Section II

CLEANUP OPERATIONS

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A MOBILE PLANT PROTOTYPE FOR THE RESTORATION OF POLLUTED BEACHES BY WASHING OILY SAND

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ABSTRACT: *A research program was undertaken in 1980 with the support of the European Economic Community and the French Ministry of the Environment to develop a technique for treating beaches polluted by an oil spill, after the bulk of the oil has been removed from the surface of the sand by mechanical equipment. Final cleanup is often necessary, especially in the case of recreational beaches, when the oil remaining in the upper layer of sand—frequently in the range of 2 to 3 percent—in unacceptable. There is some controversy regarding the use of dispersants for this purpose.*

The basic principle of the technique is to wash oil-contaminated sand in transportable equipment which is operated either close to the polluted beach or at a centralized location, the washed sand then being returned to the beach or used for other purposes.

The selected equipment and three different cleaning agents were tested in pilot trials carried out on sand polluted with heavy fuel oil. A plant prototype was set up and tested in 1985. It is composed mainly of a horizontally rotating wash drum associated with a screen, a hydrocyclone to separate the sand from the wash-water phase and a vibrating screen for sand dewatering. These three pieces of equipment are mounted on the bed of a semi-trailer along with two transfer pumps. Oil and sand fines are separated from the water, before recycling, in several ground tanks in which a flocculating agent may be added. The operating parameters of the process are discussed on the basis of trials carried out at a throughput of 18 metric tons of sand per hour, giving a washed sand with an average oil content of 0.2 percent in the case of moderate weathering.

Following an accidental spill and despite efforts to prevent oil from coming ashore, beaches are often polluted and must be cleaned in order that economic activities, including touristic ones, and the ecological balance be restored.

The first action is removing oil residues from the surface of sand. The picking up operation can use selective techniques which aim at producing oil-rich waste in order to reduce transport and further treatment costs.[1] Apart from the fact that, depending on the nature of the pollutant, selective pickup is not always feasible, a more or less thick subsurface layer of sand frequently remains, containing 2 or 3 percent oil. Natural biodegradation takes a long time, and even if fertilizers are provided it can be limited by oxygen availability in the bulk sand. The use of dispersants for beach cleaning has been proposed but is controversial owing to the possible toxicity and to the fate of the oil which can be dragged down more deeply into the sand. This technique also is not very effective when oil is really adsorbed on sand particles or tightly trapped.

On-site washing of polluted sand in a mobile device was thought to be an interesting alternative. As early as 1980, a research program was undertaken with financial support from the French Ministry of Environment and the European Economic Community (DG XI). The objective was to define a modular process which could be implemented mainly with available and easily transportable equipment and which would be able to wash polluted sands of variable grain-size distribution at different stages of weathering.

This work was carried out in two distinct stages: laboratory and pilot-scale trials to define the process and washing products, and to select the equipment; and construction and trial of a prototype with a throughput of 20 tons of polluted sand per hour.

A study on the same subject was conducted in England by the Warren Spring Laboratory[2] resulting in somewhat different equipment. The conclusions of both studies were discussed in July 1985 during an internal EEC seminar (proceedings to be published).

Preliminary tests

Laboratory simulation of a contaminated sand having natural pollution properties must take into account mainly the particle-size distribution of the mineral skeleton and the degree of pollutant adhesion (adhesion related to the dehydration of the sand increases with weathering).

The choice of the type of sand, the pollutant, its *incorporation* method, and the degree of weathering was determined precisely in order to obtain realistic samples. The sand is a silico-calcareous sand with 40% carbonates whose grading extends from 0.8 to 1 mm. At certain sites, smaller sizes may be encountered as, for example, at the bottom of the Abers, or larger sizes as in the vicinity of rocky coasts.

To appreciate the difficulty of the scrubbing operations, an extractability test using cold water under mechanical agitation was developed. If the pollutant in a concentration of 25 g/kg of sand is a heavy fuel oil (HFO) introduced as is, or a crude oil emulsified to form a "chocolate mousse" type product, the desorption of the oils in a freshly prepared sand is easy—there is only 5 to 10% residual oil. On the other hand, for a sand weathered in an oven at 50° C or after storage for one week in a thin layer (a few centimeters) under natural radiation, the oil retention is greater. In the tested cases (HFO or emulsion), 80 to 90% of the oils remain adsorbed and the finer fractions (less than 0.25 mm) contain more hydrocarbons. It was consequently decided to carry out the tests with HFO, a pollutant which is quite appropriate for this purpose.

Results

The optimum washing procedure was defined on the basis of tests conducted for different scales of sand quantities, ranging from a few hundred grams to several tens of kilograms. All the facilities were tested in terms of the following main functions:

- Washing function for the desorption of the pollutant
- Solid/liquid separation function to transfer the pollutant to the water phase and leave a wet sand with a very low hydrocarbon content
- Liquid/liquid separation function to concentrate the pollutant in fluid form for subsequent treatment and recycling of wash water

Washing function. This phase of the study made it possible to determine the relative importance of essential parameters: cleaning agent, temperature, solids concentration, and agitation method.

Three products were adopted for their washing efficiency under standard testing conditions. Product A, a non-ionic surfactant, was used in a concentration of 20% in a 270–315° C petroleum cut with 18% aromatics. In this case, sodium carbonate was previously added to the sand in a certain number of tests. Product B is a commercial formula with a low surfactant content in a mixture of non-aromatic solvents. Product C is a 270–300° C non-aromatic petroleum cut. The products were used in the proportion of 25 g/kg of sand.

Depending on the degree of weathering, the washing temperature may range from ambient temperature, 15 to 20° C, to 50–60° C. The average contact time between the sand and the washing solution under these conditions may be about 5 to 10 minutes.

Different water concentration values were examined. Washing efficiency with a given cleaning product content increases as the ratio of water (sweet or sea water) to sand decreases. The adopted value is 1 : 1. In the following discussion, all tests were conducted with sweet water.

Equipment was selected on the basis of actual industrial availability and the possibility of integrating it within a continuously operating mobile system. Three devices were compared. The drum scrubber is a horizontal-shaft cylinder equipped with lifting blades designed to move the materials forward and mix them with water. The attrition cell is a vertical-shaft hexagonal tank equipped with an agitator having three levels of helical blades. The flotation cell resembles an attrition cell in which the agitator blades are provided with holes for the diffusion of air bubbles in the water/sand mixture.

The results of this comparative study have shown that the highest desorption rates (higher than 80%) are obtained with attrition and flotation cells. However, the results obtained with the drum scrubber are only 2 to 3 points lower. In view of the drawbacks exhibited by the cell systems (higher power consumption, semi-continuous operation, sensitivity to bulky particles), the choice was oriented toward the drum scrubber. It will also be noted that this equipment is better known to personnel called upon to operate it in real applications. In the case of a weathered polluted sand, the average temperature observed is from 35 to 40° C to rid the sand of 80% of pollutant, or 6 g/kg of residual oil.

Solid/liquid separation function. The mixture of sand and water containing desorbed hydrocarbons which comes out of the scrubber must be subjected to solid/liquid separation and the sand must be rinsed to displace the associated interstitial water containing large amounts of hydrocarbons. Two separation techniques may be used simultaneously for this double operation.

Hydrocyclone. Water/sand separation is obtained by creating a vortex. For the normal operation of this equipment, the solids concentration should not exceed 25% by weight. The addition of water at the discharge of the scrubber is thus essential. The sand is recovered by gravity in the underflow of the cyclone while the water and petroleum are removed as overflow with the fines.

Lavodune sand washer. This is a cylindrical-conical machine in which the oil-laden water and sand are separated by an upflow of water. Here too, dilution is necessary but, as in the preceding case, the sand is rinsed.

Before testing this function with these two machines, continuous washing tests at the rate of 400 kg per hour led to the following desorption results.

	Product A	Product B
Hydrocyclone	84%	76%
Lavodune sand washer	80%	62%

For practical reasons, the cycloning technique was adopted.

An indispensable complement to cycloning, which accentuates oil removal, is the dewatering of the sand underflow by means of a vibrating belt.

Liquid/liquid separation function. Along with the solid/liquid separation tests, products previously separated in the laboratory and favoring the settlement of wash water were tested in a continuous injection process. In the case of unweathered washed sand with the petroleum cut alone, separation is obtained very easily and the recycled effluent contains little oil.

After these laboratory and continuous operating tests for 6 hours at the nominal rate of 400 kg/hour, the essential conclusions were reached. They are summarized below and in Tables 1, 2, and 3.

- The heating of the water is essential for a weathered sand.
- The recycling of wash water is possible with suitable products.
- Residual oil levels obtained with optimum washing conditions vary from 1.5 g/kg for a recently polluted sand to 6 g/kg in the case of highly weathered sands, corresponding respectively to pollutant desorption of 90% and 75%.

Table 1. Operating conditions for obtaining between 1 and 6 g of residual oil per kg of washed sand

Pollution	Product	Temperature (°C)	Water/sand ratio
Recent	C	Ambient	1 : 1
Weathered	B	20–40	1 : 1
Highly weathered	A	30–50	1 : 1

Table 2. Quality of washed sands

Sand	Cleaning product	Residual oil concentration (g/kg)
Recent	C	2.5–3
Weathered	A or B	5–8
Weathered and water recycled	A	6–7 puis 5–6 with rinsing on vibrating belt

Table 3. Quality of cyclone overflow water

Cleaning product	Hydrocarbon content before flocculation (g/L)	Hydrocarbon content after flocculation (g/L)
A	1–2	0.5
B	0.3–0.6	0.2–0.3
C	0.1–0.4	0.05–0.1

Prototype tests

The elements making up the prototype were selected for their road transportability. Washing, solid/liquid separation and belt dewatering units were grouped on a semi-trailer bed. In light of the results of former work, the actual washing takes place in a scrubber, the washed sand and the polluted water are separated by hydrocyclone, the sand is dewatered on a vibrating screen, and the oil and water are separated by gravity settlement with the possible use of a suitable flocculating agent.

Washing and flocculation products are stored in 500-liter tanks which are easily transportable. Oil settlement is obtained in four tanks of 15 m^3 each, enabling them to be drained alternately by isolating them from the water circulation system. A heat exchanger connected to a mobile boiler provides the calories necessary for raising the temperature. The diagram of the installation is given in Figure 1 and an overall view in Figure 2.

Operation. The contaminated sand is fed into a hopper by means of a shovel loader and then taken by belt conveyor up to the drum scrubber. At the same time, the wash water is heated in a heat exchanger and the cleaning agents are added. The mixture of polluted sand, water, and cleaning products is stirred before being transferred onto a 5 mm grate to eliminate the bulky products such as gravel, stones, and seaweed. The recovered sand is then diluted with recycled water before going into the cyclone. The oil-rich liquid phase leaving in the overflow, which also contains fines whose maximum diameter is defined by the adjustment of the cyclone, is carried by gravity into the settlement tanks (Figure 3). The solid phase (washed sand) leaving in the underflow of the cyclone drops onto the vibrating belt for the maximum elimination of interstitial water, and then may be stored before being returned to the site from which it was taken.

The sand used for these tests is a dredged shell sand. The pollution of 350 m^3 of sand was obtained in a test section of 30 to 40 cm by spreading heavy fuel oil using a farm-type spreader. The mixing is carried out by means of a rotary cultivator in several passes on almost the entire thickness. The average pollution rate measured is of the order of 20 to 22 g of oil per kg of sand.

Performance. Two series of tests were carried out: one in July 1985 (15 days after sand preparation) and the other in October 1985. These tests permitted an overall evaluation of the operation and performance of the prototype over continuous periods of 3 and 6 hours. In all, 350 metric tons of polluted sand were washed.

July tests. These tests were intended mainly to check the proper continuous operation of the installation and to assess the performance of washing and water recycling operations.

The washing plant operated at an average of 18 metric tons of washed sand per hour. As the throughput was adjusted by means of the feed hopper gate, supply irregularities were spotted owing to the formation of vaults in the hopper. These throughput fluctuations, however, had no effect on washing efficiency.

Regular sampling of sand and water at different phases of the washing cycle led to the results given in Tables 4 and 5. These tables show that washing quality is excellent, with a desorption rate of the order of 85 to 90% for a temperature of about 30° C. In the particular case of this unweathered sand, the addition of a surfactant to the petroleum cut does not improve washing efficiency; the desorption rates are all high (higher than 85%) in spite of the low mixing temperature.

Water recycling makes it possible to operate with makeup water limited to the 5–6 m^3/h necessary to compensate for water removed with the washed sand and with the pollutant skimmed on the surface of the tanks (see Figure 3).

Table 5 gives the measured amounts of hydrocarbons recycled in the rinsing and washing water. These values are less than 0.3 g/L for the products B and C, and of the order of 2.3 g/L for the product A (this high value is explained by the force of the surfactant used).

October tests. The polluted sand was allowed to weather naturally since its preparation in June: it would thus be more difficult to clean. The washing temperature was brought to an average value of 40° C,

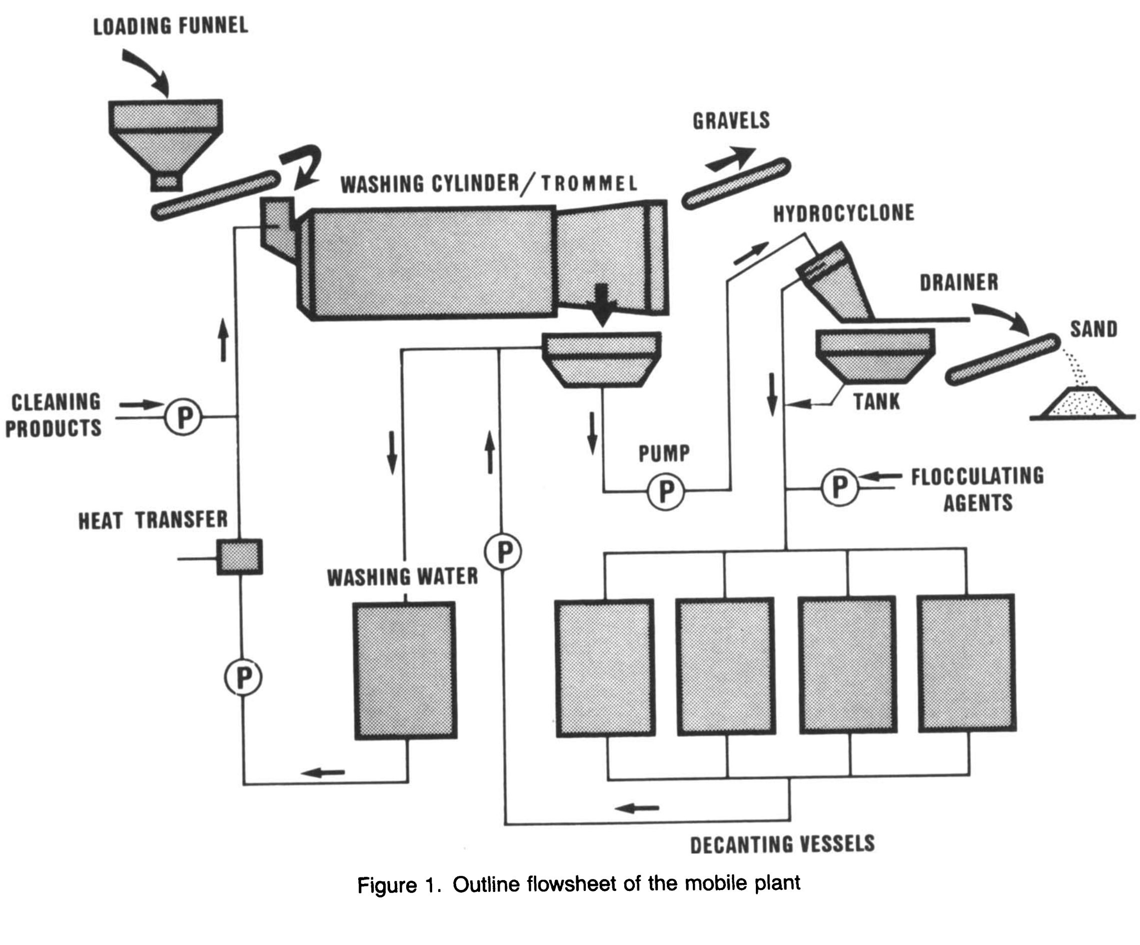

Figure 1. Outline flowsheet of the mobile plant

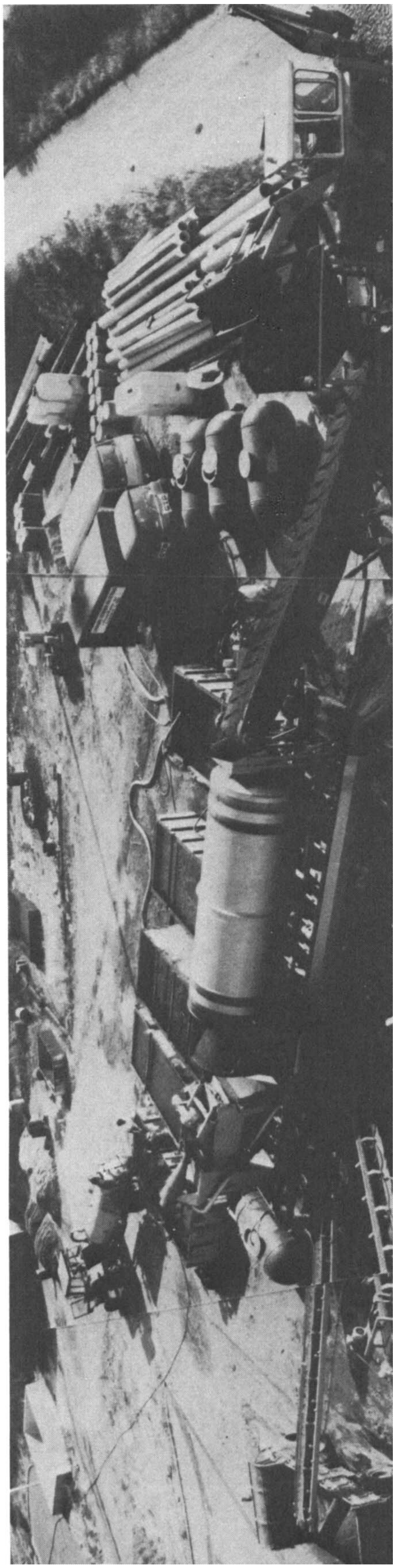

Figure 2. The plant prototype set up in Brest for trials

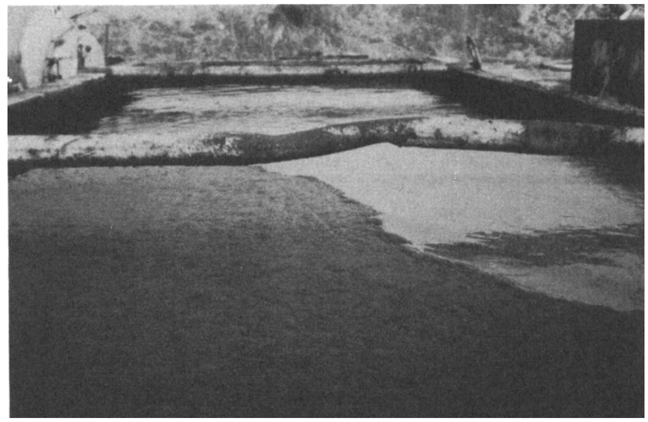

Figure 3. Separation of oil from washing water in one of the decanting tanks

Table 4. Washing efficiency

Cleaning product	Test time (h)	Hydrocarbon content of sand at scrubber discharge	Hydrocarbons in washed sand (g/kg)	Desorption (%)
C	start	4.9	2.5	87
	1		1.5	92
	2		1.9	90
	4		2.2	86
	7	9.4	1.8	90
B	start		2.8	84
	1.25	5.5	2.0	88
	2.5		1.7	90
A	start		2.0	88
	1.25	10.63	2.5	86
	2.5		2.9	83

Table 5. Followup of recycled water at the exit of the settlement tanks and extracted fines

Cleaning product	Test time (h)	Hydrocarbon content (g/L)	Fines content (g/L)
C	1	—	3.46
	2	0.26	2.05
	4	0.05	0.05
	7.5	0.30	1.17
B	0.17	0.27	0.42
	1.17	0.05	0.19
	2.17	0.17	0.09
A	start	0.01	0.01
	1.25	2.4	4.50
	2.5	2.3	9.25

and product B was used. This experimentation served as a demonstration.

The residual hydrocarbon contents in the washed sand was of the order of 4 g/kg on the average, while the recycled water contained 0.8 to 1 g/L of oil.

An attempt was made during these tests to improve final rinsing and to better determine the problems involved, by the follow-up of fluid circulation. Manual regulation of levels in the different compartments (settlement tanks, cyclones) required particular attention by personnel in the prototype version. As the removal of oil floating on the surface of settlement tanks was obtained by suction into a farm-type spreader tank, the skimming system was improved by allowing simple overflow from the settlement tank into gutters connected to the spreader tank.

Ecological impact

The final purpose of sand washing is the return of the washed sand to its original site. Experiments were undertaken to evaluate the ecological impact of such redepositing. The University of Western Brittany (Université de Bretagne Occidentale) was assigned the task of following the recolonization of this sand by marine fauna.

The main factors likely to influence the recolonization of the washed sand are the residual pollutant content and the particle size of the deposited sand, which differs from the sand in place in the case of the tests conducted.

Five experimental sections of 200 m^2 each were thus set up in order to determine the influence of these parameters on the recolonization of the polluted sand, compared with a control section on the beach. On the first four sections, the following volumes were respectively discharged and spread out in a basin 10 cm deep: 20 m^3 of sand washed in October, 20 m^3 of sand washed in July, 20 m^3 of polluted sand, and 20 m^3 of clean sand. On the fifth section, 20 m^3 of sand washed in October was deposited and left in a pile on the strand.

Measurements carried out over a period of 3.5 months and after the depositing of the sand covered both the identification and quantification of meiofauna and macrofauna present in the sediments and the evaluation of possible decontamination.

The main conclusions which may be drawn from this impact study are the following:

- The particle size difference between the imported sand and the sand initially present on the beach modifies the composition of the ecological populations and groups. It is preferable for the washed sand to be returned to the beach from which it came, which will in fact always be the case in the normal use of the plant.
- The residual oil and any residual washing products in the imported sand disturbs the recolonization of sediments. This recolonization is better with the sand washed in July, which was better rinsed and cleaner. The depositing of the treated sand on the beach in a pile improves the recolonization possibilities of the sediments by favoring natural rinsing.
- Washing of polluted sand in a plant facilitates the natural sediment decontamination process, as the sediment is made more mobile under tidal action.

In fact, in the case of the operations conducted on a polluted and hence already relatively impoverished coast, the local impact of sand washing appears to be marginal compared with the acceleration of the recolonization process it allows.

Conclusions

The objectives set for the washing of oil contaminated sand are achieved and are in conformity with the predictions of laboratory studies.

Washing quality is excellent in the case of recent pollution (90%) and very satisfactory in the case of old pollution (80%).

The throughput of the installation (18 metric tons of washed sand for 500 liters/hour of washing product) is as expected; nevertheless, it could be slightly increased.

The amount of makeup water required is small, of the order of 5 to 6 m^3/h.

Operational improvements were defined during the two test series. Provision has been made for them in the industrial unit.

The system represents a transportable unit of standard highway gauge. The assembly of the different external parts (boiler, heat exchanger, feed and recycling tank) obtained by means of flexible couplings is very easy.

Moreover, the results obtained during the tests suggest the possibility of extension to a wider range of materials (pebbles or sand more heavily laden with oil for example) by adapting the filtering device at the scrubber discharge.

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