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Concept Evaluation: Recovery of Floating Oil Using Polyurethane Foam Sorbent

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CONCEPT EVALUATION: RECOVERY OF FLOATING OIL USING POLYURETHANE FOAM SORBENT

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ABSTRACT

Individual components of an oil spill recovery system were evaluated using Bunker C oil and three crude oils ranging in API gravity from 14° to 42°. The system was designed to shred and broadcast polyurethane foam sorbent onto an oil slick, herd the sorbent to a shipside conveyor by a water spray boom, squeeze the sorbent to extract the oil and rebroadcast the sorbent. The initial concept was to build a half-size, full scale system; however, initial foam losses indicated the necessity for a re-evaluation of the program, and specific studies on the broadcasting and "squeezing" systems were undertaken.

The shredder-broadcaster, a commercial straw mulcher, produced acceptable shredding of dry foam. However, multiple cycling degraded oil-soaked foam to unrecoverable sizes in relatively few cycles. With Bunker C oil, 47 percent of the foam was reduced to sizes less than 1/2" in 5 cycles. With light Canadian crude oil, 29 percent was reduced to less than 1/2" in 100 cycles.

A sorbent-oil separator using perforated rolls, was designed to extract viscous oils from the foam at 20°C, without heating, at rates of up to 5000 gph. This device showed good recovery of oil from foam. Multiple cycling of Bunker C-oil-soaked foam through the full scale device resulted in a small loss of foam by size reduction (3.5 percent in 77 cycles). After 77 cycles of extracting Bunker C oil, foam damage by loss of resiliency reduced oil extraction per cycle to about 25 percent of the initial amount. No loss of resiliency was observed up to about 50 cycles.

Because of the high sorbent losses in the shredder-broadcaster, the system as initially proposed is not recommended for use with Bunker C oil.

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CONTENTS

Section		Page
I	Conclusions	1
II	Recommendations	5
III	Introduction	7
IV	Design and Construction of Experimental and Prototypical Subsystems	17
V	Evaluation of Subsystems	33
VI	Acknowledgments	59
VII	References	61
VIII	Glossary	63
IX	Appendix	65

FIGURES

Number	Title	Page
1	Overall System Concept	8
2	Flow Channel and Apparatus for Determining Conveyor Angle and Dewatering Rates	19
3	Schematic of Sorbent-Oil Separator	21
4	Sorbent-Oil Separator Under Construction Showing Internal Mechanism	22
5	Perforated Rollers in the Full Scale Sorbent-Oil Separator	23
6	The Completed Full Scale Sorbent-Oil Separator	24
7	Scale Model Sorbent-Oil Separator	25
8	External Loads and Reactions on Spray Boom	28
9	Onloading Conveyor Support Frame	30
10	Sorption, Separation and Retention of Bunker C Oil in Polyurethane Foam Recycled in Model Sorbent-Oil Separator - One-Inch-Thick Foam	34
11	Sorption, Separation and Retention of Bunker C Oil in Polyurethane Foam Recycled in Model Sorbent-Oil Separator - One-Half-Inch-Thick Foam	35
12	Sorption, Separation and Retention of San Joaquin Crude Oil in Polyurethane Foam Recycled in Model Sorbent-Oil-Separator - Spray Mixing	38
13	Sorption, Separation and Retention of Light Canadian Crude Oil in Polyurethane Foam Recycled in Model Sorbent-Oil-Separator - Spray Mixing	39
14	Water-Oil Ratio Obtained in Spray Mixing Tests with Santa Maria Crude Oil - One-Half-Inch-Thick Foam	40
15	Conveying of Foam on Simulated Conveyor Belt for Canadian and San Joaquin Crude Oils - Velocity 1.0 Knots	42

Number	Title	Page
16	Conveying of Foam on Simulated Conveyor Belt for Canadian and San Joaquin Crude Oils - Velocity 1.5 Knots	43
17	Conveying of Foam on Simulated Conveyor Belt for Canadian and San Joaquin Crude Oils - Velocity 2 Knots	44
18	Drainage of Fresh and Emulsified Santa Maria Crude Oil from Polyurethane Foam	46
19	Particle Distribution of One-Inch-Thick Foam in a Single Pass Through the Mulcher-Spreader	47
20	Average Particle Area Distribution from the Mulcher-Spreader - One-Inch-Thick Foam	48
21	Total Particle Area of One-Inch-Thick Foam from a Single Pass Through the Mulcher-Spreader - Calm Conditions	49
22	Total Particle Area of One-Half-Inch-Thick Foam from a Single Pass Through the Mulcher-Spreader - Quartering Wind 1 to 3 Knots	51
23	Total Particle Area of One-Half-Inch-Thick Foam from a Single Pass Through the Mulcher-Spreader - Tailwind 1 to 3 Knots	52
24	Reinco Model TM7-30 Mulcher and Test Apparatus for Recycling Oil-Soaked Sorbent	53
25	Particle Size Distribution of Light Canadian Crude-Oil-Soaked Sorbent from 0 to 100 Cycles Through the Mulcher-Spreader	54
A-1	Appearance of Foam after 50 Cycles Through Squeeze-Roller Processing Bunker C Oil	71
A-2	Appearance of Foam after 60 Cycles Through Squeeze-Roller Processing Bunker C Oil	72
A-3	Appearance of Foam after 70 Cycles Through Squeeze-Roller Processing Bunker C Oil	73
A-4	Apperance of Foam after 77 Cycles Through Squeeze-Roller Processing Bunker C Oil	74

TABLES

Number	Title	Page
1	System Cycle Times and Weights	17
2	Results of Water Spray Herding Experiments with Sorbent and San Joaquin Crude Oil	36
3	Results of Water Spray Herding Experiments with Sorbent and Light Canadian Crude Oil	36
4	Onloading Conveyor Drainage for One-Half-Inch Mesh Screen as a Function of Time	45
5	Foam Particle Distribution - Mulcher-Spreader Cycling Test	50
6	Foam Particle Size Distribution - Sorbent-Oil Separator Cycling Test	56

SECTION I

CONCLUSIONS

The system, as proposed, included: (a) an unmodified straw mulcher to first shred 1/2-inch to 3/4-inch thick sheets of sorbent to about 5" x 5" pieces, broadcast it onto the water surface, convey the sorbent in the suction air stream after pressing and rebroadcast the sorbent, (b), a squeeze-roller to separate the oil (and water) from the sorbent after the sorbent was herded to the side of a recovery vessel by (c) a water spray boom and transported aboard ship by (d), a mesh belt conveyor extending into the water.

Conclusions reached in the course of this project, based on tests of individual components and foam sorption experiments, were:

1. Polyether-based polyurethane foam is capable of sorbing high amounts of oil per pound of sorbent from floating oil slicks with relatively short contact times. Sorption of up to 53 pounds of Bunker C oil per pound of dry sorbent on the third cycle was demonstrated with ideal mixing conditions and a contact time of 3 minutes per cycle. For other oils, the material sorbed up to 32 lbs/lb of a heavy asphaltic crude oil and up to 39 lbs/lb of a light crude oil in the third cycle of simulated spray boom mixing tests with a mixing time of 60 seconds per cycle. It appears that oiled foam sorbs oil more efficiently than dry foam.

2. A squeezing operation can be successfully used to extract Bunker C and crude oils but the life of the foam used in these tests would be limited when processing heavier oils such as Bunker C, without heating. See item 11 of these conclusions for extrapolated foam losses and replenishment rates.

3. The perforated squeeze-roller type of sorbent-oil separator showed good results in separating Bunker C oil from polyurethane foam sorbent without the addition of heat. Extraction of up to 30 pounds of oil per pound of dry foam was achieved with the scale model unit at 20°C. Extraction of 18 to 20 lbs/lb and 25 lbs/lb was achieved for heavy asphaltic crudes and light crudes, respectively. Little or no oil was extracted on the first cycle, but extraction increased with succeeding cycles. The third cycle showed good extraction rates.

   For light oils, loss of foam through perforations in the squeeze-roller was restricted to particles less than 1/4 inch as determined by tests with the small-scale squeeze-roller. For Bunker C oil, foam losses in the full-scale squeeze-roller were restricted to particles of 3/8-inch and less. Foam losses attributable to the full-scale squeeze-roller alone, based on recycling material shredded by one pass only of the mulcher, were 3.5% of the initial sorbent amount for 77 cycles when processing Bunker C oil. If the material were passed through the mulcher each cycle,

these losses would be much higher. Foam losses for light oils in the squeeze-roller alone should be less but this figure was not determined experimentally.

Repeated squeezing of foam soaked with Bunker C oil caused a loss of resiliency and sorption capacity of the foam. After 77 cycles of extracting Bunker C oil, this loss of resiliency reduced oil extraction per cycle to about 25% of the initial amount. No loss of resiliency was observed up to about 50 cycles. Tests by Schatzberg[1] indicate that this loss of resiliency does not occur in foam soaked with light oils (e.g. No. 2 fuel oil) when squeezed up to 100 cycles or more. Thus there is evidence that resiliency and sorption capacity of the foam would be less affected when processing light oils but this was not investigated in this study.

4. An unmodified straw mulcher with an open, radial blade, centrifugal blower was not suitable for multiple recycling of oil-soaked foam in the system concept. While the device performed certain tasks adequately, e.g.: 70 ft throw, acceptable particle size distribution in one or more passes of dry foam, and adequate coverage of broadcast foam, it produced size reduction of oil-soaked foams judged to be unacceptable. When soaked with a light crude oil, 29% of the foam was shredded to particle sizes less than one-half inch in 100 cycles. For Bunker C oil this figure was 47% in 5 cycles. Although improvements were possible by modifying the blower, it was judged that a pneumatic broadcaster of a different design would be more satisfactory.

5. The most effective conveyor angle to transport foam sorbent pieces of a general cubical shape soaked in a light oil is 25° to 30°. The angle for foam pieces soaked in a heavy, viscous oil is not critical up to 45°. Flat pieces (1/2 inch thick with rectangular dimensions of 2 inches or more) soaked in a light or heavy oil will be transported by a conveyor at angles up to 45°. Because sorbent would be reduced in size and shape by recycling, an angle of 30° was selected for the system concept.

6. A conveyor belt mesh size of 1/2 inch would provide a good balance between dewatering and sorbent conveying capability. Tests showed that smaller sizes tended to plug with heavy oil and debris.

7. The use of a water spray boom appears to be an effective means of mixing sorbent and oil on a water surface. However, still to be investigated is the potential problem of driving oil into the water column and possibly forming an emulsion. Small scale experiments of spray mixing yielded sorption of up to 32 lbs of oil/lb of dry foam with a heavy asphaltic crude oil and up to 39 lbs/lb of light crude oil from slicks 0.8 mm thick. Herding

of oil-soaked sorbent by a water spray, already shown to be moderately effective in large scale tests, was also demonstrated in small scale experiments in currents up to one knot. A spray angle of 30° relative to the water surface was found to be most effective in small scale tests with a flat spray nozzle.

8. An emulsified oil would be expected to have a higher draining rate from sorbent (e.g. oil lost by draining through a mesh belt) than a fresh oil. Tests of an emulsified heavy asphaltic crude showed the drainage rate of the emulsified oil to be 3 to 4 times that of fresh (unemulsified) oil.

9. Heavy, viscous oils such as Bunker C increase the rate and amount of sorbent degradation and losses, as illustrated in items 3 and 4 of this section. Based on the data obtained, it was concluded that the system, as designed would function most effectively on light and medium oils and least effectively on unheated, heavy, viscous oils such as Bunker C.

10. The available contact time for sorption of oil is 35 seconds for operation of the proposed system at 3 knots. The required contact time for absorption of Bunker C oil in polyurethane foam is several hours. Thus the adsorption process, which is immediate on contact of the foam with Bunker C, would be utilized in the system. This contact-adsorption would take place on one side of foam particles which landed on the oil. It would be required that the remainder of the mixing of oil and sorbent take place in the spray boom mixing area. Sorption of 32 lbs/lb of a heavy, viscous oil, Santa Maria Crude, 14°API, was demonstrated in a small scale spray test with a 60 second mixing time.

    The required contact time for absorption of about 12 lbs/lb of a light oil, such as No. 2 fuel oil, by polyurethane foam is about 5 seconds. Sorption of up to 39 lbs/lb of a light Canadian crude was demonstrated in the small scale spray mixing tests in 60 seconds.

    Additional experiments on a large scale are needed to establish the required mixing times for both heavy and light oils in the spray mixing area. Time and funding limitations did not permit such evaluation in this study.

11. Extrapolating foam losses through individual components to a full-size system indicates the following foam losses and replenishment rates:

    (a) For light oils with the system as proposed (using mulcher)-- In 75 cycles (one hour of boat operating time) the mulcher would reduce about 6% of the foam to particles less than 1/4 inch; these would be lost during the 75 cycles of the squeeze-roller. Neglecting other system losses, which were not determined in this work, the foam replenishment rate would be about 6% per 75 cycles (per hour) or about 7 lbs of foam per hour for a full-size system.

(b) For heavy, viscous oils such as Bunker C, with the system as proposed (using mulcher)--In 5 cycles (4 minutes of boat operating time) the mulcher would reduce about 47% of the foam to particles less than 1/2 inch; assuming that all of these were lost in the 5 cycles of the squeeze-roller (this high rate would override any loss rate attributable to size reduction by the squeeze-roller) the replenishment rate would approximate 47% every 4 minutes or about 800 lbs of sorbent per hour.

(c) For light oils using a different broadcaster producing no reduction in foam size--Losses through the squeeze-roller would amount to less than 3.5% for 75 cycles. Neglecting other system losses, the foam replenishment rate would be on the order of 4 pounds of sorbent per hour.

(d) For heavy, viscous oils such as Bunker C, using a different broadcaster producing no reduction in foam size--The sorbent would degrade by loss of resiliency after about 75 cycles through the squeeze-roller and would require replacement. The foam replenishment rate would be one system inventory per hour or 114 pounds/hour.

SECTION II

RECOMMENDATIONS

1. The sorbent-oil separator developed under this project should be used and evaluated in a full-scale operation on an oil recovery system using polyurethane foam sorbents. Prior to such use, some minor modifications should be made to improve synchronization of the rollers and hinging of the internal oil scrapers. Such a system should employ pre-cut, flat-thin pieces of foam (from 3" x 3" x 3/4" to 6" x 6" x 3/4") or similar sized pieces shredded from large sheets of 3/4" thick foam by one pass through the mulcher. The system should use a different pneumatic broadcaster to avoid the size degradation which occurred from recycling foam through the mulcher-broadcaster.

2. Different polyurethane foams should be investigated for resistance to damage by pressing and shredding operations in multiple cycling with heavier oils such as Bunker C. Stronger foams or specially processed foams, e.g. reticulated, may be more resistant to loss of resilience or to tearing.

3. The spray boom concept for mixing and herding oil and sorbents should be evaluated on a large scale. A spray boom is more maneuverable and easier to propel than a mechanical boom and could possibly eliminate problems associated with hang-up of debris and oil-soaked foam on conventional herding booms. In addition, it should enhance pick up of oil by the sorbent since it would mix oil and sorbent that would not otherwise come in contact with each other. That is, a sorbent piece broadcast onto plain water in a discontinuous oil slick would not sorb oil, but because the spray boom herds both oil and sorbent, a forced mixing would take place at the spray line.

4. For a water spray boom, additional work is needed to define foam losses under or around the boom, possible choking at the entrance to the onloading conveying system, and the effectiveness of the mixing action at the spray line. Possible problems of forming emulsions and driving oil out of the foam and into the water column by the water spray should also be studied.

5. A comparative analysis should be made of the economics of oil recovery by a recycling mechanical sorbent harvesting system compared to present methods of oil spill cleanup, i.e., spreading, recovery and disposal of non-recyclable straw by (largely) manual means.

SECTION III

INTRODUCTION

The physical removal of oil from water with the aid of sorbent materials has been demonstrated as a desirable method of mitigating the potentially disastrous effects of oil pollution arising from tanker and offshore drilling accidents or operating errors. A great number of natural and synthetic sorbents have been tried and evaluated[2,3,4]. Many appear quite promising, but have yet to be effectively utilized for recovering large quantities of oil, owing to the lack of appropriate equipment and/or systems.

This study was concerned with the development and evaluation of a system concept for recovering floating oil slicks from unprotected waters with the aid of a polyurethane foam sorbent (see Figure 1).

The system was to be capable of recovering floating oil at the rate of 10,000 gallons per hour from a slick thickness of 1.5 mm or less in five-foot seas with superimposed winds up to 30 mph and 2 knot currents, close to shore in less than 80-foot water depths, with oil temperatures of 20°C. Other details of system requirements are listed in this section under "Design Goals".

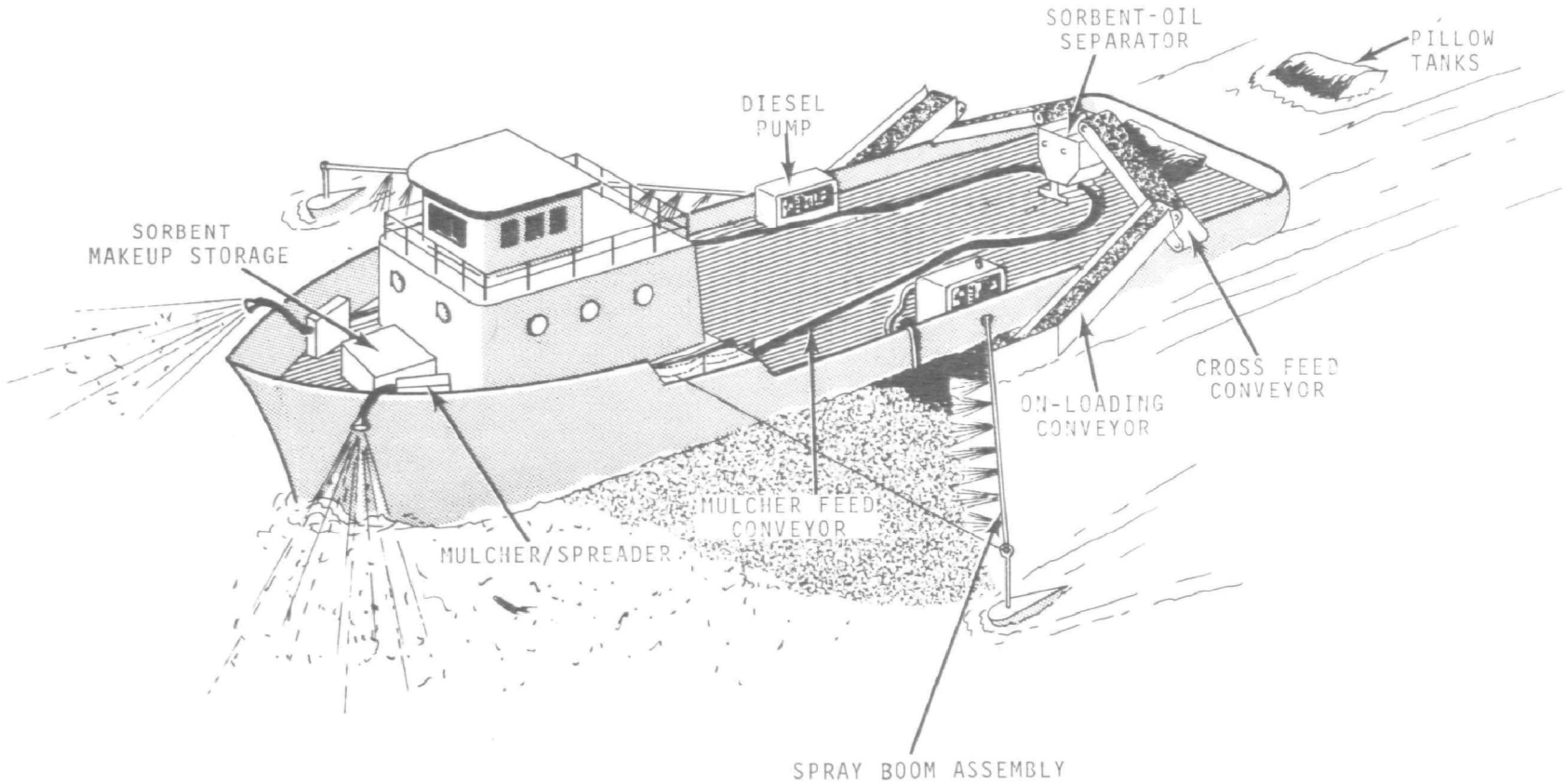

Figure 1

Overall System Concept

BACKGROUND

Prior studies[5] and experimental work by Battelle-Northwest and others[3], later confirmed by Schatzberg[4], showed that open-cell polyurethane foam was superior to other available sorbents in: (a) sorption capacity after multiple cycles; (b) oil extractability; (c) speed of sorption; (d) sorption capacity of virgin material; (e) ability to sorb materials of interest and (f) hydrophobic-oleophilic characteristics. Other in-house research also indicated that sorbents generally would require pre-heating to enable ready release of sorbed Bunker C oil.

With these findings as a basis, a system concept was synthesized to meet specific design goals described later in this section. The project as originally conceived was intended to result in a full-scale half-system which was to consist of a water spray boom for herding oil-soaked sorbent on one side of a test vessel plus onloading, conveying, extracting and oil storage equipment. However, information from similar ongoing EPA projects and consultations with EPA's laboratory personnel indicated that a redirection of research effort was needed in order to define the problems of recycling polyurethane foams through mulching and squeezing equipment at least 50 to 100 times. Degradation to small, unrecoverable pieces and loss of resiliency were believed possible. If such stress occurred, system losses would be high.

Special studies were conducted on key foam handling equipment pieces to establish whether or not the foam would perform effectively after multiple cycling. If the foam were rapidly degraded in these portions of the cycle, or sorbent losses were high, there would be little to be gained by a complete system test using the particular foam handling equipment chosen. That is, failure of one component in the system to provide reasonable recycling life could negate the entire system regardless of the merits of the other components.

Re-direction of the program resulted when the sorbent size degradation was high in the mulcher-spreader, especially for Bunker C oil, an oil which was of major interest for the recovery system. As a consequence, the full-scale half-system was neither fully assembled nor tested. Rather, information was developed on foam behavior in the separate process steps.

CONCEPT DESCRIPTION

The system concept utilized water spray booms, extending outward and forward from a support vessel, to concentrate oil-soaked polyurethane foam on the water surface. The foam would be broadcast in front of the vessel by mulcher-spreaders; contact time for the foam-oil sorption process was 35 seconds. Additional sorption was provided by the water spray boom which would concentrate and mix the oil and foam before pickup. The concentrated material would be withdrawn

from the water surface by means of partly submerged conveyors and deposited on crossfeed conveyors and then into a sorbent-oil separator. This unit would extract the oil by squeezing between two perforated, counterrotating drums. Recovered oil would then flow by gravity to a receiving tank from where it would be pumped to moderately-sized pillow tanks which, when filled, would be dumped overboard for pickup or towing by other vessels. The sorbent from which the oil had been extracted would be conveyed forward by means of pneumatic conveyors to the mulcher-spreaders which would re-distribute the sorbent on the water surface. Figure 1 shows the overall system concept.

The initial concept included a heating system with the sorbent-oil separator to allow extraction of viscous oils such as Bunker C. Because of the large amount of heat required, and the size requirements for such a heater, the design was modified to allow a pressing operation without heat. Development of a sorbent-oil separator to function and extract Bunker C at 20°C without heating is described in a subsequent section of this report.

The use of water spray jets for concentrating the oil-soaked sorbent was selected because it would make it possible to achieve the desired rate of oil recovery without excessive support vessel speed and with minimal equipment penetrating the water surface. Control and concentration of oil slicks by hydraulic streams is described in a previous EPA report[6].

DESIGN GOALS

The system concept was designed to meet the following goals:

System Capacity - The system was designed to be capable of coping with a spill of at least one million gallons with an oil recovery rate of 10,000 gallons per hour under the maximum environmental operating conditions. Recovery of oil was to be from a slick thickness of 1.5 mm or less.

Environmental Conditions - The system was designed to effectively recover oil and oil products from the surface of unprotected waters under operational conditions of: five foot seas (average wave height 5 ft) with superimposed winds up to 30 mph and 2 knot currents; close to shore in less than 80-foot water depths; and oil temperatures of 20°C.

Transportability and Deployment - The system was designed to be transportable to the scene of a spill by air, rail, highway, or water and to be readily adaptable to normally available vessels at the scene.

Spectrum of Petroleum Products to be Recovered - The system was designed to recover floating oil products ranging from light

diesel oil to Bunker C oil over the range of operational environmental conditions previously described.

End Product Quality - A design goal for the recovered oil was that it contain not more than 10 percent by volume of seawater. The effluent water discharged to the environment was to contain not more than 10 mg/ℓ of oil.

MODEL DEVELOPMENT FOR DESIGN INPUT

Prior to the start of design of the full-scale, half-system prototype, a number of unknowns required developmental or experimental input. These unknowns included: an effective onloading conveyor angle, foam sorption rates, contact times and draining characteristics, required conveyor belt size, effect of spray jet flow and angle on mixing and herding of sorbent and oil, and evaluation of a squeeze-roller concept to extract Bunker C oils from sorbent without the use of heat. Experiments were conducted with scale models and an indoor testing basin to provide this needed data.

To determine oil and water draining rates (from a mesh belt onloading conveyor retrieving oil-soaked sorbent) and the suitable angle for an onloading conveyor, experiments were made on an apparatus simulating a conveyor belt. Sections of varying size wire mesh were drawn out of a circulating water stream at measured velocities to simulate the action of a mesh conveyor belt traveling through the water and retrieving oil-soaked sorbent. This apparatus, installed in an indoor testing basin, was used to determine the required angle for an onloading conveyor, optimum mesh size and draining rates.

Work to determine other data in the indoor basin included experiments in sorption rates and contact times of different oils with polyurethane foam, optimum sorbent dimensions for conveyor belt transport and sorption efficiency, effectiveness of spray jets in mixing oil and sorbent, and the effect of varying the spray jet flow and angle on retention (herding) of oil-soaked sorbent. The apparatus and test results from these experiments are discussed in Sections IV and V of this report.

For the initial evaluation of the concept for oil extraction, a model of a squeeze-roller type of sorbent-oil separator was constructed using a 12" diameter perforated drum rolling against a non-perforated neoprene-covered drum. Information from the performance of this device provided design information for the larger (3-foot-diameter rolls) full-scale squeeze-roller.

SYSTEM DESIGN

A major effort of the program involved the design of a full-scale half-system. Using input from the scale model and experiments performed on the indoor testing basin, a design was generated for the

full-scale half-system. This design provided a full-size spray boom mounted on one side of the 35 ft test vessel in the outdoor vessel testing basin plus other equipment for an operable system to recover 5000 gallons per hour of oil. Other equipment consisted of onloading and crossfeed conveyors, a squeeze-roller, a pneumatic conveyor, a mulcher-spreader, oil and sorbent storage, water pumping equipment, oil pumping equipment and a gasoline-engine-driven hydraulic power supply.

Individual components were designed (or, in the case of the mulcher-spreader, procured as commercially available equipment) to be installed on the test vessel. This design effort, discussed in Section IV of this report, included calculation of the system capacity requirements, interfacing of components with respect to a support vessel and water surface motions, structural analysis of the spray boom, and preparation of design drawings.

EVALUATION PROGRAM DESCRIPTION

Following design of the system, certain key equipment pieces were procured for evaluation. These were the spray boom and framework to support the onloading conveyor, the mulcher-spreader, the squeeze-roller and a hydraulic power supply to drive the squeeze-roller.

Since the system concept required re-use (recycling) of the polyurethane sorbent, it was important to determine the degradation in foam particle size and potential loss rate in the system. The amount of sorbent lost in recycling through the mulcher-spreader and the squeeze-roller would significantly affect the practicability and economics of the system as well as requirements for onboard storage of sorbent for replenishment. Also, additional work is undoubtedly needed to define losses via the spray boom and pneumatic conveyor; however, limited funds prevented such an evaluation.

Accordingly, the evaluation program was directed toward determining potential sorbent degradation and losses in the mulcher-spreader and squeeze-roller. Experiments were performed with the mulcher-spreader to determine foam particle size, throw distance and coverage for one pass. In this work 1/2" to 1" thick sheets of dry (un-oiled) foam were run through the mulcher-spreader in one pass and data taken on the resulting size distribution, coverage, and distance.

Further experiments to determine sorbent degradation such as reduction of size and reduction of sorption capacity were made using oil-soaked foam. For the mulcher-spreader a quantity of foam was soaked in a light Canadian crude oil and recycled through the mulcher-spreader 100 times, simulating approximately two hours of operating time. A similar test was performed using foam soaked in Bunker C oil. This test was terminated at 5 cycles because of excessive size reduction.

In the evaluation of the squeeze-roller, foam pieces of the size generated by one pass through the mulcher-spreader (typically 3/4" x 6" to 7" maximum rectangular dimension) were soaked in Bunker C and cycled through the squeeze-roller. The foam was soaked each cycle and the testing was terminated at 77 cycles at which time foam damage from loss of resiliency reduced oil recovery to about 25% of the original value.

CONCEPT EVALUATION

Evaluation of the mulcher-spreader, a Reinco-Model TM7-30 straw mulcher, showed that without modification, it produced acceptable sorbent sizes in one pass of dry foam from sheets of polyurethane foam 1/2-inch to 3/4-inch thick, 15 inches wide and up to 6 feet long. The majority of pieces produced were flat, thin pieces ranging from 2 inches to 7 inches in maximum rectangular dimension, a shape ideally suited for rapid oil sorption and stable travel up an inclined conveyor. Size reduction of the dry foam was negligible in 3 passes through the mulcher, producing a 10 percent increase in number of particles in the second cycle and almost no change for the third cycle. Distribution (surface coverage) of the foam was good and the maximum throw was 70 feet in calm air. However, the tests using oil-soaked foam revealed that size degradation occurred in multiple cycles. When soaked with light Canadian crude oil (42° API) 29 percent of the foam was shredded to particle sizes less than 1/2 inch in 100 cycles. For foam containing Bunker C fuel oil, (Venezuela based, 22.9° API) 47 percent of the foam was reduced to particle sizes less than 1/2 inch after 5 cycles through the mulcher-spreader. This was judged to be an unacceptable rate of size reduction because tests with the scale model squeeze-roller indicated that particles of foam less than 1/2 inch would pass through the perforated roller along with the recovered oil when processing Bunker C oil.

The mulcher-spreader blower wheel is an open, radial blade, centrifugal design. It is believed that the foam particles are sheared by the rotating wheel blades where they interface with the stationary front and rear scroll housing plates. Addition of front and rear blade shrouds on the blower wheel or selection of a blower better suited to handle the foam could improve this subsystem; however, such modification or redesign was beyond the scope of this project.

Evaluation of the squeeze-roller was conducted initially on the scale model and later on the full scale prototype. Initial results with the scale model (12-inch diameter rolls; one perforated, one neoprene covered), showed good extraction of oil, up to 30 pounds of oil per pound of dry foam with Bunker C oil, up to 18 lbs/lb with San Joaquin Crude (14° API), up to 20 lbs/lb with Santa Maria Crude (14.7° API) and up to 25 lbs/lb with light Canadian Crude (42° API). Losses of foam containing light Canadian crude oil were negligible for the entire particle size range (less than 1/2 inch to the 7-inch size) in the

small scale model. However, for foam containing the Bunker C oil, the material less than 1/2 inch passed through the 1/4-inch-diameter perforations of the small scale model along with the oil. Material greater than 1/2 inch was recovered for reprocessing. (Note: the small scale model showed loss of 1/2 inch foam with Bunker C oil whereas the full scale prototype showed loss of 3/8 inch foam with Bunker C).

Tests of the full scale squeeze-roller (36" diameter rolls, both perforated with 1/4 inch holes) were made by multiple cycles of foam pieces soaked in Bunker C oil for each cycle. This evaluation was directed primarily at determining foam damage from size degradation and loss of resiliency or sorption capacity. The oil extraction rate achieved was 4.6 lbs of oil per pound of sorbent which is lower than the design value of 10 lbs/lb. However, the sorbent was not completely saturated for each cycle because of time limitations. It is believed that the squeeze-roller can extract at least 10 lbs/lb from sorbent saturated with Bunker C in the same manner that the scale model accomplished rates in excess of this figure.

Results of the evaluation for size reduction and loss of resiliency showed that after 60 cycles with Bunker C oil, moderate size reduction had occurred and the amount of oil extracted had reduced to about 50 percent of that originally extracted. At 77 cycles, when the test was terminated, the amount of oil able to be extracted had decreased to 25 percent of that originally extracted and the total foam volume had reduced to about 25 percent of its original volume from loss of resiliency. The fact that the sorbent recovered its original volume after washing in solvent indicated that the viscous Bunker C oil was causing the foam to retain the volume reduction noted. This indicates that internal foam damage (destruction of cell walls) occurred. It is probable that the Bunker C caused the damage while being pressed out of the tortuous internal paths. Lighter oils, such as diesel or light crudes would likely not cause this type of damage for several hundred cycles, but this effect was not evaluated.

The total amount of sorbent lost to the system in the squeeze-roller evaluation was very low, amounting to 3.5 percent for the 77 cycles when using foam that was pre-shredded by only one pass through the mulcher. These losses were 3/8-inch and smaller particles which passed through the 1/4-inch perforations and were trapped in the recovered oil. No particles larger than 3/8 inch were found to have passed through the perforations. It was concluded that 1/2 inch and larger particles would be recovered as re-usable sorbent under operating conditions similar to those used in the evaluation. It should be pointed out that if the foam were run through the mulcher each time it was run through the squeeze-roller (i.e. as in the proposed system) the losses would be much higher.

Size reduction in the squeeze-roller resulted primarily from a shearing action of the two rollers because of failure of the hydraulic motors to synchronize the rollers. The size range of the original foam was from 1 inch to 7 inches, maximum rectangular dimension (3/4 inches thick) with 77.3 percent being in the 1 to 5 inch range and 18.5 percent in the 1 to 2 inch range. After 77 cycles, 54.5 percent of the pieces were in the 1 to 2 inch range and the maximum size was 3 inches.

SECTION IV

DESIGN AND CONSTRUCTION OF EXPERIMENTAL AND PROTOTYPICAL SUBSYSTEMS

GENERAL-SYSTEM CAPACITY REQUIREMENTS

The design goal for the components of the full-size half system was a capacity of 4000 pounds per hour of sorbent material or a sufficient volume of sorbent to absorb oil at the rate of 5000 gallons per hour, whichever amount was smaller. The following criteria and data were used for the review of the system capacity requirements (mass, volume, energy requirements).

Sorbent recovery capacity	-	10 lb oil/lb dry sorbent
Oil density	-	8 lb/gal
Oil collection rate	-	5000 GPH/side
Dry sorbent density	-	1.0 lb/ft^3 (conservative)
Speed of advance	-	3 knots
Sweeping width	-	20 ft/side

From the above data, the rate of sorbent processing is 4000 lb/hr-side of dry sorbent.

The following table presents the cycle duration for each system component and the sorbent inventory of the component.

TABLE 1

SYSTEM CYCLE TIMES AND WEIGHTS

	Time-Min.	Foam Wt-Lbs
Mulcher-spreader flight - 60 ft @ 60 FPS	0.017	1.13
Floating travel* - 180 ft @ 304 FPM	0.59	39.30
Onloading conveyor - 3 ft x 24 ft @ 304 FPM	0.08	5.32
Crossfeed conveyors - 3 ft x 20 ft @ 304 FPM	0.066	4.43
Oil-sorbent separator - 3 ft dia 4 ft wide 32 RPM	0.01	0.67
Mulcher-conveyor - 160 ft @ 60 FPS	0.04	2.67
Total	0.80	53.52

*This provides a contact time of 35 seconds at the 3 knot rate of advance.

Assuming approximately 1.5 lbs each for the hoppers of the mulcher-spreader and the mulcher-conveyor, the system operating inventory is 57 lbs/side. The time for a particle of sorbent to be completely recycled is 48 seconds.

The upper limit to which each component was designed was dictated by the maximum absorption achievable under optimum conditions of mixing, available oil, energy required to process, material loadings, temperature and exposure time. Additional structural and energy requirements are imposed by the accelerations and drag during marine operations.

ONLOADING CONVEYOR

The design of the onloading conveyor required experimental input for optimization. The features of maximum conveying angle for foam sorbents, mesh size as related to dewatering and oil drainage, and maximum belt speeds were unknown factors.

A flow channel, 2 ft wide by 3 ft deep and 18 ft in diameter, was assembled and fitted with an 18 HP energy source applied through a propeller to generate a current up to 3 knots velocity. Surface currents were measured by time and distance of small floating particles of buoyant material. The flow channel was fitted with a framework to support sections of wire mesh screens with provision to vary the screen angle relative to the water surface from 10 degrees to 60 degrees and to provide screen travel speeds up to 300 FPM. Figure 2 shows the experimental device installed in the flow channel. Upstream of the screen framework, the flow channel was fitted with a single flat spray pattern water nozzle with provision to vary the angle of impingement of the spray on the flowing water surface. The spray was used to simulate the oil herding-retention and dynamic mixing of the water spray boom to be used in the prototypical system. Traveling screens with mesh sizes of 1/8, 1/4, 1/2 and 3/4 inches were evaluated in these experiments.

FOAM SORPTION

The circular flow channel was also used to provide some preliminary data on foam sorption of oils in the mixing action of a water spray jet and the herding-holding capabilities as a function of current velocity and spray angle. Features were provided to vary the angle of impingement of the spray jet with the water surface from 10-40 degrees.

SORBENT-OIL SEPARATOR

A sorbent-oil separator (squeeze-roller) was designed to extract the heavy residual oils from polyurethane foam sorbents at a temperature of 20°C. Conventional bulk press extraction techniques require heating oils such as Bunker C to as high as 50°C for satisfactory removal. The concept developed in this work provided for passing thin layers of the oil-soaked sorbent between two perforated, spring-loaded rollers.

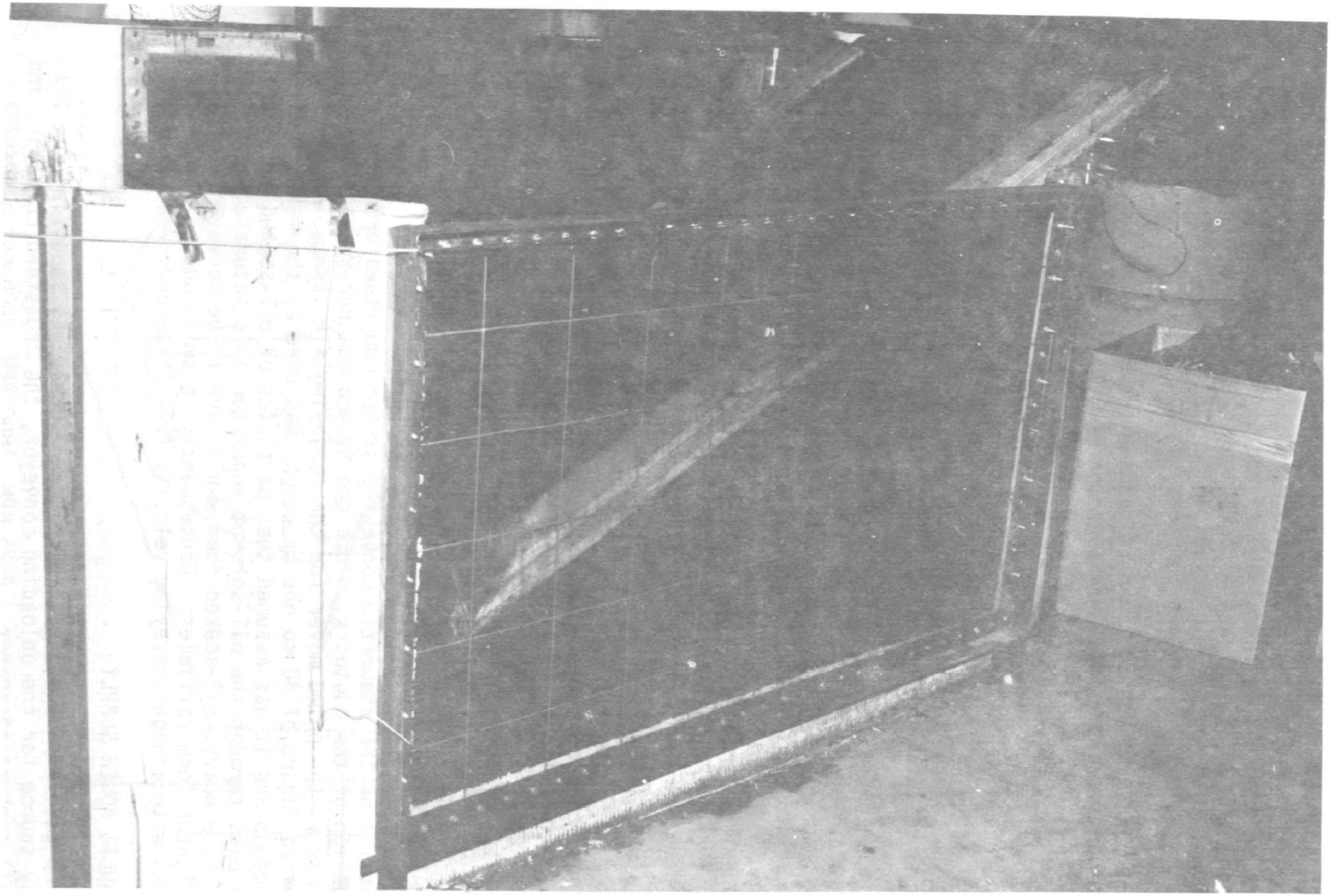

Figure 2

Flow Channel and Apparatus for Determining
Conveyor Angle and Dewatering Rates

The oil is pressed out of the sorbent through the perforated rollers and scraped from the inner wall of the roller at the point of maximum compression. The oil is drained to a central collection point and the sorbent material drops out of the apparatus for re-processing. See diagram in Figure 3. Figure 4 shows the squeeze-roller during fabrication with the end plate removed. Figure 5 illustrates the perforated rolls and Figure 6 shows the completed device.

A small model (Figure 7) was designed and fabricated to evaluate the concept and develop scaling factors for the design of the full scale prototype. The model comprised: a one-foot-diameter by one-foot-long perforated roller, a one-foot diameter by one-foot-long neoprene covered pressing roller, and a one horsepower, variable speed, gear-head motor. The rollers were driven and synchronized by chain belts and had features for adjusting the pressing force. The design of the full scale prototype differed from the model in that both of the opposing rollers were perforated allowing a dual flow path for the recovered oil. Also, the rollers were hydraulically driven by independent motors. The rollers were designed to be synchronized by series flow of the hydraulic fluid. Experiments described in Section V led to the scale factor input to the prototype design to meet the design separation rate of 40,000 pounds of oil per hour (5,000 gph). The diameter, length and RPM of the prototype perforated rollers required to accomplish this processing rate were 3 foot diameter, 4 feet length, and 32 RPM respectively. The energy required for the design performance was calculated to be 5 horsepower.

CROSSFEED CONVEYORS

The crossfeed conveyors were designed using state-of-the-art technology for conveyor belts. From the experiments described in Section V, a conservative figure for maximum absorption (40 gms oil per gm dry foam) was selected for establishing a belt loading of 8.85 lb/ft^2. The conveyors were designed for an upper limit belt speed of 400 FPM.

PNEUMATIC CONVEYOR

The design of the pneumatic conveying system comprised principally the design of the ductwork, since the Reinco mulcher-spreader was to serve as the prime mover for the conveying air stream. A conservative figure of 40 to one by weight was used as the maximum oil absorption and it was assumed that particles of oil-soaked sorbent would pass through the oil-sorbent separator in a saturated condition. Thus, some heavy, oil-soaked foam would have to be conveyed along with the lighter foam particles. Consequently, a small duct diameter (10" square) with a high conveying velocity (220 ft/second) was selected.

HYDRAULIC POWER SUPPLY

A 65 hp gasoline-driven hydraulic power supply was specified for the energy source for the onloading conveyor, the crossfeed conveyors and the oil-sorbent separator. A 25 GPM, 1800 RPM, 2000 psi hydraulic power unit was selected for this service. The unit provided 1.5

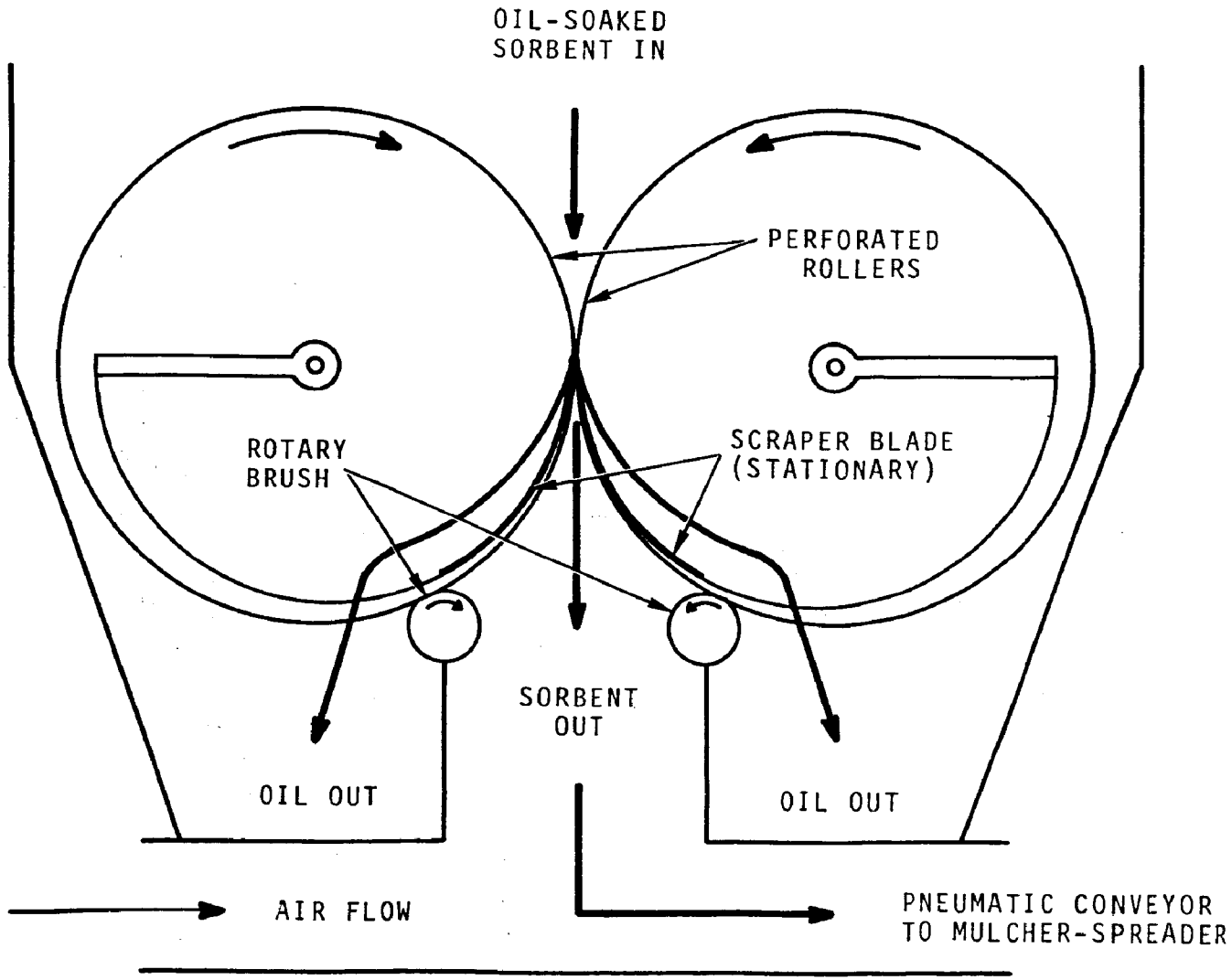

Figure 3

Schematic of Sorbent-Oil Separator

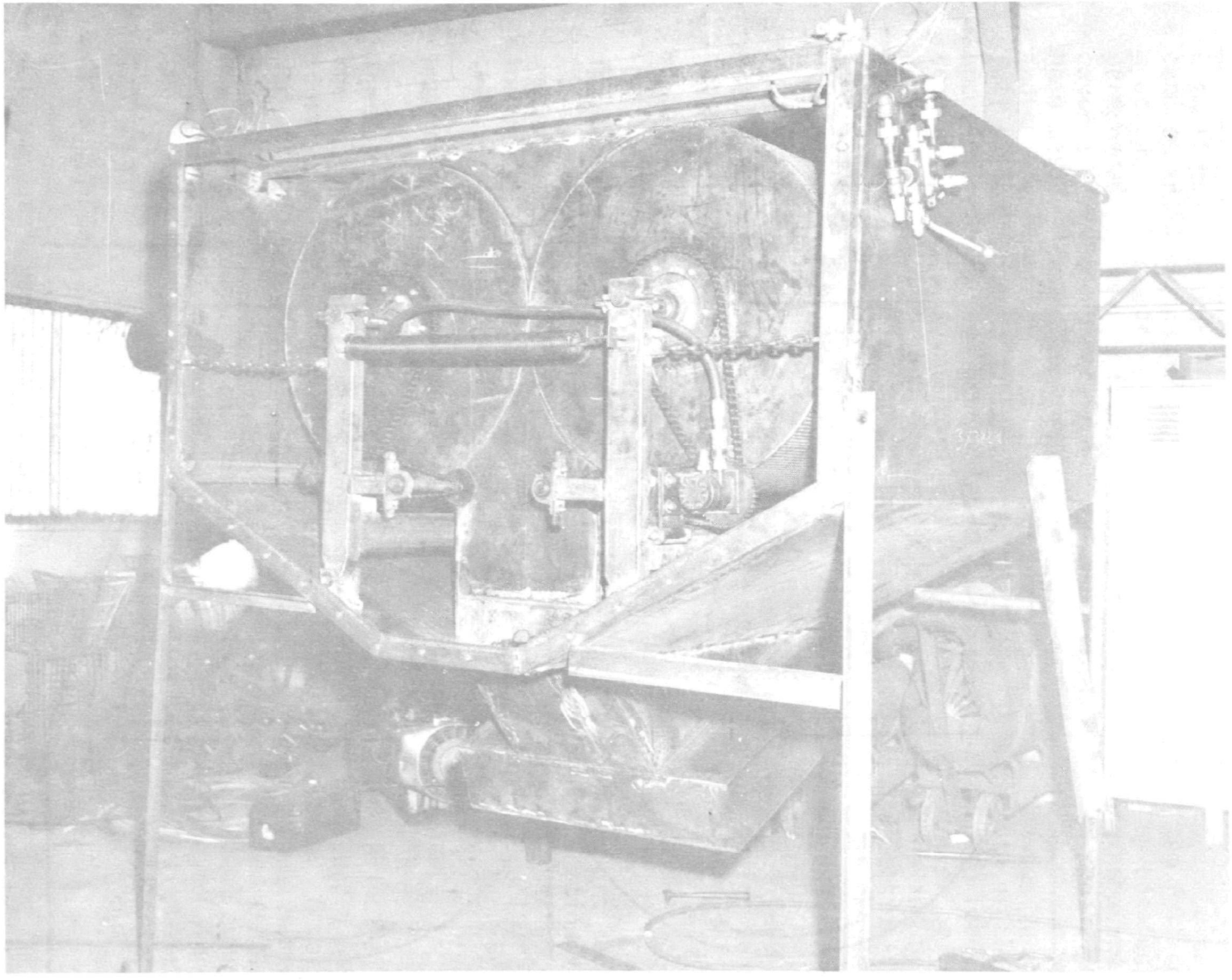

Figure 4

Sorbent-Oil Separator Under Construction
Showing Internal Mechanism

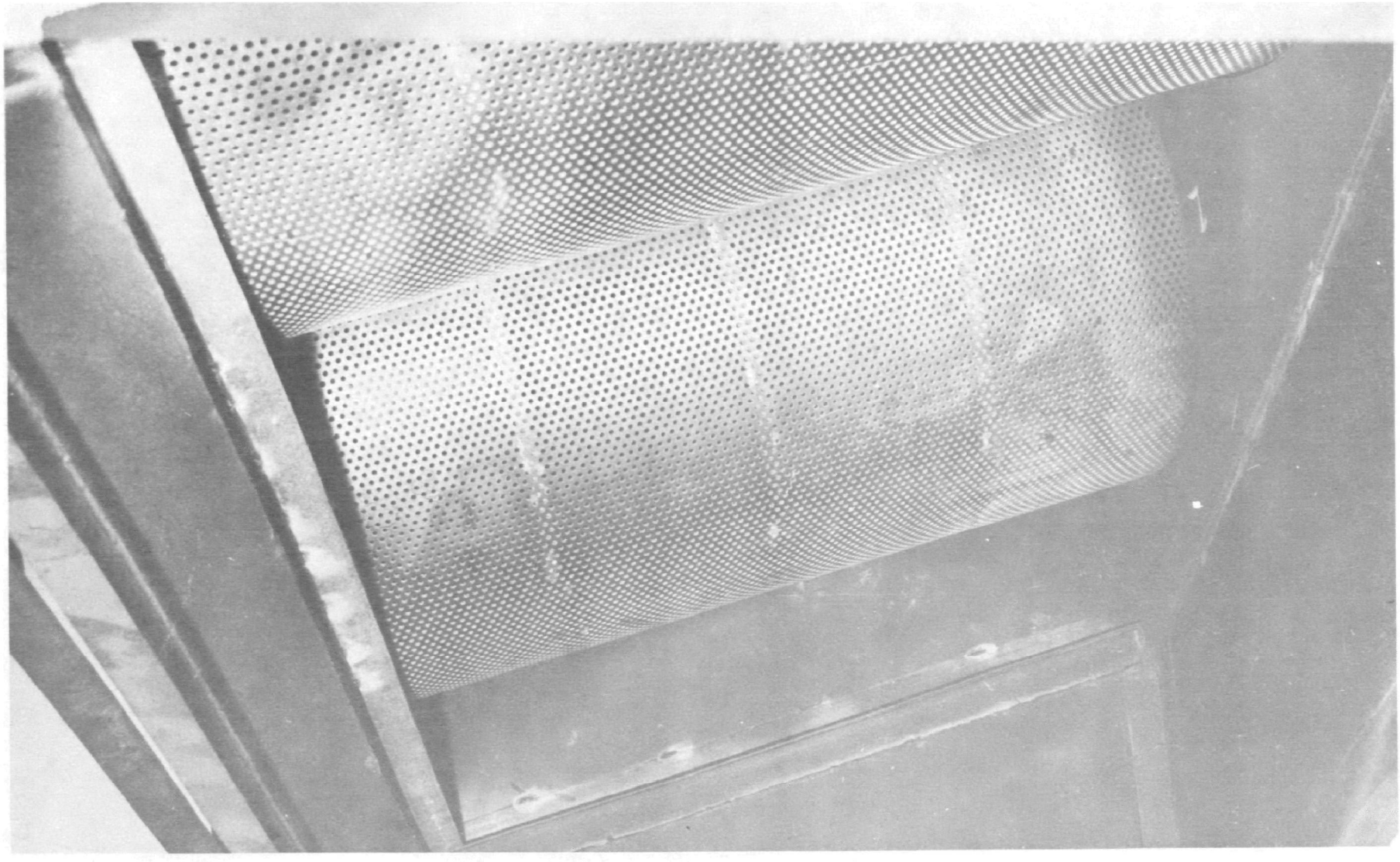

Figure 5

Perforated Rollers in the Full Scale
Sorbent-Oil Separator

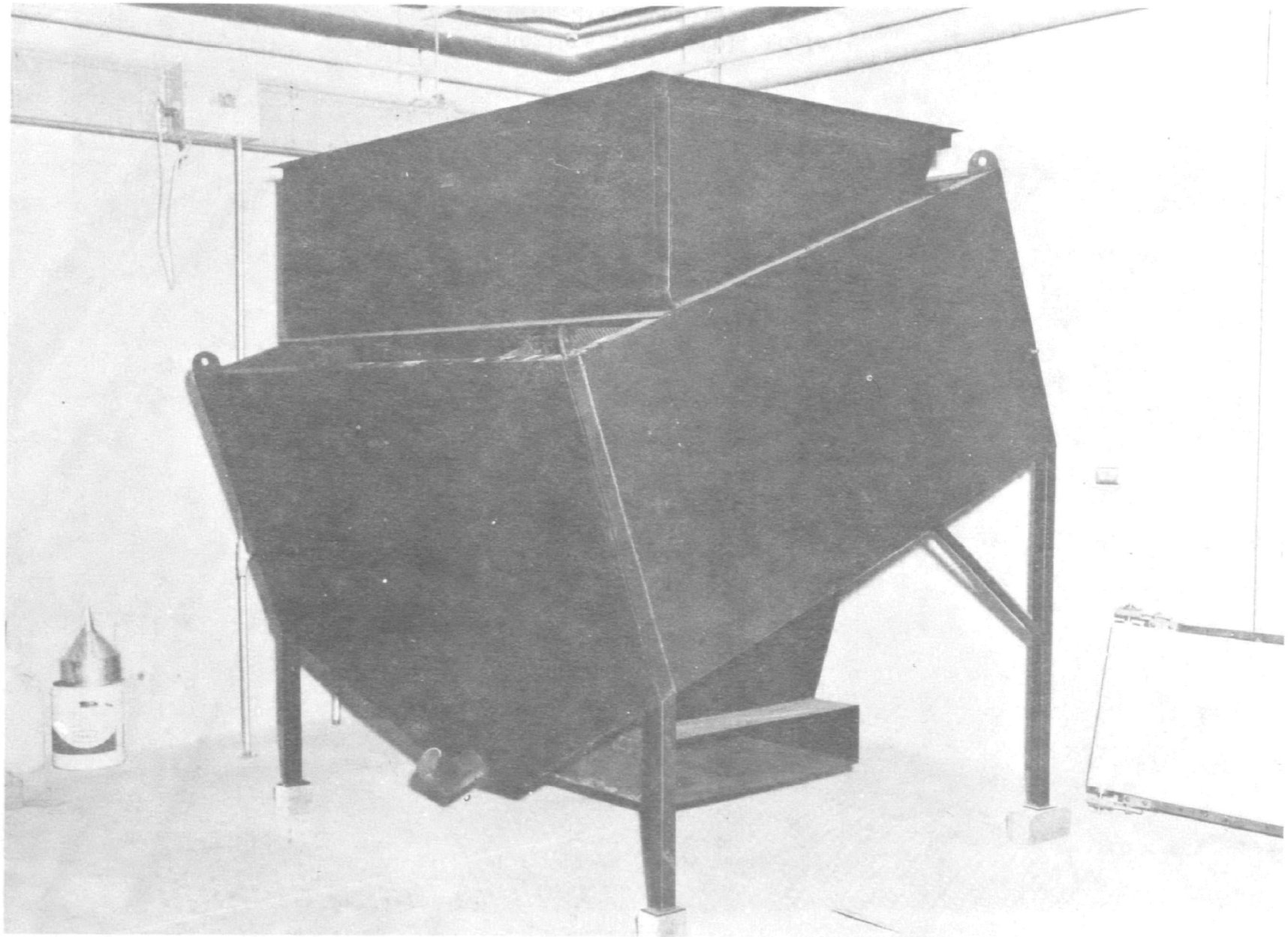

Figure 6

The Completed Full Scale Sorbent-Oil Separator

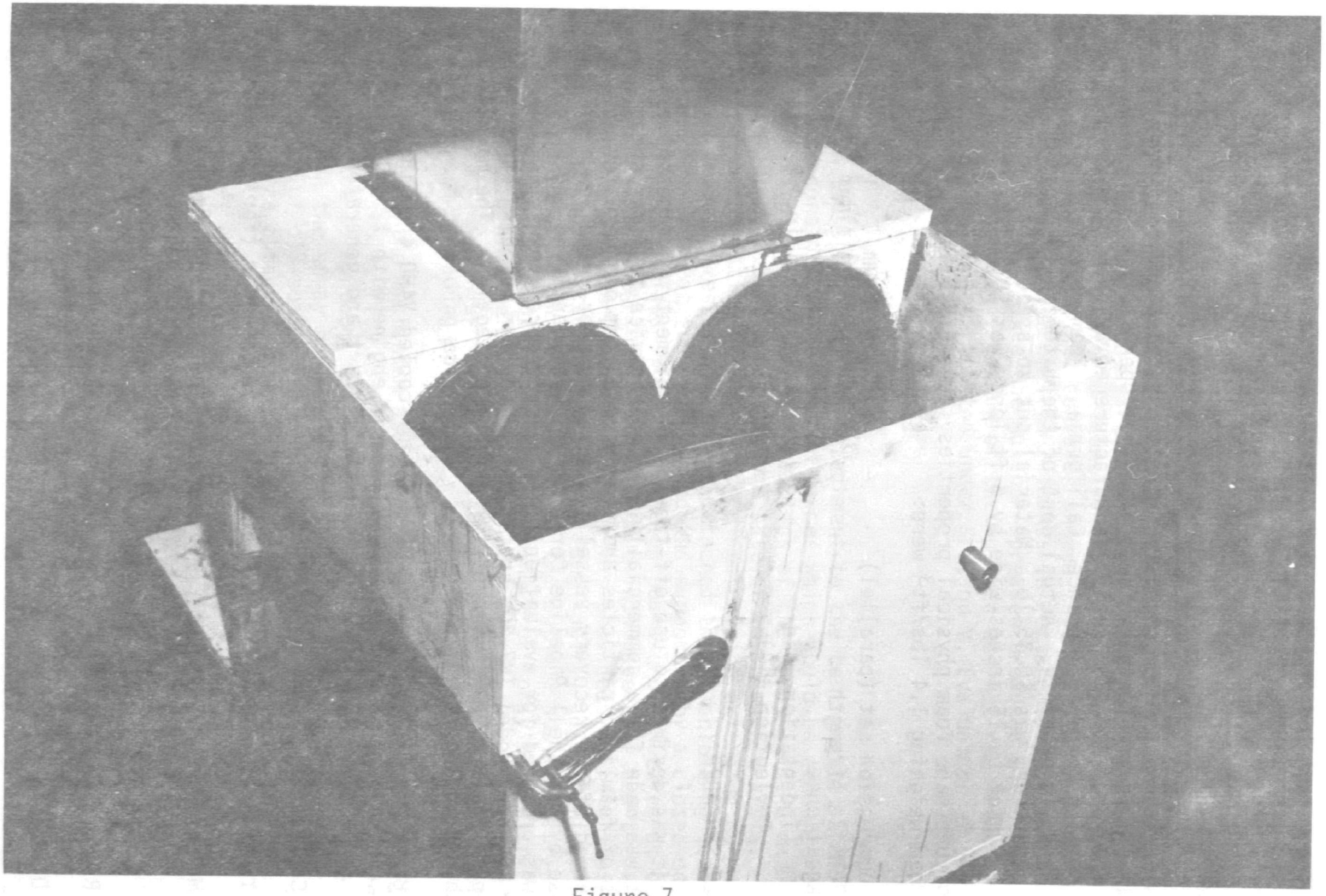

Figure 7

Scale Model Sorbent-Oil Separator

times the calculated power requirements of the prototypical sorbent harvesting system components to allow for overloads and continuous duty.

POLYURETHANE FOAM

The polyurethane foam procured for sorption testing and component evaluation was a polyether-based, flexible, open-cell, polyurethane foam of 80 ppi, CPR 9700 series, manufacturered by the CPR division of the Upjohn Company, Torrance, California. Foam density varied from 1.2 to 1.9 lbs/ft^3. Actual cost of the material in shredded or scrap sheet form was $0.35/lb. Material cut to specifications, i.e. 1/2 inch thick by 15 inches wide by 6 ft long, was $0.75/lb.

The polyurethane foam physical properties (per ASTM D1564-62T) typical of a foam weighing 1.4 lbs/ft^3 were:

Compression set (parallel)	-	10%, maximum
Tensile strength	-	15 lbs/in^2 minimum
Resilience	-	35% minimum
RMA (Indentation load Deflection $\pm$ 3)	-	32 (25% on 4 in.)

MULCHER-SPREADER

Since it was desired to use off-the-shelf equipment where possible, a search was made for a commercially available device to first shred sheets of foam into particles and then spread them on the water surface ahead of the recovery vessel. A straw mulcher, used for a similar purpose by the Shell Pipeline Corporation, was identified and a new unit was procured for evaluation. The mulcher-spreader was a Reinco Power Mulcher, Model TM7-30, specifically made for mulching straw and applying it to earth slopes for erosion protection. The machine had the following specifications:

Power:	30 H.P. air cooled V4HD 4 cylinder Wisconsin engine with 12 volt electric start and generator
Capacity:	4 tons/hr of straw
Throw distance:	Up to 60 ft in calm air (for straw)
Mulcher:	3 sets of adjustable hardened chain flails mounted on shaft leading to inlet of blower fan
Blower:	Open, radial blade material conveyor fan
Discharge velocity:	150 miles per hour

Discharge chute movement:	360° horizontal and 60° vertical movement, manual control
Mounting:	Skid-mounted for truck mounting, with tie down holes and lifting ring.

It had been planned to modify the mulcher portion of the device if necessary, to obtain foam particles of the required dimensions. However, the experiments to identify the optimum shape for sorbing and travel up an inclined conveyor showed that flat, thin pieces (1/2" to 3/4" thick, from 1 to 7 inches in rectangular dimensions) were best suited. Since the mulcher-spreader produced pieces in this size range, modification of the mulcher was not required. Details of the evaluation are reported under Section V, Evaluation of Subsystems.

SPRAY BOOM

Design of the spray boom for attachment to the test vessel, a 35-foot lifeboat, considered the maximum forces which would be encountered in basin testing. These were the reaction of the spray jets, a maximum wave height of 2.0 ft and a maximum rate of advance of 5 knots. A spray boom consisting of a six-inch diameter pipe extending out and forward from the vessel at 45° was attached to the onloading conveyor support framework at the inboard end and supported by a closed-cell, foam-filled fiberglass sponson at the outboard end. Nozzles at one-foot intervals along the length of the 6-inch pipe provided the water spray for herding sorbent. Adjustment was provided for height of the spray boom above water (6" to 3') and longitudinal adjustment of 8 feet was provided to allow determination of the optimum position for sweeping into the conveyor inlet. The angle of spray boom with respect to the vessel and the angle of spray jets with the water was made adjustable also. Figure 8 illustrates the overall relationship of the boom and onloading conveyor.

Discussion of the mechanism and theoretical considerations of spray impingement angle, flow, speed of advance, spray boom angle, current, etc. for the spray boom may be found in the previously referenced report[6] on the spray boom development. That data is also applicable to herding of oil-soaked sorbent. The forces on the boom, shown on Figure 8 were obtained from the following formulas:

Drag[7]:

$$\text{Force} = 1/2\ \rho C_d A V^2$$

Where:

ρ = 2 slugs/ft^3 (mass density of water)

C_d = 1.0

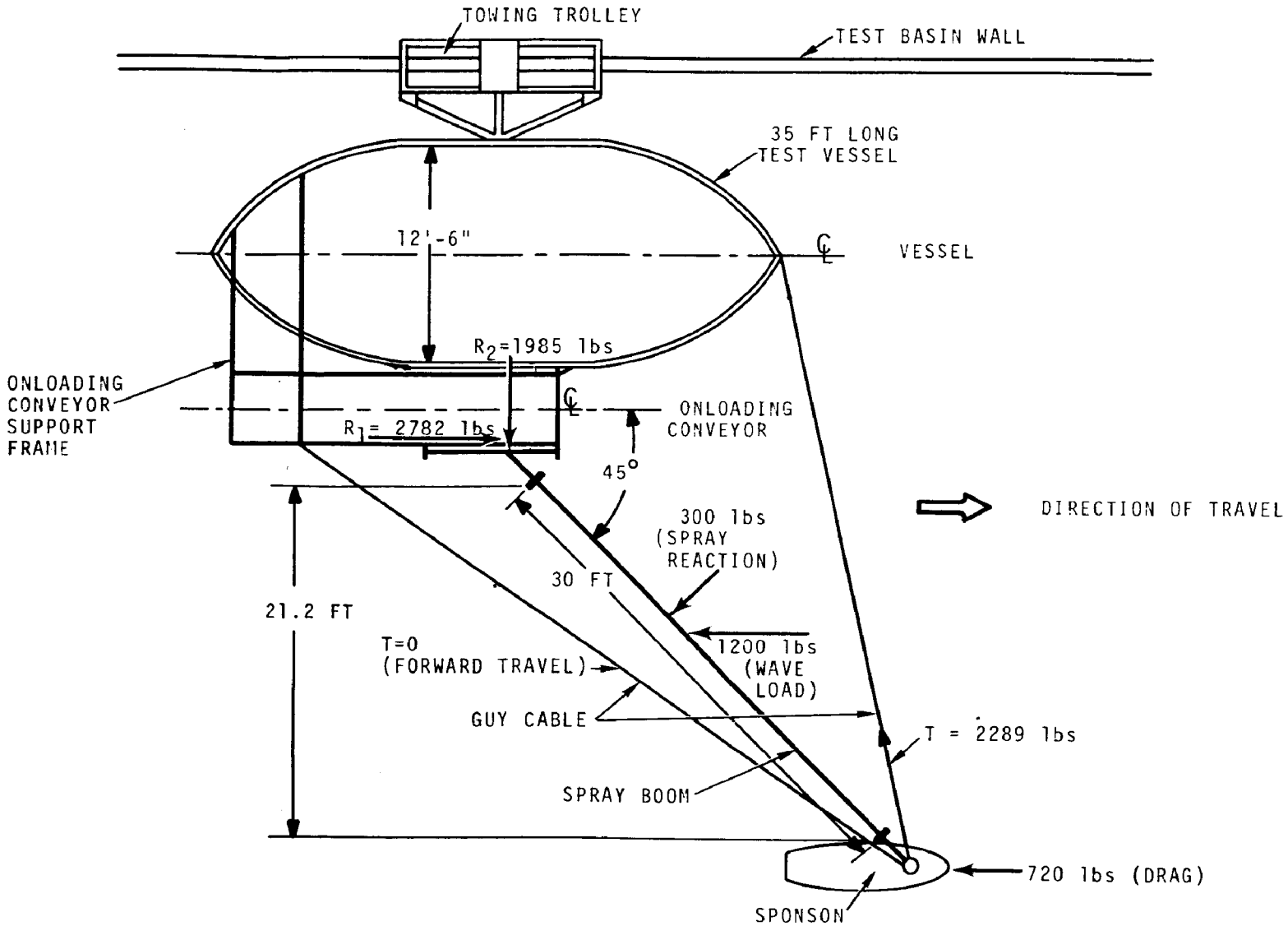

Figure 8

External Loads and Reactions on Spray Boom

A = projected area (of sponson) in ft^2

V = velocity in ft/sec

Inertial force from wave acceleration on the spray boom[7]:

$$\text{Force} = \rho Cm(\text{Volume})\frac{2\pi H^2}{T^2}$$

Where:

ρ = 2 slugs/ft^3

Cm = 1.0

Volume = volume of water displaced by the structure in ft^3

H = wave height, ft

T = wave period, seconds

Note: $\frac{2\pi H^2}{T^2}$ is acceleration $(\frac{dv}{dt})$

Units are ft/sec^2

Spray jet reaction was computed by standard fluid mechanics analysis techniques.

A structural analysis was made for the onloading conveyor support framework by conventional methods of static analysis using as input the computed wave, spray reaction and drag forces, dead and live loads, and inertial loads from vertical acceleration from waves. A design was prepared using structural tubing as shown in Figure 9. The spray boom and onloading conveyor support framework were fabricated by a local contractor and installed on the test vessel.

STRUCTURAL CONNECTIONS, HYDRAULIC CONNECTIONS AND ANCILLARY SYSTEMS

Structural connections required for the system were for attachment of the onloading conveyor support framework to the vessel. Connections were designed to handle the loadings shown in Figure 8 plus drag on the conveyor which was calculated to be 1732 lbs for a 5 knot speed in 4 ft waves. Dead and live vertical loads from the spray boom, onloading conveyor and equipment, and inertial loads from vessel motion were included. These vertical loads were calculated to be 2850 lbs, total. Welded connections were used.

The remainder of the equipment such as the mulcher-spreader, hydraulic power supply, squeeze-roller, oil storage tanks, etc. was designed to be attached to a vessel deck by bolting, clamping or lashing. Hydraulic connections were specified to be quick disconnect type using hydraulic hoses so that equipment pieces locations could be varied for adapting the system to a vessel of opportunity.

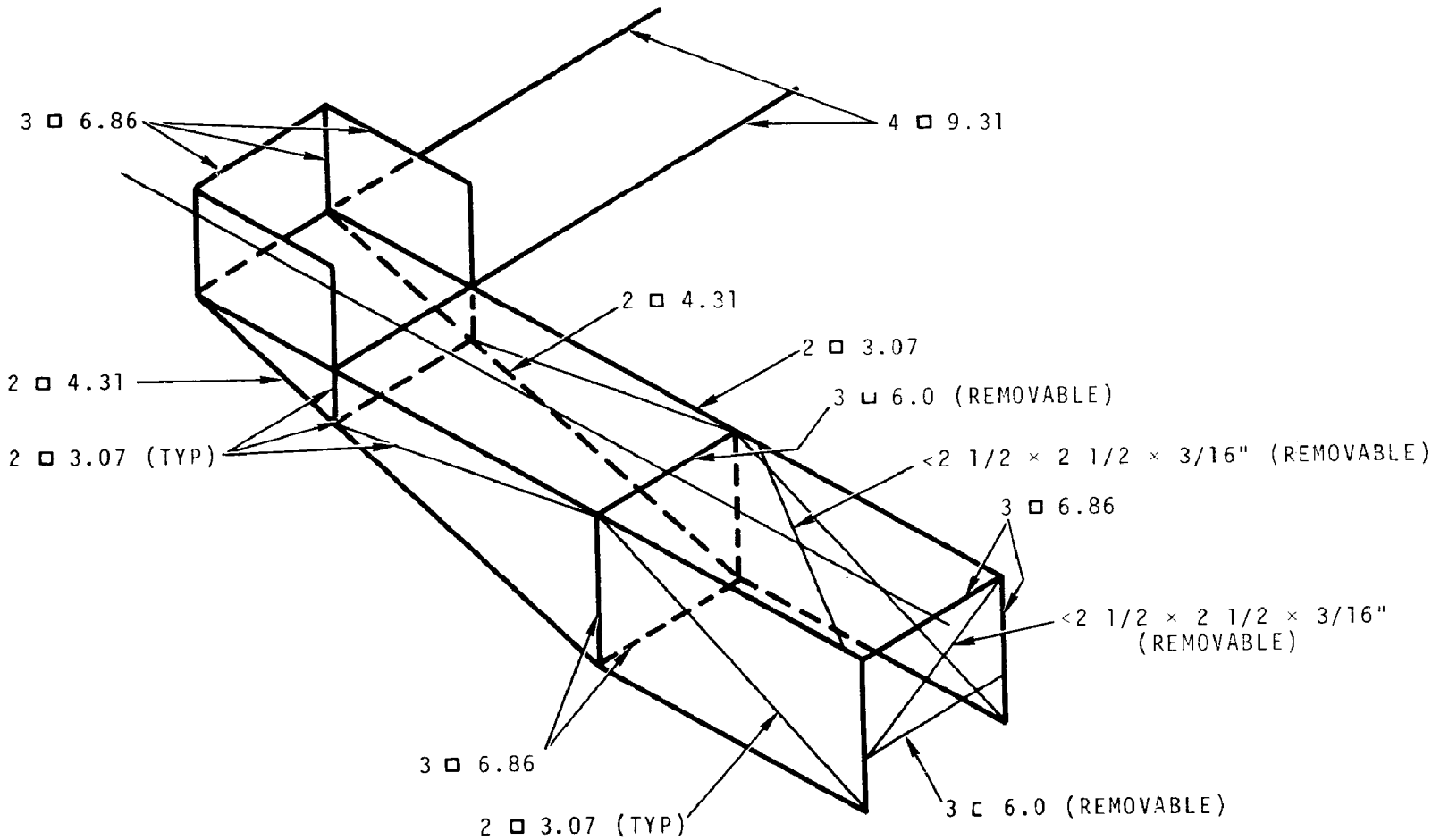

Figure 9

Onloading Conveyor Support Frame

Ancillary equipment included diaphragm-type pumps for transfer of oil from the squeeze-roller to the oil storage tank. Diaphragm pumps were selected to minimize emulsification of the oil and because of their capability to pump viscous oils, such as Bunker C, and some debris or trash, without clogging. Other equipment which was on hand for the full-size, half-system included a 450 gallon tank for oil storage, and a 1000 gpm diesel-powered pump for the spray boom water supply (existing and installed in lifeboat).

SECTION V

EVALUATION OF SUBSYSTEMS

FOAM SORPTION AND HERDING EXPERIMENTS

Preliminary foam sorption experiments were performed to provide design input for the components of the full-scale system. Data obtained from these experiments were used to establish an upper limit for the requirements of the components.

In laboratory experiments, 1/2" pieces of shredded polyurethane foam were added to beakers containing No. 2 fuel oil floating on water. Gentle agitation by a stirring rod was applied for a controlled period of time and the foam was allowed to drain for 30 seconds after removal. The oil sorption under these conditions was determined for different contact times. The results of these experiments showed that sorption of No. 2 fuel oil from 1/8" to 1/4" thick slicks was 12 lbs/lb in 5 seconds, 13.5 lbs/lb in 10 seconds, 15 lbs/lb in 15 seconds and 16 lbs/lb in 30 seconds.

On the water surface of the indoor flow channel, polyurethane foam sections having a density range of 1.2 to 1.9 pounds per cubic foot were mixed with Bunker C oil under optimum conditions of mixing and contact duration until coated. The process took 2 to 3 minutes but the coating action (adsorption) was immediate on contact. The specimens were allowed to drain until an equilibrium weight was reached. The specimens were then weighed, processed through the oil-sorbent separator model and reweighed. The sorption-extraction process was repeated for several cycles to determine the effect of recycling. Figure 10 presents the results of the recycling for one-inch-thick foam sections containing Bunker C fuel oil. Figure 11 presents similar data for one-half-inch-thick foam sections. It should be noted that most of the Bunker C oil sorbed was by a process of adsorption. That is, most of the oil attached itself to the surface of the foam. The adsorption process is immediate on contact. Thus, pickup of Bunker C oil would be enhanced by bringing the oil and foam into contact as in the spray boom mixing area.

The data from these tests indicated that the separator could successfully extract Bunker C oil from 1/2-inch-thick foam at 20°C at the rate of 30 lbs of oil per pound of dry sorbent after three cycles. It was concluded that there would be little oil extracted on the first cycle and that about 3 cycles would be required to reach an extraction rate of 30 pounds of oil per pound of sorbent. Note that the amount of oil sorbed in a cycle increases with each cycle suggesting that sorbent which has already been oil soaked sorbs oil more efficiently than the dry, unoiled sorbent. In reading Figures 10 and 11 note that the "oil sorbed in a cycle" added to "total oil retained in foam after squeezing" of the previous cycle equals the "total oil in foam before squeezing" of the cycle (e.g. Figure 11, for cycle 3 "oil sorbed in a cycle"

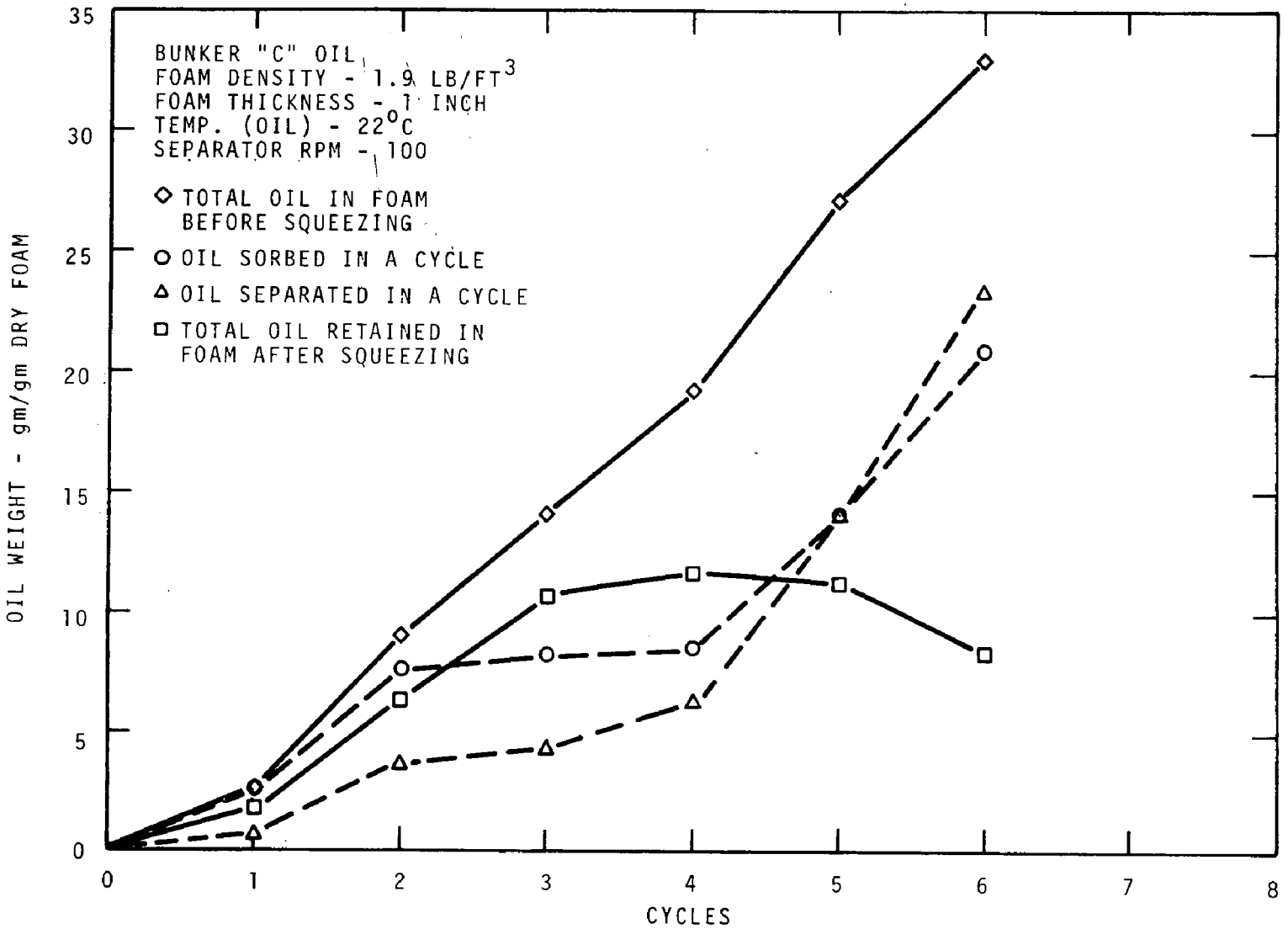

Figure 10

Sorption, Separation and Retention of Bunker C Oil in Polyurethane Foam Recycled in Model Sorbent-Oil Separator - One-Inch-Thick Foam

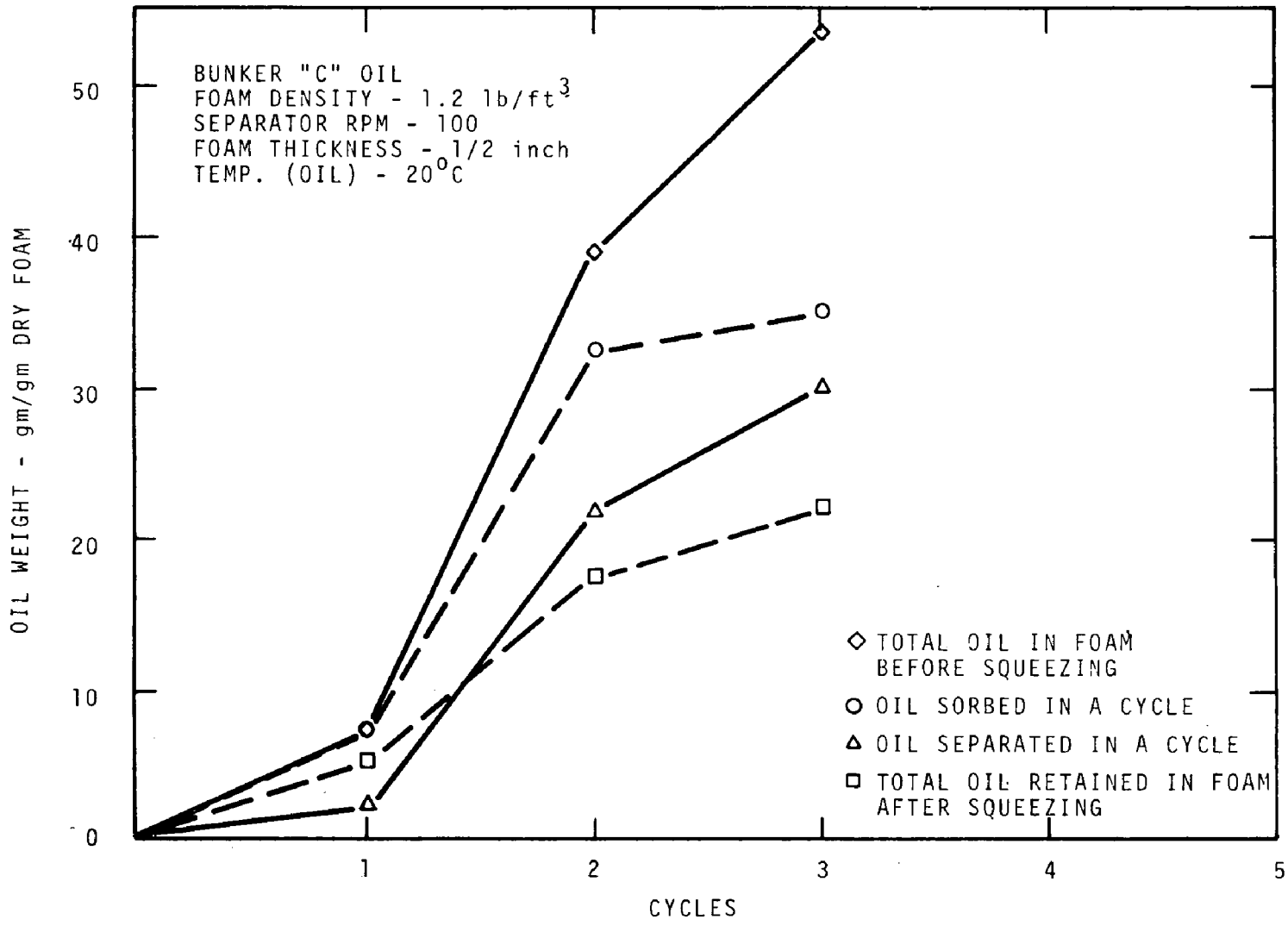

Figure 11

Sorption, Separation and Retention of Bunker C Oil in Polyurethane Foam Recycled in Model Sorbent-Oil Separator - One-Half-Inch-Thick Foam

(35 grams) plus "total oil retained in foam after squeezing" for cycle 2 (18 grams) equals the "total oil in foam before squeezing" for cycle 3 (53 grams). The "oil separated in a cycle" plus the "total oil retained in foam after squeezing", equals the "total oil in foam before squeezing", in any one cycle).

A series of experiments were performed to evaluate the sorption performance of polyurethane foam sorbent in the mixing action of water spray jets impinging on the surface of a flowing body of water. The first series of tests were conducted to optimize the angle of impingement for the function of herding or holding the foam sorbent and oil. For these tests one half-inch-thick foam sections of varying rectangular dimensions were used to evaluate the effect of geometry on the holding or herding operation. The current velocity for this evaluation was one knot and the oil sorbed was a heavy asphaltic San Joaquin crude (14° API). Table 2 shows the percentage of the foam sections held against the current as a function of impingement angle and foam geometry. These data indicate that the optimum spray angle for the particular nozzle used was 30° to the horizontal. Other nozzle types and current velocities could require a different angle.

TABLE 2

RESULTS OF WATER SPRAY HERDING EXPERIMENTS WITH SORBENT AND SAN JOAQUIN CRUDE OIL

Spray Impingement Angle	Current Velocity	Percent Retained in Spray — Foam Dimensions (1/2" thick) 4" x 4"	2" x 2"	1" x 2"	1" x 1"
10°	1 knot	100	100	50	100
20°	1 knot	100	100	25	100
30°	1 knot	100	100	100	100
40°	1 knot	100	100	100	10

A similar test was conducted using a light Canadian crude oil (42° API). Table 3 presents the results of those experiments.

TABLE 3

RESULTS OF WATER SPRAY HERDING EXPERIMENTS WITH SORBENT AND LIGHT CANADIAN CRUDE OIL

Spray Impingement Angle	Current Velocity	Percent Retained in Spray — Foam Dimensions (1/2" thick) 4" x 4"	2" x 2"	1" x 2"	1" x 1"
10°	1 knot	100	66	100	66
20°	1 knot	0	33	0	0
30°	1 knot	100	100	100	100
40°	1 knot	0	0	0	0

From these tests it was concluded that an angle of 30° to the horizontal was optimum for herding under these particular conditions. For other nozzle designs and different velocities, a different angle could be optimum. Additional studies would be required on a full scale spray boom to identify the best spray angle for varying velocities, spray flow rates, sorbent sizes, oil type and wind and wave conditions. This was not undertaken because of funding limitations. The spray pattern and spray velocity used during these tests were not prototypical and imparted considerably less energy than that expected to be used in the full scale system. Nevertheless, it did provide a significant mixing action to the foam sections and the collected oil.

Tests were conducted to assess the absorption capacity of polyurethane foam sorbents in a simulated spray sweeping operation. The tests were conducted in the circular flow channel at current velocities of one knot with a spray impingement angle of 30°. The foam specimens were allowed to mix with the oil held against the current for 60 seconds. Specimens were removed and weighed, oil was extracted in the model oil-sorbent separator, and the foam re-weighed. The foam specimens were then recycled in the same manner. Figure 12 presents these data for sorbing a San Joaquin crude oil, 14° API. Similar tests were conducted using a light Canadian crude, 42° API. Figure 13 shows the results of these tests. For these experiments, oil was added to the flow channel to provide an initial slick thickness of 0.8 mm.

As shown in Figures 12 and 13, the spray mixing resulted in total oil sorption of 32 grams of oil/gram of dry sorbent (or lbs/lb) for the San Joaquin crude in the third cycle. For the light Canadian crude this figure was 39 lbs/lb. The data also corroborates the previous conclusion that about 3 cycles would be required to reach reasonable extraction rates (i.e. 20 to 25 lbs of oil/lb of dry sorbent). The first 1 to 2 cycles sorb oil but extraction is low on these cycles. Because the squeeze roller does not extract all the oil, a residual of about 10 to 13 lbs of oil is left in each lb of foam after repeated cycling.

Tests were conducted to determine the sorbed water-oil ratio for polyurethane foam sorbent. In these tests a Santa Maria crude oil (14.7° API) was used. The sorbent and oil were mixed by spray action as in the previous tests. The total liquid extracted from the sorbent was separated into oil and water and weighed (see Figure 14).

These data show that after 3 cycles the liquid extracted from the foam contained about 20 percent water and 80 percent oil. The water content was high (47 percent) on the first cycle. This test indicated that water content would reduce as cycling progressed and that oil-soaked foam tended to sorb less water than dry foam. Additional tests could provide corroboration of these effects and quantify expected water content for different oils sorbed in spray mixing conditions. Such tests were not done because of time and funding limitations.

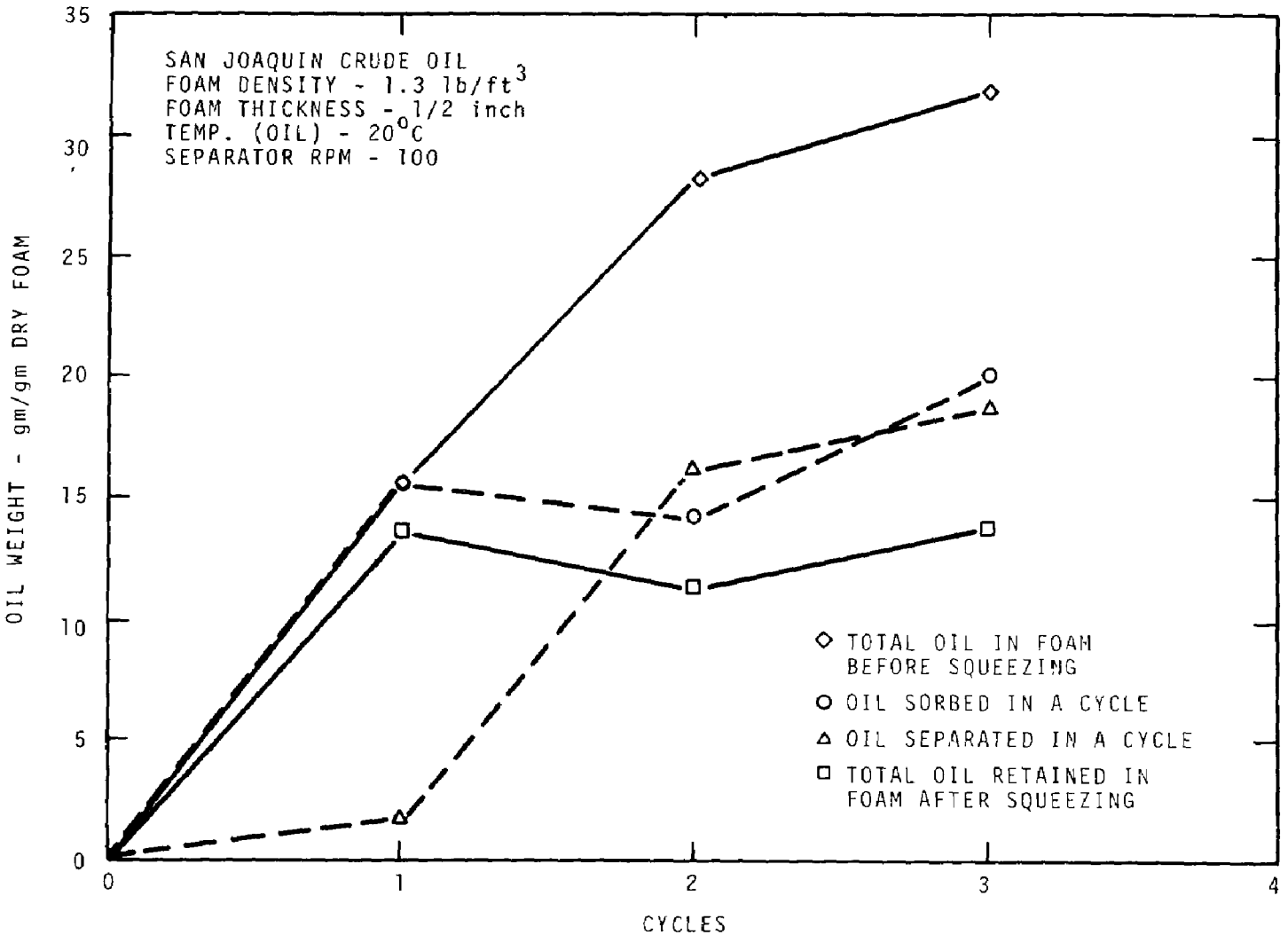

Figure 12

Sorption, Separation and Retention of San Joaquin Crude Oil in Polyurethane Foam Recycled in Model Sorbent-Oil-Separator - Spray Mixing

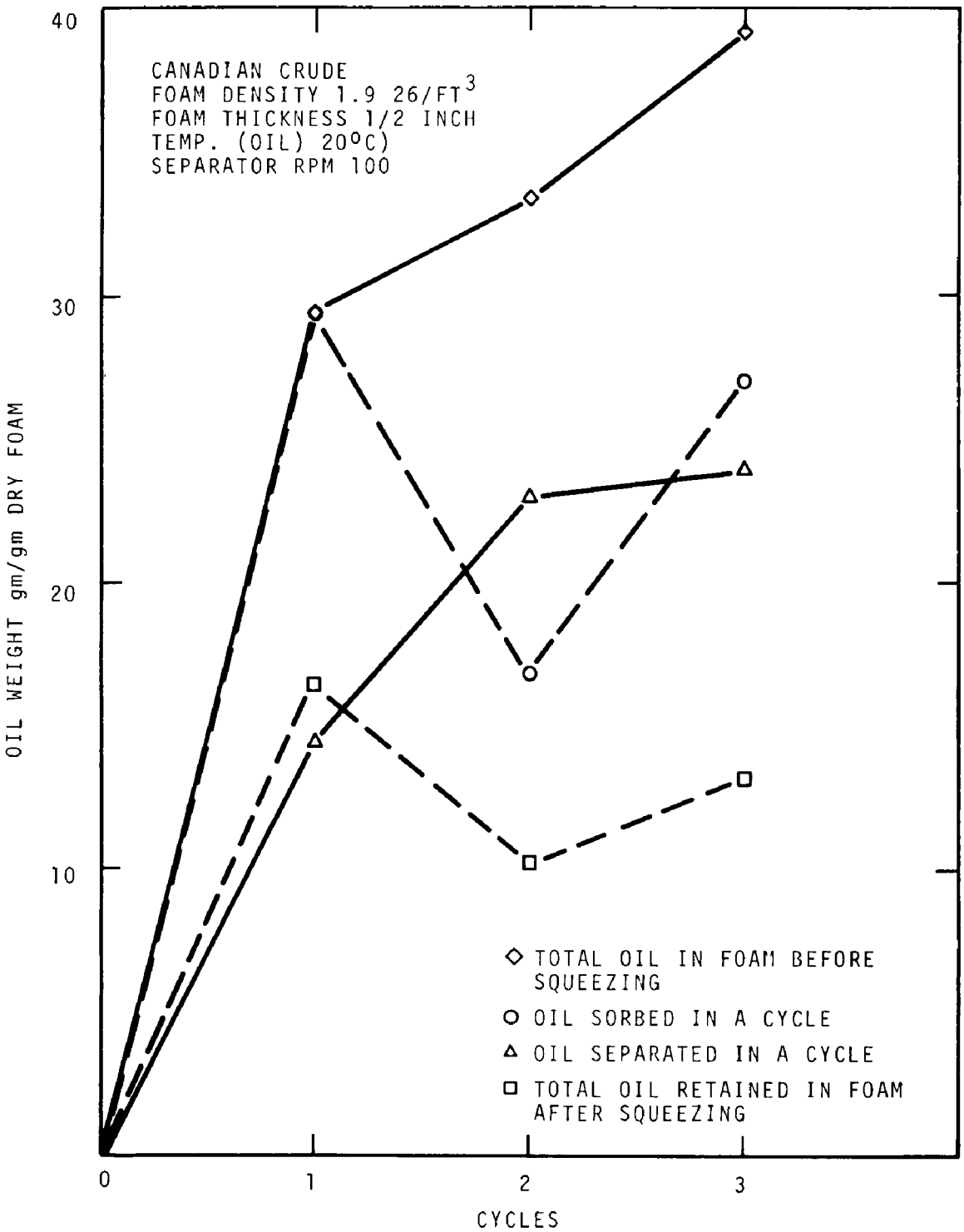

Figure 13

Sorption, Separation and Retention of Light Canadian Crude Oil in Polyurethane Foam Recycled in Model Sorbent-Oil-Separator - Spray Mixing

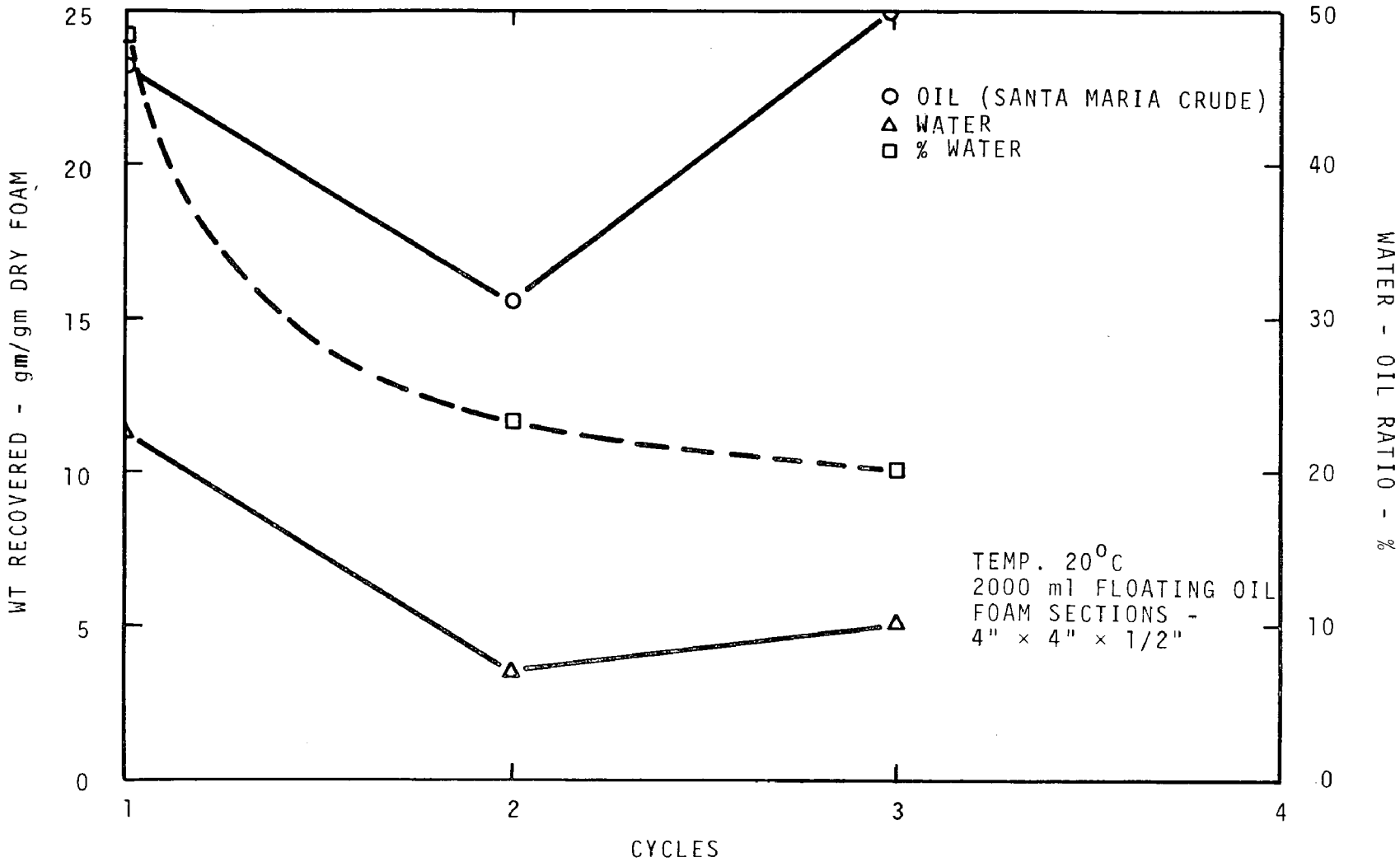

Figure 14

Water-Oil Ratio Obtained in Spray Mixing Tests with Santa Maria Crude Oil - One-Half-Inch-Thick Foam

ONLOADING CONVEYOR EXPERIMENTS

Several items required for the design of the onloading conveyor were unknown for processing oil-soaked sorbent materials. These items were: most effective conveying angle as a function of sorbent geometry, and an effective mesh size for conveying and dewatering functions. Four mesh sizes were evaluated for service as candidate onloading conveyor belting mesh sizes (1/8, 1/4, 1/2 and 3/4 inch).

A series of tests were conducted to determine the most effective angle for conveying oil-soaked sorbent. Two oils were used for these experiments, a heavy asphaltic San Joaquin crude, 14° API, and a light Canadian crude, 42° API. The tests were conducted with current velocities of 1, 1-1/2 and 2 knots, conveying angles of 25, 30 and 45 degrees, and belt speeds of 300 FPM. The test sequence to investigate the effect of the conveyor angle on performance was as follows: 1) the flowing current was adjusted to the desired velocity, 2) a measured amount of oil was added to the water surface, 3) the water spray was turned on to collect and hold the floating oil, 4) foam sorbent particles were broadcast upon the water surface upstream of the point of impingement of the water spray, 5) the particles were allowed to mix with the oil retained by the water spray for 60 seconds, 6) the water spray was shut off allowing the foam particles and oil to flow to the wire mesh screen, and 7) the wire mesh screen was accelerated to conveying velocity immediately prior to impact by the foam particles. It was noted that the foam particles were either accelerated and conveyed on the screen or they tumbled and rolled down the screen.

The first series of tests showed that the conveying of foam sorbents was insensitive to mesh size, i.e. all particles conveyed by the large mesh were equally well conveyed by the smaller meshes. The smaller meshes (1/8 and 1/4 inch) were found to be susceptible to plugging from both the heavier oils and the fines and fibrous floating debris encountered. The half-inch mesh provided a good balance between dewatering features and sorbent conveying capabilities. Figures 15, 16 and 17 show the results of these tests for current velocities of one, one and one-half and two knots, respectively. For processing sorbent material and heavy oils, the conveying capability was unaffected by the conveying angle (up to 45°), the speed of advance or the foam geometry. However, for the lighter oils only the shallower conveying angles (around 25° to 30°) yielded consistent, satisfactory results. Conveyor draining and dewatering tests were conducted for the 1/2 inch mesh screen with both a Santa Maria crude oil, 14.7° API, and a light Canadian crude oil, 42° API. An additional sequence of tests was performed to assess the effect of processing an emulsified oil. For these experiments, the Santa Maria crude oil and sorbent sections were retained and mixed by the water spray nozzle for a period of 20 minutes to produce an oil-water emulsion. The oil and sorbent were removed from the water surface and the drainage measured as a function of time. No attempt was made to assess the amount of water in the emulsion. Table 4 presents the results of these tests.

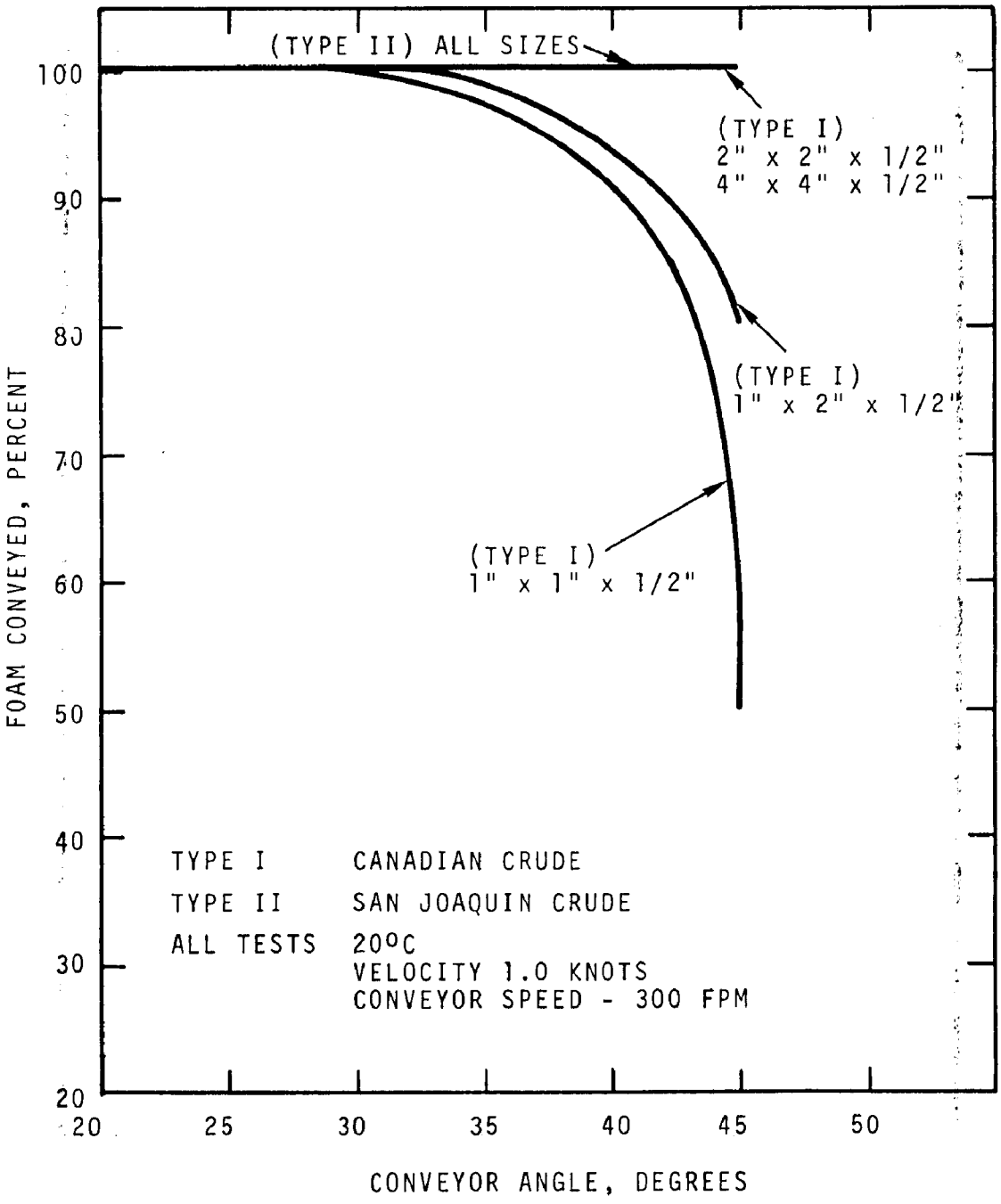

Figure 15

Conveying of Foam on Simulated Conveyor Belt for Canadian and San Joaquin Crude Oils - Velocity 1.0 Knots

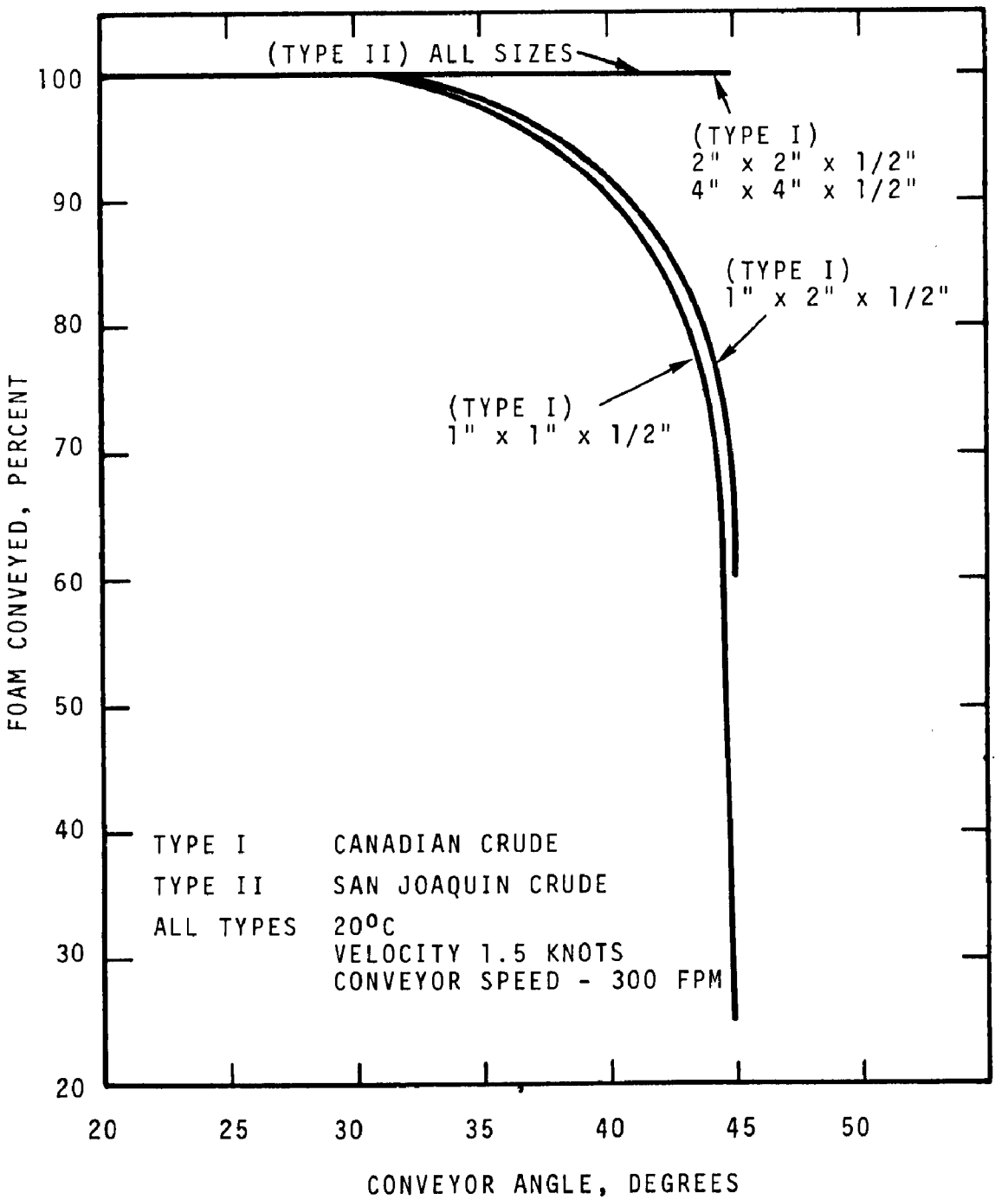

Figure 16

Conveying of Foam on Simulated Conveyor Belt for Canadian and San Joaquin Crude Oils - Velocity 1.5 Knots

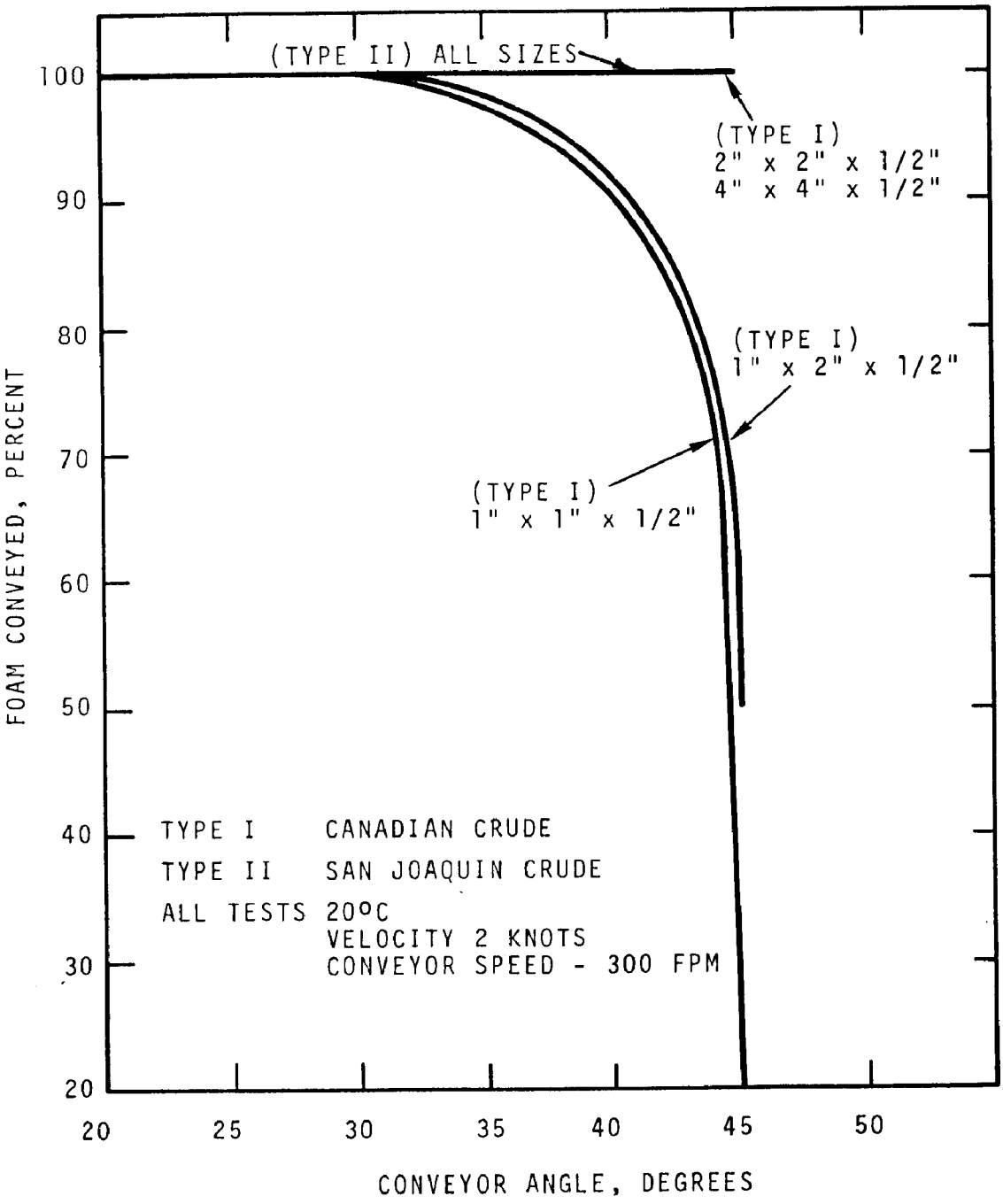

Figure 17

Conveying of Foam on Simulated Conveyor Belt for Canadian and San Joaquin Crude Oils - Velocity 2 Knots

TABLE 4

ONLOADING CONVEYOR DRAINAGE FOR 1/2-INCH MESH SCREEN AS A FUNCTION OF TIME

Liquid Drained GM/GM Dry Foam, Cumulative

Time Sec.	Santa Maria Crude Oil: Fresh Oil: Oil Wt	Santa Maria Crude Oil: Fresh Oil: H_2O Wt	Santa Maria Crude Oil: Emulsified Oil: Oil + H_2O Wt	Canadian Crude Oil: Oil Wt	Canadian Crude Oil: H_2O Wt
5	13.0	0	58.7	0	1.0
10	18.5	0	68.3	0	2.5
15	20.3	0	72.8	0	3.4
20	21.2	0	75.8	0	4.3

NOTES: 1. Temperature 20.5°C
2. Foam sections 4" x 4" x 1/2"

In Figure 18, a graphic comparison of the drainage rate of the fresh and emulsified oils shows that drainage of the emulsified oil is nearly four times greater than the fresh oil. It was concluded that provisions for collecting this drainage oil should be included in the design and that calculations should be based on the rate for emulsified oil which represented the worst case.

With a design belt velocity of 300 FPM, the residence time for a particle of foam or oil in the prototypical onloading conveyor would be 4.8 seconds. This residence time along with the drainage data was used to calculate the potential drainage losses. Based on these calculations, a collection trough was added to the onloading conveyor design in a location that would collect these potential losses while still providing the minimum system drag in the sea.

FOAM SHREDDING EXPERIMENTS - DRY FOAM

A series of experiments were performed to evaluate the effectiveness of the REINCO TM7-30 mulcher-spreader as a media for transferring sorbent material from the squeeze rollers to the water surface ahead of the spray boom. The standard chain flails used in the mulcher-spreader proved to be adequate for shredding continuous strips of foam sorbent material into smaller, more numerous particles for enhancing oil pick up. As a measure of the effectiveness, sheets of foam sorbent material one-inch thick were fed into the mulcher-spreader and the position and surface area of the expelled particles were measured. The location of each particle was determined by direct measurement from the blower discharge duct to the particle. The surface (top surface only) areas were approximated by dividing the surface into a series of triangles and rectangles and summing up the individual contributions. Typical test results for dry foam sorbent material are shown in Figures 19, 20 and 21. The greatest concentration of particles were seen from Figure 19 to lie in the 40 to

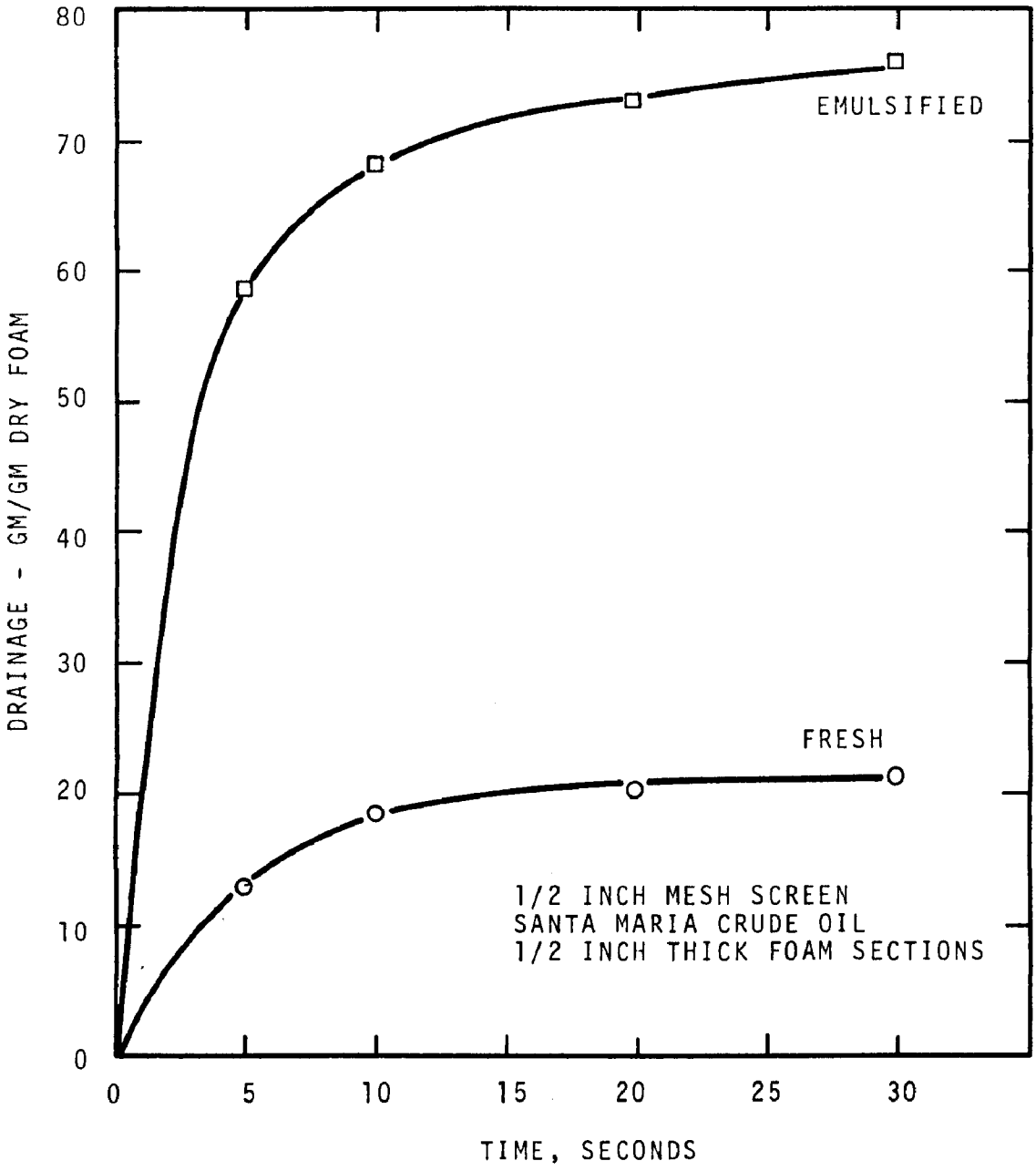

Figure 18

Drainage of Fresh and Emulsified Santa Maria Crude Oil from Polyurethane Foam

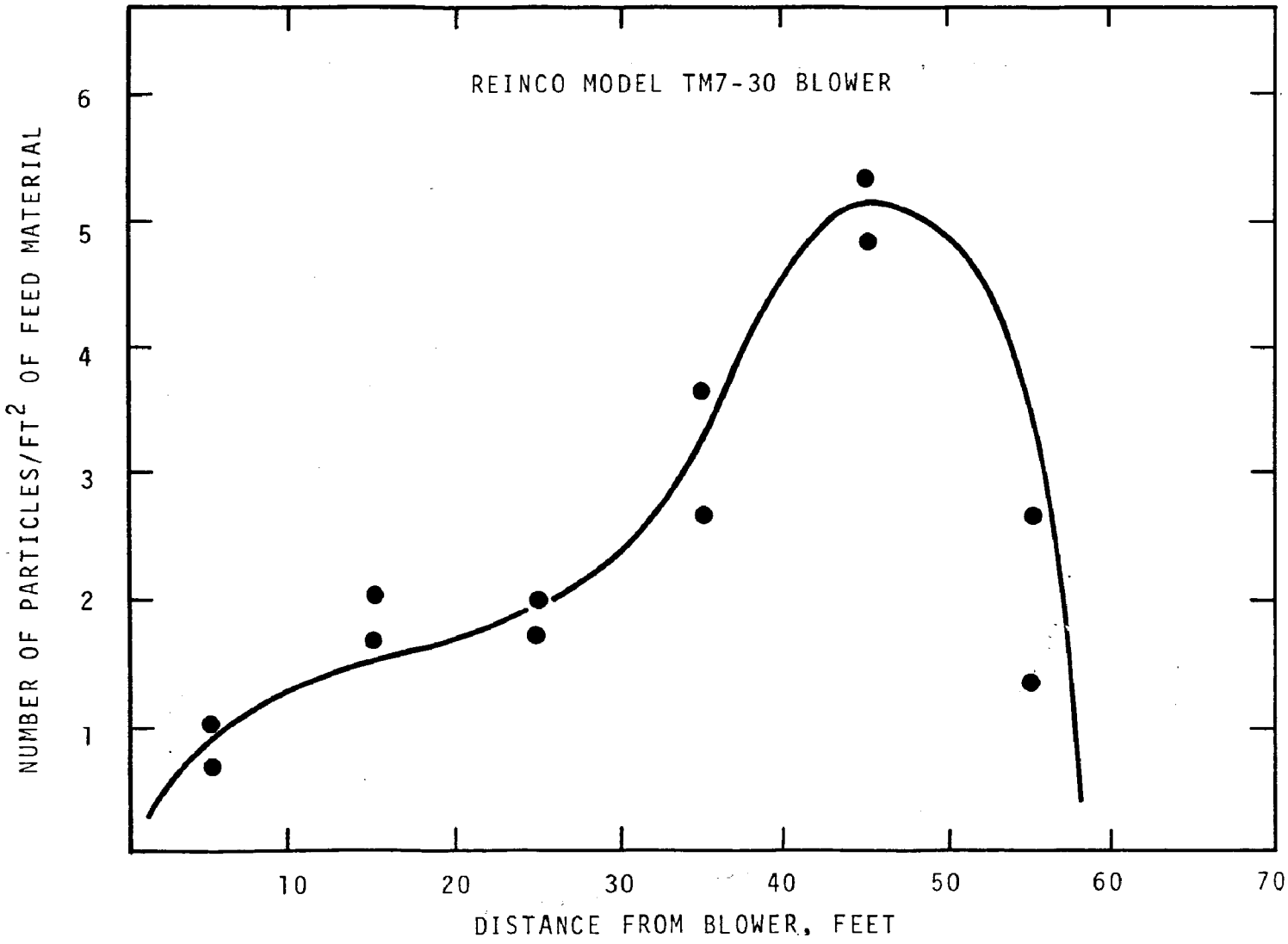

Figure 19

Particle Distribution of One-Inch-Thick Foam in a Single Pass Through the Mulcher-Spreader

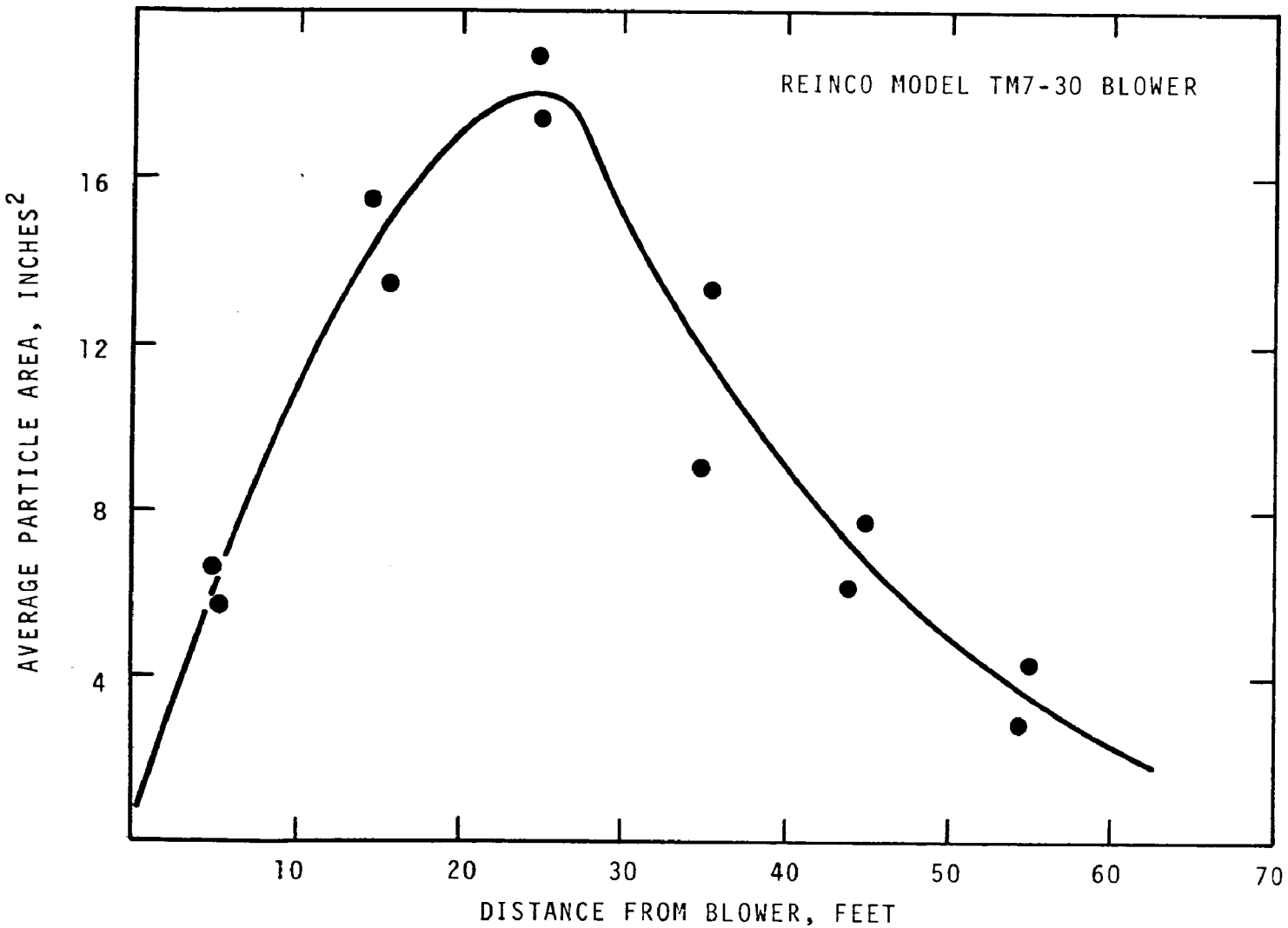

Figure 20

Average Particle Area Distribution from the Mulcher-Spreader - One-Inch-Thick Foam

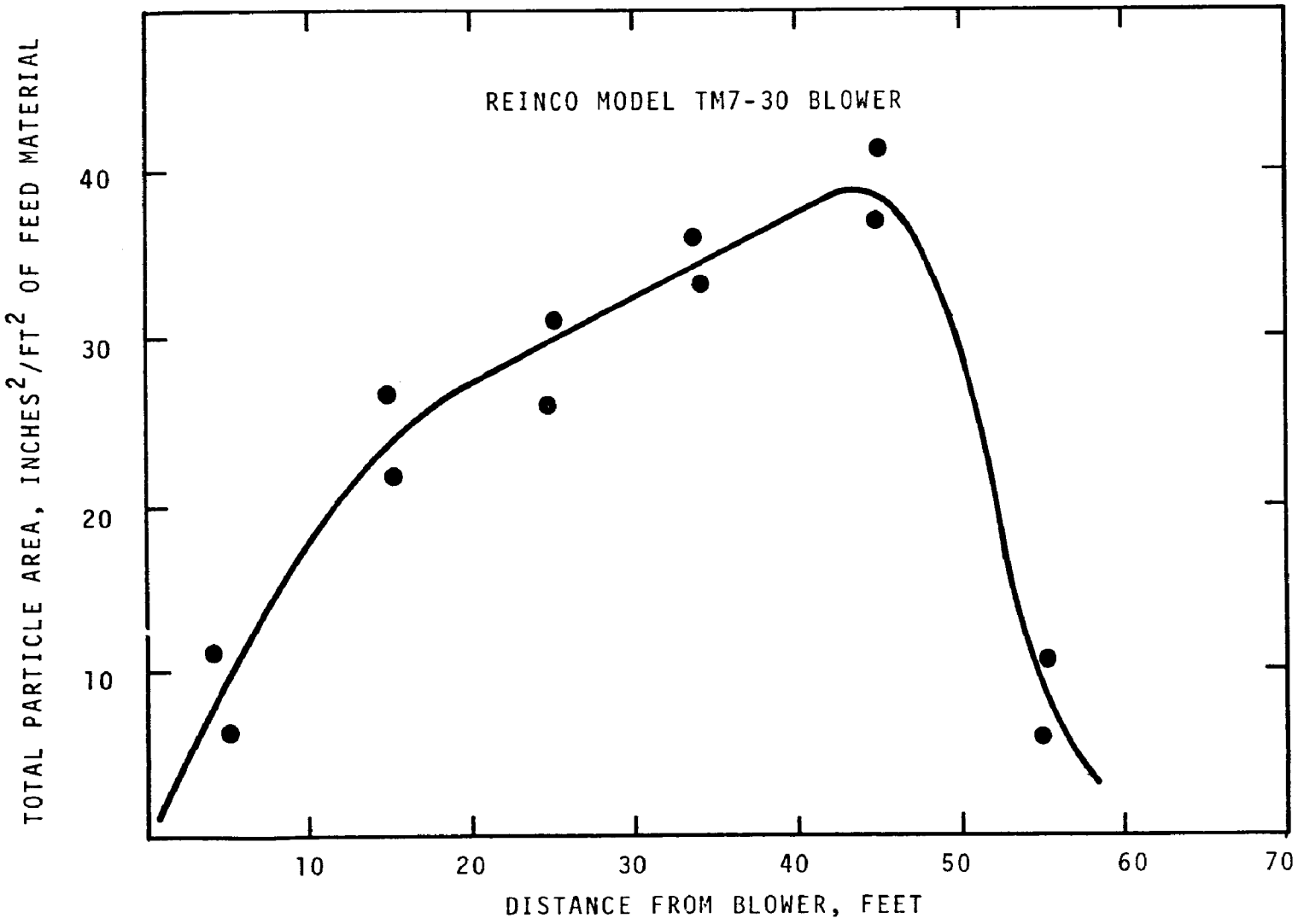

Figure 21

Total Particle Area of One-Inch-Thick Foam from a Single Pass Through the Mulcher-Spreader - Calm Conditions

50 ft range while in Figure 20, the particles with the greatest surface area lie in the 20 to 30 ft region. Although particles with large surface areas were found in 20 to 30 ft regions, the greatest majority of surface area occurred at the 40 to 50 ft location (see Figure 21). These data are consistent with the ideal case of having all of the foam located as far ahead as possible to increase the residence time on the water surface. Similar tests were conducted in light winds (1-3 knots) using one-half-inch-thick foam. Figures 22 and 23 present the results of these experiments.

Additional experiments were conducted with the mulcher-spreader unit to determine the sorbent degradation as a function of repetitive cycling. For these tests, one-half-inch-thick foam sheets were processed through the mulcher-spreader, dry, for one cycle. The material was soaked with a light Canadian crude, then squeezed in the model sorbent-separator to simulate the sorbent conditions after squeezing. This treated sorbent material was then recycled through the mulcher-spreader for 100 cycles. Figure 24 shows the mulcher-spreader and recycling test apparatus. The sorbent material was screened and weighed to determine the particle size distribution after 10, 20, 40, 80 and 100 cycles. Figure 25 presents the results of these tests. A similar experiment was conducted using Bunker C oil. After five cycles the testing was terminated because of excessive degradation of the sorbent material.

Table 5 presents the particle size distribution by percent total volume for this material before and after the five cycles.

TABLE 5

FOAM PARTICLE SIZE DISTRIBUTION - MULCHER-SPREADER CYCLING TEST

Dry Foam at Start of Test		Bunker C-Soaked Foam at 5 Cycles	
Minimum Rectangular* Dimension, Inches	Percent	Minimum Rectangular* Dimension, Inches	Percent
6-7	5.7	< 1/2	47.1
5-6	7.6	1/2-1	35.9
4-5	13.0	1-2	17.0
3-4	19.4		
2-3	26.4		
1-2	18.5		
0-1	8.4		

* Obtained by screening

SORBENT-OIL SEPARATOR

The purpose of the initial testing of the sorbent-oil separator was to evaluate the concept for processing heavy residual oils without the addition of heat and to provide scaling factors for input to the prototypical design. These tests were performed concurrently with the foam sorption

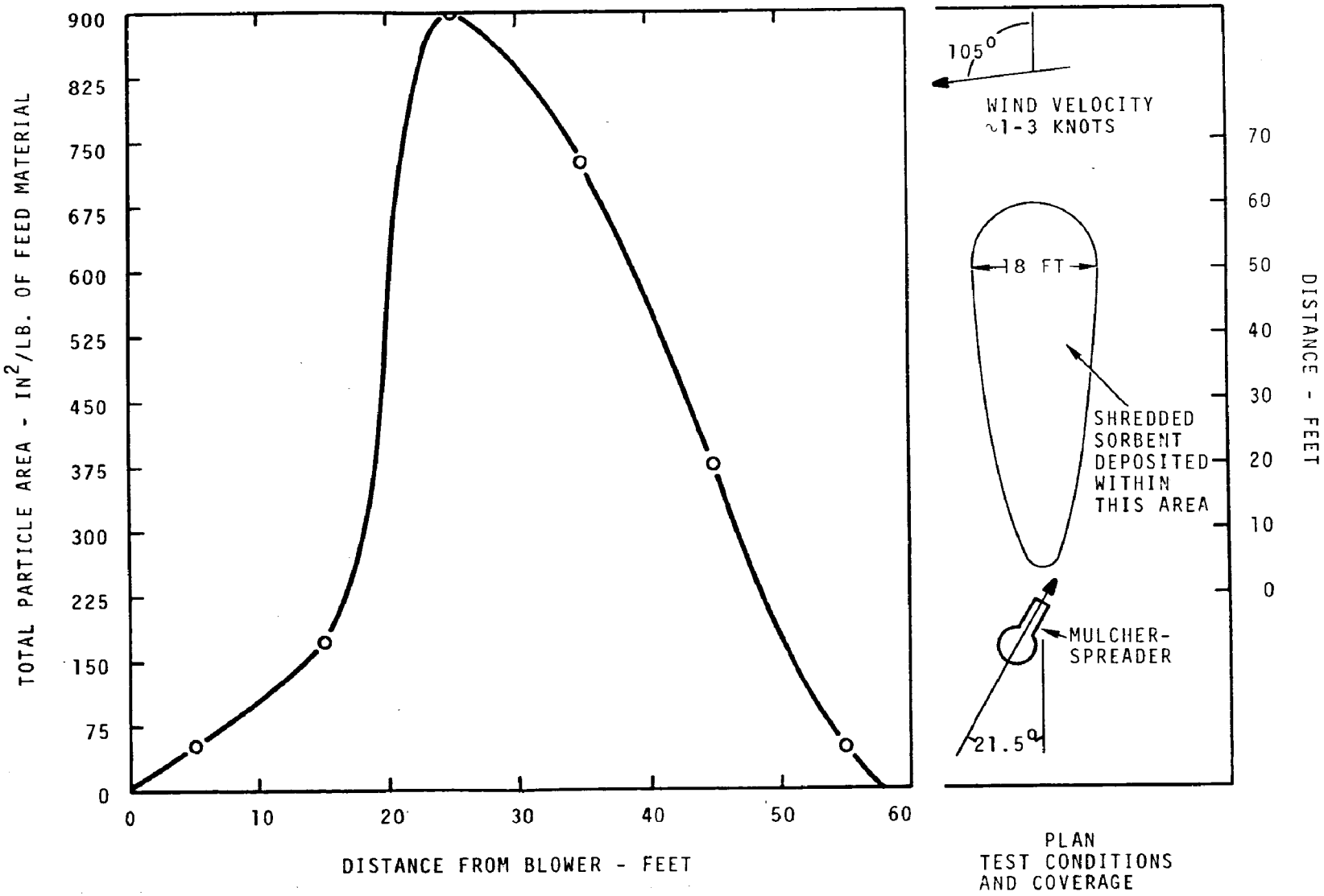

Figure 22

Total Particle Area of One-Half-Inch-Thick Foam from a Single Pass Through the Mulcher-Spreader - Quartering Wind 1 to 3 Knots

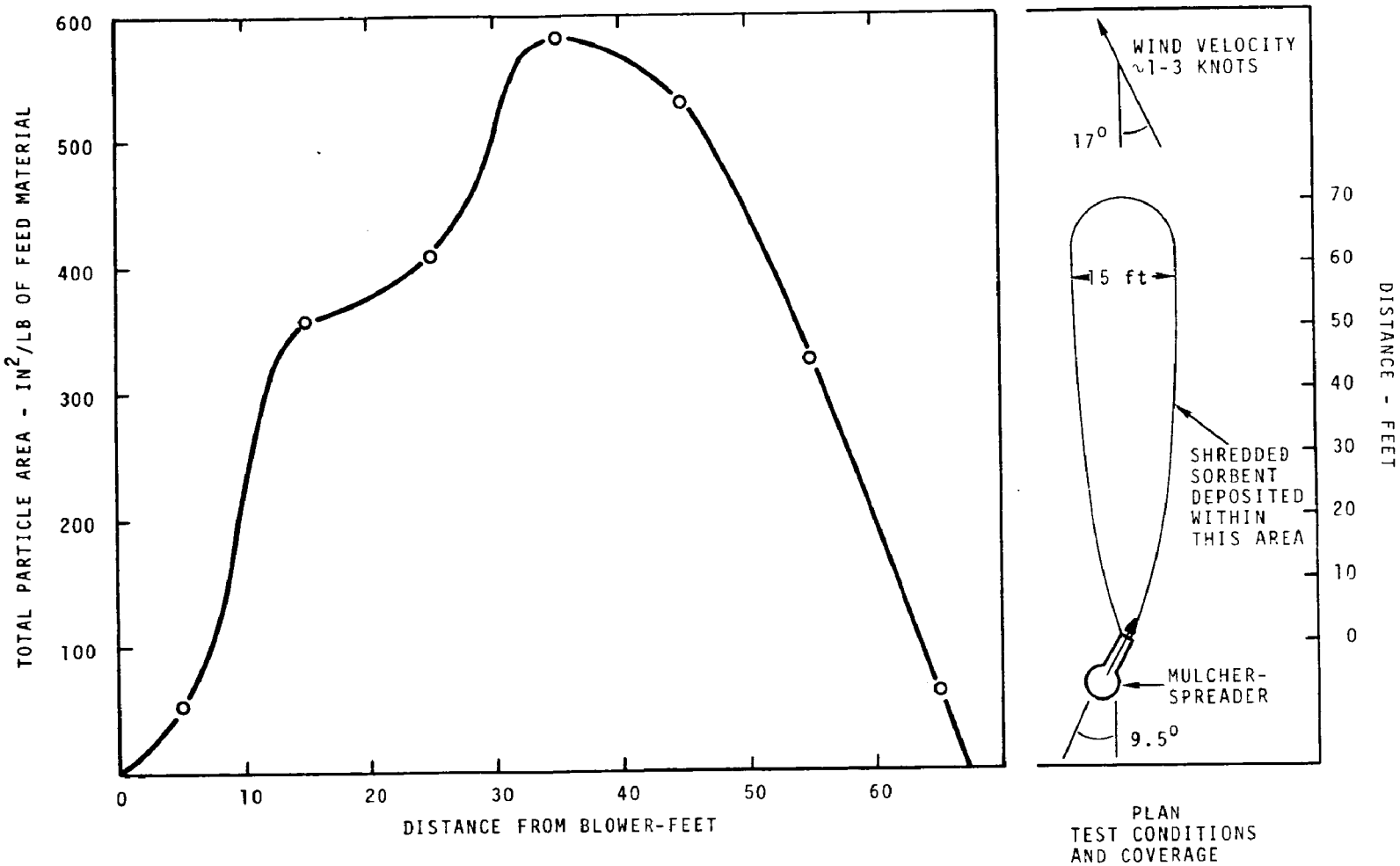

Figure 23

Total Particle Area of One-Half-Inch-Thick Foam from a Single Pass Through the Mulcher-Spreader - Tailwind 1 to 3 Knots

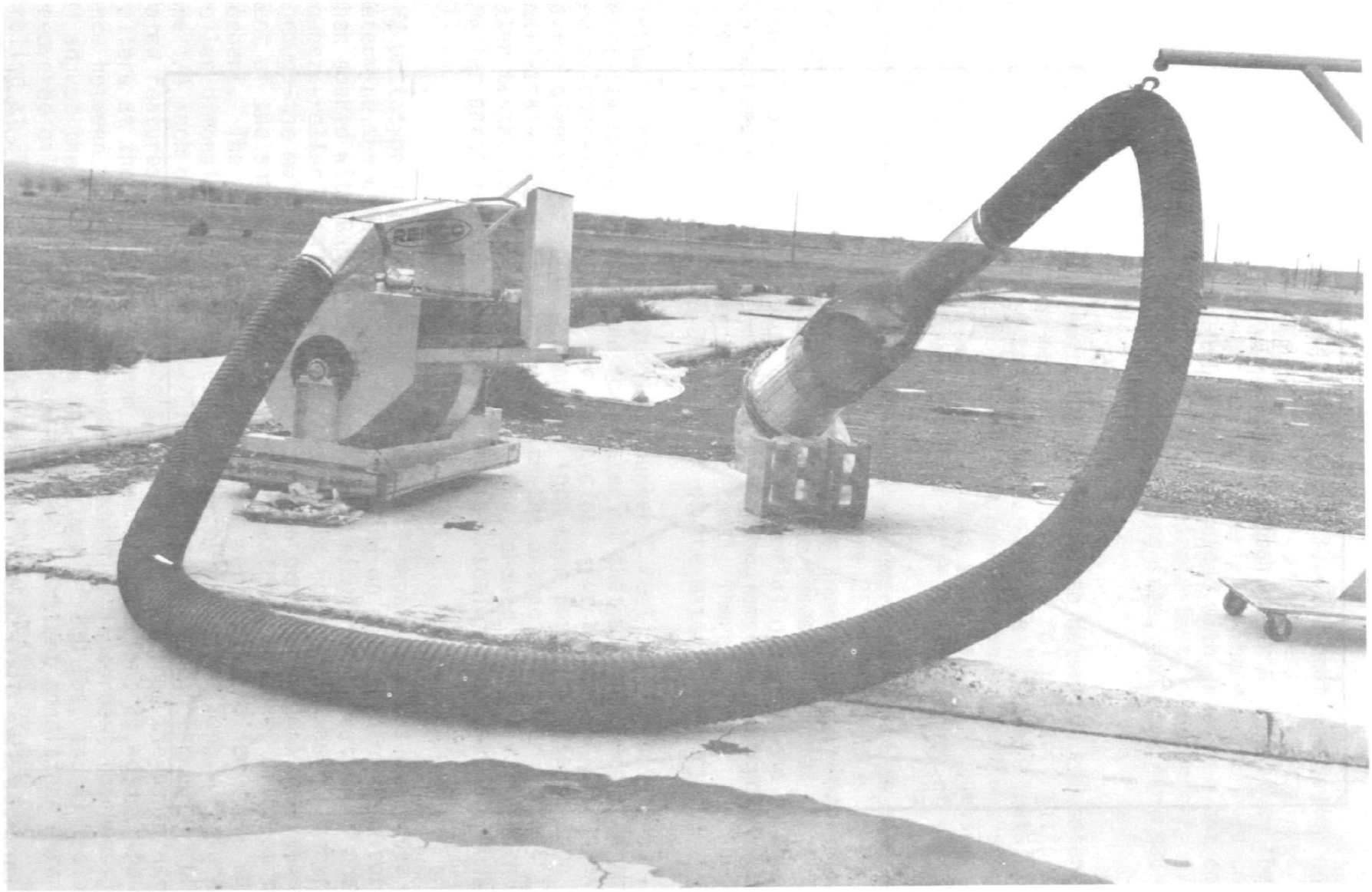

Figure 24

Reinco Model TM7-30 Mulcher and Test Apparatus
for Recycling Oil-Soaked Sorbent

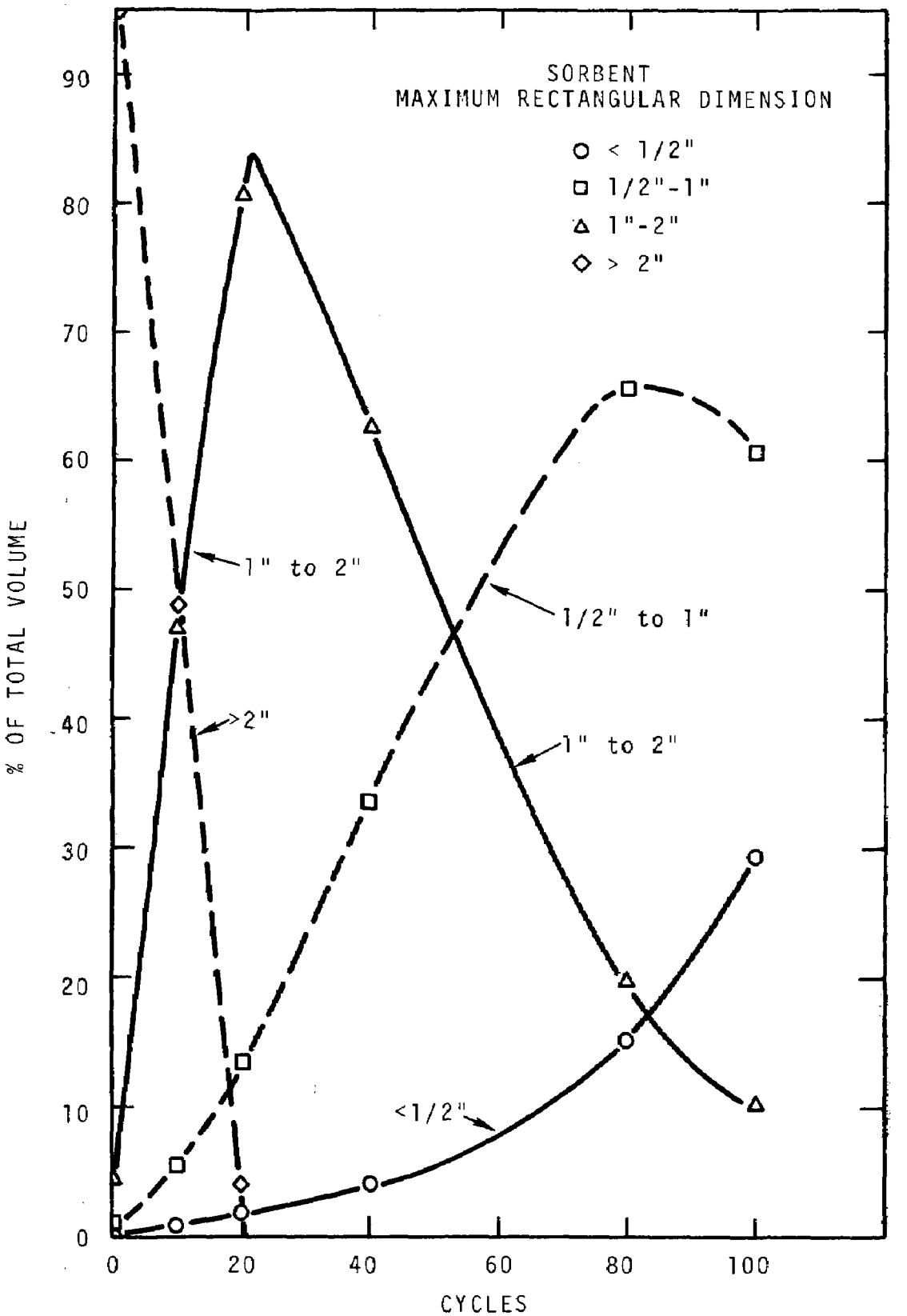

Figure 25

Particle Size Distribution of Light Canadian Crude-Oil-Soaked Sorbent from 0 to 100 Cycles Through the Mulcher-Spreader

and herding experiments. Figures 10 and 11 show that the design goal, separation of ten to one by weight of oil to sorbent, was achieved after the first cycle for one-half-inch-thick foam material and after the fourth cycle for one-inch-thick foam material. These tests were conducted at a roller RPM of 100 which coincided with an equivalent conveyor feed belt speed of 315 FPM. In a separate test, the capacity of the model sorbent-oil separator for processing free, unheated Bunker C oil (no sorbent) was found to be 50 GPM.

An additional series of tests was performed to determine the potential losses of oil-soaked foam material through the roller performations as a function of particle size and oil type. For the light oil tests, the screened material from the 100-cycle mulcher-spreader test was saturated with a Canadian crude oil (42° API). This material was processed through the small scale squeeze roller in separate batches of <1/4" only, 1/4"-1/2" only, 1/2" - 1" only, 1" - 2" only and 2" - 3" only. The material was also processed as an agglomerate (all sizes mixed together in the proportions shown in Figure 25 at 100 cycles). For the separate size batches, the <1/4" particles showed a loss which averaged 1.5 percent per cycle. The losses for the tests with mixed particle sizes also showed losses of the <1/4" material only and the losses were 1.5 percent of the <1/4" material in the agglomerate per cycle. The <1/4" material was 15 percent of the total; therefore, for the agglomerate, the losses were 0.225 percent of the material per cycle.

Similar tests were conducted with Bunker C fuel oil for both a commercially shredded foam and foam material that had been recycled through the mulcher-spreader unit for 100 cycles. For both materials, particles having dimensions of less than 1/2 inch were found to pass through the small-scale roller perforations with the extracted Bunker C fuel oil. Later tests, described in the following, showed that only 3/8 inch and smaller particles passed through the full scale prototype with Bunker C oil.

The prototype squeeze-roller (sorbent-oil separator) was evaluated to determine the effect of repetitive cycling on polyurethane foam sorbent when spaked with Bunker C oil. The test simulated operation of the squeeze-roller with precut or pre-shredded foam which was not recycled through the mulcher. The evaluation also provided a qualitative assessment of the squeeze roller's ability to extract Bunker C oil from the sorbent. The apparatus consisted of two perforated roller drums with roller dimensions of 36 inches diameter by 48 inches long. Perforations are 1/4 inch diameter on a 1/2 inch diagonal matrix. The unit incorporated features to: 1) separate the extracted oil from the perforated rollers at the point of maximum sorbent compression, 2) adjust the clearance between the rollers (amount of reduction in sorbent thickness), 3) adjust the squeezing force to a maximum of 800 lbs, and 4) isolate the recovered oil from the processed sorbent. Ambient conditions were controlled at 20°C. The sorbent material was processed by one pass through the mulcher-spreader to provide typical particle size distribution.

A fixed amount (3 lbs) of sorbent was manually mixed with Bunker C fuel oil at a ratio of 10 lbs of oil to 1 lb of sorbent by weight (minimum system design value). This oil-soaked sorbent was processed through the separator and the oil and sorbent recovered in separate containers. Additional fresh oil was added during the initial cycles until the system oil holdup volume reached an equilibrium (i.e. for each gallon of oil added to the sorbent, one gallon was recovered). Then the recovered oil only was recycled. During the first 20 cycles, the oil recovery ratio under these conditions was 4.6 to 1 by weight, i.e. 4.6 pounds of oil were extracted from each pound of sorbent.

The sorbent, 3/4" thick, was broken into pieces in the 1 to 7 inch size range by one pass through the mulcher-spreader. The squeeze rollers compressed the sorbent to 1/6 its original thickness when processed singly (3/4" thickness) and to 1/5 its thickness when processed in double layers (1-1/2" thick). The test was terminated at 77 cycles because of reduction in quantities of oil recovered per cycle. Foam degradation, both in size reduction and thickness reduction when soaked with oil, caused reduced foam efficiency. Particle distribution during the recycling period was not obtained because the oil-soaked sorbent could not be screened. Particle distribution before starting and after 77 cycles were obtained which are shown in Table 6. To enable screening, the sorbent was washed in Stoddard solvent. The sorbent, which had been reduced to about one quarter its original volume, recovered its original volume when washed with the solvent. The foam was run through the mulcher spreader only one time for this test. Foam degradation in this test was due solely to the squeeze-roller. If the foam had been run through the mulcher each time it was run through the squeeze-roller, the losses would have been much higher.

TABLE 6

FOAM PARTICLE SIZE DISTRIBUTION
SORBENT-OIL SEPARATOR CYCLING TEST

At Start of Test*		At 77 Cycles	
Minimum Rectangular** Dimension, Inches	Percent	Minimum Rectangular** Dimension, Inches	Percent
6-7	5.7	2-3	15.5
5-6	7.6	1-2	54.5
4-5	13.0	1/2-1	24.5
3-4	19.4	3/8-1/2	2.0
2-3	26.4	0-3/8	3.5
1-2	18.5		
0-1	8.4		

* Particle size from one pass of 6' x 15" x 3/4" foam sheets through the mulcher-spreader.

** Obtained by screening.

Qualitative assessments of size distribution at 5, 10, 30, 40, 50, 60 and 70 cycles indicated a gradual decrease in particle size starting at about 20 cycles. Visible tearing and surface damage became apparent at 30 cycles and the foam volume was reduced to one half the original volume. The foam thickness was proportionately reduced. The tearing is attributed to the fact that one roller rotated slightly faster than the other and created a shearing action. The reason for this is that one hydraulic motor apparently had more slip than the other (the drums are independently powered and the motors are in series so each has the same hydraulic oil flow). At 40 cycles the volume was reduced to one-third. At 60 cycles, a decrease in the amount of oil recovered was noted. Approximately one half as much oil could be recovered as compared to the first 50 cycles. At 77 cycles, oil recovery was about 25% of the original, and the squeezed sorbent had reduced to about one-fourth of its original dry volume. The total amount of sorbent lost to the system was 3.5% during the 77 cycles. These losses were 3/8" and smaller particles which were trapped in the recovered oil. No particles larger than 3/8" were found to have passed through the perforations in the rollers. It was concluded that 1/2" and larger particles would be recovered as reusable sorbent under operating conditions similar to those used in the test. It was also concluded that the usable life of sorbent in the squeeze-roller (under conditions of little or no sorbent losses so that the same sorbent pieces were recycled) would be about 60 to 100 cycles. At that time, oil recovery rates would be about 25 percent of the original and the sorbent inventory would have to be replaced if it had not been replaced gradually by addition of foam to make up for losses. Observations and photographs made during the sorbent-oil separator evaluation are contained in the Appendix.

SECTION VI

ACKNOWLEDGMENTS

Design and evaluation of the system and components were performed by a team from Battelle Memorial Institute's Pacific Northwest Laboratories at Richland, Washington. Members of this team were:

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Mr. Lester M. Finch
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Mr. John D. Smith

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SECTION VII

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SECTION VIII

GLOSSARY

Terms used in this report are defined below:

cycle	-	one pass of sorbent through the mulcher-spreader or squeeze-roller, or, for the system, one complete trip by the sorbent through the system
foam	-	as used in this report refers to polyurethane foam used as a sorbent
mulcher-spreader	-	a term used to denote the device used for shredding and broadcasting polyurethane foam sorbent
mulching	-	applied to the polyurethane foam, this term describes tearing or shredding large sheets into smaller pieces
open cell	-	applied to foam to denote that all or nearly all the cells are connected as in an open lattice arrangement
ppi	-	pores per lineal inch; applies to polyurethane foam
sorbent	-	a material which sorbs oil or other liquids by absorption or adsorption
squeeze-roller	-	the sorbent-oil separator employing perforated squeeze rolls

SECTION IX

APPENDIX

APPENDIX A - Observations and Photographs on Sorbent-Oil Separator Cycling Test

APPENDIX B - Vessels of Opportunity - Atlantic Coast

APPENDIX A

OBSERVATIONS AND PHOTOGRAPHS ON SORBENT-OIL SEPARATOR CYCLING TEST

Cycle	Remarks
5	A few pieces < 3/8 in^3 attached to inner surfaces of separator. Representative sample of 20 pieces - one piece 5" x 6", one 5" x 5", two 3" x 6", one 3" x 4", six 4" x 2", five 3" x 2", two 2" x 1", two 1" x 1" (no surface damage to all 20 pieces).
10	A slight increase in number of pieces < 3/8 in^3 attached to inner surfaces of separator. Representative sample of 20 pieces - two 5" x 6", one 5" x 5", one 4" x 6", one 3" x 6", six 2" x 3", four 2" x 1", five 1" x 1". Larger pieces had some tears one-half through thickness.
20	Continued slight increase in number of pieces < 3/8 in^3 attached to inner surfaces of separator. Representative sample of 20 pieces - 2 large pieces - 3" x 4", 3" x 5" Some tears one-half through thickness probably due to shearing of the two surfaces. Irregular spacing from 1/4" apart to 1-1/2" apart. About 1/2" to 2" long. Material thickness diminished slightly. 8 medium size pieces - 2" x 2", 2" x 4", 2" x 5" Larger pieces are not as damaged as smaller ones. Some deep tears 2/3 through thickness close to edges of surfaces. Irregular edges on some pieces appear to be more easily torn. 10 small pieces - 1" x 1", 1" x 2" Surface damage is not severe although these pieces may have been formed due to reduction of medium size pieces. This size may be stable from damage because of the more uniform thickness in all directions. Material is more likely to roll instead of shearing when squeezed.
30	Representative sample of 20 pieces: 2 large pieces - 3" x 3" and 3" x 5" Some tears one-half through thickness probably due to shearing of the two surfaces. Irregular spacing from 1/4"

Cycle	Remarks
30 (cont'd)	apart to 1-1/2" apart. About 1/2" to 2" long. Material thickness diminished slightly.
	7 medium size pieces - 2" x 4", 1-1/2" x 5", 2" x 2"
	Larger pieces are not as damaged as smaller ones. Some deep tears 2/3 through thickness close to edges of surfaces. Irregular edges on some pieces appear to be more easily torn.
	11 small pieces - 1" x 1", 1" x 2"
	Surface damage is not severe although these pieces may have been formed due to reduction of medium size pieces. This size may be stable from damage because of the more uniform thickness in all directions. Material is more likely to roll instead of shearing when squeezed.
40	2 large pieces - 3" x 5", 3" x 3"
	Some surface tearing 1/3 to 1/2 thickness deep, 1/4" to 1-1/2" long. Some deeper tears near edges. Pieces are somewhat irregular.
	3 medium size pieces - 3" x 2", 3" x 3"
	Surface tears as above with some deeper tears near the edges. One piece has a hole torn in the middle and deep tears on the periphery. It is amazing that it hasn't torn apart in this condition. Generally equal sided pieces with no irregularities.
	15 smaller pieces - 2" x 2", 1" x 1", 3/4" x 3/4"
	The larger of the small pieces have varying conditions. Some have deep (1/2 to 2/3) tears, some do not. Some are irregular with edge tears and some are equal sided (1/2 each way). The smaller pieces are a little smaller than from 30 cycles with some pieces being torn and some appearing quite good and stable from more damage. One piece 1/2" x 1/2" x 1/2" (irregular) was found having not been squeezed through the roller and lost. This is encouraging to find that the apparent loss is for pieces smaller than 1/2" sides.
	Some accumulation (probably small) is found inside the oil area of the squeezer having been lost. They appear to be small, 1/4" and less.

Cycle	Remarks
50	1 large piece, 3" x 4" Some surface cracks to half way through generally covering the piece, generally parallel and averaging 1/4" apart. Some good areas on surface. Two deep 2/3 to through material are located next to long end where shearing of the piece is evident. 2 medium size pieces - 2" x 2" One piece is triangular with some surface tearing, mostly at the edges 1/3 to 1/2 through. The other piece has some surface tears 1/3 through but has a 1-1/2" x 1/2" open hole in the middle where a piece was torn clear. 17 smaller pieces - 1-1/2" x 2-1/2", 1" x 1", 1" x 1-1/2", 1" x 1/2" The larger of the small pieces are generally rectangular with the appearance that they may have been sheared from an end of a larger piece. Deep tears are noted lengthwise although by being narrow they may now be stable. Some of the smaller pieces are regular and in good shape at about 1" x 1" x 1". Others (50% of small ones) are irregular having come from tears in larger pieces. Pieces are getting smaller in general and the surfaces are more degraded (much 1/2 to 2/3 thru tears) compared to 30 or 40 cycles. Effectiveness does not seem to be diminished and small pieces in the oil stream are more evident now than at 20 cycles.
60	1 large piece - 2-1/2" x 4" Much surface tears 1/3 to 1/2 through on 1/4" spacing over most of area. Some 2/3 through tears on edges. Dimensional thickness approximately 30% of initial due to compression of foam. 2 medium sized pieces - 1-1/2" x 3" Much surface tearing of foam, especially near edges. It may begin scaling off the flat surfaces due to the shearing. Some surface holes are becoming evident. 17 small pieces One piece is severely torn in several places along its length and is folded and twisted. Much surface tearing is

Cycle	Remarks
60 (cont'd)	evident on all surfaces. Other of the larger ones (1-1/2" x 1") have tears of all sorts, some deep, 1/2 to 2/3 through. Several 1" x 1" x 1" pieces are present and look reasonably good. Also several small pieces (1/2" x 1/2" x 1/2" up to 3/4" cubes) are present, having been torn from the larger pieces. They were not extruded into the oil discharge however. The smallest pieces seen to go through okay are on the order of 1/4" cubes.
	Effectiveness was much reduced from the first 50 cycles down to about 1/2 as much oil squeezed from the sorbent. The sorbent appeared to hold more oil through the squeezing process. This may possibly be because of compression of the foam, a minimum contact thickness for the rollers and from surface scaling of the foam.
77	No large pieces.
	3 medium sized pieces - 2" x 2", 1-1/2" x 1-1/2"
	Deep cuts (tears) in surfaces 1/2 to 2/3 through. Two pieces are regular shapes, a third has a long deeply cut appendage attached which has not been completely severed. Cuts in all surfaces show voids where small pieces have been removed, 1/4" and less.
	17 small pieces - 1" x 1", 1" x 1-1/2", 1/2" x 1/2", 1/8" x 1/8" x 1/8"
	The larger of these particles are regular in shape with a few deep cuts and surface tears. Some having hanging appendages which would eventually break down to 1" cubes. Surface tears are not as prevalent as in large particles. The smaller particles (less than 3/4" cubes) vary in size down to very small particles, 1/8" cubes. These are regular and numerous. It is surprising that these were not carried with the oil. They must have been carried in a matrix with larger particles as they are squeezed.

The series of separation tests was discontinued after 77 cycles. The general performance of the system had diminished to a point where only 25% of the original volume of oil extracted per cycle was being separated from the foam. This was due to the problem of processing matted clumps of sorbent and oil mentioned earlier which was further compounded by the increased volume of small sized particles. The bulk volume of sorbent and oil had been reduced to 30-40% of its original value due to matting and packing which would indicate a change in the resiliency of the sorbent material.

To prepare for cleaning, the front cover plate was removed from the separator apparatus at which time it was discovered that 25% of the total volume of sorbent material was inside the unit. Closer examination revealed that the bearing mount for one end of one of the two rotary brushes had shifted its position. The brushes were used to insure that the sorbent material would be separated from the perforated roller and fall into the transport duct. This action provided a free passage for the sorbent between the brush and the perforated roller and was responsible for the buildup of sorbent in the apparatus and some of the apparent loss in batch volume. Of all the material collected from within the unit, 10% had dimension less than 1/2 in^3 and the remaining 90% was 1/2 and one inch cubes. In order to get an accurate assessment of the particle size distribution of the sorbent used in this series of tests, the Bunker C fuel was removed from the sorbent material by washing in a solvent solution. As a result of the solvent washing and subsequent drying, the polyurethane sorbent material returned to its original volumetric proportions. The particle size distribution of the foam sorbent after 77 cycles of oil sorbing and squeeze extraction is presented below.

> 2"	-	15.5%
2"-1"	-	54.5%
1"-1/2"	-	24.5%
1/2"-1/4"	-	2.06%
< 1/4"	-	3.44%

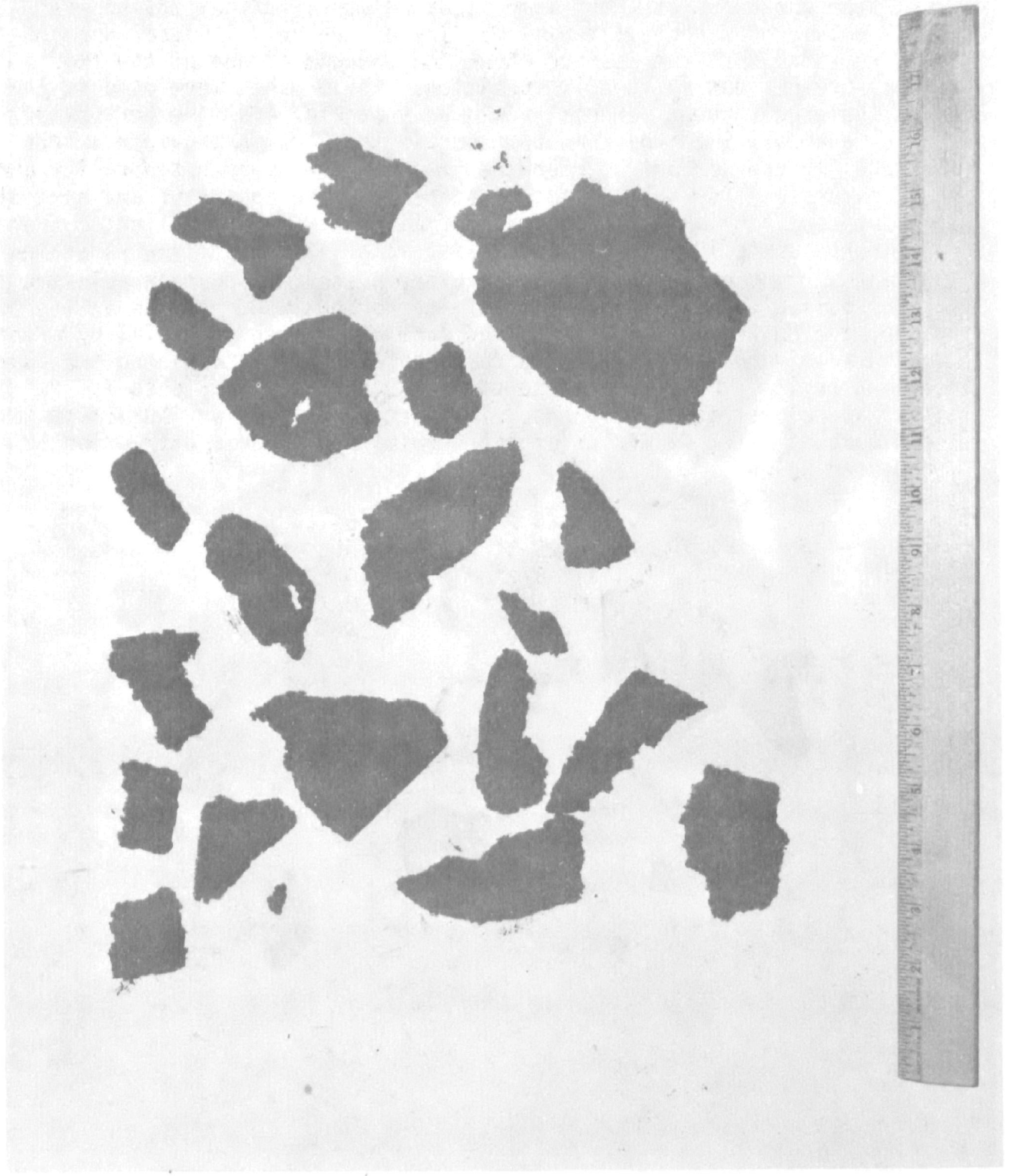

Figure A-1

Appearance of Foam After 50 Cycles Through Squeeze-Roller Processing Bunker C Oil

Figure A-2

Appearance of Foam After 60 Cycles Through Squeeze-Roller Processing Bunker C Oil

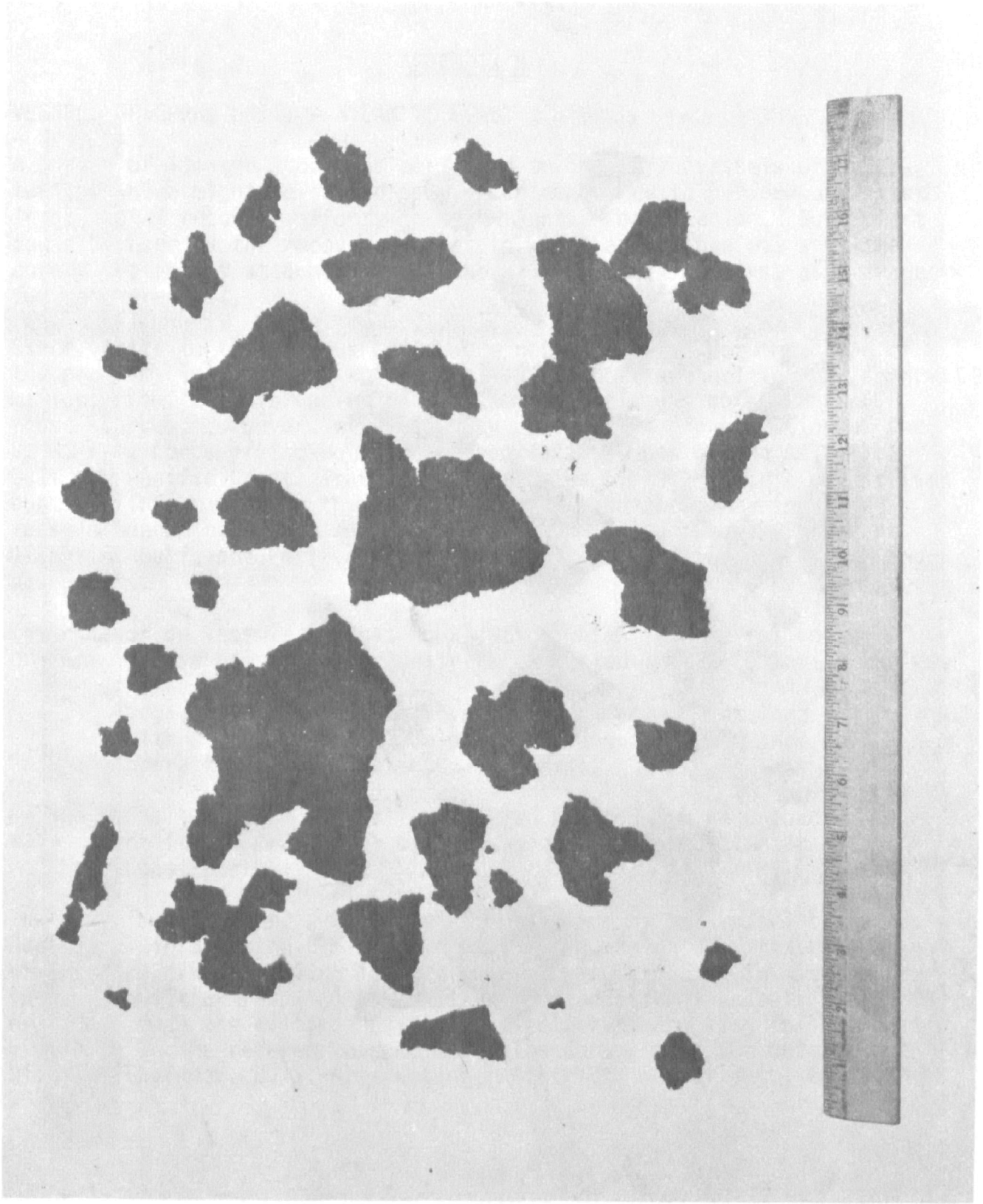

Figure A-3

Appearance of Foam After 70 Cycles Through Squeeze-Roller Processing Bunker C Oil

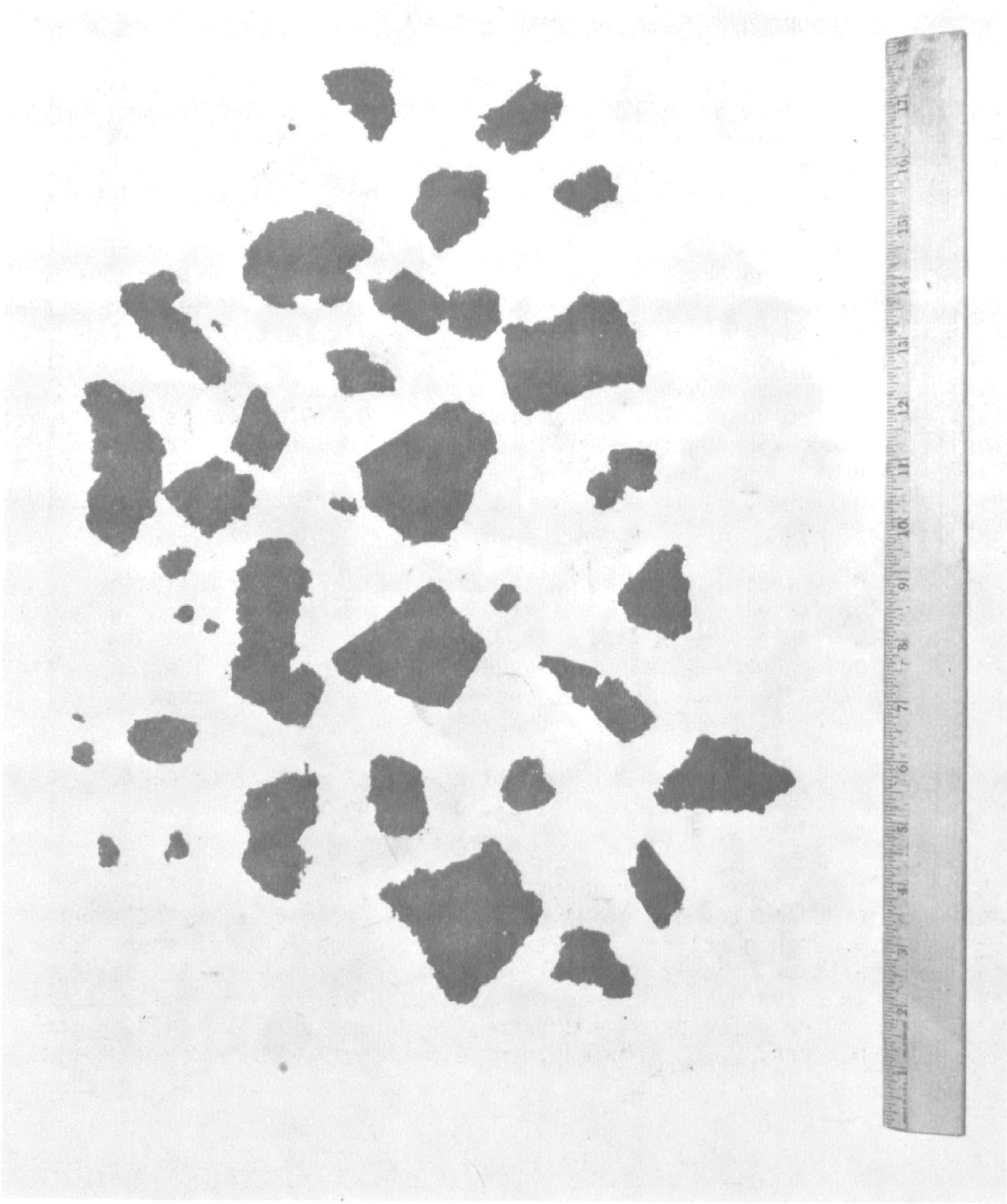

Figure A-4

Appearance of Foam After 77 Cycles Through
Squeeze-Roller Processing Bunker C Oil

APPENDIX B

VESSELS OF OPPORTUNITY - ATLANTIC COAST

A survey of limited scope was performed to identify "vessels of opportunity" which might be called upon in an emergency to perform or assist in oil spill recovery efforts in the Atlantic Coast region. Such craft could be used as the recovery vessel to which a portable oil spill recovery system was attached or, in the case of small tankers, as storage for recovered oil.

Since visits to the various ports were not possible under the scope of the program, letters were written to several port authorities for information. Limited information on available vessels was obtained from these sources. However, one authority recommended a publication of the U. S. Army Corps of Engineers, "Transportation Lines on the Atlantic, Gulf and Pacific Coast, Transportation Series 5, 1970". This publication contains information on the vessel operators and their American flag vessels operating or available for operation on 1 January 1970 on the Atlantic, Gulf, and Pacific coasts in the transportation of freight and passengers.

Information on vessels in that publication which fit the following criteria for vessels of opportunity is extracted in the following tables.

- Tugs, towboats and motor vessels 65 ft to 150 ft long with a minimum draft (unloaded) of about 12 feet and operating from Atlantic Coast ports.

- Small tankers and self-propelled barges with an unloaded draft of about 12 ft or less, operating from Atlantic Coast ports.

The vessels are listed in alphabetical sequence by the vessel operator. Additional information on these vessels, (e.g. heights of fixed superstructures, cargo handling facilities, carrying capacity in short tons and year built or rebuilt) and a listing of additional vessels smaller or larger than the criteria used for selection of the list following is available in the referenced document. The document is for sale by the District Engineer, U. S. Army Engineer District, New Orleans, Louisiana 70160.

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Ainsley Transportation Corp.	Convoy	Towboat, diesel steel	63	74.0	20.0	9.6	400	Norfolk, VA
American Dredging Co.	Arthur N. Herron	Towboat, steel	81	93.5	23.2	11.0	1000	Philadelphia, PA
	Frank H. Caven	do	85	83.4	22.5	10.5	1400	do
	Lone Star	do	78	88.5	25.0	11.2	900	do
	Nathan Hayward	do	84	83.8	20.2	10.0	1000	do
Anderton Marine Transportation Co.	Marylander	Motor vessel, diesel, steel, welded	202	151.5	23.3	6.0	450	Salisbury, MD
	Virginian	Motor vessel, diesel, steel, welded and riveted	256	146.1	23.0	8.0	320	do
Atlantic Richfield Co.	Atlantic 5	Tug, diesel, steel, welded,	77	96.3	25.2	11.4	1000	Philadelphia, PA
	Atlantic 7	do	76	96.3	25.2	11.4	1000	do
Backus, Howard, Towing, Inc.	Atlas	Tug, diesel, steel	66	65.0	19.0	8.0	650	Miami, FL

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Baker-Whiteley Towing Co., The	6 tugs, diesel, steel, welded, from 79.0 to 96.9 ft long by 20.0 to 27.2 ft wide, min. draft, 9.0 to 12.2 ft, HP 700 to 1800, operating from Baltimore, MD							
Baltimore Gas and Electric Co.	GE 2	Tug, diesel, steel, welded and riveted	79	79.0	20.0	9.8	500	Baltimore, MD
	GE 3	Tug, diesel, steel, welded	81	79.5	20.1	9.0	600	do
Baltimore & Ohio Railroad Co.	Howard E. Simpson	Towboat, diesel steel, welded	161	104.2	26.1	11.0	1600	New York, NY
	Roy B. White	do	161	104.2	26.1	11.0	1600	do
	William C. Baker	do	161	104.2	26.1	11.0	1600	do
	Lehigh	Towboat, diesel, steel	169	87.5	25.7	10.0	960	Baltimore, MD
Bang, Valdemar	Hourless	Motor, gasoline, wood	15	80.0	16.0	5.0	230	Boston, MA
Banks, Charles T., Towing Line	Grace Ann	Towboat, iron	62	79.2	18.0	10.0	400	Philadelphia, PA
	Phyllis	do	83	88.7	19.0	10.2	450	do
	Rabco	do	63	75.0	17.0	8.0	320	do
Barge Vegoil No. 6 Corp.	Vegco	Tug, steel	92	81.0	23.0	5.0	720	New York, NY
Bath Canning Co.	Helen McColl	Motor, diesel, wood	17	65.7	16.5	6.6	200	Bath, ME

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Bay Ridge Water & Lighterage Co., Inc.	Aqua	Lighter, steam, steel	191	99.3	35.4	10.0	350	New York, NY
Bay Towing Corp.	Bay Queen	Towboat, diesel, steel	46	68.3	20.1	10.0	400	Norfolk, VA
	Bay King	Towboat, diesel, iron	26	66.6	16.0	8.0	600	do
Belcher Towing Co.	I.E. Schilling	Tug, diesel, steel, welded	90	66.7	24.0	6.0	1020	Miami, FL
	W.C. Smith	do	121	84.5	28.0	10.8	2000	do
	Admiral Leffler	Tug, diesel, steel	102	86.4	23.0	8.0	1500	do
	Edwin N. Belcher	do	130	84.5	28.0	10.6	2000	do
Berg Boat Co.	Queen Bee	Pusher tow-boat, steel, welded	90	68.9	23.8	8.0	1450	Wilmington, DE
Berg Towing Co.	Matton 20	Tug, diesel, steel, welded	58	67.8	20.0	8.5	400	Wilmington, DE
	Tina	Tug, diesel, steel	45	68.1	20.2	7.0	450	do
Bernstein & Jacobson, Inc.	P.M. Arnold	Tug, steel, riveted	75	80.2	20.0	12.0	690	Portland, ME
	William Cramp	Tug, iron, welded and riveted	43	69.0	17.5	9.0	400	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Brooklyn Eastern District Terminal	Integrity	Tug, diesel-electric, steel	159	102.6	26.1	9.8	1000	New York, NY
	Intrepid	do	159	102.7	26.1	10.1	800	do
Brown, Thomas J., & Sons, Inc.	Cecilia J. Brown	Tug, diesel, steel, welded	99	81.1	24.0	9.0	700	West Brighton, NY
Bush Terminal Railroad Co.	Irving T. Bush	Towboat, diesel, steel	187	98.6	26.0	10.3	1200	New York, NY
Cape Fear Towing Co.	Carl Blades	Towboat, diesel, steel, welded	36	71.8	19.4	10.0	240	Wilmington, NC
	Comet	Towboat, diesel, iron, welded	64	95.6	20.5	10.0	1050	do
	Meteor	do	47	94.5	18.6	8.0	690	do
	Shamrock	do	86	93.6	22.0	10.0	1800	do
Carteret Towing Co.	A. T. Piner	Towboat, diesel, steel, welded	62	78.0	20.0	8.0	575	Morehead City, NC
	Suwannee	do	69	67.5	19.6	8.0	650	do
Central Railroad of N.J.	Sandy Hook	Towboat, diesel, steel	158	104.2	25.5	9.0	1600	New York, NY
	Sound Shore	do	158	104.2	25.5	9.0	1600	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Central Wharf Towboat Co., Inc.	E.F. Moran Jr.	Tug, diesel, steel, welded	140	95.0	26.0	11.0	1750	Portland, ME
	Susan A. Moran	do	140	95.0	26.0	11.0	1750	do
	Edmond J. Moran	Tug, diesel-electric, welded	143	115.5	29.5	12.0	1900	do
	Richard J. Moran	Tug, diesel, wood	119	97.8	25.3	11.2	1200	do
	Thomas E. Moran	Tug, diesel-electric, steel, riveted	139	103.0	26.1	12.0	1200	do
Central Wharf Towboat Co., Inc. (Portsmouth Navigation Div.)	Bath	Tug, diesel, wood and iron, riveted	133	89.0	25.1	11.9	1600	Portsmouth, NH
	New Castle	Tug, diesel, steel, welded	132	93.1	25.1	12.6	1200	do
	Pegasus	Tug, steam, steel, riveted	145	100.1	24.1	12.9	850	do
Chesapeake Corp. of Virginia	Carl O.	Towboat, steel, welded	70	85.6	20.0	8.0	700	West Point, VA
	Ellis O.	do	107	85.6	20.0	8.0	650	do
	Chesapeake	Towboat, iron barge, steel	52	75.2	18.0	7.7	450	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Colonial Sand & Stone Co., Inc.	9 towboats, diesel, steel, from 74.0 to 89.4 ft wide by 20.0 to 28.1 ft wide, min. draft 7.2 to 9.6 ft, HP 400 to 1200 operating from New York, NY							
Coppedge, J. H., & Co.	BETJI	Tug, diesel steel, welded	76	66.1	22.0	7.5	920	Jacksonville, FL
Curtis Bay Towing Co.	Cove Point	Tug, diesel, steel, welded	65	75.9	23.0	10.0	1080	Baltimore, MD
	F. F. Clain	do	146	82.0	24.0	9.0	750	do
	Hawkins Point	do	161	100.0	27.0	12.0	1750	do
	Thomas Point	do	69	100.0	25.1	11.5	1200	do
Curtis Bay Towing Co. of Pennsylvania	Eagle Point	Tug, diesel, steel, riveted	69	100.2	25.1	11.3	1200	Philadelphia, PA
	North Point	do	131	93.6	25.0	10.5	1000	do
	Sewells Point	do	143	100.2	25.1	11.3	1200	do
	Quaker	Towboat, steel	80	77.8	20.5	10.0	615	do
Curtis Bay Towing Co. of Virginia	5 tugs, diesel, steel from 91.8 to 115.0 ft long by 23.6 to 27.1 ft long, min. draft 10.0 to 12.0, HP 1000 to 1750, operating from Norfolk, VA							
Davis, R. K., Transportation Co.	Deborah	Towboat, steel	45	74.0	20.0	7.5	400	Newport News, VA
	Kirth	do	57	81.4	18.2	9.0	480	do
	Ray	do	45	74.0	20.0	7.5	400	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Chesapeake & Ohio Railway Co., The	M.I. Dunn	Towboat, diesel, steel, welded	158	104.2	26.1	11.0	1600	Newport News, VA
	J. Speed Gray	Towboat, oil screw, steel	158	104.2	26.1	11.0	1600	do
	R. J. Bowman	do	114	102.4	28.1	14.5	800	do
	Walter J. Tuohy	Towboat, diesel, steel	158	104.2	26.1	11.0	1600	do
Chrisnick Towing Corp.	Chrisnick	Towboat, steel	99	81.1	24.0	9.8	700	New York, NY
	Ferry Point	Tug, diesel, steel	99	81.1	24.0	9.8	700	do
	Nancy Hinson	do	38	74.0	18.9	7.5	400	do
Coastal Petroleum Transport Co.	Alan Martin	Tanker, steel	287	160.0	25.0	6.0	140	New York, NY
	Jane Frank	do	158	96.0	26.0	6.0	240	do
	Sam Berman	do	382	160.3	30.0	10.8	375	do
	Jonathan B	Tug, diesel, steel	99	72.0	21.0	9.0	450	do
Coastline Towing	Castle Hill	Tug, diesel, steel, riveted	155	80.4	23.0	9.6	1700	Fall River, MA

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Delmarva Oil Transportation Co., Inc.	Hay-De	Tug, diesel, iron, riveted	81	82.0	19.5	12.2	440	Salisburg, MD
Eastern Maine Towage Co., Inc.	Candace A. Holmes	Towboat, diesel, steel	112	97.2	23.6	11.0	1200	Belfast, ME
	Evelyn M. Holmes	Towboat, diesel, wood	156	92.5	23.5	11.0	1200	do
	Pauline H. Holmes	do	78	69.6	2-.1	10.0	600	do
	Clyde B. Holmes	Towboat, steam, steel	177	112.5	25.6	11.0	1000	do
Eastern Marine Equipment, Inc.	Birgit Ann	Towboat, diesel, steel	41	68.9	20.1	8.6	400	Newport News, VA
	Monica Renee	do	36	75.3	19.0	8.0	512	do
Eklof Marine Corp.	Plus 5 steel tankers from 134.0 to 252.9 ft long by 26.0 to 40.1 ft wide, min. draft 4.0 to 9.0 HP 240 to 1200, operating from Staten Island, NY							
Empire Petroleum Co.	Luzitania	Tanker, diesel, steel, welded	206	115.3	26.0	6.5	280	Elizabethport, NJ
Erie Lackawanna Railway Co.	10 steel tugs or towboats from 94.8 to 98.3 ft long by 25.5 to 26.0 ft wide, min. draft 11.4 to 12.0 ft, HP 1000 to 1350, operating from New York Harbor, NY							
Esterhill Boat Service	Rendezvous	Motor vessel, wood	94	101.9	19.4	6.0	450	Boston, MA

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Eubank, A.R.	Eugenia	Motor, wood	84	90.0	24.0	5.0	250	Lewisetta, VA
Evans, C. Calvert	Sarah C. Conway	Diesel, wood	64	77.4	23.5	7.0	340	Vienna, MD
Fesmire, James M., and Son	Jim Jac	Tanker, diesel, steel, riveted, compartmented	180	120.5	23.6	4.6	265	Baltimore, MD
Florida Towing Corp.	5 steel towboats, diesel, from 72.5 to 79.9 ft long by 19.1 to 21.4 ft wide, min. draft 8.0 to 12.0 ft, HP 450 to 1600, operating from Jacksonville, FL							
Forster Towing & Trans. Co., Inc.	Atlas	Tug, steel	59	92.3	20.6	9.2	575	New York, NY
	H.A. Meldrum	do	61	85.0	21.6	10.5	400	do
	Samson	do	93	83.5	21.0	9.0	450	do
Gallagher Bros. Sand & Gravel Corp.	John Murray	Towboat, steel	84	90.6	20.2	9.8	805	New York, NY
	Peter C. Gallagher	Tug, steel	104	97.2	21.0	10.9	1200	do
General Marine Transport Corp.	Richard K	Tug, diesel, steel	99	72.0	21.0	9.0	450	New York Harbor, NY
	Susan Frank	Tanker, steel	813	249.3	43.6	6.0	1300	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Gillen's, Henry, Sons Lighterage, Inc.	Chippewa II	Towboat, diesel, steel	57	69.9	19.3	8.6	525	New York, NY
	Gillen Brothers	do	164	98.6	28.0	9.6	2250	do
	Lester J. Gillen	do	98	84.7	24.0	8.8	1200	do
Globe Transport Co.	J. T. O'Connell	Towboat, steel	77	95.2	24.1	10.6	1000	Providence, RI
	Pilot	do	82	83.8	20.2	8.0	450	do
Cowanus Towing Co., Inc.	Cowanus	Tug, diesel	99	81.1	24.0	9.8	700	New York, NY
	Taurus	do	99	82.0	24.0	7.9	700	do
Guardino & Sons, Inc.	Progress 9	Shell barge	302	126.3	24.7	5.0	420	New York, NY
Gulf Atlantic Towing Corp.	Gatco Delaware	Tug, diesel, steel, welded	41	68.9	20.1	8.0	400	Norfolk, VA
	L.M. Winslow	do	82	80.4	23.0	9.6	575	do
	Sharon Lee	do	74	88.9	26.0	7.0	1000	do
Gulf Oil Corp.	Paratex	Tanker, diesel	1360	286.5	43.0	3.0	1200	New York, NY
	Regent	do	708	247.0	40.0	3.0	850	do
	Yacona	do	612	212.5	37.0	3.0	814	do
	Girard Point	Tug	98	79.0	23.0	9.5	650	Girard Point, PA

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Haldeman Towing Co.	Evelyn	Towboat, oil screw, steel	55	90.6	23.5	11.0	900	Hampton, VA
Harbor Towing Corp.	12 diesel tugs 69.0 to 105.3 ft long by 16.0 to 28.1 ft wide, min. draft 7.0 to 12.3 ft, HP 320 to 1950, operating from Baltimore, MD							
Harper, Charles H., & Associates, Inc.	A.J. Harper	Tug, diesel, steel, welded	62	75.5	20.1	9.0	560	Baltimore, MD
	Charles H. Harper	do	103	91.6	22.2	9.0	805	do
	Hamilton	do	65	78.0	24.0	11.0	1200	do
Hays Tug & Launch Service	Prince	Tug, steel	76	81.0	21.0	9.0	600	Marcus Hook, PA
	Princess	do	61	78.0	21.0	9.0	600	do
Hercules Co., The	Chief	Motor, diesel, steel, riveted	229	123.3	28.4	8.0	325	Baltimore, MD
Hudgins, M. Lee, Associates, Inc.	Aubrey L. Hudgins	Tanker, steel	65	90.9	18.1	6.0	160	Norfolk, VA
	Haven Belle	do	106	118.1	23.2	6.0	210	do
	Rosalyn B. Hudgins	do	171	132.6	23.0	6.5	330	do
	Rebecca	Towboat, wood	24	58.5	15.4	7.5	240	do
Hudgins, W.C.	Valencia	Tanker, steel	71	88.6	20.1	5.0	120	Mobjack, VA

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Humble Oil & Refining Co., Marine Dept.	6 diesel tugs, steel, 94.0 to 146.1 ft long by 25.2 to 31.5 ft wide, min. draft 7.2 to 11.0 ft, HP 450 to 1200, operating from New York, NY (3), Baltimore, MD (1), Norfolk, VA (1) and Paulsboro, NJ (1).							
Hunt, W.P., Co.	Elizabeth Hunt	Tug, diesel, steel	79	83.0	22.0	8.0	700	Norfolk, VA
I.B.C. Co.	Pamlico	Towboat, diesel steel, welded	189	100.0	34.0	7.5	1900	Pamlico River, NC
	Roanoke	do	189	100.0	34.0	7.5	2400	do
Independent Towing Co.	6 diesel towboats from 80.6 to 104.6 ft long by 19.0 to 24.6 ft wide, min. draft 8.5 to 10.0 ft, HP 1080 to 1700, operating from Philadelphia, PA							
International Paper Co. (So. Kraft Div.)	SK 6	Towboat, diesel, steel, welded	43	75.0	19.0	8.0	400	Georgetown, SC
	SK 8	do	64	69.0	20.1	7.5	600	do
	SK 9	do	69	73.5	21.7	8.0	600	do
	SK 7	Pusher towboat, diesel, steel, welded	47	70.0	20.0	5.5	430	do
Interstate Oil Transport Co.	10 diesel tugs 79.7 to 99.0 ft long by 21.1 to 30.2 ft wide, min. draft 3.5 to 11.3 ft, HP 700 to 3300, operating from Philadelphia, PA							
J & A Tug Corp.	Carmen A	Tug, diesel, steel	95	89.3	23.6	10.0	925	New York, NY
	Joseph Panzera	Tanker, diesel steel	55	64.8	18.3	7.0	134	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Jordan, Frank L.	Jerome Clark	Tanker, steel	64	64.6	20.9	5.6	120	Hampton, VA
Kehoe Bros. Transportion Co., Inc.	5 towboats from 69.5 to 76.7 ft long by 19.3 to 21.0 ft wide, min. draft 8.0 to 9.0, HP 450 to 575, operating from New York, NY and Brooklyn, NY							
Lehigh Marine Disposal Corp.	Baltic	Tugboat, steel	54	72.0	17.3	8.7	400	New York, NY
Lehigh Valley R. R. Co.	Bethlehem	Towboat, diesel-electric, steel, welded	161	96.0	26.0	11.0	1350	Jersey City, NJ
	Cornell	do	161	96.0	26.0	11.0	1350	do
	Lehigh	do	161	96.0	26.0	11.0	1350	do
Levon Properties Corp.	Sea Traveler	Tug, diesel, steel	62	70.0	22.0	7.0	765	Jamesport, NY
Lewis Transportation Corp.	Lewis 8	Towboat, steel	99	81.8	24.0	8.0	700	Port Washington, NY
Manhattan Oil Transportation Corp.	Michael Tracy	Tug	65	82.2	25.0	11.0	900	New York, NY
Marine Contracting & Towing Co.	5 diesel towboats from 85.3 to 95.7 ft long by 19.0 to 21.6 ft wide, min. draft 8.0 to 11.5, HP 350 to 1800, operating from Charleston, SC							
Marine Movements, Inc.	Evelyn	Tug, diesel, steel	99	81.1	24.0	9.8	700	New York, NY

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
McAllister Brothers, Inc.	5 diesel, steel tugs or towboats from 91 to 130 ft long, 21.0 to 27.0 ft wide, min. draft 8.5 to 11.2, HP from 1000 to 1200, operating from Philadelphia, PA							
	18 diesel, steel tugs or towboats from 78 to 104 ft long, 20 to 27 ft wide, min. draft of 8 to 12 ft, HP from 880 to 1800, operating from New York Harbor, NY							
	5 steel diesel towboats from 80.2 to 104.2 ft long by 21.1 to 26.1 ft wide, min. draft from 9.0 to 11.0 ft, HP from 450 to 1600 operating from Norfolk, VA							
McKie Lighter Co.	Wm. R. Farrell	Towboat, steel	17	76.0	18.0	7.5	235	Boston, MA
McLoon, A.C., and Co.	A.C. McLoon	Motor, wood	33	76.4	17.0	6.8	220	Rockland, ME
	William McLoon	Tanker, steel	81	72.0	20.5	7.0	270	do
Mobil Oil Corp.	Mobil Service	Tanker, steel	46	89.7	21.0	4.5	560	New York, NY
	Mobil Trader	do	790	210.0	35.0	6.0	932	do
	Plus 5 diesel, steel, towboats from 80.3 to 96.7 ft long by 24.0 to 26.0 ft wide, min. draft 8.3 to 10.0 ft, HP 1200 to 1600, operating from New York, NY							
Montauk Oil Transportation Co., Inc.	Girard Point	Tug, steel	98	80.0	23.0	9.5	1200	New York, NY
Moran Towing & Transportation Co., Inc.	15 tugs, diesel, steel welded from 81.1 to 101.8 ft long by 22.1 to 28.0 ft wide, min. draft 7.9 to 12.0 ft, HP from 700 to 3165 operating from New York, NY							

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Morania Oil Tanker Corp.	Morania Abaco	Tanker, steel	1011	264.0	47.0	5.0	2000	New York, NY
	Morania Marlin	do	619	217.6	43.1	7.5	2000	do
	Morania 300	do	2042	296.5	43.2	6.0	1700	do
	Plus 8 tugs, diesel, steel, from 80.8 to 88.5 ft long by 23.1 to 27.1 ft wide, min. draft 8.0 to 12.0 ft, HP 700 to 1800, operating from New York, NY							
New Bern Shipyard, Inc.	Alfred S	Towboat, diesel, steel	26	68.6	14.5	7.6	220	New Bern, NC
New York, City of (Dept. of Water Resources)	5 steel tankers, diesel, from 249.3 to 304.6 ft long by 43.6 to 49.6 ft wide, min. draft 9.0 to 11.0 ft, HP 1300 to 3000, operating from New York, NY							
New York Dock Railway	Brooklyn	Towboat, steel	171	98.4	26.2	12.1	1200	Brooklyn, NY
New York, State of, D.O.T.	Governor Cleveland	Towboat, steam, steel	49	74.1	19.6	9.0	250	Albany, NY
Norfolk, Baltimore & Carlina Line, Inc.	Carolina	Towboat, steel	94	90.9	20.6	8.6	900	Norfolk, VA
	Edward F. Farrington	Motor, steel	295	123.6	30.1	7.6	400	do
	Maryland	Towboat, diesel, steel	83	96.2	22.0	8.6	450	do
	Russel Hogshire	Towboat, diesel steel	42	68.4	18.8	7.5	510	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Norfolk Towing & Lighterage, Inc.	Carl D. Colonna	Towboat, oil screw, iron	79	86.4	19.5	9.5	800	Norfolk, VA
	Evelyn Colonna	Towboat, steel	33	75.5	19.0	8.6	350	do
Penn Central Co.	11 steel towboats from 74.0 to 98.4 ft long by 19.0 to 26.3 ft wide, min. draft 9.7 to 12.0 ft, HP 250 to 1200, operating from Jersey City, NJ							
Patterson Lighterage & Towing Corp.	Atlantic	Towboat, wood	121	98.6	27.2	8.4	550	New York, NY
	Bon	do	46	77.1	19.3	7.9	450	do
	Blairstown	Towboat, steam steel	263	123.9	35.9	10.0	950	do
	Victor	do	220	115.0	32.0	8.0	550	do
	Mary J. Pontin	Lighter, diesel, steel	166	96.5	30.0	11.0	900	do
Plymouth Towing Co.	Roper	Towboat, diesel, steel, welded	63	73.0	19.0	8.0	400	Plymouth, NC
Poling Transportation Corp.	June C	Tug, steel	114	81.3	28.1	10.7	2110	New York, NY
	Phoenix	do	82	95.0	25.0	10.6	1200	do
	Plus 11 steel tankers from 121.0 to 289.0 ft long by 27.0 to 40.0 ft wide, min. draft 6.7 to 10.5 ft, HP 300 to 2160, operating from New York, NY							

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Potomac Sand & Gravel Co.	M.V. Keystone	Pusher towboat, steel, welded	206	101.1	26.6	6.5	1050	Washington, D.C.
Providence Steam-boat Co.	Gaspee	Towboat, diesel, steel, welded	136	94.0	24.1	12.3	1800	Providence, RI
	King Philip	do	125	95.0	25.9	9.0	1600	do
	Maurania II	do	123	94.1	25.1	9.0	1200	do
	Roger Williams	do	133	95.0	27.0	10.0	1800	do
Reading Co.	Shamokin	Towboat, diesel, steel, welded	166	104.2	26.1	11.0	1600	Port Reading, NJ
	Tamaqua	do	166	104.2	26.1	11.0	1600	do
	Brandywine	Towboat, diesel, steel, welded	115	87.5	25.0	10.0	960	Wilmington, DE
	Delaware	do	115	87.5	25.0	10.0	960	Phildelphia, PA
	Schuykill	do	115	87.5	25.0	10.0	960	do
Red Circle Towing Corp.	Thomas F. Drew	Tug, diesel, steel, welded	65	75.9	23.0	10.8	900	New York, NY
Red Star Towing Co.	Devon	Tug, steel	121	94.0	25.0	11.2	1600	New Haven, CT
	New Haven	do	99	78.0	24.0	8.0	1500	do
	Ocean King	do	121	94.0	25.0	11.1	1000	do

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Red Star Towing and Trans. Co.	9 towboats, steel, from 83.7 to 100 ft long by 23.6 to 30.0 ft wide, min. draft 9.2 to 10.2 ft, HP 1800 to 2100, operating from New York, NY							
Reichert Towing Line, Inc.	Elizabeth	Tug, diesel, wood	69	79.0	21.0	8.5	650	Green Point, NY
Reinauer Transportation Companies	Hiram Abiff	Tug, steel	99	75.8	23.0	10.0	700	New York, NY
	Janice Ann Reinauer	do	101	90.0	24.0	8.7	1700	Staten Island, NY
	Laurie Ann Reinauer	do	67	76.7	21.0	10.0	805	New York, NY
Reliable Fuel Supply Co., Inc.	John J. Tabeling	Tanker, steel	509	180.0	30.1	10.0	450	Brooklyn, NY
	Mary A. Whalen	do	499	170.0	32.5	12.0	450	do
	Reliable	do	224	125.4	28.0	7.9	360	do
	Venture	Towboat, steel	136	93.8	25.0	11.1	1000	do
Ross Towboat Company, Inc.	Mary De	Towboat, diesel, iron	82	75.0	21.0	10.0	690	Boston, MA
	Providence	Towboat, diesel, steel	86	83.0	22.5	11.0	805	do
Sadler Materials Corp.	Terrell	Towboat, diesel steel	99	81.1	24.0	9.0	700	Virginia Beach, VA

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Southern Materials Co., Inc.	Soumatco	Towboat, steel	64	71.0	19.3	9.5	425	Norfolk, VA
Southern Transportation Co., Inc.	9 diesel towboats, from 71.0 to 115.0 ft long, by 16.5 to 27.3 ft wide, min. draft 8.0 to 12.1 ft, HP 330 to 1800, operating from Norfolk, VA							
Spentonbush Fuel Transport Service	11 steel tugs or towboats from 81.7 to 95.0 ft long by 22.5 to 25.6 ft wide, min. draft 8.2 to 11.5 ft, HP 805 to 1800, operating from New York, NY							
	12 steel tankers from 191.6 to 280 ft long by 31.6 to 49.6 ft wide, min. draft 6.0 to 14.0, HP 450 to 1500, operating from New York, NY							
Steuart Transportation Co.	Little Curtis	Tug, diesel, steel	100	75.6	24.0	8.6	1300	Piney Point, MD
	Esther S	Towboat, diesel, steel	134	99.5	29.1	11.0	2100	do
	Papa Guy	do	133	86.0	26.0	8.0	1530	do
Stinson Canning Co.	Joyce Marie	Motor, diesel, wood	40	69.0	18.0	7.0	400	Prospect Harbor, ME
Stone Towing Line	Pocahontas	Towboat, diesel, steel, welded	111	91.0	22.4	9.4	900	Wilmington, NC
	R.R. Stone	do	49	85.0	22.0	10.5	700	do
	Socony 8	Towboat, steam, steel, welded	146	99.1	24.1	9.0	900	do
Sun Oil Co.	Chesapeake Sun	Pusher towboat, steel	100	95.9	28.1	8.6	1800	Marcus Hook, PA

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
TMT Trailer Fery, Inc.	Fort Johnson	Tug, diesel, iron, riveted	102	89.3	22.1	9.0	1500	Jacksonville, FL
	H.B. Coppedge	Tug, diesel, steel, riveted	135	95.1	26.3	12.1	610	do
	W.T. Coppedge, Jr.	do	99	94.4	23.6	10.2	1800	do
	J.K. Burnetta	Towboat, diesel, steel, riveted	75	86.7	21.5	11.4	1800	do
Taylor & Anderson Towing & Lighterage Co.	7 steel tugs from 78.9 to 95.0 ft long by 21.5 to 28.0 ft wide, min. draft 7.6 to 11.0 ft, HP 800 to 1800, operating from Philadelphia, PA							
Texaco, Inc.	Texaco Fire Chief	Motor, steel	143	93.4	26.3	10.0	1700	New York, NY
	Texaco Marfak	Tug, steel, welded	168	92.2	28.0	11.6	2450	do
	Texaco Sky Chief	Tug, diesel, steel, welded	156	93.0	26.1	10.1	1571	Bayonne, NJ
Texaco, Inc., Norfolk	Richmond	Towboat, steel	65	75.9	23.0	8.5	560	Norfolk, VA
Thomas Transportation Corp.	Harbor Star	Towboat, diesel, steel	119	95.0	25.0	11.0	1025	Perth Amboy, NJ
	Mary Ann	Towboat, steel	64	75.0	19.3	9.5	600	do
Tidewater Towing Co.	Frank T. Shearman	Towboat, diesel, steel	56	85.0	20.0	10.0	1000	Norfolk, VA

DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Todd, Samuel J. E.	North State	Motor, diesel, steel, riveted	107	106.5	20.1	6.3	220	Salisbury, MD
Townsend Transportation Co.	Dandy	Tug, diesel, steel	57	92.8	20.0	8.5	400	New York, NY
	Relief	do	285	119.0	25.0	12.0	900	do
	Syosset	do	96	102.6	23.0	10.0	700	do
Tracy Towing Line, Inc.	Helen L. Tracy	Tug, diesel-electric, steel	7	99.8	27.0	12.0	1350	New York, NY
	Kathleen C. Tracy	do	11	99.8	27.0	12.0	1350	do
	Thomas Tracy	Tug, steel	7	99.8	27.0	12.0	1600	do
	Walter Tracy	do	63	68.9	20.0	6.0	400	do
	William J. Tracy	do	7	99.8	27.0	12.0	1600	do
Trawler Oil Corp.	Sea Bee	Tanker, diesel, steel, welded, compartmented	33	61.9	15.2	5.0	135	Boston, MA
Tucker Towing Co.	Anne	Tug, diesel, steel	31	65.5	18.0	7.6	1000	Philadelphia, PA
	Rose	do	65	68.5	20.1	7.6	500	do
	Margaret	Tug, steel	109	91.5	24.1	11.0	1200	do
	Shamokin	Tug, diesel, steel, welded	134	104.2	26.1	11.0	1800	do

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DESCRIPTION OF VESSELS

Operator	Vessel Name or Number	Type and Construction	Net Tons	Length	Breadth	Min. Draft	Horse-power	Local Operating Base
Turecamo Coastal & Harbor Towing Corp.	11 steel towboats, diesel, from 75.0 to 89.0 ft long by 21.0 to 27.2 ft wide, min. draft 8.6 to 12.1 ft, HP 800 to 2100, operating from New York, NY							
Union Camp Corp.	Corinthia	Towboat, diesel iron	38	68.5	16.9	9.0	680	Franklin, VA
Valliant, W.E., & Co.	Marydel	Motor, diesel, wood	116	97.6	28.2	5.8	220	Cambridge, MD
	W. E.	Motor, diesel, steel, riveted	223	134.0	24.0	9.0	220	do
Whaling City Dredge & Dock Corp.	Bateleur	Tug, diesel, wood	90	97.5	22.0	9.0	400	Groton, CT
Willis, C.G., Inc.	Capt. C.G., Chauncey, Patricia, & Roleta	Towboat, steel, welded (4)	168	83.7	28.1	7.0	1535	Paulsboro, NJ
Wright Bros, Inc.	J. B. Wright	Motor, diesel, wood	87	96.9	22.5	6.0	275	Bridgeport, NJ
	Wright Bros.	do	101	90.8	22.8	7.0	300	do

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS INPUT TRANSACTION FORM
	05D	

5 Organization

Pacific Northwest Laboratories of Battelle Memorial Institute, Richland, Washington

6 Title

Concept Evaluation: Recovery of Floating Oil Using Polyurethane Foam Sorbent

10 Author(s)

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16 Project Designation

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23 Descriptors (Starred First)

Evaluation*, Oily Water*, Separation Techniques*, Technical Feasibility, Efficiencies, Hydraulic Systems, Hydrodynamics, Jets, Testing, Water Pollution Treatment

25 Identifiers (Starred First)

Sorbent*, Polyurethane Foam*, Concept, Equipment Development, Oil Recovery

27 Abstract Individual components of an oil spill recovery system were evaluated using Bunker C ~~oil~~ and three crude oils ranging in API gravity from 14° to 42°. The system was designed to shred and broadcast polyurethane foam sorbent onto an oil slick, herd the sorbent to a ship-side conveyor by a water spray boom, squeeze the sorbent to extract the oil and rebroadcast the sorbent. The initial concept was to build a half-size, full scale system; however, initial foam losses indicated the necessity for a re-evaluation of the program, and specific studies on the broadcasting and "squeezing" systems were undertaken. The shredder-broadcaster, a commercial straw mulcher, produced acceptable shredding of dry foam. However, multiple cycling degraded oil-soaked foam to unrecoverable sizes in relatively few cycles. With Bunker C oil, 47 percent of the foam was reduced to sizes less than 1/2" in 5 cycles. With light Canadian crude oil, 29 percent was reduced to less than 1/2" in 100 cycles. A sorbent-oil separator using perforated rolls, was designed to extract viscous oils from the foam at 20°C, without heating, at rates of up to 5000 gph. This device showed good recovery of oil from foam. Multiple cycling of Bunker C-oil-soaked foam through the full scale device resulted in a small loss of foam by size reduction (3.5 percent in 77 cycles). After 77 cycles of extracting Bunker C oil, foam damage by loss of resiliency reduced oil extraction per cycle to about 25 percent of the initial amount. No loss of resiliency was observed up to about 50 cycles. Because of the high sorbent losses in the shredder-broadcaster, the system as initially proposed is not recommended for use with Bunker C oil. (Henager - Battelle)

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