Treatment and Utilization of Oil-Containing Produced-Water in Oman

1. Background
The economy of Oman is supported by petroleum; on average, petroleum income accounted for 85% of the nation’s income from 1991 to 1995. Its percentage of GDP hovers between 37 and 48%. At the center of oil development in Oman is Petroleum Development Oman (PDO), a government-related public corporation which accounts for 94% of total petroleum production. Recent increases in the volumes of petroleum production have contributed to rapid expansion of the nation’s economy, but the resulting environmental problems such as oil sludge and oil in produced water have become major concern in Oman. The impact of the oil-containing wastewater is significant, because the volume of the produced water is so huge. It would be of great benefit to an arid country such as Oman, if this wastewater could be reused. A study has been conducted jointly with Sultan Qaboos University to establish a technology to treat and utilize the produced water.

2. Overview of cooperative projects in the petroleum industry to solve environmental problems
(1) Survey of environmental problems in the petroleum industry (FY 1996 survey)
   • Objective: Identification of critical environmental problems associated with the petroleum industry in Oman
   • Content: Environmental problems in Oman were investigated; tank sludge and oil-containing wastewater were chosen as major problems associated with the petroleum industry, and current situations were studied.

(2) 1st stage Fundamental experiments on treatment of oil-containing wastewater (FY 1997 survey)
   • Objective: Laboratory scale on possible technology to treat containing wastewater
   • Content: Using oil-containing wastewater obtained from petroleum-related facilities in Oman, laboratory experiments were conducted on a two-stage treatment, namely, coagulation/flotation, and absorption treatment, and its effectiveness was determined.

(3) Experiments on continuous treatment of oil-containing wastewater (FY 1998 survey)
   • Objective: Scale-up of the laboratory experiments and continuous treatment
   • Content: Experimental equipment was developed with a treatment capacity of 2m³/day; oil containing wastewater was continuously treated with the coagulation/flotation and absorption processes, and the treatment performance was investigated.
(4) Investigation for practical application of oil-containing wastewater treatment (FY 1999 survey)

- Objective: Determination of the costs of treating oil-containing wastewater and design of a practical-scale plant

- Content: In continuous treatment experiments, the volumes of coagulant and adsorbent were optimized, and treatment costs were estimated. Irrigation experiment using three kinds of crops was also conducted to study an impact of the using treated water on their growth. In addition, a real-scale treatment plant was designed based on the experimental results.

Executing companies: Shimizu Corporation, Ebara Corporation

Counterpart: Sultan Qaboos University

3. Results of each fiscal year

(1) Survey of environmental problems in the petroleum industry in Oman (FY 1996 survey)

The environmental problems that have surfaced are a few because the industry is still not matured in Oman, and its population density is low. Although sewage and waste loom as major potential problems, these are problems of the social system rather than technological problems.

In the petroleum industry, which supports Omani economy, the problems of oil-containing produced water and sludge involve technological issues, and it was found that the solving the problem of the produced water, in particular, would have much greater impact overall.

- Problems of oil-containing produced water

In the oil fields of Oman, the underground water (oil-containing water) drawn up associated with oil production amounts to more than three times the volume of the produced oil. As shown in Figure 1, the total volume of produced water at present is approximately 500,000 tons per day, and it is forecasted that the volume will increase to 750,000 tons per day by the year 2005. In the oil fields of the southern district, underground water does not have to be re-injected to maintain pressure of reservoirs. In the northern region, on the other hand, it is discharged to a shallow aquifer at 100~200 m and a deep formation at approximately 1000 m. Since there is a danger that the oily-water discharged to the shallow layer could contaminate underground water sources, the discharge is scheduled to be prohibited in the near future. It is, therefore, desirable to treat this massive volume of oil-containing wastewater and reuse it as a water source.

Main features of the oil-containing wastewater problem can be summarized as the followings.

(1) Volume of the oil-containing wastewater is extremely large.

(2) Material needs to be removed from the water can be specified to oil components.

(3) Treated water should be effectively used for irrigation.

Each of these features should be investigated in this project.
Figure 1 Volumes of oil-containing produced water in Oman

- **Problems of sludge**
  The oil sludge are mainly generated at oil storage tanks and oil-contaminated soil caused by leakage from corroded pipeline. Total volume of both the sludge is, however, small at about 10,000 m$^3$ per year. Although, the sludge is treated using bacterial treatment, the degradation speed is slow and an alternative method is recommended.

(2) **Laboratory Experiments to treat oil-containing produced water (FY 1997 survey)**

Based on the survey of the previous year, the target of technological development for fiscal year 1997 was chosen to treat oil-containing wastewater to remove the oil by satisfying the following two conditions.

1) Oil content in wastewater into public seage system must be less than 30 ppm.

2) Oil content for re-use of wastewater for irrigation must be less than 0.5 ppm.

Oil analyzers, air-flotation test devices and other laboratory equipments were installed at the Sultan Qaboos University, and the following experiments were conducted.

1) **Analysis of oil-containing produced water**: Produced water in the Marmul oil field, a major oil field in the southern district, was analyzed. An average oil content of 300 ppm was reduced to 100 ppm through a CPI process and its performance was about 50%. The 100 ppm appears the limit of CPI treatment.

2) **Air-flotation with coagulation**: A one-liter and 15-liter air-flotation devices were used to study effect of coagulants. Coagulants that were tested include ferric chloride, aluminum sulfate, poly-aluminum chloride (PAC), which are inorganic coagulants; and polyacrylamide copolymers and gelatin as polymer materials. Test results showed that the most effective coagulant is ferric chloride with addition of polyacrylamide. Combination of PAC and polyacrylamide was found also effective. With the coagulants, the oil concentration of the raw water of 100-200 mg/l could be reduced to less than 20 mg/l.
3) Absorption treatment: Among several kinds of absorbents tested, activated carbon was found to be the most effective one, which can reduce oil content from 10-20 mg/l to less than 0.5 mg/l. Oil absorption capability of attapulgite, a locally produced silty mineral, has an absorption capacity similar to the activated carbon for water with a relatively high oil content at 30-50 mg/l. The attapulgite, however, has little absorption capacity for low oil content (< 10 mg/l) water.

4) Attapulgite: The unit price of active carbon is high. In the interest of reducing costs, the mineral attapulgite (ATT) was investigated as a possible absorbent which can be produced in the nation of Oman. Deposit of ATT can be found on the ground surface in the southern region of Oman, and its underground deposit is estimated large. Surface area per unit volume of ATT, however, is small, less than 1/10 of the area of active carbon. Absorption performance of ATT was equivalent to that of active carbon for relatively high oil concentrations of around 50 ppm. The absorption effectiveness of ATT against low concentrations of oil about 5 ppm was slight. Hence ATT may be used as a pre-treatment agent of active carbon.

(3) Pilot scale study using (FY 1998 survey)

This study was conducted to achieve reduction of oil contents in the produced water using a continuous treatment system as obtained through the laboratory batch methods (less than 20 mg/l after air-flotation and less than 0.5 mg/l after absorption). Applicability of the treated water to irrigation was also studied.

1) Coagulation and air-flotation in continuous treatment:

A continuous treatment plant, capable of processing 60 to 430 liters of water per hour, was installed at the Sultan Qaboos University campus. Oilfield water storage tanks and treated water storage tanks were installed adjacent to the treatment devices. As illustrated in Figure 2, the plant consisted of produced water storage tanks, a tank to mix the water with coagulants, a flotation water tank, absorption columns, and treated water storage tanks. Oil removal efficiency was investigated by varying conditions of the pressurized water ratio and coagulant concentrations. In the continuous experiment, PAC was used as the main coagulant because of easier handling and transportation.

Oil in the oilfield water with concentrations of 20-200 mg/l was successfully reduced to 5-20 mg/l through the air-floatation process with the following conditions: oily water flow rate of 200 liters per hour, pressurized water ratio of 30 percent, and use of 250 ppm PAC and 1 ppm SP52a as coagulants. These results were about the same as those obtained from laboratory experiments in the previous fiscal year.

2) Absorption process in continuous treatment

Water that had undergone the air-floatation process was then passed through columns of anthracite and granular activated carbon to remove remaining oil via filtration and absorption processes. The anthracite mainly filters out remaining oil flocks and to reduce load to activated carbon, which is much more expensive than anthracite. After the absorption process, concentrations of oil were reduced to 0.15 ~ 0.3 ppm regardless oil concentrations of the in-flowing water, satisfying the Omani standard of reuse of wastewater for irrigation (< 0.5 ppm).
3) Irrigation experiments

A plot to grow plants was set next to the pilot plant with a square area of 20m x 20m. The plot was divided into 6 sub-plots, each measuring 10m x 6.5m. Three plots were used for irrigation with the treated water, and the other three plots received normal tap water. Original soil was replaced with sand, mixed with large amount of organic matter, up to a depth of 30 cm. The watering amount was 3-15 mm per day per square meter. Spring heads were used to ensure that the water was distributed evenly over the entire area. Three plants, rhodesgrass, alfalfa, and barley, were selected for cultivation, since they are tolerant to a relatively high salt concentration. All plots were irrigated with tap water for first one month to allow germination and establishment of the plants.

(4) Investigation for practical application of produced water treatment (FY 1999 survey)

In the survey scheduled for this year, experiments in continuous treatment will be continued, and operational data, costs and impacts on plant growth will be determined. Based on these results, a practical plant will be designed and a cost of real scale plant will be estimated for construction and maintenance.

1) Pilot plant continuous treatment

Using the continuous treatment plant, oil concentrations of treated water will be investigated while varying operating conditions such as coagulant volume, type and volume of absorbent, and pressurized water circulation ratio. Through the experiment, the operating conditions and costs required to design a real-scale plant will be obtained. Various kinds of absorbents will be examined with a laboratory scale columns experiment to find more cost efficient materials to remove oil.
2) Irrigation experiments

Irrigation experiment will be continued to determine the impact of treated water on growth of crops. Results obtained thus far indicate that each plant can fully grow with a period of about three months. As shown in Figure 2, analysis of growth weights of harvested crops has revealed that there is no significant difference in growth between crops with the treated water and ones with fresh water.

![Figure 2](image)

**Figure 2** Comparisons of plant growth using treated water and fresh water

3) Design of a real-scale plant

A treatment plant will be designed corresponding to - a capacity of 40,000 tons per day in Nimr; initial costs and running costs will be estimated, and feasibility of the current treatment technology will be investigated.
4. Conclusion

It is our hope that the findings obtained through this research project will be applied to the
development of technology to treat oil-containing produced water in Oman. It is also hoped
earnestly that in the near future, a water treatment plant on a practical scale, as shown in Figure
3, will be constructed to contribute to a water resource and environmental conservation in the
country of Oman.

Figure 3  Large-scale greenery through treatment of oil-containing
produced water

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