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Development of A Mobile System for Cleaning Oil-Contaminated Beaches

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DEVELOPMENT OF A MOBILE SYSTEM FOR CLEANING OIL-CONTAMINATED BEACHES

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ABSTRACT

A system has been developed for the restoration of oil-contaminated beach sands. The method involves washing of the sand in a high energy jet-contactor washer and separation of the cleaned sand from the washing fluid in a conventional solid-liquid cyclone. Separation and concentration of the oil-water effluent from the washing process is also accomplished in cyclones. The two separate stages of this process have been demonstrated on a pilot scale equivalent to about 3 tons of wet, oil contaminated sand per hour.

The sand washing process has been shown capable of removing over 99% of the contaminating oil from a simulated beach sand. Oils used were No. 4 and No. 6 fuel oil at 4 to 8% of the dry weight of the sand. The oil-water separation tests yielded a highly enriched oil product stream with less than 20% water, while the water removed from the system was suitable for recycle to the sand washing system.

A conceptual design for a mobile beach-cleaning system based on the processes studied is presented and is shown to be feasible within the state-of-the-art.

This report was submitted in fulfillment of Project FIG, Contract No. 14-12-830, under the sponsorship of the Environmental Protection Agency.

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SECTION 1

CONCLUSIONS

The following conclusions have been reached as a result of the work conducted in the course of this study.

Sand Washing and Separation

1) The ability to wash oil from contaminated beach sands and to separate the sand from the washing fluid for return to the beach has been demonstrated in a pilot scale system.

2) The apparatus and procedures involved are straightforward and are within the state-of-the-art.

3) Requirements for power in the sand washer are small, of the order of one horsepower for each ton of sand processed per hour.

Oil-Water Separation

4) Oil water mixtures can be separated in 10 mm cyclones. The results of the tests can be predicted well enough for pilot plant design.

5) Underflow (heavy-phase stream) oil concentrations of 0.1% can easily be obtained but overflow (light-phase stream) concentrations above 80% cannot be achieved.

6) Test data from the 6 inch cyclone does not match trends established by the 10 mm cyclones. The 6 inch data do not fit any pattern and cannot be resolved without further test work.

7) The small cyclones can be staged and product streams routed to other cyclones for further processing. No adverse effects were found from staging the cyclones.

8) The most important variable affecting the cyclone performance is the split, i.e. the ratio of the overflow rate to the underflow rate. Feed oil concentrations, water type, and temperature have only minor affects.

Full-Scale System

9) Presently, no problems are seen regarding the extrapolation of the laboratory data to the design of a full-scale, beach-rated sand cleaning system. This presumes the use of 10 mm cyclones for the oil-water separation stage.

10) The operation of such a system should be straightforward, with small requirements for power, operating personnel and supplies.

11) All of the equipment needed for the system is within the state-of-the-art, and no new breakthroughs are needed to make the system practical.

SECTION 2

RECOMMENDATIONS

A three-pronged program is recommended for future work with this beach cleaning concept.

1) Continue test work on oil-water separation in large cyclones to determine if effluent oil streams with less than 20% water can be attained. The applicability of centrifuge, flotation, coalescing and filtration systems to this separation should be studied, with the objective of achieving less than 3% water in the final oil product. Also investigate a wider variety of oil types at this stage.

2) From the data, design, fabricate and test a complete beach cleaning system, include the sand washing and separation and multiple stages of oil-water separation. The problems of interfacing and controlling the two processes must be studied. In connection with this program, a study of instrumentation which can provide on-line analyses of the effluent streams should be undertaken. Any attempt to build a full-scale system must include provisions for monitoring and controlling the process.

3) Finally, a systems analysis study needs to be undertaken to permit use of existing performance data for designing a beach cleaning plant which will meet specific operational requirements. This systems analysis should also be used to optimize the process design from the standpoint of capital and operating costs and performance.

SECTION 3

INTRODUCTION

The spillage of oil from ships, at offshore drilling sites and during transfer operations, can result in contamination of adjacent shore areas. An American Petroleum Institute study (Ref. 1) analyzed some 38 major spills in the period 1956 to 1969 to determine the size and nature of the oil spill problem. From that study, the following information was extracted:

1) 85% of the spills investigated occurred off recreational shoreline,

2) 70% of the spills were larger than 5000 barrels, the median size being about 25,000 barrels, and

3) crude or residual oils were involved in 90% of the spills.

Further, a 1968 Report to the President (Ref. 2) presents several estimates of the frequency of spills, including a U. S. Coast Guard report of 371 "cases of record" in 1966. Viewed together, these statistics graphically illustrate the potential damage associated with oil spills.

Where spills have contaminated beaches, the major efforts directed toward restoring the shoreline have usually included physical removal of the oiled sand, adsorption of the oil with various sorbing material (notably straw) and the use of chemical dispersants; however, none of these procedures have been completely satisfactory. Imprudent sand removal practices can result in permanent changes to the beach features. The sorption of oil from the sand is a highly labor-intensive procedure that is slow and only marginally successful in cleaning the beaches. Chemical dispersants can be effective when systematically and correctly applied; however, improper application can result in severe damage to the littoral ecosystem.

To a large extent, beaches have been left to restore themselves through the physical and chemical action of the winds, waves and tide. Biological degradation of oil on beaches has also been observed. These natural processes can reclaim a contaminated beach, but the time frame may be from several months to a year or more.

Thus, it becomes apparent that new means must be devised for quickly and effectively cleaning oil-contaminated beaches and to restore them to their natural state.

This study was one of several initiated by the Environmental Protection Agency (the Federal Water Pollution Control Administration at the beginning of the project) to investigate new methods for restoring oil-contaminated beaches. The concept proposed includes washing of the sand in a jet contacting washer, followed by cyclonic separation of the sand from the washing water and cyclonic separation of the oil and water.

The primary objective of this program was to demonstrate the feasibility of the proposed sand washing and oil-water separation systems for restoration of oil-contaminated beach sands. By using pilot scale test apparatus, the efficiency of and parameters controlling the sand washing process were to be determined. Also, the effectiveness of oil-water separation in cyclones was to be studied, with the goal of achieving an oil product containing less than 3% water. The results of these investigations were to be used to form the basis for the conceptual design of a mobile system for cleaning oil-contaminated beaches and to make recommendations regarding the operation of the system and the disposition of the recovered sand and oil streams.

In the next section we will briefly discuss the background leading to the development of this concept, including the preliminary bench-top washing tests, and present arguments for using cyclones in the separation stages. Also, a survey is presented of the characteristics of sands and oils likely to be encountered in beach related spills.

Next, the experimental programs aimed at evaluating the performance of the sand washing and oil-water separation processes are laid out. Finally, the results of the testing programs are presented, followed by a discussion and extrapolation of the data to a full-scale system design.

SECTION 4

BACKGROUND

Sand Washing

A simple method was devised for determining the effectiveness of different means for washing oil-contaminated sands, e.g. solvent and detergent washing, hot and cold water washing etc. The method consisted of vigorously agitating oiled sand in a container filled with the washing medium. A successful washing test would show a layer of clean sand at the base of the container, a layer of clear water above that, and a free layer of oil at the air interface. For cases in which detergents or solvents were used, the washing solution generally contained, at the end of the cycle, a large fraction of the input oil as an emulsion or in solution.

One of the basic ground rules of these preliminary investigations was that the sand would be water-wetted prior to its contamination with oil. This appears to be a reasonable assumption since the oil is transported to the shore area by water and is able to contact sand only after the water advances ahead of it through the sand.

Using cold (70°) tap water as the washing fluid in these "jar" tests, we were able to effectively clean sand which had been contaminated with both No. 4 and Bunker C fuel oils. The oil from these tests usually formed a free floating surface within about 30 seconds after agitation ceased. Tests using hot water (up to 200°F) and detergent and solvent washing were similarly successful in stripping oil from the sand, but the oil was left in a less than desirable condition--emulsified or in solution. The determination of cleanliness in these tests was qualitative; i.e. no direct measurements of oil remaining in the sand were made. However, sand extracted from the containers appeared clean and little or no oil would rub off onto clean filter paper.

Based primarily on these limited tests, we proposed to investigate a mobile system for cleaning oil-contaminated beach sand. The process to be studied would incorporate cold water washing of the sand in a turbulent jet washer/ mixer followed by separation of the sand from wash water in a cyclone.

Oil-Water Separation

The sand washing system discussed above discharges cleaned sand and a mixture of oil and water. This oil-water mix must be separated into its component parts in order to reduce the volume of liquid to be handled for disposal. In keeping with the concept of a mobile beach cleaning system, we suggested the use of cyclones to effect this separation process. Cyclones appear attractive for this application because of their high throughput rates and small space requirements. Also, the performance of a cyclone is insensitive to the orientation of its major axis (horizontal, vertical, or positions in between) making it ideal for use on a platform moving across a beach surface.

Data available in the literature (Ref. 3) and supplied by Dorr-Oliver Incorporated (Ref. 4) pointed the way to using a system of staged cyclones to promote a high degree of separation of the oil from the influent wash water, and to provide a relatively clean water stream which could be recycled to the sand washing system.

In the staged concept, the oil-water mixture from the sand washer is used as feed for the first stage of separation. Here, the cyclone is operated to extract the maximum possible amount of clean water at the underflow. The oil-enriched overflow then passes on to become feed for the second stage.

The second stage cyclone can be operated in the same manner as the first one (clean water underflow with a concentrated oil overflow) or it can be used to yield a highly enriched oil overflow with a dirty water underflow. When operation is in the first of these modes, the overflow is treated further in subsequent stages and the underflow is recycled to the washer. If the second mode is used, the dirty underflow can be recycled to the feed stream for the first stage and the overflow pumped to storage and/or disposal. Figure 1 schematically shows the general arrangement of this cyclone staging/recycling system.

Though important information with regard to the operating characteristics of the cyclone in separating oil-water mixtures was still needed, we were sufficiently confident of the expected performance to propose cyclones for this application.

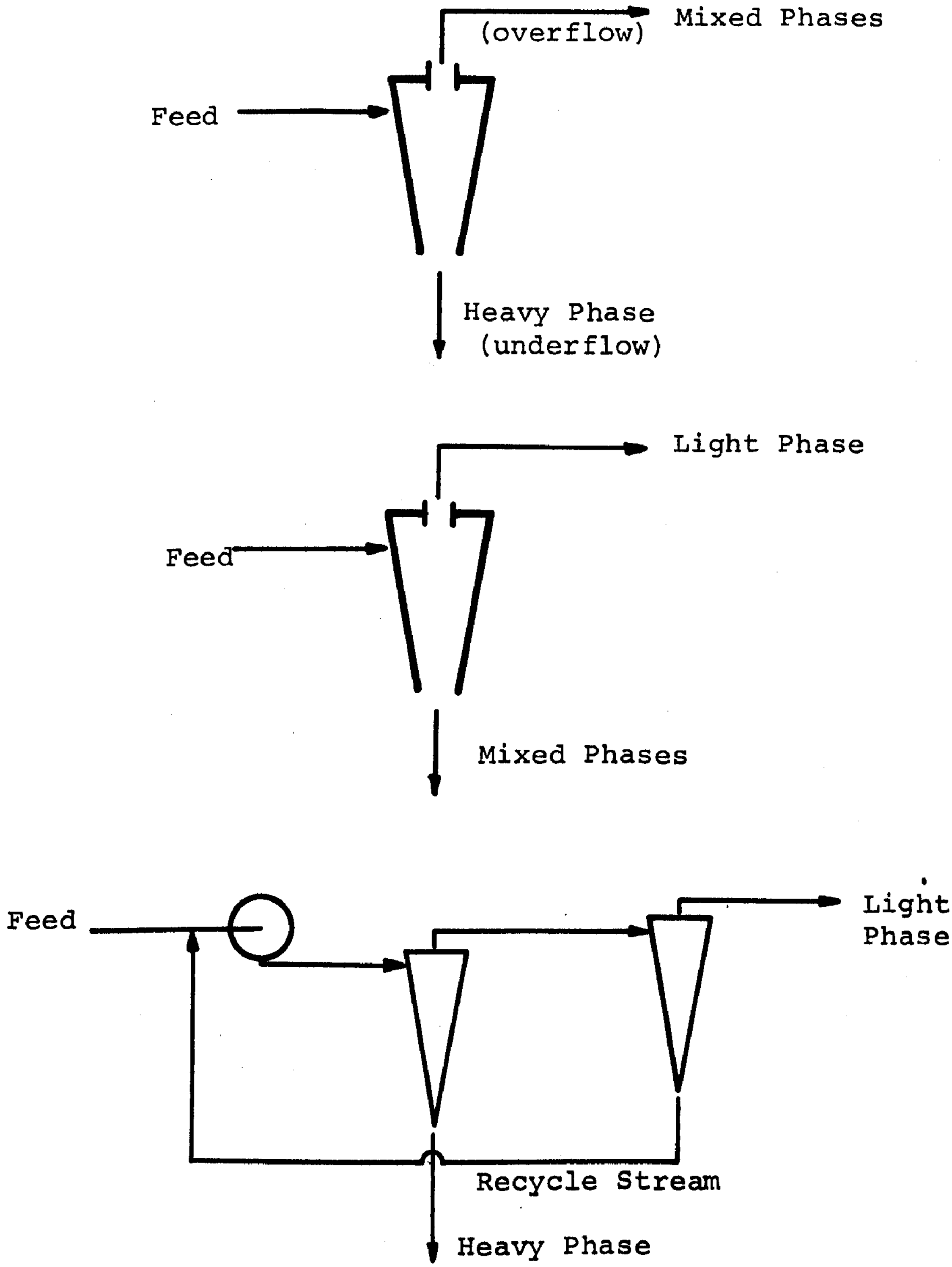


Figure 1. OPERATING MODES FOR LIQUID-LIQUID CYCLONES

Characteristics of Beach Sands

As part of the overall study, we were to establish the characteristics of beach sands that might be encountered in an oil spill situation. Also, it was necessary to make a brief preliminary survey to determine the nature of sand most suitable for the pilot-scale testing.

Probably the most consistent comment found regarding beach sands of the coastal U. S. is the high degree of sorting associated with the materials found. The following quotation (Ref.5) is typical of the discussions found.

"If a mixture of pebbles, sand and fine silt is placed on a beach foreshore, the fine silt may be carried away from the shore zone by suspension, whereas the sand and pebbles are distributed along the foreshore and nearshore bottom zones. The pebbles tend to concentrate along the seaward edge of the foreshore or they may become associated with the shifting portion of the plunge zone. The sand is predominantly distributed over the foreshore, or it may be partly shifted to seaward of the low tide line."

Thus, it can be seen that the active hydraulic forces of the tides and waves work to segregate beach sediments into restricted size ranges that are very consistent for any particular beach. And, when sand is present, it is preferentially deposited where water-borne oil is most likely to contaminate it -- along the intertidal zone and the wave-washed region.

Extensive sampling programs (Refs. 6 and 7) verify the predominance of siliceous sand beaches along the Atlantic coast of the United States, except for the southern tip of Florida and the Florida Keys. In this region, the beaches are made up largely of shell deposits and crushed coral.

Sand particles on Atlantic coast beaches range in size from 0.005 inch to 0.020 inch, but the range for any beach was much narrower than this, with sorting coefficients of the order of 1.3. Sorting coefficient is defined as the square root of the ratio of the particle sizes at the "one-quarter greater than" and "three-quarters greater than" distribution points. The mean particle diameter on these beaches is around 0.008 inch.

The Gulf Coast beaches, too, show remarkable sand size uniformity (Ref. 8) and chemical makeup. Again, with the exception of Florida's southern tip, the sands are generally siliceous, although magnetite is present in abundance. Mean particle size shows some differentiation east and west of the Mississippi River Delta region. The Texas and Louisiana beach sands have mean diameters ranging from 0.0035 inch to 0.0085 inch with sorting coefficients around 1.17.

Beach sands along the Pacific Coast have generally larger mean particle diameters (about 0.014 inch) and sorting coefficients around 1.3 (Refs. 9 and 10). These sands are almost entirely free of calcareous deposits ($CaCO_3$ amounting to 7%) and the little that is present is made up of broken shells in a very thin surface layer.

Sand particles, in general, tend to sphericity in shape and the mean particle size can be shown to influence the slope of a beach. Temporary alterations to the texture of a beach can result from severe storms, but equilibrium is usually rapidly restored by the normal wind, wave and tidal conditions. There is also a tendency for the beach characteristics (sand distribution, dunes, slope, etc.) to change seasonally, especially where there is a wide seasonal variation in the tides and storm activity. Man-made shore installations, e.g. piers, jetties, groins, dikes, etc., can also disturb the natural condition of a stretch of beach and attempts at restoring beaches (Ref. 11) have altered the texture significantly from the norm.

The major conclusions regarding coastal beaches in the U. S. that can be drawn from this review are:

1) beach sand particle mean diameters range from about 0.008 to 0.014 inch, with sorting coefficients around 1.2,

2) sand in any one stretch of beach will be very well sorted under normal conditions,

3) sand size variations do occur from the low tide line to the berm (beginning of backshore region) but the variation is probably very narrow, and

4) the predominant material making up the beach sand is silica.

The discussion above has been restricted to a consideration of beach sands. Beaches composed of shingles and boulders could present a problem to some of the elements of the sand washing apparatus, and we would therefore expect to screen out these materials (along with ordinary beach debris and trash) prior to introducing the oily sand to the washing machine.

Based on the results of this survey, we selected a well washed and graded silica sand for use in the testing program. The sand is designated as #50 sand (for the mean mesh size) and has a mean particle size of 0.0114 inch with a sorting coefficient of 1.3. Figure 2 shows the size distribution curve for the sand as supplied.

Characteristics of Spilled Oils

Reference 1 summarizes the types and quantities of oil implicated in a review of major spills. Crude oil represented the largest volume of oil spilled (80%) as well as being involved in the greatest number of spills (18 of 35). Residual oils make up the next largest number of spills (14 of 35), although they represented only one percent of the total spilled volume. Light oils make up the remaining fractions. It appears, based on these limited data, that crude and residual oil will probably be involved in any future spills.

The oils selected for use in the sand washing and oil-water separation test programs were #4 and #6 fuel oil. Crude oil (South Louisiana and Bachaquero, obtained from EPA, Edison, New Jersey) was used to a limited extent in the sand washing program. The fuel oils were obtained from bulk oil handlers and are presumed to meet all commercial specifications for these grades. The specific gravity (at 60°F) for the No. 4 and No. 6 oils was measured and found to be 0.91 and 0.96 respectively. Crude oil in quantities sufficient to be used in the pilot-scale testing was not readily available and so all major testing was accomplished with the No. 4 and No. 6 fuel oils.

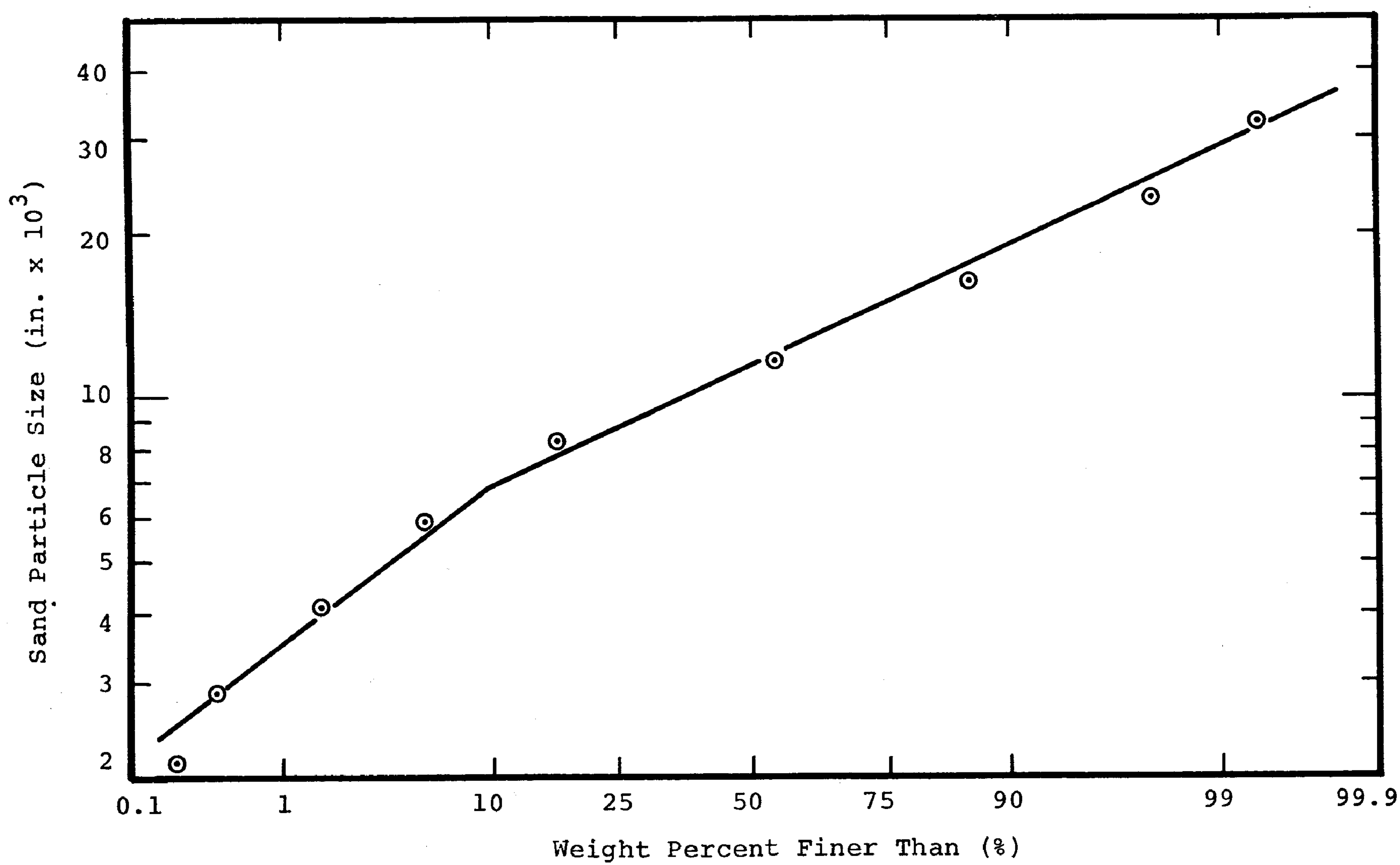


Figure 2. PARTICLE SIZE DISTRIBUTION CURVE FOR #50 SAND

SECTION 5

EXPERIMENTAL PROGRAMS

The experimental portion of this study was carried out in two separate phases:

1) design and testing of the sand washing and separating system, and

2) separation of oil-water mixtures using cyclones.

Because they were conducted as individual efforts, these programs will be so presented in the discussions following. A conceptual marriage of the systems will be presented in Section 6.

Sand Washing and Separation

Design of the apparatus

The primary purpose of this phase of the program was to devise and test a system for cleaning oil from beach sand and for separating the cleaned sand from the washing fluid. Our preliminary "jar" tests demonstrated that a turbulent mixer would be capable of stripping the oil from the sand if sufficient mixing time and/or energy were provided. Using this turbulent mixer concept and the basic requirement that the process under investigation be adaptable to a mobile platform, we devised the flow-through jet washer shown in Figure 3.

In this assembly, sand is fed via a vibrating screw feeder to the inlet of the washing section. The washer consists of a cylindrical tube with radial and inclined water inlet nozzles machined circumferentially around the chamber. A second tube surrounds the washing section and the annular space between them forms a plenum for distributing water to the nozzles. As oily sand enters the washer, it is violently stirred by the impinging water jets. This stirring action serves to strip the oil from the water-wet sand particles and reduce the size of the oil droplets as determined from the oil-water interfacial properties and the power input to the washer. The major source of energy for this mixing process is supplied as kinetic energy in the water jets. For a

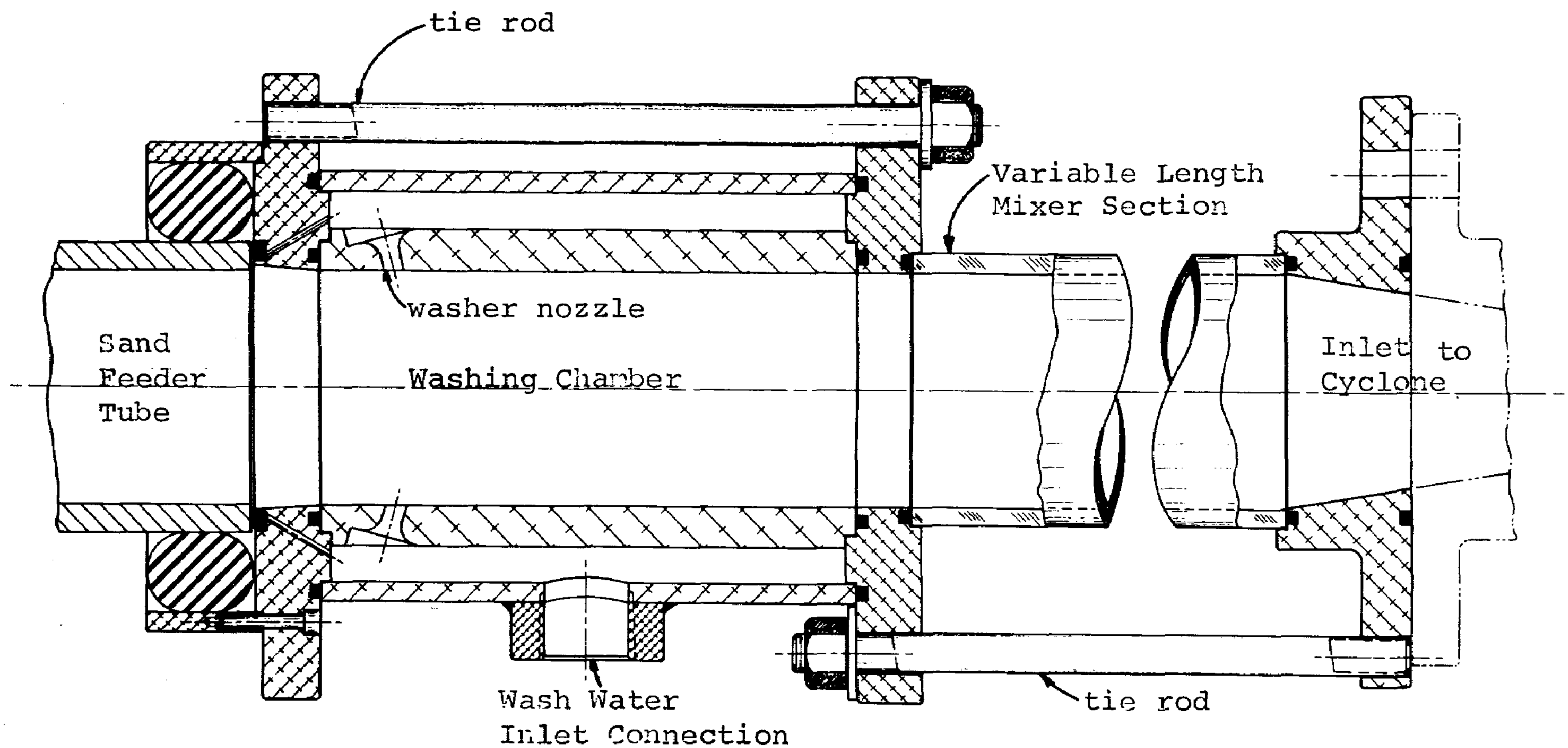


Figure 3. SAND WASHER ASSEMBLY DETAIL

typical mass ratio of 3 lb_m of water per 1 lb_m of sand, the kinetic energy in the water jets is about 30,000 times greater than that in the oil-coated sand.

Following the washer is a constant diameter, variable length section of pipe in which mixing of the sand with washing fluid continues. In some of the modeling studies performed in the early phases of this program, it was shown that the duration of the washing/mixing process might be an important variable. This variable length section made possible an approximate 3.5:1 increase in the total residence time for a fixed volumetric feed rate through the system. For maximum feed rates, the holdup time in the washer/mixer is about 0.5 seconds per foot of length. This mixing section was fabricated from clear acrylic tubes permitting visual observation of the washing process as the mixture proceeded downstream.

At the end of the mixing section, an adaptor flange is used to provide smooth transition from the mixer tube to the smaller diameter inlet of the sand-separating cyclone. The cyclone used for this phase of the program was a 6-inch diameter, type FR, DorrClone, manufactured by Dorr-Oliver Incorporated. This unit was purchased with three different vortex finders (overflow tube), 1-1/4, 1-5/8, and 2-1/2 inch diameter. The apex valve (underflow port) was supplied as 3/4 and 1-1/2 inch diameter, although it was possible to reduce this by squeezing the walls of the rubber discharge nozzle with a hose clamp.

The cyclone was operated to give a rope-like discharge at the underflow. This condition was set by varying the size of the apex opening until the discharge alternated between the solid-appearing rope flow and a splashing, vortex flow. Then the port size was decreased slightly until the rope discharge was stable. In this manner, the maximum amount of washing fluid (along with the oil droplets) was discharged to the overflow, carrying along little or no clean sand, and the underflow carried away only enough water to keep the sand fluid. Under normal operation, the underflow was about equally divided between sand and water (volume basis). This means that for a case where the mass flow of water was about three times that of the sand, 85% of the wash water was recovered at the cyclone overflow.

The apparatus for feeding sand to the washer consisted of a helical wire screw feeder with a vibrating bin and screw tube. This vibrating action, induced by means of an eccentric flywheel attached to the drive shaft, aided in preventing clogging of the feed port and screw. The unit was manufactured by Vibra Screw Incorporated, and was designated as a 3" live bin feeder. Through the use of a variable speed transmission, the sand feed rate was adjustable from about 7 to 70 cubic feet per hour (one cubic foot of wet sand weighs about 100 lb).

Coupling of the washer to the sand feeder presented somewhat of a problem, since the screw feeder tube assembly (partially shown in Figure 3) must be allowed to vibrate freely about its axis, but a watertight seal was also required at the interface of the screw tube and washer flange. The solution shown incorporates an O-ring face seal in contact with the vibrating tube.

To help maintain alignment of the vibrating screw relative to the axis of the washer, a flexible collar was fitted into the annulus formed by the outside of the tube and a sleeve.

Figure 4 shows the flow diagram for the sand cleaning pilot plant. As may be seen, the system was operated closed-loop with the cyclone overflow returning to the oil water storage tank. This tank provided a holdup period to allow oil to separate from the recycled wash water. The water was gravity fed to the lower tank wash water storage tank, passed to the inlet of the main feed pump, and then to the washer inlet plenum. Sand from the underflow of the cyclone was dumped into a separate collecting tank. A drawing of the major equipment in this pilot plant is presented in Figure 5.

In the event of system upsets and for startup transients, it was possible to backflush oil from the sand collecting tank, allowing the overflow to drain to the wash water storage tank. After sufficient oil had collected in these two tanks, it was skimmed from the surface of the water and transferred to barrels for disposal.

During the shakedown testing of the pilot plant, we found that wash water would back up the screw feeder tube and

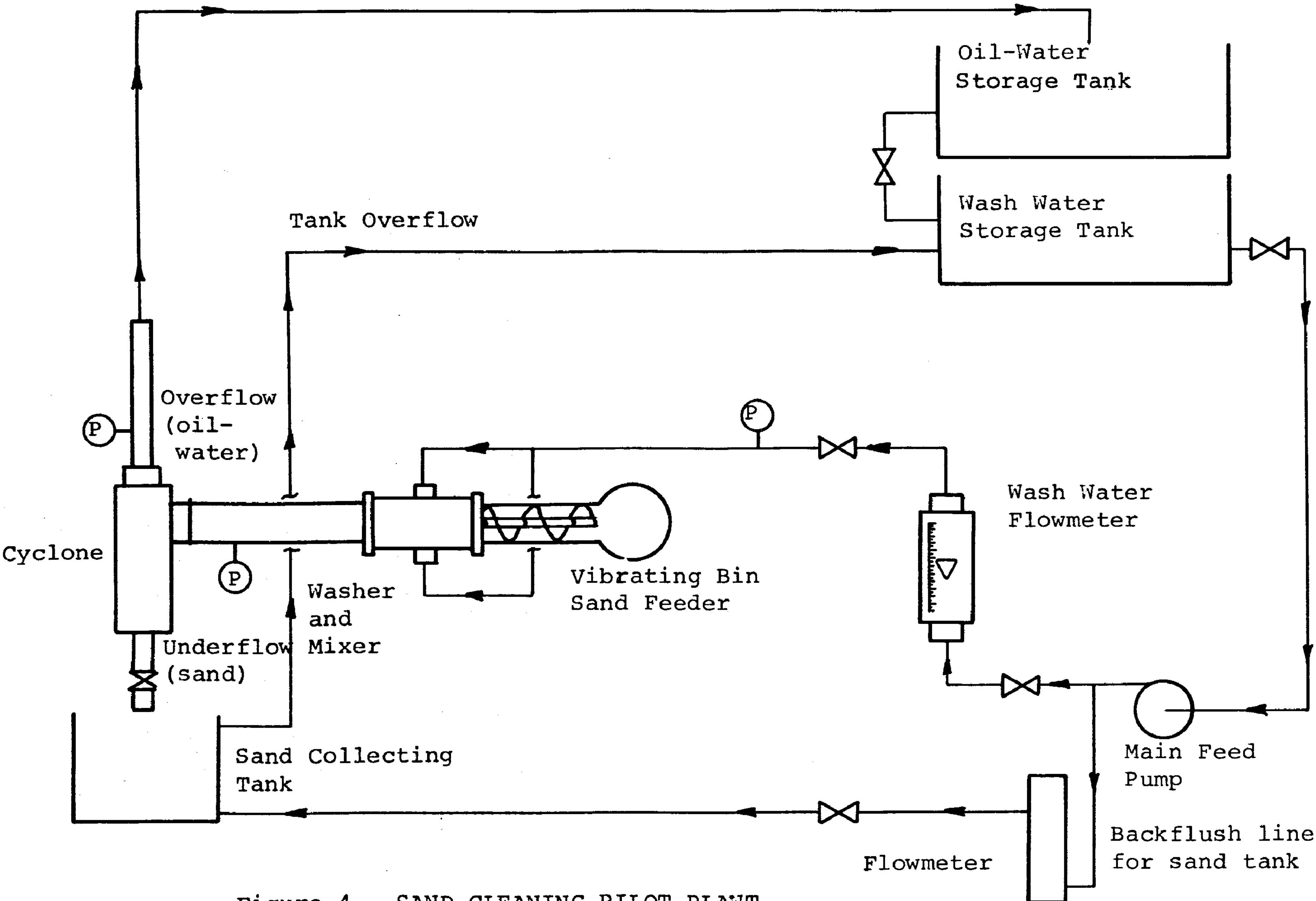


Figure 4. SAND CLEANING PILOT PLANT FLOWSHEET

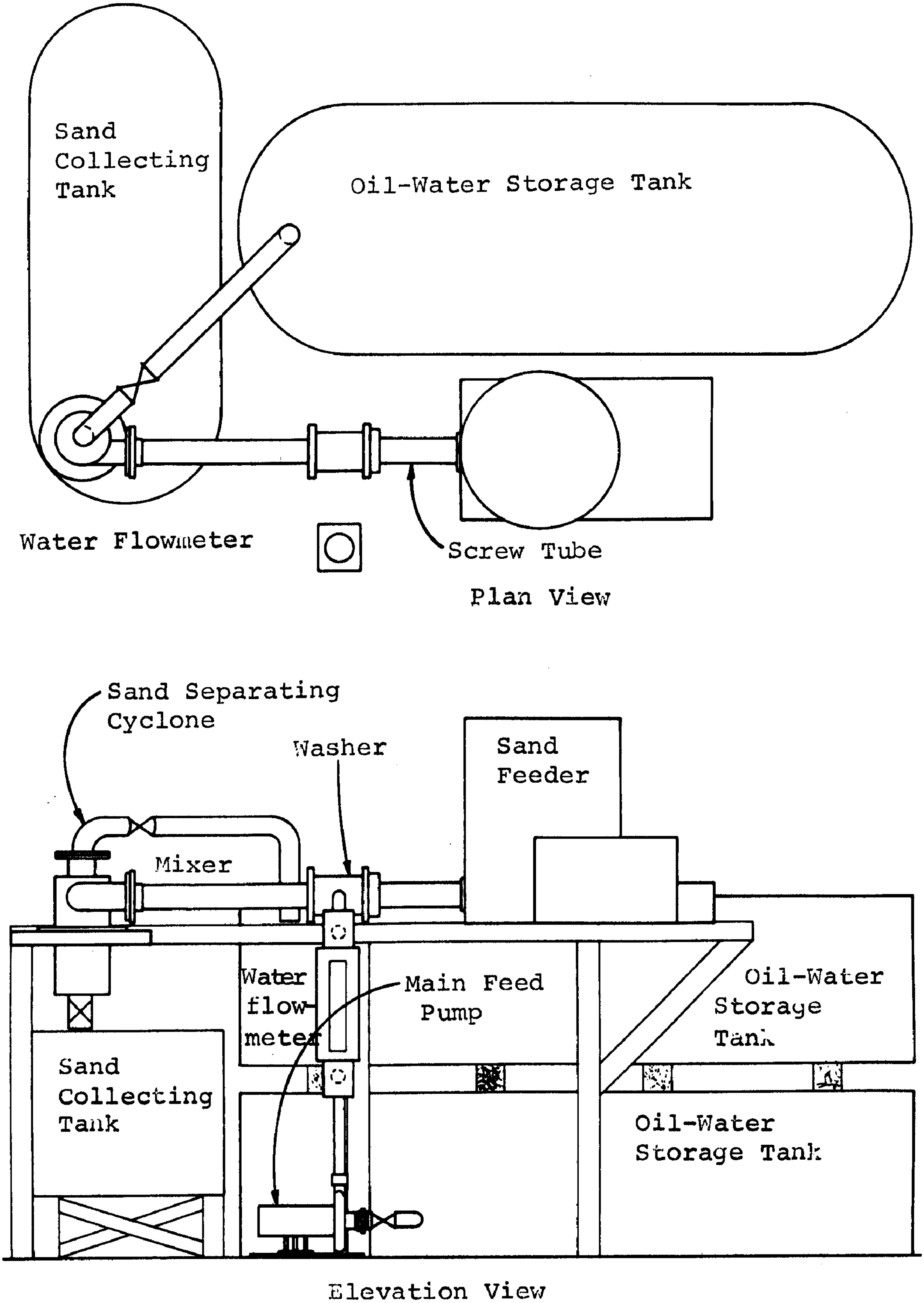


Figure 5. SAND WASHING EQUIPMENT SKETCH

into the hopper, thereby stopping the flow of sand. Theoretical calculations indicated that the sand in the screw tube should be capable of supporting a pressure drop of about 15-20 psi, based on the flow of water through a uniform bed of packed sand particles. However, the vibratory nature of the screw feeder prevents the sand from packing in the tube, resulting in a much reduced pressure drop and hence the water backup problem. A solution was provided by fitting a tight cover to the top of the sand supply hopper and balancing the back pressure on the washer with air so that a stationary air-water interface was maintained downstream of the screw tube. This necessitated operation of the pilot plant in a batch mode, since the hopper could be loaded only when open to atmosphere. No problem was encountered with this batch operation because the hopper contained sufficient sand to permit reaching steady-state operation at all feed rates.

Range of variables

There were three sets of variables investigated in the sand washing phase of this program:

1) feed variables

   a) sand type
   b) oil type
   c) oil/sand condition
   d) inclusion of sorbers in feed

2) process variables

   a) sand and water feed rates
   b) ratio of water to sand in feed
   c) feed temperature
   d) solvents, detergents, etc.
   e) cyclone operation

3) washer/mixer variables

   a) nozzle geometry
   b) mixing length

The first set of parameters is dependent on the nature of the oil spill under consideration. For our test purposes, we fixed the sand type and used No. 4 and No. 6 fuel oils to determine if oil type affects the sand washing process.

Regarding the condition of the oil/sand mix fed to the washer, we generally used freshly mixed (less than 24 hours old) batches of oily sand. The sand was always wet with water (and excess water drained away) prior to mixing in the oil. Some testing was done with oily sand mixtures which had been allowed to "age" under infrared lamps for two days. The condition of the mix after this aging was not much different than the fresh mix, except that no excess water was present and the sand particles were slightly more cohesive. "Tar balls" could be formed by rolling a mass of aged sand in the hands, but with only minor agitation these clumps broke apart.

Finally, the only sorber utilized in this program was straw. Mulched straw was mixed in with oily sand (No. 4 oil) at about 2% of the weight of the sand. The results of tests with this feed will be discussed separately in Section 6.

In the case of the process variables, the last three remained fixed throughout the program. No attempt was made to include temperature as a controlled process variable for two reasons. First, in the preliminary "jar" tests sand washing was seen to be equally effective at 35°F and 100°F. Second, the wash water used in the system is recycled, resulting in a net heating effect due to the work input from pumping. This warmer water, mixed with cold, oiled sand, will increase the temperature of the sand since the water has a severalfold larger heating capacity. The feed temperature varied only slightly from test to test (in the range from 50° to 65°F). No solvents, detergents or other agents were added to the feed. Their use was not indicated by the results of the washing process. As mentioned previously, the cyclone was operated to give a rope discharge in all tests, although the vortex finder and apex valve were varied in size for several of the tests. Then, for the set of process parameters listed, only the absolute and relative feed rate of water and sand were included as variables in the test program. The water flow rate was varied from 20 to 40 gpm, and the mass ratio of water to sand ranged from 3 to 9, at all water flow rates.

The geometry of the washer nozzle and the mixing length were also included as variables in the test program. Two sets of nozzles were available (each set was machined into a different washing section) requiring disassembly of the washer in order to change them. In the washing nozzle assembly designated No. 1, six 1/4 inch diameter jets were drilled into the wall of the chamber and equally spaced around the periphery. The axis of each jet lies at a 45° angle to the longitudinal axis of the washer pointing downstream, and is also rotated 45° toward the side of the washer, each jet rotated in the same direction (See Figure 3). Thus, liquid entering the washer chamber through these jets tends to travel in a helical motion toward the discharge end. The reasoning behind this nozzle geometry was that the water, traveling in a downstream direction, would transfer some of this momentum to the sand and sweep it along. It was surmised that the helical motion could increase the residence time of the sand in the washer and thereby increase the washer efficiency. Also, it was hoped that this geometry would reduce the back pressure on the sand feeder tube and prevent water from backing up the tube.

Nozzle No. 2 was similar to No. 1 in that three of the jets were arranged on the 45° x 45° pattern, with the other three set to point radially inward at the influent sand. The angled and straight jets were alternated around the periphery. In this case, the job of the straight jets was to act as a "water knife" to slice up clumps of sand as they entered the washer.

As mentioned previously, the length of mixing section downstream of the washer was variable. Early in the shakedown testing it was noticed that, when the shortest length of mixing section (1 inch) was in place, the washer would tend to plug on startup, due to a piling up of sand in the mixing tube caused by a decrease in cross-sectional area at the entrance to the cyclone. Because of this problem, we abandoned use of the short mixing section and all future tests were run with either the 12 inch or 24 inch mixing sections downstream of the washer.

Appendix A lists all of the tests run (except for special tests using sorbers or aged sand) and the combination of parameters for each.

Experimental Procedure

A typical test was carried out as below:

1) 400 lb of wet sand were thoroughly coated with oil at 4 to 8% of the sand weight,

2) the sand feeder bin was loaded with the oiled sand and the feeder run to fill the screw tube,

3) the sealing cover was fitted to the top of bin,

4) main feed pump was started and the desired flow rate set,

5) simultaneous with (4) the air supply to the bin was set to match the pressure in the washer,

6) the sand feeder was turned on and the speed control set to give the desired sand flow rate,

7) the cyclone apex valve port size was manipulated to give the desired rope discharge, and

8) as conditions stabilized, flow and pressure data were recorded and samples of the cyclone underflow and overflow were collected for later analysis (samples of the feed were collected prior to sealing the bin).

For any given water rate, the sand feed was varied over its full range. After all data was collected for a single water feed rate, it was changed and the procedure repeated. In some cases, it was necessary to shut down for refill of the hopper in order to collect a full set of data for one set of washer or cyclone geometries, with one oil.

The critical information desired from any particular test was the effect of operating variables on the cleaning and separating of sand. Thus it was necessary to determine the degree to which the process was able to remove oil from sand. The analytical technique used to determine the oil in the feed and cleaned sand and in the overflow water was taken from Reference (11) and is quoted below:

1) Weigh 50 grams of sample (oiled sand) into 250 ml Erlenmeyer flask.

2) Slurry four times, or until extraction is complete, with 50 ml of 10% acetone in chloroform, which has been heated to just below its boiling point.

3) Decant solvent after each extraction through fluted number 4 filter paper into a 250 ml beaker.

4) Evaporate combined extracts on a steam bath to approximately 25 ml and transfer quantitatively to a tared 50 ml beaker.

5) Evaporate extracts to dryness, then add 5 ml of acetone, and again evaporate to dryness.

6) Wipe off excess water from outside of beaker, then dry 10 minutes in an oven at 103°C.

7) Cool in desiccator and weigh (extract).

Using this technique, we were able to determine the percentage of oil removed from a given feed sand and thereby evaluate the performance of the sand washing system.

The results of the sand washing tests and a discussion of the data is presented in Section 6.

Oil-Water Separation Tests

Design of the apparatus and procedures

In this phase of the study, conventional, commercially-available cyclones were used to perform the oil-water separation tests. During the course of the experimental program, four different test setups were used. Appendix B lists all of the tests performed and shows the scope of variables investigated.

Preliminary testing was done with a TML DorrClone (manufactured by Dorr-Oliver Incorporated, as were all of the cyclones in this program) taking feed from a pre-mixed oil-water storage tank. The TML unit contained four 10 mm Nylon cyclones arranged so that they are fed from the same inlet and discharge through the same overflow and underflow connections. Oil and water were added to the baffled tank and agitated to produce the feed; product streams were returned directly to the tank. A schematic of the test rig is shown in Figure 6. This apparatus and procedure was adequate for the preliminary testing, but it did not produce consistent feed analyses and the continuous heavy agitation and pumping tended to stabilize an oil in water emulsion. Tests 1 through 18 in Appendix B were conducted with this setup.

The next series of tests (19 through 62) continued in the TML DorrClone, but separate feed pumps were used for the oil and water. Mixing of the two components was obtained by blending the two streams upstream of a throttling valve and taking a controlled pressure drop across the valve. The pressure drops taken across the mixing valve were of the same order of magnitude (5 to 15 psi) as the pressure drops measured across the sand washer and cyclone combination during the sand washing program. This system produced a more consistent feed than the batch feeding approach and also permitted the use of heated water for the feed. Underflow and overflow rates were controlled by valving in the product lines. The apparatus is shown in Figure 7.

When two-stage cyclone testing was initiated (tests 63 through 67, 75 through 78, and 86 through 95), the modified flow loop shown in Figure 8 was used. In this setup, two TML units were used; the first one contained nine 10 mm cyclones while the second had four. This two-stage system was also used for recycle tests 79, 80 and 81 in which the underflow from the second stage was returned to the inlet of the water pump and blended with the raw feed. The recycle system yields only two product streams, rather than the three in the non-recycled two-stage setup.

The fourth group of tests used a single-stage system employing 6 inch diameter cyclones. Two series of tests (68 through 74 and 82 through 85) were carried out with the 6 inch units in the setup shown in Figure 7.

In all the tests, identical procedures were followed. Pumps were started and control valves set to produce the

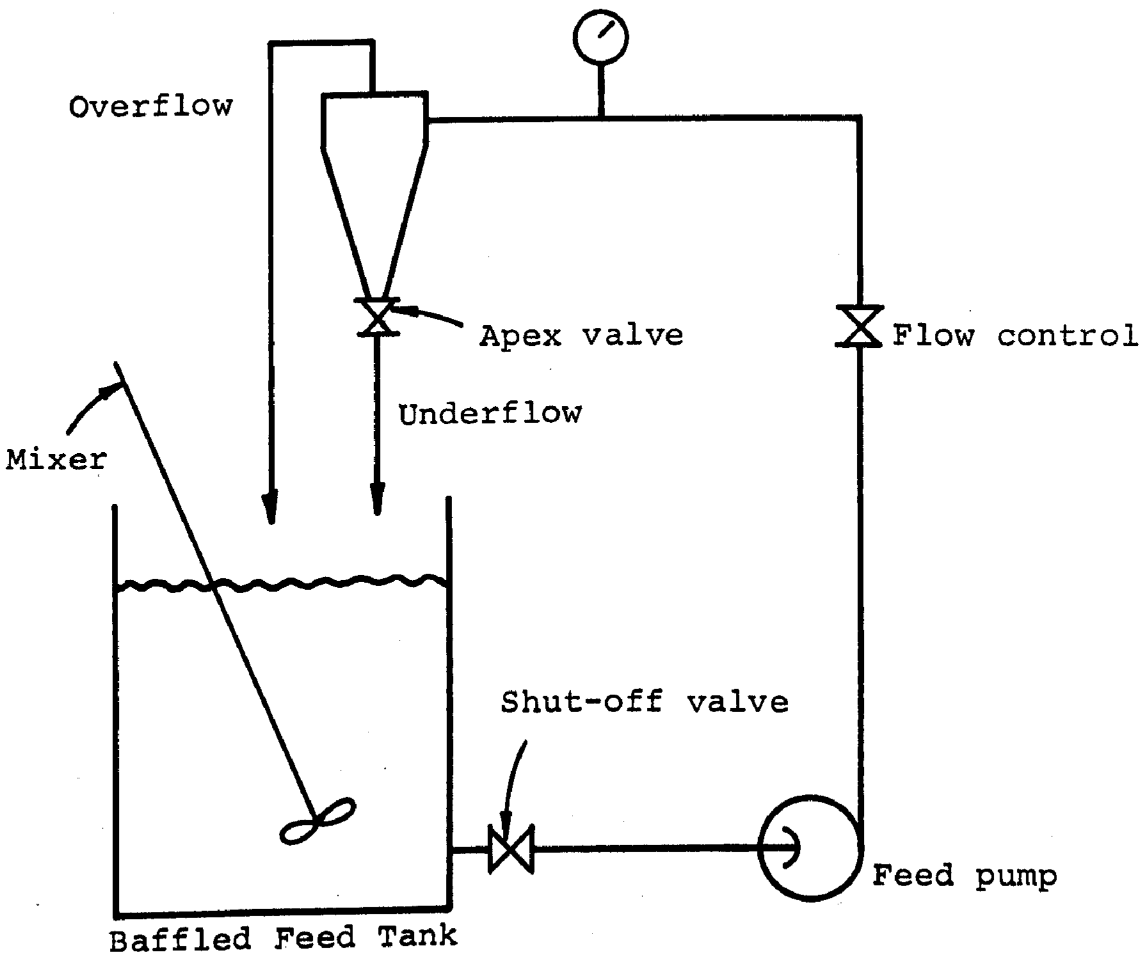


Figure 6. DORRCLONE TEST APPARATUS SCHEMATIC

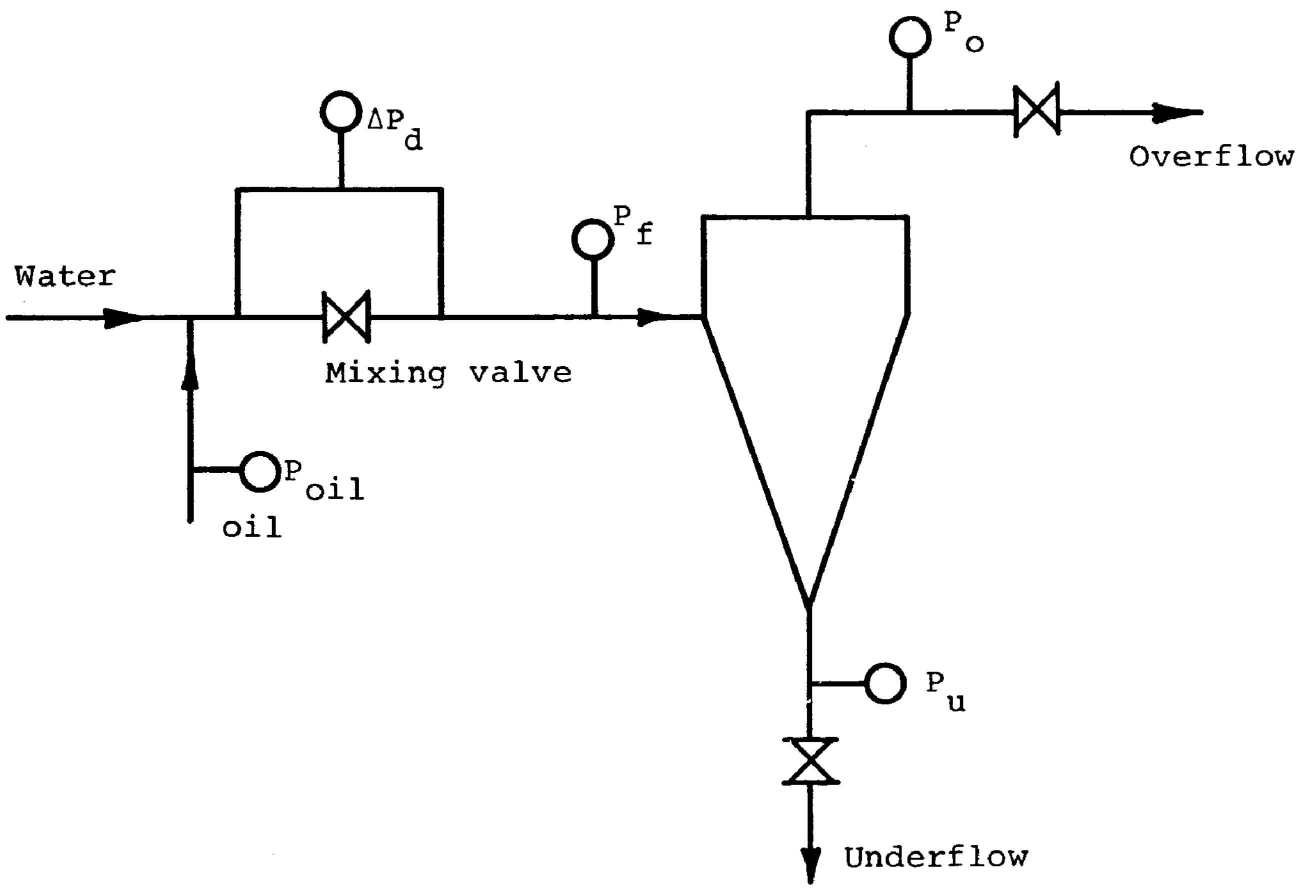


Figure 7. TML DORRCLONE AND 6 INCH DORRCLONE OIL-WATER SEPARATION FLOWSHEET

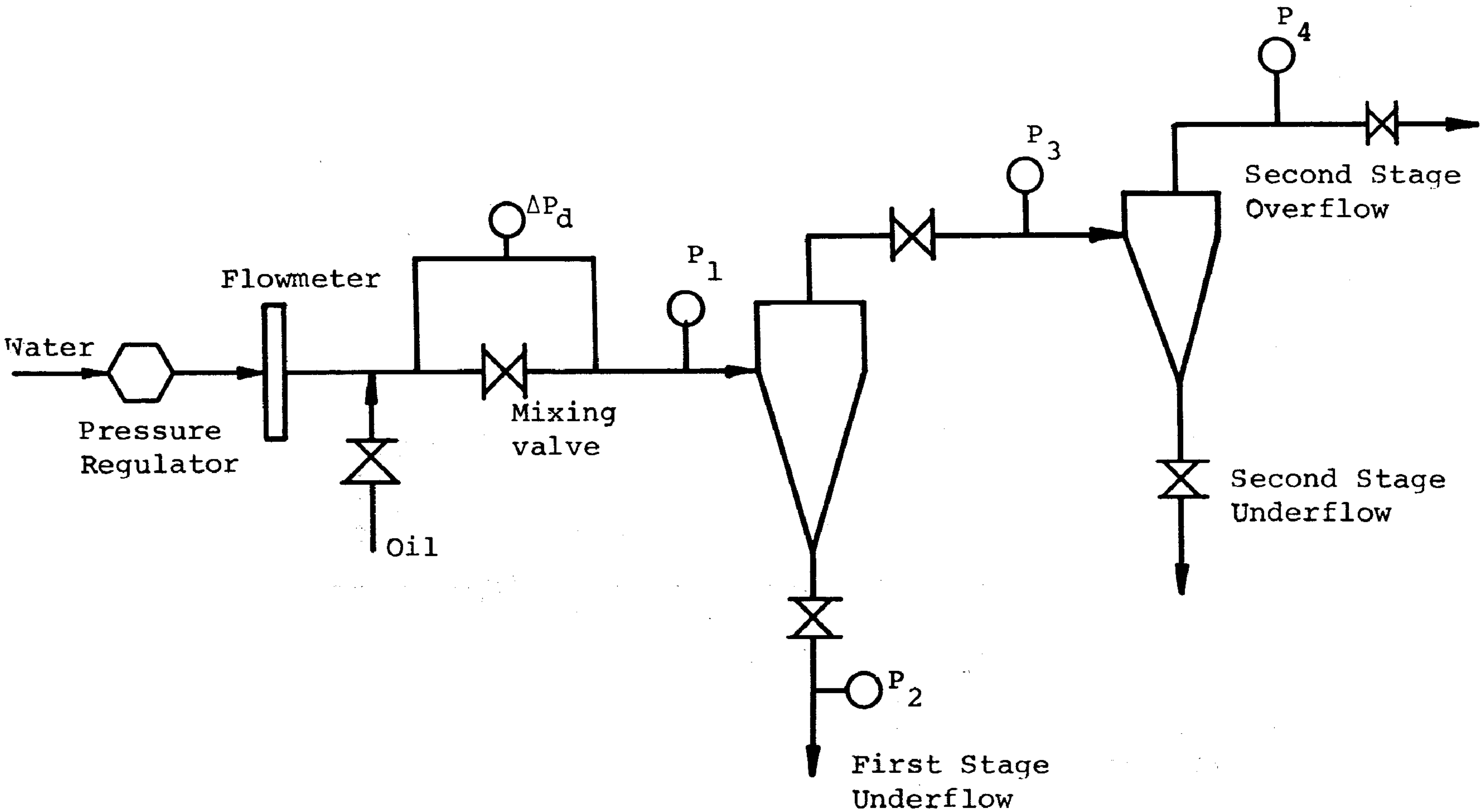


Figure 8. <u>TWO STAGE OIL-WATER SEPARATION FLOWSHEET</u>

desired ratio of overflow to underflow volume flow rates (this ratio is called the "split" and the terminology will be frequently used throughout the remainder of this report) or the desired visual clarity of the underflow streams. When the system was considered to be at equilibrium, flow rate and pressure data were recorded and samples of the product streams were collected for laboratory analysis.

Oil-water sample analysis

The fraction of oil in the various feed and product streams was determined by either of two methods, depending on the relative amounts of oil and water in any sample. In samples with low oil concentration, the oil from a sample of known volume or mass was extracted using chloroform. The chloroform was evaporated on a steam bath and the remaining oil volume or mass measured. The fraction of oil in the sample was then determined by comparing the mass of the extracted oil to the mass of the initial oil-water mixture.

In samples with low water content, the analysis was accomplished with a distillation technique. Here, toluene was added to the oil-water sample (of known volume or mass) in a distilling flask. The toluene and water were evaporated, condensed and collected in a trap. Here the two immiscible liquids separated and the toluene was returned to the distilling vessel. Water could be withdrawn from the trap and collected in a graduate, as needed. The distillation was continued until water flow from the condenser ceased. The volume of water collected was then used to determine the analysis of the original sample.

In the next section, we present the results of the two experimental programs and discuss these results and their implications on the feasibility of the proposed beach cleaning concept.

SECTION 6

RESULTS AND DISCUSSION

In this section are presented the results of the separate sand washing/separating and oil-water separating programs. A discussion of the results from each phase of the study is given and a preliminary conceptual design for a mobile beach cleaning plant is discussed.

Sand Washing and Separation Data Analysis

At the beginning of the sand washing program, a theoretical model of the washing mechanism was developed in order to try to understand which variables would be important in our analysis of the data.

This analysis showed that the oil stripping action is the result of viscous shearing caused by the relative velocity between the oil covered sand particles and the surrounding washing fluid. Interparticle and particle/wall abrasion may also be important to the cleaning process, but their effects were not included in the model. Neither did the model consider the problem of re-coating of the sand particles with the just stripped oil. However, based on the simple jar tests it did not appear that re-coating was a problem, since continued agitation of the cleaning mix revealed no detectable recontamination of the sand. What did result from this agitation though was emulsification of the oil in the water and loss of the easily separable nature of oil and water.

The conclusions drawn from study of the model were that too many uncertainties remained with regard to the effects of water film thickness (between the oil and sand particle), adhesion, and surface tension effects to permit useful interpretation of the theoretical results. For instances, by including a water film between the oil and sand, it was shown (in the model) that the time required to strip oil from the sand was reduced by several orders of magnitude from the case where the sand was oil-wetted only.

Though the model did not prove satisfactory in the analysis of our data, we did find after careful review of the results from preliminary tests, that the degree of oil removal from the sand was related to energy dissipation in the washer. Following is a brief discussion of this energy dissipation relationship and the results of the testing program are evaluated in terms of this energy expenditure and some of the feed and geometry parameters presented in Section 5.

The purpose of the fluid jets in the washer is to create viscous shear between the water and oil films. The level of shearing is related to the amount of energy dissipated in the washer. As mentioned earlier, the energy input to the washer comes primarily from the kinetic energy of the water jets and so the power (rate of energy utilization) consumed in the washer is:

$$\phi = Q \, \Delta p_w \tag{1}$$

where :

ϕ = power dissipated ($ft\text{-}lb_f/sec$)

Q = volume flow rate of water (ft^3/sec)

Δp_w = static pressure drop from washer inlet plenum to exit of washer (lb_f/ft^2)

By dividing the power dissipated, for any particular water flow rate and pressure drop situation, by the mass flow rate of sand in the washer, we can obtain an expression for the specific energy consumption.

$$SE_w = \frac{\phi}{W_s} = \frac{Q \, \Delta p_w}{W_s} \tag{2}$$

where:

SE_w = specific energy consumed in the washer ($ft\text{-}lb_f/lb_{sand}$)

W_s = mass flow rate of sand (lb_m/sec)

The cyclone also exacts a pressure drop penalty on the fluid system, resulting in further dissipation of energy. Here the specific energy term is:

$$SE_c = \frac{Q \ \Delta p_c}{W_s} \tag{3}$$

where:

SE_c = specific energy dissipated in cyclone ($ft\text{-}lb_f/lb_{sand}$)

Δp_c = pressure drop from inlet to outlet of cyclone (lb_f/ft^2)

The sum of SE_w plus SE_c gives the total specific energy consumed in the sand washing apparatus, for a particular set of feed parameters.

Oil removal effectiveness is the principal dependent variable of interest in the washing study and is defined as:

$$OR = \ell n \left(\frac{f_i}{f_o}\right) \tag{4}$$

where:

OR = oil removal effectiveness

f_i = fraction of oil in the sand feed

f_o = fraction of oil in the cleaned sand

In terms of the oil left in the sand after washing, an OR of 4 results in about 182 ppm of residual oil per percent of oil originally in the feed. OR's of 5 and 6 mean 67 and 25 ppm of oil remaining per percent oil in the feed. Feed oil concentrations ranged from 4.5% to 7.5% of the dry sand weight.

Table 1 lists the results of all the tests, including tabulations of the specific energy dissipations in the washer and cyclone and the oil removal effectiveness.

TABLE 1

RESULTS OF SAND WASHING TESTS

Test No.	Oil Removal Effectiveness OR	Washer Specific Energy SE_w ($ft\text{-}lb_f/lb_m$)	Cyclone Specific Energy SE_c ($ft\text{-}lb_f/lb_m$)	Mass Ratio (Sand/ Water)
1111-01	2.9	78	45	0.25
1111-02	3.79	111	62	0.176
1111-03	2.78	175	96	0.118
1111-04	2.11	154	96	0.112
1111-05	2.2	98	62	0.176
1111-06	2.72	69	45	0.25
1113-01	2.23	17	19	0.33
1113-02	2.19	23	25	0.249
1113-03	2.20	32	34	0.177
1113-04	2.28	51	54	0.111
1113-05	0.99	150	61	0.246
1113-06	1.13	177	71	0.208
1113-07	2.49	332	129	0.111
1123-01	2.36	61	17	0.328
1123-02	2.73	78	25	0.25
1123-03	3.28	108	38	0.176
1123-04	3.61	169	58	0.112
1123-05	3.05	24	11	0.33
1123-06	3.06	32	15	0.249
1123-07	3.41	46	12	0.177
1123-08	3.46	72	32	0.111
1123-09	3.33	140	30	0.246
1123-10	3.45	163	38	0.208

(Continued)

TABLE 1 (Cont)

RESULTS OF SAND WASHING TESTS

Test No.	Oil Removal Effective-ness OR	Washer Specific Energy SE_w ($ft\text{-}lb_f/lb_m$)	Cyclone Specific Energy SE_c ($ft\text{-}lb_f/lb_m$)	Mass Ratio (Sand/ Water)
1123-11	3.46	301	75	0.111
1124-01	3.08	49	23	0.328
1124-02	2.84	64	30	0.25
1124-03	3.27	91	41	0.176
1124-04	3.37	144	64	0.112
1124-05	3.12	17	19	0.33
1124-06	3.19	23	25	0.249
1124-07	3.63	32	34	0.177
1124-08	2.87	51	54	0.111
1124-09	3.02	131	30	0.246
1124-10	3.95	154	35	0.208
1124-11	7.25	290	64	0.111
1201-01	3.27	70	23	0.328
1201-02	3.33	92	30	0.25
1201-03	3.34	131	41	0.176
1201-04	4.13	205	64	0.112
1201-05	4.01	171	50	0.246
1201-06	3.94	201	56	0.208
1201-07	4.37	379	102	0.111
1202-01	3.75	66	27	0.328
1202-02	4.12	87	35	0.25
1202-03	4.48	124	48	0.176
1202-04	4.70	195	75	0.112
1202-05	4.1	159	71	0.246

(Continued)

TABLE 1 (Cont)

RESULTS OF SAND WASHING TESTS

Test No.	Oil Removal Effectiveness OR	Washer Specific Energy SE_w ($ft\text{-}lb_f/lb_m$)	Cyclone Specific Energy SE_c ($ft\text{-}lb_f/lb_m$)	Mass Ratio (Sand/Water)
1202-06	5.02	188	83	0.208
1202-07	4.23	353	151	0.111
1203-01	3.61	66	35	0.328
1203-02	2.96	87	45	0.25
1203-03	3.15	124	62	0.176
1203-04	3.68	195	96	0.112
1203-05	3.53	159	92	0.246
1203-06	3.61	188	107	0.208
1203-07	3.46	353	194	0.111
1214-01	3.94	70	47	0.328
1214-02	5.17	106	69	0.216
1214-03	5.86	131	83	0.176
1214-04	5.79	206	130	0.112
1214-05	5.6	168	92	0.246
1214-06	5.94	199	107	0.208
1214-07	5.43	374	194	0.111
1214-08	4.52	8	29	0.33
1214-09	3.74	37	40	0.249
1214-10	3.63	52	55	0.177
1214-11	3.85	83	86	0.111
1218-01	5.70	70	31	0.328
1218-02	5.49	92	40	0.25
1218-03	5.49	131	55	0.176

(Continued)

TABLE 1 (Cont)

RESULTS OF SAND WASHING TESTS

Test No.	Oil Removal Effectiveness OR	Washer Specific Energy SE_w ($ft\text{-}lb_f/lb_m$)	Cyclone Specific Energy SE_c ($ft\text{-}lb_f/lb_m$)	Mass Ratio (Sand/ Water)
1218-04	5.10	205	85	0.112
1218-05	6.05	159	92	0.246
1218-06	5.64	188	107	0.208
1218-07	6.23	353	194	0.111
1218-08	3.83	24	27	0.33
1218-09	4.15	32	35	0.249
1218-10	4.95	45	48	0.177
1218-11	4.87	72	75	0.111

These results are plotted in Figures 9 through 14 with the oil removal effectiveness (OR) as a function of the specific energy (both the specific energy dissipated in the washer alone and the total dissipated in the washer plus cyclone are used). All of the plotted data show the same general trend of increasing effectiveness with added energy dissipation. However, a flattening or fall off in the curves is seen indicating that the sand washing capability of the system does not increase without limit.

It appears that once a certain level of energy dissipation has been reached, further mixing does little to enhance the process and may, in fact, be detrimental. The drop in efficiency seen for some of the data could be caused by emulsification of the stripped oil and the subsequent carry-over of this oil in the water which discharges with the sand. In the analysis for oil in the underflow samples, we did not attempt to determine whether the oil fraction was actually adhering to the sand particles or if it had been carried through with the water.

In any event, the effectiveness of the sand washing system is impressive. The maximum OR achieved for sand contaminated with No. 4 fuel oil was 6.0 at a total specific energy consumption of 500 ft-lb_f/lb_m (Figure 12), while for the No. 6 oil the maximum OR was 5.0 at specific energy of 270 ft-lb_f/lb_m (Figure 13). Based on these maximums it should be possible to clean No. 4 oil from a beach and leave behind a trace of oil at a concentration of about 125 ppm (assuming 5% oil on the beach initially) with an expenditure of about 0.6 horsepower per ton of sand washed per hour, in the washer/cyclone combination. If the contaminant had been No. 6 oil, the residual would be at about 350 ppm (5% oil initially in the sand), but the power expenditure would drop to 0.3 horsepower per ton per hour. Cleaning of No. 4 oil to an OR level of 5 would require only about 0.15 horsepower per ton per hour.

Figure 9 shows the results from tests conducted with No. 6 oil and with both the washer nozzle geometry and the mixing length as parameters. The best performance was obtained when nozzle No. 1 and the shorter mixing section (12") were used in combination. For tests run with the longer mixer (24"), the data are indistinguishable between nozzle No. 1 and nozzle No. 2.

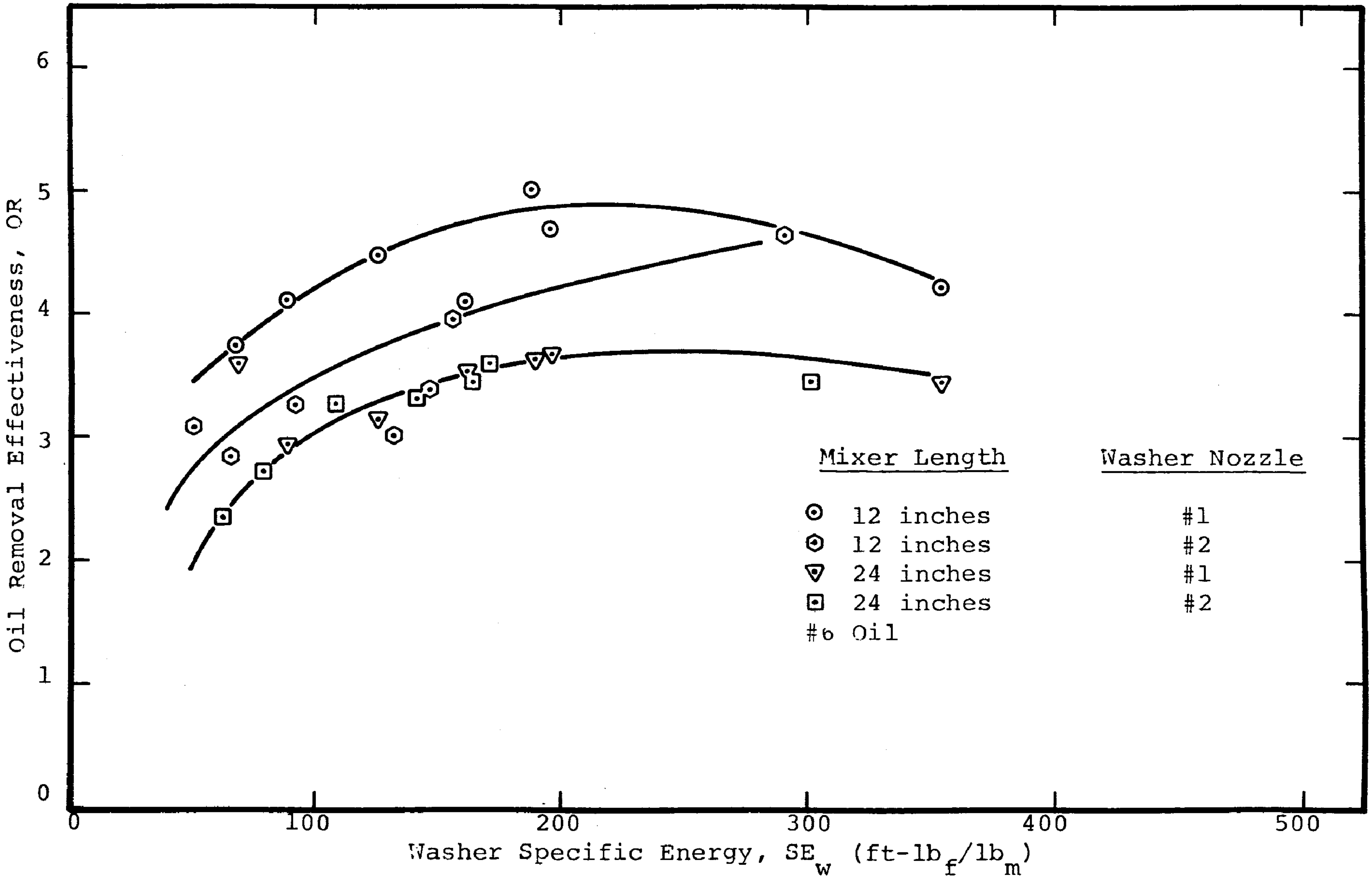


Figure 9. PERFORMANCE OF SAND WASHING PILOT PLANT

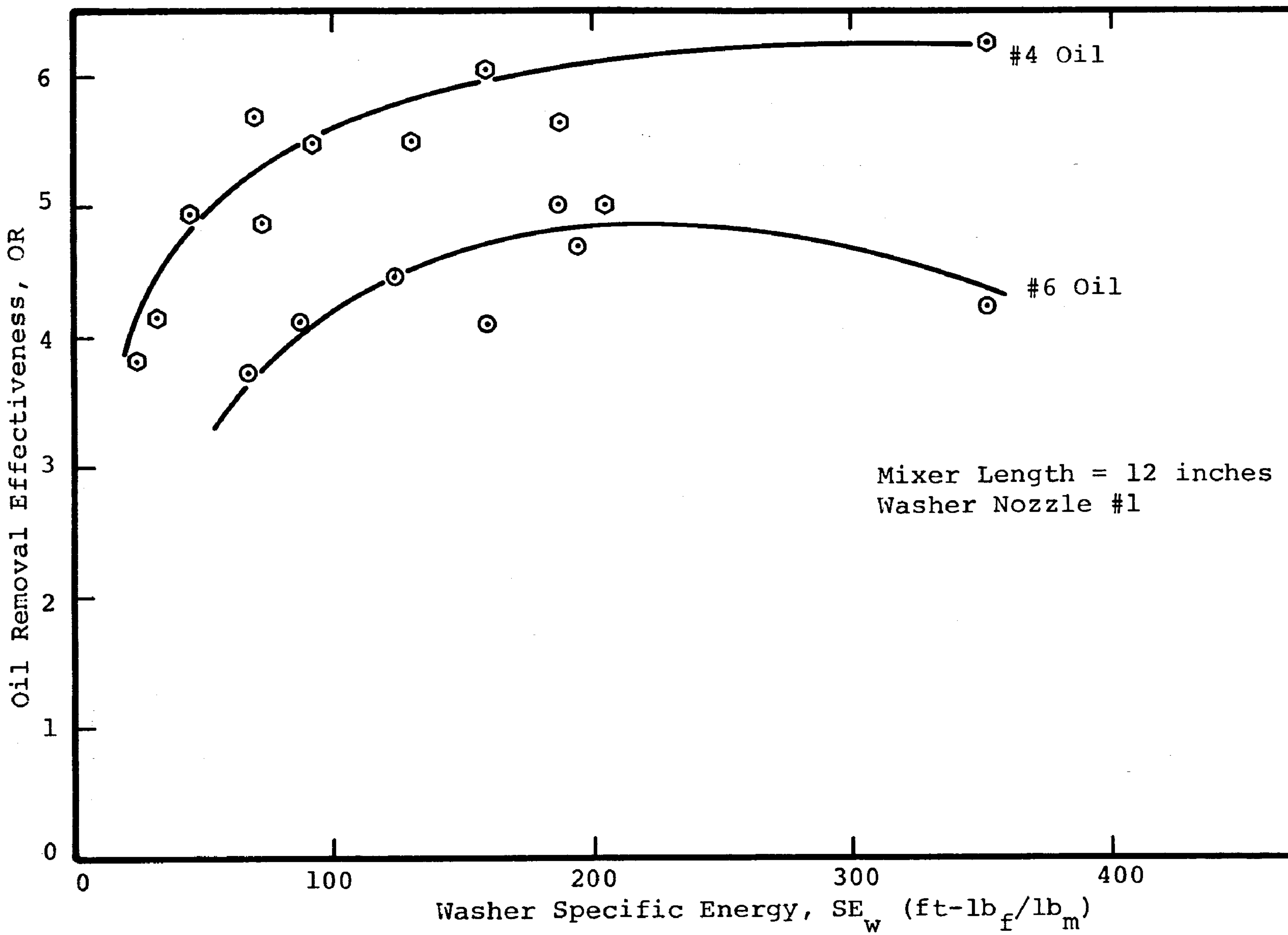


Figure 10. PERFORMANCE OF SAND WASHING PILOT PLANT

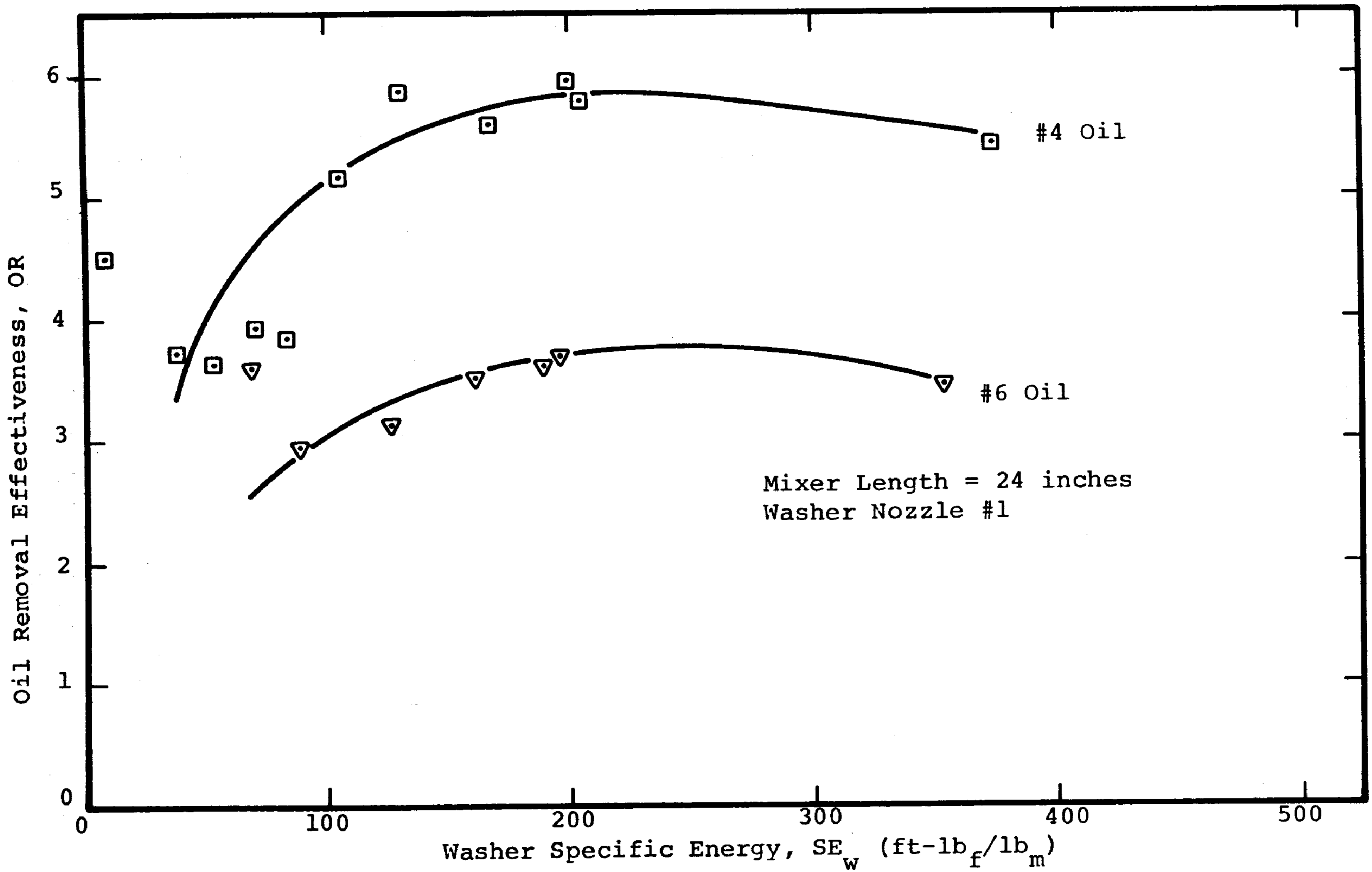


Figure 11. PERFORMANCE OF SAND WASHING PILOT PLANT

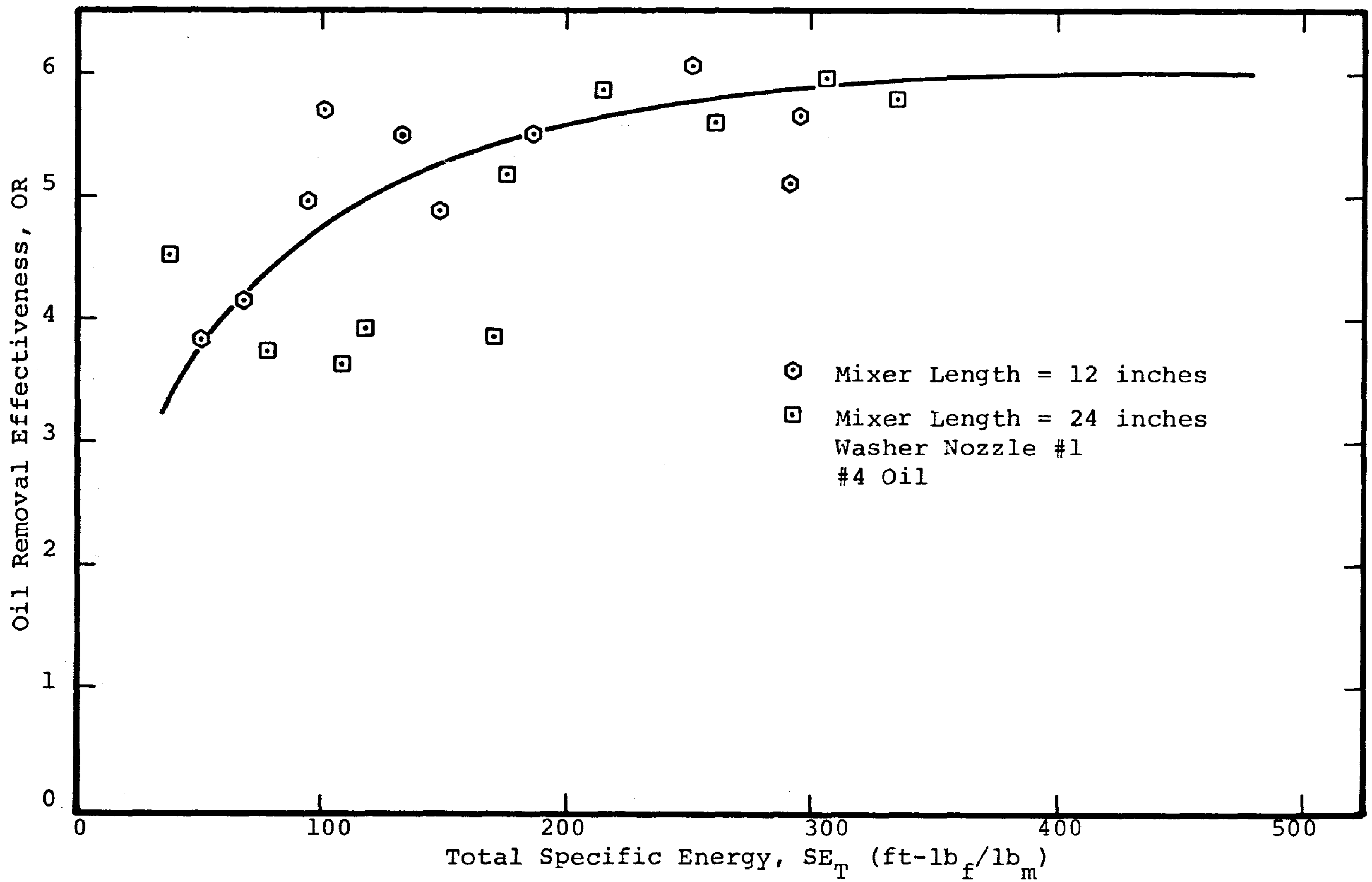


Figure 12. PERFORMANCE OF SAND WASHING PILOT PLANT

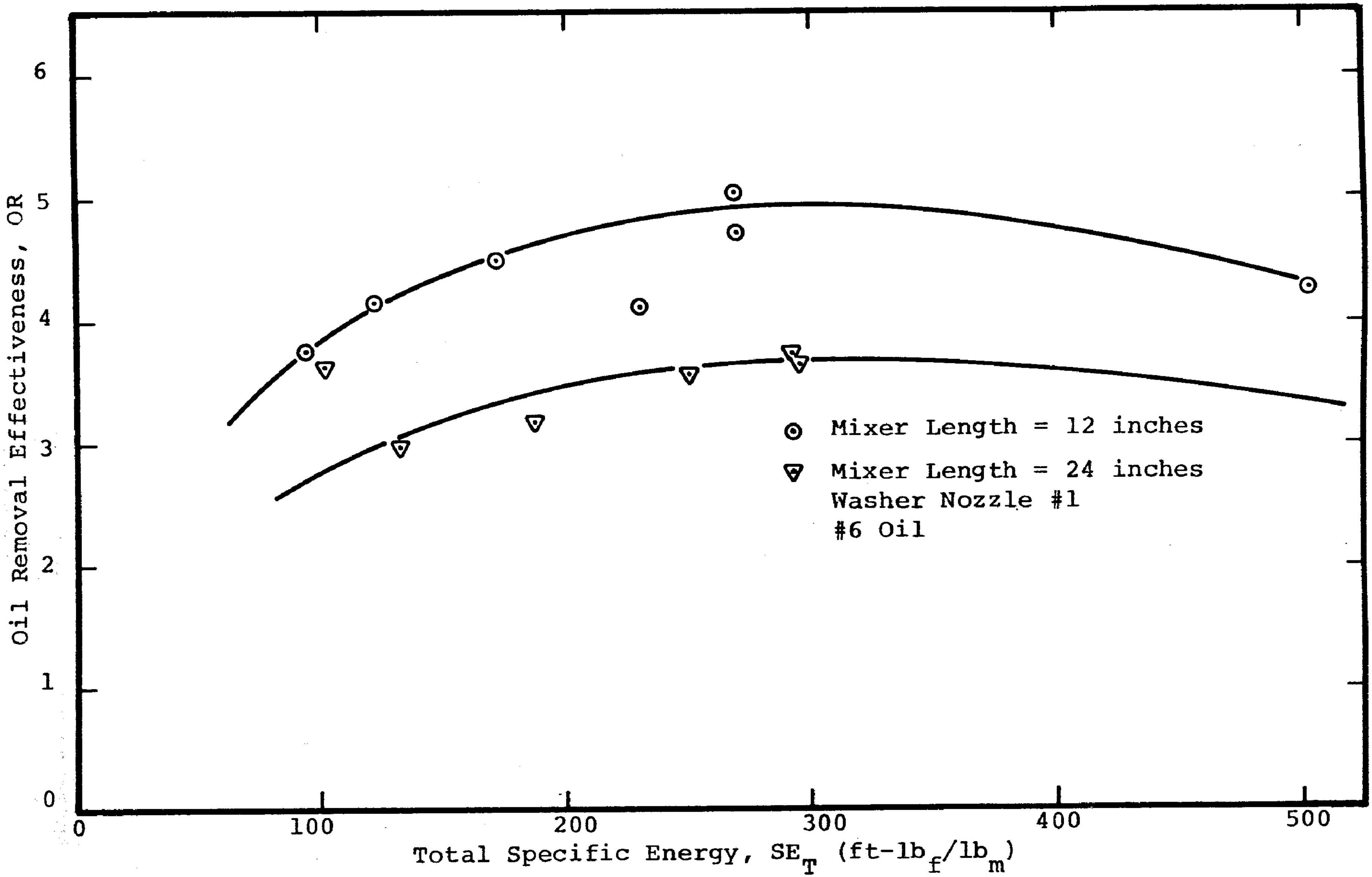


Figure 13. PERFORMANCE OF SAND WASHING PILOT PLANT

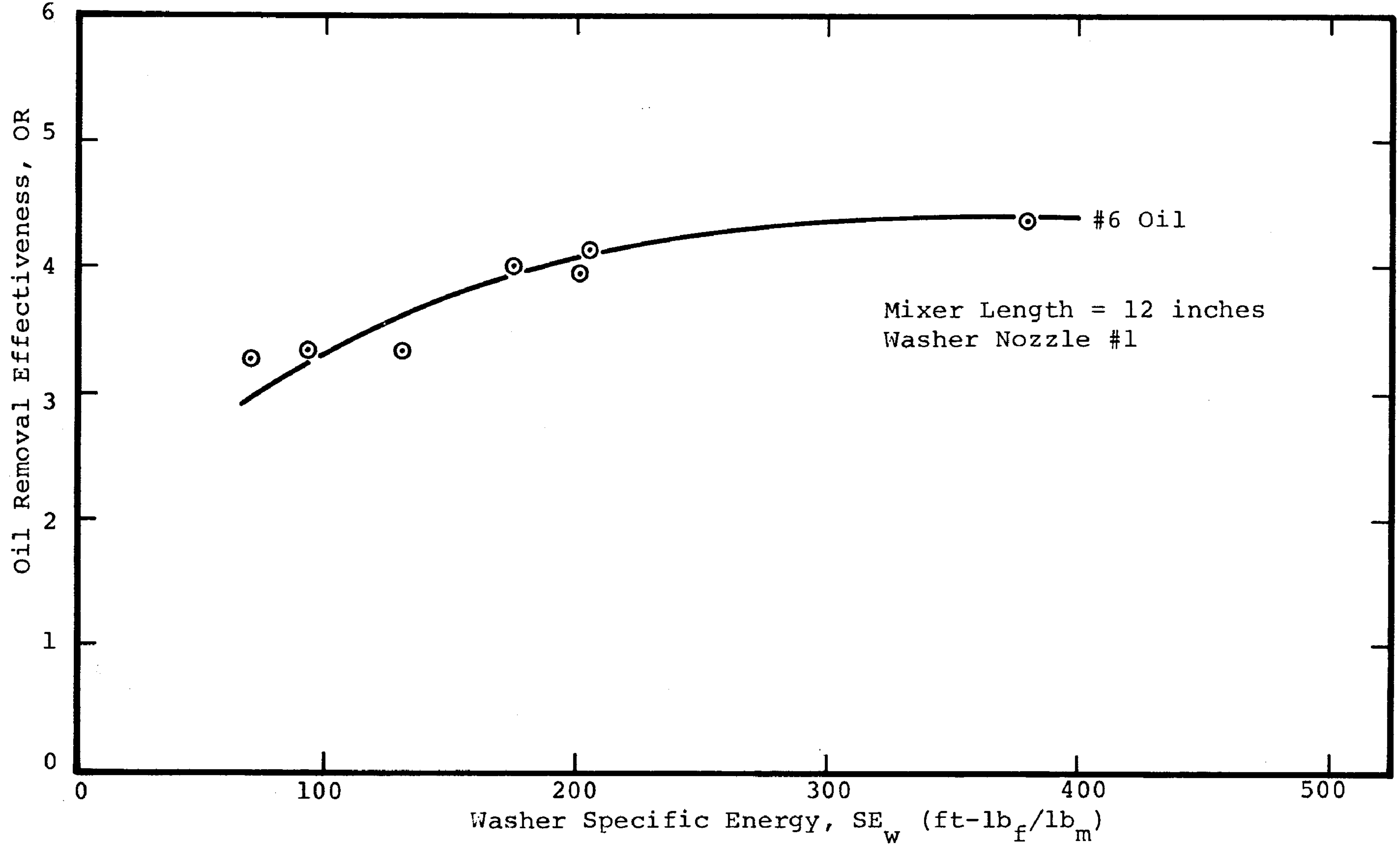


Figure 14. PERFORMANCE OF SAND WASHING PILOT PLANT "AGED" SAND/OIL TESTS

In Figures 10 and 11, comparisons are made between tests run with the two types of oil and with variable mixing lengths. These curves show that No. 4 oil is considerably easier to clean from sand than the heavier No. 6 oil, as might be expected. By comparing the two figures, it is seen that the shorter mixing length gives better results in terms of oil removal effectiveness, for either oil type, although the distinction between the 12 inch and 24 inch data is not great for the No. 4 oil. Figure 12 shows the same data for the No. 4 oil plotted against the total specific energy consumption, and here the difference in performance between the tests run with the two mixing lengths is obscured by the scatter in the data.

The test results are the No. 6 oil are plotted in Figure 13 against total specific energy with the mixer length as a parameter. Again the shorter mixer length gives better performance.

All of the plotted data show a higher OR for the washer fitted with the shorter of the two mixing lengths. The original reason for including this variable was to increase the holdup time of the washer and hopefully allow more time for the scrubbing action to take place. For the same specific energy level, the shorter mixing length (and time of mixing) results in a more vigorously stirred reactor, dissipating a higher level of horsepower per pound of sand in the washer. Now, it appears that the longer holdup time is not needed, rather a very intense scrubbing action of short duration is sufficient to effect a very high degree of oil removal.

<u>Special Sand Washing Tests</u>

In Section 5, it was mentioned that several special tests had been run using "aged" oil contaminated sand and in which sorbers had been added to the feed.

<u>"Aged" sand tests</u>

The tests listed in Table 1 in the sequence 1201-01 through 1201-07 were run with aged oil-coated sand. The mix was prepared by applying about 5% by weight of a No. 6 oil to the surface of a 4 inch thick layer of wet sand. Two, 500 watt, infrared heat lamps were placed above the mix (about 4 feet from the surface), and over the course of 48 hours the sand was exposed to this light source for a total of about 20 hours. The surface of the oily sand did not rise above about 120°F. At this temperature level, oil seeped through the layer of sand to a depth of about 2 inches, coating at least 50% of the sand. After the exposure period, the sand-oil layer was thoroughly mixed into the clean, underlying sand and allowed to cool to room temperature.

This mix was loaded into the feeder and a series of washing tests performed. The results of these tests are plotted in Figure 14 as oil removal effectiveness versus washer specific energy consumption. The peak OR is not as great as that shown for similar test conditions with freshly mixed sand and No. 6 oil (Figure 10), however, the performance is quite good.

This method of "aging" oil does not exactly duplicate the characteristics of naturally weathered oil found on beaches after spills; however, within the time available and the limited nature of the feasibility study, no further work along these lines appeared justifiable.

Sorber testing

Only two tests were run with straw mixed into the sand feed and they proved to be of limited success. Straw, at 2% of the weight of the sand, was used as the sorber and was thoroughly mixed into the sand along with No. 4 oil which was at 5% of the sand weight. With this feed, the unit ran quite smoothly for about 15-30 seconds after which time the overflow from the cyclone stopped completely and flow backed up through the mixing section. During the steady operation the underflow sand was clean as in previous tests, but it contained small shreds (1/4" - 1/2" long) of straw which were quite black with oil. After tearing down the cyclone, it was found that 2 to 3 inch lengths of straw had formed a plug at the inlet to the vortex finder (overflow port), effectively blocking the flow.

The test apparatus was completely cleaned out, a larger vortex finder (2-1/2") was installed in the cyclone and the test repeated. Now the unit operated at steady-state for about 2 minutes processing about 50 pounds of sand per minute with a water feed rate of 30 gpm. The overflow carried away most of the straw with the oil and wash water, however, a considerable amount of straw was swept along with the sand underflow. The effect of straw in the underflow was to give a dirty appearance to the sand, since the straw still retained sorbed oil.

Although we did not test other sorbing agents, it is possible to extrapolate the results of the present program to the processing of beach sands which contain quantities of other available sorbers, e.g. talc, polyurethane foam chips and a large assortment of commercially available products. One common characteristic of the agents used for sorbing oil is that when they are mixed with oil their specific gravity is such that they will float on water. For this reason, sorbers which enter the sand washing separation system under study will for the large part pass out of the system with the oil. As was seen in the tests discussed above, some uncleaned straw came out in the sand underflow and this is to be expected since the high volume flow of sand can "trap" sorber and sweep it along.

It is evident that the sorber should be segregated from the sand prior to feeding it through the sand washing system, particularly if the sorber is of sufficient size to cause plugging of the washer or cyclones. Also, sorber passing from the sand separation stage with the oily water is included as feed for the oil-water separation cyclones and the effect it might have on this process is not known, although it is not expected to be favorable.

Oil Water Separation Results

Evaluation parameters

Before presenting the results of the oil water separation tests, it might be useful to examine some of the liquid-liquid separation parameters and discuss their relationships.

The correlating parameter most frequently found in the literature on liquid-liquid separation in cyclones is the separation number or efficiency, E_s. This number considers the cyclone product streams to be pure phases (in the present case water at the underflow, and oil at the overflow) and then defines E_s as the sum of the rates of pure components, expressed as a fraction of the feed flow.

$$E_s = \frac{Q_o}{Q_f} \left[\frac{y_o - y_f}{y_f(1-y_f)}\right] \quad (5)$$

where:

Q_f = volume rate of feed

Q_o = volume rate of overflow

y_f = fraction of light component (oil) in feed

y_o = fraction of light component (oil) in overflow

This efficiency term is quite misleading when the objective of the separation is to obtain a pure product of either the light or heavy phase, since high values of E_s can be reached with neither product stream in the pure state. Better terminology for the present case might be to look at the recovery of water at the underflow and the recovery of oil at the overflow, R_w and R_o respectively.

$$R_w = \left(\frac{1 - y_u}{1 - y_f}\right) \left(\frac{Q_u}{Q_f}\right) \quad (6)$$

and,

$$R_o = \left(\frac{y_o}{y_f}\right) \left(\frac{Q_o}{Q_f}\right) \quad (7)$$

where:

Q_u = volume rate of underflow

y_u = fraction of light component in underflow

Then, an R_o of unity means that all of the oil in the feed was discharged to the overflow, while an R_w of unity means that all of the water in the feed passed to the underflow.

Two other terms of interest in analyzing the separation data are:

$$S = \text{split} = \frac{\text{overflow rate}}{\text{underflow rate}} = \frac{Q_o}{Q_u} \qquad (8)$$

and,

$$C = \text{enrichment factor} = \frac{\text{volume fraction of oil in overflow}}{\text{volume fraction of oil in feed}}$$

$$= \frac{y_o}{y_f} \qquad (9)$$

There are various other manipulations which can be made and which could prove useful in analyzing the data. For instance, the oil recovery R_o can be re-written as:

$$R_o = C[\frac{S}{S+1}] \qquad (10)$$

and it is seen that increasing either C or S improves the recovery of oil at the overflow.

The volume split S has been recognized in the cyclone literature (Ref. 3) as being the primary controlling process variable, as will be seen in the later discussion of the oil-water separation data. The enrichment factor C is important in that it describes the increase in oil concentration across the stage. This parameter will be of particular interest in the discussion on the conceptual design of a full-scale sand washing system.

Evaluation of the data

In evaluating the results of the complete test program, some data has been used more extensively than other information. For example, the tests numbered 1 through 18 Appendix B have been eliminated here because the data did not fit the trends found in later work. There are several reasons for this inconsistency.

1) No attempt was made to control the feed characteristics in this early series of tests. The oil and water were placed in a tank and agitated with a small propeller, also product streams from the cyclone were returned to this same tank.

2) Feed mixture was pumped from the tank and the cyclone inlet pressure was controlled via the throttle valve used to control the flow rate of oil and water. Varying the drop across this valve would create significant differences in the feed to the cyclone.

Although this data is not included in the following discussion, it should be noted that these early tests demonstrated the feasibility of the concept of cyclone separation of oil and water and pointed the direction for further work.

Most of the analyses were done with data from the one and two stage 10 mm cyclone tests, supplemented with information from the recycle and No. 6 oil tests. The results of the 6 inch cyclone work are shown in several of the figures, however, they do not correlate as well as would be expected. It is not certain at this time why this discrepancy exists, but further test work with the larger cyclones would surely eliminate some of this difference, or point out the proper scaling factors.

An overview of all the data shows a pronounced effect on the separation due solely to the volume split (overflow rate divided by underflow rate). In Figures 15 and 16, the enrichment factor C is plotted as a function of S. For Figure 15, data points were selected so that curves of constant feed oil concentration would result. Study of the figure reveals that there is little dependence on feed oil concentration, in the range presented, on the enrichment factor. As a result, all of the No. 4 oil data were replotted in Figure 16, without regard to feed oil concentration.

This latter figure is indicative of the expected trend of the data, since oil should preferentially be discharged at the overflow and water at the underflow. As the percentage of feed reporting as overflow decreases (split decreases), the concentration of oil in the overflow should increase relative to that of the feed (enrichment increases).

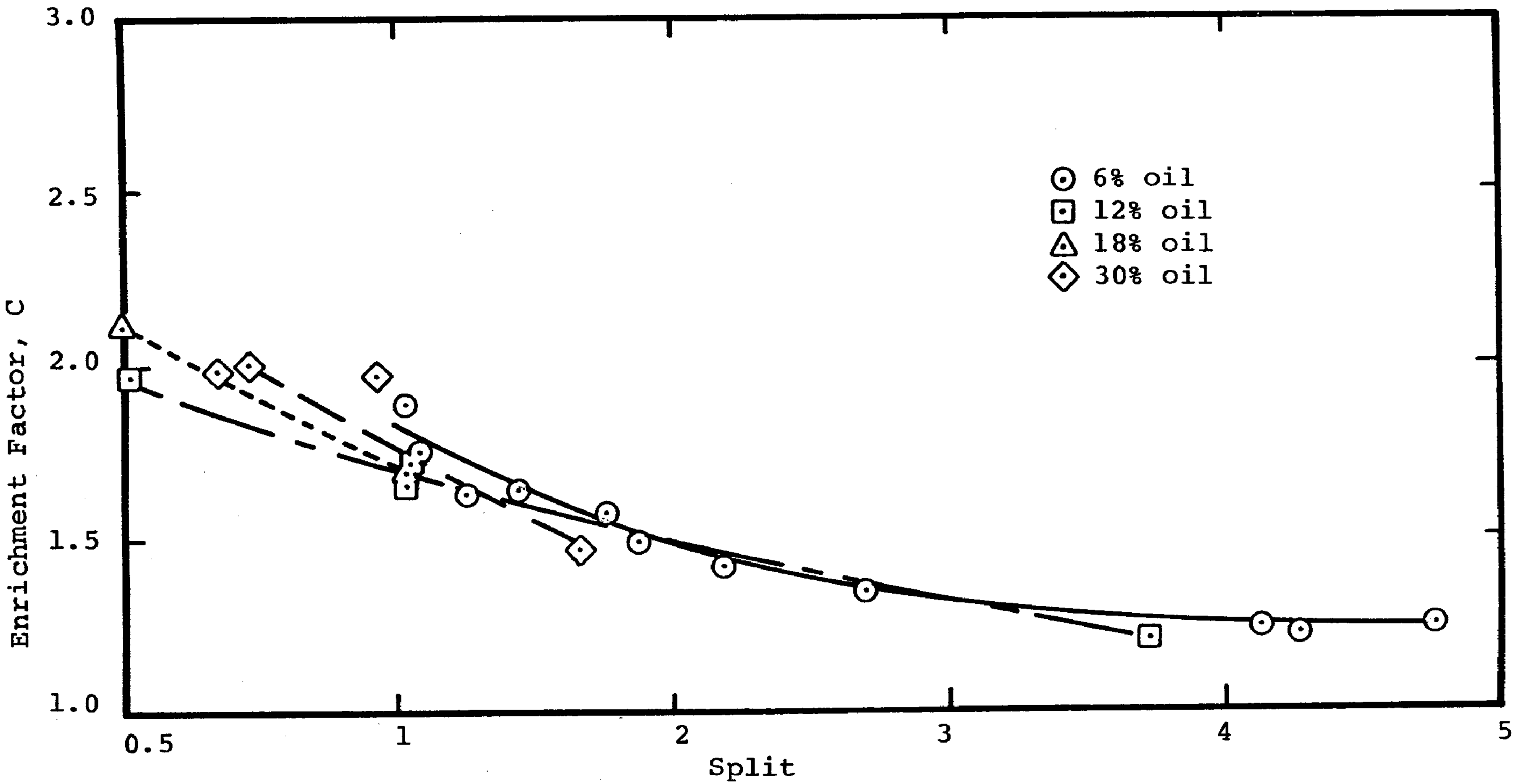


Figure 15. PERFORMANCE OF OIL-WATER SEPARATING CYCLONES

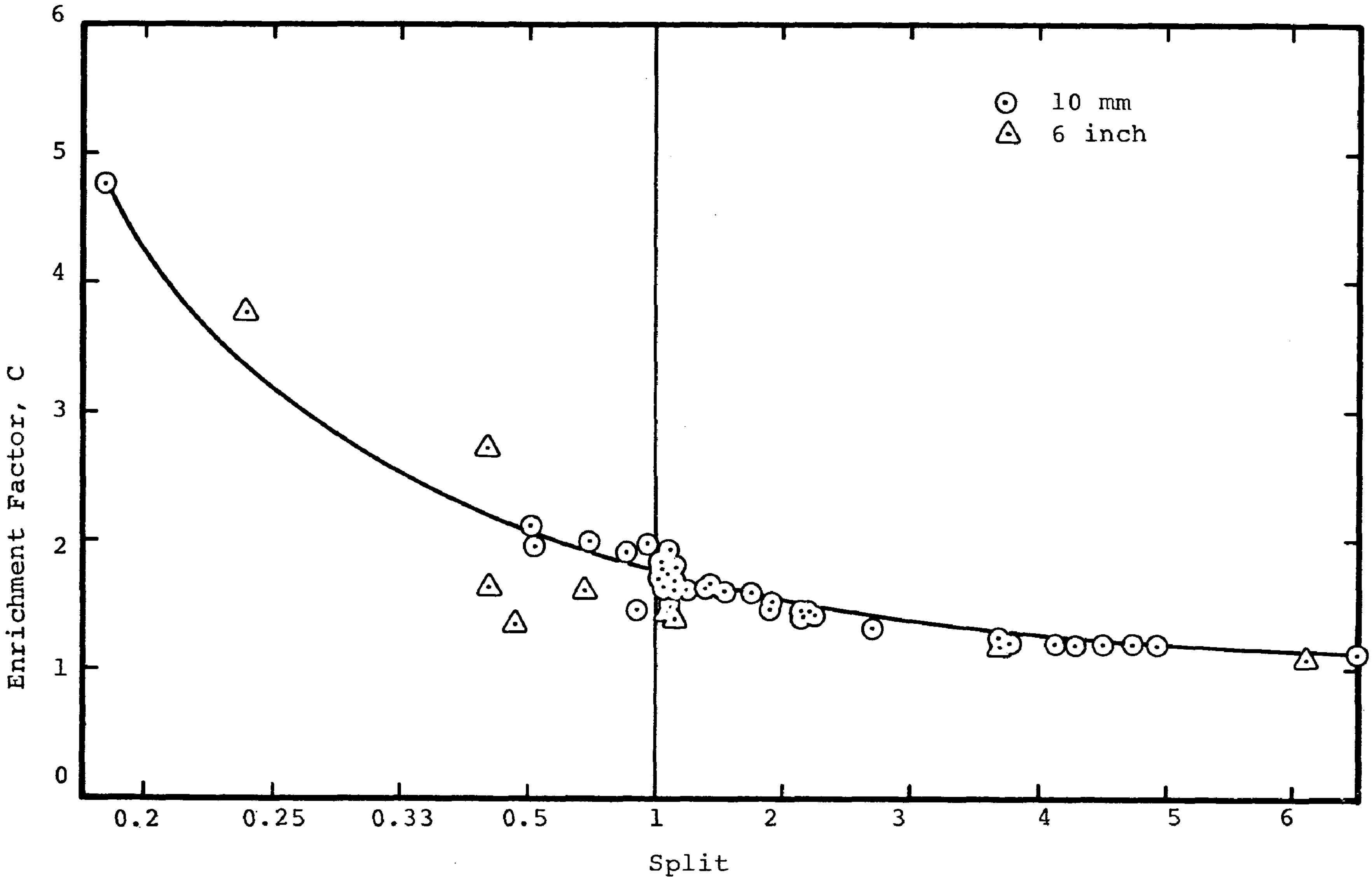


Figure 16. PERFORMANCE OF OIL-WATER SEPARATING CYCLONES

And, as the percentage of overflow increases, with smaller flows removed as underflow, the value of C should decrease to unity. The enrichment factor can never go below unity, unless there is something seriously wrong with the operation of the cyclone. The recovery of oil R_o has not been included in these graphs, and a high value of C does not necessarily mean a high recovery.

From Figure 15 it appeared that feed oil concentration did not markedly affect the enrichment factor; however, by replotting C versus y_f, with constant values of S (Figures 17 and 18), a different conclusion is reached. At high splits the earlier assumption is seen to hold true, but as the split decreases to unity and below, feed oil concentration does begin to influence the enrichment. Generally, the enrichment factor is insensitive to y_f until the split approaches 1 and then the enrichment factor decreases with increasing y_f.

The data in Figures 17 and 18 should not be extrapolated beyond the feed concentrations shown. During the testing it was found that the maximum overflow oil concentration attainable with the setup was 75 to 80% and if, for instance, the S = 0.6 line in Figure 18 was extrapolated to a y_f of 0.50 the expected overflow concentration would be about 85% (C = 1.7). It is doubtful whether even this small a gain would be possible.

In all tests after the first 18, a throttling valve was used to blend the oil and water streams. The effect of mixing valve pressure drop Δp_d on C is shown in Figure 19. As expected, C decreases with increasing Δp_d, although the drop is not too great. This behavior was also demonstrated in the two stage testing in which the high shear (and pressure drop) from the first stage cyclone did not appear to affect the performance of the second stage.

Some of the early test work seemed to indicate that the water type (tap, brackish, and sea water) and temperature (water temperatures up to 155°F were used) affected the separation. However, a more detailed evaluation of the

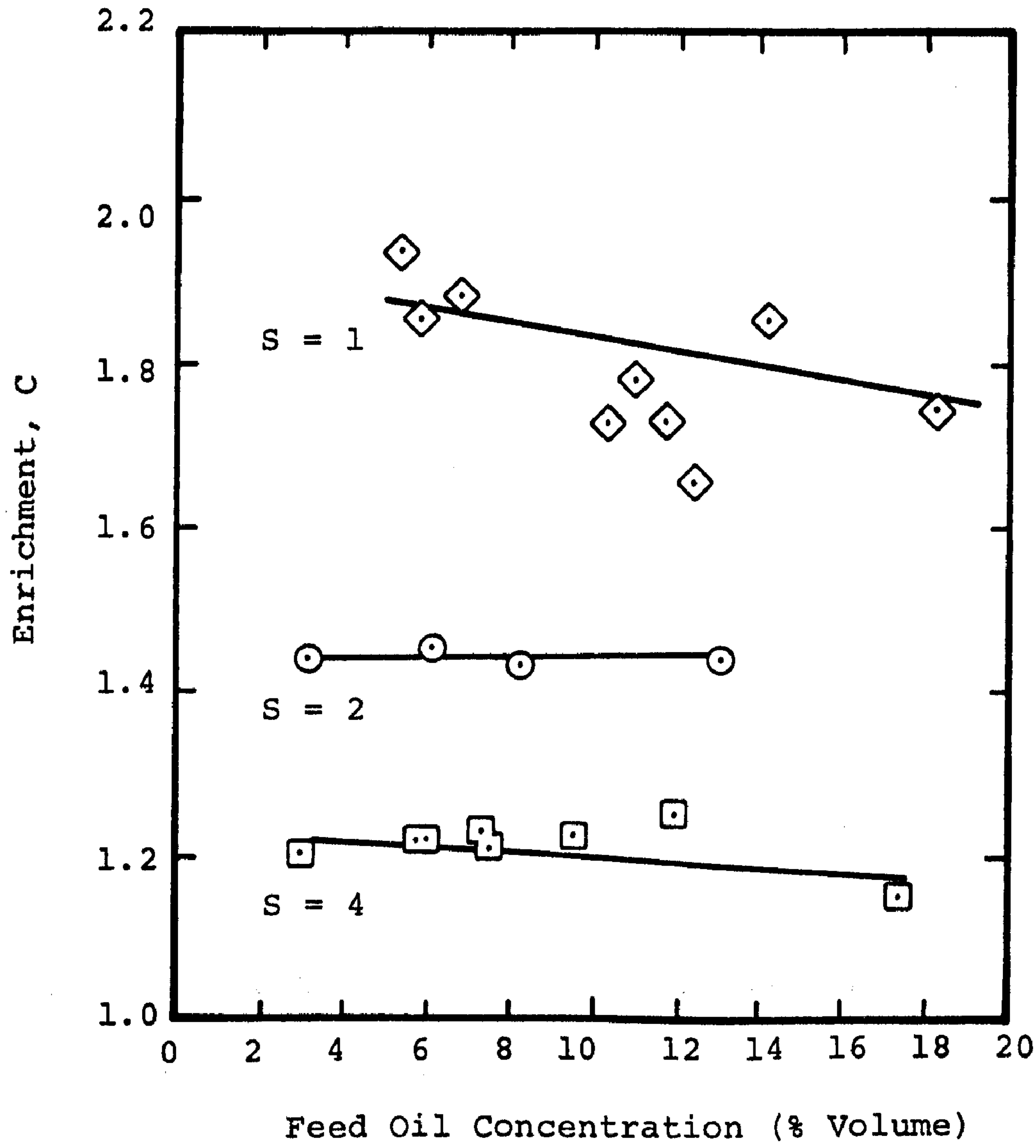


Figure 17. EFFECT OF FEED CONCENTRATION ON ENRICHMENT

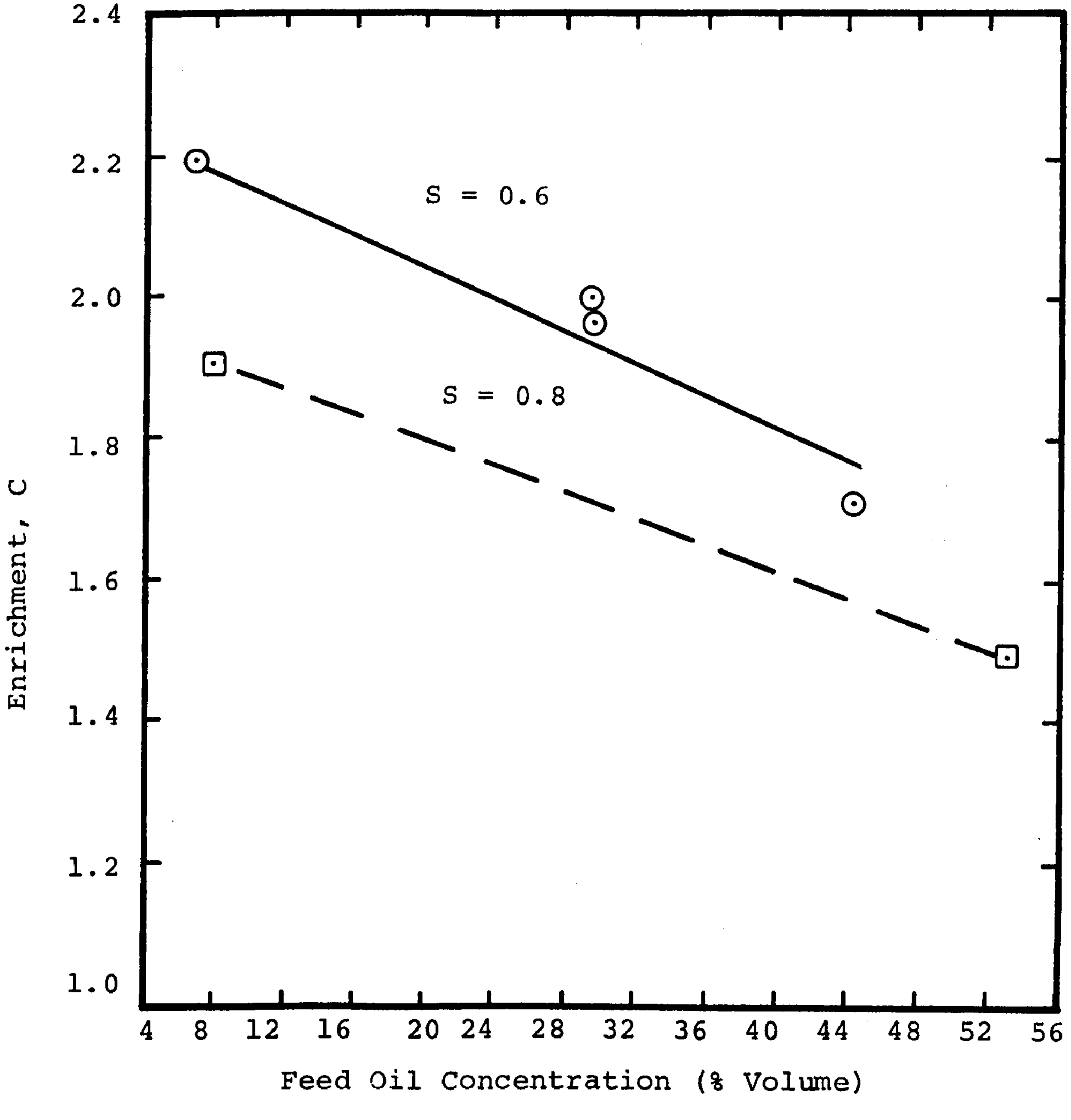


Figure 18. EFFECT OF FEED CONCENTRATION ON ENRICHMENT

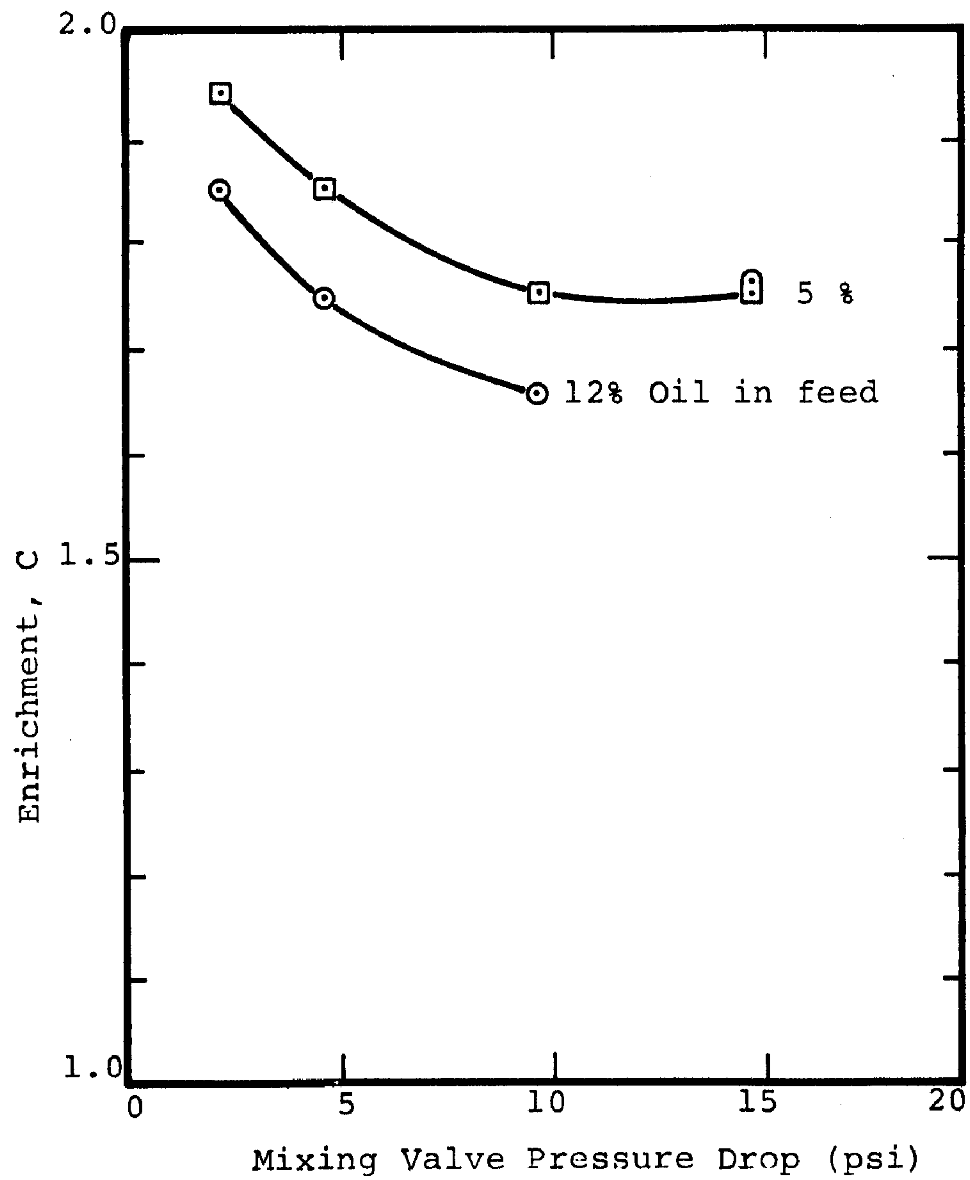


Figure 19. EFFECT OF PRESSURE DROP AND FEED CONCENTRATION ON ENRICHMENT

data refutes this original hypothesis. Although the increase in water temperature decreases the oil viscosity significantly and the salt water has emulsion inhibiting and breaking properties, the gain in performance is small. Even the higher specific gravity of sea water showed no great benefit. Tables 2 and 3 show that the enrichment factor attained using brackish (100 ppm NaCl in tap water) and sea waters could be predicted using the results from the fresh water testing. The only indicated benefit is a small increase in oil recovery R_o over similar tests run with room temperature fresh water.

Even the type of oil appeared to be of little significance in determining the enrichment factor C. Table 4 shows predicted C values for No. 6 oil, using data from the No. 4 oil tests, against the C values actually attained. The No. 6 oil tests were run with the oil heated to about 120°F to aid in pumping, and this may have had some beneficial effect on the performance. Only further testing with the heavier oil at reduced temperatures will settle this question.

In Table 5, the predicted performance for the recycle tests is compared with that actually attained with the two stage recycle setup. There is some discrepancy in these data, but the maximum error in predicting C is only 8%.

As may be seen in Figure 16, the data attained with the six inch cyclones did not agree well with the 10 mm data and it was not always possible to predict the performance of these larger units from the available data (Table 6). At high split values, the enrichment factor could be predicted but at values near or below 1, that correlation is poor. Careful examination did reveal that the data from the plastic cyclone were more predictable than that from the rubber lined FR unit. This seeming anomaly might be explained by the closer geometric similarity between the 6 inch plastic and the 10 mm units than the FR and 10 mm. In any case, the complete explanation for the behavior of the 6 inch unit must await further testing and analysis.

In summary, the feasibility of oil-water separation in cyclones has been demonstrated and sufficient data are

TABLE 2

EFFECT OF WATER TYPE ON PREDICTING ENRICHMENT

Oil in Feed (Vol. %)	Split ($S=Q_o/Q_u$)	Water Type	Enrichment Factor ($C=y_o/y_f$) Predicted	Actual
13.2	2.24	Salt*	1.42	1.44
8.3	1.91	Salt	1.51	1.53
9.0	1.54	Salt	1.60	1.62
17.4	6.52	Salt	1.15	1.15
8.3	1.40	Sea	1.62	1.65
6.5	2.69	Sea	1.36	1.34
6.6	1.74	Sea	1.55	1.58
9.3	1.49	Sea	1.62	1.67
8.4	1.44	Sea	1.63	1.68

* Salt Water - 100 ppm NaCl added to tap water

TABLE 3

EFFECT OF FEED TEMPERATURE ON PREDICTING ENRICHMENT

Oil in Feed (Vol %)	Split ($S=Q_o/Q_u$)	Temperature (°F)	Enrichment Factor ($C=y_o/y_f$) Actual	Predicted
8.1	2.54	55	1.38	1.36
11.2	1.09	55	1.76	1.71
6.7	1.98	55	1.49	1.45
10.0	1.77	55	1.55	1.56
6.1	6.34	115	1.13	1.12
6.9	2.34	115	1.36	1.38
5.7	1.98	152	1.47	1.48
8.4	1.40	152	1.72	1.66
5.3	1.36	122	1.70	1.70
9.0	1.63	122	1.61	1.58
7.7	1.43	76	1.66	1.65
8.0	1.25	76	1.90	1.94
6.2	2.17	105	1.45	1.44

TABLE 4

EFFECT OF OIL TYPE ON PREDICTING ENRICHMENT

Oil in Feed (Vol %)	Split ($S=Q_o/Q_u$)	Enrichment Factor ($C=y_o/y_f$) Actual*	Predicted**
8.4	1.47	1.66	1.64
13.9	1.59	1.58	1.56
7.7	1.40	1.57	1.66
12.1	1.08	1.76	1.74
3.8	1.20	1.79	1.75
6.8	0.6	2.20	2.20
6.2	4.30	1.23	1.24
7.6	1.20	1.79	1.74

*Data from tests with No. 6 oil

**Predicted from test results with No. 4 oil

TABLE 5

EFFECT OF CYCLONE UNDERFLOW RECYCLE ON PREDICTING ENRICHMENT

Oil in Feed (Vol %)	Split ($S = Q_o/Q_u$)	Enrichment Factor ($C=y_o/y_f$)	
		Actual	Predicted
4.6	5.11	1.17	1.17
5.4	1.99	1.46	1.48
4.7	1.28	1.62	1.72
7.6	0.9	1.96	1.80
13.2	1.36	1.70	1.68
22.4	4.20	1.19	1.24

TABLE 6

PREDICTION OF 6 INCH CYCLONE OPERATION

Oil in Feed (Vol %)	Split ($S = Q_o/Q_u$)	Cyclone Type	Enrichment Factor ($C=y_o/y_f$) Actual	Predicted
4.9	3.7	Pl*	1.24	1.26
3.4	0.24	Pl	3.79	3.30
5.7	6.1	Pl	1.14	1.15
4.6	0.48	Pl	1.37	2.10
2.8	0.44	Pl	2.75	2.15
3.4	6.1	Pl	1.15	1.10
2.7	0.44	Pl	1.68	2.15
8.7	20.0	FR	1.05	1.0
4.3	1.09	FR	1.49	1.78
5.0	1.15	FR	1.44	1.76
6.2	0.65	FR	1.63	2.0

*Pl - Plastic

FR - Rubber Lined

available to predict the performance of a system needed to process the effluent from the sand washing machine (or from any other oil-water treatment system, for that matter). The failure of the present technique to achieve an oil overflow with only 3% water should not be construed as a failure for the entire concept. Rather, the testing showed that the oil could be concentrated up to about 75% of the volume of the waste effluent stream, opening up many new possible routes for disposal of the oil, e.g. incineration, use as low grade fuel, or further processing in centrifuges or other equipment to achieve the low water content needed in order to make the oil acceptable for recycle to a refinery.

It is not certain whether this last route is even open to the oil collected from the sand washing system. As was pointed out earlier, sorber material is discharged with the oil-water overflow from the sand separating cyclone and would likely pass through the final oil overflow stream from the oil-water separation system. In this event, the oil would be contaminated with a foreign material which might make it unacceptable for refinery feedstock.

The possibilities of improving the oil overflow in cyclones of different geometry, or with changes in the operating variables still remain and should not be ruled out in the consideration of future test programs.

Concept for a Complete Beach Cleaning System

The objectives of the extensive test programs of sand washing and oil-water separation were to demonstrate that the processes involved in the proposed mobile, beach cleaning plant were viable and also to obtain data for a preliminary design of such a unit. Presented below is the preliminary design for a mobile system and recommended logistics and operating features.

System design

Shown in Figure 20 is the process flowsheet for the complete beach cleaning system. This concept includes screens and trash racks for removal of sorbers, normal beach debris and trash from the feed stream. Since problems were encountered

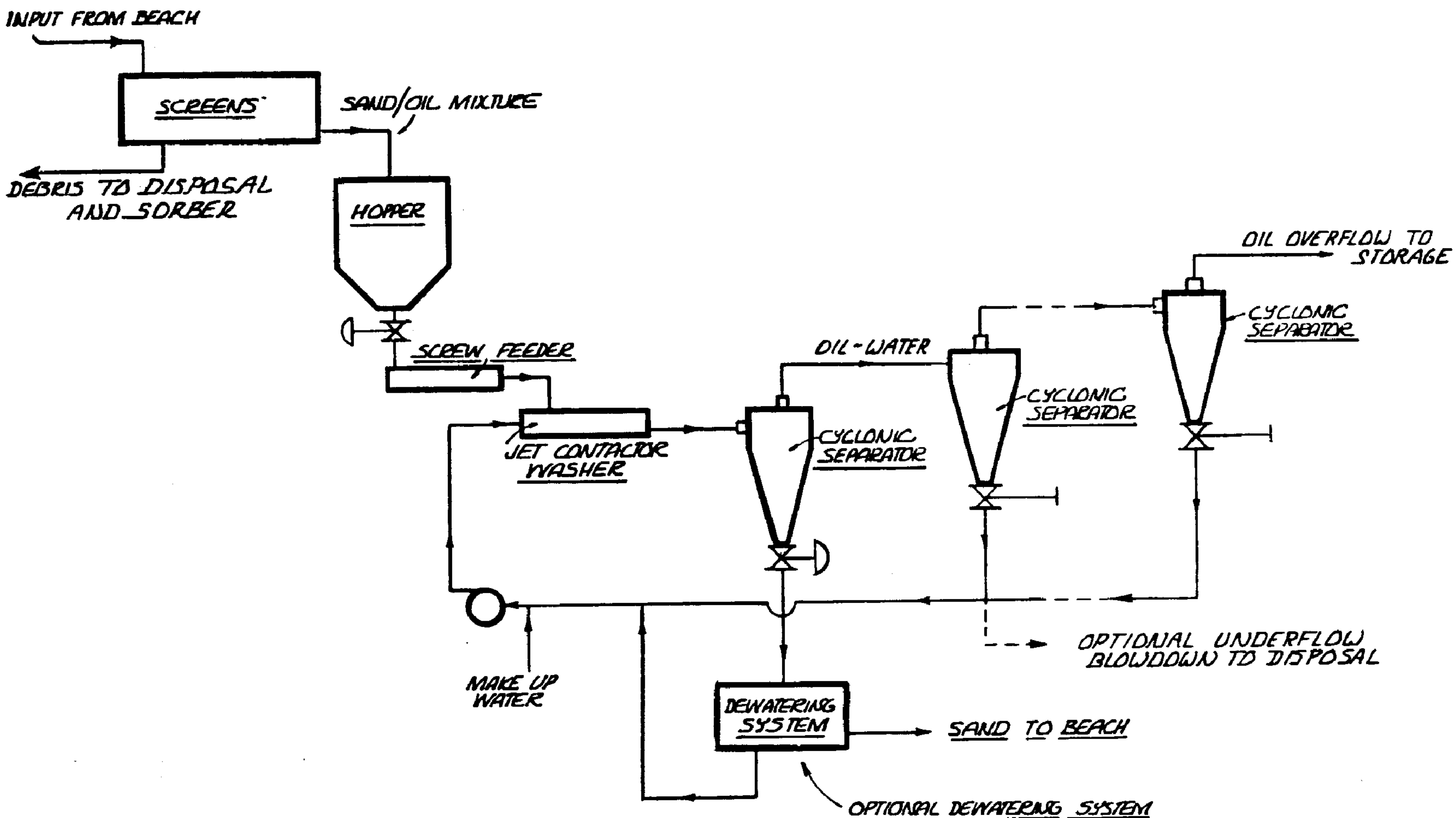


Figure 20. SAND WASHING PROCESS FLOWSHEET

in processing sand with small quantities of straw mixed in, it is important that the screening (a flotation system could be used) system be designed to remove even very fine (down to 1/4") debris to prevent plugging of the process equipment. The scavenged materials will likely be coated with oil and so must be properly disposed of. This is discussed further below. The sand, oil and residual trash passing the screening stage is loaded into the sand feeder hopper. A screw feeder (or other type of positive displacement solids feeder) transfers the oily sand to the washing stage.

As in the pilot scale test rig, the oil is stripped from the sand in a washer/mixer and then passes to a cyclone for separation of the sand from the washing fluid and oil. At the underflow of the cyclone, the sand may be further dewatered, since it is expected that at least 15% of the influent wash water will be needed to transport sand from the cyclone. The water recovered at this point is either returned to the inlet of the washer feed pump, or is cycled to a disposal tank. The sand from the washer may be dumped directly onto the beach.

The oil-water mixture reporting at the overflow of the sand separating cyclone then passes to the second stage of the process, i.e. the liquid-liquid separation. Shown on the flowsheet is a two-stage process for recovering oil, although the ultimate selection of the number of stages is largely dependent on the concentration of oil desired. If the recovered oil is to be as high as 75 to 80% of the final overflow stream (y_o), then 5 to 6 stages of separation are indicated from the test results. The underflow streams from these cyclones are shown being returned to the washer feed pump and blended with makeup. It may be necessary to recycle the underflow from the first stage (oil-water separation) cyclone as blowdown from the system to prevent the buildup of a stable emulsion of oil. Also, instead of returning the underflow from the second stage to the washer, it could be recycled directly into the inlet of the first stage oil-water separator as was done in some of the recycle tests.

Variations in the process parameters could be optimized for any particular specified feed characteristics and required product streams. This optimization might be based on minimizing the capital investment for a given feed rate or increasing the throughput capacity for a specified set of equipment.

Figure 21 shows a suggested arrangement for the apparatus on a transportable skid. Table 7 gives an indication of the size and capacity of some of the equipment needed to process 100 ton/hour of oil-contaminated sand.

Logistics and operations

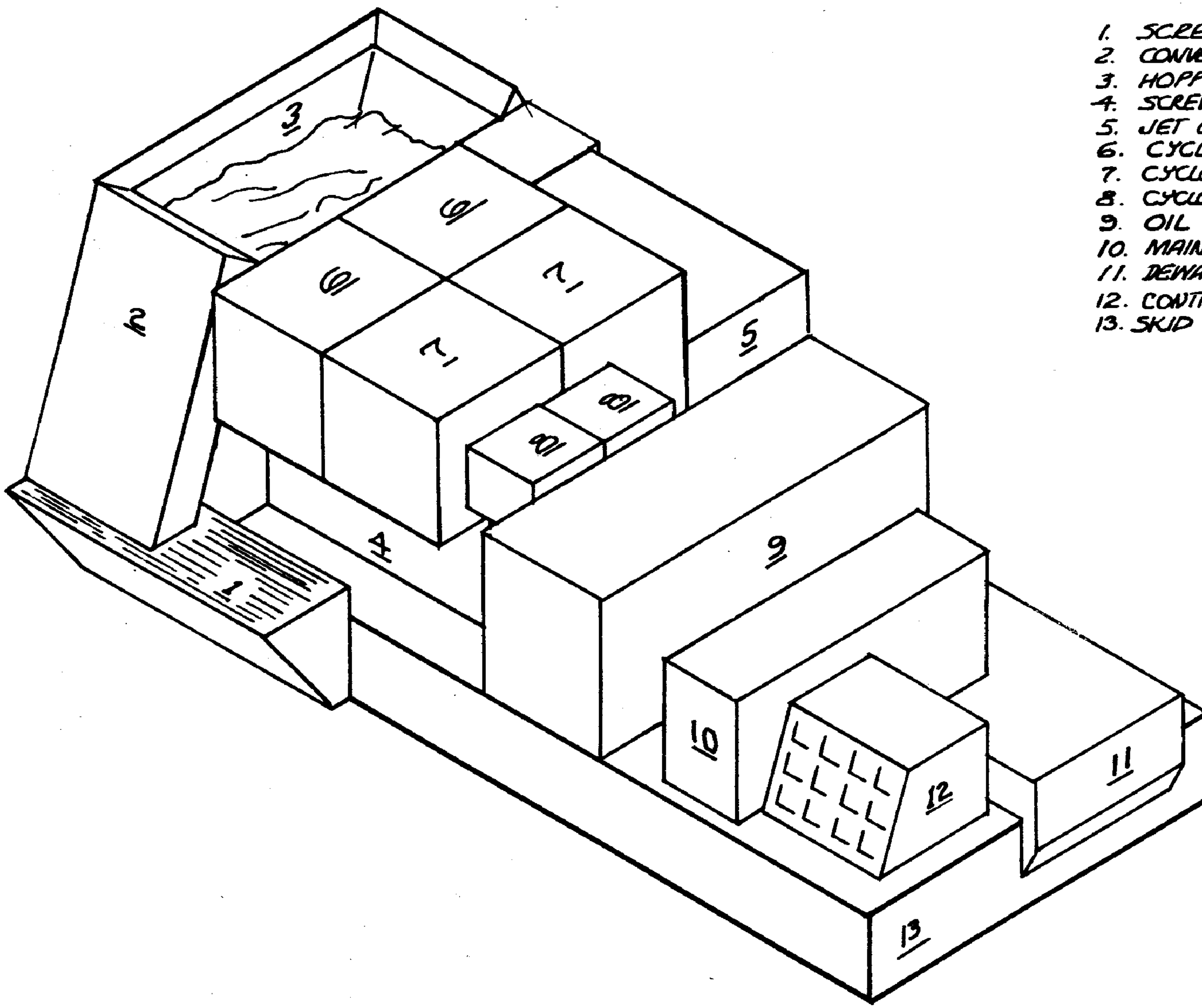
There are several important areas in regard to the logistics of cleaning an oil-contaminated beach that need to be addressed. In the first place, the system as proposed is mobile, i.e. it can travel to the spill site over land at trucking speeds (where road access is possible) and proceed across the beach, under its own power. If direct access to the spill site is not possible, the mobile rig could be transported to the shore by a landing craft or similar vessel. This approach could also be used to enable the cleaner to "leapfrog" natural and manmade shoreline obstructions, e.g. mouths of rivers, harbors, cliffs, groin, jetties, etc.

The collection of the contaminated sand for loading onto the beach cleaner is accomplished using conventional road building equipment. This was suggested in our proposals in early 1969, and has since been proved to be a viable approach (Ref. 12). Figure 22 is an artist's rendition of the proposed beach cleaning plant showing some of the features of the system as discussed here.

Ultimate disposal of effluent streams

Disposal of the effluent oil, wash water and screened trash streams is a matter of great concern. In the case of the trash, incineration followed by land-fill disposal of the residue seems to be the only realistic approach. No new development work needs to be done, both the technology and equipment are available, only the logistics of who and where remain to be settled.

The wash water and blowdown streams, containing small mass fractions of oil, present a more difficult problem.



1. SCREENS
2. CONVEYORS
3. HOPPER
4. SCREW FEEDER
5. JET CONTACTOR WASHER
6. CYCLONIC SEPARATOR Nº 1
7. CYCLONIC SEPARATOR Nº 2
8. CYCLONIC SEPARATOR Nº 3
9. OIL TANK
10. MAIN PUMP
11. DEWATERING CONVEYOR SYSTEM
12. CONTROL PANEL
13. SKID

Figure 21. BLOCK DIAGRAM OF SYSTEM ARRANGEMENT

TABLE 7

SYSTEM COMPONENTS (Refer to Figure 21)

Component	No.	Capacity	Size
Sand Screens	2	50 T/hr	4'x4'x6'
Conveyors	2	50 T/hr	3'x3'x10'
Hopper	1	100T/hr	3'x6'x6'
Jet Washer	1	100T/hr sand 1200 gpm water/ oil	2'x6'x6'
Cyclone No.1 (Sand Removal)	2	"	24" OD
Cyclone No.2 (oil-water separation stage #1)	2	1200 gpm water/ oil	24" OD
Cyclone No.3 (oil-water separation Stage #2)	3	120 gpm	6" OD
Sand Dewaterer (Optional)	1	100T/hr sand 25T/hr water	3'x4'x10'
Main Pump (Diesel or Gasoline)	1	1200 gpm, 100hp	4'x4'x12'
Transfer Pump (To Tank Truck)	1	500 gpm, 10 hp	4'x4'x6'
Water Pump (Suction)	1	200 gpm, 5 hp	3'x3'x4'
Oil Storage Tank	1	3000 gallons	5'x7'x12'
Control Panel	1		2'x4'x6'
Water Surge Tank	1	600 gallons	4'x4'x5'

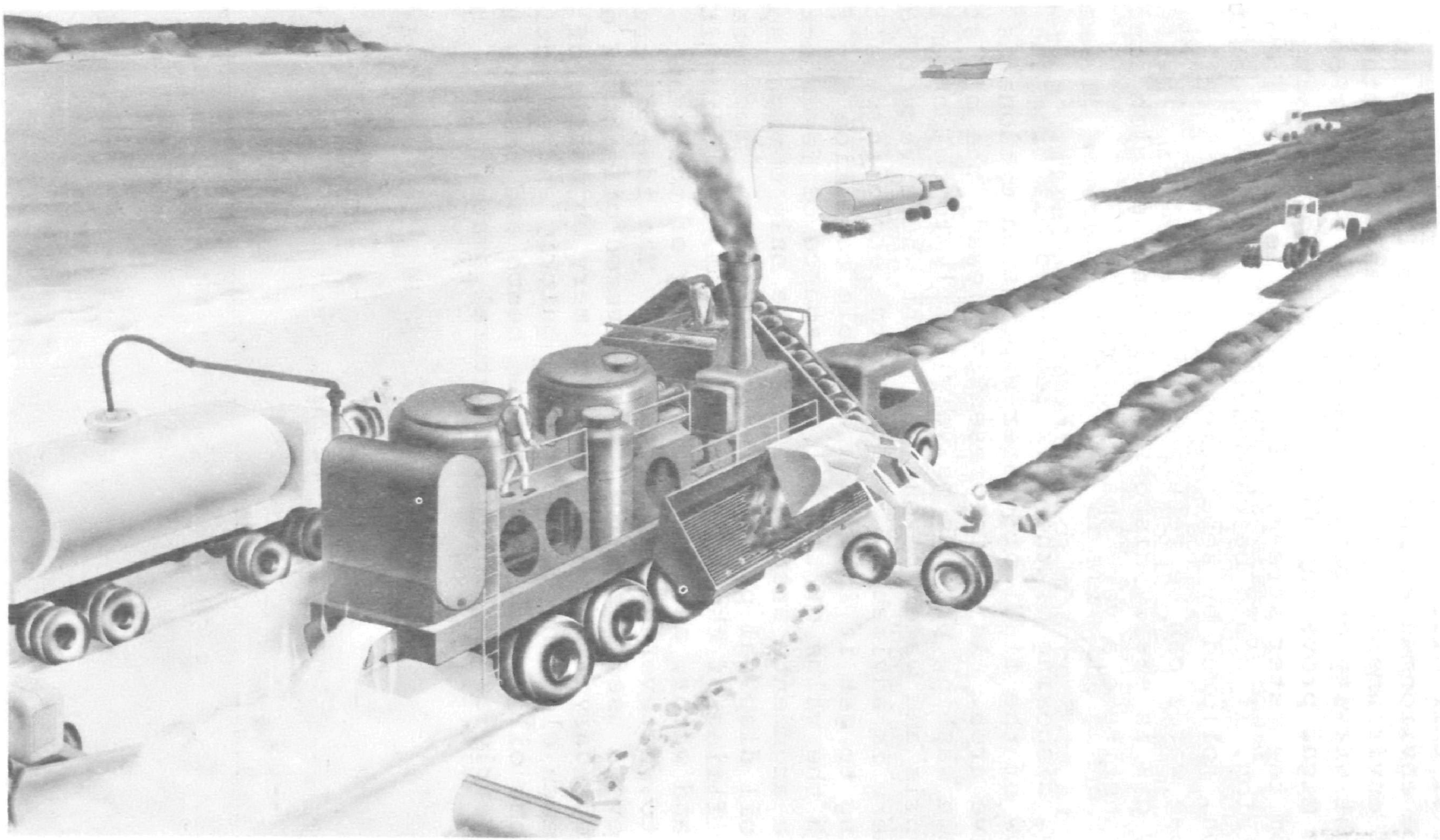


Figure 22. BEACH RESTORATION PROCESS

Dumping of this oiled water at land fills could present a severe environmental hazard and would likely be in violation of environmental protection ordinances. Flotation (straight gravity or froth induced), filtering or coalescing schemes might prove suitable as a means for removing the oil from the water stream. If the oil is in the form of an emulsion, it could be chemically treated to break the emulsion, followed by separation in a flotation cell. Then, the clean water can be returned to its source. The recovered oil is easily disposed of by incineration since it would constitute a very small volume.

Finally, disposing of the bulk recovered oil from the overflow of the final oil-water separation cyclone is a sensitive area. As it is presently viewed, the oil stream from this washing process is very likely to be contaminated with debris and water beyond the point where recycling to a refinery is advisable. Further, the economic penalty of trying to get it into an acceptable condition may far outweigh the value of the oil as a source of feedstock. If these arguments are valid, then the only obvious solution to the oil disposal problem is incineration. Incineration meaning firing of the total waste stream, including its debris and water, and possible recovery of the heat energy to whatever use it may be put. The idea of trying to achieve a useful end for the recovered oil should only be of secondary importance. The primary objective of the whole beach cleaning concept is to quickly and effectively remove the oil from a contaminated beach and restore it to, as nearly as possible, its natural state.

SECTION 7

ACKNOWLEDGEMENTS

All of the test work and report preparation under this program were carried out by Creare Incorporated, Hanover, New Hampshire and Dorr Oliver Incorporated, Stamford, Connecticut, under subcontract to Ecological Research Corporation, Miami, Florida. Francis X. Dolan of Creare and James P. Bowersox of Dorr-Oliver were the project engineers principally responsible for the conduct of the program.

The authors wish to thank the EPA Project Officers responsible for monitoring this program, Ralph L. Rhodes and Richard R. Keppler, for their help, encouragement and patience throughout this undertaking.

SECTION 8

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SECTION 9

NOMENCLATURE

C = oil enrichment factor

E_s = oil-water separation efficiency

f = fraction of oil in sand

OR = oil removal effectiveness

Δp = pressure drop

P = pressure

Q = volume flow rate

R = recovery of oil or water

S = volume split

SE = specific energy

W = mass flow rate

Y = volume fraction of oil in water

ϕ = power

<u>Subscripts</u>

c = cyclone

d = mixing valve in oil water separator

f = feed

i = feed stream or initial (in context)

o = oil, overflow stream or final (in context)

s = sand

T = total

u = underflow stream

w = washer

SECTION 10

APPENDICES

APPENDIX A

RANGE OF VARIABLES USED IN SAND WASHING PROGRAM

Oil Type #6 for tests 1111-01 through 1203-07

Oil Type #4 for tests 1214-01 through 1218-11

Test No.	Water Flow (GPM)	Sand Flow (lb/min)	Oil in Sand (mass %)	Plenum Pressure (psig)	Mixer Pressure (psig)	Mixer Length (inch)	Washer Nozzle (No.)
1111-01	30	62.5	6.2	13	4.5	24	2
1111-02	30	44	6.2	13	4.5	24	2
1111-03	30	28	6.2	13	4.5	24	2
1111-04	30	28	6.2	12	4.5	24	2
1111-05	30	44	6.2	12	4.5	24	2
1111-06	30	62.5	6.2	12	4.5	24	2
1113-01	20	55	6.65	5	2.5	24	2
1113-02	20	41.5	6.65	5	2.5	24	2
1113-03	20	29.5	6.65	5	2.5	24	2
1113-04	20	18.5	6.65	5	2.5	24	2
1113-05	40	82	6.65	22	6	24	2
1113-06	40	69.5	6.65	22	6	24	2
1113-07	40	37	6.65	22	6	24	2
1123-01	30	82	5.85	11	2.25	24	2
1123-02	30	62.5	5.85	11	2.5	24	2

APPENDIX A - (Cont.)

Test No.	Water Flow (GPM)	Sand Flow (lb/min)	Oil in Sand (mass %)	Plenum Pressure (psig)	Mixer Pressure (psig)	Mizer Length (inch)	Washer Nozzle (no.)
1123-03	30	44	5.85	11	2.75	24	2
1123-04	30	28	5.85	11	2.75	24	2
1123-05	20	55	5.85	5	1.5	24	2
1123-06	20	41.5	5.85	5	1.5	24	2
1123-07	20	29.5	5.85	5	1.5	24	2
1123-08	20	18.5	5.85	5	1.5	24	2
1123-09	40	82	5.85	18	3	24	2
1123-10	40	69.5	5.85	18	3.25	24	2
1123-11	40	37	5.85	18	3.5	24	2
1124-01	30	82	7.45	10	3	12	2
1124-02	30	62.5	7.45	10	3	12	2
1124-03	30	44	7.45	10	3	12	2
1124-04	30	28	7.45	10	3	12	2
1124-05	20	55	7.45	5	2.5	12	2
1124-06	20	41.5	7.45	5	2.5	12	2
1124-07	20	29.5	7.45	5	2.5	12	2
1124-08	20	18.5	7.45	5	2.5	12	2
1124-09	40	82	7.45	17	3	12	2

APPENDIX A (Cont)

Test No.	Water Flow (GPM)	Sand Flow (lb/min)	Oil in Sand (mass %)	Plenum Pressure (psig)	Mixer Pressure (psig)	Mixer Length (inch)	Washer Nozzle (no.)
1124-10	40	69.5	7.45	17	3	12	2
1124-11	40	37	7.45	17	3	12	2
1201-01	30	82	5.53	13	3	12	1
1201-02	30	62.5	5.53	13	3	12	1
1201-03	30	44	5.53	13	3	12	1
1201-04	30	28	5.53	13	3	12	1
1201-05	40	82	5.53	23	4.75	12	1
1201-06	40	69.5	5.53	23	4.75	12	1
1201-07	40	37	5.53	23	4.75	12	1
1202-01	30	82	5.30	13	3.50	12	1
1202-02	30	62.5	5.30	13	3.50	12	1
1202-03	30	44	5.30	13	3.50	12	1
1202-04	30	28	5.30	13	3.50	12	1
1202-05	40	82	5.30	24	7	12	1
1202-06	40	69.5	5.30	24	7	12	1
1202-07	40	37	5.30	24	7	12	1
1203-01	30	82	5.041	14	4.5	24	1
1203-02	30	62.5	5.041	14	4.5	24	1

APPENDIX A (Cont.)

Test No.	Water Flow (GPM)	Sand Flow (lb/min)	Oil in Sand (mass %)	Plenum Pressure (psig)	Mixer Pressure (psig)	Mixer Length (inch)	Washer Nozzle (no.)
1203-03	30	44	5.041	14	4.5	24	1
1203-04	30	28	5.041	14	4.5	24	1
1203-05	40	82	5.041	26	9	24	1
1203-06	40	69.5	5.041	26	9	24	1
1203-07	40	37	5.041	26	9	24	1
1214-01	30	82	4.58	16	6	24	1
1214-02	30	54	4.58	16	6	24	1
1214-03	30	44	4.58	16	6	24	1
1214-04	30	28	4.58	16	6	24	1
1214-05	40	82	4.58	27	9	24	1
1214-06	40	69.5	4.58	27	9	24	1
1214-07	40	37	4.58	27	9	24	1
1214-08	20	55	4.58	5	3.75	24	1
1214-09	20	41.5	4.58	8	4	24	1
1214-10	20	29.5	4.58	8	4	24	1
1214-11	20	18.5	4.58	8	4	24	1
1218-01	30	82	5.091	14	4	12	1
1218-02	30	62.5	5.091	14	4	12	1

APPENDIX A (Cont.)

Test No.	Water Flow (GPM)	Sand Flow (lb/min)	Oil in Sand (mass %)	Plenum Pressure (psig)	Mixer Pressure (psig)	Mixer Length (inch)	Washer Nozzle (no.)
1218-03	30	44	5.091	14	4	12	1
1218-04	30	28	5.091	14	4	12	1
1218-05	40	82	5.091	26	9	12	1
1218-06	40	69.5	5.091	26	9	12	1
1218-07	40	37	5.091	26	9	12	1
1218-08	20	55	5.091	7	3.5	12	1
1218-09	20	41.5	5.091	7	3.5	12	1
1218-10	20	29.5	5.091	7	3.5	12	1
1218-11	20	18.5	5.091	7	3.5	12	1

APPENDIX B

OIL WATER SEPARATION IN 10 MM DORRCLONE

Test No.	Feed Rate (GPM)	Oil Concentration			Split	Recovery	
		Feed (Vol %)	Overflow (Vol %)	Under Flow (Vol %)		Oil (%)	Water (%)
1	2.02	3.50	4.57	2.62	0.83	59.3	55.2
2	2.54	3.10	4.71	1.72	0.87	70.4	54.5
3	2.92	2.43	3.29	1.37	1.24	74.8	45.1
4	3.90	1.59	2.27	0.49	1.62	88.4	38.6
5	2.89	2.54	3.50	1.53	1.05	70.7	49.3
6	2.78	2.53	3.23	1.21	1.90	83.8	34.9
7	2.51	2.81	3.11	1.16	5.50	93.7	15.7
8	2.98	3.16	3.19	3.15	0.38	28.0	72.3
9	2.76	3.23	4.62	2.07	0.84	65.1	55.2
10	2.04	1.96	2.36	1.18	1.97	79.6	33.9
11	2.05	1.62	1.78	0.96	4.16	88.6	19.5
12	3.14	1.44	1.82	0.86	1.51	75.9	40.0
13	3.37	1.45	1.68	0.66	3.48	90.1	22.5
14	3.33	1.48	1.74	1.32	0.63	45.6	61.3
15	2.63	3.63	6.33	0.99	0.98	86.0	52.0
16	3.47	2.51	4.24	0.38	1.23	93.2	45.8

APPENDIX B - (Cont.)

Test	Feed Rate (GPM)	Oil Concentration: Feed (Vol %)	Oil Concentration: Over-Flow (Vol %)	Oil Concentration: Under-Flow (Vol %)	Split	Recovery: Oil (%)	Recovery: Water (%)
17	2.92	2.25	2.82	0.44	3.12	95.4	24.4
18	3.49	3.32	4.94	0.50	1.75	94.6	37.5
19	2.74	6.9	12.8	0.9	1.01	93.6	52.6
20	2.81	10.3	17.8	2.7	1.02	87.4	53.6
21	2.96	11.1	19.8	2.2	1.03	90.2	54.2
22	3.08	11.8	20.5	2.8	1.04	88.7	53.9
23	3.32	18.4	32.1	4.1	1.05	89.1	57.6
24	2.85	6.7	11.7	1.3	1.07	90.3	51.3
25	3.10	12.3	20.3	4.1	1.01	83.0	54.2
26	1.42	6.8	11.1	1.3	1.25	90.6	47.1
27	1.59	14.7	25.1	3.1	1.12	90.3	53.6
28	2.74	6.0	8.9	0.6	1.88	96.6	36.6
29	2.67	5.9	7.2	0.5	4.13	98.2	20.7
30	1.46	8.3	11.9	0.6	2.13	97.2	34.6
31	1.43	7.9	9.6	0.3	4.50	99.8	19.7
32	3.67	2.2	3.6	0.7	1.15	85.4	47.5
33	3.51	3.9	7.1	0.3	1.15	97.6	48.3
34	3.63	10.7	16.0	4.8	1.10	78.4	51.0

APPENDIX B (Cont.)

Test	Feed Rate (GPM)	Oil Concentration			Split	Recovery	
		Feed (Vol %)	Over-Flow (Vol %)	Under-Flow (Vol %)		Oil (%)	Water (%)
35	3.40	3.6	5.2	0.3	2.12	97.8	33.1
36	3.20	3.0	3.6	0.1	4.93	99.7	17.4
37	3.22	4.7	8.2	0.8	1.12	91.9	49.1
38	3.04	6.1	7.4	0.2	4.74	99.9	18.4
20-A	2.71	5.9	10.9	0.9	1.01	92.4	52.3
22-A	2.73	14.3	26.5	1.9	1.02	93.4	56.4
25-A	2.99	12.1	20.7	3.1	1.05	87.6	53.7
29-A	2.96	12.0	15.0	0.9	3.70	98.4	24.1
39	2.70	5.1	8.8	1.0	1.08	90.5	50.0
40	3.04	11.0	19.6	2.0	1.04	90.8	53.9
41	1.43	7.3	9.0	1.1	3.77	97.2	22.5
42	2.72	5.3	10.2	0.05	1.09	99.7	50.7
43	2.69	14.0	25.9	1.9	1.02	93.6	56.3
44	1.53	7.6	9.2	1.0	4.28	98.0	20.3
45	2.29	32.1	63.9	2.2	0.941	96.5	74.2
46	1.67	29.4	58.8	10.2	0.653	79.0	76.8
47	1.73	52.9	78.8	31.1	0.840	68.1	79.3

APPENDIX B (Cont.)

Test	Feed Rate (GPM)	Oil Concentration			Split	Recovery	
		Feed (Vol %)	Over-Flow (Vol %)	Under-Flow (Vol %)		Oil (%)	Water (%)
48	2.91	11.6	22.9	5.9	0.508	66.4	70.3
49	3.16	4.6	21.9	1.3	0.188	75.2	86.7
50	2.90	19.1	40.6	8.3	0.503	71.1	75.3
51	1.48	7.7	12.8	0.4	1.43	97.6	44.5
52	1.35	8.0	15.2	2.3	0.80	84.4	58.9
53	1.49	6.2	9.0	0.05	2.17	99.3	33.7
54	1.49	13.2	19.0	0.2	2.24	99.5	35.5
55	2.30	8.3	12.5	0.01	1.91	100.0	37.4
56	1.55	9.0	14.6	0.3	1.54	98.2	43.3
57	2.18	17.4	20.0	0.1	6.52	99.7	16.1
58	1.37	8.3	13.7	0.8	1.40	96.4	44.9
59	1.33	6.5	8.7	0.5	2.69	97.7	28.7
60	1.56	6.6	10.4	0.1	1.76	100.0	39.1
61	2.34	9.3	15.5	0.1	1.49	99.9	44.2
62	2.12	8.4	14.1	0.3	1.44	99.1	44.7

APPENDIX B (Cont.)

TWO STAGE OIL-WATER SEPARATION
IN A 10MM DORRCLONE

No. 4 Oil
Tap water (Test 67, 100 ppm NaCl in water)

Test	Flow rates in GPM					Split	
	First Stage			Second Stage		First Stage	Second Stage
	Feed	U'Flow	O'Flow	U'Flow	O'Flow		
63	4.79	1.35	3.44	1.65	1.79	2.54	1.09
64	3.74	1.26	2.48	0.89	1.59	1.98	1.77
65	3.87	0.53	3.34	1.00	2.34	6.34	2.34
66	4.34	1.46	2.88	1.20	1.68	1.98	1.40
67	4.38	1.86	2.52	0.96	1.56	1.36	1.63

Test	Oil Concentration (Vol %)				
	First Stage			Second Stage	
	Feed	U'Flow	O'Flow	U'Flow	O'Flow
63	8.1	0.4	11.2	1.9	19.7
64	6.7	0.3	10.0	0.3	15.5
65	6.1	1.3	6.9	0.1	9.4
66	5.7	0.2	8.4	0.1	14.4
67	5.3	0.3	9.0	0.1	14.5

APPENDIX B (Cont.)

TWO STAGE OIL-WATER SEPARATION IN 10MM DORRCLONE

No. 6 Oil
Tap water tests 75, 76
Salt Water (100 ppm NaCl) tests 77, 78

Test	Flow Rate in GPM					Split	
	First Stage			Second Stage		First	Second
	Feed	U'Flow	O'Flow	U'Flow	O'Flow	Stage	Stage
75	3.97	1.61	2.36	0.91	1.45	1.47	1.59
76	3.77	1.57	2.20	1.06	1.14	1.40	1.08
77	3.37	1.53	1.84	1.15	0.69	1.20	0.6
78	3.50	0.66	2.84	1.29	1.55	4.30	1.20

	Oil Concentration (Vol %)				
	First Stage			Second Stage	
Test	Feed	U'Flow	O'Flow	U'Flow	O'Flow
75	8.4	0.3	13.9	1.0	22.0
76	7.7	1.0	12.1	2.0	21.3
77	3.8	0.3	6.8	1.8	15.0
78	6.2	0.1	7.6	0.3	13.6

Recycle Tests with 10 mm DorrClones

No. 4 Oil
Salt water (100 ppm NaCl)
Water temperature 125°F to 140°F

Test	Flow rates in GPM					Split	
	First Stage			Second Stage		First Stage	Second Stage
	Feed	U'Flow	O'Flow	U'Flow	O'Flow		
79	3.36	0.55	2.81	0.94	1.87	5.11	1.99
80	3.24	1.42	1.82	0.96	0.86	1.28	0.90
81	3.70	1.57	2.13	0.41	1.72	1.36	4.20

Test	Oil Concentration (Vol %)					
	Feed		First Stage		Second Stage	
	Fresh	with Recycle	U'Flow	O'Flow	U'Flow	O'Flow
79	6.1	4.6	0.1	5.4	0.5	7.9
80	6.2	4.7	0.9	7.6	1.0	14.9
81	14.3	13.2	0.7	22.4	4.7	26.7

APPENDIX B (Cont.)

OIL WATER SEPARATION IN 6 INCH DORRCLONE

Plastic Cyclone
No. 4 Oil
Water temperature, 66 °F tests 68, 69, 70, 71; 130°F tests 72, 73, 74
Tap water tests 68, 69, 70. tap plus 100 ppm; NaCl for 71, 72, 73, 74

Test No.	Feed Rate (GPM)	Oil Concentration: Feed (Vol %)	Oil Concentration: Over Flow (Vol %)	Oil Concentration: Under Flow (Vol %)	Split	Recovery: Oil %	Recovery: Water %
68	42.0	4.9	6.1	0.4	3.7	98.2	22.4
69	50.8	3.4	12.9	1.0	0.24	76.6	81.7
70	38.5	5.7	6.5	0.9	6.1	97.8	14.7
71	50.4	4.6	6.3	0.9	0.48	94.0	33.6
72	50.7	2.8	7.7	0.6	0.44	84.2	71.0
73	36.1	3.4	3.9	0.4	6.14	98.4	14.6
74	50.7	2.7	6.2	1.1	0.44	71.3	70.5

APPENDIX B (Cont.)

OIL-WATER SEPARATION IN 6 INCH DORRCLONE

Rubber lined (FR) cyclone
No. 4 oil
Water temperature 130-150°F
Tap water plus 100 ppm NaCl

Test No.	Feed Rate (GPM)	Oil Concentration			Split	Recovery	
		Feed (Vol.%)	Over Flow (Vol.%)	Under Flow (Vol.%)		Oil %	Water %
82	42.4	8.7	0.9	9.1	20.2	99.5	5.1
83	59.4	4.3	2.0	6.4	1.09	77.7	49.0
84	43.4	5.0	2.4	7.2	1.15	77.5	47.7
85	61.4	6.2	3.7	10.1	0.65	63.8	62.4

APPENDIX B (Cont.)

HIGH OIL CONTENT TESTS IN

10MM DORRCLONE

(Two Stage Separation)

No. 4 oil
Salt Water (100 ppm NaCl)

Test	in GPM						
	First Stage			Second Stage		First	Second
	Feed	U'Flow	O'Flow	U'Flow	O'Flow	Stage	Stage
86	2.33	0.09	2.24	1.39	0.85	24.9	0.61
87	2.43	0.38	2.05	1.28	0.77	5.39	0.60
88	3.41	1.30	2.11	1.32	0.79	1.62	0.60
89	2.46	0.92	1.54	0.73	0.81	1.67	1.11
90	2.24	0.32	1.92	0.77	1.15	6.0	1.49
92	2.94	0.30	2.64	1.20	1.44	8.8	1.20
93	3.45	0.58	2.87	1.37	1.50	4.94	1.09
95	3.04	0.38	2.66	1.41	1.25	7.0	1.13

Test	Oil Concentration (Vol %)				
	First Stage			Second Stage	
	Feed	U'Flow	O'Flow	U'Flow	O'Flow
86	28.6	0.9	29.7	12.3	58.3
87	37.4	1.3	44.0	23.6	73.3
88	22.2	0.3	35.7	18.9	63.8
89	30.3	6.5	44.5	9.5	76.3
90	56.9	42.9	59.2	40.5	71.6
92	91.3	89.8	91.5	88.8	93.8
93	79.6	78.5	80.0	80.0	80.0
95	90.7	89.7	90.8	90.5	91.5

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16. Abstract A system has been developed for the restoration of oil-contaminated beach sands. The method involves washing of the sand in a high energy jet contactor washer and separation of the cleaned sand from the wa shing fluid in a conventional solid-liquid cyclone. Separation and concentration of the oil-water effluent from the washing process is also accomplished in cyclones. The two separate stages of this process have been demonstrated on a pilot scale equivalent to about 3 tons of wet, oil contaminated sand per hour.

The sand washing process has been shown capable of removing over 99% of the contaminating oil from a simulated beach sand. Oils used were No.4 and No.6 fuel oil at 4 to 8% of the dry weight of the sand. The oil-water separation tests yielded a highly enriched oil product stream with less than 20% water, while the water removed from the system was suitable for recycle to the sand washing system.

A conceptual design for a mobile beach cleaning system based on the processes studied is presented and is shown to be feasible within the state-of-the-art.

This report was submitted in fulfillment of Project FIG, Contract No. 14-12-830, under the sponsorship of the Environmental Protection Agency.

17a. Descriptors *Oil Spill Cleanup, *Liquid-Liquid separation, *Sand Washing Hydrocyclones, Beach Cleanup

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