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Restoration of Beaches Contaminated by Oil

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RESTORATION OF BEACHES CONTAMINATED BY OIL

By

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ABSTRACT

Based on laboratory studies, a 30 ton per hour pilot plant was built for cleaning oil contaminated beach sands. The plant utilized the principle of froth flotation. Extensive field testing considered different oils, feed concentrations, both brackish and sea water, and a range of processing conditions. Forty one field tests were conducted at the U. S. Navy's Fleet Anti-Air Warfare Training Center at Dam Neck, Virginia. These varied from nominal runs with sand feed rates of 30 tons per hour and oil concentrations of 0.5% to oil/water separations at high capacity. Using the test results, a mobile unit was designed, constructed, field tested, and delivered to the Environmental Protection Agency. Data was obtained on the effects on cleaning efficiency of relevant process parameters: (1) sand feed rate, (2) feed steadiness, (3) oil type, (4) oil concentration, (5) sand age, (6) feed homogeneity, (7) water rate, (8) water type, (9) slurry density, (10) residence time, (11) aeration, (12) temperature, (13) surfactant effects, (14) organic solids effects, and (15) oil deposition on wet or dry sand. The mobile unit operated successfully under a wide range of conditions. This device should prove a valuable adjunct to existing oil spill cleanup procedures.

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CONCLUSIONS

The primary conclusion from the entire project (as discussed in detail in the main body of this report) was that froth flotation can be used to clean oil contaminated beach sand and that a mobile beach cleaner as supplied to the Environmental Protection Agency can be used as a cleanup device during appropriate oil spill emergencies. Other, more detailed, information was obtained in the course of the project and is summarized briefly in the following section.

1.1 <u>Demonstration Plant</u>

Demonstration studies run with a stationary pilot plant facility at Dam Neck, Virginia led to several conclusions; the first point made in the following list is most critical to the overall project objective while the additional four points represent supplementary information obtained during the course of the study.

1) Oily sand cleaning using froth flotation is feasible but, process water recycle and scrubbing or pumping of oil/sand/water slurries (if used) degrade the process significantly. Froth flotation should be utilized by feeding oily sand and process water directly into the feed box of a froth flotation machine with a minimum of prior agitation.

The system is limited mainly by the total flow of oil through it with a maximum acceptable level of oil contamination at a 30 ton/hour sand feed rate of about 1%.

2) Attrition scrubbing of straw with standard process equipment is not feasible for the purpose of cleaning the straw for disposal or reuse.

3) Oil/water separation at high capacity is possible using froth flotation. Considerable development work beyond standard mineral processing techniques will be necessary to take advantage of this basic principle to obtain high efficiencies.

4) In principle, oily sand scrubbing and dewatering is possible as a cleaning technique; however, necessitites for a very large process water supply, oil/water separation, and multiple scrubbing operations make the overall approach infeasible.

1.2 <u>Mobile Beach Cleaner</u>

The second major phase of the project discussed in this report was the construction, field testing, and delivery of a mobile beach sand cleaner to the Environmental Protection Agency. The following conclusions pertain:

1) "Typical" operating conditions for the mobile beach cleaner are:

30 tons/hour sand feed rate

No. 4 fuel oil as the contaminant at 0.5%

oil deposition on wet sand

oily sand aged for about one week

sand as found at the Dam Neck test site without the presence of surfactants, dispersants or organic solids, homogeneously mixed with the contaminating oil, and fed steadily to the flotation machine

process sea water rate of 250 gallons/minute

process temperature of about 60°F

aeration rate of 250 cubic feet/minute

residence time (function of sand and water rates) of 4 minutes

160 ppm oil in the effluent water

75 ppm oil in the cleaned sand

130 ppm oil in the total effluent stream

Many factors affect the operation of the mobile beach cleaner, and some of these can be used to adjust operation from the conditions above which are only suggested as nominal.

2) The processing cost is about 77 cents per ton of sand. This compares favorably to the estimated costs incurred in removing and disposing of oily sand during spill incidents such as the one in San Francisco Bay during the spring of 1971 even though actual spill experiences at 100 to 200 cents per ton of oily sand do not consider replacement of the sand removed from a beach.

3) The Mobile Beach Sand Cleaner is indeed mobile and can be operated with minimum logistical support and personnel.

4) The unit does away with the problem (especially in the long run) of securing and maintaining permanent storage for oily sand.

5) The unit also assures that valuable sand (e.g., Hawaiian sand at something like $20/ton) on recreational beaches is not depleted.

The following effects of operating conditions should be noted (these effects are discussed in considerable detail in the bulk of this report);

1) Other factors remaining the same, increased sand feed rate results in increased residual oil concentrations on almost a proportional basis.

2) Unsteady sand feed degrades performance.

3) The heavier the oil, the easier the separation.

4) Increased feed oil concentration results in increased residual oil on a proportional basis.

5) Within the limits of the studies, aging of oily sand improved the separation process.

6) Wide variation in homogeneity of the feed sand degrades performance.

7) Increasing the water rate decreases residual oil concentrations but also the overall process efficiency.

8) Sea water enhances separation.

9) Greatly increased slurry density appears to degrade performance.

10) Increasing residence time has an inversely proportional effect on residual oil concentrations.

11) Increasing or decreasing aeration rate about an optimum results in poorer separations.

12) Increased temperature enhances oil recovery.

13) Dispersants in the contaminating oil may either improve or degrade the process.

14) Organic solids (e.g., straw) hinder the process of oil separation by competing for attachment to air bubbles.

15) Oil deposition on wet sand (as opposed to dry) enhances oil recovery.

16) Water can be recycled from the oil recovery tank without significantly degrading the sand cleaning process.

17) Settling ponds can be used to decrease the impact of residual oil.

18) Flotation reagents are not necessary in the use of froth flotation for oily sand cleaning.

SECTION II

RECOMMENDATIONS

The following major recommendations relating to the Mobile Beach Sand Cleaner result from the information gathered during the course of the Project:

1) The Mobile Beach Sand Cleaner should be used in cleaning up oil contaminated beaches. For this, both the results of the demonstration projects as presented in this report and the operating and maintenance manuals as supplied with the mobile unit should be studied and followed closely.

2) Oil dispersants and sorbents should not be used on beaches where the Mobile Beach Sand Cleaner is to be used.

3) Use of the mobile unit must take cognizance of the fact that cleaning costs (under particular site conditions) greater than $5.00 a ton are in competition with simply removing the sand, disposing of it, and replacing it with fresh sand.

4) Mobile Beach Sand Cleaners should eventually be strategically placed around the country; Hawaii, West Coast, Gulf Coast, Great Lakes, and East Coast emplacements would seem most reasonable.

5) Design of further units should carefully consider the results of the studies as presented in this report and experience with the existing Mobile Beach Sand Cleaner; larger processing capacity using standard equipment and a conventional flatbed trailer may be possible.

6) Development of a more rugged water supply system should be pursued in order to extend the range of environmental conditions under which the Mobile Beach Sand Cleaner can be used.

Finally, before the inherent advantages of the froth flotation principle can be practicably utilized for high capacity oil/water separations, significant development work must still be done.

SECTION III

RESTORATION OF BEACHES CONTAMINATED BY OIL

3.1 General Introduction

3.1.1 Oil Contaminated Beaches - The Problem

When oil pollutes a sandy beach, no single form of contamination takes place: it depends on the type of oil, length of time at sea, temperature, time the oil has been on the beach, and type of sand. Some oils, sufficiently long at sea, will arrive at the beach as pebbles or streaks, and can be removed easily by a beach cleaner. Other types of oil (particularly crudes) which have been at sea for a long time are water-oil emulsions that are somewhat similar to butter, and look like chocolate mousse. These emulsions, while on the beach, are altered by environmental and biological impact; they become putty-like and finally brittle. This type of pollution can also be cleaned up by a beach cleaner or dry screening. Fresh crude (and many fuel oils) will penetrate the sand, coating sand particles and filling some of the interstitial voids in the beach.

Beach materials vary greatly in the ease with which oil can wet them. Quartz sand is difficult to wet with oil in the presence of water, while many shell materials are more readily wetted. Consequently, when a beach is contaminated by oil a complex situation may exist where several forms of contamination occur. Hence, a cleanup which does not consider the broad spectrum of contamination will not be successful.

Experience with liquid oil falls indicates that the depth of penetration and position of the contaminant is not easily ascertained from the surface. Uncontaminated sands may bury the contaminated part, and the width and depth of the oil contamination may vary markedly within short distances; thus, finding the contaminated sand can be expensive. Modern practice has been to take large swathes of the beach and, as spots of contamination remain, to either take a second cut of sand or dig out the contaminated spots by hand. This results in a large amount of sand in which relatively small sections are contaminated. Thus, any cleanup procedure must either concentrate contaminated sands or be very economical in the treatment of the contaminants.

A figure of $5.00 a ton for the replacement of sand on a beach is a reasonable estimate. This price includes removal of contaminated sand, finding clean sand, transportation, and addition of the sand to the beach. Any process used in beach restoration must consider that cleaning costs greater than something like $5.00 a ton are in competition with simply removing the sand, disposing of it, and replacing it with fresh sand. In any treatment of the sand to remove the oil, care must be taken not to trade oil pollution for other types of pollution. Any burning techniques must have superior combustion and generate few harmful gases or particles; likewise, harmful chemicals must not be allowed to escape to contaminate the ground water or ocean. Froth flotation appears to be an inexpensive method of cleaning oil-contaminated beach sand. It has the advantages of concentrating oil contaminated sand, stripping oil from sand, and working for a wide variety of oils and conditions.

3.1.2 Froth Flotation - Laboratory Studies

Froth flotation is considered to be one of the most revolutionary developments in industrial history because it is particularly suited to treating (at very low cost) large quantities of low-value materials. In 1960 some 200 million tons of ore were treated by froth flotation in over 200 plants in the U.S. alone. Because froth flotation is so cheap and so effective in so many separation processes, it has been used by many industries all over the world.

Large quantities of sand are cleaned by flotation in the United States. New Jersey optical sand is cleaned by floating iron-bearing minerals from the bulk of the siliceous sand; iron stains on the sand surface are removed by the violent actions occurring in pumps, flotation cells, and cyclones; this sand, after cleaning, is sold for $3.00 a ton. In North Carolina, sands are float-cleaned and scrubbed by pumps and cyclones; they are sold throughout the country for use in golf traps; this sand is exceedingly white. Dark brown tar sands in Canada are floated in hot water to remove the oil, using an otherwise standard flowsheet; these sands come out very white. Flotation has often been used to clean and to separate oil from sands.

Commercial flotation cells are produced by several manufacturers and are available in capacities ranging from a few pounds per hour to several hundreds of tons per hour. Many machines are self-aerating; i.e., air is drawn into the cell by the action of the agitator (an impeller); with others an external air supply is required. These units are not expensive, they are essentially self-contained and they adapt readily to portable operation.

In the usual applications of this process to mineral industries, crushed minerals are made hydrophobic (usually by chemical treatment), suspended in water, and then violently agitated. When air is passed through the agitated suspension, hydrophobic particles become attached to air bubbles and rise to the surface, where they are collected in the froth. The hydrophilic particles, however, remain in aqueous suspension. A reagent, such as pine oil, is added to help form a stable froth.

Oil-soaked sand is an ideal material for cleaning by froth flotation because very little chemical or physical pretreatment is called for. It does not need crushing because it is naturally finely divided, but it is also relatively free of "slimes." The sand is naturally hydrophilic and the oil is naturally hydrophobic. Many oils froth rather easily. The oil is less dense than either the water or the sand, thereby facilitating flotation.

Extensive laboratory experiments at Meloy Laboratories indicated that froth flotation with appropriate scrubbing permits the cleaning of a wide range of sands contaminated with a wide variety of oils. "Oils", ranging from a very light crude whose nature was much like gasoline to a baked solid fuel oil, were successfully removed from mixtures with sands, ranging from Dam Neck beach with 100% of its grains smaller than 841 microns to a yellow river sand with almost 10% by weight larger than 1.68 mm. The oils were aged and unaged and deposited on both wet and dry sand. In every case in which it was attempted, it was relatively easy to select a combination of operating conditions under which the cleaning process worked. In short, flotation seemed to have considerable promise for the cleaning of oil contaminated beach sands.

3.1.3 Froth Flotation - Plant Construction

Based on the laboratory experiments and on consultation with individuals and literature familiar with the glass sand cleaning industry, Meloy Laboratories proceeded with the design and construction of a beach cleaning demonstration plant. Preliminary design of the plant involved considerations analogous to the design of sand cleaning and froth flotation plants in the mining industry. Two criteria were primary in the initial design: first, the plant was to operate at a sand feed rate of about 30 tons/hour and be entirely self-contained, and, second, the cleaning system was to be closed as completely as was practical so that no extraneous oil contamination could result from the operation of the plant during the demonstration studies. Of course, all the plant components had to be relatively resistant to a marine environment, and provision had to be made for running analyses of oil concentrations in both sand and water at the site.

A suitable site was found in the vicinity of Virginia Beach, Virginia; specifically, it was on the U.S. Navy's Fleet Anti-Air Warfare Training Center at Dam Neck, Virginia. Navy representatives reviewed the proposed project and conferred with Meloy Laboratories' technical staff before leasing the site in early 1970. Three problems immediately came to fore concerning the actual site which was now to be used. First, the actual plant site was some distance from the Atlantic Ocean; 550 feet to be exact. Second, the area to which the plant was restricted (about 7,500 square feet) was about half that originally specified. And, third, the available electric power was further from the site (750 feet) than had been planned. These problems were eventually overcome by using wellpoint water for most of the demonstration tests, rearranging the general layout of the plant and drastically restricting the movement of support vehicles, and spending more (over and above the original estimate) of the project funds for a high tension power line.

To obtain fixed price bids on plant construction a detailed final design was necessary. This final design was made by the Meloy Laboratories technical staff with major and invaluable assistance from Mr. J. D. Glenn, consulting engineer, and his engineering assistants in Norfolk, Virginia. The final design was completed in May of 1970 and bids for plant construction were requested immediately. The bids were received in June of 1970, and the Welch Contracting Corporation of Norfolk, Virginia was selected on the basis of both the lowest bid and the earliest guaranteed delivery time. Construction began in early July and was essentially completed by mid-September of 1970. Meanwhile, the high tension power line had also been constructed; Woodington Electric Inc., also of Norfolk, Virginia, performed this task. All the above subcontractors performed admirably under very short term conditions.

Meloy Laboratories engineering staff supplied the construction subcontractor with the major items of process equipment. These included an attrition scrubber, flotation machine and horizontal slurry pump from the Denver Equipment Company, a vertical slurry pump from the Galigher Company, a belt feeder and feed hopper from Link-Belt, Inc., a dewatering cyclone from Krebs Engineering, a process water pump from Worthington Corporation, and a process water tank. A work-laboratory trailer was also placed at the site under the direction of Meloy Laboratories; this trailer was supplied by the U.S. Government.

Check out of the plant unit operations began in mid-September of 1970 and was completed in less than the month originally projected. This was so even though the project engineering staff had to integrate a leased wellpoint system into the process and obtain appropriate sheaves for the horizontal slurry pump on very short notice. The first actual plant demonstration took place on October 6, 1970.

3.1.4 Froth Flotation - Demonstration Studies

The demonstration studies took place under conditions comparable to those of a medium size minerals processing plant. The major differences were due to the comparative isolation of the site from the, sometimes, necessary support services. These differences were, however, themselves a valuable education since a mobile beach cleaning unit may very well have to be operated under similar isolation. Five demonstrations were required by the original contract, but by the time this report was written 41 had actually been performed. Although directly aimed at demonstrating the efficacy of the froth flotation process for cleaning oil contaminated beach sands, the project also provided a variety of knowledge about other processing schemes and the field operation of such a system. This knowledge ranged from the problems expected in operating unmodified heavy equipment on a beach to the deleterious effect noticed for the attrition scrubbing of a "normal" oil/sand mixture to the possibility of making high capacity oil/water separations with a standard froth flotation machine.

The results of the tests on oily sand cleaning were briefly as follows. Under nominal conditions with the closed loop process, sand was cleaned to an acceptable level (less than 150 ppm oil in the water saturated cleaned sand), and the change to a heavier oil improved the efficiency of the process only slightly. Lowering the sand feed rate had significant positive effect on the process water and little effect on the cleaned sand. The presence of straw demands much more continuous attention to the belt feeder unit operation; there was a slight indication that straw also promotes dispersion of oil into water. Finally, the system is limited mainly by the total flow of oil through it with a maximum acceptable level of oil contamination at a 30 ton/hour sand feed rate of about 1%. The sand cleaning demonstrations are discussed in more detail in section 3.4.2.

An elevating scraper and front end loader were necessary for plant operation. One of the first problems with the demonstrations was getting this equipment to operate satisfactorily in loose beach sand; there was no problem on the beach itself; the problems came when the heavy equipment had to move between the plant and the beach across the loose sand on the back beach. Reliable transport was finally achieved when pierced steel planking was laid in a single track from the plant to the beach; some such provision should also be made for a mobile unit since vehicles with balloon tires or tracks may not be available. Other observations were made during the project relative to support equipment; these are discussed in some detail in section 3.4 below

The field work did show that the major items of process equipment are very dependable under even very severe weather conditions; this portends well for a mobile unit. The components which did give trouble were the pumps and dewatering cyclone; since none of these items are envisioned for use in actual emergency operations, problems with them are not particularly relevant. The hopper and belt feeder, flotation machine, and leased submersible pump operated very dependably over long time periods; maintenance was also only of minor concern. Since these three items represent (along with a suitable power supply) a mobile beach cleaner, the results of the field tests were quite heartening.

Oil/water separation using the froth flotation machine at the demonstration plant with high flow rates proved more difficult than was originally anticipated. Such processing was much more sensitive to the nature of the feed stream than when used for cleaning oily sand. By implication, the tests indicated that considerable active flotation cell bypass occurs when a relatively low density oil is processed. In the actual tests, oil recovery efficiencies ranged from about 50 to 80% for total flow rates up to 1000 gallons/minute and oil concentrations as high as 5%. This performance indicates probable success for the basic separation principle in a system designed to utilize it fully while the success with standard processing equipment has to be judged as marginal.

Besides the two basic types of tests mentioned above, straw cleaning by attrition scrubbing and sand cleaning by scrubbing and dewatering were attempted. The former, due to both a lack of oil removal and extreme difficulty in effecting the processing, was judged impractical. Although scrubbing and dewatering of oily sand was demonstrated to be, in principle, possible by the test results, the practical engineering problems associated with such an approach (i.e., multiple scrubbing operations, oil/water separation as necessitated by the dispersion due to scrubbing, the necessary large process water supply for a 30 ton/hour processing rate, and large oily water storage facilities) make it infeasible for emergency field use.

3.1.5 Mobile Unit Field Demonstrations

Twenty four full scale demonstrations were run with the mobile beach cleaner in the field. The results of these demonstrations are discussed in some detail in section 3.5.4 of this report and tabulated in entirety in Appendix D. Briefly, the field demonstrations substantiated the performance estimates for the mobile beach cleaner and provided information for modifications of the unit. Some of the difficulties inherent in remote, field operation of such a unit were more clearly delineated by the field tests (e.g., problems with weather conditions on a beach and with obtaining a reliable supply of water).

The general result of the field tests was that under nominal operating conditions (see 3.5.6) the cleaned sand and total effluent stream are expected to contain approximately 75 and 130 ppm oil respectively; this effluent quality applies to a sand feed rate of 30 tons/hour with an oil concentration of 0.5%. Other effects which were studied related to such things as the deleterious effects of straw on the process, the feasibility of water recycle from the oil recovery tank, the feasibility of using settling ponds to isolate the process effluent stream, and the ease with which the mobile unit could be moved to and from a location on the beach. Indicators were also formulated for the dependence of the effluent stream quality on the many process parameters; due to the large number of parameters involved, some of these indicators were quantitative and some qualitative in nature.

3.2 Laboratory Studies

3.2.1 Introduction

The purpose of the laboratory studies in Phase I of this program was twofold. First, flotation cleaning of oil contaminated beach sand was shown to be feasible in the context of the original proposal (the feasibility studies); experiments which simulated the "natural" contamination of beaches were also successful (simulated beach conditions). Second, by attempting to clean severely contaminated samples of beach sand, limits were placed upon the probable, successful operation of the proposed plant. These limits were found to confine a zone of plant operation which is much broader than originally thought possible.

Specifically, the laboratory studies led to or assisted in leading to a number of important conclusions:

(1) An attrition scrubber should be considered for the full scale system.

(2) A belt feeder should be utilized to assure steady-state plant operation.

(3) The pulp level in the flotation cells should be controlled.

(4) Irreversibly contaminated sand grains will be substantially removed by the flotation process.

(5) Residual contamination due to pine oil frothing reagent should be negligible.

(6) At the very least an oil-sand specific, quantitative technique for measuring sand contamination should be used in evaluating demonstration tests; such a technique was developed in Phase I and used in Phase II. A more general analytical methodology was beyond the scope of the contract.

The following sections discuss the laboratory work which was performed. Where pertinent, analyses and extensions of this work are also presented. The laboratory work was intensely practical; such should be the case since the flotation cleaning of oil contaminated beach sand is an intensely practical problem.

3.2.2 Feasibility Studies

The feasibility studies in Phase I involved obtaining estimates of the importance of five systems' phenomena: (1) aging of crude oils, (2) materials' recovery, (3) residence times and pulp density, and (4) the effect of salt water on flotation. The study of the aging of crude oils must embrace both long and short range effects as well as whether the aging process occurs on the ocean or on a beach.

The short range effects were found to be nil for the three crude oils investigated; contrary to what one might expect, the long range effects appeared to be most severe for heavy crude oils. Studies of aging were made for oil on sea water and on beach sand. Inspection of the processing materials in the laboratory led to the conclusion that only trace amounts of oil are present in the cleaned sand or in the sea water accompanying it. Similarly, the recovered oil carries with it enough sand and water to be important from a handling or disposal standpoint but not from the standpoint of the feasibility of the overall process. Based on both the laboratory studies and a review of similar processing units, the residence times (calculated) of the various unit operations in the beach cleaning plant were estimated; in certain cases these turned out to be different from the values estimated from the preliminary laboratory tests but not to a degree which could have been considered detrimental to the overall program objectives. Due to the results of the laboratory tests, pulp density estimates were also revised; in all cases these revisions were favorable to the process. Only actual operation of the plant will show whether such revisions hold for a full scale system, also. The effect of salt (or sea) water on the flotation process is of considerable importance in the treatment of ocean beach sand: it means the difference between having or not having to provide fresh water in an area where salt water abounds. Fortunately, salt water did not prove to have an adverse effect on flotation and, in fact, eventually proved favorable from the standpoints of both frothing and the actual oil separation.

The feasibility studies indicated that, at worst, the flotation cleaning of oil contaminated beach sand would work as initially expected.

3.2.2.1 Aging of Crude Oils

Perhaps the most critical systems' parameter in any scheme for the physical removal of oil from contaminated beach sand is the physical state of the oil itself. This state is the result of aging processes on both the ocean's surface and the beach. The most significant phenomena affecting the oil are evaporation, oxidation, absorption of solids and gases, chemical and microbial reactions, solubilization, and interaction with sea water. Of interest here is the effect which aging has upon the flotation cleaning of sand rather than the various phenomena which comprise the aging process; for this reason, oils were aged by exposure to the ambient in a relatively uncontrolled manner. The ease with which this oil may then be floated from a sand-oil-sea water mixture indicated the effect of aging on the flotation process to the degree which is necessary for process design and development.

Three crude oils were aged: light, South Louisiana mix; medium, mixed sweet (high grade crudes); and heavy, Bachequero 17 (all supplied by the Humble Oil and Refining Company). A 1500 ml sample of each oil was aged for about four weeks in a perforated cylindrical container nested in a rectangular plastic pan filled with sea water. In the main, only drastic changes in the properties of the oil were looked for. Both the light and the medium crudes (API gravities of about 45 and 35 respectively) showed little in the way of significant changes; some tendency to form the so-called "chocolate mousse" emulsions was noted. There were most probably some changes in density, viscosity, surface character, and state of emulsion for the two lighter crude oils, but these changes were definitely not enough to provide a basis for judging the aged oils as similar to Number 6 fuel oil which was being used as a standard for the flotation cleaning up to this point in time.

The Bachequero 17 or heavy crude oil (API gravity of about 19) showed marked changes upon aging. In fact, a surface layer, due probably to evaportaion, reactions, and the deposition of solids, was very apparent. This effect was of considerable importance since the heavy crude oil was initially very similar to a Number 6 fuel oil (even in asphaltene content which is estimated to be about 15% by weight). It should be noted that this aged oil was essentially an asphalt and that, therefore, the attempt to remove it from an oil-sand-sea water mixture was an extreme test for the flotation process. Such a separation cannot be effected with only a laboratory flotation cell because the energy input per unit volume of pulp is too low. An ordinary kitchen blender allows a more reasonable simulation of the conditioning process (scrubbing) in the laboratory. Some such conditioning is necessary for the cleaning of sand contaminated with asphaltic crude oils or for the flotation removal of the solid hydrocarbon residues which are sometimes created when oils age upon a beach.

3.2.2.2 Materials' Recovery

Materials' recovery affects the overall processing scheme most importantly in the residual oil contamination of the process water and the cleaned sand. Since crude oil is very slightly soluble in sea water (on the order of parts per million) a certain amount of residual contamination is unavoidable. A similar consideration holds for the adsorption of hydrocarbons on at least some constituents of the solids matrix which comprises a sand grain. The sensory and perceptual impact of such tract contamination is, however, negligible. It should be pointed out that in some tests the processed sand appears to be cleaner than the sand prior to contamination with oil; this is due to the removal of iron oxides by the flotation process. The same effect is not observed for sand from the actual beach site.

Consider that 10 pounds per minute of oil enters the plant (about 1% by weight oil in sand), the amount of oil which is lost as residual contamination in the processed sand and water can be calculated quite simply. The oil lost amounts to 100 to 200 ppm. Since the water (from the dewatering cyclone in the process plant) exits at about 65 gpm or 540 pounds per minute, it, therefore, carries with it 0.054 to 0.108 pounds per minute of oil. The fraction of the oil which remains as residual contamination can now be calculated, but it should be remembered that the rate of oil carry-over is about the same for considerably larger levels of initial oil contamination. The percentage recoveries which are calaulated in the following are, therefore, conservative with respect to more severe contamination. Oil losses are obviously 0.54 to 1.08% by weight; it follows that oil is recovered at the rate of 98.92 to 99.46% of the rate of oil input. These are conservative, yet excellent, values when the large processing rates of the efficiencies of other separation techniques are considered.

The rates at which sand and water are carried over with the recovered oil may also be calculated. However, these rates are not nearly as critical as that for residual oil contamination. Furthermore, the sand which is carried over often should be since it is permanently contaminated with oil, and water carry-over depends greatly on the total oil recovery rate and the height of the oil froth in the flotation cells. Anyway, the maximum contamination rates for the recovered oil were expected to be 300 pounds per hour of sand and 600 pounds per hour of water based on an oil input of 600 pounds per hour.

3.2.2.3 Residence Times and Pulp Density

Although the laboratory flotation machine was found to operate optimally at a pulp density (about 11% by weight solids; see Figure 1) like those often used in the minerals dressing industries, the pulp densities proposed for the beach plant do not stand up to the same comparison. A cleaning operation as that envisioned here usually runs at 25 to 35 weight % solids. Fortunately, an increase in pulp densities leads to increased residence times for the same process equipment and the same solids processing rates. Based on the results of the laboratory studies this is a route which was eventually pursued.

Long conditioning times in minerals processing allow for the action of various reagents; conditioning of the sand (about 7.5 minutes) promotes other effects. Combined with a high pulp density (about 75 weight % solids), scrubbing allows the release of the oil from the surface of the sand particles and promotes oil-in-water dispersion. Although of opposite relevance, these two effects are of primary importance in the cleaning process..

Since the aeration rate is relatively fixed in a given flotation machine, an increased pulp density in the flotation cells (and the concomitant increase in residence time) means that the contaminating oil is exposed to possible contact with air bubbles for a longer period of time. The result is, will be, and was a considerable increase in the efficiency of the separation. The laboratory studies have indicated that these increases are, indeed, beneficial. Therefore, the design pulp density for flotation was increased to 25% by weight sand, and the residence time in the flotation cells to about 4.4 minutes.

Changes in pulp densitites also had an effect on the overall processing plant. Pump capacities were lowered, storage facilities made smaller (except for the oil recovery tanks and the areas for sand piles), and control of the plant made simpler.

3.2.2.4 Effect of Salt Water on Flotation

There was some reason for concern over the use of salt water in the flotation cleaning of oil contaminated beach sand. Since surface phenomena are of primary importance in flotation unit operations and since solutions with highly ionic character often have peculiar surface properties, this effect was considered closely. Contact between covalent and ionic media (for particle sizes of more than a few microns) leads to both more stable dispersions and enhanced differences in surface properties. Fundamentally, this leads to a rationale for the information of stable oil-sea water emulsions (chocolate mousse). As far as flotation processing is concerned, dispersion stability can be bad and enhancement of differences in surface properties can be good.

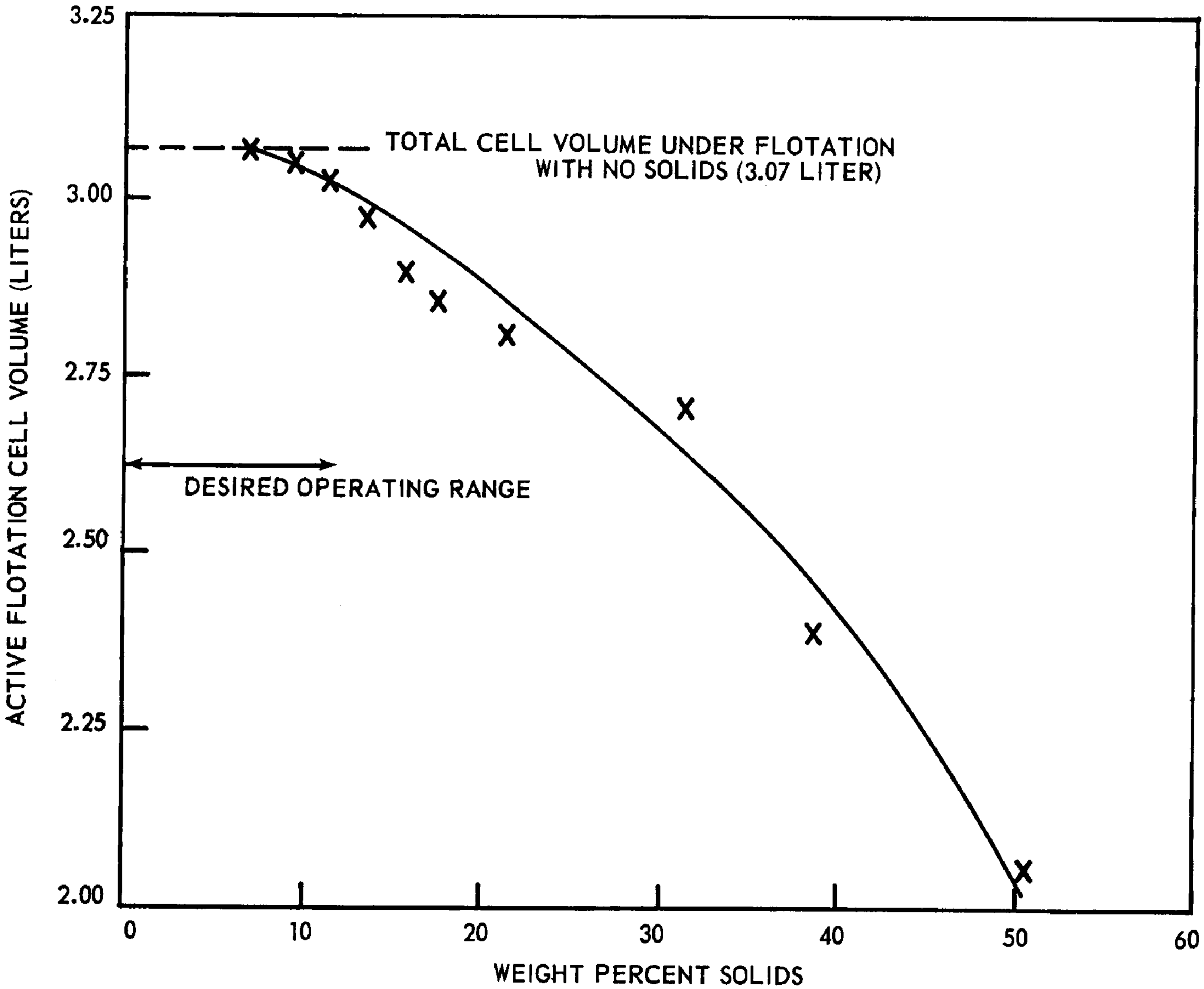

FIGURE 1

ACTIVE CELL VOLUME VS. WEIGHT PERCENT SOLIDS

Qualitative experiments (i.e., using sea rather than fresh water) indicated that the flotation process is effected only marginally if it is not helped. Separation of oil droplets from sea water was observed to occur very rapidly (in approximately 15 seconds); on the other hand, more water was contained in the froth column when sea water was used (about 10% rather than the previous 1 to 5). Both these observations are in line with the previous conclusions: the former with the enhancement of surface properties, the latter with increased dispersion stability. In principle, the rate of sand processing can be increased because the separation occurs more rapidly; however, the recovered oil contains more water. This can be somewhat adjusted by increasing the height of the oil froth column so that more water drainage occurs.

In conclusion, salt water does not (on the laboratory scale) appear to have an appreciable effect on the flotation process.

3.2.3 Simulated Beach Conditions

Since this phase of the laboratory studies covered less than half the time which was spent on the feasibility studies, its scope was considerably more limited. Four areas of interest were considered: (1) flotation testing different oil types, (2) finding an oil to replace aged crudes during the demonstration, (3) simulating beach aging, and (4) testing different sand types. A large number of oils were cleaned from sands by flotation; these included crude oils (light, medium, and heavy as previously indicated), fuel oils (both blended and unblended; numbers 2, 4, 5, and 6), aged and unaged oils, medium crude oil blended with selected organic chemicals (e.g., carbon disulfide and benzene), baked heavy fuel oil, and oil which was heavily dosed with powdered graphite. Significant flotation sand cleaning was found to occur with each of these substances; furthermore, in every case where it was attempted a combination of scrubbing and flotation conditions could be found which produced essentially complete cleaning of the contaminated sand. The series of fuel oils, as well as blends of same, were considered as replacements for aged crude during the demonstration runs. Since fuel oils figure in a significant portion of the reported oil spills and because the heavy fuel oils are highly visible, No. 4 fuel oil was selected as a suitable replacement. The simulated beach aging of various contaminating oils showed that prolonged contact with sea water enhances the flotation cleaning process. Three sands were successfully tested; they varied considerably in their content of both fine and coarse particles as well as in appearance. All could be cleaned under appropriately selected conditions.

3.2.3.1 Testing of Different Oil Types

Probably the most obvious way in which oils can vary is in viscosity. In this portion of the laboratory studies oils with viscosities ranging from that of gasoline, about 0.5 centipoise, to that of glycerol, better than 100 centipoise, were successfully removed from sand mixtures. Since flotation is a process based predominantly on differences in surface properties, the most difficult oils to clean up were some of those which one would expect to have radically different surface characteristics; viscosity and density, in fact, often play a relatively minor role. For instance, a medium crude oil with a high concentration of aromatic hydrocarbons was blended in the laboratory; it was quite difficult to separate this oil from sand and salt water in the flotation cell. This should not be too surprising since aromatics have a considerable tendency to maintain contact with both sand and water. Fortunately, the cleaning process can still be adjusted to be relatively successful, and most aromatics will have vaporized from actual oil contamination on a beach. On the other hand, a medium crude oil whose sulfur content was upped to a known value of 15% by adding carbon disulfide cleaned more easily than the original crude; this occurred in spite of the fact that the blended crude oil was both more dense and more viscous than the original crude. Of course, organic sulfides do have less of a tendency to wet sand and water than do the alkanes and alkenes.

As far as the flotation process is concerned, it makes little difference whether the hydrocarbon to be separated from a sand-sea water mixture is present as an oil or as a solid residue. In either case, the primary concern is that the hydrocarbon be dispersed as small enough particles to allow air bubbles to float it out of the pulp. Even when the oil or hydrocarbon has a very high affinity for silica particles (e.g., crude oil which has been carbonized or literally baked onto the surface of the particles due to the action of sunlight) beach sand can still be cleaned; in this case the permanently contaminated sand particles are floated with the hydrocarbon. This principle was, in fact, the basis for some of the first minerals' flotation processes. Since cleaning under more extreme conditions is possible, provision was made for this in the demonstration plant design; the attrition scrubber and two screening unit operations do this. The attrition scrubber both conditions the flotation pulp and reduces most of the agglomerates to single sand particles coated with hydrocarbons. The froth flotation process is then able to remove from the cleanable sand both the crude oil and the silica particles which are "irreversibly" coated with hydrocarbon. Flotation functions as both an oil-sand separator and a sand sorter.

All the crude oils and fuel oils which were considered could be cleaned from beach sand; this included whether they were aged or unaged, blended or unblended, or deposited on wet or dry sand. A generalization can be made from the study of different oil types: the drier the sand the oil is found upon and the more viscous the contaminating oil, the greater the need for scrubbing of some sort in a successful flotation cleaning process. The extremes of both these points are illustrated by the cleaning of carbonized oil (almost infinitely viscous from baked sand (extremely dry).

3.2.3.2 Oil to Replace Aged Crudes

Initially it was thought that there might be some problem in selecting an oil suitable as the contaminant for the demonstration tests. However, the success of the process in the laboratory and familiarity with the nature of aged crude oils eliminated this concern. In fact, other factors were now of primary importance. For the purpose of demonstrations, high contaminant visibility was desirable. The oil used was to be fairly standard in its properties so that lots bought at different times could still be counted upon to behave similarly. It was also desirable that the oil have some direct relevance to the problem of oil spills and beach pollution. These points all indicated the use of a fuel oil. The cost of these oils was not prohibitive, and they are very widely available. A choice had to be made between numbers 4, 5, and 6 fuel oils. The selection of the fuel oil was finally made on the basis that the Humble Oil Company in Norfolk, Virginia was willing to supply No. 4 fuel oil in the quantities necessary for the demonstrations at no charge.

3.2.3.3 Simulated Beach Aging

The simulated beach aging, flotation tests were very successful. Both a heavy crude oil and Number 5 fuel oil were aged on sea water for several weeks; they were then deposited on samples of Dam Neck beach sand and aged for about one more week. During this last week the oil-sand mixture was periodically wet with sea water to simulate tidal action. The sand was then cleaned by flotation; essentially no scrubbing (other than that received in the flotation cells) was necessary to obtain a very clean product sand. The same result occurred for a medium crude oil which was aged only upon sand, not upon sea water. It is obvious that when water is readily available for contact with the sand, the oil may mix with the sand, thereby producing an unsightly mess, but there is little or no real interaction between the sand grains and the oil.

3.2.3.4 Different Type Sands

Three types of sand were successfully cleaned: a yellow river sand, a commercial white sand, and Dam Neck beach sand. These sands differed markedly in their distributions of particles; Figures 2 and 3 on the following pages illustrate this graphically. The yellow river sand was much the coarser of the three; just a bit less than 10 weight percent was larger than 1.68 mm. The Dam Neck sand was much finer with 100 percent smaller than 841 microns. The white sand fell between these two in coarseness. All three were easily cleaned and handled in the flotation process. The appearance of the sands was effected differently, however. The Dam Neck sand was darkened by the cleaning process; this was shown by cleaning uncontaminated sand which still resulted in the darkening effect. The yellow river sand looked cleaner after flotation; this was because the process removed some of the iron which gave the sand its very yellow color. The commercial white sand showed very little change in color upon flotation cleaning; this was true whether or not it was contaminated. Coral sand was also obtained in the latter stages of the laboratory studies. When contaminated with No. 4 fuel oil, this sand also cleaned very easily with only slight darkening; this cursory analysis indicates that coral beaches will be restorable using the froth flotation process.

3.2.4 Pine Oil Toxicity and Contamination

The book, Clinical Toxicology of Commercial Products by Gleason, Gosselin, and Hodge, rates the toxicity of pine oil as the same as turpentine, pinene, crude petroleum, petroleum distillates, kerosene, and fuel oil to name only a few stubstances. These materials are all moderately toxic; for instance, the probable lethal dose is 500 mg to 5 gm of the substance per kilogram of body weight or about 1 ounce to 1 pound for a 150 pound man. However, the toxicity of pine oil cannot be related on a one to one basis with these other materials since it is, due to its aromatic and hydroxylated nature, significantly more soluble in water (although still infinitely miscible with the various hydrocarbon liquids). Since pine oil is a complex and variable mixture of organic compounds, it is even more difficult to attach a value to either its toxicity or solubility in other liquids. Its great preference for dissolution in No. 5 fuel oil over water does assure that any residual contamination in effluent water streams due to

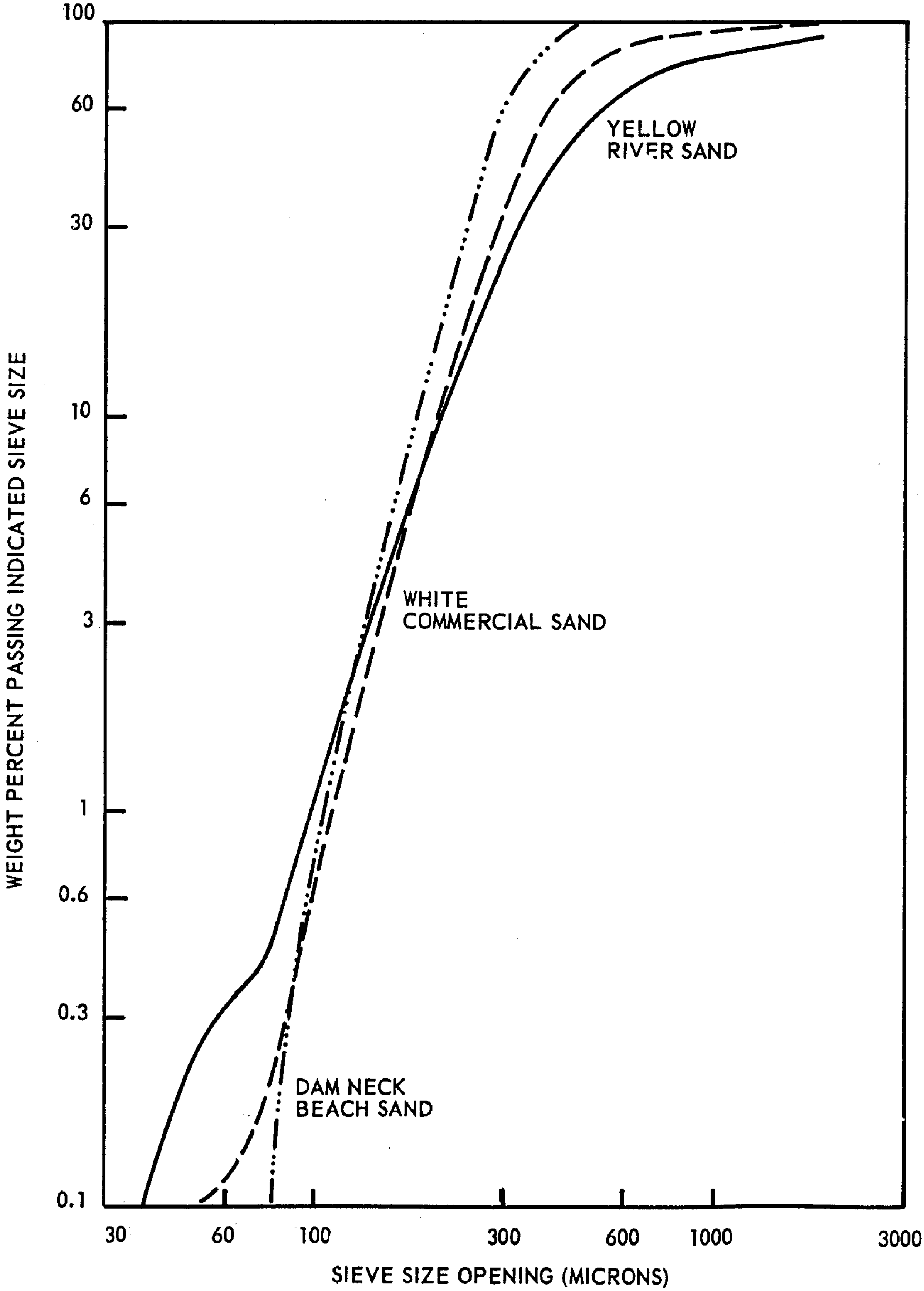

FIGURE 2
WEIGHT PERCENT PASSING VS. PARTICLE SIZE FOR THREE SANDS

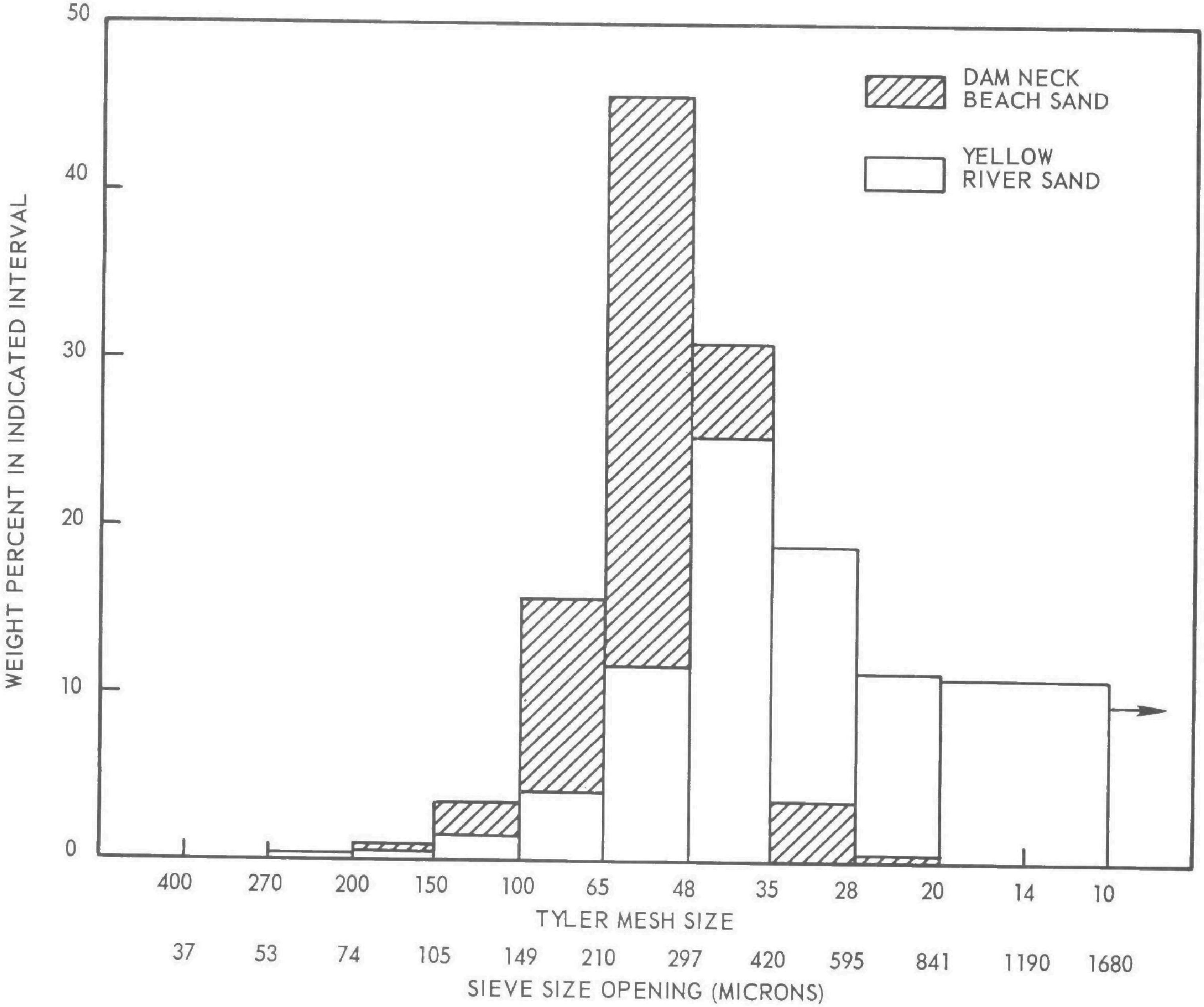

FIGURE 3

PARTICLE DISTRIBUTIONS FOR DAM NECK AND YELLOW RIVER SANDS pine oil will be small when compared to the high initial (and, relatively, high final) concentrations of fuel oil.

Laboratory measurements indicate that pine oil is infinitely soluble in No. 5 fuel oil and soluble in water to the extent of about 1 part in 2000. It is reasonable to assume that solutions of pine oil with both these solvents are essentially ideal. Water solutions can be considered ideal since they must be quite dilute while fuel oil-pine oil mixtures are ideal since both materials are very similar in physical and chemical properties. The fact that fuel oil and pine oil are not homogeneous substances raises some doubt about treating them as if they were, but, for the purposes here, this should be acceptable.

Consider equilibrium of oil (subscript A) and water (subscript B) solutions of pine oil; the activities, a_A and a_B, must be equal. For dilute enough solutions (less than about 1% by weight pine oil) these activities may be expressed as the product of a constant activity coefficient, C_A of C_B, and the mass fraction of pine oil, x_A or x_B; we find, therefore, that

$$x_B = (C_A/C_B)x_A.$$

However, when the oil phase is completely pine oil, the water phase is saturated so the ratio of activity coefficients is equal to $x_{B,\ saturation}$. With the total masses of both phases given by m_A and m_B and the total mass of pine oil in the system given by m_p, a mass balance may be made. The mass balance and the equilibrium expression give us two equations in two unknowns (x_A and x_B):

$$x_A = x_B/x_{B,\ saturation}$$

and

$$x_A m_A + x_B m_B = m_p$$

The general solution to these two equations is a quadratic; however, when both phases are quite dilute, the total masses may be set equal to the initial masses of fuel oil and water, $m_{A,o}$ and $m_{B,w}$ respectively. Solving for x_B then gives

$$x_B = m_p x_{B,\ saturation}/(m_{A,o} + m_{B,w}x_{B,\ saturation}).$$

For the purpose of the beach cleaning plant we may express the masses in the above equation in terms of mass flow rates. As mentioned previously, the saturation value for pine oil in water is about 1 part in 2000 or a mass fraction of 5×10^{-4}. The expected operating flow rates are about 300 gallons (2500 pounds) per minute of water, 10 pounds per minute of fuel oil, and 0.0022 pounds per minute (or about 1 cc/minute) of pine oil. Substitution in the equation for x_B shows that the mass fraction of pine oil in the process water is about 1×10^{-7} or 0.1 parts per million. Considering that this calculation is a conservative one and that pine oil is only moderately toxic, this residual concentration in effluent water should be entirely acceptable if pine oil is, indeed, needed as a frothing reagent.

3.2.5 Quantification of Oil-in-Sand Contamination

The general problem of determining quantitatively the contamination of sand by oil was beyond the scope of the contract. Both sands and oils are too variable to expect that there is any easy way to do this. What was needed, however, was a quantitative technique which worked specifically for a given oil and Dam Neck sand. A number of possible techniques were considered: photometrically measuring the reflectance of visible light from beds of sand, spectrometrically measuring the oil concentration in a solvent which has been used to extract oil from sand, chemically determining the concentration of carbon in a solution obtained by digesting a sample of sand with an appropriate chemical, measuring the transmittance of light through an oil-sand-liquid mixture where the liquid has a refractive index which is the same as the sand's, and using a gas analyzer (methane or general hydrocarbon) to detect the "odor" of contaminated sand. The second of these was finally settled upon as being most practical and amenable to field test conditions.

Solvent extraction combined with spectrometric analysis does not have the same limitations as visual and photometric evaluations. In principle, this technique may be used to detect oils which are invisible to the human eye. Wavelengths may also be sought which maximize absorption and, thereby, maximize detection sensitivity; unfortunately, for complex mixtures like oils no general analytical scheme is available. Spectrometric analysis is much more suited for detecting the components of a mixture than the mixture itself. However, in the case of a known contaminant a suitable correlation can be developed. Much of the discoloration due to oil pollutants can be related to suspended solids: asphaltenes, carbenes, carboids, etc.; these solids are not removed by most solvent extractions and, therefore, are not usually detected by this analysis technique. For fixed oil, sand, and solvent this method should be successful; it was, for this reason, used during the demonstration study.

Several solvents were tested for the analysis of sand and water samples. Benzene was finally selected due to its efficacy with the fuel oils most commonly used in the demonstration plant (numbers 4 and 6). The first solvent used in the extraction of oil from sand was heptane which worked well with light crude medium crude oil and some No. 4 fuel oils. In preparing No. 5 fuel oil solutions fine, dark particles appeared in the heptane and these did not dissolve but settled to the bottom. Other solvents were tried (i.e., chloroform, carbon tetrachloride and benzene). All three were suitable as solvents for the heavier oils, but benzene was selected for its lower cost and toxicity.

Briefly, the analytical scheme went as follows. A sample of the oil to be used as a contaminant was put into solution with benzene; known amounts of both materials were used to make up these standard solutions. The concentrations of oil in the benzene solutions were then correlated in the usual manner with transmittance readings from a Spectronic 20 spectrophotometer from Fisher Scientific Company. As expected, concentration varied linearly with the logarithm of the transmittance at a fixed wavelength of incident light. Plots or correlations of this sort had to be made up for each sand-oil combination considered; since such correlations involve standard, classical analytical chemistry, no examples of plots are presented here. The wavelength of light was generally around 450 millimicrons. Before unknowns could be confidently considered, the standard correlations had to be available; if they were not, the best that could be done was to express contamination levels in terms of equivalence to some known oil contamination.

When actual process samples were considered, sand samples were usually dried before solvent extraction at about 65 - 70°C while water samples were solvent extracted in a wet state overnight. Checks were run on the sand analysis both in the laboratory and the field by extracting from both dry and wet samples; the differences were small enough so that the convenience of working with dry samples could be continued as standard practice (for an example of this see the analytical results of field demonstration number 4 in Appendix C). Knowing the amount of sample (sand or water) analyzed, the amount of benzene used, and the apparent concentration of oil in the benzene, the oil contamination in the sample was quite simply back calculated. Since parts per million oil could be detected in this manner, several interesting conclusions were reached in the field analyses. Generally, large variability of samples was discovered under full scale, field test conditions; this was not unexpected. Background contamination in the sand at the field site was not insignificant. The analytical results of demonstration number 9 indicated a background contamination of about 20 ppm (expressed as No. 4 fuel oil) in the Dam Neck beach sand prior to contamination.

Sampling and analysis for the stationary and mobile unit feed sand were identical. A sample bottle was half filled by physically moving the bottle against the flow of the feed belt. Care was taken not to visually inspect the sand being sampled. Portions of these samples from 2 to 10 gms were used for subsequent analysis. These samples were not dried. Samples were weighed on a torsion balance to the nearest 10th of a gram and benzene added (10 to 100 ml depending upon the oil content). The sample was agitated by stirring and shaking until the oil was extracted from the sand. A benzene aliquot was placed in round Bausch & Lomb cuvettes, and the transmittance measured at 450 mμ on the Spectronic 20. Transmittance was then compared to the calibration curve for the particular oil used, and the oil content of the sand calculated.

Samples were obtained from the sand discharge streams by passing a sample bottle through the discharge flow, filling the bottle from 1/2 to 3/4. The sample bottle was passed vertically (from bottom to top) through the discharge stream to sample all stream components (sand, water and oil) since they were not completely mixed. Samples were weighed and shaken thoroughly, the solids allowed to settle for a few seconds, and the liquid poured into another bottle; the original bottle was then reweighed to obtain the weight of the liquid. Benzene was added to the liquid, and the oil was extracted by shaking until the water no longer contained oil. If an emulsion formed, the sample was allowed to set until enough benzene could be extracted for analysis. Analysis was as above. The solid portion of the sample was dried and then thoroughly mixed making sure that all visible oil was removed from the sides of the bottle. A portion was weighed and extracted with benzene, and the oil content determined spectrophotometrically.

Samples must be taken so as to be representative and unbiased. Samples taken at the stationary plant or mobile unit were placed in 16 oz. screw cap bottles obtained from Fisher Scientific Company of Silver Spring, Maryland. Caps for the bottles were black plastic and vinyl coated liners. These caps deteriorated after a few analyses so molded PVC caps should be used instead. Intervals between samples varied depending upon the length of the particular run. Ten samples were desired for each process stream during a particular demonstration; this is in line with statistics since, for large standard deviations, a standard deviation increase of about 10% results. Due to particular test conditions, at times fewer than 10 samples were acquired. Two to 10 grams from the well mixed total were analyzed for oil.

Note also that oils with the same classification occasionally differ greatly as to their color, viscosity and density with light oils being especially so prone. Calibration curves should be prepared for each shipment. Equal volumes of oil can be drawn from each barrel and mixed before taking an aliquot for use in obtaining the calibration curve. To cite an extreme example, one shipment of No. 5 fuel oil had a viscosity of 175 centipoise and an API gravity of 22.5 compared to another shipment with a viscosity of 48 centipoise and an API gravity of 25.3. The latter shipment was nearer in both viscosity and density to a No. 4 fuel oil than the usually accepted No. 5 fuel oil.

Since analysis for oils was done colorimetrically, lighter oils were less sensitive to analysis. When using marine diesel (light yellow), a gallon of No. 6 fuel oil was mixed with each barrel to give it a color detectable with sufficient sensitivity by the Spectronic 20. These analyses were run at 400 mμ to further increase sensitivity.

When pouring the liquid off the sand in sample bottles, a film of oil sometimes remained on the sides of the bottle. This would tend to cause the calculated oil-in-sand concentrations to be higher than the actual concentrations, but, more importantly, the results for total oil content remain accurate. Furthermore, as was noted time and again at the demonstration site, oily water runoff from contaminated sand does leave free oil or oily froth residue on the underlying sand; the residue on the sides of the bottles can be thought an analog to this residue. Perhaps more important is the definition of oil concentration in contaminated sand itself. Obviously, the oil is not <u>in</u> the sand. At best it may be on the surface of sand grains but usually is dispersed in the water within the interstitial voids of the sand. Given that total oil content measurements for process streams are accurate, a degree of arbitrariness remains in measuring sand and water oil concentrations. Selection of a specific analytical technique settles this arbitrariness as was done in the studies being discussed in this report.

Towards the end of Phase I of the program, the analytical technique described above was used in some limited laboratory studies aimed at the effect of varying froth flotation operating parameters. The results of these studies are discussed in the following section.

3.2.6 Quantitative Laboratory Studies

The first series of tests in these studies sought to attach numbers to the effect of increasing turbulence in the laboratory flotation cell. The analytical results for these tests are presented in Table 1 of Appendix A. Aeration rates were varied in three steps from the minimum rate to the maximum for each of four impeller speeds; the minimum rate was dictated by the lower limit of the rotameter used to measure aeration and was, therefore, the same for each impeller speed while the maximum rate was itself a function of the impeller speed. Average residual oil concentrations in the cleaned sand increased fairly regularly with increasing impeller speed: averages of 107, 101, 190 and 300 parts per million by oil by weight for 1000, 1200, 1800 and 2400 rpm impeller speeds respectively. There is an implication in this averaged data that an optimum exists with respect to impeller speed; "a priori," this must be the case since at zero impeller speed contaminated sand would settle to the bottom of the cell, never contact air bubbles, and therefore, never be cleaned while at very high impeller speeds any oil which rose to the top of the flotation cell would immediately be remixed with the sand slurry due to the intense mixing action, and, therefore, cleaning would once again not occur. The data is not, however, precise enough to allow a determination of the optimum impeller speed on the basis of only 16 laboratory tests. Such a result relative to precision is classically found for froth flotation on any scale; comprehensive test work in the minerals industry always involves large numbers of repetitive tests on large numbers of samples.

The series one tests may also be used to gain a semi-quantitative grasp of the effect of aeration rate on the process. Each impeller speed was tested at four aeration rates which may be designated as low, medium low, medium high and high; the averages over the four impeller speeds at each of these levels is 273, 183, 153 and 89 parts per million residual oil respectively. This result shows clearly that increased aeration decreases residual oil contamination over the range of conditions considered; this was not unexpected although high enough aeration rates should eventually promote a degradation in residual oil concentrations.

The second series of laboratory tests looked for the effect, on a quantitative basis, of three variables: magnitude of sand charge, initial oil concentration and aeration rate. The results of these tests are presented in Table 2 of Appendix A. The data for increasing sand charge is somewhat inconclusive although a general trend towards increasing residual oil with increasing charge can be seen. This makes sense for fixed feed concentration, impeller speed, flotation time and (relatively) aeration rate; increased sand charge implies increased total oil in the cell which, in turn, implies increased solubilized and dispersed oil in the process water, some of which is always recovered with the cleaned sand.

The twelve tests which considered three fixed aeration rates (see Table 2, Appendix A) confirmed the semi-quantitative results of the series one tests. The averages over the four initial oil concentrations were 109, 139 and 160 parts per million of residual oil for aeration rates of 11.8, 6.1 and 1.35 liters/minute respectively. This is good quantitative evidence that increased aeration decreases the amount of residual oil in the cleaned sand. Again, the data was averaged over four tests at the same aeration rate; a more comprehensive test program would have to involve repetitive testing under identical conditions to allow statistical evaluation of the analytical results. Fortunately, the test work discussed here was more to verify the practicability of the technique used to measure oil contamination levels rather than to study, in depth, the laboratory scale cleaning of oil contaminated beach sand by froth flotation. Such an in depth study could be a project in its own right, although its value relative to full scale cleaning operations would be dubious.

Averaging over the three aeration rates (see the second part of Table 2) for the four initial oil concentrations gives a quantitative indication of the effect of feed oil concentration on the process: 76, 102, 149 and 218 parts per million residual oil for initial oil concentrations of 1, 3, 5 and 9% respectively. This result substantiates quantitatively what had been observed qualitatively in previous tests: for "significant" feed oil concentrations there is apparently a bottoming out of residual oil concentration; in other words, there is a minimum (and finite) exit concentration of oil in the cleaned sand which cannot be eliminated except by decreasing the feed concentration of the oil to a very low level (this is, from an applications viewpoint, an impractical way to reduce the residual oil level). This minimum oil concentration is (considering the data and range of operating conditions presented above) about 60 ppm or 0.006%; feed oil concentrations would have to be reduced to about this level to effect any further large decreases in residual contamination.

The analytical problems observed during the laboratory tests were also to be of importance during the field demonstrations. Over and above this, the field tests presented their own special difficulties: lack of, for instance, homogeneity of the feed sand, control over operating temperatures, truly representative sampling, and absolute control over all process materials. Such considerations were important during the laboratory test program; it was mandatory that they be kept constantly in mind when the analytical results of the full scale test program were considered.

3.3 Plant Construction

3.3.1 Introduction

This section covers the construction phase of the program which, including the final design, took approximately four months to complete. Construction can be expressed as the sum total of work in three categories: 1) preliminary design and procurement of necessary unit processes and support equipment, 2) final design and specification of plant structures and materials, and 3) subcontract construction and unit process emplacement. The following subsections follow this general outline.

3.3.2 Preliminary Design and Unit Process Procurement

3.3.2.1 Process Flowsheet

The final result of the flowsheet considerations may be found in Figure 17 in Appendix B. Naturally, many similar flowsheets were generated over the course of the project. The first such conceptual guideline was prepared by the Meloy Laboratories' technical staff with assistance from a number of consultants. Figure 17, since it is a final version, includes equipment call outs and estimated power requirements; the first design flowsheet contained just the basis for calculations (30 tons of sand processed per hour), typical data, suggested residence times, and general flow requirements for all process materials through every unit process.

For the flowsheet presented here, sand enters the system through a feed hopper; a moving belt then transports the sand from the hopper to an attrition scrubber. The scrubber was added to the originally proposed system as a safety precaution; it was to prevent any sand from becoming irreversibly contaminated during the demonstration studies; laboratory studies had shown that, given enough processing time, scrubbing could be used to clean essentially any oil-contaminated sand. Sand leaves the attrition scrubber through a 1/4 inch screen and drops into a sump. A vertical slurry pump then delivers the sand to the flotation machine. Sand leaves the flotation machine in two streams; most of the sand exits through the discharge port while some is carried over with the recovered oil (indicated as about 10 pounds/minute on the flowsheet). The sand which exits the discharge enters a sump from which it is pumped by a horizontal slurry pump to a dewatering cyclone. A small amount of sand (mainly clay and very fine silica particles) enters the cyclone overflow and is deposited in the process water tank; the vast majority of the cleaned sand exits from the cyclone underflow in close to a water saturated state.

The contaminating oil follows essentially the same path as the sand. Most of it is discharged as froth from the top of the slurry or pulp in the flotation machine. Of the oil which is not separated by flotation, most is delivered to the process water tank while some exits with the cleaned sand. Under severe conditions during certain demonstration tests, the visual impact of the buildup of oil in the process water tank was quite startling due mainly to frothing of the oil upon turbulent contact with water in the tank.

Make-up water enters the system either from a submersible pump when sea water is used or a large, vacuum assisted centrifugal pump when wellpoint water is used. Water is fed to the plant in general with a pump for that purpose. The plant design allows for water addition at six points: as a wash at the feed hopper, as addition water at the scrubber, as a screen wash and addition at the 1/4 inch screen and following sump, at the flotation machine as addition water, as carrier for frothing reagent and as wash for the oil froth which exits via the launder oveflow. Some water leaves the system in the flotation machine's overflow; this is a natural phenomena. Water which is used to wash the oil froth into the recovery tank must be included in this stream for the purpose of material balance. Water also exits in both streams from the dewatering cyclone; most returns to the process water tank for reuse while some has to exit with the underflow since this is a water saturated sand stream.

If reagent is used in the process, most of it will leave the system with the recovered oil. Some will, however, solubilize or disperse into water and leave the system with same.

3.3.2.2 Preliminary Design

In essence, this flowsheet in its first form was delivered along with supporting data to Mountain States Mineral Enterprises, Inc., of Tucson, Arizona. Mountain States had won the subcontract, at $4,000, to assist Meloy Laboratories

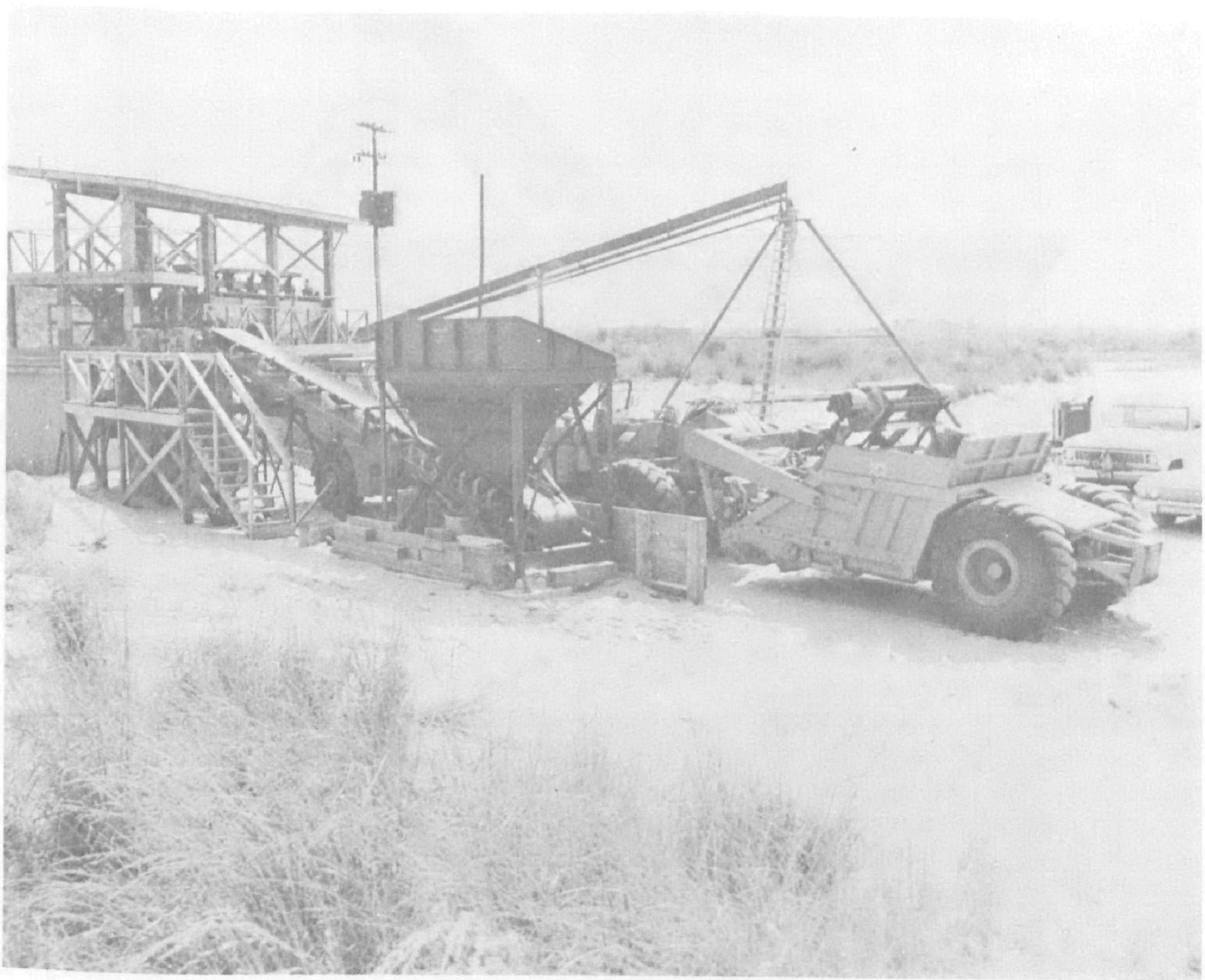

FIGURE 4. DEMONSTRATION PLANT FROM FEED·HOPPER END

FIGURE 5. VIEW EMPHASIZING THE PROCESS WATER TANK AND FLOTATION MACHINE AND PLATFORM

FIGURE 6. OIL RECOVERY TANK AND CYCLONE WITH TRIPOD SUPPORT

FIGURE 7. FULL VIEW OF PLANT FROM THE DISCHARGE END

in preparing the preliminary design and conceptual specifications for the demonstration plant. This task was completed during Phase I of the project. The general character of all foundations, supports and piping were specified during the preliminary design, the results of which were submitted with the Interim Report for this project. Although an attempt was made to get bids for plant construction on the basis of the preliminary design, it failed. Potential construction subcontractors could not quote a firm price without much more detailed information; upon learning this, the Meloy Laboratories' technical staff set out to provide such detailed information. This task comprised the final design which is covered in a later section of this report.

3.3.2.3 Unit Processes

In general, competitive bids were procured for each item of process equipment. It is beyond the scope of this report to go over the procurement process in detail; therefore, each item of process equipment is considered only briefly with a rationale for its selection, a short identification and specification summary, and a description of its operation and relation to the rest of the plant.

The belt feeder and feed bin or hopper were ordered as light duty installations since it was not expected that long continuous duty would be necessary or that the plant would be in place for a long period of time. This item, including the necessary supports and framing, was supplied by Link-Belt, a division of FMC Corporation on the basis of both low cost and superior design; the cost was $7,950. The hopper is 100 cubic feet in volume and is equipped with stiffeners, columns and bracing, a regulating gate, and a 1 inch Grizzley screen. The belt is 24 inches wide and operates around 31 foot centers; it is powered by a 2 horsepower drive unit at a speed of 23 feet/minute. The combined belt-hopper system is capable of delivering at least 40 tons per hour of damp beach sand containing oil and salt water. The 2 horsepower, 1800 rpm drive motor is wound for 440 volt, 3-phase, 60 cycle electric current. The hopper is filled with sand by a front end loader; since the belt operates at constant speed, the sand feed rate is controlled by adjusting the regulatory gate. Sand leaves the belt going directly into the feed box of the attrition scrubber.

The attrition scrubber was supplied by the Denver Equipment Company, It is a 4-cell machine with a total volume of 100 cubic feet or 25 cubic feet per cell. Since the scrubber is a standard piece of minerals processing equipment, it is of heavy welded steel construction and capable of operating under extended continuous duty. Agitation is supplied to each cell by a shaft with two opposed pitch propellers; each shaft is driven by a 15 horsepower, 900 rpm, 3-phase, 60 cycle, 440 volt, high starting torque motor. The interior of the machine is Neoprene lined for protection from both abrasion and oil. The attrition scrubber cost $9,940. As was mentioned earlier, the scrubber was added to the process to assure that all the sand contaminated at the site could be cleaned even under the most unfavorable conditions imaginable; it also permits study of the effect of scrubbing in a manner independent of the froth flotation process. Sand enters this machine directly from the feed belt; the sand is mixed with water at the feed box to form a slurry with at most 80% by weight solids. The slurry exits the scrubber onto a 1/4 inch screen from which it flows into the vertical pump's sump.

The vertical pump was supplied by The Galigher Company and was selected on the basis of the lowest bid under the required specifications. The pump cost $1,141 amd was rated at 194 gallons/minute of water-sand slurry (specific gravity 1.38) against a 34.3 foot dynamic head with an impeller speed of 1430 rpm. The pump includes a variable speed V-belt drive and a 15 horsepower, 1800 rpm, 230-460 volt, 3-phase, 60 cycle drive motor. This pump delivers the sand-water slurry from the scrubber to the froth flotation machine.

The flotation machine was supplied by the Denver Equipment Company and was selected on the basis of low bid as well as for more than meeting the process design specifications. Total cost, including a level controller and compressor as well as an air supercharger, was $10,065. The flotation machine was a 6-cell, No. 21 machine with a total volume of 240 cubic feet or 40 cubic feet per cell. The DR shaft assemblies are complete with disc impellers and diffusers for the supercharged air. The bottom of the tank is lined with Neoprene for abrasion and oil resistance. The machine is equipped with a built in air header, air valves and flexible connections from the header to the diffuser mechanisms. The impellers are driven by dual cell V-belt drives powered by three 10 horsepower, 1800 rpm, 3-phase, 60 cycle, 440 volt motors. Froth paddles and 1/4 horsepower drive motor are also included. Level control consisted of a Denver Auto-Flot Level Control system containing a controller, resistance probe, air regulator, dart valve; the control system operates with 60 cycle, single phase, 120 volt electrical power and 50 to 100 psi air. The air for the control system is supplied by an Oil-Less air compressor (74 psi maximum air pressure) with a ten gallon receiver, pressure gauge, cut-off controller and 1/4 horsepower, single phase, 60 cycle, 110 volt motor. Air is supplied to the flotation machine by a Denver Supercharger rated at 280 cubic feet/minute against a 16 ounce discharge pressure; the supercharger is powered by a 3 horsepower, 3500 rpm, 3-phase, 60 cycle, 440 volt motor; a 6 inch blast gate and flexaust air duct interface the supercharger to the flotation machine. Sand slurry is delivered to the machine by a vertical pump and diluted to the desired pulp density at the feed box. Since this is a right-hand machine, the concentrated oil froth overflows into a launder on the right when the machine is viewed from the feed end; each cell is equipped with slots and weir bars for individual control of the froth overflow. Since most of the recovered oil is floated in the first cells of the machine, the weirs for these cells are usually adjusted to provide most of the machine's overflow; to make this adjustment, the froth paddles must be turned off. The froth paddles assist in removing the froth from the top of the pulp in the machine; an additional assist from wash water is rarely needed. Processed sand slurry leaves the flotation machine through either an overflow weir or an underflow discharge port. Experience with the machine showed that the overflow discharge caused pulse-like outputs of small amounts of oil froth in the product slurry; this is due to the slow accumulation of oil froth at the wall of the last cell adjacent to the discharge box. Periodically some of this accumulated froth breaks loose, enters the discharge box and passes over the weir; however, if the weir overflow is not used, "tramp" froth just collects on the surface of the pulp in the discharge box. Manual removal of this froth at regular intervals prevents it from discharging with the underflow. The slurry discharge from the machine drops directly into the horizontal pump's sump.

The horizontal slurry pump was also supplied by the Denver Equipment Company at a cost of $1,550. It was selected for both meeting specifications and being least cost. This 5" x 5" Frame Three SRL pump has Neoprene runner and casing liners, a water gland, variable speed V-belt drive, and a 15 horsepower, 3-phase, 220/440 volt, 1800 rpm motor. The pump is rated at 405 gallons/minute for a 25% by weight sand slurry against a 54 foot total dynamic head. This pump delivers the processed sand slurry to the dewatering cyclone. Although equipped with a variable speed drive, the lowest possible capacity was often still too high; for this sort of flow situation, additional dilution water is supplied to the horizontal pump's sump.

The dewatering cyclone was supplied by Krebs Engineers for $1,529. This D15-B cyclone is of steel construction with molded Neoprene liners, a nickel hardened vortex finder, and an adjustable apex valve. Included with the cyclone was a No. 160 Pine Operator for hydraulic control over the apex valve. Although the dewatering cyclone is rated as being able to process 30 tons/hour of beach sand, the adjustable apex prevented this for the very monosized beach sand found at the Dam Neck site. When operated with the adjustable apex, the cyclone sent a large portion of the sand to the system's process water tank. This problem was resolved by removing the apex and the Pine Operator; after this was done, the cyclone operated in an acceptable, although somewhat wet, fashion. Cleaned sand which is discharged in the cyclone underflow is returned to the beach; the process water which exits via the overflow of the cyclone is returned to the process water tank.

While the oil recovery tank was of wooden construction and supplied by the construction subcontractor, the process water tank was a standard, 24 foot diameter backyard swimming pool; these are widely available and suitable, in a restrictive sense, for systems which demand portability. This tank was included in the plant for study as to how it stood up under relatively rough use. The only problem comes in trying to remove large amounts of sand from the tank; great care has to be taken to avoid puncturing the liner. However, during the whole series of demonstrations in which many tons of sand were removed from the tank by shoveling, pumping and flushing, the tank was punctured only once. Such a tank should be useful as an oil recovery tank in a mobile system.

3.3.2.4 Support Equipment

Three pieces of support equipment were required for the demonstration project; an elevating scraper for picking up and returning sand to the beach, a front end loader to dump sand into the feed hopper, and a 4-wheel drive truck for general plant support. In an actual emergency field operation a scraper would be necessary for about one third of the total plant operating time; considering shipping charges, day-by-day rental charges, and possible waiting periods for acquisition, however, it was both cheaper and more convenient to have the scraper available on a full time basis for the demonstration project.

The elevating scraper was supplied by the Furnival Machinery Company at $2,100 per month; it was selected on the basis of a low bid and at the suggestion of heavy equipment suppliers for the intended task. It is a WABCO D111A scraper with a capacity of approximately 11 cubic yards or 15 tons of beach sand. Although one of the smallest elevating scrapers manufactured, this machine is more than adequate for supplying sand to a 30 ton/hour plant; in approximately 20 minutes it can supply and return sand for an hour of plant operation. A larger scraper (say 30 cubic yards) could obviously spend much less time supporting the plant. Under ideal conditions this scraper could make an efficient 2 to 3 inch cut on the beach. However, usually the Dam Neck beach has undulations in it which significantly cut down on this efficiency; under "normal" surf conditions a best cut of 4 to 5 inches is quite acceptable. After severe storms, a 6 inch cut was often all that was possible. Although the scraper moves quite easily within the tidal zone on the beach, it has considerable trouble in the loose sand above the high water mark. Using matting or pierced steel planking overcomes this problem while restricting the mobility of the heavy equipment; a mobile system must take this into account.

The front end loader was also supplied by the Furnival Machinery Company at $1,000 per month; it was selected on a least cost basis. It is a WABCO 150B front end loader and was by far the most reliable piece of support equipment at the demonstration site. This loader has a 1-1/2 cubic yard bucket and is able to feed the plant at its maximum rate of about 60 tons/hour; at such a high rate it takes two men to conveniently keep up with the operation. A front end loader is mandatory for general plant and site housekeeping. It is also very useful when the last traces of oil contaminated sand are picked up from the beach; that is, the front end loader in conjunction with a shovel crew can be used to gather up the oily sand which is necessarily missed in a scraping operation. Like the scraper, even a 4-wheel drive front end loader with standard tires needs a bed of pierced steel planking to move efficiently in the loose sand above the high water mark.

Although a 4-wheel drive truck was very useful during the demonstration project, this would probably not be the case during an actual emergency field operation. Heavy equipment (loaders, scrapers, graders, etc.) should be sufficient for transport to and from the beach proper and the nearest road; standard road transportation would, of course, still be necessary. The truck used at the Dam Neck site is a 3/4 ton, 4-wheel drive, Ford pickup leased from Ted Britt Ford at $475 per month. It has been used for such varied tasks as delivering wellpoint sand and fuel oil in 55 gallon drums. In a field project such a vehicle is invaluable for general plant and project maintenance.

Early in the plant chek out it became obvious that it would not be possible to reliably obtain water from the ocean's surf over a distance of 550 feet; first, pumping over this distance required more power than the available pumps had, and second, even with an adequate pump in the surf, the field engineering staff would not have it under their direct control; the latter could easily result in losing the pump to the ocean. A wellpoint system was, therefore, installed to obtain water for general use. This system was supplied by the Moretrench Corporation at a cost which eventually leveled out to $262 per month. The water which it supplies is brackish and contains a large amount of unoxidized iron. In the course of the demonstration tests it was found that this water is deleterious to the froth flotation process relative to sea water. Whenever possible, sea water should be used in actual emergency field operations.

Besides the structures, electrical wiring and piping which were assembled at the site, an office-laboratory trailer and a tank for diesel fuel were required. The M-20 Coastal Trailer was supplied by the U.S. Government while the diesel fuel tank was supplied by the Hampton Roads Oil Supply Company at no cost other than the purchase of diesel fuel.

The rest of the demonstration plant (other than incidental materials and supplies) was supplied by construction subcontractors; their work is reviewed briefly in Section 3.3.4 while the following section discusses the final design upon which the construction work was based.

3.3.3 Final Design and Specifications

Appendix B contains the 11 engineering drawings which resulted from the final design work. As was mentioned earlier, the final structural design was completed by Joe D. Glenn, Jr. and Associates, Consulting Engineers. Figures 8 through 12 represent the input of Mr. Glenn to the final design. Figures 13 and 14 present the essence of the electrical specifications for the plant; these drawings were prepared by Mr. Robert L. Payne, an electrical engineer with Melpar, Inc., and are based upon the recommendations of the Meloy Laboratories' technical staff, the equipment vendors, and Mr. Joe D. Glenn. Figures 15 and 16 were prepared by the project engineers and are based on revisions of the preliminary design work done by Mountain States Mineral Enterprises, Inc. Figure 17, the plant flowsheet in final form, was prepared by the Meloy Laboratories' engineering staff and is a result of the previous design and consultation work; the staff also prepared the drawing presented in Figure 18 for additional support for the attrition scrubber.

The following sections consider each of the drawings in Appendix B in more detail as a means of explaining the plant design. This then provides a base for Section 3.3.4 on the plant construction.

3.3.3.1 General Layout and Electrical Shed

First, note that all the drawings have been halved in size for the purpose of this report; therefore, for the General Layout of the Pilot Plant in Figure 8 the scale is actually 1/16" = 1' rather than the 1/8" = 1' indicated on the figure. The trapezoidal area for the plant as represented in Figure 8 is approximately 8000 square feet; this is considerably less than the 15,000 square feet originally sought. The plant had to be arranged in a "U" shape to fit the available area which was bounded by a sand road (at the bottom of the figure), a hill and a target drone launching complex (at the top), and grassy dunes (on both sides); it was imperative that none of these restricting influences be disturbed. Contaminated sand for feeding the plant is placed in the area bounded by the ramp, scrubber, oil recovery tank, cyclone tripod, and road. Access to the back of the plant with the truck and heavy equipment was obviously hindered by the shape of the site. The shed pictured in section in Figure 8 is mainly to protect the plant's control panel from the elements. It also provides a small storage area for tools and supplies; due to the sandy nature of the site, wind and rain protection did not demand a floor for the shed. During construction the shed was modified to have doors on both ends. Figure 8 also contains general notes on plant construction and specifications as well as references to other drawings.

3.3.3.2 Attrition Scrubber Foundation and Platform

As indicated in Figure 9, the service and viewing platform for the attrition scrubber is of wood construction; this platform also allows easy access for sampling during demonstration tests. The foundation for the attrition scrubber is also indicated and is just a concrete pad. The foundation details for the belt feeder are also included in Figure 9; the relative location of these anchor bolts was supplied by the Link-Belt engineering staff and proved to be correct when the hopper and belt feeder were finally put into place.

3.3.3.3 Scrubber Foundations and Recovery Tank

Figure 10 shows the lattice arrangement which was used as a structure to support the attrition scrubber. 10" x 10" beams were spiked together to form the base upon which the scrubber sets; this base, in turn, sets upon a concrete pad. Unfortunately, this approach, although simple in concept and seemingly reliable, produced an unstable support; the scrubber wobbled on the lattice and would have walked off it if additional support had not been provided. Figure 18 shows the additional support; an extra concrete pad was formed, and steel "L's" were anchored to it and welded to the side of the attrition scrubber. This steel frame and pad kept the scrubber from moving around on the lattice. Figure 10 also includes details of the oil recovery tank. It is of wood construction with steel overflow and drain pipe. Heavy duty posts were used to brace the sides of the tank not so much to support the weight of the recovered oil as to prevent the tank from being collapsed by external factors (the front end loader, for example). The liner of the tank was supplied by the construction subcontractor and is formed of a polymeric vinyl film, 30 mils in thickness; this sort of thickness is, in general, desirable so that the tank can withstand some accidental abuse without rupturing. Details for the vertical pump's sump are also included in Figure 10; this sump is of concrete construction, and its bottom is approximately 4 feet below finish grade. The pump is supported by two 8" x 8" timbers which are anchored to the top edges of the sump. The screen and chute which follow the scrubber are pictured in the same drawing.

3.3.3.4 Flotation Machine Foundation and Platform

The platform for the flotation machine is supported by 4 concrete pads and is comprised of three levels (see Figure 11). The first level is finish grade. The second level supports the flotation machine; in this fashion, the froth flotation machine is as separate from the rest of the system as possible. Although dependent upon the operation of the vertical and horizontal pumps, it is not hydrodynamically connected to them. For instance, the horizontal pump's sump can partially sand-in and overflow without transmitting an upstream effect to the flotation machine; the overflow from the sump is just carried by a chute into the oil recovery tank. Similarly, the flow into the machine is positive for both the feed sand slurry from the vertical sump pump and the dilution water from the process water pump. Air is supplied to the flotation machine by the pressure blower which is located on the second level under the third level platform. The third level (a small platform) permits feed of reagents or contaminants to the flotation machine by gravity; during selected tests, for example, pine oil was fed to the feed box of the flotation machine to assess its ability to stabilize oily froth. The roof on the flotation platform served to provide some protection from inclement weather. The entire platform was designed to withstand gale force winds; more severe winds might tear off the roof of the platform but the rest of the structure should remain intact. Regarding this structure in particular, note that the eye of hurricane Ginger hit the East Coast 120 miles south of the demonstration plant site in September 1972; the flotation machine platform and the rest of the plant withstood the storm in excellent condition.

3.3.3.5 Dewatering Cyclone Tripod Support

The dewatering support frame was constructed substantially of iron pipe. A 21 foot high tripod was selected for this support to allow access to the dewatered sand from any direction (see Figure 12). Since dewatered sand drains rapidly to an even drier state, pools were expected to form around the cleaned sand pile; if access to the sand was limited to a particular direction, these pools could prevent timely removal and return of cleaned sand to a beach by preventing the operation of a front end loader or elevating scraper in the area of the cleaned sand. The tripod support performed admirably during the demonstration tests and stood up very well under the severe environmental conditions sometimes encountered at the test site.

3.3.3.6 Electrical Services

Figures 13 and 14 are schematics of the electrical wiring for the demonstration plant. The first figure shows the general layout for the entire plant from the main transformers to the various stations. Note that both 110 volt, single phase and 440 volt, three phase power was required for the plant. 110 volt electricity served for plant lighting and general support services while the 440 volt power served to power the major plant equipment. In general, the electrical wiring necessary for the demonstration plant was of a very simple nature. Figure 14 is a schematic of the plant's main control panel; other than the main disconnect and disconnects and starters for each motor in the plant, there was a spare disconnect, a welding receptable, and a 15 KVA, 480 volt primary, 240/120 volt secondary transformer with corresponding junction control panel.

3.3.3.7 Piping Run and Detail Callouts

Figure 15 includes an isometric of the piping runs for the demonstration plant; pipe hangers and supports are specified on other of the construction drawings. Other than the obvious runs for the process streams (water and oil-sand-water slurry), extensive wash water lines were provided; additionally, seal, reagent dilution, and spray water piping was provided.

Figure 15 also includes details for the 1/4 inch stationary screen which was placed after the attrition scrubber and before the sump for the vertical pump; two rows of spray nozzles were included to assist in moving wet sand through the screen. In actual practice the spray nozzles proved unsuitable and were simply replaced with 1/4 inch holes in the feed pipe for the original nozzles; the nozzles continually plugged up due to trash material in the water (sea or wellpoint) at the site. In its final configuration, the 1/4 inch stationary screen performed well for all input slurry conditions (including up to 80% solids). The trash material also caused plugging of the lines for wash and seal water; fortunately, the wash water lines were only rarely used and the seal water line to the horizontal slurry pump could be quite easily cleared.

Figure 16 gives additional detail for the launder, oil recovery tank, and stationary 1/4 inch screen. As noted, the launder was of simple wood construction; although recovered oil discharged through the launder, the wooden seams still swelled up enough after a short period of operation to stop any leaks which could have produced a continuing mess around the flotation machine platform. The 1/4 inch stationary screen was held in place by wedges to permit easy replacement and servicing; however, even after long term contact with salt water, this screen only had to be repaired once. The details for the oil recovery tank include a water drain and overflow trough. Although the water drain functioned properly in its original configuration, it proved subject to burying and plugging by the sand at the site and eventually, while buried, was put out of commission by a front end loader working around the dewatering cyclone. Although the overflow trough worked, its capacity proved insufficient as compared to either pumping or dipping oil out of the tank. This was due mainly to the extremely viscous nature of the oil which, in turn, was due to the presence of a variety of solid particles, air bubbles, and water droplets in the recovered oil. A skimming slurry pump is, therefore, suggested for removal of oil from such a tank.

3.3.3.8 Final Flowsheet

Figure 19 is the process flowsheet in its final form. Except for the wash water at the feed hopper and flotation machine launder, the indicated flows are substantially those utilized under nominal operating conditions. This flowsheet is, in fact, representative of the one used in finalizing the process unit operations, the structural design for the plant, and the electrical power requirements and design. Besides typical flow rates for water, sand, and oil, the flowsheet calls out major process equipment with vendors' names and relevant equipment characteristics and specifications. The flowsheet (FS) numbers are for reference purposes (e.g., see Figure 13 and 14 relating to the plant's electrical services). Typical materials data, estimated power requirements, and estimated residence times are included on the flowsheet. The residence times are based on input flow rates; this means that the values for the oil recovery tank and the process water tank are nominal times to fill and empty the tanks respectively.

3.3.3.9 Additional Support for the Scrubber Platform

In terms of the plant structures, only one major modification was necessary after construction was essentially completed. The lattice support platform for the attrition scrubber (constructed of 10 inch timbers) did not furnish stable enough support; the scrubber tended to wobble and "walk" on this platform due to an inherent lack of level in the platform. To stop this tendency, side bracing was welded to the scrubber and anchored to a concrete slab formed at its side. The result was a very stable structure, still at a relatively low cost as compared to a more elaborate platform (e.g., the platform which housed the froth flotation machine). Such a simple structure has much to recommend it for use in demonstration projects in the field.

3.3.4 Conclusions

As is the case with most projects, the result of the construction project represented the inputs of a large number of people. Since, with the time allotted, the entire plant could not be specified in complete detail, considerable creative thought had to be applied to tasks at hand during the actual construction work. This, in turn, necessitated very close cooperation and communication between all participants in the construction project.

3.4 Demonstration Studies

3.4.1 Introduction

Forty one tests were run using the demonstration pilot plant. The results of and operating conditions for these tests are presented in detail in Appendix C. The tests using the stationary plant can be broken into five main categories: (1) Sand Cleaning Using the Entire Plant (16 tests), (2) Mobile Unit Simulation (7 tests), (3) Straw Scrubbing (3 tests), (4) Oil/Water Separation (11 tests), and (5) Sand Scrubbing and Dewatering (4 tests).

The sand cleaning tests using the entire pilot plant were run to assess the basic feasibility of froth flotation for recovering oil contaminated beach sand. By considering the effects of oil type and condition, operating parameters, scrubbing and dewatering, and recycle of process water, probable configurations and specifications for a mobile sand cleaning unit could be made.

Bypassing the attrition scrubber and eliminating the dewatering and water recycle operations, allowed the probable mobile unit process configuration to be simulated. The resulting mobile unit simulation tests served both to confirm the design estimates of the specifications for a mobile unit and to firm up the process configuration for such a unit. These tests were deemed necessary to avoid building a complete mobile system on the basis of (perhaps, misleading) extrapolation of data obtained using the entire stationary plant.

Since the equipment was available at the site and the necessary tests were quite simple, the feasibility of attrition scrubbing oil from straw was assessed. If this were feasible, straw could be either reused or disposed of much more easily.

Based on the success of the sand cleaning tests, 11 oil/water separations were run at full scale using the process plant in essentially an "as is" configuration. Although froth flotation is used commercially to separate oil and water, such separations are usually with low flow rates (very high residence times) and for low feed oil concentrations. The tests with the stationary plant were designed to look at conditions just the opposite to these: high flow rates (low residence times) and high feed oil concentrations. The intention was to determine whether the stationary plant equipment could be used in essentially an unmodified state for rapid oil/water separation. Evidence to the contrary might possibly give leads as to what modifications would give acceptable performance or what critical factors must be considered in designing new equipment to do the job using the same basic principles.

Scrubbing and dewatering of oily sand was tested because the sand cleaning demonstrations using the entire plant had shown that oil was quite easily scrubbed from beach sand (and thereby dispersed into water) with an attrition scrubber. Perhaps oily sand could be scrubbed and put in an acceptable state for discharge on a beach by successive dewaterings in conjunction with a large settling pond(s).

The following sections review the results of the tests in the five categories as outlined above. The detailed data for and discussion of the tests are presented in Appendix C. Only the information judged as most crucial in gaining value from the test results is presented in the following paragraphs.

3.4.2 Sand Cleaning Using the Entire Plant

Demonstrations 1-13, 21, 22, and 41 in Appendix C involved the use of all the unit processes in the plant. These demonstrations were used to gain first estimates of the projected operation of a mobile beach cleaner as well as an idea as to what the typical operating difficulties with such a system would be. Although the tests followed a logical sequence and there were more tests run than originally scheduled, much information was obtained by just going through the operations involved in running a demonstration. For instance, manual control of the froth level in the flotation machine was found to be most suitable for field operation, and severe build up of oil in the discharge box of the flotation machine was observed when the machine was operated without overflow.

Demonstration 1 took place with a sand feed rate of 30 tons/hour at a No. 4 fuel oil concentration of 0.5%. Water exited the system at about 450 gallons/minute. The residence times in the attrition scrubber (750 gallon volume) and flotation machine (1800 gallon volume) were 4.8 and 3.6 minutes respectively. Aeration was set at 280 cubic feet/minute (47 cubic feet/minute/cell) in the froth flotation machine. Note that with the scrubber in use additional scrubbing was a always supplied by the vertical slurry pump which delivered the discharge from the scrubber to the flotation machine's feed box. The oil in the feed sand was not analytically determined during this test, but, based on observations of the homogeneity of the feed sand on the feed belt, such analyses were made for the tests which followed. For this demonstration the cleaned sand contained an average oil concentration of 133 ppm and the exit water 286 ppm. Note that brackish water from a wellpoint system was used rather than sea water.

Demonstration 2, because of problems with sanding in of the process water tank, involved a decreased sand feed rate of 23 tons/hour; the level of No. 6 fuel oil in the sand was measured at 3,770 ppm. The total exit water rate was 445 gallons/minute, and the scrubber and flotation residence times were 5.2 and 3.8 minutes respectively. Aeration was 280 cubic feet/minute. The cleaned sand contained 147 ppm oil and the exit water 232 ppm. The test demonstrated that given essentially the same operating conditions there was no radical difference in performance between removing No. 6 or No. 4 fuel oil.

Demonstration 3 involved a sand feed rate of 19 tons/hour with a No. 4 fuel oil concentration of 4100 ppm. The total water rate was 450 gallons/minute with residence times of 5.2 and 3.7 minutes for the scrubber and flotation machine respectively. Aeration was again set at 280 cubic feet/minute. During this test pine oil was fed to the feed box of the flotation machine at a rate of one cc/minute; this frothing agent was used in an attempt to stabilize the froth and, thereby, possibly enhance the oil collection efficiency of the flotation machine. The pine oil appeared to have little effect since the cleaned sand contained 196 ppm oil and the exit water 138 ppm. The decrease in oil in the exit water (which was quite significant) should be attributed entirely to the lower sand feed rate (compare to the first demonstration).

Demonstration 4 involved a moderate sand feed rate of 25 tons/hour with No. 4 fuel oil as the contaminant. A higher feed rate was feasible for this (and following) tests because the adjustable orifice on the dewatering cyclone had been removed in order to prevent sanding in of the process water tank. The feed sand contained 5,480 ppm oil by dry analysis and 5,220 ppm by wet analysis; given the inherent errors in sampling, these analyses compare very favorably so the simpler dry analysis was adopted as a standard technique. Aeration was still maintained at 280 cubic feet/minute. The total water rate during the test was 420 gallons/minute with residence times of 4.9 and 3.9 minutes for the scrubber and flotation machine respectively. Pine oil was again added at a rate of one cc/minute to the flotation feed slurry. Note that for this test each half barrel of contaminating oil was mixed with a bale of wheat straw before contaminating the sand. 160 and 806 ppm oil respectively in the cleaned sand and exit water was the result. Again, the pine oil appeared to have little, if any, effect while the straw apparently caused an increase in the oil dispersed into the process water. This phenomena was also observed in later tests and is best explained by competition for attachment to air bubbles between the oil and the straw, the straw being preferred. The very oily appearance of the feed water during this test led to the inclusion of feed water oil analyses for the following tests. Oil build up in the process water supply was obviously leading to overly high oil concentrations in the exit water from the plant.

Demonstration 5 involved a sand feed rate of 30 tons/hour at a concentration of No. 4 fuel oil of 8,361 ppm. Note that the feed sand was prepared (by estimate) to contain about 6 times the oil as that in the previous tests; the analyses did not bear this out, illustrating once again the need for them. The practice of estimating oil concentrations from the procedure used in preparing feed sand was obviously subject to large errors. Water was fed to the plant at 560 gallons/minute with residence times in the scrubber and flotation machine of 4.1 and 3.0 minutes respectively. Aeration was 280 cubic feet/minute and pine oil was again added at one cc/minute. Samples of beach sand were taken prior to contamination and showed an average equivalent oil level of 23 ppm; although not very significant for this particular demonstration, such a background level could be for the sort of performance desired and projected for a mobile unit. The cleaned sand and exit water contained average oil concentrations of, respectively, 711 and 537 ppm while the feed water contained an average of 1,186 ppm oil. Obviously, the process was working well during this test, but the water recycle was <u>severely</u> degrading the effluent. The data for demonstration 5 clearly indicated the rise in feed water and residual oil concentrations which took place with time. The high residual oil levels were not due entirely to the recycle water, however; the high feed oil concentration, low flotation residence time, and severe dispersing action by the attrition scrubber and vertical pump also served to promote unacceptable cleaned sand and exit water.

Demonstration 6 used a sand feed rate of 20 tons/hour with 4,090 ppm No. 4 fuel oil. Aeration was 280 cubic feet/minute while the total water rate was 320 gallons/minute. Pine oil was again fed at one cc/minute. The scrubber residence time was very high at 9.4 minutes while the flotation residence time was set at 5.1 minutes. The feed water contained an average of 251 ppm oil while the cleaned sand and exit water contained 329 and 1,011 ppm respectively. The deleterious effect of scrubbing the oily sand is graphically illustrated by the results of demonstration 6. Of special interest is the fact that the feed water increased in oil concentration by a factor of about 55 during the test while the exit water oil concentration increased only by a factor of 2. The results of this demonstration pointed out the necessity for a scrubber bypass (and possibly bypass of the vertical pump) to promote better cleaning and also simulate the operation of a mobile system.

Demonstration 7 involved feeding oily sand (5,020 ppm, No. 4 fuel oil) which had been aged for 15 days prior to the test; the feed rate was 25 tons/hour. Air and pine oil were again fed to the froth flotation machine at 280 cubic feet/minute and one cc/minute respectively. The total water rate was 550 gallons/minute while the scrubber and flotation residence times were 3.8 and 3.1 minutes respectively. The feed water, cleaned sand, and exit water contained an average of 628, 140 and 749 ppm oil respectively. Froth stability was observed to have decreased due to the aging of the oil for this demonstration; sufficient pine oil to overcome this would have implied adding more pollutant to the effluent streams. Extra aeration capacity was deemed to be a more reasonable way to increase the frothing action. Although only in a qualitative sense, the data does appear to indicate that aging of the oily sand (obviously within limits) facilitates the cleaning process. Loss of volatile and water soluble oil fractions accounts for this effect in light of the results for different oil types.

Demonstration 8 involved a sand feed rate of 19 tons/hour with a No. 4 fuel oil concentration of about 5,000 ppm (see below for exact values). The water rate to the attrition scrubber was 215 gallons/minute (a residence time of 3.1 minutes) while the total process water rate was 250 gallons/minute. Tests were run sequentially using the first four, three, two, and one cells of the froth flotation machine with aeration rates of 280, 210, 140, and 70 cubic feet/minute respectively; note that aeration was 70 cubic feet/minute/active cell throughout the demonstration. Pine oil was again fed to the process at approximately one cc/minute. The feed sand, feed water, cleaned sand, and exit water contained respectively the following amounts of oil for each of the four tests: (four cells) 5,630, 296, 155, and 477 ppm, (three cells) 4,700, 322, 214, and 529 ppm, (two cells) 5,480, 257, 159 and 540 ppm, and (one cell) 4,630, 232, 168, and 669 ppm. The active cell flotation residence times for the four, three, two and one cell tests were, respectively, 4.2, 3.2, 2.2. and 1.1 minutes. The test results indicate that the major portion of the separation took place in the first cell of the flotation machine while the latter cells served as "cleaners." This is most clearly illustrated by the fact that the <u>additional</u> oil added to the process water as a result of the sand cleaning process was 181, 207, 283, and 437 ppm for the four, three, two and one cell tests respectively; although these values correlate with the residence times, the effect of the individual cells is obviously not the same relative to the degree of oil removal attained by each. These tests gave a most favorable projection for the performance of a trailer mounted mobile unit involving only froth flotation with sand and water feed.

Demonstration 9 involved a sand feed rate of 30 tons/hour with a No. 4 fuel oil concentration of 3,590 ppm; the total water rate was 250 gallons/minute and the scrubber and flotation residence times were 3.1 and 4.2 minutes respectively. Using the experience gained in the previous demonstration, this entire test was run with only four active cells, the idea being to obtain long term, "steady state" data on such an operation. Pine oil was again added to the feed at one cc/minute. Aeration was set at 210 cubic feet/minute (52 cubic feet/minute/active cell) to allow better comparison to the tests with all six cells active. The feed water, cleaned sand, and exit water contained respectively an average of 260, 167, and 349 ppm oil during this test. Such a result was thought to be quite favorable for a mobile operation since dispersion with both the attrition scrubber and vertical pump must have degraded the operation significantly.

Demonstration 10 took place with a bypass of the attrition scrubber using a metal sluice. Sand was fed to the plant at 19 tons/hour (No. 4 fuel oil at 7,020 ppm) with a total process water rate of 440 gallons/minute (a flotation residence time of 3.8 minutes with all six cells active) and an aeration rate of 280 cubic feet/minute. The feed water, cleaned sand, and exit water analyzed respectively at 273, 106, and 496 ppm oil for this demonstration. Given the relatively high feed oil concentration, continuing dispersion by the vertical pump, and a low flotation residence time, these results are quite good.

Demonstration 11 involved a very high sand feed rate of approximately 60 tons/hour with a No. 4 fuel oil concentration of 5,110 ppm. The total process water rate was 395 gallons/minute with scrubber and flotation residence times of 3.4 and 3.7 minutes respectively. Aeration was again set at 280 cubic feet/minute with all six flotation cells active. Although pine oil had an aesthetic impact in the previous tests (it definitely masked the smell of residual oil and possibly decreased the oily feel of the cleaned sand and exit water), its use was discontinued as of this test since it had no apparent effect in aiding in removal of oil from beach sand. The results of the test were 1,992, 389, and 2,141 ppm oil in the feed water, cleaned sand, and exit water respectively. Given the high sand feed rate and low flotation residence time, these values are quite respectable. Low water temperatures at the site were also responsible for a degree of degradation in the cleaning process; the process water was estimated to be at 5°C.

Demonstration 12 involved a decreased sand feed rate of about 8 tons/hour with a high No. 4 fuel oil concentration at 16,980 ppm. The total process water rate was 320 gallons/minute with scrubber and flotation residence times of 3.5 and 5.4 minutes respectively. Aeration was 280 cubic feet/minute. The measured water temperature during this test was 5°C. Feed water, cleaned sand, and exit water oil concentrations measured 1,200, 392, and 1,678 ppm respectively. Given the dispersal action of the scrubber and vertical pump, the low water temperature, and the high feed oil concentration, the results of this demonstration were about as expected.

Demonstration 13 involved the use of sea water rather than the brackish well-point water which had been used in the previous tests. This water was obtained with a submersible pump deposited in the surf 450 feet from the plant and a run of hose to the plant's process water tank. The water temperature for this test was 7°C, and the total process water rate was 305 gallons/minute with scrubber and flotation residence times of 3.6 and 5.1 minutes respectively. Aeration was again 280 cubic feet/minute. Sand was fed to the plant at 30 tons/hour and contained a somewhat high level of oil, 8,250 ppm. The feed water, cleaned sand,

and exit water contained 296, 137 and 353 ppm oil respectively. These are very good results. Sea water obviously facilitates the removal of oil by froth flotation. Since, based on the results of the previous results, it is known that low water temperatures degrade the process, higher sea water temperatures should produce quite high quality effluent streams.

Demonstration 21 involved a medium crude oil as the contaminant; sand with an oil concentration of 9,550 ppm was fed to the plant at 30 tons/hour. Aeration was still 280 cubic feet/minute, and the process water temperature had risen to 10°C which is still 11 Centigrade degrees below the nominal design value. The total process water rate was 370 gallons/minute with scrubber and flotation residence times of 3.8 and 4.3 minutes respectively. The feed water, cleaned sand, and exit water contained 350, 185, and 517 ppm oil respectively. Given the high feed oil concentration this was quite an acceptable performance, and the major implication was that a crude oil could also be removed from sand using the same basic process as heretofore had been used only for fuel oils.

Demonstration 22 involved an increased aeration rate of 350 cubic feet/minute (58 cubic feet/minute/cell); this increased rate was made possible by the acquisition of a larger air blower. Sand with 6,920 ppm No. 4 fuel oil was fed to the plant at 30 tons/hour. The total water rate was 360 gallons/minute with scrubber and flotation residence times of 3.2 and 4.4 minutes respectively. The feed water, cleaned sand, and exit water contained 1,970, 243, and 1,780 ppm oil respectively. Although the water temperature was low and the feed oil concentration somewhat high during this test, the results still indicate that (with the pilot plant) this increased aeration was deleterious. The extra agitation supplied by the higher aeration rate apparently caused more oil to be "permanently" dispersed into the process water. An optimum aeration (of a semiquantitative sort) of 50 cubic feet/minute/active cell had, therefore, been determined for the stationary plant.

Demonstration 41 was a long term operation run which lasted for 20 hours, samples of the feed and effluent streams being taken for the first 6-1/2 hours. Sand with 4,750 ppm No. 4 fuel oil was fed to the plant at 30 tons/hour. The process water rate was 330 gallons/minute with residence times of 3.5 and 4.8 minutes for the scrubber and flotation machine respectively. Aeration was at 280 cubic feet/minute. The feed water, cleaned sand, and exit water contained an average of 2,050, 703, and 2,460 ppm oil respectively. The major conclusions from this demonstration were: (1) with closed loop operation of the stationary plant, oil can build up in and hold at very high levels in the process water, (2) long term operation of such a process plant to clean oily sand presents no special problems, and (3) night operation of such a process is not difficult given adequate lighting and stockpiles of feed sand.

3.4.3 Mobile Unit Simulations

Demonstrations 14 - 20 in Appendix C involved the use of only the froth flotation machine and process water supply of the stationary plant. A leased, portable belt feeder was used to lift oil contaminated sand from grade level to the first level of the flotation machine platform where a chute directed the oily sand into the feed box of the flotation machine. The cleaned sand slurry was discharged with an overflow chute from the horizontal pump's sump to the underflow discharge area for the dewatering cyclone. In summary: the feed sand was not scrubbed by either the attrition scrubber or the vertical pump during these tests. The feed sand entered the flotation machine directly at the feed box. Process water was not recycled, and the cleaned sand/water slurry was sampled directly as discharged from the flotation machine. Sea water was also used throughout this series of tests.

Demonstration 14 involved a sand feed of 17.5 tons/hour with a No. 4 fuel oil contamination level of 5,290 ppm. The aeration rate to the flotation machine was 350 cubic feet/minute (for six active cells), and the water rate was 280 gallons/minute for a flotation residence time of 5.9 minutes (water temperature: 8°C). The cleaned sand and exit water contained 115 and 276 ppm oil respectively. Given the use of cold feed water, this result was quite acceptable.

Demonstration 15 involved a sand feed rate of 24.5 tons/hour at 6,130 ppm No. 4 fuel oil. Aeration was again 350 gallons/minute, and the water feed rate was 250 gallons/minute (a flotation residence time of 6.3 minutes). The cleaned sand and exit water contained respectively 157 and 280 ppm oil. Again, given the low temperature of the feed water and comparing to the results of the previous demonstration, this result is quite good.

For demonstration 16 a sand feed rate midway between those of the previous two tests was selected (22.5 tons/hour); as in the previous test, the feed concentration of No. 4 fuel oil was unintentionally high at 6,680 ppm. Aeration was again 350 cubic feet/minute while water was fed to the process at 250 gallons/minute for a flotation residence time of 6.3 minutes. The cleaned sand contained 233 ppm oil, a result which is hard to explain in light of the results of the previous tests. The exit water contained 260 ppm oil which is lower than the values for the previous tests and perhaps explains why the apparent residual oil level in the cleaned sand was high. Although somewhat anomalous, the results were still fairly good.

Demonstration 17 involved a much reduced process water rate (125 gallons/minute) which with a sand feed rate of 27 tons/hour (5,320 ppm No. 4 fuel oil) gave a flotation residence time of 10.9 minutes. The exit oil concentrations in the cleaned sand and water were 135 and 407 ppm respectively. Since, especially, the latter value appears high, the conclusion must be that the dense slurry (about 46% by weight sand) used in this test served to trap oil and hinder separation in a manner which even the considerably higher residence time could not overcome. However, note that the field engineers judged (by visual appearance) the discharge slurry during this demonstration to be much more acceptable than those of the previous three. A dense slurry more readily traps and holds residual oil keeping the oil from surfacing as a froth which accounts for this visual enhancement.

Demonstration 18 took place under conditions similar to 17 (sand feed of 26 tons/hour, process water at 116 gallons/minute, and aeration 350 cubic feet/minute) except for the feed sand oil concentration which was intentionally high at 6,930 ppm. The water temperature had dropped to 6°C for this test, and the flotation residence time was 11.6 minutes. The cleaned sand and exit oil contained 183 and 524 ppm oil respectively. Again, due probably to the high slurry density, the analytical results for residual oil do not appear very good; once again, however, the field engineers reported that the discharge appeared quite acceptable to the eye.

Demonstration 19 involved No. 6 fuel oil as the contaminant at a level of 5,730 ppm in sand fed to the process at 26 tons/hour. The process water rate was 206 gallons/minute, and the flotation residence time 7.3 minutes. The cleaned sand and exit water contained 92 and 100 ppm oil respectively. Given the low water temperature on the day of this demonstration, this was an excellent result.

Demonstration 20 involved, intentionally, a very high feed concentration of No. 4 fuel oil at 19,810 ppm. To compensate for this high oil input to the system, the sand feed rate was decreased to 13 tons/hour. The process water rate was 200 gallons/minute which set the residence time at 7.7 minutes. The cleaned sand and exit water contained 181 and 599 ppm oil respectively. Given the low feed water temperature (6°C) and the very high feed oil concentrations, this is a reasonably good result.

3.4.4 Straw Scrubbing

Demonstrations 23, 24, and 25 were run to determine if oil could be scrubbed from straw to facilitate disposal of the latter material. Straw saturated with No. 6 fuel oil was attrition scrubbed for various lengths of time, under various conditions. Liberation of oil into the carrier water was determined by analyzing for the oil.

Demonstration number 23 involved scrubbing for 6 minutes and resulted in 34 parts per million oil in the exit water.

Demonstration number 24 involved scrubbing for 12 minutes and resulted in 40 parts per million oil in the exit water.

5 gallons of diesel fuel was added to the slurry in the attrition scrubber for demonstration number 25; after 12 minutes of scrubbing, the exit water contained 64 parts per million of oil. Addition of 5 more gallons of diesel fuel and scrubbing for 12 more minutes resulted in an exit concentration of 75 parts per million.

Although the data for the dispersion of oil into the process water moves in the right direction for these tests, the results are hardly favorable. Perhaps more important are the extreme operating difficulties which the field engineering crew had with performing this task. The straw/oil mass tended to wrap around the impeller shaft in cell number 1 of the scrubber and was then extremely difficult to remove. This problem is similar to that observed around the impellers of the flotation machine; in this latter case, however, the air diffusing from the area of the impeller serves to keep straw away, and, therefore, when such a straw buildup occurs, it occurs very, very slowly. The conclusion from these tests is that the recovery of oil contaminated straw by attrition scrubbing is not feasible.

3.4.5 Oil/Water Separation

Demonstrations 26 - 36 considered the separation of oil from water using the standard minerals processing equipment existent at the plant site. Most of these tests took place at high flow rates, in some cases elevated by the use of more than one water supply pump. Generally, the results showed that standard processing equipment is not very efficient for oil/water separation; however, for a rough separation at high capacity such equipment may be of value. The data illustrates both the potential usefulness of the mobile beach cleaner as an oil/water separator and the need for redesign and/or modification in operation to attain very efficient oil/water separations using the same basic principle (froth flotation).

Demonstration 26 involved a feed water rate of 485 gallons/minute with 5,130 ppm No. 4 fuel oil. The oil was added to the suction side of the vertical pump which delivered the oil/water mixture to the flotation machine. Aeration was set at 280 cubic feet/minute or 47 cubic feet/minute/cell. The residence time in the flotation machine was 3.7 minutes resulting in an average of 897 ppm oil in the discharge. The efficiency of the oil/water separation was, therefore, about 83%.

Demonstration 27 was run under conditions equivalent to 26 except for an incresed aeration rate of 560 cubic feet/minute or 93 cubic feet/minute/active cell. The result was an effluent oil concentration of 803 ppm or a recovery efficiency of about 84.5%. Although the increased aeration improved the separation somewhat, the improvement was not startling.

Demonstration 28 involved a feed water rate of 455 gallons/minute with 5,460 ppm of a 1:1 mixture of No. 4 fuel oil and No. 260 diesel fuel. The oil was again fed to the suction side of the vertical pump, air was supplied at 560 cubic feet/minute, and the residence time was 3.9 minutes. The effluent water contained 1,370 ppm oil for a recovery efficiency of about 75%. The added difficulty in recovering lighter oils is again illustrated by this data.

Demonstration 29 was a check on the ease with which oily straw could be removed from water by froth flotation; an indication was also gained as to the extent of dispersion of oil into water by the process. The feed stock was prepared by mixing 3 bales of wheat straw with 14 gallons of No. 6 fuel oil. With a water rate of 465 gallons/minute to the flotation machine and residence time of 3.9 minutes, this material was placed into the feed box of the flotation machine by hand; the feed water stream carried the oily straw into the first cell of the flotation machine. Visual observations both of the cells in and the discharge from the flotation machine indicated that <u>all</u> the straw separated in the first cell and none left with the effluent. The test lasted for ten minutes and resulted in an average residual oil concentration of about 2 ppm. Since, during the test, 4,650 gallons of water and 14 gallons of oil were fed to the machine, the equivalent feed concentration of the oil was about 3,000 ppm; this implies 99.98% recovery of the oil which is excellent.

Demonstration 30 was essentially a repeat of 27 with oil added directly to the feed box of the flotation machine. An input No. 4 oil concentration of 4,830 ppm with a water rate of 515 gallons/minute and a residence time of 3.5 minutes resulted in an average effluent oil concentration of 2,870 ppm for a recovery efficiency of 41%. Addition of oil at the feed box had been expected to increase efficiency;

the contrary result points to channeling within the flotation machine which degrades operation (i.e., the larger water feed stream apparently keeps the oil feed stream away from the active cell volume so that it cannot readily be separated).

Demonstration 31 involved the same conditions as 30 except that four tests were run sequentially with air to the 6th; 5th and 6th; 4th, 5th and 6th; 3rd, 4th, 5th and 6th cells shut off. Residence times of 2.9, 2.3, 1.7, and 1.2 minutes and aeration rates of 112, 140, 187, and 280 cubic feet/minute/active cell respectively were the pertinent operating conditions. The four tests resulted in average effluent oil concentrations of 3,350, 3,430, 3,110, and 2,560 ppm respectively. This implies oil recovery efficiencies of 31, 29, 36, and 47% respectively. Obviously the increased aeration per active cell served to counteract the effect of decreasing residence time; however, decreased efficiency with oil feed to the feed box of the flotation machine was again apparent. Due to this, oil feed to the suction side of the vertical pump was resumed in the following tests.

Demonstration 32 involved a feed oil prepared by scrubbing to a more dispersed state in the attrition scrubber; water was fed to the scrubber at 120 gallons/minute with a No. 4 fuel oil concentration of 20,000 ppm for a residence time of 6.2 minutes. This dispersion was pumped to the flotation machine with additional water to make a total water rate of 515 gallons/minute and an input oil concentration of about 4,660 ppm. With a residence time of 3.5 minutes in the flotation machine, the discharge stream contained 1,340 ppm oil implying a recovery efficiency of about 71%. Performance was substantially degraded by the dispersal of the oil into the water with the scrubber (compare to the results of demonstration 27).

Demonstration 33 involved a decreased feed water rate of 250 gallons/minute with No. 4 fuel oil from the suction side of the vertical pump at 5,000 ppm. Aeration was set at 560 cubic feet/minute and the flotation residence time at 7.2 minutes. The discharge water contained 2,790 ppm oil for a recovery efficiency at 44%. This result implies that the increased residence time caused increased internal circulation within the flotation machine which, in turn, caused an increase in dispersion of the oil into the water with the resulting decrease in efficiency.

Demonstration 34 was similar to 27 except that the feed stream contained 48,500 ppm No. 4 fuel oil. The result was an average effluent oil concentration of 22,100 ppm for a recovery efficiency of 54%. Note that the presence of a quantitatively large amount of oil in the flotation machine appears to decrease the efficiency of the separation process significantly.

Demonstration 35 was similar to 27 except that No. 6 fuel oil was used as the contaminant. The flotation residence time was 3.5 minutes with a feed oil concentration of 4,850 ppm. The exit water contained an average of 517 ppm oil for a recovery efficiency of 89.3%; again, the relative ease of separating the heavier oils was apparent.

Demonstration 36 involved a much increased feed water rate of 1,050 gallons/minute with a No. 4 fuel oil concentration of 4,760 ppm; the resulting residence time was 1.7 minutes with an applied air rate of 560 cubic feet/minute. The exit water contained an average of 3,160 ppm oil for a recovery efficiency of 34%. With all other conditions being approximately the same, the decrease in residence time obviously decreased the efficiency of the process very significantly (see the results of demonstration 27).

3.4.6 Sand Scrubbing and Dewatering

Demonstrations 37 - 40 involved scrubbing oily sand and then dewatering using the Krebs cyclone. The purpose of these tests was to gain a quantitative idea as to the feasibility of cleaning oily sand by repeated scrubbing and dewatering. Given a large water supply and sufficient settling tanks or ponds, such an approach may be feasible.

Demonstration 37 considered a sand feed rate of 30 tons/hour with No. 4 fuel oil at an average concentration of 4,500 ppm. The oily sand was scrubbed for 3.0 minutes and then dewatered with a total water flow rate of 537 gallons/minute. The cleaned sand contained an average of 278 ppm oil while the feed and exit water had 1,127 and 1,540 respectively; these latter values indicate an addition of about 413 ppm oil to the exit water by the scrubbing process. Since the cyclone underflow contained an average of 64.4% sand, the data indicates that 88.7% of the feed oil, exclusive of the oil in the feed water, was being removed during the test; therefore, if the water entering the process was entirely free of oil (i.e., if the process water tank was infinitely large, or the process was run intermittently to allow the oil to float free from the feed water, or 100% oil/water separation was made on the overflow water from the dewatering cyclone), the sand would have to pass through the scrubbing/dewatering system at least one more time to achieve the same result as was usually achieved with one pass through the froth flotation machine.

Demonstration 38 also involved a 30 tons/hour sand feed rate but with an increased scrubbing time of 6.7 minutes and a total water rate to the cyclone of 477 gallons/minute. No. 4 fuel oil was present in the feed sand at 3,860 ppm. Feed water, cleaned sand, and exit water contained 1,280, 271, and 1,710 ppm oil respectively; these numbers indicate an increase in the exit water oil of 430 ppm due to the scrubbing. With 64.8% sand in the cyclone underflow, 87% removal of the feed oil is indicated. This is little different than the result of the previous test, and, again, another pass would be necessary to obtain results similar to froth flotation separation given that oil free feed water was available.

Demonstration 39 involved No. 6 fuel oil; scrubbing took place for 4.9 minutes, and the total water flow to the cyclone was 517 gallons/minute. The feed sand contained 4,120 ppm oil. The feed water, cleaned sand, and exit water contained 625, 272, and 829 ppm oil which indicates an increase of 204 ppm in the feed water oil due to scrubbing. With 62.8% sand in the cyclone underflow, this data indicates 95.4% feed oil removal. Again, to obtain results similar to those with froth flotation removal of No. 6 fuel oil, another pass through the system would be necessary as well as the use of oil free feed water.

Demonstration 40 involved No. 4 fuel oil in the feed sand at 19,600 ppm. The sand was scrubbed for 5.6 minutes, and the total water flow to the cyclone was 473 gallons/minute. The feed water, cleaned sand, and exit water contained

3,870, 890, and 4,700 ppm oil respectively, indicating an increase in the water's oil content of 830 ppm due to scrubbing. A 64.0% sand content in the cyclone underflow, therefore, implies 93.1% oil removal by the process. Again, another pass through the system would be necessary to obtain results equivalent to froth flotation separation; of course, this projection again assumes an oil free feed water and implies oil/water separation of the cyclone overflow.

3.4.7 Conclusions

The basic conclusions as evolved from the demonstration studies are as follows:

1) Sand cleaning using froth flotation is feasible although the following factors (if included in the overall process) hinder performance.

a) Recycle of water with a reasonably large process water tank leads to a buildup of oil in the process loop and, therefore, unacceptable overall performance.

b) Scrubbing or pumping of oil contaminated sand leads to degradation in process performance since dispersion of oil into the carrier water more than compensates for any additional release of oil from the sand.

2) Froth flotation should be utilized by feeding sand and water directly into the feed box of a froth flotation machine with a minimum of prior agitation; the data from the demonstration studies allowed specification of the operation of a mobile unit, the result of which is presented in section 3.5.3.

3) Attrition scrubbing of straw with standard process equipment is not feasible.

4) Oil/water separation at high capacity is possible using froth flotation although with standard mineral processing equipment the process is not very efficient; considerable development work would probably be necessary to take advantage of the basic principle with better separation efficiency.

5) In principle, oily sand scrubbing and dewatering works; however, necessities for a very large process water supply, oil/water separation, and most probably multiple scrubbing operations make the overall approach infeasible.

3.5 Mobile Beach Cleaner

3.5.1 Introduction

Based on the results of the work with the stationary plant, a mobile beach cleaner was constructed, tested, and modified. This unit involved basically a froth flotation machine in combination with a belt feeder for sand, a submersible pump for water, a supercharger for air, and a diesel generator for electrical power; the entire process plant was mounted on a 40 foot trailer. Intentionally, the mobile process involves no scrubbing, pumping, or dewatering of oil/water/sand slurries. Scrubbing and pumping had been found to degrade the oil separation process (i.e., make it much more difficult). Dewatering for water recycle was deemed undesirable due to buildup of oil in the process water; dewatering only to segregate effluent water and sand at an actual beach site was judged to be an unnecessary, additional unit operation.

On January 18, 1972, after extensive field testing and reconditioning, the mobile beach cleaner was delivered to the Environmental Protection Agency at the Edison Water Quality Laboratories of Edison, New Jersey.

3.5.2 Design Specifications

Standard over-the-road trailers without special permits are limited to a 40 foot length and 8 foot width in most States of the Union; additionally, the per axle weight for a tractor-trailer combination is limited typically to a maximum of 8 tons. Therefore, a trailer which conforms to these specifications can generally travel through the United States without special license or permit. Slight deviations from these limits, however, have little or no effect on transport under emergency conditions.

The basic trailer limitations just mentioned place limits on any processing operation which is to be mounted on a single trailer. Maximum deck area on a 40 foot trailer is attained by having an elevated deck on the forward section of the trailer of about 12 feet in length. This deck is suitable for placement of low profile equipment and storage during transport; it also provides a good work area during actual plant operation. Control panels, diesel generator, air supercharger, and fuel tanks were, therefore, placed on the upper deck with the rest of the deck clear except during transit. The 8 x 28 foot lower deck was available for the larger process equipment plus storage. Since approximately 10 feet was the minimum length necessary to accommodate a 100 cubic foot feed hopper plus a steeply inclined conveyor belt, an area 8 by 18 feet was left for a froth flotation machine including open area at the discharge end. The available area essentially specified the size flotation machine which could be incorporated into the mobile system. With the data from the demonstrations using the stationary plant, specific equipment selection could be made accompanied by relevant design operating estimates.

Although the design of the mobile unit considered equipment specification and performance estimates in a concurrent fashion, these two elements of the design are separate in the paragraphs which follow. First, the equipment specification is considered. Including the trailer, there were six major process items to be specified; these are called out with appropriate identification below.

1) Trailer: Basically a standard 40 foot flatbed trailer with an oak plank upper deck; the lower deck was supplied as open to the structural web and was eventually filled in by the process equipment and storage areas. The trailer has dual axles, a reinforced push bar at the rear, both six and seven wire connectors for the running lights, standard commercial hitch, and mechanical leveling and support jacks at each of the four corners of the main frame. The trailer (serial number 20BDH7101S) was supplied by General Engines Co., Inc.

of Thorofare, New Jersey.

2) Hopper and Belt Feeder: To fit into the limited space available, the hopper and belt feeder had to be specially designed and constructed. As originally conceived, this unit came with a fixed speed, cleated belt conveyor. Sand left the approximately 100 cubic foot hopper at the bottom by gravity flow; a vibrator was supplied within the main hopper volume, attached to the main structural cross beam, to assist in moving the sand through the bin. A slide gate was supplied at the bottom exit port of the bin to control the sand feed rate; sand, in principle, fell through the gate opening onto the conveyor belt which then lifted it to the feed box of the flotation machine into which it dropped. A 6 inch bar screen and 1/4 inch wire mesh screen were supplied at the top of the feed hopper. In practice, the single vibrator proved inadequate; at the request of Meloy Laboratories, the manufacturer supplied an additional vibrator for the hopper which was installed on the outside, near the bottom of the hopper, Similarly, the 6 inch bar screen proved to be an annoyance during actual use of the unit; therefore, during most operations the screen was removed. The 1/4 inch screen proved inadequate to pass the required amount of oily, wet sand; Meloy Laboratories' engineers, therefore, removed this screen and replaced it with a (nominally) 1-1/2 inch expanded steel screen which eventually proved adequate. Most importantly, the fixed speed conveyor in combination with the exit slide gate proved incapable of providing a steady sand feed rate; furthermore, this combination did not supply a feed rate as low as required by the system design (about 40 tons/hour). Meloy Laboratories' field engineers, therefore, had to replace the original drive unit for the conveyor with a properly sized variable speed drive unit. A 3 horsepower U.S. Varidrive was procured and installed in the field; this unit gave steady operation over the required sand feed range (10 to 40 tons/hour). Very positive control over the conveyor belt proved to be the only feasible way to reliably feed oily, wet sand to the froth flotation machine. The bin and belt feeder, as originally designed and constructed, was supplied by the American Industrial Corporation of Virginia Beach, Virginia. The U. S. Varidrive, additional vibrator, and modified inlet screen were (to correct the aforementioned deficiencies in the equipment as originally supplied) engineered into the system by the Meloy Laboratories staff.

3) Flotation Machine: Given the space available and existing froth flotation machines similar to the machine used in the stationary plant, a maximum capacity machine was easily selected. The Denver Equipment Company of Denver, Colorado supplied a 4-cell D-R 21 froth flotation machine. This machine has a volume per cell of 40 cubic feet for a total of 160 cubic feet and is 16 feet 10 inches long, 4 feet 11 inches wide, and 7 feet 4 inches high. Diffuser impellers in the machine are powered by two 10 horsepower motors, and a manifold is supplied so that the diffusers can be operated with supercharged air. The machine was supplied with feed and discharge boxes, and the latter item had four discharge ports so that the cleaned sand/water slurry could be piped in three directions away from the machine. A manually operated dart valve was supplied for control of the rate of sand discharge from the machine. Meloy Laboratories supplied a sheet metal launder for the oil froth overflow from the machine.

4) Submersible Water Pump: This item was supplied by Prosser

Industries of Anaheim, California. This marine pump (No. 9-16034) is totally submersible and rated at 15 horsepower, 440 volts, 3-phase. It has a large inlet screen and a 4 inch diameter threaded outlet pipe and with its high volume impeller can deliver the maximum design water rate of 350 gallons/minute against a 90 foot head and the nominal water rate of 250 gallons/minute against a 110 foot head. The pump was supplied with waterproof electrical cable and 4 inch diameter flexible hose. Meloy Laboratories mounted the pump on a sled for deployment into the process water reservoir.

5) Air Blower: This item (size N19P-5) was supplied by the New York Blower Company of Chicago, Illinois. With a 6 inch discharge pipe this blower (5 horsepower, 440 volts, 3-phase) can deliver 550 cubic feet/minute of air against a static head of 30 inches of water. The actual air delivered by the blower is set with a blast gate.

6) Diesel Generator: North American Engines Co., Inc. of Alexandria, Virginia supplied the diesel generator. Powered by a Perkins diesel engine, this unit supplies 50 kilowatts at 440 volts, 3-phase. A 5 kilowatt, 110 volt, single phase transformer was supplied as an integral part of the generator.. Fuel tanks, electrical connections to the generator, and control panels were supplied by Meloy Laboratories.

In addition to the six main items, a very large amount of support material, as well as structural additions and modifications, for the basic unit was supplied by Meloy Laboratories. Ladders, catwalks, stairways, storage compartments, piping, flow indicators, oil recovery tank, electrical wiring, control panels, tow hooks and chain, and fuel tanks are major examples of these. Relatively minor items (such as pipe support tripods, stakes, floodlamp poles and sockets, shovels, rope, hand tools, hose clamps, and tie-down chains) were supplied in very large numbers. The aim was (except for fuel supply, front end loader and elevating scraper support, and major equipment repair) to make the mobile beach cleaner an entirely self contained processing plant.

3.5.3 Performance Estimates

Since the sizes of the basic unit process were limited by the space available on a 40 foot flatbed trailer (multiple trailers having been ruled out as unnecessarily elaborate for a first approach to mobilization), the data from the demonstrations with the stationary plant was used to estimate the performance of the mobile unit. The data had to be considered without including the effects of slurry pumping, slurry scrubbing, and water recycle. Sand, water, and aeration rates had to be set based on the observations and measurements made during the demonstration studies with the stationary plant. Contaminating oil type and concentration also had to be specified based on prior experience. This may appear as a somewhat arbitrary approach, but, in the absence of independent criteria for required performance, no other approach was possible.

Observations with the stationary plant indicated that a 30 ton/hour sand feed rate to a 4- cell, D-R 21 flotation machine should promote reasonably good sand cleaning from an aesthetic viewpoint. Note that this was the opinion of the project engineers and is subject to much individual interpretation as to what constitutes acceptable sand cleaning.

An oil contamination level of 0.5% or 5,000 ppm in the feed sand was also assumed in making the above judgement. Fresh No. 4 fuel oil was selected as the contaminant since it had been used extensively in the stationary plant studies and was known to be intermediate in difficulty of removal as compared to the lighter (more difficult) and heavier (less difficult) oils. Fresh No. 4 fuel oil also provides a worst case in terms of the effects of aging oily sand since observations with the stationary plant had indicated that any aging up to four weeks improves the recovery process.

Use of sea water at a temperature of 70°F (21°C) was also assumed in making the performance estimates; sea water was considered because it is a reasonably well defined solution and would be the water present for the majority of large beach oil spills. The design temperature was selected both for improved performance (as compared to considering fresh No. 4 rather than No. 6 fuel oil which allowed for degraded performance) since temperature decreases had been observed to degrade the separation and for realism in process operation since decreased temperatures usually imply adverse weather conditions on an ocean beach.

The water feed rate was assumed to be 250 gallons/minute to give a flotation residence time of 4.0 minutes. Realizing that its effect (within reasonable limits) was not drastic, aeration was assumed to be 300 cubic feet/minute or 75 cubic feet/minute/cell.

The sand was, of course, that found at the Dam Neck site; variations from this process parameter are subject to future experience or testing. The oil was assumed to be fairly well mixed with the sand (standard deviations in random one pound samples of less than 10%) since previous observations had indicated that large variations of the oil concentration in the feed sand degraded performance; if such variations are the case, the sand feed rate must be decreased. Large variations in the sand feed rate also degrade process performance and, therefore, are to be avoided; attention must be paid to a factor like belt slippage which can cause feed rates to vary. Large step changes in the other feed rates must also be avoided.

Given the set of process parameters outlined above, the data from the stationary plant studies indicated that the following effluent oil concentrations could be expected (subject to verification by actual sand cleaning data from full scale operation of the mobile unit):

SAND	100 parts/million or less
WATER	175 parts/million or less
TOTAL	150 parts/million or less

The following qualitative variations about these effluent values are expected given that the design criteria are an "optimum:"

(1) With all other parameters held constant, increasing the sand feed rate will increase the residual effluent levels.

(2) Similarly, increasing the feed oil concentration will increase the

effluent oil concentrations.

(3) Increase of the water feed rate should decrease the effluent oil concentrations but also decrease the percentage of oil in the feed sand which is recovered.

(4) Either increasing or decreasing the aeration rate should lead to a decrease in recovery percentage and an increase in residual oil; the former is due to decreasing oil/air contact and the latter to increased turbulence which more than compensates for increased oil/air contact.

(5) Lower process temperatures will lead to increased effluent oil concentrations while, up to an undetermined limit, higher process temperatures will result in better oil recovery.

(6) Aging of the oily feed sand (again, up to an undetermined limit) will improve oil recovery.

(7) Separation of heavier oils will be more effective while lighter oils will be less easily and efficiently recovered.

(8) Use of fresh or brackish process water or water contaminated with large amounts of interfering hydrocarbons should lead to decreased process efficiency.

The following section discusses actual data obtained with the mobile beach cleaner in the field under simulated full scale emergency conditions.

3.5.4 Mobile Beach Cleaner Demonstrations

Twenty four full scale demonstrations were run using the mobile beach cleaner. The unit was pulled with a D7E Caterpillar Tractor to the beach at the Dam Neck, Virginia demonstration site; sand contamination and cleaning took place on the beach proper with only a WABCO 150B Front End Loader for support. During four months of work on the beach, the unit had to be moved back from the beach three times due to adverse weather conditions (one hurricane and two severe northeast storms); approximately three weeks downtime, therefore, occurred due to the weather. The first three demonstrations involved the feed hopper and conveyor as originally supplied; since there was unfavorable control over the sand feed rate with this unit, the results of the first three tests should be considered only in a semiquantitative sense. Except for one demonstration in which considerable, erratic belt slippage occurred, the last 21 tests may be considered as quantitatively reliable. The detailed test results for these demonstrations are presented in Appendix D of this report.

Demonstration 1 involved an average (but instantaneously very erratic) sand feed rate of 32 tons/hour with a process water rate of 240 gallons/minute, a residence time of 4.2 minutes, and an aeration rate of 300 cubic feet/minute. No. 4 fuel oil was used as the contaminant in the feed sand at an average concentration of 5,620 ppm. The exit water and cleaned sand contained an average of 307 and 47 ppm respectively. The high feed oil concentration and sand feed rate plus the erratic behavior of the belt feeder definitely caused a high residual oil concentration in the process; the residual oil in the cleaned sand was low so that the total oil concentration in the effluent was not far from the design goal of 150 ppm.

Demonstration 2 was an attempt to repeat the first test but with No. 6 fuel oil as the contaminant at 3,960 ppm. The water and aeration rates were 245 gallons/minute and 300 cubic feet/minute respectively. The process water flow plus an average (again, very erratic) sand feed rate of 33.5 tons/hour resulted in a flotation residence time of 4.1 minutes. The exit water and cleaned sand from the process contained an average of 40 and 14 ppm oil respectively. Even adjusted for the relatively low feed oil concentration, these results are substantially within the performance levels which are to be expected for a heavier oil.

Demonstration 3 was run under conditions similar to the first test except for an increased sand feed rate of 39 tons/hour; the sand contained an average of 5,950 ppm No. 4 fuel oil. Water and aeration rates were equivalent to those used during the first demonstration; the flotation residence time was 4.0 minutes. The exit water and cleaned sand contained respectively 315 and 28 ppm oil. This result is almost exactly the same as for the first demonstration even though both the sand feed rate and the input oil concentration were significantly higher. The less erratic behavior of the feed conveyor at the higher sand feed rate explains this otherwise anomalous result.

Demonstration 4 was the first to involve very positive control of the sand feed rate. During the first three demonstrations, problems with the belt feeder (both in operation and performance) were so severe that modification of the unit became quite obviously necessary; therefore, a variable speed drive was installed in place of the constant speed drive motor originally supplied with the unit. Nominal design conditions were selected for this demonstration but with a feed oil concentration of 1.0% or 10,000 ppm; the actual measured No. 4 fuel oil in the sand was an average of 8,900 ppm. Sand, water, and air feed rates were 28.5 tons/hour, 240 gallons/minute, and 300 cubic feet/minute respectively. The results of the test were 425 ppm oil in the exit water and 74 ppm in the cleaned sand. The mobile beach cleaner was run for about 4-1/2 hours during this demonstration; no special difficulties were noted during this extended operating period. Although the oil concentration in the exit water was high for this test (due to the high concentration in the feed sand) the results compare favorably on a proportional basis to the following tests. The importance of the degree of aging of No. 4 fuel oil was becoming quite obvious at the time of this test. Runs with the stationary plant had involved sand freshly contaminated with No. 4 fuel oil in the sense that the oil had been mixed with sand a day or two prior to the test. Ease of operation (given good weather conditions) made it possible to contaminate sand immediately prior to a demonstration with the mobile unit. Effects on performance were noted for aging No. 4 fuel oil on sand for as short a period as half a day; unfortunately, the scope of the field test program and the restraint imposed by the approach of winter prevented the acquisition of data sufficient to quantitate the aging effect in an exact fashion.

Demonstration 5 involved oily sand which had been aged for not quite one week; other conditions were substantially nominal (except for the water temperature which was 14°C): sand feed rate of 28 tons/hour, water rate of 255 gallons/minute, aeration rate of 300 cubic feet/minute, and feed concentration of No. 4 fuel oil of 5,740 ppm. The exit water and cleaned sand contained 180 and 76 ppm oil respectively. Two facts had become apparent by this point in the test series: (1) Especially for the Dam Neck beach site, and probably for most beaches, the design water temperature was specified at too high a value; 50 to 55°F is a reasonable water temperature range. (2) Completely fresh oily sand is an unreasonable criteria since oil washed onto beaches will already be aged and since the capacity of the mobile beach cleaner is such that, typically, oily sand will have to be stored in piles prior to cleaning; oily wet sand aged in piles for at least 4 days (preferably a week or more) is a more reasonable design criteria. Since the effects of these two factors are counterbalancing (lower process temperatures degrade the process while sand aging improves it), the results of the field tests are still viewed as quite reasonable.

Demonstration 6 was essentially a repeat of the previous test; such a repetition is valuable for gaining at least a semiquantitative grasp of the repeatability of both process parameters and performance. The sand feed rate was 28 tons/hour, water rate 248 gallons/minute, aeration rate 300 cubic feet/minute, and average No. 4 fuel oil concentration in the feed sand of 5,410 ppm. The same sand was used as during the previous test resulting in exit water and cleaned sand residual oil of 160 and 67 ppm respectively. The comparison of the results of demonstrations 5 and 6 is excellent.

Demonstration 7 involved an increased sand feed rate of 40 tons/hour with a No. 4 fuel oil concentration of 4,480 ppm. Water and aeration rates were 248 gallons/minute and 300 cubic feet/minute respectively. As expected, the effluent stream contained increased amounts of residual oil; the cleaned sand has 102 ppm, and the exit water 344 ppm. Although proportional adjustment of these results does not produce very good agreement with the nominal design specifications, very fresh oily sand was used for the test, and the process water temperature was again low.

For demonstration 8 water and aeration rates were increased by one half (to 385 gallons/minute) and one third (to 400 cubic feet/minute) respectively. Sand, with 5,450 ppm No. 4 fuel oil, was fed to the beach cleaner at 29.6 tons/hour. The exit water and cleaned sand contained 228 and 97 ppm oil respectively. Proportional adjustment for the slightly high feed oil concentration and the sand feed rate does not account for the increased residual oil concentrations. However, proportional adjustment for the low residence time during this test (2.8 minutes versus the nominal design value of 4.0 minutes) does account for the difference in performance. A major conclusion from this test is that the 300 cubic feet/minute aeration rate (as well, of course, as the 400 cubic feet/minute rate) was too high and that, therefore, a lower aeration rate may, in fact, promote better separation.

Demonstration 9 was basically a nominal run but with 3-1/2 bales of wheat straw added to 2 drums of oil prior to sand contamination. The resulting sand with 4,940 ppm No. 4 fuel oil was fed to the unit at 29.4 tons/hour. Aeration and water rates were 300 cubic feet/minute and 255 gallons/minute respectively. The exit water contained an average of 274 ppm oil which is significantly higher than the results for previous tests under essentially identical conditions (except for the presence of straw). The cleaned sand contained 48 ppm oil which is somewhat less than the results of previous tests but not enough to balance the effect of the increased amount of oil in the effluent water. The following are apparent: (1) the straw holds oil and thereby hinders oil/sand contact and mixing which decreased the residual oil in the cleaned sand, (2) although much straw is screened from the feed sand, enough enters the flotation machine to compete for air bubble contact (note that observations indicate that straw air bubble contact is much preferred since essentially all the straw is floated in the first cell of the machine) which, in turn, causes an increase in the residual oil in the exit water, and (3) the presence of straw in the sand makes the feed operation much more difficult for the front end loader operator. In conclusion, all other things being equal, the use of straw on a beach which is to be cleaned up with the mobile beach cleaner is undesirable.

Demonstration 10 involved a moderate increase in the No. 4 fuel oil concentration in the feed sand to 6,410 ppm. The field engineering staff performing the demonstrations had major difficulties with conveyor belt slippage during this test. Unsteady sand feed resulted in additional residual oil contamination over and above that due to the increased amount of oil in the feed sand. Sand was fed to the unit at 30 tons/hour, water at 243 gallons/minute, and air at 300 cubic feet/minute. The exit water and cleaned sand contained an average of 483 and 108 ppm oil respectively. Adjusted for the high feed oil concentration, this residual oil in the sand is quite reasonable (equivalent to 84 ppm) while that in the water is not and does not agree with the results of the previous tests. As already mentioned, the postulate is that the erratic sand feed due to belt slippage caused large pulses of oil to be sent through the froth flotation machine resulting in increased average residual oil.

Demonstration 11 took place on October 15, 1971 with representatives of the Environmental Protection Agency in attendance. The tests run were under nominal conditions with No. 6 fuel oil as the contaminant. On request, two sand feed rates were demonstrated. The feed sand contained an average of 5,120 ppm oil. The first test involved a sand feed rate of 30 tons/hour, a water rate of 250 gallons/minute, and an aeration rate of 300 cubic feet/minute. The exit water and cleaned sand contained 79 and 100 ppm oil respectively. The second test involved a sand feed rate of 16.4 tons/hour, a water rate of 146 gallons/minute, and an air rate of about 225 cubic feet/minute. The exit water and cleaned sand contained 14 and 52 ppm oil respectively. The water temperature at the field test site was still at about 14°C on the date of this test. The residual oil levels met or exceeded the design specifications under both sets of operating conditions although the Agency representatives seemed to feel that the unit's performance was not completely acceptable. During the first test (with a residence time of about 4.1 minutes) approximately 95.0% of the oil in the feed sand was removed by the process. During the second (with a residence time about 7.5 minutes) approximately 98.4% of the oil in the feed sand was removed. Note that, if absolutely necessary, an even larger percentage of the oil in the sand could have been removed by decreasing the sand feed and water rates; that is, by putting less oil into the flotation machine per unit time residual oil concentrations can be reduced proportionally, and by processing the sand with a larger residence time a larger percentage (up to some limiting value) of the feed oil can be removed. The major conclusion from this demonstration was that, although there may be some aesthetic reservations on the part of third party observers, the mobile beach cleaner quite efficiently removes oil from contaminated sand.

Demonstration 12 involved variation of process residence time with the same stock of feed sand (contaminated with No. 4 fuel oil at 4,287 ppm and aged for about two weeks). Aeration was set at 250 cubic feet/minute (a 17% decrease as compared to the previous tests) throughout the demonstration. Sand and water feed rates were 10.2 and 83, 15 amd 125, 22.5 and 190, and 30 and 250 tons/hour and gallons/minute respectively for the four consecutive tests. The residence times equivalent to these four sets of operating conditions are 12, 8, 5.5 and 4 minutes, and the exit water and cleaned sand contained 45 and 56, 61 and 73, 143 and 102, and 162 and 92 ppm oil respectively. With respect to the residence times of 12, 8, 5.5, and 4 minutes, the total effluent oil concentrations were 49, 65, 129, and 139 ppm. The inversely proportional relation between residence time and residual oil concentration is very good for this data.

Demonstration 13 was a repeat of demonstration 12 except that very fresh No. 4 fuel oil was used as the contaminant. For the residence times of 12, 8, 5.5, and 4 minutes, the exit water, cleaned sand, and total effluent oil concentrations were 75, 59 and 69, 149, 75 and 125, 284, 122 and 230, and 405, 164 and 325 ppm respectively. Again, the inversely proportional correlation between residence time and effluent oil concentration is excellent. Comparison of the results of demonstrations 12 and 13 illustrates in a very quantitative fashion the effect of aging oily sand. On the average, the fresh oil produces about 87% more residual contamination than the oil aged for two weeks. Unfortunately, the data for both the stationary plant and the mobile beach cleaner indicate that this aging effect is very dependent on the particular oil being processed and cannot be linearly interpolated or extrapolated with aging period.

Since, due to the residual oil in the water discharged from the plant, oily froth had been observed on the beach, demonstration 14 included taking samples along the beach. Samples were taken at 50 foot intervals from the point where the discharge entered the surf. Sampling was very selective (perhaps overly so) in that oily froth was carefully scraped from the surface of the beach where waves lapped the shore; care was taken to assure that a minimum of sand and water was picked up with the oily froth. Since "only" oily froth was collected, the measured oil concentrations are misleading in that they do not reflect the oil concentration on the beach but only the concentration in the froth; an area or volume based oil concentration on the beach during a demonstration would have been very small, indeed, due to the low concentration in the froth and because there was so little froth on the beach that, in fact, it was quite difficult to gather an adequate sample. Sand with 3,210 ppm No. 6 fuel oil was fed to the mobile unit at 30 tons/hour suring the test. Water and aeration rates were 250 gallons/minute and 250 cubic feet/minute respectively. The exit water and cleaned sand contained 55 and 42 ppm oil respectively which is quite an acceptable result.

Demonstration 15 was a nominal run with settling ponds used to isolate the discharge stream from the process. Relatively fresh oily sand (prepared the day before the demonstration) which contained 5,450 ppm No. 4 fuel oil was cleaned; the sand, water, and aeration rates were 30 tons/hour, 250 gallons/minute, and 250 cubic feet/minute respectively. The exit water and cleaned sand contained an average of 225 and 45 ppm oil respectively. Given the low water temperature on the date of this test (about 13°C) and the relative freshness of the oily sand, the results are still reasonably satisfactory; the total residual oil concentration was about 165 ppm for a process residence time of 4.1 minutes. Settling ponds were found to be quite useful and practical in isolating residual oil.

Demonstration 16 took place at night; night operation presented no special problems, but the importance of proper floodlight placement was made more explicit. Samples were again taken along the beach during this test. No. 4 fuel oil was used as the contaminant during this test at an intermediately high level (6,830 ppm); sand, water, and aeration rates were 30 tons/hour, 250 gallons/minute, and 250 cubic feet/minute respectively. The exit water and cleaned sand contained 362 and 63 ppm oil which, with the process parameters used plus a residence time of 4.1 minutes, is about the result expected. Analysis of the beach samples led to three relevant conclusions: (1) the amount of oil along the beach changed only very slowly with time, (2) the oil physically on the beach was concentrated near where the process discharge entered the surf, and (3) the amount of oil on the beach was very small and unstable in that it did not maintain its presence on the beach as a pollutant given even only several hours of aging.

Demonstration 17 considered the effect of pine oil on the cleaning process. Two levels of residence times and pine oil concentrations were used. Both these test conditions involved No. 6 fuel oil in the contaminated sand at 6,680 ppm. First, the sand, water, and aeration rates were 30 tons/hour, 250 gallons/minute, and 250 cubic feet/minute respectively for a residence time of 4.1 minutes. The first 7 samples involved no pine oil addition while the next 7 involved pine oil addition at a rate sufficient to give a concentration of about 50 ppm; these two conditions gave exit water and cleaned sand residual oil concentrations of 102 and 56 and 100 and 49 ppm respectively. Second, sand, water, and aeration rates were 15 tons/hour, 125 gallons/minute, and 250 cubic feet/minute respectively for a residence time of about 8.2 minutes. Again, the first 7 samples involved no pine oil addition; the second set of samples involved a pine oil addition rate sufficient to give a concentration of about 100 ppm. Respectively, these two test conditions gave exit water and cleaned sand residual oil concentrations of 47 and 54 and 45 and 52 ppm. The above results show dramatically that the addition of pine oil has no significant, measurable effect on the separation process. That is, pine oil, a frothing agent, would have to be added to the system at unacceptably high levels to overcome the effect of the contaminating oil, a froth depressant.

Demonstration 18 was similar to 12 and 13 except that No. 6 fuel oil was used as the sand contaminant; aeration was set at 250 cubic feet/minute for all 4 tests. Sand and water feed rates of 10.2 and 83, 15 and 125, 22.5 and 190, and 30 and 250 tons/hour and gallons/minute led to residual oil concentrations in the exit water and cleaned sand of 7 and 10, 12, and 25, 24 and 20, and 27 and 39 ppm respectively. These results are equivalent to total effluent oil concentrations of 9, 16, 23, and 31 ppm for residence times of 12, 8, 5-1/2, and 4 minutes respectively. The results represent, again, an excellent, almost proportional, correlation.

Demonstration 19 was as 18 except that diesel fuel mixed with No. 6 fuel oil in a ratio of 25:1 was used as the contaminant; the oily sand contained 4,670 ppm oil and aeration was again set at 250 cubic feet/minute. The residence times (equivalent to the conditions of the previous demonstration) of 12, 8, 5-1/2, and 4 minutes led to total residual oil concentrations of about 64, 113, 122, and 190 ppm respectively. Again, the inverse correlation implied by these results is reasonably good and the relative difficulty of separating lighter oils is illustrated.

Demonstration 20 involved a high concentration of diesel fuel in the feed sand (15,200 ppm) with samples again taken along the beach. Sand, water, and air were fed to the plant at 30 tons/hour, 250 gallons/minute, and 250 cubic feet/minute respectively. For the resulting residence time of 4 minutes, the exit water and cleaned sand contained 800 and 130 ppm oil respectively; on a proportional basis, this provides a good comparison with the results of the previous demonstration. Even with quite a dirty effluent stream, relatively little oil was found in the froth along the beach. The main effect of the higher oil concentration in the exit water seemed to be a greater extent of froth deposition along the beach. Again, the oil on the beach increased only slowly with time, was more concentrated near the point where the effluent water entered the surf, and did not persist once sand cleaning had ceased.

Demonstration 21 was run to ascertain the effect of recycling oily water from the oil recovery tank to the froth flotation machine. Sand, water, and aeration rates were 30 tons/hour, 250 gallons/minute, and 250 cubic feet/minute respectively; No. 4 fuel oil was the sand contaminant at 4,960 ppm. The first 6 samples were taken under conditions without the water recycle and contained 208 and 75 ppm oil (total 164 ppm) in the exit water and cleaned sand respectively. Samples 7-9 were for sand cleaning with the water recycle and results in 220 and 49 ppm (total 163 ppm) respectively. To bracket the results with the oily water recycle, 7 final samples were taken without recycle resulting in exit water and cleaned sand residual oil concentrations of 190 and 56 ppm (total 146 ppm). Given the standard deviations in the data (about 15%), the conclusion is that recycle of oily water from the oil recovery tank does not significantly degrade the sand cleaning operation. This result is crucial for the long term, continuous operation of the mobile beach sand cleaner.

Demonstration 22 involved addition of dispersants to the contaminating oil; two different dispersants were used while three separate sets of test data were taken. All test conditions considered no. 4 fuel oil mixed with dispersant in a ratio of 53:1 prior to sand contamination. The first test (22A) used the dispersant "Corexit" and sand, water, and aeration rates of 30 tons/hour, 250 gallons/minute, and 250 cubic feet/minute respectively. A feed oil concentration of 3,860 ppm led to 104 and 76 ppm in the exit water and cleaned sand respectively. This result is acceptable. The second test (22B) involved the dispersant "Magnus." A feed sand oil concentration of 4,980 ppm and a residence time of about 4 minutes led to exit water and cleaned sand oil levels of 517 and 119 ppm respectively. The conclusion is that "Magnus" severely effects the separation process. In fact, the effluent stream was so obviously unacceptable that the field engineer in charge decreased the sand feed rate and increased the residence time; operation under these conditions constituted test 22C. Sand, water, and aeration rates were 10.2 tons/hour, 75 gallons/minute, and 200 cubic feet/minute respectively. A feed sand oil concentration of 4,660 ppm and a residence time of about 13 minutes led to 59 and 86 ppm oil in the exit water and cleaned sand respectively.

The conclusion is that acceptable results can be attained over a wide range of operating conditions and that the presence of a dispersant in the contaminating oil does not necessarily mitigate against the use of the mobile beach cleaner.

Demonstration 23 took place on December 16, 1971 for representatives of the Environmental Protection Agency. Conditions were nominal except that a reduced sand feed rate and a settling pond were used to minimize the aesthetic impact of the residual oil. No. 4 fuel oil was the contaminant at 5,020 ppm in the feed sand; sand, water, and aeration rates were 22.5 tons/hour, 195 gallons/minute, and 250 cubic feet/minute respectively for a residence time of 5.3 minutes. The temperature was 12°C, and the oil and sand were very freshly and thoroughly mixed on the morning of the day of this test. The exit water and cleaned sand contained 130 and 28 ppm oil respectively; corrected proportionally for a sand feed rate of 30 tons/hour, the same residence time, and, therefore, a 40% by weight sand slurry (which is within the operating capability of the froth flotation machine), the data implies residual oil concentrations of about 37 and 127 ppm in the cleaned sand and total effluent stream respectively. 94.2% recovery of the oil was achieved during the test which is quite good considering the low processing temperature and the fact that very fresh No. 4 fuel oil was used as the contaminant.

Demonstration 24 also took place on December 16, 1971 before representatives of the Environmental Protection Agency. Conditions were substantially the same as for the previous demonstration except that No. 6 fuel oil was used as the contaminant at 3,480 ppm. The exit water and cleaned sand contained 26 and 14 ppm oil respectively for a total oil recovery of 98.0%. Corrected to a 30 ton/hour sand feed rate and an input oil concentration of 5,000 ppm (still with a residence time of about 5.3 minutes) this data implies residual oil in the cleaned sand at 27 ppm and the total effluent stream at 42 ppm. Compared to the design criteria, the performance of the mobile beach sand cleaner during this demonstration was excellent.

3.5.5 Process Operating Costs

Figure 19 on page 66 and page 67 is a schematic of the mobile beach cleaner. As of the date of this report, the cost for such a unit was estimated to be about $85,000. The major elements of this piece of equipment as labeled by the numbers on the drawing are as follows:

1) Motor, Froth Paddle

2) Launder

3) Discharge, Recovered Oil

4) Discharge, Cleaned Sand

5) Valve, Flush Water

6) Valve, Wash Water

7) Deck, Trailer

8) Tank, Diesel Fuel

9) Generator, Diesel-driven Electric

10) Panelboard, Electrical

11) Panelboard, No. 1, Electrical Control

12) Panelboard, No. 2, Electrical Control

13) Pipe, Water Supply

14) Panel, Instrument Control

15) Blower, Pressure

16) Air-duct, Flexible

17) Air Header

18) Pulley, Drive, Flotation Cell #4

19) Motor, Drive, Flotation Cells #3 & 4

20) Pulley, Drive, Flotation Cell #3

21) Pulley, Drive, Flotation Cell #2

22) Motor, Drive, Flotation Cells #1 & 2

23) Pulley, Drive, Flotation Cell #1

24) Elevator, Conveyor Belt

25) Hopper, Sand

26) Push-bar

27) Machine, Flotation

28) Door, Elevator Clean-out

29) Hand Wheel, Process Water Control

30) Valve, Main Process Water

More unit process and equipment detail was supplied as a portion of the package delivered to the Environmental Protection Agency with the first mobile beach cleaner in January of 1972.

Given the cost of the basic hardware and operation of the unit for 30 full (24 hour) days per year, the following cost estimate can be made for using the unit;

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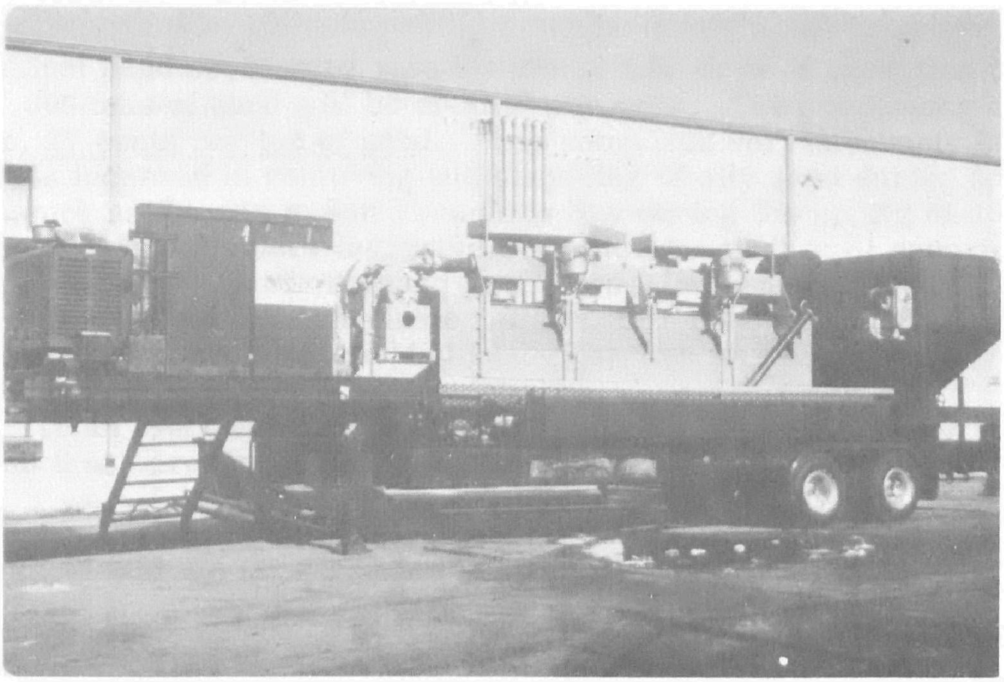
RIGHT SIDE VIEW



LEFT SIDE VIEW

FIGURE 20. PHOTOGRAPHS OF MOBILE BEACH CLEANER

Basic Hardware

mobile unit depreciation ($85,000 over 20 years)	$ 4,250
Labor	
field engineer, 36 days @ $48	1,730
field engineer, 50% field overhead	860
field engineer per diem, 33 days @ $25	820
travel for field engineer, 3 spill incidents	720
local hire field engineer, 30 days @ $60/12 hour day	1,800
local hire 30 days @ $36/12 hour day	1,080
Support Functions	
front end loader rental, 30 days @ $50	1,500
elevating scraper rental, 10 days @ $100	1,000
tracked vehicle support, 6 instances	390
truck tractor transport of mobile unit	1,100
diesel fuel and miscellaneous materials	500
Maintenance	
materials, 1% of total unit cost	425
labor, ditto	425
Total Yearly Cost	$16,600

If the nominal sand processing rate for the 30 full days of operation is 30 tons/hour, 21,600 tons of sand will be cleaned per year. The processing cost is, therefore, 77 cents per ton of sand. This compares very favorably to the estimated costs incurred in removing and disposing of oily sand during spill incidents such as the one in San Francisco Bay during the spring of 1971. Note that this comparison is very favorable even though actual spill experiences at 100 to 200 cents per ton of oily sand do not consider replacement of the sand removed from a beach. In conclusion, the mobile beach cleaner should be useful for treatment of oil contaminated sandy beaches for three primary reasons:

1) Present indications are that this proposed technique will be less costly than those presently being used.

2) The problem (especially in the long run) of securing and maintaining permanent storage for oily sand is eliminated.

3) The sand on a beach is not depleted by using the mobile beach cleaner.

3.5.6 Conclusions

The mobile beach cleaner was found to function very well under design conditions. The following factors, in the quantitative or qualitative fashion indicated, were found to effect performance; all factors other than the one being considered specifically are assumed to be held "constant."

1) Residual oil concentrations vary in direct proportion to sand feed

rate.

2) The more stable the sand feed rate, the cleaner are both the cleaned sand and exit water.

3) More viscous oils result in lower residual oil levels.

4) Residual oil concentrations vary in direct proportion to feed oil concentrations.

5) Within the limits considered during field testing, the older the oily sand is, the lower are the residual oil concentrations in the effluent stream.

6) The more homogeneously the contaminating oil is distributed in the sand, the cleaner the effluent stream.

7) Increasing the process water rate decreases the residual oil concentrations.

8) Sea water promotes a more effective oil recovery than does brackish or fresh water.

9) Denser slurries appear to promote less efficient oil recovery.

10) Residual oil concentrations vary in inverse proportion to froth flotation residence time.

11) Process effectiveness is a fairly complex function of aeration rate; for the particular machine which was field tested, an aeration rate of about 250 cubic feet/minute appeared to be an optimum.

12) Increased temperature results in increased process efficiency.

13) Surfactants or dispersants may either hinder or help oil recovery.

14) Organic solids (e.g., straw or kelp) hinder the flotation process by competing with the oil for attachment to air bubbles.

15) Oil deposited on wet sand is easier to recover than that deposited on dry sand.

Given the results of the field test program, the following can be assumed to be typical operating conditions for the mobile beach cleaner about which the above factors operate:

30 tons/hour sand feed rate

No. 4 fuel oil as the contaminant

oil deposition on wet sand

oily sand aged for about one week

sand as found at the Dam Neck test site without the presence of surfactants, dispersants or organic solids, homogeneously mixed with the contaminating oil, and fed steadily to the flotation machine

process sea water rate of 250 gallons/minute

process temperature of about 60°F

aeration rate of 250 cubic feet/minute

residence time (function of sand and water rates) of 4 minutes

160 ppm oil in the effluent water

75 ppm oil in the cleaned sand

130 ppm oil in the total effluent stream

SECTION IV

ACKNOWLEDGEMENTS

The author expresses considerable appreciation for the work performed by the project engineering staff during the course of this project. In a special sense these individuals are co-authors of this report although the author must accept sole responsibility for all analyses, conclusions, and recommendations. Mr. B. C. Langley, Senior Chemical Engineer, was assigned to the project almost from its inception; he played a major role during the demonstration plant design and construction and as supervisor of all the field testing, both with the stationary plant and the mobile beach cleaner. Mr. B. C. Comstock, Senior Mechanical Design Engineer, stepped into the breach during the design and construction of the mobile beach cleaner; his performance under a very tight time schedule was outstanding. Mr. K. W. Benson, Field Engineer, saw the project through all construction and field test work; his performance under sometimes very adverse conditions was an inspiration to others. Mr. S. J. Rose, Junior Chemical Engineer, assisted the author and the rest of the engineering staff throughout the project; he assisted the author during feasibility studies and was responsible for the oil concentration analyses throughout the project.

Mrs. K. A. Riddle not only typed this report but also coordinated the day-to-day expenses for the field engineers throughout the project in a typically efficient manner. Mr. L. K. Eliason, formerly Manager of Meloy Laboratories' Environmental Sciences Division, helped the project engineers through several crises during the course of our work. Dr. T. P. Meloy, Vice President, was a major driving force during the inception and early stages of the project and provided invaluable assistance in obtaining a project site. Mr. J. E. Riley, formerly Director of Marketing for Meloy Laboratories, was the project's most enthusiastic backer and salesman during the first one and a half years of work.

During the course of this project Meloy Laboratories became indebted to many parties. Thanks go to those individuals from both government and industry who encouraged the project staff in their efforts and showed an active interest in the project by visiting the demonstration site; such attention does much to restore the flagging spirits of a field crew.

Special thanks go to the U.S. Navy which supplied the site for the project. Captain Alwyn Smith, Jr., Commanding Officer of the Fleet Anti-Air Warfare Training Center at Dam Neck, backed Meloy Laboratories continually in requests for lease extensions. Lt. Commanders John Jelkes, Public Affairs Officer, and Paul Bonham, Public Works Officer, regularly gave their support; they also gave the project engineers much useful advice and assisted immeasurably in helping to both run the project and display it to interested visitors. Lieutenant Stevens, Lieutenant MacPherson, and Chief Petty Officer Badners of the drone launching complex gave a helping hand on several occasions when problems came up which necessitated outside assistance.

Approciation is also expressed for the jobs done by the various subcontractors; Mr. Joe D. Glenn and his staff completed their portion of the final design in a very short time and still came across with an excellent product. The Welch

Contracting Corp. did a superb job in putting up the plant on a two month schedule; Mr. N. Crowder, Vice President, Mr. R. Saunders, Planner, and Mr. A. Van der Reet, Foreman, were a pleasure to work with and gave valuable assistance to the field crew not only during construction but also during the demonstration tests. Woodington Electric Inc. also delivered the high tension power line under short time conditions; special commendation goes for locating and obtaining appropriate transformers by a non-standard route. Woodington Electric also dismantled the demonstration plant and restored the site upon the completion of the project. Wilbar Truck Equipment, Inc. of Alexandria, Virginia supplied the space and expertise necessary to assemble the mobile beach cleaner. Denver Equipment Company, General Engines Co., Inc., and North American Engines Co., Inc. were suppliers of major unit process items.

Professor A. M. Gaudin provided a valuable input by critiquing the project in its early stages and giving advice on the future mobilization of the process. Mr. H. Young of the Humble Oil Company gave valuable assistance by supplying fuel oil for the demonstrations; Mr. Young's cooperation was a credit to both himself and Humble Oil.

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SECTION V

APPENDICES

APPENDIX A

LABORATORY DATA

Table 1. Analytical Results for Series One Lab Tests*

Impeller Speed (revolutions per minute)	Aeration Rate (liters per minute)	Oil in Cleaned Sand (parts per million by weight)
1000	1.35	173.1
1000	3.55	84.3
1000	6.10	82.1
1000	8.85	87.5
1200	1.35	131.9
1200	4.80	118.4
1200	8.85	94.5
1200	13.25	60.1
1800	1.35	483.0
1800	8.85	127.6
1800	16.2	75.6
1800	19.2	72.5
2400	1.35	302.2
2400	6.10	400.0
2400	11.8	360.4
2400	26.8	137.1

*These tests were run with the Wemco laboratory test flotation machine; eash involved a 300 gram charge of sand contaminated at 5.00% with number 4 fuel oil and a froth flotation time of 3.5 minutes. A standard 3 liter cell was used for each test.

Table 2. Analytical Results for Series Two Lab Tests

Sand Charge (grams)	Aeration Rate, Maximum (liters per minute)	Oil in Cleaned Sand (parts per million by weight
100	12.8	49.4
250	12.5	107.4
400	11.8	128.9
550	11.8	130.0
700	10.4	82.8

These fests were run with an impeller speed of 1200 rpm, a feed No. 4 fuel oil concentration of 5.00%, and a 3.5 minute flotation time; again, the standard test cell was used

***

Initial Oil, Concentration (No. 4 Fuel Oil) (percent by weight)	Aeration Rate (liters per minute)	Oil in Cleaned Sand (parts per million by weight)
1	11.8	135.1
3	11.8	64.6
5	11.8	77.5
9	11.8	160.1
1	6.1	54.5
3	6.1	110.4
5	6.1	186.1
9	6.1	203.6
1	1.35	39.0
3	1.35	130.2
5	1.35	182.6
9	1.35	289.8

These tests involved an impeller speed of 1200 rpm and a 250 gram charge of contaminated sand; again, a standard test cell and a 3.5 minute flotation time were used.

APPENDIX B

CONSTRUCTION DRAWINGS

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APPENDIX C

PLANT DEMONSTRATION DATA

This appendix contains the basic operating and analytical data relating to each of the forty one tests which were performed on the demonstration pilot plant. Relevant flow rates and general operating conditions are included for each test. The results of the analyses for oil concentrations in the various critical process streams are presented in total; the statistical averages for these concentrations are presented as well. No attempt has been made to reproduce all data and calculation sheets; however, this material will be supplied at the direction of the Project Officer as Government Property. Accompanying the tabulated operating criteria and analytical results for each demonstration are the special conditions under which a particular test may have been run and any extraneous circumstances which are believed to have significance in the consideration of the data.

Demonstration Number 1

Sand feed rate: 30 TPH
Total water feed rate: 450 GPM
Water rate to attrition scrubber: 110 GPM
Water rate to vertical pump: 100 GPM
Water rate to flotation machine: 220 GPM
Aeration rate: 280 CFM

Screen spray rate: 20 GPM
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	n/a	n/a	133	286
Standard Deviation	n/a	n/a	5%	39%

A "standard run" with a concentration of No. 4 fuel oil of about 0.5%. The term "standard run" is used to imply a relatively high water rate (about 500 gallons per minute) and a nominal sand feed rate (25 to 30 tons per hour). Within the category standard run there is still considerable opportunity for variation in operating conditions; where applicable, these variations are listed as special conditions.

Demonstration Number 2

Sand feed rate: 23 TPH
Total water feed rate: 445 GPM
Water rate to attrition scrubber: 110 GPM
Water rate to vertical pump: 100 GPM
Water rate to flotation machine: 215 GPM
Aeration rate: 280 CFM

Screen spray rate: 20 GPM
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: approximately 1 cc/minute
No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	3,768	not measured	147	232
Standard Deviation	36%		20%	10%

A standard run with No. 6 or Bunker C fuel oil at 0.5%

Demonstration Number 3

Sand feed rate: 19 TPH
Total water feed rate: 450 GPM
Water rate to attrition scrubber: 115 GPM
Water rate to vertical pump: 40 GPM
Water rate to flotation machine: 215 GPM
Aeration rate: 280 CFM
Screen spray rate: 80 GPM
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: approximately 1 cc/minute
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	4,096	not measured	196	138
Standard Deviation	29%		21%	77%

A low sand feed rate (about 19 tons per hour) with all other conditions substantially the same as in Demonstration No. 1.

Demonstration Number 4

Sand feed rate: 25 TPH
Total water feed rate: 420 GPM
Water rate to attrition scrubber: 115 GPM
Water rate to vertical pump: none
Water rate to flotation machine: 195GPM
Aeration rate: 280 CFM
Screen spray rate: 110 GPM
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: approximately 1 cc/minute
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand (dry analysis)	Feed Sand (wet analysis)	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	5,484	5,223	not measured	160	806
Standard Deviation	127%	97%		9%	26%

A standard run with the oil (No. 4 fuel oil) partially sorbed into straw before deposition.

Demonstration Number 5

Sand feed rate: 30 TPH
Total water feed rate: 560 GPM
Water rate to attrition scrubber: 137 GPM
Water rate to vertical pump: 66 GPM
Water rate to flotation machine: 277 GPM
Aeration rate: 280 CFM
Screen spray rate: 80 GPM
Launder wash rate: approximately 30 GPM
Water rate to horizontal pump: none
Rate of pine oil addition: approximately 1 cc/minute
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Sand (prior to contamination)	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	23	8,361	1,186	711	537
Standard Deviation	216%	42%	24%	30%	60%

A low sand feed rate with a high level of No. 4 fuel oil contamination (about 3%).

Demonstration Number 6

Sand feed rate: 20 TPH
Total water feed rate: 320 GPM
Water rate to attrition scrubber: 50 GPM
Water rate to vertical pump: 54 GPM
Water rate to flotation machine: 156 GPM
Aeration rate: 280 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: approximately 1 cc/minute
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	4,088	251	329	1,011
Standard Deviation	36%	115%	29%	30%

High residence times for both scrubbing and flotation with No. 4 fuel oil at about 0.5%.

Demonstration Number 7

Sand feed rate: 25 TPH
Total water feed rate: 550 GPM (546 final)
Water rate to attrition scrubber: 160 GPM (166 final)
Water rate to vertical pump: 80 GPM (0 final)
Water rate to flotation machine: 230 GPM
Screen spray rate: 80 GPM (53 final)
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: approximately 1 cc/minute
Oil type: No. 4 fuel oil

Aeration rate: 280 CFM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	5,024	628	140	749
Standard Deviation	36%	37%	19%	23%

A standard run with No. 4 fuel oil at about 0.5% in sand which had been aged in piles for 15 days.

Demonstration Number 8

Sand feed rate: 19 TPH
Total water feed rate: 250 GPM
Water rate to attrition scrubber: 215 GPM
Water rate to vertical pump: none
Water rate to flotation machine: none
Aeration rate: 280 (Test A), 210 (Test B), 140 (Test C), and 70 (Test D) CFM
Screen spray rate: 35 GPM
Launder wash rate: none
Water rate to horizontal pump: 140 GPM
Rate of pine oil addition: approximately 1 cc/minute
Oil types: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
A) Average	5,633	296	155	477
Standard Deviation	31%	9%	29%	33%
B) Average	4,696	322	214	529
Standard Deviation	16%	19%	33%	29%
C) Average	5,480	257	159	540
Standard Deviation	57%	24%	35%	11%
D) Average	4,628	232	168	669
Standard Deviation	26%	8%	14%	23%

A standard run using only the first through fourth flotation cells to obtain kinetic data from a single, continuous demonstration.

Demonstration Number 9

Sand feed rate: 30 TPH
Total water feed rate: 250 GPM
Water rate to attrition scrubber: 215 GPM
Water rate to vertical pump: none
Screen spray rate: 35 CFM
Launder wash rate: none
Water rate to horizontal pump: 140 GPM

Water rate to flotation machine: none
Aeration rate: 210 CFM

Rate of pine oil addition: approximately 1 cc/minute
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	3,589	260	167	349
Standard Deviation	34%	36%	36%	22%

A standard run using only the first four flotation cells with a low scrubber residence time and a high flotation residence time.

Demonstration Number 10

Sand feed rate: 19 TPH
Total water feed rate: 440 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: 235 GPM
Water rate to flotation machine: 205 GPM
Aeration rate: 280 CFM

Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: 140 GPM
Rate of pine oil addition: approximately 1 cc/minute
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	7,020	273	106	496
Standard Deviation	34%	26%	14%	40%

A standard run with a low sand feed rate and a scrubber bypass: the initial attempt at simulating the operation of a mobile beach cleaner.

Demonstration Number 11

Sand feed rate: approximately 60 TPH
Total water feed rate: 395 GPM
Water rate to attrition scrubber: 130 GPM
Water rate to vertical pump: 50 GPM
Water rate to flotation machine: 185 GPM
Aeration rate: 280 CFM

Screen spray rate: 30 GPM
Launder wash rate: none
Water rate to horizontal pump: 150 GPM
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	5,112	1,992	389	2,141
Standard Deviation	49%	43%	35%	24%

A standard run with a very high sand feed rate (about 60 tons per hour).

Demonstration Number 12

Sand feed rate: approximately 8 TPH
Total water feed rate: 320 GPM
Water rate to attrition scrubber: 200 GPM
Water rate to vertical pump: 70 GPM
Water rate to flotation machine: none
Aeration rate: 280 CFM
Screen spray rate: 50 GPM
Launder wash rate: none
Water rate to horizontal pump: 200 GPM
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	16,980	1,200	392	1,678
Standard Deviation	20%	37%	23%	37%

A run with low scrubber residence time, high flotation residence time, very low sand feed rate (about 7 tons per hour), and an increased oil contamination level (better than 1.5% of No. 4 fuel oil).

Demonstration Number 13

Sand feed rate: 30 TPH
Total water feed rate: 305 GPM
Water rate to attrition scrubber: 165 GPM
Water rate to vertical pump: 55 GPM
Water rate to flotation machine: 35 GPM
Aeration rate: 280 CFM
Screen spray rate: 50 GPM
Launder wash rate: none
Water rate to horizontal pump: 165 GPM
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	8,236	296	137	353
Standard Deviation	40%	44%	23%	17%

A standard run with sea water rather than the brackish water from the well-point system which had been used previously; the contaminating oil was No. 4

fuel oil at about 0.8%.

Demonstration Number 14

Sand feed rate: 17.5 TPH
Total water feed rate: 280 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 280 GPM
Aeration rate: 350 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	5,290	N/A	115	276
Standard Deviation	17%		25%	8%

Demonstrations 14 through 20 were mobile unit simulation studies. Contaminated sand slurry entered the flotation machine directly at its feed box. Process water was not recycled and cleaned water-sand slurry was sampled directly from the discharge box of the flotation machine. Essentially nominal conditions except for the sand feed rate which was set at 17.5 tons/hour. Sand was fed to the system using a leased, portable belt feeder, and water was obtained from the ocean using a leased submersible pump.

Demonstration Number 15

Sand feed rate: 24.5 TPH
Total water feed rate: 250 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 250 GPM
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	6,130	N/A	157	280
Standard Deviation	8%		15%	14%

A mobile unit simulation, as 14, but with a sand feed rate of 24.5 tons/hour.

Demonstration Number 16

Sand feed rate: 22.5 TPH
Total water feed rate: 250 GPM
Screen spray rate: none
Launder wash rate: none

Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 250 GPM
Aeration rate: 350 CFM
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	6,680	N/A	232	260
Standard Deviation	19%		19%	7.7%

A mobile unit simulation, as 14 and 15, but with a sand feed of 22.5 tons/hour.

Demonstration Number 17

Sand feed rate: 27.0 TPH
Total water feed rate: 125 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 125 GPM
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	5,230	N/A	138	425
Standard Deviation	23%		17%	13%

A mobile unit simulation with a sand feed rate of 27.0 tons/hour and a water feed rate of half that of the previous tests or 125 gallons/minute (i.e., the residence time in the flotation machine was considerably higher than for the previous tests).

Demonstration Number 18

Sand feed rate: 26 TPH
Total water feed rate: 116 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 116 GPM
Aeration rate: 350 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	6,930	N/A	183	524
Standard Deviation	35%		23%	15%

Similar to 17 with an intentionally increased oil concentration (from 5230 to 6930 parts/million).

Demonstration Number 19

Sand feed rate: 26 TPH
Total water feed rate: 206 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate toflotation machine: 206 GPM
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	5,730	N/A	92	100
Standard Deviation	22%		43%	22%

A nominal mobile unit simulation with No. 6 fuel oil used in place of the No. 4 of the previous tests.

Demonstration Number 20

Sand feed rate: 13 TPH
Total water feed rate: 200 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 200 GPM
Aeration rate: 500 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	19,810	N/A	181	589
Standard Deviation	6.2%		16%	24%

A nominal mobile unit simulation with a very high feed oil concentration (about 2%) and a, therefore, reduced sand feed rate (13 tons/hour).

Demonstration Number 21

Sand feed rate: 30 TPH
Total water feed rate: 370 GPM
Water rate to attrition scrubber: 150 GPM
Water rate to vertical pump: 105 GPM
Water rate to flotation machine: 115 GPM
Aeration rate: 280 CFM
Screen spray rate: N/A
Launder wash rate: none
Water rate to horizontal pump: 145 GPM
Rate of pine oil addition: none
Oil type: medium crude oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	9,550	350	185	517
Standard Deviation	12.9%	41%	36.2%	34.6%

A nominal run using the entire demonstration plant loop. A medium crude oil was used as the contaminating medium at 1% concentration.

Demonstration Number 22

Sand feed rate: 30 TPH
Total water feed rate: 360 GPM
Water rate to attrition scrubber: 190 GPM
Water rate to vertical pump: 95 GPM
Water rate to flotation machine: 75 GPM
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: 145 GPM
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	6,920	1,970	243	1,780
Standard Deviation	8.2%	42%	20%	15.8%

A nominal run using the entire plant with an increased aeration rate to the flotation machine (350 cubic feet/minute).

Demonstration Numbers 23, 24 and 25

The purpose of these tests was to determine whether or not oil could be scrubbed from straw to facilitate disposal of the latter material. Straw saturated with No. 6 fuel oil was attrition scrubbed for various lengths of time, under various conditions. Liberation of oil into the carrier water was determined by analyzing for the oil.

Demonstration number 23 involved scrubbing for 6 minutes and resulted in 34 parts per million oil in the exit water.

Demonstration 24 involved scrubbing for 12 minutes and resulted in 40 parts per million oil in the exit water.

5 gallons of diesel fuel was added to the slurry in the attrition scrubber for demonstration number 25; after 12 minutes of scrubbing, the exit water contained 64 parts per million of oil. Addition of 5 more gallons of diesel fuel and scrubbing for 12 more minutes resulted in an exit concentration of 75 parts per million.

Although this data for the dispersion of oil into the process water moves in the right direction for these tests, the results are hardly favorable. More important are the extreme operating difficulties which the field engineering crew had with performing this task. The straw/oil mass tended to wrap around the impeller shaft in cell number 1 of the scrubber and was then extremely difficult to remove. This problem is similar to that observed around the impellers of the flotation machine; in this latter case, however, the air diffusing from the area of the impeller served to keep straw away, and, therefore, when such a straw buildup occurs, it occurs very, very slowly. The conclusion from these tests is that the recovery of oil contaminated straw by attrition scrubbing is not feasible.

Demonstration Number 26

Sand feed rate: none
Total water feed rate: 485 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 485 GPM
Aeration rate: 280 CFM

Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type & rate: No. 4 fuel oil at 2.5 GPM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	N/A			897
Standard Deviation				7.2%

Demonstrations 26 through 36 were for oil/water separation using the standard froth flotation equipment of the demonstration plant. The first test involved a water feed of about 500 gallons/minute with an oil concentration of 1/2% and an aeration rate of 280 cubic feet/minute. Oil was added at the vertical sump pump.

Demonstration Number 27

Sand feed rate: none
Total water feed rate: 485 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 485 GPM

Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type and rate: No. 4 fuel oil

Aeration rate: 560 CFM at 2.5 GPM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average				803
Standard Deviation				3.7%

A repeat of 26 with double the aeration rate.

Demonstration Number 28

Sand feed rate: none
Total water feed rate: 455 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 455 GPM
Aeration rate: 560 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type and rate: 1:1 No. 4 fuel oil–Diesel 260 at 2.5 GPM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average				1,370
Standard Deviation				2,9%

As 27 with a 1:1 mixture of No. 4 fuel oil and diesel fuel used as the feed contaminant rather than straight No. 4.

Demonstration Number 29

Sand feed rate: none
Total water feed rate: 465 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 465 GPM
Aeration rate: 560 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average				1.96
Standard Deviation				49.5%

Three bales of straw were thoroughly mixed with 1/4 drum of No. 6 fuel oil. This oily straw was then fed by hand to the flotation machine over a period of 10 minutes with a water rate of 465 gallons/minute and an aeration rate of 560 cubic feet/minute. The straw was floated very readily and little oil was released to the water.

Demonstration Number 30

Sand feed rate: none
Total water feed rate: 515 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 515 GPM
Aeration rate: 560 CFM

Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: 2.5 GPM No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated	Cleaned Sand (H_2O saturated)	Exit Water
Average				2,870
Standard Deviation				3.0%

The same as 27 except that the oil was added directly to the feed box of the flotation machine rather than at the vertical pump. Channeling within the flotation cells was very evident.

Demonstration Number 31

Sand feed rate: none
Total water feed rate: 515 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 515 GPM
Aeration rate: 560 CFM

Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump:none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil at 2.5 GPM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average (first sample set, 1-7)				3,350
Standard Deviation				4.1%
Average (second sample set, 8-14)				3,430
Standard Deviation				6.0%
Average (third sample set, 15-23)				3,110
Standard Deviation				3.3%
Average (fourth sample set, 24-31)				2,560

	(total 2,990)
Standard Deviation	11.7%
	(total 12.1%)

Similar to 30 except that aeration to the downstream cells was cut off sequentially during the test. Little parallel variation in performance of the total system was noted which implies that most of the effective separation occurs in the first one or two cells of the froth flotation machine.

Demonstration Number 32

Sand feed rate: none
Total water feed rate: 515 GPM
Water rate to attrition scrubber: 120 GPM
Water rate to vertical pump: 110 GPM
Water rate to flotation machine: 285 GPM
Aeration rate: 560 CFM

Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average				1,340
Standard Deviation				9.9%

An emulsion of oil in water was prepared as the feed contaminant by scrubbing. This emulsion plus additional water was delivered to the flotation machine by the vertical pump. The equivalent oil concentration in the feed to the flotation machine was about 2%. The water rate to the flotation machine was 515 gallons/minute and the aeration rate 560 cubic feet/minute.

Demonstration Number 33

Sand feed rate: none
Total water feed rate: 250 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 250 GPM
Aeration rate: 560 CFM

Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type and rate: No. 4 fuel oil at 1.25 GPM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average				2,790
Standard Deviation				9.3%

An oil/water separation test with an increased residence time relative to the previous tests (250 gallons/minute of water) with a feed oil concentration of

1/2% and an aeration rate of 560 cubic feet/minute.

Demonstration Number 34

Sand feed rate: none
Total water feed rate: 515 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 515 GPM
Aeration rate: 560 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type: No. 4 fuel oil at 25 GPM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average				22,100
Standard Deviation				10.5%

A very high feed oil concentration (approximately 5%) with a water rate of 515 gallons/minute and an aeration rate of 560 cubic feet/minute.

Demonstration Number 35

Sand feed rate: none
Total water feed rate: 515 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 515 GPM
Aeration rate: 560 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type and rate: No. 6 fuel oil at 2.5 GPM

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average				517
Standard Deviation				11.1%

Similar to the previous demonstration but with No. 6 fuel oil as the contaminant at a concentration of about 1/2%.

Demonstration Number 36

Sand feed rate: none
Total water feed rate: 1,050 GPM
Water rate to attrition scrubber: none
Water rate to vertical pump: none
Water rate to flotation machine: 1,050 GPM
Aeration rate: 560 CFM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: none
Rate of pine oil addition: none
Oil type and rate: No. 4 fuel oil at 5 GPM

Analytical Results

(parts per million by weight oil)

	Feed Sand	Feed Water (calculated)	Cleaned Sand (H_2O saturated)	Exit Water
Average				3,160
Standard Deviation				25.6%

The last of the oil/water separation tests. A very low residence time was used due to a water flow of 1050 gallons/minute. No. 4 fuel oil at 1/2% was used as the contaminant with an aeration rate of 560 cubic feet/minute.

Demonstration Number 37

Sand feed rate: 30 TPH
Total water feed rate: 537 GPM
Water rate to attrition scrubber: 205 GPM
Water rate to vertical pump: 82 GPM
Water rate to flotation machine: none
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: 250 GPM
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	4,500	1,127	278	1,540
Standard Deviation	17.0%	46.1%	11.8%	22.6%

The first in a series of four scrubbing and dewatering tests. Sand with about 1/2% No. 4 fuel oil was fed to the attrition scrubber at 30 tons/hour; water was added to the scrubber at 205 gallons/minute. The exit sand was pumped to the horizontal pump and then to the dewatering cyclone. Total water flow to the cyclone was 537 gallons/minute.

Demonstration Number 38

Sand feed rate: 30 TPH
Total water feed rate: 477 GPM
Water rate to attrition scrubber: 67 GPM
Water rate to vertical pump: 130 GPM
Water rate to flotation machine: none
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: 280 GPM
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	3,860	1,280	271	1,710
Standard Deviation	44.7%	23.4%	9.1%	28.5%

Similar to 37 but with an increased scrubbing time of about 7 minutes obtained by decreasing the scrubber's feed water rate to 67 gallons/minute.

Demonstration Number 39

Sand feed rate: 30 TPH
Total water feed rate: 517 GPM
Water rate to attrition scrubber: 107 GPM
Water rate to vertical pump: 120 GPM
Water rate to flotation machine: none
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: 290 GPM
Rate of pine oil addition: none
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	4,120	625	272	829
Standard Deviation	3,4%	47.5%	25.6%	24.8%

Similar to the previous test but with No. 6 fuel oil as the contaminant.

Demonstration Number 40

Sand feed rate: 30 TPH
Total water feed rate: 473 GPM
Water rate to attrition scrubber: 88 GPM
Water rate to vertical pump: 135 GPM
Water rate to flotation machine: none
Aeration rate: none
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: 250 GPM
Rate of pine oil addition: none
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	19,600	3,870	890	4,700
Standard Deviation	17.8%	47.8%	19.0%	20.4%

The last of the scrubbing and dewatering tests. A repeat of 38 except that the feed oil concentration was about 2%.

Demonstration Number 41

Sand feed rate: 30 TPH
Total water feed rate: 330 GPM
Water rate to attrition scrubber: 170 GPM
Water rate to vertical pump: 110 GPM
Water rate to flotation machine: 50 GPM
Screen spray rate: none
Launder wash rate: none
Water rate to horizontal pump: 145 GPM
Rate of pine oil addition: none

Aeration rate: 280 CFM | Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Feed Water	Cleaned Sand (H_2O saturated)	Exit Water
Average	4,750	2,050	703	2,460
Standard Deviation	37.5%	28.3%	26.6%	27.6%

A 20 hour long operational run. Day laborers were used to augment the field staff. Water was recycled through the plant, and the process parameters were maintained at essentially nominal values. Adequate lighting and stockpiled feed sand were crucial for this demonstration.

APPENDIX D

MOBILE BEACH CLEANER DEMONSTRATION DATA

The following pages contain the results of 24 sand cleaning demonstrations using the mobile beach cleaner which was constructed during the spring and summer of 1971. The format for the data given below is essentially the same as that of Appendix C. Again, no attempt has been made to reproduce all the data and calculations, but these are available and can be submitted in their raw state as Government property. Immediately below is a table of contents for the test data plus a general, relatively qualitative description of each demonstration.

Demonstration Number 1

Sand feed rate: 32 TPH
Water feed rate: 240 GPM
Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	5,620	307	47
Standard Deviation	6.1%	11.0%	68.1%

Essentially a nominal run with the mobile beach cleaner as originally constructed. Sand feed was somewhat high at 32 tons/hour with slightly more than 1/2 % No. 4 fuel oil, water rate was 240 gallons/minute, and aeration was set at 300 cubic feet/minute. Water temperature was below the nominal design value of 21°C, and, most importantly, the belt feeder operated in a very erratic and unreliable fashion.

Demonstration Number 2

Sand feed rate: 33.5 TPH
Water feed rate: 245 GPM
Aeration rate: 300 CFM
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	3,960	40	14
Standard Deviation	77.3%	16.9%	28.1%

A nominal run like the first demonstration but with No. 6 fuel oil at a somewhat low concentration. Erratic and unreliable operation of the belt feeder was again a severe problem.

Demonstration Number 3

Sand feed rate: 39 TPH
Water feed rate: 240 GPM
Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	5,950	315	28
Standard Deviation	7.7%	15.1%	47.9%

Similar to the first demonstration but with a higher sand feed rate, 39 tons/hour. Sand feed was more reliable and less erratic at the higher feed rate; this was reflected by better removal of the oil from the feed slurry.

Demonstration Number 4

Sand feed rate: 28.5 TPH
Water feed rate: 240 GPM

Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	8,900	425	74
Standard Deviation	9,8%	30.4%	51.6%

Took place about 3-1/2 weeks after the third demonstration; the drive for the feed belt had been replaced with a more positive and reliable unit. The feed oil concentration was high at about 0.9%. Aeration was again 300 cubic feet/minute which eventually was proved to be too high.

Demonstration Number 5

Sand feed rate: 28.5 TPH
Water feed rate: 255 GPM

Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	5,740	180	76
Standard Deviation	5.2%	44.9%	54.3%

Essentially a nominal run with No. 4 fuel oil. Although the water temperature was low at 14°C, the performance of the beach cleaner (adjusted) was substantially within the design criteria. The oily sand had aged for approximately one week prior to this test.

Demonstration Number 6

Sand feed rate: 28 TPH
Water feed rate: 248 GPM

Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results

(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	5,410	160	67
Standard Deviation	9.9%	29.2%	49.0%

A repeat of the previous test with sand freshly contaminated with No. 4 fuel oil. Results were essentially identical to the previous test proving that the modified system was acting reliably.

Demonstration Number 7

Sand feed rate: 40 TPH
Water feed rate: 248 GPM
Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	4,480	344	102
Standard Deviation	8.9%	13.7%	19.8%

The same as the previous run but with a sand feed rate of 40 tons/hour.

Demonstration Number 8

Sand feed rate: 29.6 TPH
Water feed rate: 385 GPM
Aeration rate: 400 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	5,450	228	97
Standard Deviation	6.0%	12.9%	23.9%

As demonstration 6 but with water and aeration rates increased to 385 gallons/minute and 400 cubic feet/minute respectively. Performance was degraded significantly.

Demonstration Number 9

Sand feed rate: 29.4 TPH
Water feed rate: 255 GPM
Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)

Average	4,940	274	48
Standard Deviation	4.7%	25.4%	38.3%

Contaminating oil was prepared by mixing 3-1/2 bales of wheat straw with 2 drums of No. 4 fuel oil. Other system's parameters were set at nominal values. With straw present, the front end loader operator had trouble maintaining the sand feed to the unit and overall performance was degraded somewhat.

Demonstration Number 10

Sand feed rate: 30 TPH
Water feed rate: 243 GPM
Aeration rate: 300 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	6,410	483	108
Standard Deviation	8.8%	48.2%	32.8%

Feed oil concentration was set at 0.64% with other conditions nominal. Due to the oil which had by this time worked its way into the system, there was trouble with belt slippage. The resulting erratic feed caused a degradation in system performance.

Demonstration Number 11

Sand feed rate: 30 TPH	(A)	16.4 TPH	(B)
Water feed rate: 250 GPM	(A)	146 GPM	(B)
Aeration rate: 300 CFM	(A)	225-250 CFM	(B)

Oil type: No. 6 fuel oil (A and B)

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average - (A)		79	100
Standard Deviation		11.9%	19.5%
Average - (B)	5,120 (total)	14	52
Standard Deviation	4.8% (total)	27.4%	20.9%

Representatives of the Environmental Protection Agency witnessed this nominal run with No. 6 fuel oil. At the request of these representatives sand was fed to the unit first at 30 tons/hour and then at 16.4 tons/hour. Although the water temperature was low, the unit performed substantially within the design criteria.

Demonstration Number 12

Sand feed rate: 10.2 (1-7), 15 (8-14), 22.5 (15-21), 30 (22-28) TPH
Water feed rate: 83 (1-7), 125 (8-14), 190 (15-21), 250 (22-28) GPM
Aeration rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average (1-7)		45	56
Standard Deviation		20.0%	37.5%
Average (8-14)		61	73
Standard Deviation (8-14)		11.5%	21.9%
Average (15-21)		143	102
Standard Deviation (15-21)		15.5%	31.8%
Average (22-28)	4,287 (total)	162	92
Standard Deviation (22-28)	22.1% (total)	8.8%	15.0%

Sand feed rates and water rates were varied during this run: 10.2, 15, 22.5, and 30 tons/hour and 83, 125, 190, and 250 gallons/minute respectively and concurrently. Aeration was lowered to 250 cubic feet/minute and the feed oil concentration was somewhat low. The oily sand had been aged for about 2 weeks and, of course, the water temperature was still low. The relation between residence times and effluent oil concentrations was shown to be quite consistent by this demonstration.

Demonstration Number 13

Sand feed rate: 10.2 (1-8), 15 (9-16), 22.5 (17.24), 30 (25-32) TPH
Water feed rate: 83 (1-8), 125 (9-16), 190 (17-24), 250 (25-32) GPM
Aeration rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average (1-8)		75	59
Standard Deviation (1-8)		37.3%	52.5%
Average (9-16)		149	75
Standard Deviation (9-16)		29.5%	24.0%
Average (17-24)		284	122

Standard Deviation (17-24)		9.9%	26.2%
Average (25-32)	5,740 (total)	405	164
Standard Deviation (25-32)	11.9% (total)	5.4%	25.6%

Essentially a repeat of 14 but using sand freshly contaminated with No. 4 fuel oil. Water temperatures were again low but still a good correlation was obtained between residence time and effluent oil concentration. The use of a settling pond to isolate the effluent was demonstrated, and once again the effect of aging No. 4 fuel oil was observed.

Demonstration Number 14

Sand feed rate: 30 TPH
Water feed rate: 250 GPM

Aeration rate: 250 CFM
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	3,210	55	42
Standard Deviation	20.3%	22.7%	26.1%

Analytical Results of Beach Samples
(parts per million by weight oil)

Samples by Sets

Sample No.	Beach Sand
Average (3S)	240
Standard Deviation	87.9%
Average (4S)	18
Standard Deviation	113%
Average (5S)	197
Standard Deviation	160%
Average (6S)	150
Standard Deviation	129%
Average (7S)	39
Standard Deviation	110%
Average (8S)	164
Standard Deviation	143%

Samples by Position

Sample No.	Beach Sand
Average (S1)	272
Standard Deviation	76.5%
Average (S2)	21
Standard Deviation	107%
Average (S3)	87
Standard Deviation	210%

Demonstration 14 was the first during which samples were taken along the beach. This test lasted for about 2-1/2 hours and involved No. 6 fuel oil as the contaminant at a somewhat reduced concentration with other process variables at their nominal values; the results of the cleaning process itself were, as usual, quite good. Due to the prevailing current along the beach (southwards) only those samples collected south of the plant's discharge contained oil. The code numbers for the beach samples refer to the following: the "S" indicates south of the discharge point; the first number refers to the time (multiples of 10 minutes after processing had begun; and the second number refers to the distance (in multiples of 50 feet) from the discharge point on the beach. Beach samples were taken in a very (perhaps overly) selective manner; from an area of about two feet in diameter centering around the indicated distance from the discharge point, a sample was scraped from the beach surface at the point where waves were lapping material onto the sand; great care was taken to assure that only oily residue was picked up. The major problem with this sampling technique was the difficulty in obtaining enough material for analysis. The major advantage was, of course, that the individual doing the sampling was gathering only material which (visually) appeared to be unacceptable. Average oil concentrations over all positions at the same point in time (the left hand column above) indicate little increase in the oil present on the beach over approximately a one hour time span and at the positions samples; in fact, the standard deviations involved make it difficult to say that any increase occurred at all. Averages at the same position over all the sampling times indicate a decrease in the oil present on the beach farther from the discharge point; this is as expected although, except for the sample position right next to the discharge point, there was really not much oil on the beach (as the analyses indicate). In making these conclusions, it must be emphasized again that samples were taken in the very selective manner described above and that in no way do the respective oil contamination levels represent typical oil concentrations for all the sand along the beach during a demonstration.

Demonstration Number 15

Sand feed rate: 30 TPH
Water feed rate: 250 GPM
Water feed rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	5,450	225	45
Standard Deviation	32.3%	25.1%	54%

A nominal run with No. 4 fuel oil. Dual settling ponds were used and proved feasible although in a long term continuous operation such an approach to isolating the effluent would entail the use of additional front end loaders.

Demonstration Number 16

Sand feed rate: 30 TPH
Water feed rate: 250 GPM
Aeration rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	6,830	362	63
Standard Deviation	6.5%	47.8%	37.6%

Analytical Results of Beach Samples
(parts per million by weight oil)

Samples by Sets		Samples by Position	
Sample No.	Beach Sand	Sample No.	Beach Sand
Average (1S)	666	Average (S1)	673
Standard Deviation	94.9%	Standard Deviation	90.5%
Average (2S)	211	Average (S2)	208
Standard Deviation	48.7%	Standard Deviation	60.2%
Average (3S)	674	Average (S3)	347
Standard Deviation	132%	Standard Deviation	83.0%
Average (4S)	203	Average (S4)	149
Standard Deviation	46.2%	Standard Deviation	64.1%
Average (5S)	444	Average (S6)	239
Standard Deviation	137%	Standard Deviation	35.8%
		Average (S8)	936
		Standard Deviation	120%
		Average (S10)	104
		Standard Deviation	5.4%
		Average (S12)	488
		Standard Deviation	79.1%
		Average (S14)	87
		Standard Deviation	15.5%

Took place at night with a slightly high feed oil concentration, other operating conditions being nominal. Samples were again taken along the beach. Proper floodlight placement was determined to be very important for night operation.

Demonstration Number 17

Sand feed rate: 30 TPH (1-14), 15 TPH (15-28)
Water feed rate: 250 GPM (1-14) 125 GPM (15-28)
Aeration rate: 250 CFM
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average (1-7)		102	56
Standard Deviation		24.9%	20.56%
Average (8-14)		100	49
Standard Deviation		11.5%	15.2%
Average (15-21)		47	54
Standard Deviation		13.6%	33.9%
Average (16-28)	6,680	45	52
Standard Deviation	17.6%	28.9%	27.5%

A run with No. 6 fuel oil at an, inadvertently, somewhat high feed concentration. Sand feed rate was changed from 30 to 15 tons/hour and water rate from 250 to 125 gallons/minute halfway through the test. During the second and fourth sets of data presented above pine oil was metered into the feed box of the flotation machine at about 60 cc/minute; this rate was sufficient to produce pine oil concentrations of about 50 to 100 ppm for the high and the low sand feed rates respectively.

Demonstration Number 18

Sand feed rate: 10.2 TPH (1-8), 15.0 TPH (9-16), 22.5 TPH (17-24), 30 TPH (25-32)
Water feed rate: 83 GPM (1-8), 125 GPM (9-16), 190 GPM (17-24), 250 GPM (25-32)
Aeration rate: 250 CFM
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average (1-8)		7	10
Standard Deviation		25.9%	34.8%
Average (9-16)		12	25
Standard Deviation		19.2%	89.2%
Average (17-24)		24	20
Standard Deviation		13.4%	21.9%
Average (25-32)	4,600	27	39
Standard Deviation	17.2%	30.0%	71.5%

Demonstration 18 took place under conditions identical to those in 12 and 13 except that No. 6 fuel oil was used as the contaminant. Total operating time was 1-1/2 hours. Again, residual oil concentration correlated very well with residence time in the flotation machine. Total residual oil concentrations of about 9, 16, 23, and 31 ppm resulted from residence times of 12, 8, 5.5, and 4 minutes respectively.

Demonstration Number 19

Sand feed rate: 10.2 TPH (1-8), 15 TPH (9-16), 22.5 TPH (17-24), 30 TPH (25-32)
Water feed rate: 83 GPM (1-8), 125 GPM, (9-16), 190 GPM (17-24), 250 GPM (25-32)
Aeration rate: 250 CFM
Oil type: Marine diesel fuel

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average (1-8)		48	96
Standard Deviation		35.26%	45.5%
Average (9-16)		132	76
Standard Deviation		9.5%	48.9%
Average (17-24)		152	64
Standard Deviation		8.6%	55.3%
Average (25-32)	4,670	251	70
Standard Deviation	14.1%	10.9%	23.9%

This test was identical to number 18 except that marine diesel fuel was used as the contaminant. The diesel fuel was colored (to facilitate its analysis) with No. 6 fuel oil at a ratio of 1 to 25. Residual oil levels again correlate quite well with residence time; total residual oil concentrations of 64, 113, 122, and 190 ppm resulted from residence times of 12, 8, 5.5 and 4 minutes respectively.

Demonstration Number 20

Sand feed rate: 30 TPH
Aeration rate: 250 CFM
Water feed rate: 250 GPM
Oil type: Marine diesel fuel

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	15,200	800	130
Standard Deviation	18.3%	11.2%	32.1%

Analytical Results of Beach Samples
(parts per million by weight oil)

Samples by Sets: Sample No.	Beach Sand	Samples by Position: Sample No.	Beach Sand
Average (1N)	81	Average (N1)	81
Standard Deviation	35.2%	Standard Deviation	34.4%
Average (2N)	1,010	Average (N2)	44
Standard Deviation	78.0%	Standard Deviation	20.8%
Average (3N)	47	Average (N3)	43
Standard Deviation	41.5%	Standard Deviation	41%
Average (4N)	54	Average (N4)	240
Standard Deviation	30.9%	Standard Deviation	179%
Average (5N)	57	Average (N5)	40
Standard Deviation	53.7%	Standard Deviation	21.8%

Demonstration 20 involved marine diesel fuel (prepared as in the previous test) at a high concentration in the feed sand (about 1-1/2%). Samples were taken along the beach but this time in a northwards direction since the current along the beach had shifted 180 degrees. Due to the high feed concentration of oil, the effluent stream was quite dirty. Again, there was little, if any, change with time in the amount of oil found on the beach; in fact, for this very light contaminating oil there was even little difference in the amount of oil on the beach at the various positions.

Demonstration Number 21

Sand feed rate: 30 TPH
Water feed rate: 250 GPM
Aeration rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average (1-6)		208	75
Standard Deviation		9.7%	21.2%
Average (7-9)		220	49
Standard Deviation		7.8%	16.3%
Average (10-16)	4,960	190	56
Standard Deviation	16.5%	10.2%	22.7%

During demonstration 21, dual settling ponds were used while the plant operated at otherwise nominal conditions. After 6 samples had been collected, recycle of water from the oil recovery tank to the feed box of the flotation machine was initiated; this recycle, which is absolutely necessary for long term continuous operation of the system, continued for 30 minutes and then nominal operation was resumed. The use of dual settling ponds proved feasible.

Demonstration Number 22

TEST 22A

Sand feed rate: 30 TPH
Water feed rate: 250 GPM

Aeration rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average-22A	3,860	104	76
Standard Deviation	6.3%	14%	25.9%

TEST 22B

Sand feed: 30 TPH
Water feed rate: 250 GPM

Aeration rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average-22B	4,980	517	119
Standard Deviation	3.4%	10.6%	19.7%

TEST 22C

Sand feed rate: 10.2 TPH
Water feed rate: 75 GPM

Aeration rate: 200 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average-22C	4,660	59	86
Standard Deviation	4.2%	52.7%	18.8%

22A took place under nominal conditions with approximately 2% of the dispersant Corexit added to the contaminating oil. The process was not significantly degraded. 22B took place under nominal conditions with approximately 2% of the dispersant Magnus added to the contaminating oil. Performance was degraded substantially but brought back within the effluent design criteria by reducing the sand feed to 10.2 tons/hour and the water to 75 gallons/minute.

Demonstration Number 23

Sand feed rate: 22.5 tons/hour
Water feed rate: 195 GPM

Aeration rate: 250 CFM
Oil type: No. 4 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	5,020	130	28
Standard Deviation	5.5%	13.8%	43.7%

Representatives of the Environmental Protection Agency witnessed this nominal test on December 16, 1971. The water was quite cold (about 12°C) and sand was fed at 22.5 tons/hour. Adjusted to the design criteria, the effluent concentrations were within their design values. This is an excellent result for No. 4 fuel oil.

Demonstrtion Number 24

Sand feed rate: 22.5 TPH
Water feed rate: 195 GPM

Aeration rate: 250 CFM
Oil type: No. 6 fuel oil

Analytical Results
(parts per million by weight oil)

	Feed Sand	Exit Water	Cleaned Sand (H_2O saturated)
Average	3,480	26	14
Standard Deviation	27.8%	4.8%	24%

Also took place on December 16, 1971 and witnessed by representatives of the Environmental Protection Agency. Consisted of a nominal run with No. 6 fuel oil in sand at 22.5 tons/hour. The feed concentration of the oil in the sand was unintentionally somewhat low; however, proportional adjustment to 30.0 tons/hour and 5000 ppm oil in the feed sand still placed the performance very much within the design goal, again with a low operating temperature.

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

5 *Organization*

Meloy Laboratories, Inc.
6715 Electronic Drive
Springfield, Virginia 22151

6 *Title*

RESTORATION OF BEACHES CONTAMINATED BY OIL

10 *Author(s)*

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16 *Project Designation*

EPA, ORM Project No. 15080 EOT

21 *Note*

22 *Citation*

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23 *Descriptors (Starred First)*

*Oil Pollution, *Beach Restoration, *Water Pollution, Contaminated Beaches, Sand, Spilled Oil

25 *Identifiers (Starred First)*

Froth Flotation, Mobile Facility, Field Operation

27 *Abstract*

Based on laboratory studies, a 30 ton per hour pilot plant was built for cleaning oil contaminated beach sands. The plant utilized the principle of froth flotation. Extensive field testing considered different oils, feed concentrations, both brackish and sea water, and a range of processing conditions. Forty one field tests were conducted at the U.S. Navy's Fleet Anti-Air Warfare Training Center at Dam Neck, Virginia. These varied from nominal runs with sand feed rates of 30 tons per hour and oil concentrations of 0.5% to oil/water separations at high capacity. Using the test results, a mobile unit was designed, constructed, field tested, and delivered to the Environmental Protection Agency. Data was obtained on the effects on cleaning efficiency of relevant process parameters: (1) sand feed rate, (2) feed steadiness, (3) oil type, (4) oil concentration, (5) sand age, (6) feed homogeneity, (7) water rate, (8) water type, (9) slurry density, (10) residence time, (11) aeration, (12) temperature, (13) surfactant effects, (14) organic solids effects, and (15) oil deposition on wet or dry sand. The mobile unit operated successfully under a wide range of conditions. This device should prove a valuable adjunct to existing oil spill cleanup procedures.

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