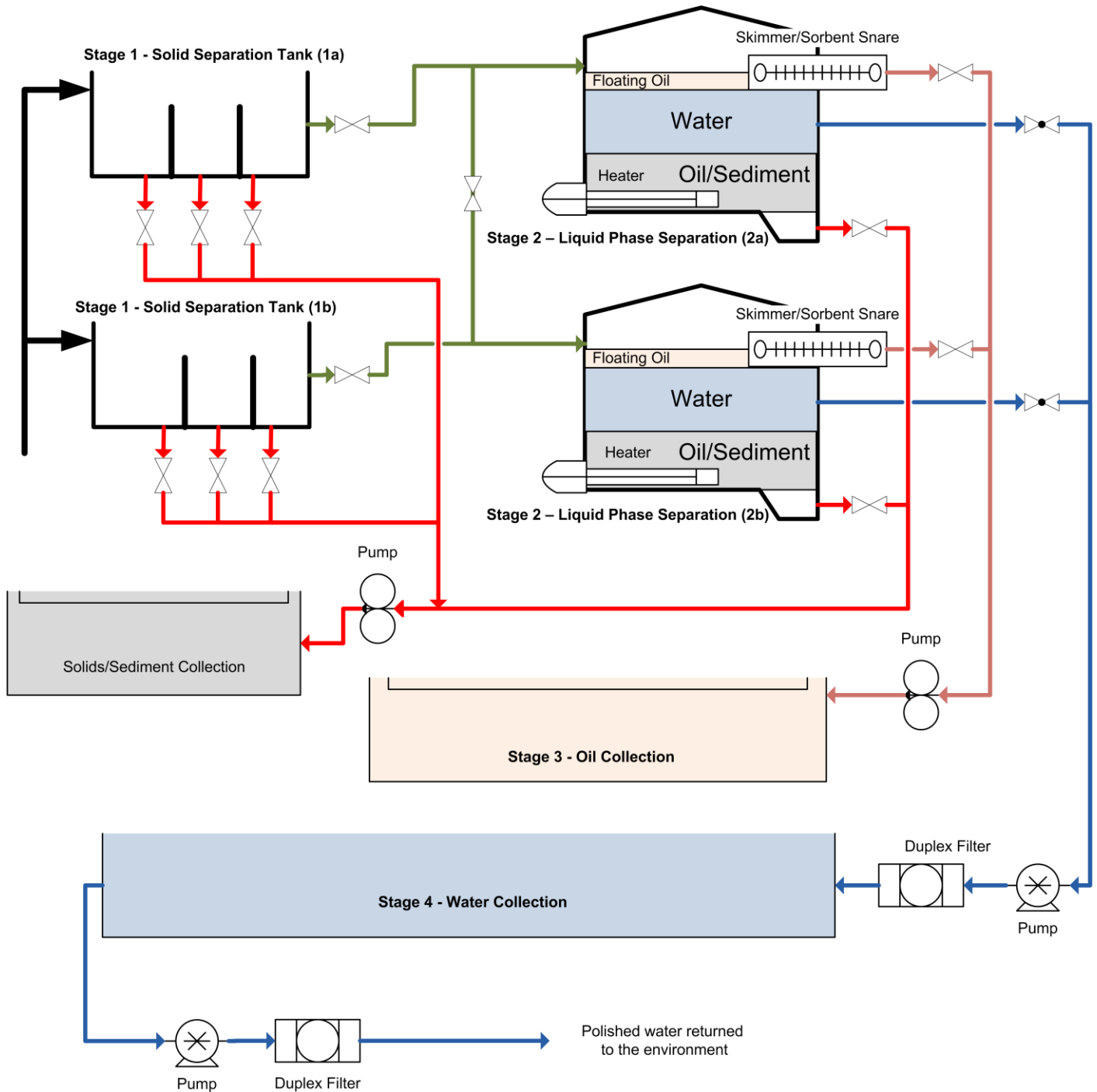


Figure F-1. Recommended decanting system.



Heavy Oil Recovery Ohmsett Test Report

Stage 1: Solid separation in tank 1 using baffles, filters, and/or gravity settling – time required will depend on the nature of the solids. Liquid portion is pumped to tank 2. Solids will need to be removed from the bottom of the tank. Tank 1A may need to be replaced with tank 1B (tank 1B put into service) for this to be accomplished. This operation may require the introduction of heavy machinery to aid in efficient solid waste management (i.e., the use of a crane with clam bucket or an excavator appropriately outfitted) as well as placement of appropriate secondary solid waste containers at the site.

Stage 2: Liquid phase separation in tank 2. Separate oil from water using aeration, heating, and/or gravity separation. In most cases some oil will sink and some will float.

Stage 3: Collection of oil. Floating oil can be collected from tank 2 using skimmers and/or sorbent snares and pumped to or placed in tank 3. Sunken oil will need to be removed from the bottom of the tank. Tank 2A may need to be replaced with tank 2B for this to be accomplished.

Stage 4: Collection of water. Water (middle layer between floating and sunken oil needs to be pumped from tank 2 into tank 4.

Stage 5: Polishing of water. Water in tank 4 can be polished using filters or oil absorbent systems and returned to the environment. Typical filtration systems applied to oil spill decanting operations include sand and carbon filtration units, specialized bag/chamber filtration methodologies, and some custom designed filter devices that fit on the end of discharge hoses. In each case the selection process for specifying the filter media should be based on compatibility with the type of oil that will be encountered. It is also important to ensure that the filter methodology selected allows for the required flow rate of the system as a whole, a decision factor that may require multiple banks of filters to ensure that a bottleneck condition does not occur at this final step in the process, resulting in shutting down operations to clear space in tanks ahead of the filtration process.

Stage 6: Disposal of oil, oiled debris, and decontaminated sand/sediments.



APPENDIX G. USCG INTERNAL REFERENCES

- EIC Laboratories, Inc., USCG Contract HSCG32-10-C-R00004, *Subtask Task No. 4.7E, Final Report, Polarized Fluorescence Sensor*.
- Johnson, G. W., (2010). *SEA HORSE (SEagoing Adaptable Heavy Oil Recovery SystEm) Phase I Final Report*, Alion Science & Technology, New London CT., September 2010.
- Johnson, G.W., Oates, C., Shalaev, R., Kasunick, G., Hansen, K., (2012). *SEA HORSE USCG RDC Prototype Demonstration Report*, Alion Science & Technology, April 2012.
- MAR Inc., (2011). USCG Sunken Oil Test, *Ohmsett Task Order 511*.
- Marine Pollution Control, (2011). USCG Contract #HSCG32-10-C-R00004, *Task No. 4.9, Deliverable 9, Prototype Demonstration Report*, December 2011
- OSBORS, (2011). Adapting a Unique Dredging Technology to Submerged Oil Recovery from the Sea Floor. USCG Contract No. HSCG32-10-C-R00003, Final Report, *Oil Stop Division of American Pollution Control Corp*, OHMSETT, Leonardo NJ, November 2011.
- OSBORS, (2010). Final Report, USCG Contact No. HSCG32-10-C-R00003, *Purchase Req. No. 2410320E04001*, October 2010.
- RESON, USCG Contract HSCG32-10-C-R00004, *Appendix, Prototype Demonstration Report*.
- SEAmagine, (2011). Oil Recovery Nozzle Development, *OHMSETT Post Report*, Onsite dates November 2011.
- Usher, D., Hazel III, W., and Kohnen, W., (2010). MPC, the Evolution of Submerged Oil Recovery (design report), August 2010.



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