Report No. CG-D-23-97

Test and Evaluation of Oil/Water Separators:

Intr-Septor 250
and
FRAMO "Skimmer Separator"

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Final Report
September 1996

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National Technical Information Service, Springfield, Virginia 22161

Prepared for:

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United States Coast Guard
Marine Safety and Environmental Protection, (G-M)
Washington, DC 20593-0001

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Technical Report Documentation Page

1. Report No. CG-D-23-97	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Test and Evaluation of Oil/Water Separators: Intr-Septor 250 and FRAMO "Skimmer Separator"		5. Report Date September 1996
		6. Performing Organization Code Project Element No: 4120.4.1
7. Author(s) M. Fickel and G. Bretz		8. Performing Organization Report No. R&DC 04/97
9. Performing Organization Name and Address Naval Facilities Engineering Service Center Port Hueneme, CA 93043-4370	Sponsoring Agency Marine Spill Response Corporation 1350 I Street, NW Suite 3000 Washington, DC 20005	10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address U.S. Department of Transportation United States Coast Guard Marine Safety and Environmental Protection (G-M) Washington, DC 20593-0001	U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, CT 06340-6096	13. Type of Report and Period Covered Final Report
		14. Sponsoring Agency Code Commandant (G-MOR) U.S. Coast Guard Headquarters Washington, DC 20593-0001

15. Supplementary Notes

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16. Abstract

This report presents the results of testing two candidate Oil/Water Separator (OWS) units. The tests were planned and directed by the Naval Facilities Engineering Service Center (NFESC) at Port Hueneme, California, under joint sponsorship and funding from the United States Coast Guard Research and Development Center and the Marine Spill Response Corporation. The "Intr-Septor 250" was a repeat performer, having been modified as a result of similar tests conducted by the Navy in 1992. The second candidate, the FRAMO "Skimmer Separator," arrived as a prototype machine, having recently been assembled and put through shakedown tests by the manufacturer. Each unit was subjected to a comprehensive sequence of tests that included the processing of various percentages of test oil in water and oil/water emulsion in free water (with and without emulsion breaker). In addition, tests that included the passage of entrained debris were completed to establish a baseline for performance under conditions conducive to clogging the OWS. In summary, although each machine was successful in effectively separating oil from water at particular inlet conditions, each recorded operational "hiccups" while performing over the full range of input characteristics that would be anticipated during an actual marine spill. The most significant deficiency was the inability to operate effectively and reliably through wide variations in percentage of waste oil and emulsion composition, and to handle ingested debris materials. In particular, the processing of heavy emulsions and slugs of particle debris appears to "gum up" the inner workings to such a degree that partial disassembly and cleaning of small orifices was required in order to get the OWS back on line. A recommended next step in evolution is to bypass the limitations of performance inherent in machines of this size and power by improving the consistency of the influent stream.

17. Key Words oil spill equipment oil/water separator	18. Distribution Statement This document is available to the U.S. public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

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METRIC CONVERSION FACTORS

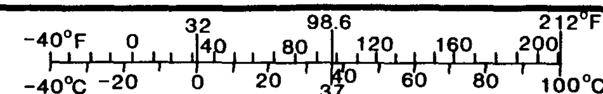
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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EXECUTIVE SUMMARY

One of the major shortcomings of the current Coast Guard (CG) spilled oil recovery capability is oil/water separation. All of the Coast Guard's skimmers are weir-type skimmers that are prone to ingesting significant amounts of water, especially in higher sea states. This water ingestion quickly translates to a temporary storage problem on the skimming vessel. Oil/water separators (OWS) were identified as a means to maximize the storage capacity for the oil. An OWS separates the recovered water from the oil, discharges the water overboard, and only sends oil to the storage device.

The U.S. Coast Guard R&D Center and the Marine Spill Response Corporation conducted a joint research project to test and evaluate lightweight, transportable oil/water separators that could be used in the CG spilled oil recovery inventory. The target OWS specifications were a weight of 4,000 pounds in use, throughput of 250 to 600 gpm, and a fit within a volume of 5 feet by 5 feet by 5 feet. A market survey was conducted, but no commercially available separators were located that met the requirements for oil/water throughput, transportation and operation weight. However, four oil/water separators were selected for testing in 1992. Tests were conducted on these separators to increase familiarity with OWS technologies, learn the operation and limitations of the oil/water separators, and evaluate how well these separators perform in a variety of oil. The results of those tests showed that the separators tested did not meet the weight, handling and performance criteria necessary to meet Coast Guard and MSRC missions. These tests are documented in a previous report (Report No. CG-D-06-96).

A second test series, which is documented in this report, was conducted in 1994 to test two separators. The Intr-Septor 250 was a repeat performer, having been modified as a result of the 1992 tests. The second candidate, the FRAMO "Skimmer Separator," was a prototype machine, having recently been assembled and put through shakedown tests by the manufacturer. Each unit was subjected to a comprehensive sequence of tests that included the processing of various percentages of test oil in water and oil/water emulsion in free water (with and without emulsion breaker). In addition, tests that included the passage of entrained debris were completed to establish a baseline for performance under conditions conducive to clogging the OWS. In summary, although each machine was successful in effectively separating oil from water at particular inlet conditions, each recorded operational deficiencies while performing over the full range of input characteristics that would be anticipated during an actual marine spill. The most significant deficiency was the inability of these separators to operate effectively and reliably through wide variations in percentage of influent oil and emulsion composition, and to handle ingested debris materials. In particular, heavy emulsions and slugs of particle debris adhered to the inner workings of these separators to such a degree that partial disassembly and cleaning of small orifices were required in order to get the equipment back on line.

It is recommended that further OWS development include a preseparator to condition the input to the main OWS by removing debris and very viscous oil from the flow stream. Further development should also apply systems engineering principles and consider the various configurations in which an OWS will be integrated with current CG oil recovery equipment.

The tests were planned and directed by the Naval Facilities Engineering Service Center (NFESC) at Port Hueneme, California.

1.0 INTRODUCTION

The United States Coast Guard (USCG) and the Marine Spill Response Corporation (MSRC) maintain and develop Vessel of Opportunity Skimming Systems (VOSS). VOSS assets are first response elements that can make a significant contribution in the early front-line containment of major marine spills, and in this mission it is mandatory that component hardware be lightweight, compact, and of modular construction to expedite rapid movement by land, ship, or air from prepositioned sites ashore to National Strike Force teams, buoy tenders, and various vessels of opportunity on site. One component currently not included in the Coast Guard's arsenal of VOSS recovery hardware because of the required constraints on size and weight is the oil/water separator (OWS). This is a processing device that might have a significant potential to reduce the volume of skimmed liquid diverted to local storage by removing free and emulsified water for return to the ambient watercourse. During incidents of marine spill, the untimely loss of available storage capacity can interrupt or prematurely end a successful skimming operation, thereby handicapping an otherwise productive VOSS operation. Thus, a readily definable need exists to upgrade the overall utility of VOSS applications by incorporating a compatibly sized, fully operational oil/water separator into the system architecture.

This report presents the results of testing two candidate OWS units at the Naval Fleet and Industrial Supply Center (FISC), located at Portsmouth, Virginia, during November 1994. The tests were planned and directed by the Naval Facilities Engineering Service Center (NFESC) at Port Hueneme, California, under joint sponsorship and funding from the United States Coast Guard Research and Development Center and the Marine Spill Response Corporation. The "Intr-Septor 250," produced by International Separation Technology of Salt Lake City, Utah, was a repeat performer, having been modified as a result of similar tests conducted by the Navy in 1992. The second candidate, the FRAMO "Skimmer Separator," arrived as a prototype machine, having recently been assembled and put through shakedown tests by the manufacturer, Frank Mohn Flatøy AS of Norway. Each unit was subjected to a comprehensive sequence of tests that included the processing of various percentages of test oil in water and oil/water emulsion in free water (with and without emulsion breaker). In addition, tests that included the passage of entrained debris were completed to establish a baseline for performance under conditions conducive to clogging the OWS. The results were mixed and similar to trends of inconsistent performance recorded by other units during the 1992 program. In summary, although each machine was successful in effectively separating oil from water at particular inlet conditions, each recorded operational "hiccups" while performing over the full range of input characteristics that would be anticipated during an actual marine spill. The most significant deficiency was the inability to operate effectively and reliably through wide variations in percentage of waste oil and emulsion composition, and to handle ingested debris materials. In particular, the processing of heavy emulsions and slugs of particle debris appeared to "gum up" the inner workings to such a degree that partial disassembly and cleaning of small orifices was required in order to get the OWS back on line. The particulars of the tests are presented in this report as tables and graphs. The notion of success is a relative measure, and although no commercial unit has to date performed to the standards of sustained purification required of a spill scenario, the technical baseline has definitely been set. A recommended next step in evolution is to bypass the limitations of performance inherent in machines of this size and power by improving the consistency of the influent stream. Techniques such as filtering, straining, and partial preseparation could serve to prevent or at least reduce the chances of shock loading, thus in effect allowing the OWS to operate more as a final clarifier than a total processor.

2.0 BACKGROUND

The Coast Guard is charged with protecting and preserving the coastal waters of the United States. The Marine Spill Response Corporation is a nonprofit organization chartered by a consortium of oil companies to handle marine spill situations, such as the disaster that occurred with the Exxon Valdez on Prince William Sound. The Oil Pollution Act of 1990 has served as a catalyst for increasing interest in spill recovery hardware. The Coast Guard is committed to major acquisitions of new equipment, including development of enhanced response assets for the National Strike Force teams. In 1992, MAR Incorporated completed a study of the commercial market to identify candidate OWSs likely to conform to the stringent size and weight restrictions required of VOSS hardware. The findings of that report concluded that "...a wide range of technologies and sizes of oil/water separators are available, but none are ideally suited to use in oil pollution cleanup within the context of Coast Guard operations, i.e. lightweight and compact." Characteristics targeted as acceptable to the VOSS program included the following list of attributes: (1) operating weight in the range of 4,000 to 6,000 pounds; (2) capacity of 250 to 500 gallons per minute; (3) footprint of 5 feet by 5 feet within a 5-foot tall enclosure; (4) ability to process oils ranging in viscosity from 1,500 to 50,000 cSt; and (5) ability to reduce the percentage of oil in the effluent water stream to acceptable levels of 50 to 100 ppm as required for legal discharge back into the ambient watercourse. Since no appropriate machines were located through industry, promising production candidates were selected for test and evaluation on the basis of perceived potential for additional development and adaptation to the specific requirements of VOSS architecture.

2.1 Previous Tests

Four oil/water separators were tested at the Amoco refinery in Yorktown, Virginia, during November 1992. The tests, sponsored jointly by the Coast Guard and the MSRC, were conducted by the Naval Civil Engineering Laboratory (NCEL), now the Naval Facilities Engineering Service Center, with logistical assistance from the Navy's Supervisor of Salvage and Diving (SUPSALV) Emergency Ship Salvage Material (ESSM) group. The test setup, operational procedures, data, and results are described in MAR Inc. (1992) and in Murdoch (1996). Three centrifugal-type commercial machines and one gravity separator were selected based on potential for this oil spill application. The centrifuge units were the Alpha-Laval OFPX 413, the Vortoil Oilspill Separation System, and the Intr-Septor 250. The gravity separator was included for baseline comparisons as to settling and debris collection. The test data provided mixed results, with strong points and weak points recorded for each of the machines. The indisputable conclusion, however, was that no single model of separator performed according to specifications and requirements set forth in Coast Guard and MSRC VOSS designs.

On a positive note, the data gathered at the Amoco site have provided a springboard for continued involvement by commercial firms as well as for investigators working in environmental cleanup and separation technology. Manufacturers were encouraged to continue efforts in product improvement through modification and basic design change.

2.2 Oil/Water Separators Invited for 1994 Tests

The Intr-Septor 250, promising because of its light weight, its compact size, and operating simplicity, was upgraded by a change in the prime mover and simplification and/or removal of internal components that affect the separation process. The electric motor used in the earlier version was replaced with a hydraulic motor that is more suitable for the VOSS application. Some of the internal components were modified. The internal weir was modified to allow changing its position to accommodate different influent compositions. Internal oleophilic materials that were intended to aid the separation process through coalescing oil droplets were deemed unnecessary and removed. The internal plumbing was modified to accommodate the new configuration.

The FRAMO "Skimmer Separator" was not available in 1992 because it was still in the preliminary design stage, but nonetheless promising from preliminary concept sketches and analytical data. The Skimmer Separator proof-of-concept design was finalized and a breadboard prototype was assembled during mid-1994. This "prototype" was laboratory tested shortly before being delivered to meet the scheduled start date of the 1994 trials.

3.0 DESCRIPTION OF SYSTEMS

3.1 VOSS Recovery

Seven primary components are used in marine spill response incidents, and all VOSS recovery systems contain most if not all of the elements discussed below.

3.1.1 Boom. A boom is a collection barrier used to divert and channel oil toward the cleanup vessel. Most types of booms are inflated to remain on the surface of the water with a portion of the boom barrier hanging under the water to keep the spilled oil from slipping under the boom.

3.1.2 Skimmer. Skimmers are fixtures that ride on the water gathering up floating materials from the surface. Recovered materials skimmed during cleanup operations may contain oils, emulsions, debris, and significant amounts of seawater (often in excess of 95 percent).

3.1.3 Pumps. Pumps are used to move collected pollutants from the skimmer to storage for containment prior to disposal or processing.

3.1.4 Primary Recovery Vessel. An optional primary recovery vessel with limited storage capacity is used in conjunction with some skimmer and pumping systems.

3.1.5 Temporary Storage Device. Barges and fuel bladders are often employed to hold recovered waste material prior to discharge for disposal or processing, particularly when a primary recovery vessel with on-site storage is not used.

3.1.6 Transporters. A transport system is necessary to move loaded barges and bladders to the shore or an alternate facility where they can be emptied for disposal or processing.

3.1.7 Off-Loading Facility. The off-loading facility provides a means of increased and long term storage for waste materials prior to disposition.

3.1.8 Current Coast Guard Oil Collection System. The Coast Guard National Strike Force teams currently do not have an oil/water separation capability. The primary high-sea recovery system at the time of the tests was the Open Water Oil Collection and Recovery System (OWOCRS), which operated without a primary recovery vessel, using instead a fixed-position weir-type skimmer that could ingest significant amounts of water. The skimmer, boom, pumps, mooring equipment, and retrieval subsystems together weigh approximately 23,050 pounds. The skimming barrier is packaged in one box, and the pumping assets are packaged in another. The pumps, three hydraulically-driven, double action diaphragm units mounted within an aluminum hull, move liquid at a combined capacity of 850 gpm.

The Coast Guard's newer recovery system, developed as the CG VOSS, includes a collection boom with a DESMI-250 model skimmer in the pocket. The vessel of opportunity skimming systems used by the MSRC include DESMI-250 skimmers and WALOPSEP W-4 skimmers and experience similar problems with excess water intake.

Because current VOSS recovery systems use weir-type skimmers, surface water is unavoidably collected along with contaminating oils. Thus, in situations of a marine spill, the loss of critical on-site storage capacity can interrupt or prematurely end a successful skimming operation, thereby decreasing the inherent utility of an otherwise productive VOSS system. The primary utility of the oil/water separator is in removing excess water from stored waste liquids for return to the ambient watercourse. Because of strict national and international regulations regarding discharge back into seas, however, the single most important function of an OWS unit must be to purify separated water to a level acceptable for discharge. The best oil/water separator, of course, is efficient at both removing and purifying water. An ideal unit would produce two purified discharge volumes, an effluent oil that is essentially free of water and effluent water that is essentially free of oil.

3.2 Oil/Water Separators Tested

Even with newer technology, a gap continues between operational requirements for readiness and response during a major marine spill and corresponding availability of expedient collection systems. However, since the Oil Pollution Act of 1990 was enacted, the Coast Guard and the MSRC have invested considerable time, resources, and effort together to test and evaluate oil/water separators for VOSS applications. The two units tested in 1994 were the Intr-Septor 250 and the FRAMO Skimmer Separator.

3.2.1 Intr-Septor 250. The Intr-Septor 250 is manufactured by International Separation Technology of Salt Lake City, Utah. It is a second generation centrifugal separator rated by the manufacturer at a process rating of 250 gpm. It is compact, lightweight, and easily handled by a forklift truck. The physical characteristics are contained in Table 1. The influent oil/water mixture is externally pumped to a port at the bottom of the machine which feeds the separation chamber. The effluent flows out from ports (equipped with cam-lock fittings) at the base of the separator.

Table 1
Oil/Water Separator Characteristics

Separator	Capacity (gpm)	Dry Weight (lb)	Dimensions (in.)
<u>Target Characteristics</u> U.S. Coast Guard VOSS Specification	250-500	4,000-6,000	Length: 60 Width: 60 Height: 60
IntrSept "Intr-Septor 250"	250	2,500	Length: 45 Width: 45 Height: 45
FRAMO "Skimmer Separator"	430	5,300	Length: 49 Width: 49 Height: 98

The weir device is somewhat adjustable using air pressure to "bubble control" the passage of effluent water and effluent oil. The adjustment is to allow for the differences in density between water and the various oils that may be encountered. The air pressure requirements are not above what would be available on most vessels of opportunity.

Inside the separation chamber is a rotor assembly that accelerates the liquid to some 500 times the force of gravity, thereby affecting separation. The rotor assembly is powered by a hydraulic motor that sits on top of the cylindrical housing. The power requirements vary according to application, which would indicate that higher flow rates and viscous influents will drive up power consumption. For testing purposes the power requirement is not a critical factor but in the VOSS scenario a large power source may not be available and a generator may not be a part of the suite of equipment. The model 250 required about 75 horsepower.

3.2.2 FRAMO Skimmer Separator. The FRAMO Skimmer Separator, manufactured by Frank Mohn Flatøy AS of Norway, is a new entry into the market of mobile, compact oil/water separators. The physical particulars are listed in Table 1. The Skimmer Separator is a breadboard prototype that, at the time of the FISC tests, had not been subjected to several of the tests recommended in ASTM 933-85 (1985). Shakedown tests conducted in Norway used oil reported to be similar to the test oil at FISC, having a density of 0.95 g/mL. However, the actual procedures used in those laboratory tests have not been reported. The test results were presented in terms of an "operational envelope" graph that plots volumetric flow rate versus influent composition (i.e., percent oil in water by volume).

In the FRAMO unit, influent flow is pumped externally to a port at the top to a cylinder that houses the high speed rotor. Effluent water and oil lines lead from manifolds at the top of the separator with the water connection located above the oil connection. The high speed rotor is perforated to allow smaller droplets of oil to pass through. The rotor in this unit is also driven by an externally-powered hydraulic motor. The power needs of the hydraulic motor are relatively high since two diesel-engine powered hydraulic power units operating in parallel are required, providing up to 500 liters per minute (300 gpm) at a pressure differential of 280 bar (4,000 psi).

4.0 OWS TEST PROCEDURES

4.1 Test Plan

The test plan developed for this program was structured to evaluate the operational characteristics and performance efficiencies of two separators under conditions reflective of an actual marine spill situation. The test plan was prepared and written by the Naval Facilities Engineering Service Center, with collaboration from the Coast Guard Research and Development Center and the Marine Spill Response Corporation. It was patterned after a similar comprehensive test plan prepared by the Naval Civil Engineering Laboratory (predecessor organization to NFESC) for the 1992 program, using the outline provided by MAR, Inc. in its final report (MAR, 1992), and ASTM 933-85 as guidelines. Complying with the ASTM Standard was especially important so the quality of the data would not be compromised. Unlike the 1992 program, however, tests simulating motion at sea and tests using crude oil as base stock were not requested in the test plan. Motion tests were eliminated because insignificant differences were recorded during 1992 when tests were conducted using a tilt platform. Crude oil was not used because of concerns over cost, safety, and disposal. Instead, a blended fuel oil was requested of a local vendor to be prepared with viscosity and density characteristics similar to those of the 1992 test oil. An additional difference was the use of fresh water drawn from the Elizabeth River as the mixing media.

4.2 Test Protocol

A summary of the key test parameters is presented in Table 2, which lists the nature of the test run, the targeted oil-to-water ratio of the influent, and the condition of the influent mix (i.e., test oil, emulsion, emulsion with breaker, or debris). Information used to produce the table includes requirements contained in ASTM 933-85 and lessons learned during the 1992 tests at the Amoco refinery site. The test protocol was finalized after each of the contributing parties had an opportunity to review and comment. Comments were received and revisions to the test plan were incorporated based on technical merit and feasibility.

Table 2
Oil/Water Separator Test Parameters

Test	Influent Composition		Petroleum Product
	Oil (%)	Water (%)	
General Separation Performance (150 & 250 gpm)	0 5 25 50 75 100	100 95 75 50 25 0	Test Oil
Optimum Volumetric Capacity	Same influent conditions as shown for General Separation above		Test Oil
Debris	25	75	Test Oil
Emulsion	Same influent conditions as shown for General Separation above		Emulsion
Emulsion with Emulsion Breaker	Same influent conditions as shown for General Separation above		Emulsion

4.3 General Performance Considerations

The composition of an influent stream may change significantly during a spill recovery operation because VOSS skimmers ingest varying amounts of water with oil, depending on sea state or other local conditions. Each separator should be evaluated over a range of oil-to-water composition to determine the effect on performance of increasing or decreasing the ratio of oil. In addition to oil percentages of 5, 25, 50, and 75, the test plan also included test runs at 100 percent water and 100 percent oil influents. No-oil tests are required to purge the unit between successive trials, while all oil/no-water tests simulate the transient condition that may exist when "slugs" of oil are picked up from the spill site.

4.4 Test Oil

The test oil requested in the test plan was carefully selected to physically simulate the crude oil product used as test oil during the Amoco tests of 1992. The goal was to be able to compare the two programs directly. Characteristics of liquid viscosity and density were specified for the local vendor of fuel oil products. The target ranges in viscosity and density were specified, respectively, as 1,200 to 1,500 cSt at 80°F and 0.90 to 0.98 g/mL.

4.5 Optimum Capacity Assessment

The test plan called for determining the optimum volumetric flow rate at which each OWS would achieve the greatest hydrocarbon removal efficiency. The strategy consisted of conducting several test runs at varying volumetric flow rates in order to establish a series of process curves. The target flow rates were selected as particular percentages of the manufacturer's rating, up to a maximum of 120 percent if possible. The planned procedure was to operate the Intr-Septor 250 at flow rates from 100 gpm to 250 gpm. For the FRAMO Skimmer Separator, the target flow rate variation was 100 gpm to 400 gpm. Should time and resources permit, the FRAMO would also be tested at the advertised rate of 100 cubic meters per hour (530 gpm).

4.6 Debris Test

The ingestion of fine solid materials along with intake oil during a skimming operation is unavoidable; thus, tests to evaluate the effects of accumulated debris on separator performance were planned. The plan required that susceptibility to clogging by debris be established by introducing graded wood and sawdust materials into the influent stream through the mixing loop. Debris was mixed manually, measured into a beaker, moistened, and manually added to the mixing loop near the pump intake line for the OWS. The breakdown in size and frequency of simulated debris was specified in the test plan as follows:

1/4-inch wood chips - 10 percent by weight
#10 mesh sawdust - 10 percent by weight
#40 mesh sawdust - 40 percent by weight
#140 mesh sawdust- 40 percent by weight

4.7 Emulsion Tests

The test plan included tests to determine the ability of each separator to process water-in-oil emulsions and free water. The development of emulsions (on the high seas) is a natural consequence of aging and weathering processes, and may be additionally accelerated by pumping action to and from the oil/water separator. Under "test" conditions, emulsions are prepared by pumping oil and water solutions around a loop, slowly adding oil as required, until the targeted properties are attained. The properties called for in the test plan were 60 to 70 percent water, with viscosity of 40,000 to 50,000 cSt at 75°F, and density in the range 0.90 to 0.98 g/mL. In addition, the emulsion tests were geared toward determining the effectiveness of each separator in breaking down an emulsion and separating the oil and water components. Since the viscosity of the emulsion was higher than most oils, it was desired to test the separator's ability to extract free water from the emulsion.

4.8 Emulsion with Emulsion Breaker

Since oil/water emulsions may contain as much as 60 to 70 percent entrapped water, it is desirable to break down emulsions under actual spill conditions so that the water component may be freed and discharged back to the sea. The test plan required that each unit be evaluated by injecting an emulsion-breaking chemical into the influent stream to break down the emulsion prior to entry into the separator. The same tests were scheduled as those for emulsions so that the performance of each separator could be compared for emulsion processing with and without the breaker. A target injection rate of 600 mL per minute of Breaxit 7877 was selected to achieve an influent concentration of 600 ppm. During the actual tests, however, that rate was not possible because of limitations with the metering pump which had a capacity of approximately 350 mL per minute under the pressure conditions. The actual injection rate used was 300 mL per minute. It is not an ASTM requirement to set a particular injection rate; the 600-ppm concentration value had been selected in order to make comparisons with the 1992 tests. The tests on Breaxit and this emulsion were not as effective as the 1992 tests. This may have been due to the difference in water salinity and/or crude/refined product used in the two tests.

5.0 TEST SITE SETUP

The layout of the test site including the specific equipment, such as tanks, instrumentation, and sampling stations, is shown in Figure 1. Specific items of hardware and associated problems, as well as limitations experienced with instrumentation and sampling, are discussed below.

5.1 Layout of Piping and Fittings

Piping, hoses, and fittings required to plumb the test site were provided by the Navy's Supervisor of Salvage (SUPSALV), Emergency Ship Salvage Material (ESSM) group, using components from the FISC Cheatham Annex, located at Williamsburg, Virginia. These assets are normally reserved for use at actual marine spill sites. Plumbing fixtures were positioned to allow the accurate measuring of influent and effluent products, and to ensure that emulsions were thoroughly mixed prior to entering each of the OWS units.

5.2 Pumps

Pumps were also provided by SUPSALV from the ESSM equipment pool. Two types of pumps were used to move the test liquids: (1) an immersible, screw-type, positive displacement pump that is typically used in skimming devices; and (2) an in-line, impeller-type centrifugal trash pump used to transfer collected oil and debris. The locations of pumps in the test setup are shown in Figure 1. Pumps were driven by hydraulic motors, powered in turn by portable, diesel-engine-driven hydraulic power packs. During the actual testing program, the lack of sensitivity on the pump controls used with the power packs created minor variations in the flow rates for all the influent streams. Flow rates were therefore monitored continuously during tests by means of both mechanical and electronic flow meters and electronic recording equipment, specifically a Campbell datalogger. Data include other measurements taken relating to the amount of oil and water that passed through the test loop.

5.3 Tanks

The tanks shown in Figure 1 were mobile in character, rectangular in cross section, and able to hold 20,000 gallons of liquid. Four such tanks were used, one for each influent liquid (i.e., water and oil) and one each for effluent oil and effluent water. Soundings were taken and levels recorded at the start and finish of each test to verify flow data recorded from flow meters.

Level data collected in this manner produced the most reliable method of measuring total liquid transfer, and was used in calculating water purification efficiency and water removal efficiency.

5.4 Mixing Loop

A mixing loop was installed to simulate the effects of on-line pumps used during actual oil spill recovery operations. The mixing loop was to allow adjustment of the oil and water stream to achieve the target ratio before it went into the separator. Additionally, the mixing loop was designed to keep liquid flow moving quickly enough to maintain the influent oil/water stream as a homogeneous mixture and also to reduce oil droplet size to levels in accordance with ASTM 933-85 standards. The mixing loop consisted of 50 feet of hose with a centrifugal pump in the middle of the run. With the centrifugal pump in the mixing loop, kinetic energy was imparted to the mixture, causing oil droplet size to decrease. Thus, the "mixed" flow was more difficult to separate than flow that had not been accelerated through the loop.

5.5 Flow Meters

The impeller type with analog output flow meters used for this program were selected on the basis of reliability and availability, from experience gained during the 1992 tests, and from the experience MSRC has had with impeller types. In addition, from the standpoint of cost savings, the flow meters actually used were taken from the MSRC stock of equipment for responders, thus rental expenses were avoided. The flow meter measuring influent oil flow was an ultrasonic device that had a very low minimum flow rate for accuracy. The influent water flow meter was an impeller type and had a considerably higher flow rate minimum. The mixture flow meter was the impeller type MSRC has used on the Oil Spill Response Vessel (OSRV).

The primary function of the influent oil and water flow meters was to estimate the ratio of oil to water in the influent stream. The flow meters were monitored while adjusting the pump speeds until the desired ratio was achieved. Once the oil-to-water ratio was at the proper ratio, a sample of the mix was extracted from the influent sample station downstream of the mixing loop. When the sample closely matched the desired ratio the test sequence was initiated. The flow meters each have electronic transducers for remote monitoring and the output signals were electronically recorded using a dedicated computer continuously through the test runs.

The function of the flow meter at the influent sample station was to monitor total flow rates of the influent stream into the OWS. The flow meter was also equipped with an electronic sensor and the output was continuously recorded on the data computer through the test runs.

5.6 Effluent Tanks

Neither of the OWS units tested had transfer pumps on the outlet side of the separator. Therefore, neither the Intr-Septor 250 nor the FRAMO Skimmer Separator could tolerate any back pressure on the outlets. Because of this limitation, oil and water outlet hoses drained directly into 500-gallon tanks. The effluent samples were taken at the outlet hoses over the tanks. The location of the tanks made it easy for the pump operators to see how much adjustment had to be made to the pump controls to maintain control of the effluent.

5.7 Sampling Stations

Sampling stations were located for convenience and practical considerations. The influent station (identified as station 1 in Figure 1) was located downstream of the mixing loop and just before the OWS to ensure the samples represented the mixture seen by the OWS. The influent station was designed to withdraw liquid from the middle of a length of hard pipe on the assumption that flow near the center would be representative of the entire cross section. The influent sampling station pipe was inclined to ensure full flow. Samples of water (station 2) and oil (station 3) effluents were taken directly from the OWS outlet hoses that were fed into the 500-gallon holding tanks before these tanks were emptied to effluent storage. The samples were taken to the mobile laboratory and analyzed to accurately determine the contents and condition of the influent and effluent streams.

5.8 Test Oil

The test oil was produced locally by a fuel oil vendor to the range of viscosity and density specified. The density was specified in a range of 0.92 to 0.96 g/mL. The viscosity was specified at 1,200 cSt at 80°F. Samples were taken from each tanker as it delivered the product. Although there were minor variations in viscosity and density, liquid properties were well within the range called for in the test plan.

5.8.1 Test Water. The water used in this series of tests was taken directly from the Elizabeth River. The range of salinities was from 1.52 to 2.09 percent. In previous tests, ocean water with a nominal salinity of 3.5 percent was used. The change in salinity could have an effect on the emulsion making and the effectiveness of the breaker.

5.9 Debris

The debris material used in this series of tests was a type of wood shavings and chips used in pet cages. This material was approximately the size and density described in the test plan. Although it was planned to gradate the debris into the sizes listed in the test plan, the weight and size makeup was conforming enough so that the labor required to further separate the debris by size was not warranted. Visual inspection of the packaged debris sample and a laboratory analysis indicated that, in fact, the debris was very nearly equal to that required by ASTM 933-85. The procedure for mixing the debris into the flow stream included adding 0.1 pound of debris per 100 gallons. The test ran for about 10 minutes, then it was stopped.

5.10 Emulsions

The water-in-oil emulsion was made by pumping water into the supply oil tank and circulating the mixture continuously until the emulsion was practically homogenous and somewhat stable. Emulsion mixing took from 8 to 10 hours for a batch of 16,000 to 18,000 gallons (60 water/40 oil). The goal of mixing was to simulate emulsions that are created by wave and weathering action on spilled oil, as well as by pumping during the recovery process.

Emulsions are more difficult to separate than oil because of the relatively small difference in density between the sea/brackish water (~ 1.014 g/mL) and the emulsion (0.96 to 0.98 g/mL).

5.11 Chemical Analysis

Chemical analyses were required in order to characterize the composition of the influent and effluent flows, particularly the purity of the water being discharged. Some on-site analysis was accomplished in the MSRC mobile laboratory staffed by chemists from Battelle. The on-site analysis included the following tests: (1) influent oil in water by percent volume, (2) oil droplet size measurement using a spectrometer produced by Mastersizer, (3) water-in-oil effluent, (4) oil and emulsion viscosity and density measurements, and (5) influent water salinity. The on-site analysis conducted in the mobile laboratory was used to determine order of magnitude results from the tests as well as droplet size and characterization of the test fluids. This allowed an on-the-spot determination of the oil/water ratio data points. Test runs that did not meet the target compositions listed in the test plan were run again to produce a meaningful range of data points.

Some of the physical samples taken during the test runs were stored in the mobile laboratory and later transported to the Battelle Ocean Sciences Laboratory in Duxbury, Massachusetts for off-site tests. The samples are in storage for possible future reference.

6.0 HYDROCARBON REMOVAL AND WATER REMOVAL EFFICIENCIES

The most important quality of an oil/water separator used in VOSS applications is its hydrocarbon removal efficiency because the separated effluent water stream cannot be returned to the sea unless it has been cleaned to sufficient purity as required by governing state, national, and international laws. On the other hand, a primary motivation for using an OWS is to reduce and conserve needed storage capacity by removing residual water that is unavoidably collected along with the offending oil pollutant. Thus, both water removal efficiency and hydrocarbon removal efficiency are considered important factors in evaluating the potential of an oil/water separator for VOSS applications. Even though Coast Guard and MSRC strike forces are most concerned with handling large volumes of influent, the amount of water in the effluent oil becomes a factor in reclaiming or recycling recovered oil products.

ASTM 933-85 defines two types of separation systems. Type A systems are those designed to produce effluent water with entrained oil less than 250 ppm. Type B systems are designed to reduce the amount of recovered water with no specific oil entrainment objective. Type B systems are not relevant to the study at hand since the objective is to develop a separator that can: (1) separate free water from oil or emulsions, (2) separate water bound in an emulsion, (3) produce "clean" water for overboard discharge, and (4) produce pure oil for temporary storage. The ASTM standard does not present a clear and sufficient definition of separator efficiency since the defining equation is ambiguously written and addresses only the resulting purity of the water-side effluent without regard to the quality of the oil-side effluent. A special report produced by MAR Inc. (1992) presents two equations for separator performance so that both the water removal (from oil) efficiency and oil removal (from water) efficiency can be calculated independently. Although the nomenclature adopted in that report used the term "water purification efficiency" to describe the removal of hydrocarbons from water, the term "hydrocarbon removal" efficiency has been adopted in this report as more appropriate since the emulsions that were tested were in fact 60 to 70 percent water.

The hydrocarbon removal efficiency, η_{hr}, is defined as:

$$\eta_{hr} = 100 - \frac{Effluent\,Water: Oil\,Fraction}{Influent\,Stream\,Oil\,Fraction}(100)$$

The water removal efficiency, η_{wr}, is defined as:

$$\eta_{wr} = 100 - \frac{Effluent\,Oil: Water\,Fraction}{Influent\,Stream: Water\,Fraction}(100)$$

The water removal efficiency equation deals only with the free water in the influent and effluent streams. Therefore, the water removal efficiency is a relative measure. The entrained water in the emulsion was not considered because, during the 1992 trials, very few tests resulted in breaking water away from the emulsion. The data confirmed this assumption during these tests. For most cases, some portion of the free water was emulsified with the oil and was then discharged through both of the outlets.

7.0 OWS TEST RESULTS

Water removal and hydrocarbon removal efficiencies presented as functions of the oil/water ratio (by percent volume) were plotted for each separator at each level of influent composition. These efficiency plots are presented in Figures 2 - 7. A summary of the test results is presented in Table 3. Table 3 presents target and actual values for oil/water ratio and flow rate for the test runs. The corresponding hydrocarbon removal and water removal efficiencies were computed using the equations above and the data presented in the other columns. The data were extracted from on-site analysis and laboratory analysis of the samples taken during the tests. Table 4 lists the sequence of test events, the flow rates, and products tested.

7.1 FRAMO "Skimmer Separator" Test Model

7.1.1 Hydrocarbon Removal Efficiency Oil Test. Statistics on hydrocarbon removal efficiency with oil are presented in Figure 2. The FRAMO unit was most efficient at processing flow rates up to 250 gpm. As a matter of record, the hydrocarbon removal efficiency was nearly 100 percent for flow rates between 100 gpm and 150 gpm at influent oil-to-water ratios as high as 50 percent. Effluent flow from the water outlet appeared clear to the eye at these lower flow rates. However, at the 300- and 400-gpm levels of testing, hydrocarbon removal efficiency dropped to approximately 80 percent. The effluent water stream appeared dirty and the resulting analysis of water quality indicated that the effluent could not be returned to any waterway without additional treatment to reduce hydrocarbons. At oil-to-water ratios in excess of 50 percent, hydrocarbon removal efficiency declined rapidly, especially when the influent flow rate was increased above 250 gpm.

Table 3. Test Summary

FRAMO Skimmer Separator

Test No.	Run No.	Flow Rates (gpm) Target	Flow Rates (gpm) Recorded	Influent Mix % Water	Influent Mix % Oil	Effluent Water & Oil: Oil in Eff. water (ppm)	Effluent Water & Oil: Water in Eff. Oil (%)	Efficiencies (%): Water Removal	Efficiencies (%): H-C Removal
5	*Test oil used to complete Test No. 5*					*Note: In each Test, run No. 1 was conducted using only water as influent liquid*			
	1	150	143.8	100	0	0	n/a	**n/a**	n/a
	2	150	100.7	75	25	250	19	**75**	**99**
	3	150	135.9	54	46	250	35	**35**	**99**
	4	150	132.6	19	81	5000	not measured	**n/a**	**99**
6	*Test oil used to complete Test No. 6*					*Note: Run No. 1 not reported (completed with water only)*			
	2	250	248.2	95	5	5000	11	**88**	**93**
	3	250	252.3	82	18	5000	11	**86**	**98**
	4	250	249.0	53	47	6000	13	**72**	**99**
	5	250	240.1	21	79	340000	15	**38**	**57**
7	*Test oil with debris injected tried in Test No. 7.*								
	2	150	133.6	78	22	24000	23	**71**	**97**
11	*Oil and Water Emulsion used in Test No. 11*					*Note: Emulsion targeted at 70% water.*			
	2	250	250.7	95	5	~40000	no flow from oil outlet	**Insufficient sample**	**20**
	3	250	251.9	80	20	110000	no flow from oil outlet	**Insufficient sample**	**45**
	4	250	256.5	52	48	310000	very low flow at oil outlet	**Insufficient sample**	**35**
	5	250	255.4	33	67	470000	very low flow at oil outlet	**Insufficient sample**	**30**
12	*Deemulsifier with oil and water emulsion in Test 12*					*Note: Emulsion approx. 70% water with 300 ppm Breaxit added*			
	2	250	258.2	95	5	50000	59		
	3	250	248.8	70	30	170000	11	**82**	**43**
	4	250	263.7	59	41	280000	22	**54**	**32**
	5	250	265.6	24	76	470000	no flow from oil outlet	**n/a**	**38**
13	*Test oil used to complete Test No. 13*								
	2	400	397.0	96	4	9000	100	**0**	**85**
	3	400	387.0	66	34	9000	47	**30**	**97**
	4	400	390.2	45	55	134000	15	**67**	**76**
19	*Oil and water emulsion used in Test No. 19*					*Emulsion targeted 70% water (actual range 39 - 60%)*			
	2	250	249.9	93	7	0	97	**0**	**100**
	3	250	249.6	80	20	600	70	**13**	**99**
	4	250	251.1	45	55	1200	22	**51**	**99**
	5	250	258.6	18	82	260000	26	**Insufficient data**	**70**
20	*Deemulsifier with oil and water emulsion in Test No. 20*					*Note: Emulsion approx. 70% water with 300 ppm Breaxit added*			
	2	250	261.4	97	3	1300	95	**0**	**96**
	3	250	241.7	80	20	2200	64	**20**	**99**
	4	250	250.8	60	40	0	25	**58**	**100**
	5	250	248.6	40	60	170000	11	**82**	**72**
21	*Test oil used to complete Test No. 21*								
	2	100	114.3	83	17	10000	16	**6**	**94**
	3	100	111	63	37	10000	0	**100**	**95**
	4	100	96.6	30	70	73000	0	**100**	**90**
22	*Test oil used to complete Test No. 22*								
	2	300	301	91	9	10000	88	**8**	**89**
	3	300	296.5	71	29	10000	41	**42**	**97**

Table 3. Continued

INTER-SEPT 250 CENTRIFUGAL SEPARATOR

Test No.	Run No.	Flow Rates (gpm) Target	Flow Rates (gpm) Recorded	Influent Mix % Water	Influent Mix % Oil	Effluent Water & Oil: Oil in Water (ppm)	Effluent Water & Oil: Water in Oil (%)	Efficiencies (%): Water Removal	Efficiencies (%): H-C Removal
1	*Test oil used to complete Test No. 1.*					*Note: test Run No. 1 was conducted using water only as influent liquid*			
	1	100	98.8	100	0	0	n/a	n/a	n/a
	2	100	102.6	88	12	250	20	**76**	**99**
	3	100	116.2	70	30	10000	12	**84**	**97**
	4	100	97.8	61	39	250	42	**22**	**99**
	5	100	110.1	44	56		No flow from the oil outlet of the separator for entire run		
	6	100		0	100	Stopped test, no flow from the oil outlet of the separator			
2	*Test oil used to complete Test No. 2.*					*Note: test aborted during run 3 as separator not working at this flow rate*			
	1	200	216.7	100	0				
	2	200	210.6	84	16	40000	No flow from the oil outlet of the separator for entire run		
	3	200	208.2	75	25	220000	No flow from the oil outlet of the separator for entire run		
3	*Test oil used to complete Test No. 3.*								
	2	150	145.3	80	20	3000	21	**77**	**97**
	3	150	121.2	76	24	250	14	**81**	**99**
	4	150	133.5	53	47	250	20	**55**	**99**
	5	150	152.2	28	72	250	8	**70**	**99**
4	*Test oil with debris injected tried in Test No. 4.*					*Note: debris not injected so tests aborted after several minutes*			
8	*Test oil with debris injected tried in Test No. 8.*								
	1	150	129.8	89	11	180000	260000	**65.33**	**28**
9	*Oil and Water Emulsion used in Test No. 9.*					*Note: Emulsion targeted 70% water (actual range 63 - 69%)*			
	2	150	147.2	92	8	18000	No flow from the oil outlet of the separator for entire run		
	3	150	154.1	59	41	190000	No flow from the oil outlet of the separator for entire run		
	4	150	151.3	50	50	280000	No flow from the oil outlet of the separator for entire run		
	5	150	151.5	17	83	480000	No flow from the oil outlet of the separator for entire run		
10	*Deemulsifier with emulsion used in Test 10.*					*Note: Emulsion approx. 70% water with 300 ppm Breaxit added*			
	2	150	143.7	97	3	35000	No flow from the oil outlet of the separator for entire run		
	3	150	102.2	79	21	170000	No flow from the oil outlet of the separator for entire run		
	4	150	98.4	76	24	140000	No flow from the oil outlet of the separator for entire run		
	5	150		55	45	450000	No flow from the oil outlet of the separator for entire run		

Table 4
Oil/Water Separator Test - November 1994

TEST (LAB CODE)

0	InterSep 250	Test trial			
1	InterSep 250	100 gpm	6 run		
2	InterSep 250	250 gpm	failed		
3	InterSep 250	150 gpm	Standard oil		
4	InterSep 250	Debris	Failed		
5	Framo	150 gpm	Standard oil		
6	Framo	250 gpm	Standard oil		
7	Framo	150 gpm	Standard oil, debris	1 run	
8	InterSep 250	150 gpm	Standard oil, debris	1 run	11.12.94
9	InterSep 250	150 gpm	Mousse	5 runs	11.14.94
10	InterSep 250	150 gpm	Mousse + deemulsifier	5 runs	11.14.94
11	Framo	250 gpm	Mousse	5 runs	11.15.94
12	Framo	250 gpm	Mousse + deemulsifier	5 runs	11.15.94
13	Framo	400 gpm	Standard oil	4 runs	
14	InterSep 250	Rerun test 3, run 2 (5% oil)			
15	InterSep 250	Step to max without circulation			
16	InterSep 250	150 gpm	Standard oil	2 runs	
17	Framo	150 gpm	Standard oil	2 run	11.17.94
18	Framo		Droplet size measurements		11.17.94
19	Framo	250 gpm	Mousse	5 runs	11.18.94
20	Framo	250 gpm	Mousse + deemulsifier	5 runs	11.18.94
21	Framo	100 gpm	Standard oil	4 run	11.18.94
22	Framo	300 gpm	Standard oil	3 run	11.18.94

The hydrocarbon removal efficiencies resulting from specific tests are presented in the following sections.

7.1.2 Water Removal Efficiency Oil Test. Skimmer Separator water removal efficiency for the oil/water influent test is presented in Figure 3. The data suggest that the FRAMO separator is very efficient at preventing water from entering the effluent oil stream at volumetric flow rates approaching 300 gpm. At levels in excess of that flow rate, a substantial percentage of free water appears in the effluent oil.

7.1.3 Debris Tests. The concentration and distribution of particulate "contaminants" used in the debris tests proved to be more than the FRAMO unit could handle without clogging. Apparently, the size of some of the debris was too large to pass through the small passages between adjacent parts even though some of the debris was discharged through the outlets. As debris accumulated it impacted the flow, and performance continued to decrease to the point that water could not flow under the "weir."

The hydrocarbon removal efficiency from the debris test was 97 percent and the water removal efficiency was 71 percent. However, the results were somewhat misleading. The debris test was only one run of 10 minutes with a target of 25 percent oil in the influent stream mixture. The measured ratio of oil in water was 22 percent. The effect of the debris on the separator performance was not realized until the emulsion tests that followed met with poor performance.

7.1.4 Hydrocarbon Removal Efficiency Emulsion Test. The low efficiency data presented in Figure 4 from tests 11 and 12 demonstrate the continuing problems resulting from the debris tests. The separator was flushed with water for cleaning (i.e., operated for 10 minutes with 100 percent water influent) after the debris test was completed. However, performance was poor and it was concluded that residual particulate matter lodged in the inner works was disrupting the flow/separation process. The first set of emulsion and free water tests resulted in the hydrocarbon removal efficiencies from 20 percent at 5 percent emulsion in water to a maximum of 45 percent with 20 percent emulsion in water. The higher ratios of emulsion in water also had low efficiencies of approximately 30 percent.

While the amount of debris lodged in the separator is at best a matter of speculation, there was still sufficient blockage to reduce performance by more than one half. The "separation chamber" was opened and the debris was removed by manually cleaning the inside prior to starting more tests.

After the FRAMO separator was more completely cleaned, additional emulsion tests were executed at 250 gpm because that was the greatest rate with the best separation performance during prior runs using the test oil. The results from emulsion tests 19 and 20 are the upper set of data points shown in Figure 4. Results show that the hydrocarbon removal efficiency approaches 100 percent at ratios of emulsion-to-free water below 50 percent, but decreases to approximately 70 percent at ratios approaching 80 percent emulsion in water. In comparing these results with the oil test results in Figure 2, it appears that the hydrocarbon removal efficiency for both emulsions and oil test samples was approximately the same after the separator was cleaned.

7.1.5 Water Removal Efficiency Emulsion Test. The water removal efficiencies for the emulsion tests were lower than the oil tests, with a maximum of 82 percent and many of the test runs in the 20 to 50 percent range. The lower efficiencies are most likely due to the fact that the free water and emulsion tend to be nearly the same density for emulsions consisting of a high percentage of water. The heavier emulsions, when mixed with free water, would force the free water into the effluent oil outlet. The water removal efficiencies for the emulsion and emulsion with breaker tests were plotted against the influent ratios and are presented in Figure 5.

7.1.6 Emulsion Test with Emulsion Breaker. The hydrocarbon removal efficiencies resulting from tests conducted by adding an emulsion-breaking chemical (Breaxit 7877) to influent emulsion and water mixtures are also presented in Figure 4. The curves demonstrate that the hydrocarbon removal efficiency remains the same for emulsions with and without the breaker when the separator is not hindered by the debris. However, while visual observation of the test process confirmed that the emulsion materials were partially broken down in the influent flow, the effluent water stream was nonetheless murky, indicating that the emulsion breaker dissolved some oil as very fine drops so as to create a "dirty water" situation. The amount of oil in the water was not measured. The emulsion breaker did not free significant amounts of the oil from the emulsion as there was a high percentage of emulsion in the effluent.

The water removal efficiencies for these tests were interesting in that the efficiency increased as the percentage of emulsion-to-free water increased after the separator was cleaned. The efficiency was 0 percent at 3 percent emulsion in water, then 20 percent at 20 percent emulsion in water, and rose to 82 percent when the emulsion-to-water ratio was 60 percent. The water removal efficiencies are presented in Figure 5.

7.2 Intr-Septor 250

7.2.1 Hydrocarbon Removal Efficiency Oil Test. The Intr-Septor 250 was evaluated first using test oil at a flow rate of 100 gpm in order to set a baseline for performance. However, the unit operated effectively only during the first two series of tests - that is, at 100 gpm and 150 gpm processing. The hydrocarbon removal efficiency for those tests, presented in Figure 6, was nearly 100 percent. In all succeeding tests, the separator ceased to function properly; very little or no oil exited the machine through the oil effluent port. It was assumed initially that the density difference between the test oil and water was insufficient for proper operation. The test oil specific density for the Intr-Septor 250 tests was measured at 0.94. This was within the range specified in the test plan and should not have been a factor.

7.2.2 Water Removal Efficiency Oil Test. The water removal efficiency characteristics for the tests that were completed are listed in Table 3. These limited data were all that was recorded since trials using the test oil were discontinued once the unit failed to separate oil from water.

The water removal efficiencies resulting from test oil tests 1 and 3 were plotted and are presented in Figure 7.

At the 100-gpm flow rate, the water removal efficiency ranged from 84 percent with the influent composition at 30 percent oil in water to 22 percent with 39 percent oil in water. The test run that attempted to achieve 50 percent oil in water resulted with no flow from the oil outlet.

The 150-gpm test oil tests had similar results with the maximum water removal efficiency of 81 percent with 24 percent oil in water and a minimum of 55 percent with 47 percent oil in water. A major difference at this flow rate was that the separator was able to process a high percentage oil in water (72 percent) influent and continue to separate. The efficiency was 70 percent during this run, which was higher than the previous run with lower influent oil content.

7.2.3 Debris Tests. The debris test was attempted but very little liquid emerged from the oil port. The unit did not separate oil from water very well at any point during this test. It was concluded at the time that the machine must have clogged with debris and stopped separating. The separation chamber inside the machine was inspected and it was found that an appreciable amount of the debris had remained inside the separation chamber, thereby limiting the machine's ability to separate.

This separator did not separate oil from water in any of the tests following this debris test. Table 3 has a note in the effluent oil column for each test where there was no flow from the oil outlet. There are no entries for tests 14, 15, or 16 because, again, there was no flow from the oil outlet and the data from those tests were not useful.

7.2.4 Emulsion Tests. The emulsion tests had no reportable results since all effluent continued to flow from the water outlet. The separator did not separate the free water from the emulsion. This machine seemed to emulsify some of the free water into the influent emulsion into a murky mixture that was emitted from the water outlet. The data from this test are less than encouraging for an oil spill application.

7.2.5 Emulsion with Breaker Tests. The emulsion with breaker test also had no appreciable results. Again, the separator did not separate oil from water. The tests on the Intr-Septor 250 were stopped after this test.

8.0 DISCUSSION

The primary purpose for this testing program was to determine if the two candidate oil/water separators could effectively separate hydrocarbons from free water under what may well be the most difficult influent conditions associated with a marine oil spill recovery operation. Specifically, the engineering parameters to be determined were: (1) how clean was the water discharge, (2) how much water was discharged through the water effluent line, (3) capacities, and (4) oil/water ratios. The guidelines developed under ASTM 933-85 provide rigorous test criteria for evaluating oil/water separators because of the sensitive environmental implications associated with recovery and return to the sea. In an oil spill recovery scenario, the ability of the separator to remove oil and other hydrocarbons will dictate whether or not the cleaned effluent discharge can be recycled back to the ambient watercourse. The current U.S. Environmental Protection Agency (EPA) regulation for allowable oil content in water discharged back to coastal areas from off-shore platforms (or vessels) is 50 ppm. In light of the results presented here, this goal appears restrictive for the two centrifugal separators tested - at least for pass-through flow rates exceeding 250 gpm.

A secondary objective of this program was to assess the applicability of oil/water separating technology to VOSS-types of marine spill recovery operations. There are benefits in providing a separation technology to reduce the need for on-site oily water storage and also to improve the quality required for possible reclaiming and recycling, The results of the 1992 tests coupled with those of the 1994 tests make the argument for advancing VOSS-compatible separation technology. However, these tests also expose the problems of trying to develop an "all purpose" machine capable of handling the spectrum of conditions that may be encountered at a marine spill. Thus, the results are indicative of an OWS future with limitations. From the standpoint of operational consistency, limits on efficiency appear to be governed by two primary factors: (1) the amount of oil in the influent mix, and (2) the density difference between the oily substance and water. Commercially available separators known to process the required flow rate and achieve the effluent requisite water quality are very large in size and too heavy for vessel of opportunity applications. (Such separators are basically large settling tanks with coalescing plates). To achieve the desired hydrocarbon removal efficiency necessary for discharge back to the sea, thousands of gallons of collected oily water would be stored aboard in the tank system. Thorough separation occurs through gravitational means that are aided by coalescing devices mentioned above such as oleophilic plates.

8.1 FRAMO Skimmer Separator

The FRAMO Skimmer Separator did separate the test oil from mixed water efficiently at the lower flow rates (150 to 250 gpm), but did not work as well at the higher flow rates of 300 and 400 gpm. FRAMO's representative indicated that influent oil/water ratios in excess of 75 percent oil were outside the operating envelope of that machine.

In terms of unfolding expectations, the advertised rating of 100 cubic meters per hour may be achievable for mixes involving low density oils. To effectively process higher density oil, it might be fruitful to operate the separator at a lower flow rate in order to increase retention time. It might be possible to control the pass-through velocity in order to accommodate the ability of the machine in each situation. This approach seems a logical consequence since increased residence time achieved by slower running times allows more time to aid in the separation process.

One mechanical problem witnessed during the testing program was vibration of the rotor which appeared to be out of balance. As the unit slowed from operating speed to standstill, it would oscillate and shake. The explanation offered by the FRAMO representative was that because the Skimmer Separator was a "breadboard" model for establishing proof of concept, the rotor was not balanced at low speeds due to anticipated additional cost and effort. The manufacturer opined that the additional expense and time were unnecessary since the shaking did not affect the operation of the machine. The problem would be corrected on production models to reduce this imbalance for safety reasons.

The operating envelope offered by the manufacturer indicated that the FRAMO unit should separate oil from water at higher flow rates, but the results turned out differently. FRAMO representatives claim that the breadboard model tested at Craney Island will be redesigned to handle higher input oil-to-water ratios.

8.2 Intr-Septor 250

For the most part, the Intr-Septor 250 did not perform well in the tests. The Intr-Septor 250 worked well during the initial test runs at 100 gpm, but suddenly stopped separating during the last run of the 150-gpm test oil series. The debris test was attempted after the 250-gpm test with the thought that the optimal flow rate might be near 150 gpm, but the separator did not separate oil from water at all after the final run of the 150-gpm test oil test. After repeated tries, it was suggested that something in the test setup or in the test materials contributed to the apparent malfunction. It was suggested that the reason the unit stopped functioning was that the test oil density was too close to the density of water for proper operation. The manufacturer's representatives present on site inspected the machine for deficiencies and reported that nothing visibly apparent was wrong with the hardware. The particular model Intr-Septor 250 used at the test site was reputedly "preset" to meet the spectrum of influent oily water conditions specified in the test plan. The test water was brackish, taken from the Elizabeth River adjacent to the test site on Craney Island. The salinity of the brackish water varied between 1.52 percent and 2.09 percent depending on the tide. Normal seawater salinity is 3.5 percent. Salt was not added to the brackish source to increase salinity since operating conditions might include brackish water.

When the Intr-Septor 250 was returned to the factory in Utah after the tests were completed, the manufacturer reported that a critical hole that governs the air bubble control of the weir, and hence the interface between the oil and water in the separator, was incorrectly drilled when the unit was modified just prior to these tests. Apparently, the weir must be somewhat adjustable to deal with the different density oils and emulsions collected in a spill. Since that feature is not controllable while the machine is operating, it is impossible to make adjustments to compensate for variation in influent conditions. This is not a desirable situation for equipment that will be used by a seaman of opportunity. There should be some avenue for adjusting the weir from the outside if it must be reset to handle differing influent compositions and properties.

A complete disassembly of the unit uncovered a damaged carbon seal located at the bottom of the rotating assembly in the separation chamber. This carbon seal serves to maintain pressure on the air system that controls the weir device inside the OWS. The new theory was that the seal was damaged while the machine was being transported from Utah to the test site in Virginia. The seal was possibly cracked during the move, but still able to maintain adequate pressure during the earliest tests. When the damaged seal finally broke, there was no control of the weir and separation was practically stopped. Even when fluids of relatively great density differences like diesel fuel and water were ingested, the machine did not perform well. The emulsion, having a small density difference with the test water, could not be separated from the water.

The manufacturer reports that the Intr-Septor 250 design has been modified to protect this seal. It is unfortunate this deficiency was determined too late for these tests to be more successful. The carbon seal should be accessible for inspection and maintenance.

8.3 Data Collection and Recording

Data presented in this report were collected by several methods. Influent flow rates were measured using in-line flow meters mounted in hard pipe sampling stations located downstream of the mixing loop, as shown in the layout sketch for the test site (Figure 1). Effluent tanks were sounded at the beginning and end of each test to confirm the flow meter data. The influent oil tank was weighed continuously via load cells under the tank. The influent water tank level was monitored continuously via an ultrasonic level gage. The electrical output from the devices was recorded by a multiple-channel electronic datalogger. The raw data were stored on floppy disks that are maintained at NFESC for later use as required.

Samples of the influent mixture were withdrawn manually from a sample port in the hard pipe just upstream from the separator. Effluent stream samples were taken at the OWS outlet hoses that fed the gravity tanks. Samples from the influent mixture and both effluent streams were then poured into 100-mL graduated cylinders to measure the oil/emulsion fraction in the sample. These data were recorded and were the basis for the efficiency calculations. A factor that could contribute to error in the efficiency calculations is the amount of oil sticking to the sides of the graduated cylinder when the sample is poured into the cylinder. At low oil-to-water ratios, the amount of oil sticking to the sides of the cylinder was a larger percentage of the total amount of oil in the sample. But, mathematically this small difference in the percentage of oil has little effect on the resulting efficiency. Therefore, the amount of oil sticking to the cylinder does not have significant effect on this calculation.

There is a practical consideration to this error, since there are only a few other ways to measure the oil content in the mixture that have more accuracy. The electronic devices available to measure the oil in water have thresholds similar to the flow meters, some will function well at low oil/water ratios but will not operate well at larger ratios. Also, these oil/water measuring devices do not automatically adjust to different types of oil in the water. So, the emulsions would have caused some problems for the device after calibration for the oil. And since the emulsions varied slightly in composition, the device would have to have been calibrated almost continually.

8.4 Accuracy

The precision of the data was governed by the accuracy of the individual measuring devices. The meters measuring passage of influent oil and water were not accurate under the conditions of low flow that existed during tests involving low percentages of water or low percentages of oil. The influent oil in particular was measured with a flow meter having a minimum sensitivity of 90 gpm, thus there were problems at flow rates of 100-gpm and lower. At 100-gpm total flow the water flow was as low as 25 gpm for the tests with 75 percent oil in water. For these cases, the water flow rate was determined by the total amount of water pumped out of the influent water tank divided by the time (in minutes) of the test.

8.5 Influent Mixture Characterization

The influent was pumped through a mixing loop by a centrifugal pump to maintain a homogeneous suspension of oil and/or emulsion in free water. In order to determine the oil/water ratio, samples were taken from the influent stream and poured into 100-mL graduated cylinders, where they were allowed to settle and stratify for 5 minutes before visual comparisons of oil level and graduation marks were recorded. The accuracy of the method proved to be sufficient for determining efficiency.

8.6 Oil Droplet Size

Measurements of oil particle droplet size were taken for every sample extracted during the course of the tests. The mixing loop was set up to reduce the droplet size so that the tests would be in accordance with ASTM 933-85 criteria. The ASTM requirement states that the oil droplet size for 20 percent of the dispersed influent oil be 50 µm (micrometers) or smaller. The Mastersizer data confirm that this requirement was more than fulfilled during the testing program. As a matter of record, some of the trials appear to have been executed with more than 20 percent of the oil droplets sized below the 50 µm requirement, an even more stringent operating condition for separation.

Volumetric flow within the mixing loop was not measured during the earlier tests because the data were not believed to be essential to the accuracy of the test results. A flow meter was installed in the mixing loop for the droplet size study of test 18 in order to compare oil droplet size to turbulent conditions within the flow pattern. Data from the mixing loop flow meter were recorded manually by test personnel operating the pumps and flow meter monitors.

8.7 Droplet Size Study

Test 18, an unscheduled departure from the test plan, was a special test conducted in order to investigate the relationship between oil droplet size and the turbulence of flow. Results presented here are based on estimations of oil and water content, as observed from the 100-mL graduated cylinder samples taken from the influent mix, and from the oil and water effluent lines. It was not possible to use more accurate laboratory methods of analysis because of the quick response times required to determine droplet size. This impromptu study was not totally supportive of the accepted model which predicts the formation of smaller and smaller droplets of oil as the level of turbulence continues to increase. A factor may not be accounted for in the accepted model. In speculation, the missing factor may be that increased energy imparted by the centrifugal pump to liquid in the mixing loop may not result in reduction of the droplet size beyond a certain minimum.

This study was conducted without advanced planning and the measurements were not as sophisticated as required to guarantee accurate and repeatable data. The flow meter in the mixing loop was connected to the datalogger because of the prevailing inclement weather conditions. It was not possible to analyze all samples with the required dispatch because the sheer numbers taken overwhelmed the working staff in the mobile laboratory. The elapsed time between withdrawal and measuring is important because oil droplets coalesce naturally whenever a sample is allowed to settle and stratify for any period of time. The test could have been more closely monitored had the weather been less stormy; the driving wind and rain caused some samples to be spilled.

9.0 CONCLUSIONS

Centrifugal separators are the most compact type that can handle the flow rates required by both MSRC and the Coast Guard. The volumes of oil and water anticipated in typical marine spills are so great that, to be practical, an OWS must have a volumetric flow rate of at least 250 gpm, and hopefully up to 400 to 800 gpm. The centrifugal concept has operational limitations, however, especially in handling heavy oils or emulsions because the theoretical basis upon which separation depends is the density difference between the liquids requiring separation.

The Intr-Septor 250 performed promisingly well during the 1992 Amoco tests, and because of its compact size and ability to separate emulsions from free water was viewed favorably as a potential candidate for further development. Unfortunately, the unit tested at Craney Island did not perform as expected, ostensibly because of one or more mechanical malfunctions. That separator continues to hold promise. The Intr-Septor 250 should be evaluated again should the opportunity arise as its compact size and light weight would make attractive complements to the VOSS suite of equipment.

The FRAMO Skimmer Separator displayed the ability to separate heavy test oil from water and was able to separate emulsion from water at low oil-to-water ratios. The Skimmer Separator definitely worked better at flow rates of 250 gpm, and there was a reduction in performance during the 300- and 400-gpm tests. However, the drop in performance was not a radical step down to no separation, rather it was a small but measurable change. But, the effluent water would have been a great improvement over the influent if required to return to an ambient waterway in an oil spill situation. Development of this system should continue because this ability to handle heavy oil, especially emulsions, is the primary criteria required of the VOSS separator system.

The sheer size of the FRAMO OWS package (separator and hydraulic power units) is prohibitive for application in the present VOSS scenario. The development efforts in the future should focus on reducing the overall size and weight of the separator. The separator tested was a prototype and should be evaluated as such. The size of the separation chamber could be reduced if the volumetric flow rates are reduced to a level comparable with the Intr-Septor. The power requirements should be correspondingly lower at lower flow rates so the power unit should be sized to meet mobility requirements of the VOSS concepts.

The test setup did not allow testing the Skimmer Separator at the advertised rate of 100 cubic meters per hour (430 gpm). This was a shortcoming of the test site setup that could not feasibly be overcome. The size of the hoses and the ratings of connecting fittings would not safely allow this flow rate. Results of the 300-gpm and 400-gpm tests indicate that this separator probably would not have fared well.

10.0 RECOMMENDATIONS

10.1 Continue Development of OWS

The FRAMO and Intr-Sept 250 models demonstrated an ability to separate oil from free water. However, neither unit was able to process entrained debris and both experienced difficulties in handling emulsions. The state of the art in centrifugal separation technology is able to meet some, but not all, of the Coast Guard/MSRC criteria for oil spill recovery systems. However, the need continues for a conforming separator in the MSRC and Coast Guard VOSS systems, thus efforts should continue to address the issues of handling and separation of water from emulsions and debris. The accomplishments to date have helped pinpoint the focus of the work effort that still remains ahead.

One concern has been the apparent lack of participation by the private sector in developing and demonstrating a suitably sized centrifugal oil/water separator. The speculation is that the total number of separators required by the USCG and MSRC (on the order of 50 units) may not provide the economic incentive to warrant the research and development effort required of a private concern. If there is insufficient economic incentive in the business community, then perhaps the government should spearhead in-house technology development that can transition to the private sector.

10.2 Continue Independent Test and Evaluation Program

One additional manufacturer (CINC, California) claims to have developed a conforming system advertised as ready for testing. It could prove beneficial to have a follow-up testing program that includes the new candidate as well as an upgraded Intr-Septor 250 and a scaled down FRAMO Skimmer Separator, and any other viable entry willing and ready to contribute.

The next series of tests can be planned to reuse the test oil if the tests are scheduled to occur in a reasonable time frame. The 1992 series of tests and the tests run at Craney Island involved "learning curve" time spent in learning what tests are important, what measurements are required, and what analysis is important. The next series of tests should cost less per separator, and should be more accurate if the lessons learned from these experiences are incorporated.

10.3 Investigate the Feasibility of Developing a Preseparator

Problems exposed during the testing program have uncovered a needed area of development: hardware and procedures to condition the influent mix to a more digestible consistency suitable for separation. Equipment to encourage droplet coalescing as well as a lowering of oil-phase density (i.e., avoidance of emulsions) is desirable. Likewise, any device that would increase the rate at which the emulsion breaks down to constituent oil and water would be extremely useful.

Passive-type coalescers may be helpful in conditioning the influent to improve the separation of oil from water. This same device may help remove some of the water from the emulsion. A typical device could be as simple as a surge tank, similar to the one tested at Amoco in 1992 with some modifications to the geometry to help slow the speed of the flow. The flow rate into the OWS may be the same as the skimmer pump capacity, but the Reynolds number will be lower because of the reduced velocity.

10.4 ASTM 933-85

The requirements of ASTM 933-85 should be reviewed for possible revision as a result of experience gained at the 1992 tests at the Amoco refinery and the 1994 tests at Craney Island. The test regimen may need to be expanded to add data points in between the influent compositions now specified.

One item specified in ASTM 933-85, but not addressed in the testing programs because of the added cost, is testing that involves ice. The probability of an oil spill on ice in or near U.S. waters is significant, as is a spill on the Canadian coast or along the coast of many northern

European countries. Ice clogging could certainly have a negative impact on the performance of separators as did the ingestion of debris. Future work to address a need for melting ice should be considered, along with improved methods of coalescing and breaking down emulsions.

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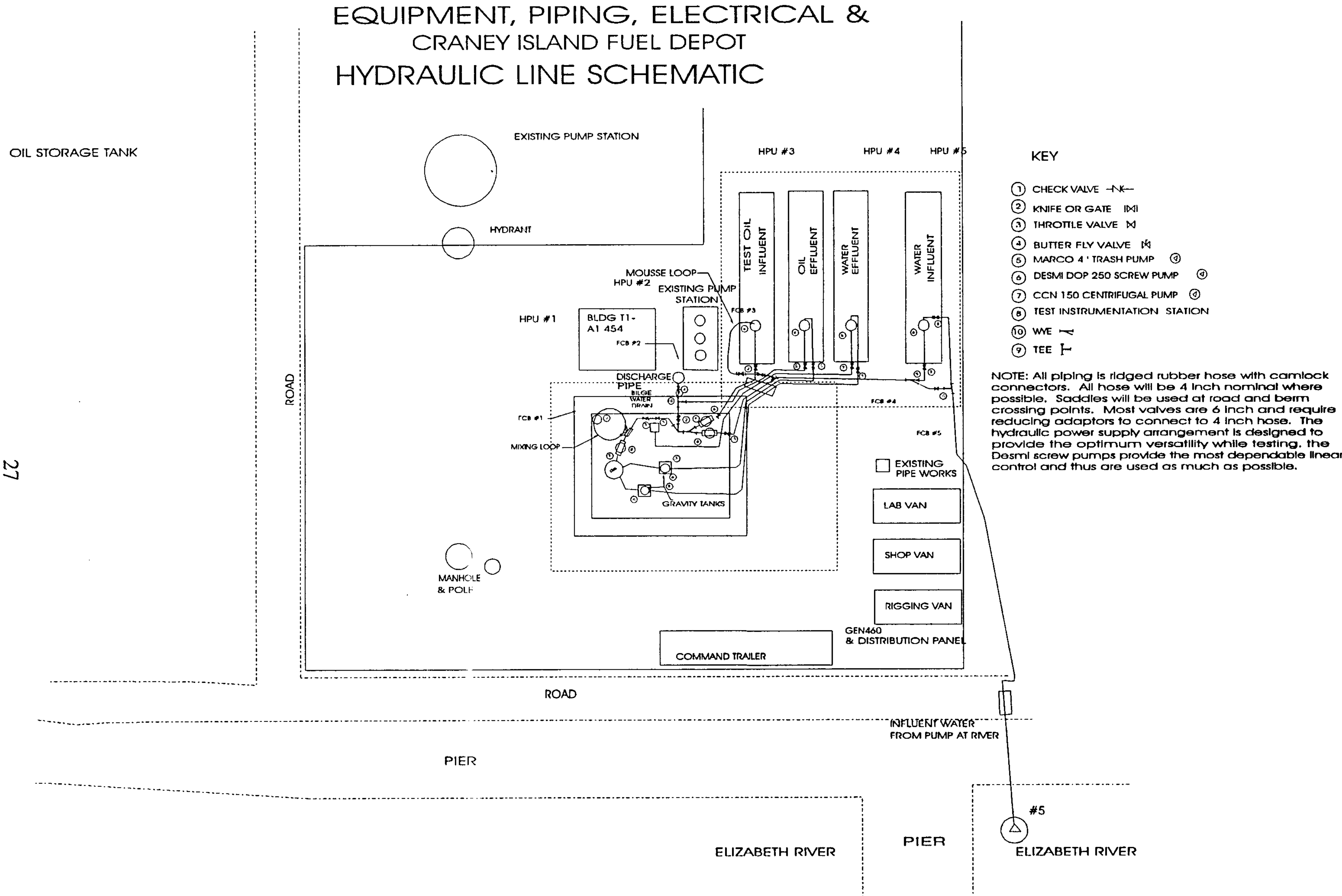

Figure 1. Test piping schematic.

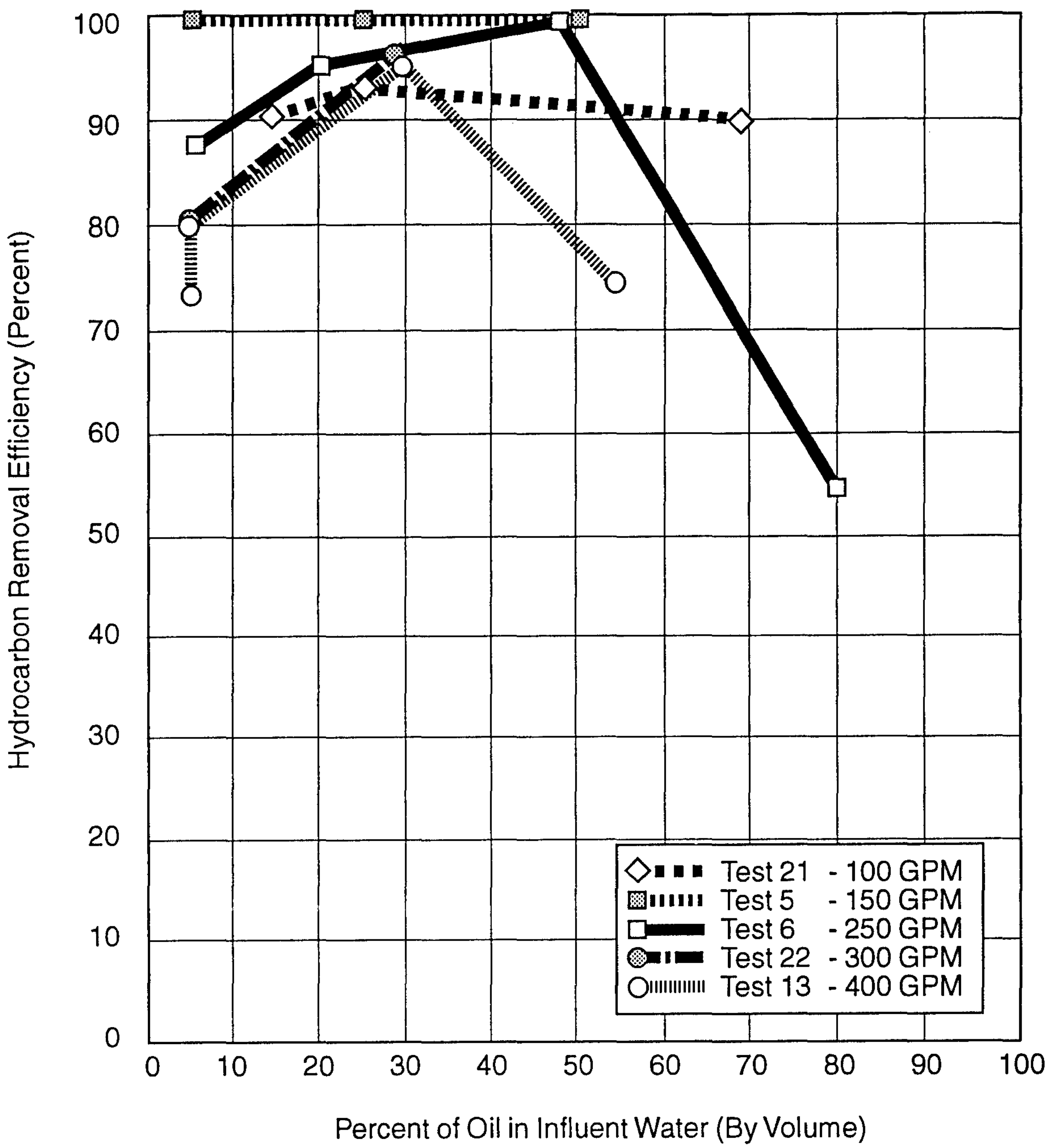

Figure 2. FRAMO skimmer separator hydrocarbon removal efficiency, test oil.

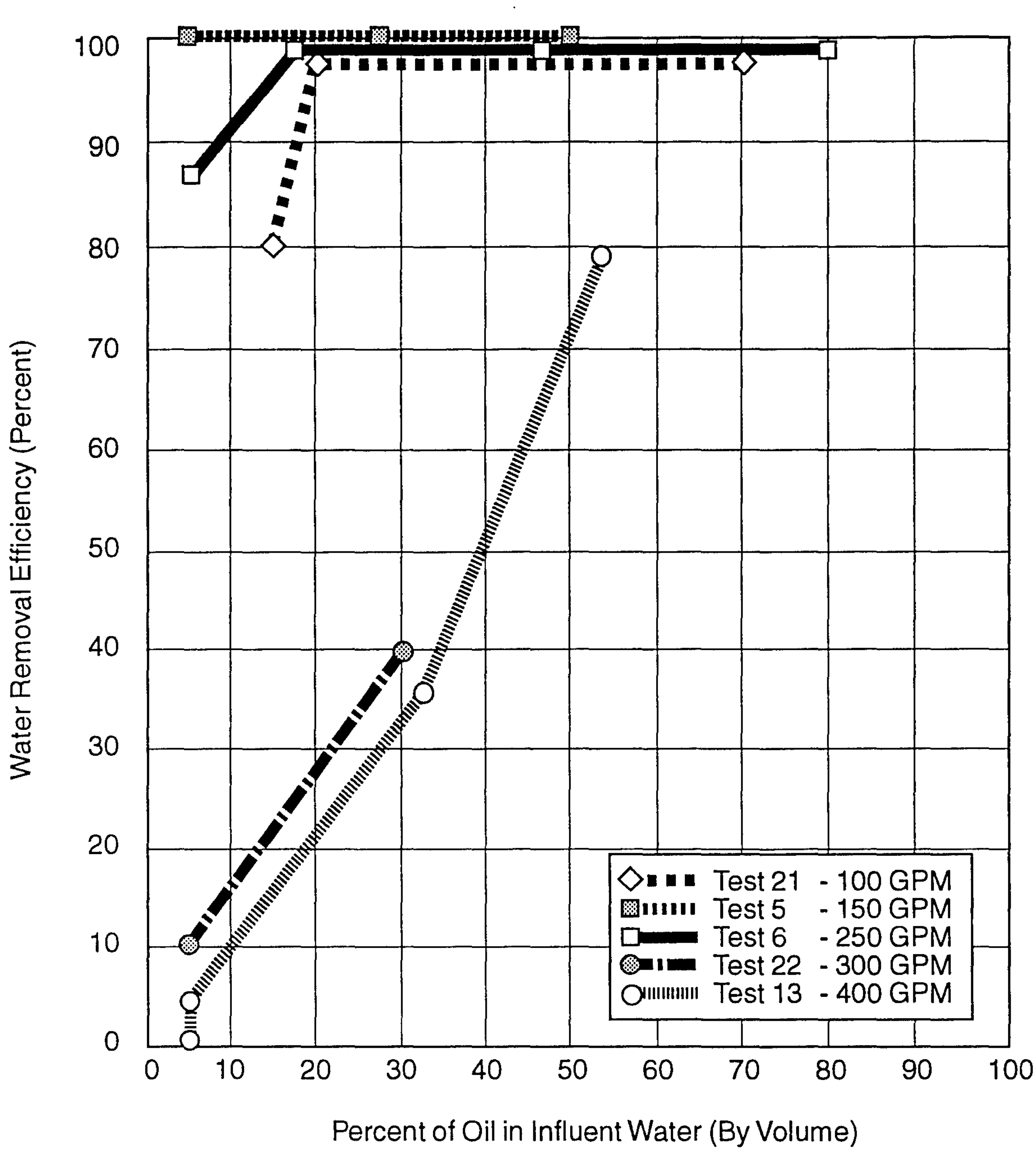

Figure 3. FRAMO skimmer separator water removal efficiency, test oil.

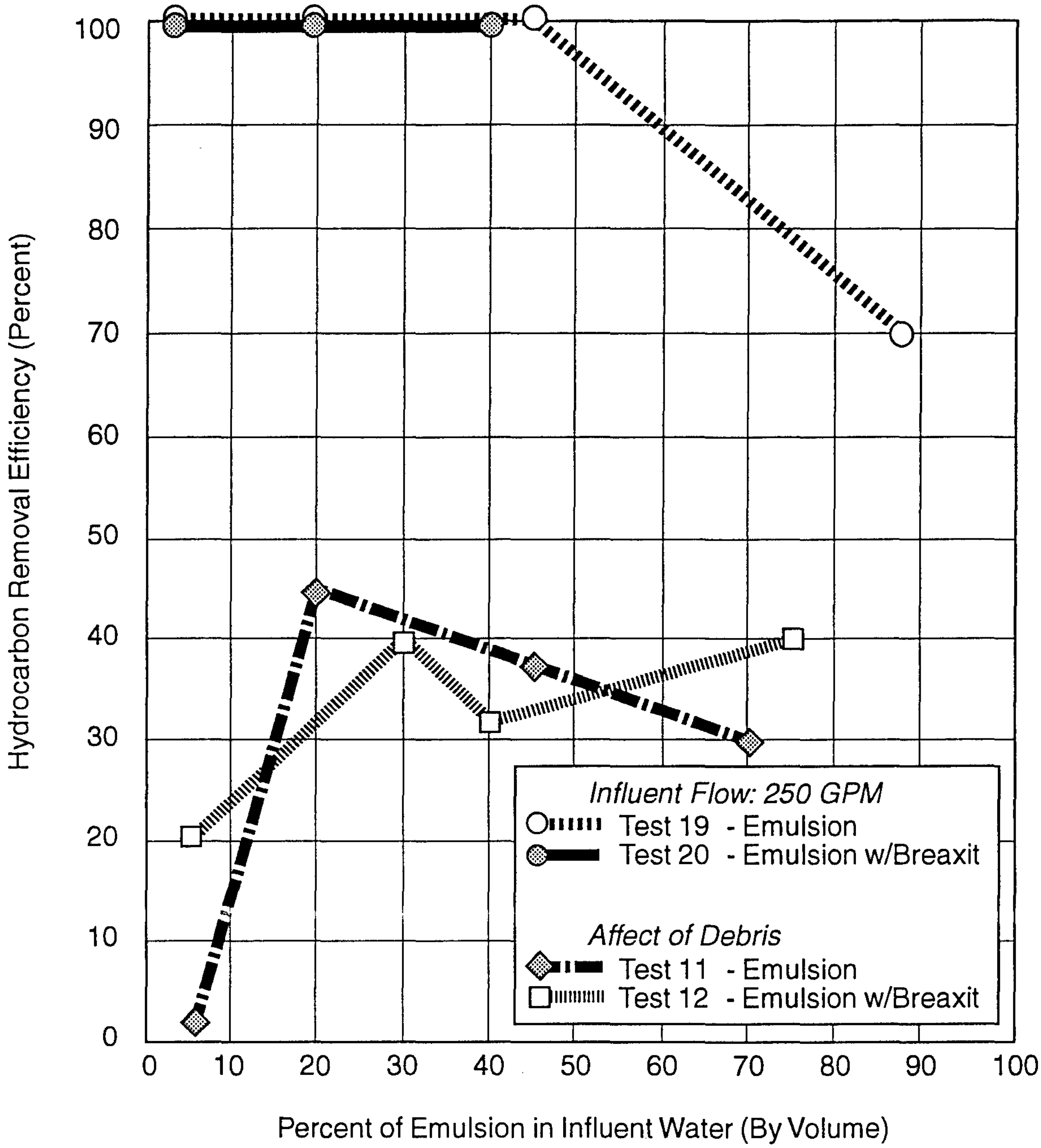

Figure 4. FRAMO skimmer separator hydrocarbon removal efficiency, emulsion and emulsion with emulsion breaker.

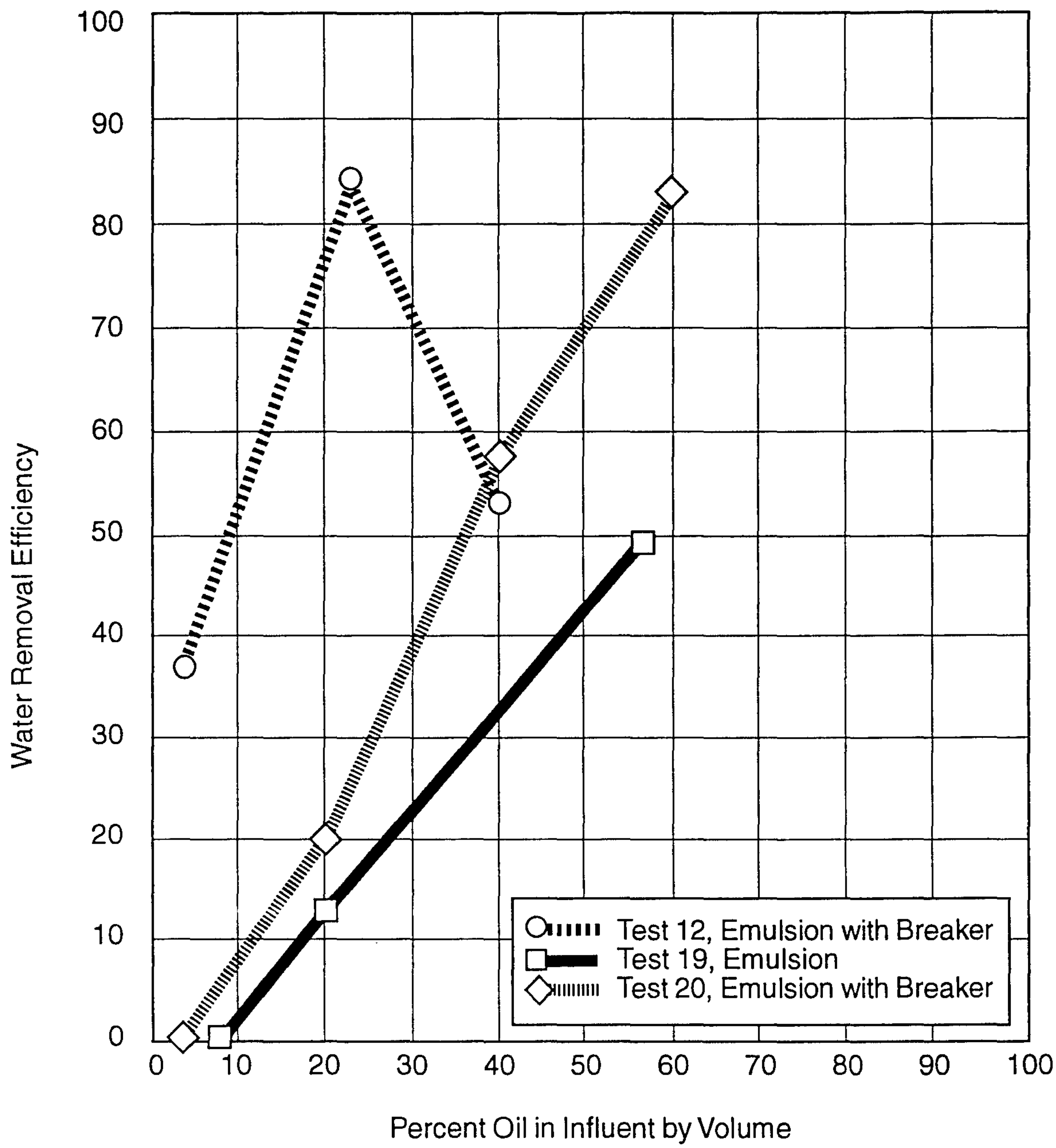

Figure 5. FRAMO water removal efficiency, emulsion tests.

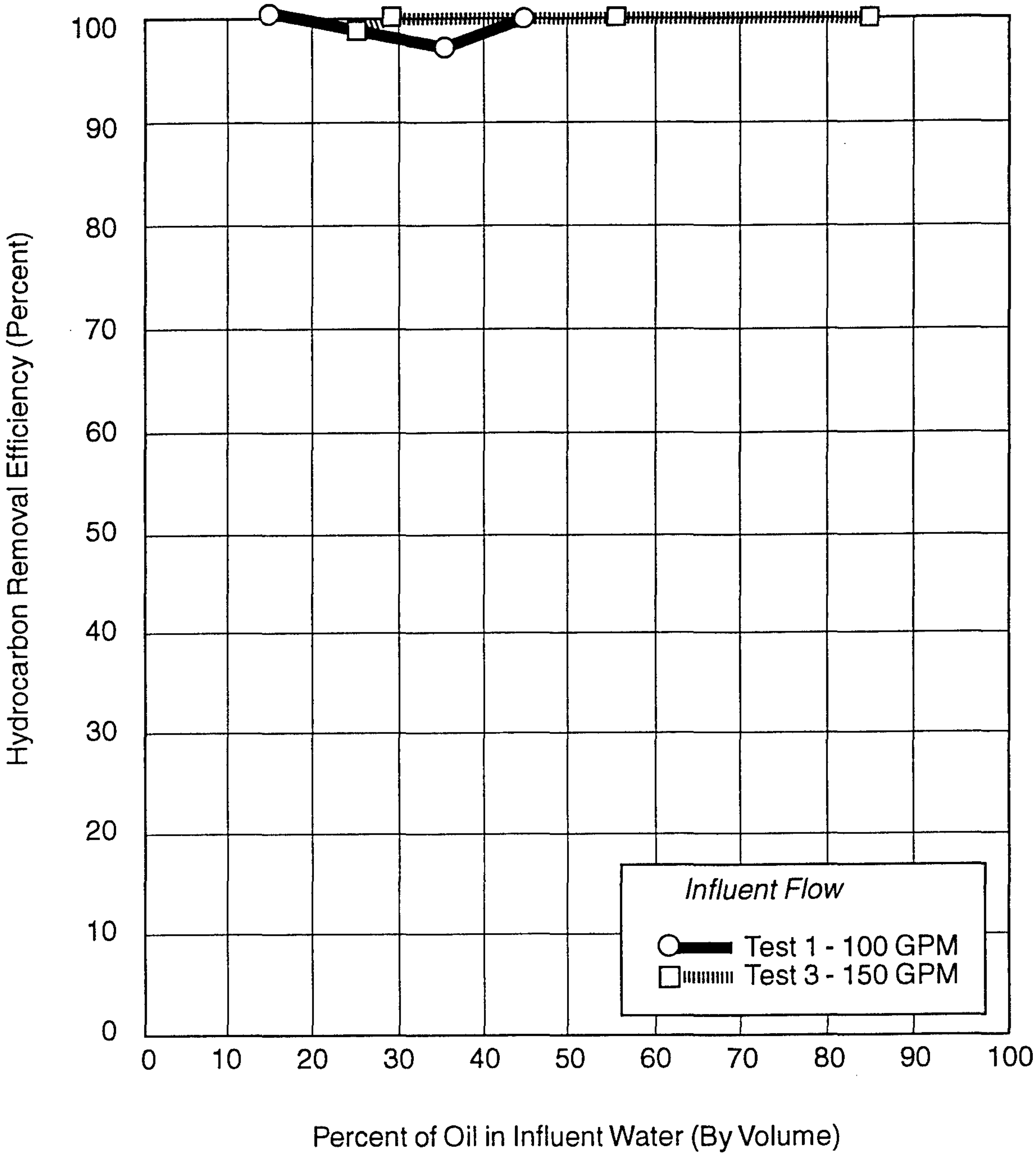

Figure 6. Intr-Septor 250 hydrocarbon removal efficiency, test oil.

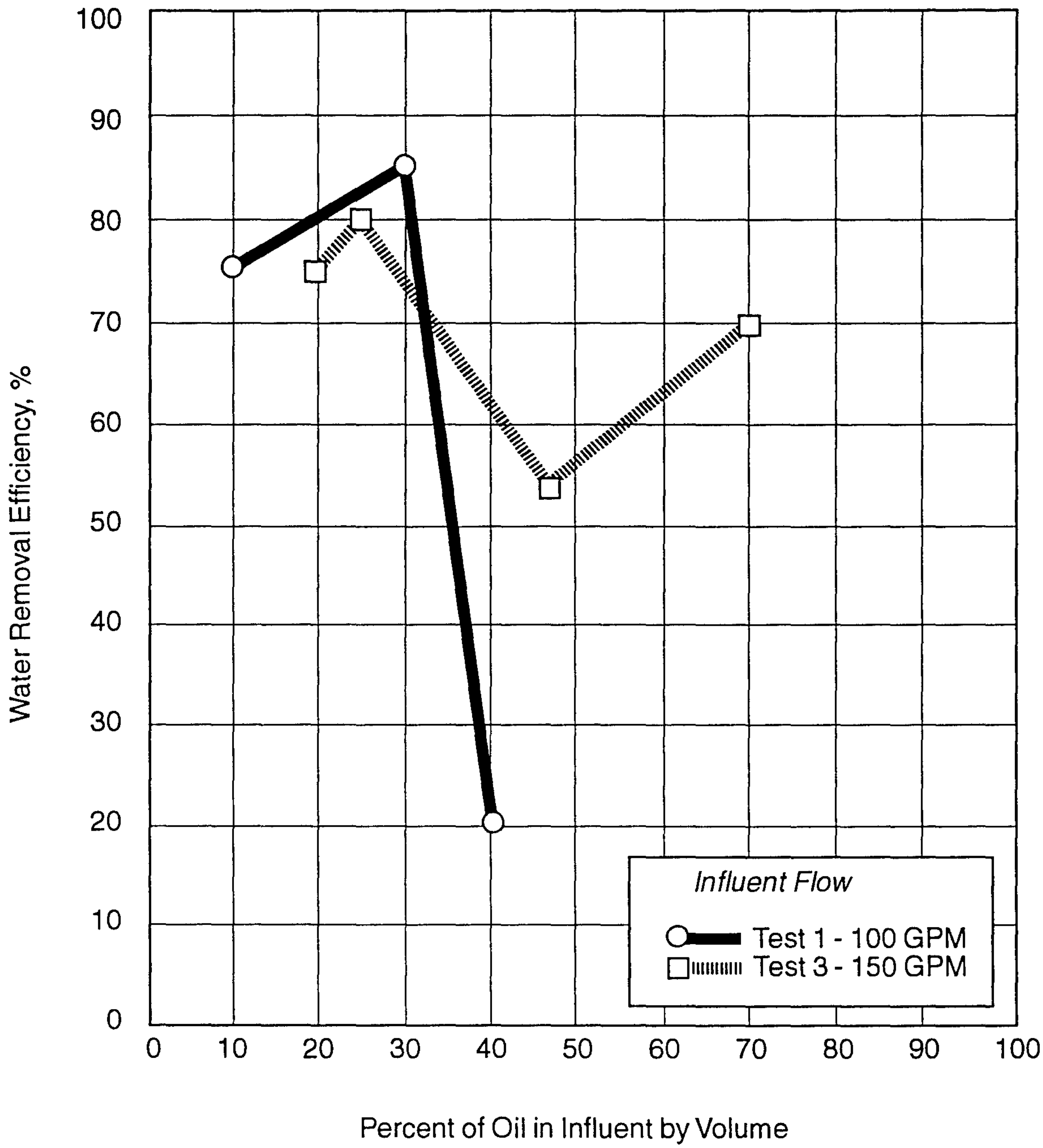

Figure 7. Intr-Septor 250 water removal efficiency, test oil.