# Chapter 6

# Countermeasures against Oil Contamination

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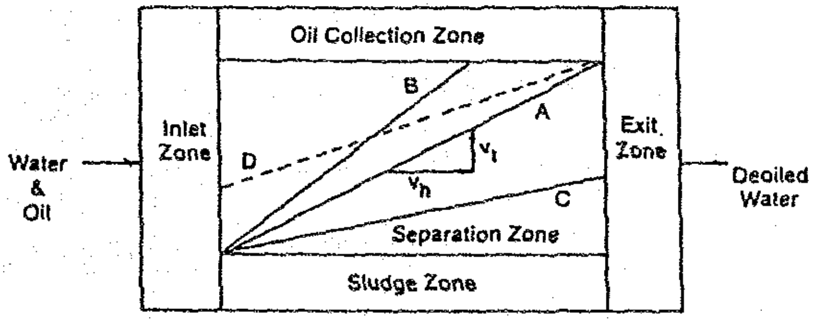
## 6.1 Treatment of Oil Polluted Product Water

### 6.1.1 Study of Various Methods for Removing Oil

Before selecting suitable methods for removing oil admixed with the product water, a review will be made on the present status of methods for removing oil from water.

#### (1) Gravity Separation Method 1)

This is a method of separating oil drops from water by difference in density. While oily water slowly flows through a separator, oil drops float up to the surface by difference in density, oil on the surface is collected and separated. As indicated in Fig. 6.1.1, oil drops in the separator follow the course of A, B, C or D depending on the size of oil drops and location of the inlet. If oil drops with the size to follow locus A enter into the bottom of the pool, they will come up to the surface following the course A, and oil drops with larger size than A will be separated.



Drop Trajectories

Fig. 6.1.1: Course of Various Oil Drops inside of Separator

Although the gravity separation is effective to remove free oil and unstable oil emulsion from oily water and is the most economical and efficient method for removing a large amount of free oil in primary treatment, dissolved oil and stable emulsion cannot be removed by this method.

Concentration of oil in water, discharged from outlet of the gravity type separator installed in an oil refinery, fluctuate widely according to the concentration in raw water to be treated, but the concentration is generally in the range of 30 to 150 mg/l. The oil removal efficiency of the gravity type separator is a function of temperature and difference in density between oil and water.

As typical examples of the gravity separation, API type and parallel plate type can be cited.

1) API Oil Separator

This separator is a basin type water tank as described in 5.3.1(3), which recovers oil floating on the surface by reducing flow speed and by a trough provided on the surface of water.

As an example of application, Fig. 6.1.3 and Table 6.1.1 indicate the separation efficiency of API separator (D = 1.5 m, W = 3.67 m, L = 36 m) when the sea water (28 °C) containing the oil (15 °API) falling within the diameter distribution of oil drops as indicated in Fig. 6.1.2 is treated in it for separation.

This system can remove oil drops with diameter of 150 μm or larger almost completely, while it requires a large installation space and its efficiency is low.

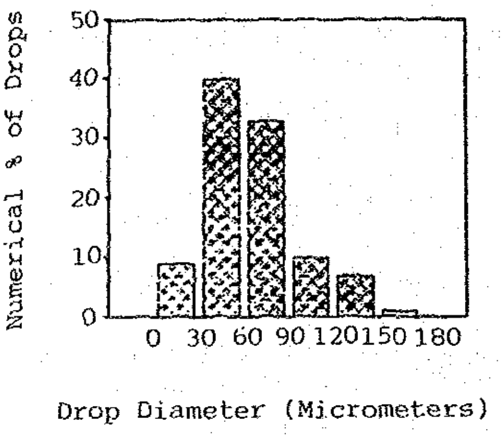


Fig. 6.1.2: Distribution of Oil Drops of Raw Water

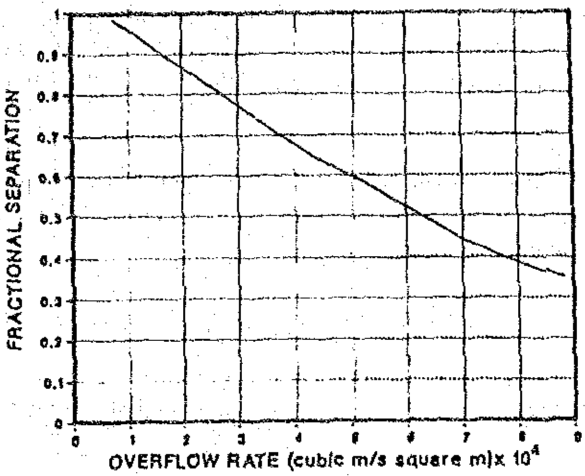


Fig. 6. 1. 3: Relations between Separation Ratio and Overflow Rate

Table 6. 1. 1: Separation Efficiency of API Separator

| Range of drop diameter μm | Oil concentration (fraction removed) Influent measured mg·l⁻¹ | Effluent measured mg·l⁻¹ |
|---|---|---|
| 0-30 | 11.4 | 9.0 (0.21) |
| 30-60 | 24.0 | 13.8 (0.43) |
| 60-90 | 23.1 | 8.6 (0.63) |
| 90-120 | 16.2 | 4.0 (0.75) |
| 120-150 | 6.7 | 1.0 (0.85) |

Observed overall fractional removal = 0.55.

2) Parallel Plate Oil Separator

This separator has a main tank in which many inclined parallel plates are inserted, thereby enlarging effective separation area for each free water surface area and straightening the flow. This separator has PPI (Parallel Plate Interceptor) type and CPI (Corrugated Plate Interceptor) type, each structure being indicated in Figs. 5. 3. 17 and 5. 3. 18.

It is said that oil particles up to the diameter of 60 μm can be separated. Comparing with API separator, the required installation space is smaller, and it can reduce oil concentration from 50 mg/l down to about 5 mg/l.

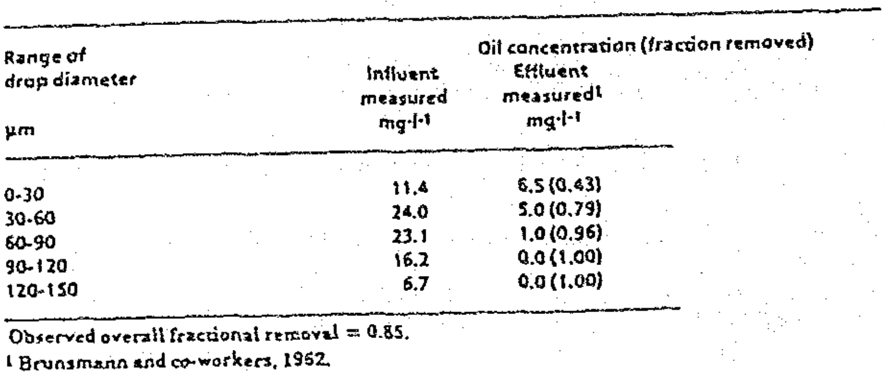
Table 6. 1. 2 shows an example of application of this separator.

This gravity separator is sometimes used in multiple combinations. An important point in this case is that distribution of diameters of oil drops at the outlet of No. 1 unit should become equal to the distribution of the diameters of oil drops at the inlet of No. 2 unit.

In other words, removal of oil starts from the oil drops with larger diameter in each unit, and therefore, diameters of oil drops in subsequent units become smaller, thereby gradually reducing the separation efficiency.

Since the practical size removable by the gravity separator is generally up to 10 and a few mg/l, this system alone is not sufficient to remove oil in the product water.

Table 6. 1. 2: Separation Efficiency of Parallel Separator



| Range of drop diameter µm | Oil concentration (fraction removed) Influent measured $mg \cdot l^{-1}$ | Effluent measured[1] $mg \cdot l^{-1}$ |
|---|---|---|
| 0-30 | 11.4 | 6.5 (0.43) |
| 30-60 | 24.0 | 5.0 (0.79) |
| 60-90 | 23.1 | 1.0 (0.96) |
| 90-120 | 16.2 | 0.0 (1.00) |
| 120-150 | 6.7 | 0.0 (1.00) |

Observed overall fractional removal = 0.85.

[1] Brunsmann and co-workers, 1962.

## (2) Air Floatation Method

General introduction of air flotation was made in 5. 3. 1, (3) (d), and here, the dissolved air floatation (DAF) which is applicable to removal of fine oil particles is presented. This method is based on a principle that air is made saturated under pressure in oily water, and when depressurized, bubbles with diameters of 30 to 120 µm are formed around a core of suspended oil and separation becomes easier because density of bubbles of oil drops becomes smaller.

DAF can be used by itself, but it displays high efficiency when used together with chemical coagulation or flocculation. Lime, iron alum or polyelectrolyte is used as a coagulant, and its addition forming flocks and making the separation easier.

Oil concentration in discharged water can generally be controlled to 20 mg/l, but there is an example of treating discharged water from the API separator with DAF and polyelectrolyte to finally reach 10 mg/l. This method has an advantage of drastically reducing the installation space owing to its large separating speed, but has a problem of disposing the produced sludge.

For treatment of polluted water containing free oil and emulsion oil, the AIP separator, chemical clarifier and DAF are usually employed.

*Fig. 6. 1. 4 indicates a flow sheet of standard DAF.* This is a *recycled* pressure type, which is generally recommended. Table 6. 1. 3 indicates its recommended design criteria.

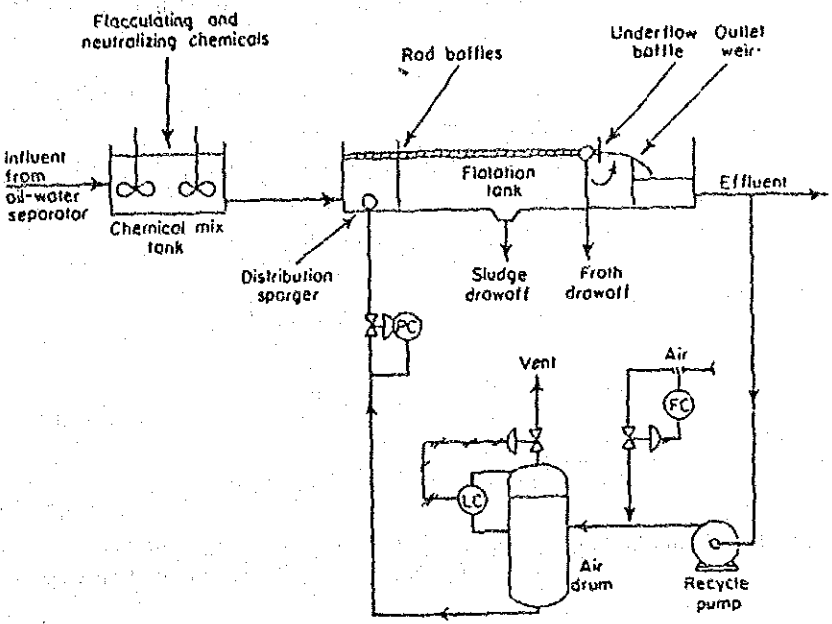


Fig. 6.1.4: Dissolved Air Floatation System

Table 6.1.3: Recommended Design Criteria of Dissolved Air Floatation System

| Items | Design Standard |
|---|---|
| Recycle Ratio for Aeration | 50% of Influent |
| Air Drum Pressure | 35 to 55 Psig |
| Retention Time at at Air Drum | 2 min |
| Retention Time at Floatation Tank | 15 to 20 min |
| Upstream Velocity inside Floatation Tank | 3.0 gal/min/ft$^2$ |
| pH | 7.5 to 8.5 |
| Flocculating & Neutralizing Chemicals | 25 mg/l Alum |
| Air | 0.25 to 0.50 SCF/100 gal |
| Depth of Floatation Tank | 6 to 8 ft |

Note: Airflow = 0.25 SCF/100 gal
Total Flow = 0.75 SCF/100 gal Recycle Flow
= 68 mg/l Recycle Flow
Equilibrante Air Solubility: 95 °F 35 psig = 68 mg/l

The following shows examples of performance by the DAF method:

(a) When alum is used as flocculant:

| Inlet Oil Concentration (mg/l) | Removal Ratio (%) |
|---|---|
| More than 100 | 90 to 95 |
| 100 | 80 to 85 |
| 25 | 65 to 85 |

(There is an example of 87% removal ratio at 32 mg/l inlet concentration.)

(b) When flow rate of stock water is 500 gal/min, and 7.3 mg/l organic polymer is added as flocculant;

| Inlet Oil Concentration (mg/l) | Removal Ratio (%) |
|---|---|
| 638 | 95 |
| 153 | 84 |
| 49 | 78 |
| 41 | 61 |

### (3) Coagulation and Sedimentation Method

Fine flocks are formed by addition of a chemical coagulant, and the oil in emulsion state is flocculated and changed to large particles, which are then precipitated and separated. This method is usually used in combination with filtration.

The system, in which polyelectrolyte is used as coagulant and which is combined with sand filtration, demonstrates much improved oil removal efficiency. This method is suitable for treatment of emulsion-state oil, having an example of 5 mg/l or less oil concentration in the treated water. The problem of this method is the disposal of produced sludge.

### (4) Filtration and Coalescence Method

As described in 5.3.1(3) this method is effective when emulsion is thick. An example of water and oil separator for ships is indicated in Fig. 6.1.5.

### (5) Membrane Process

Membrane process such as ultrafiltration or reverse osmosis has achieved good results for oil separation. However, problems such as relatively low speed, fouling and short life of membrane, etc., are presented. Fig. 6.1.6 indicates a water-purifier for home use made in combination of hollow fiber ultrafiltrating membranes and activated carbon, which has been commercialized for removal of organic matter and chlorine.

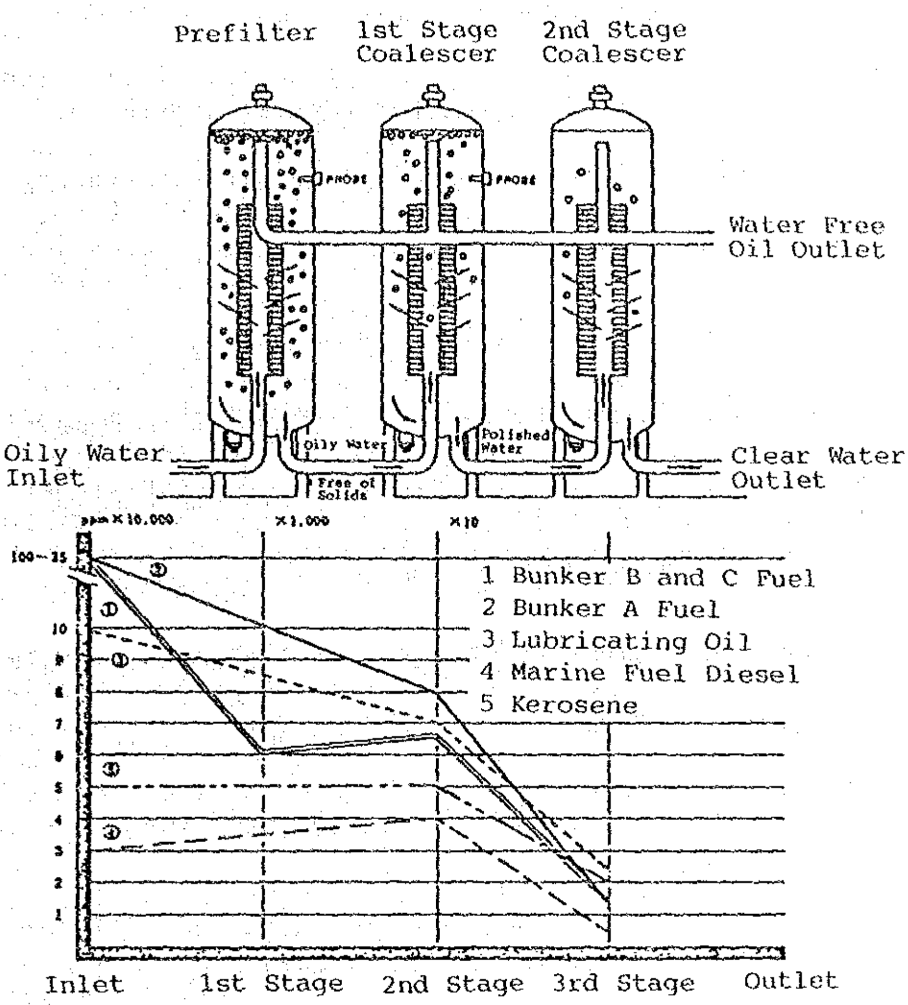


Fig. 6.1.5: Separation Efficiency of Filtration and Coagulation Method

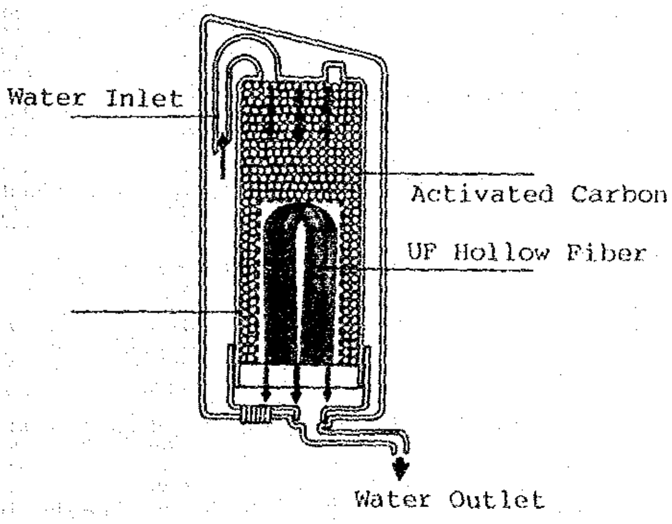


Fig. 6.1:6: Water Purifier for Home Use

### (6) Biological Treatment Process

Microorganisms act effectively on oxidation of soluble organic compounds but it has a limit in application for removal of free oil.

To apply the biological treatment process, it is necessary to remove oil beforehand up to the level of oil concentration which does not spoil its effectiveness. Also, care must be taken to the production and discharge of sludge, and filtration is needed after the biological treatment has been processed.

Table 6.1.4 shows a case 2) where waste water from a refinery plant is processed by biological treatment combined with the activated sludge process and the oxidation pond, and the actual removal of hydrocarbons has been investigated. It shows biological decomposition and a removal rate of 80 to 99.9% for aromatic group, 93 to 97% for polynuclear aromatic group, 95 to 99.5% for aliphatic group, and 97 to 99.9% for phenol group.

The oil removal efficiency of biological treatment is very high, and it can achieve the outlet oil concentration of as small as 1 μg/l or less, though this value fluctuates.

In case the polluted water contains benzene or toluene and requires high-grade refining, the treatment process combining the activated sludge and the oxidation pond is effective.

Table 6.1.4: Hydrocarbon Concentration of Inlet and Outlet of Biological Treatment Process

| Type of Hydrocarbon | Influent ($\mu g \cdot l^{-1}$) Min. | Influent ($\mu g \cdot l^{-1}$) Max. | Effluent ($\mu g \cdot l^{-1}$) Min. | Effluent ($\mu g \cdot l^{-1}$) Max. |
|---|---|---|---|---|
| Hydrocarbons | | | | |
| benzene | 1.0 | 6300 | 0.03 | 8 |
| toluene | 1.4 | 6200 | 0.03 | 4 |
| o-xylene | 1.9 | 1500 | 0.2 | 41 |
| $C_3$-phenyl | 0.3 | 450 | 0.05 | 40 |
| $C_4$-phenyl | 1.6 | 188 | 0.03 | 18 |
| hydrindene (Indane) | 1.8 | 127 | 0.05 | 9 |
| naphthalene | 1.1 | 191 | 0.06 | 9 |
| 1-methylnaphthalene | 0.2 | 332 | 0.06 | 19 |
| phenanthrene | 0.4 | 117 | 0.07 | 1.2 |
| methyl phenanthrene | 0.6 | 72 | 0.06 | 4 |
| n-$C_{10}H_{22}$ | 2.7 | 445 | 0.04 | 9 |
| n-$C_{11}H_{24}$ | 1.0 | 571 | 0.03 | 14 |
| n-$C_{12}H_{26}$ | 2.5 | 645 | 0.03 | 17 |
| n-$C_{13}H_{28}$ | 1.0 | 336 | 0.05 | 18 |
| n-$C_{14}H_{30}$ | 0.8 | 374 | 0.03 | 8 |
| Phenols | | | | |
| phenol | 100 | 10 000 | 0.1 | 5 |
| o-cresol | 200 | 30 000 | 0.3 | 0.8 |
| m-cresol | 100 | 15 000 | 0.5 | 1 |
| 3,4-dimethylphenol | 20 | 4 000 | 0.5 | 0.2 |
| 2,4-dimethylphenol | 50 | 10 000 | 0.2 | 0.7 |
| 2,6-dimethylphenol | 20 | 2 000 | nd | 0.9 |
| Ethylphenol | 100 | 400 | 0.2 | 1.5 |
| 3,5-dimethylphenol | 200 | 13 000 | nd | 0.7 |
| iso-propylphenol | 50 | 4 000 | nd | 2.0 |

### (7) Activated Carbon Adsorption Process

The activated carbon adsorption has a limited application in removal of free oil, but is basically effective for removal of low-level dissolved oil. When free oil is present, clogging and coating of activated carbon layer occur, which necessitates the pre-treatment to prevent them. If this pre-treatment is not taken, frequent backwashing and regeneration or replacement of activated carbon become necessary.

The following shows examples of the studies related to removal of oil components in water by activated carbon.

#### 1) Treatment of Waste Water from Refinery by Granular Activated Carbon 3)

An investigation revealed that treatment by activated carbon can reduce BOD in waste water to 20 mg/l and RON (Recognition Odor Number) to 10 units or less and that the odor component in organic compounds was absorbed far better than that of other polluted organic matters.

Also, while the pre-treatment is required for activated carbon process to reduce oil content to 20 mg/l or less, an activated carbon adsorption apparatus with a surface scrubber and a suitable backwashing devise can be applied directly.

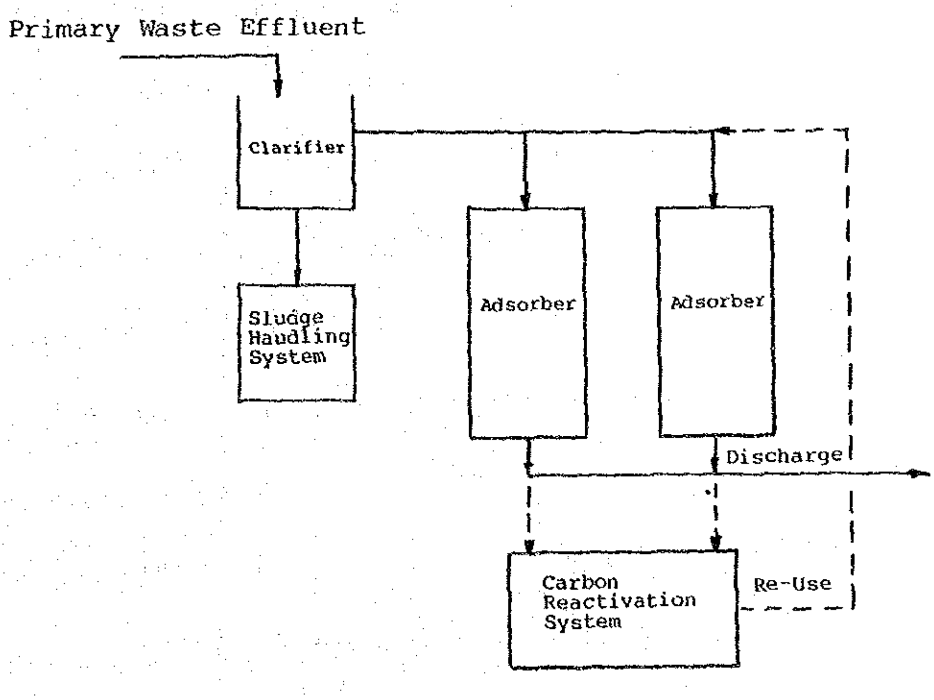


Fig. 6.1.7: Waste Water Treatment for Refinery

Table 6.1.5: Raw Analytical Data of Primary Effluent

| Effluent (mg/l) | Oil Content (mg/l) | TOC Filtered (mg/l) | Suspended Solids (mg/l) | BOD Filtered |
|---|---|---|---|---|
| 1 | 8.3 | 155 | 44 | 222 |
| 2 | 82 | 92.5 | 1,050 | 90 |
| 3 | 4.7 | 30 | 32 | 29 |
| 4 | 7.3 | 77 | 84 | 128 |
| 5 | 6.5 | 80 | 160 | 119 |

Table 6.1.6: BOD·Removal Performance and Carbon Dosage Data (Summary from Adsorption Isotherm Study)

| Effluent | Dosage (lbs/1000 gal) | Removal (%) |
|---|---|---|
| 1 | 0.5 | 100 |
| 2 | 4.0 | 100 |
| 3 | 1.1 | 90 |
| 4 | 1.9 | 100 |
| 5 | 2.6 | 85 |

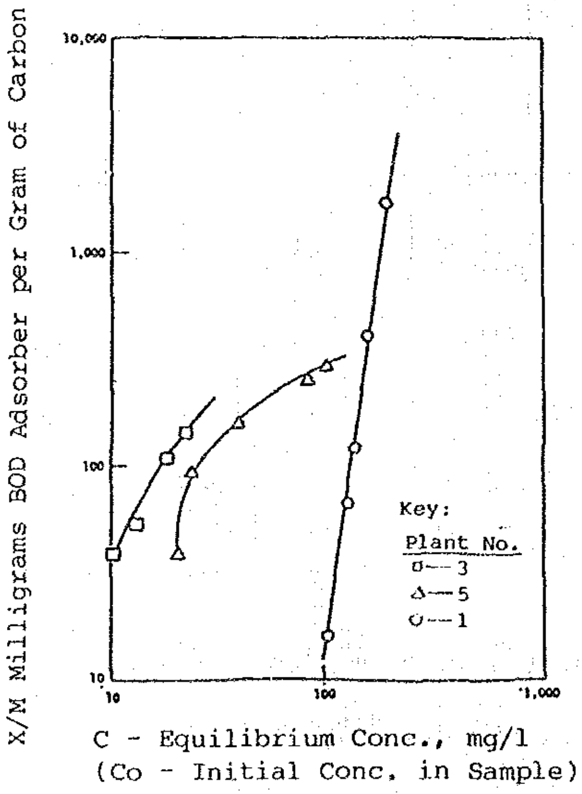


Fig. 6.1.8: Adsorption Isotherm (BOD)

### 2) Treatment of Oil-Containing Underground Water by Combined Use of Stripping and Activated Carbon 4)

The following shows an experiment in which the combination of stripping and activated carbon was used as a countermeasure against mixing of oil such as gasoline into underground water. In order to confirm effectiveness of the method in which light components of oil are first stripped and then soluble oil is removed by activated carbon, a pilot plant as indicated in Fig. 6.1.9 was installed and its performance was examined. As a result, total residual hydrocarbon (calculated as hexane) was reduced to the $\mu g/l$ order.

Fig. 6.1.10 indicates the status of oil removal in each unit process.

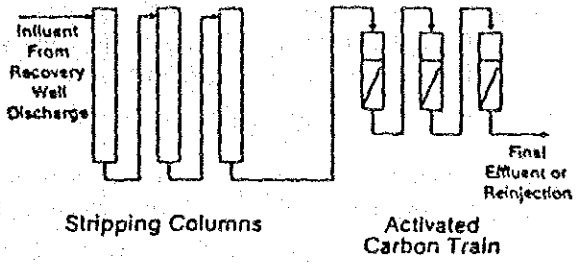


Fig. 6.1.9: Pilot Plant of Activated Carbon Process

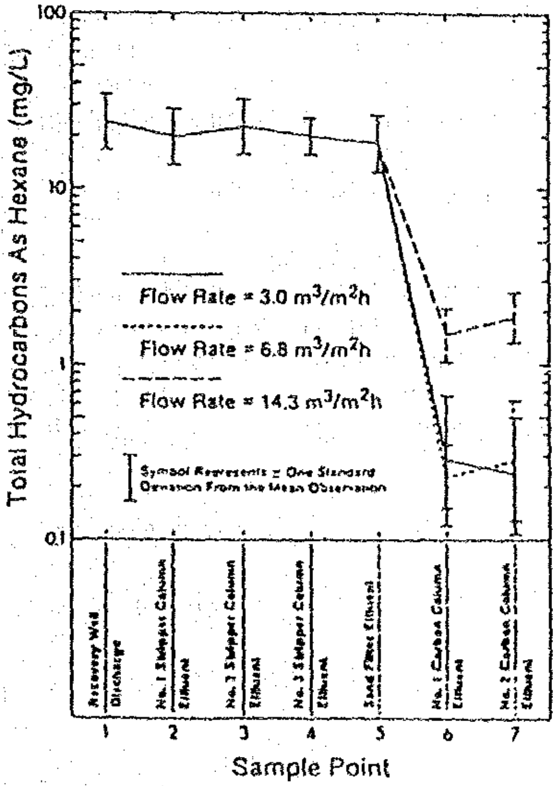


Fig. 6.1.10: Total Hydrocarbons (Outlet of Each Unit)

As an example of pre-treatment, in the reverse osmosis desalination plant in Bahrain, underground brackish water of 768,000 m³/d (specified TDS 19,000 mg/l) is treated by 16 sets of carbon filters (plus 2 sets of spares) filled with 45 tons of activated carbon, which were installed to remove oil components in raw water (specified value 10 mg/l).

### (8) Method of Discharging Exhaust Gas Condensate from Deaerator and Product Water from High Temperature Stages

Though the condensate of exhaust gas from deaerator and of extraction steam from evaporation chamber in the subject plant is designed to be returned to the process for recovery, this process is given up and the condensate is discharged.

Further, a partition is installed in the inter-stage orifice at a stage in the condensating part of high temperature evaporation chamber, and the product water up to this stage is extracted and discharged, leaving the product water from the next stage and on for recovery. This method is indicated in Fig. 6.1.11.

As described in 4.4.2, most of the oil components are evaporated in the deaerator at the high temperature stages, and oil concentration of product water can be greatly reduced by this arrangement (hereinafter called "high temperature water discharging method").

This will be further explained by taking the simulation of 100 mg/l oil concentration of raw sea water indicated in Fig. 4.4.2(2) as an example. As indicated in Table 6.1.7, if the product water of 185.6 t/h from 0 stage (deaerator) up to 4th stage is discharged together with 79.5 kg/h oil contained in it, the quantity of remaining water to be recovered is reduced to 569.1 t/h, but oil in it become 2.2 kg/h or 3.9 mg/l by oil concentration, which indicates drastic reduction in oil concentration in comparison with 108.3 mg/l during the normal operation.

Based on the above trial calculation, Table 6.1.8. indicates the status of reduction in oil concentration in product water (5th to 18th stages) when product water from 0 to 4th stages is discharged, in case of the raw sea water containing oil concentration of 10, 100, 1,000 and 10,000 mg/l. This method considerably improves the quality of water by a simple remodeling of plant, but the recovery ratio of product water is reduced to some extent.

Table 6.1.7: Estimated Product Water Oil Content based on Simulation (at 100 mg/l or Oil in Feed Sea Water)

| Stage | Product Water (t/h) | Distallation Oil (kg/h) | Oil Conc. (mg/l) | Note |
|---|---|---|---|---|
| 0 | 4.7 | 48.506 | 10,320 | |
| 1 | 44.7 | 25.799 | 577.1 | |
| 2 | 45.8 | 2.955 | 64.52 | |
| 3 | 43.9 | 1.526 | 34.76 | |
| 4 | 46.5 | 0.748 | 16.09 | |
| 0 - 4 Total | 185.6 | 79.543 | 428.5 | |
| 5 | 44.6 | 0.564 | 12.65 | |
| 6 | 45.6 | 0.446 | 9.78 | |
| 7 | 43.8 | 0.330 | 7.55 | |
| 8 | 44.8 | 0.256 | 5.72 | |
| 9 | 43.0 | 0.186 | 4.33 | |
| 10 | 41.1 | 0.134 | 3.27 | |
| 11 | 42.2 | 0.101 | 2.42 | |
| 12 | 41.8 | 0.073 | 1.76 | |
| 13 | 40.1 | 0.051 | 1.29 | |
| 14 | 39.7 | 0.036 | 0.93 | |
| 15 | 39.4 | 0.025 | 0.66 | |
| 16 | 36.4 | 0.017 | 0.47 | |
| 17 | 36.1 | 0.012 | 0.33 | |
| 18 | 30.5 | 0.007 | 0.25 | |
| 5 - 18 Total | 569.1 | 2.239 | 3.9 | |
| Total | 754.7 * | 81.772 | 108.3 | |

Note: * include of deaerator

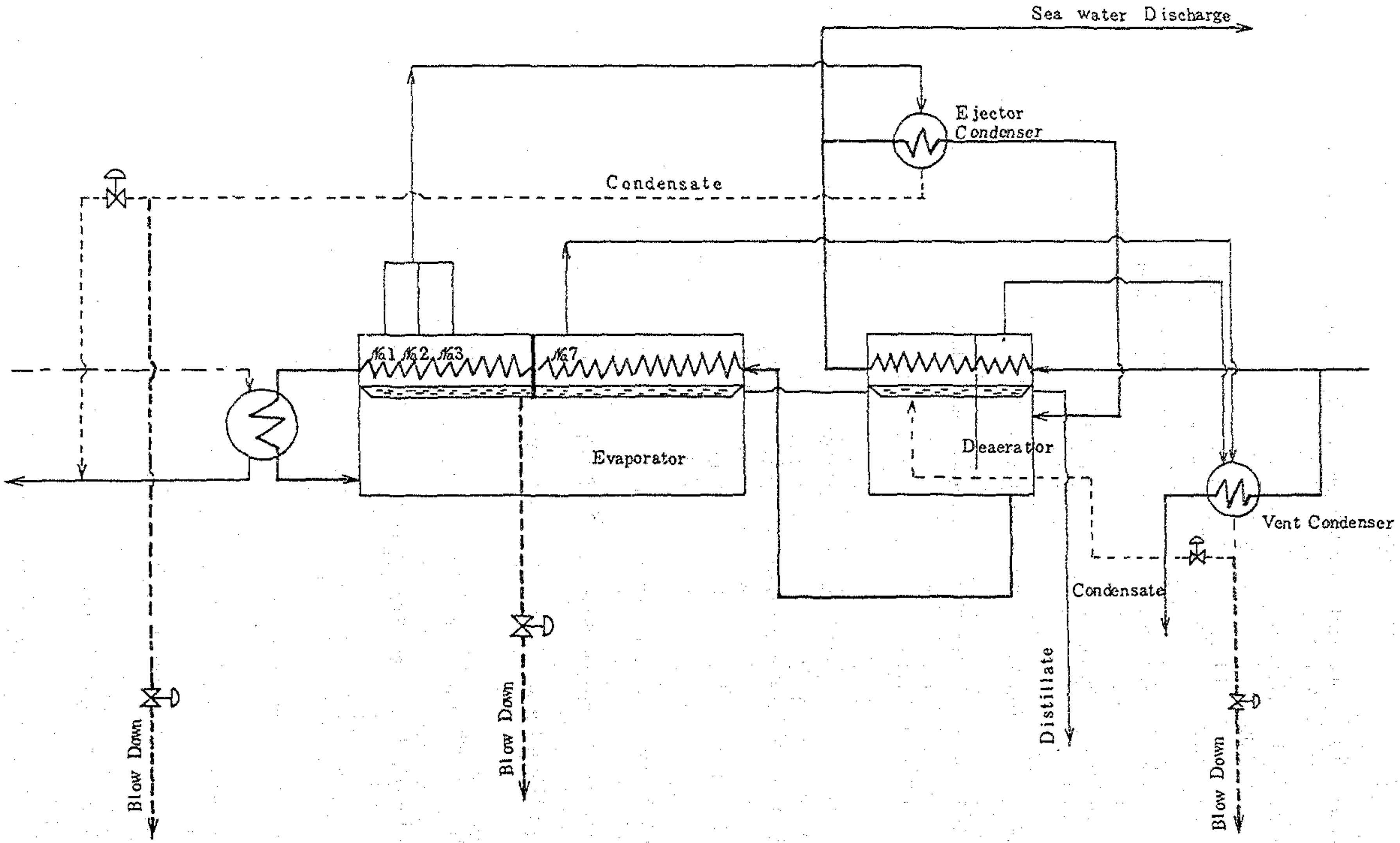


Fig. 6.1.11: Discharging Method of Vent Gas Condensate and High Temperature Product Water

Table 6. 1. 8: Simulation Result of Oil Content (Discharging Method of Vent Gas Condensate and High Temperature Product Water)

| Oil Content in Raw Sea Water (mg/l) | Operation Method | | Quantity of Product Water (t/h) | Oil Evaporation (kg/h) | Oil Concentration (mg/l) |
|---|---|---|---|---|---|
| 10 | Normal Operation | | 754.7 | 9.2 | 12.2 |
| | In Case 0 - 4 Stage Product Water is Discarded | Discarded Water (0 - 4 Stage) | 185.6 | 9.1 | 48.9 |
| | | Product Water (5 - 18 Stage) | 569.1 | 0.1 | 0.2 |
| 100 | Normal Operation | | 754.7 | 81.8 | 108.3 |
| | In Case 0 - 4 Stage Product Water is Discarded | Discarded Water (0 - 4 Stage) | 185.6 | 79.5 | 428.5 |
| | | Product Water (5 - 18 Stage) | 569.1 | 2.2 | 3.9 |
| 1,000 | Normal Operation | | 754.7 | 722.1 | 956.8 |
| | In Case 0 - 4 Stage Product Water is Discarded | Discarded Water 0 - 4 Stage) | 185.6 | 687.0 | 3,701.3 |
| | | Product Water (5 - 18 Stage) | 569.1 | 35.1 | 61.8 |
| 10,000 | Normal Operation | | 754.7 | 6,183.0 | 8,193 |
| | In Case 0 - 4 Stage Product Water is Discarded | Discarded Water (0 - 4 Stage) | 185.6 | 5,639.7 | 30,386.3 |
| | | Product Water (5 - 18 Stage) | 569.1 | 543.3 | 954.7 |

### (9) Method of Increasing Exhaust Gas Rate in MSF Plant

Transition of oil content to the product water can be reduced by increasing the quantity of exhaust gas from deaerator and steam extracted from the evaporation chamber (hereinafter referred to as "Exhaust gas increasing method").

Fig. 6. 1. 12 indicates the result of calculation pursuant to the description in 4. 4. 3, taking benzene-water system as an example, and when the exhaust gas ratio (quantity of deaerator exhaust gas + quantity of extraction steam in evaporation chamber/quantity of intake raw sea water) is 0. 1%, 0. 2% and 0. 3%, the removal rate of oil will be 88%, 96%, and 98% respectively, with oil concentration in product water as in Table 6. 1. 9. In order to increase the exhaust gas ratio, it is necessary to add the installation of a vent condenser etc., and to increase the quantity of the ejector steam, and in addition, to make an arrangement to enlarge the capacity of the deaerator. This method is effective for the removal of oil components and does not involve a great loss of product water.

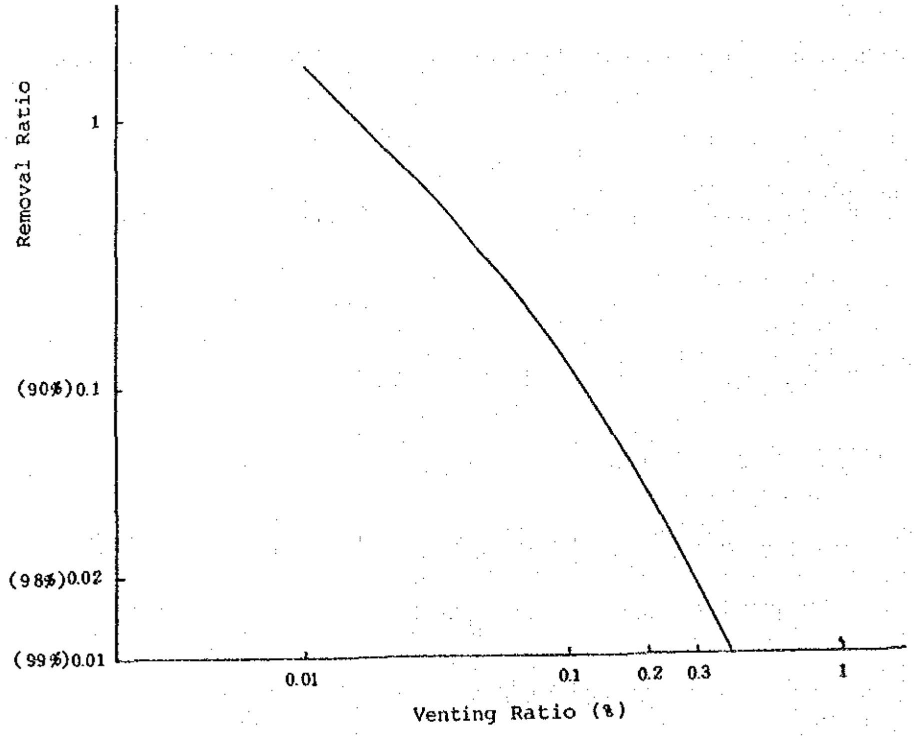


Fig. 6.1.12: Simulation Result of Oil Removal (Method of Increasing Vent Gas in Benzene/Water Phase)

Table 6.1.9: Oil Content in Product Water

| Vent Gas Rate (%) | 0.1 | | 0.2 | | 0.3 | |
|---|---|---|---|---|---|---|
| Oil Removal Rate (%) | 88 | | 96 | | 98 | |
| Oil Concentration in Polluted Sea Water (mg/l) | 100 | 10 | 100 | 10 | 100 | 10 |
| Oil Concentration in Product Water (mg/l) | 12 | 1.2 | 4 | 0.4 | 2 | 0.2 |

(10) Method of Re-Evaporating Oil Polluted Product Water in MSF Plant

By feeding oil polluted product water into MSF plant as the raw water and operating the plant, oil components can be evaporated into the distilled water side and then removed, (hereinafter referred to as "re-distillation process").

In this reprocessing, if MSF plant is operated under the same operating condition as for the production of oil polluted product water, oil content of the raw water (oil polluted product water) shows the same behavior as in the preceding operation and move totally into the distilled water side, leaving fresh water without oil in the blow down side.

In this case, 3 to 4 raw water plants (oil polluted raw water ) are reqruied to supply the raw water for one re-distillation plant, and then the yield of fresh water drops considerably.

If in this case, the high temperature water discharging method is employed in the re-distillation plant, oil concentration in the distilled water decreases and therefore, it can be recovered as product water, increasing the recovery rate of fresh water.

However, since the composition of oil component in raw water (oil-polluted product water) is different from raw sea water and leans towards heavier fraction of oil, it should be reminded that the effect of the high-temperature water discharging method on improvement of water quality in the re-distillation process is not as large as that in the original distillation process.

While this method has a advantage of low reconstruction cost such as addition o pipings and valves, it has a disadvantage of decreasing the productivity of the plants. Also, it is necessary to wash the inside of the plant to prevent the mixing of saline water.

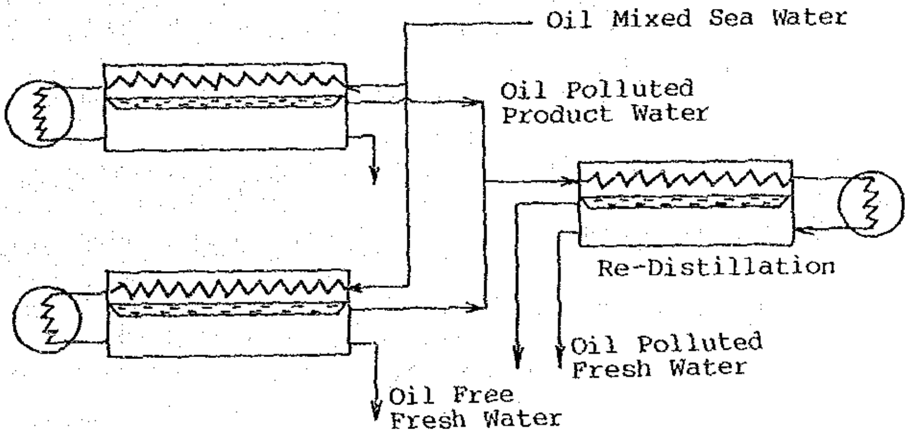


Fig. 6.1.13: Re-Distillation Process

### 6.1.2 Comparative Evaluation of All Oil-Removing Methods

#### (1) Conditions required for Establishing Oil-Removing Measures

In this project, the following points can be regarded as conditions necessary to plan a measure to remove oil content from the product water.

1) Quality of Treated Water Must Satisfy Quality Standard of Drinking Water.

Of the WHO's water quality standards related to drinking water, the standard of oil is as described in 4.4.5, the standard of benzene is 10 $\mu g/l$, and the standard for odor specifies its extent as "many consumers do not feel unpleasant".

Since the quantity of benzene contained in crude oil is very small as shown in the next table and the benzene mixed into product water seems to be less than 10% of total oil components, the standard of oil concentration can be considered as 100 μg/l. Also, in connection with the odor of oil, 220 μg/l is considered to be a sensible limit for the light oil component which is apt to remain in the product water even after the treatment for its removal, as described in 4.4.5.

From the above points, the target quality of treated water is tentatively decided here to be 50 μg/l by oil concentration on the safe side.

| Crude Oil | Content of Benzene (Vol %) |
|---|---|
| Marban | 0.16 |
| Zakum | 0.09 |
| Umm Shaiff | 0.19 |

2) Installation Cost Must be Low

Since the facilities to remove oil components are only for emergency use when oil effusion accidentally occurs and normally do not contribute to production, the installation cost is desirous to be as low as possible, even though its operation cost may be somewhat high.

3) Operation and Maintenance Must be Simple

It is desired that operation can start easily in emergency and the present employees can operate and maintain the plant without requiring any special skill. Low maintenance cost will also become one condition.

4) Accompanying Problems Must be Less

It is important that any problem related to environment or plant efficiency does not occur.

(2) Comparison and Evaluation

The following shows comparison and evaluation of all oil-removing methods described in the above paragraphs.

1) Quality of Treated Water

The gravity separation method cannot remove stable emulsion or dissolved oil and the concentration at the outlet of API separator is 30 mg/l at the lowest. In the air flotation method and the coagulation and sedimentation method, 10 mg/l or thereabouts also seems to be a limit.

In the exhaust gas increasing method and the high temperature water discharging method, product water of several mg/l can be obtained if oil concentration in the raw sea water is 100 mg/l or thereabout.

The re-distillation method makes reduction to 1 mg/l or less possible. The activated carbon adsorption process and the biological process are effective to the low level dissolved oil and can remove up to the μg/l order. However, if any free oil exists, its preliminary removal is necessary because these processes cannot treat it.

Thus, there is no method which can solely purify the product water of high oil concentration to the extent of target water quality, and therefore, a combination of two or more methods seems to be the only solution.

2) Installation Cost

Although the exhaust gas increasing method, the high temperature water discarding method, and the re-distillation process all require some remodeling such as change in piping, addition of accessory apparatus, etc., their installation cost will be small compared with the other methods.

If one apparatus can be used to function for another purpose, for example, if the gravity separator can be used as a product water storage tank during normal period, substantially less installation cost can be evaluated.

3) Operation and Maintenance

The biological treatment process requires constant maintenance and control of activated sludge, and therefore, is undesirable as an emergency measure. The membrane method and the coagulation and sedimentation method are also less qualified as the apparatus requires immediate the start-up in case of emergency.

The exhaust gas method, the high temperature water discharging method and the re-distillation method require switchover of respective plant operation.

4) Derivative Problems

Since the air flotation method, the coagulation and sedimentation method and the biological treatment process using the activated sludge generate some amount of sludge, its disposal becomes a difficult problem.

In the re-distillation method, since the function of the MSF plants are split to perform re-distillation, its effective operating rate is considerably reduced. However, in case of severe pollution of the sea water by oil, this will not be considered as a demerit since the flow speed of intake sea water must be reduced to control mixing of oil which causes reduction in quantity of sea water, and consequently some MSF plants become non-operational anyway.

### 6.1.3 Planning of Appropriate Methods to Plant

Upon summarizing the present status of various methods for removing oil components and the comparative evaluations as studied in the preceding paragraph, the following plan is proposed as one of the methods appropriate to the plant. For realization of this plan, however, it is necessary to conduct experiments under the condition close to an actual operation to collect data and confirm its effectiveness.

(1) Case 1

In case of oil concentration in raw sea water is 100 mg/l or less, condensate of deaerator exhaust gas and product water from 1 - 4 stages will be discharged, and product water from 5th stage and on will be recovered and treated by activated carbon.

As an example, material balance when the oil concentration in raw water is 100 mg/l, is indicated in Fig. 6.1.14 based on data described in 6.1.1 (7) and (8).

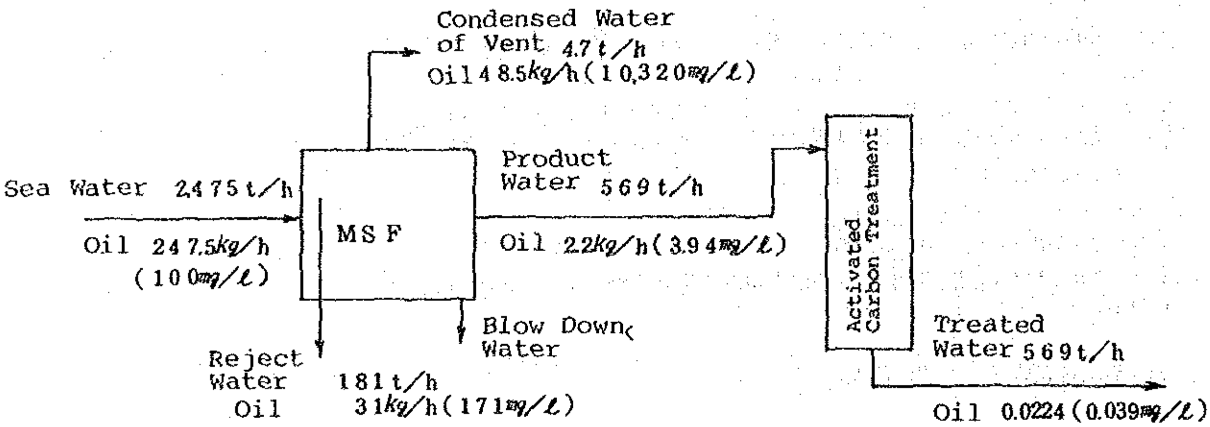


Fig. 6.1.14: Material Balance of Case 1

By this method, oil concentration in product water at MSF outlet becomes 3.94 mg/l, and by treating this with activated carbon, 39 μg/l treated water can be obtained. Also, when exhaust gas rate is raised from the present 0.2 % to 0.3 %, oil concentration in product water at MSF outlet is reduced to a half or 2 mg/l according to 6.1.1 (9). Quantity of treated water is reduced to 569 t/h or 75 % of 750 t/h which is the quantity of product water under normal conditions.

In case oil concentration in raw water is low, needless to say, it is possible to omit activated carbon treatment or discharging of product water from high temperature stages, as the occasion demands. (discharging of deaerator condensate should be continued.)

### (2) Case 2

When oil concentration in raw sea water further increases and the quality standard of of product water cannot be maintained, the Case 1 method will be combined with the re-distillation method. In other words, the product water obtained by the high temperature water discharging method will be re-distilled in MSF plant and finally be treated by activated carbon.

Fig. 6.1.15 indicates the material balance of this case. The product water obtained by 5 MSF plants is reduced to 1,586 t/h or 42% of the product water under normal operation.

If a part of the distilled water (containing an oil component) from the distillation is recirculated to the inlet of the re-distillation plant, quantity of raw water supplied to the re-distillation plant can be reduced, resulting in improvement of the operating ratio of the total plant as well as the yield of fresh water.

If the water containing distilled water from 0 to 4 stages (containing a high concentration oil) and distilled water from the re-distillation plant (containing oil) is treated by the gravity separator and the dissolved air flotation (DAF), and supplied to an activated carbon vessel, no water will be discharged, resulting in an improvement of the yield of water.

### (3) Installation and Treatment Cost

These systems require remodeling of piping, etc., to switch the operation in case of emergency and new installation of activated carbon vessels. The following shows the rough estimation of the necessary installation cost and treatment cost in the above Case 2.

#### 1) Installation Cost

The installation cost of activated carbon treatment facilities (adsorption and regeneration plants) is about US\$ 2,200 x $10^3$ based on the estimation applied to the aforementioned discharge water from the refinery 3), and the remodeling cost of the 5 MSF plants becomes about US\$ 3,000 x $10^3$ under the rough assumption that it will be a few percent of the installation cost of the plants, totaling about US\$ 5,000 x $10^3$.

#### 2) Treatment Cost

In reference to the estimation in case of the discharge water from the refinery, the treatment cost under the activated carbon consumption of 2.2 lbs/1,000 gal is 1.78 US\$/$m^3$ for regeneration, labor, electricity and activated carbon make-up expenses, 0.13 US\$/$m^3$ for maintenance fee, and 0.97 US\$/$m^3$ for depreciation and interest, totaling 2.88 US\$/$m^3$.

Further, a decline in yield of fresh water will result in an increase in the water production cost, and if the yield drops down to 42%, the present production cost of about 2 US\$/$m^3$ will rise to 4.8 US\$/$m^3$.

As a measure to keep the installation cost down, a method can be conceived of, in which the product water from the stages preceding to activated carbon treatment in the above Case 1 and Case 2 is supplied as city water, and the water separately treated by a small-scale activated carbon plant is supplied to consumers only as drinking water by water wagons, since the oil concentration in the water other than drinking water under regulation is not so strict. If the city water supplied to consumers needs further purification, use of a water-purifier described in 6. 1. 1 (5) can be considered.

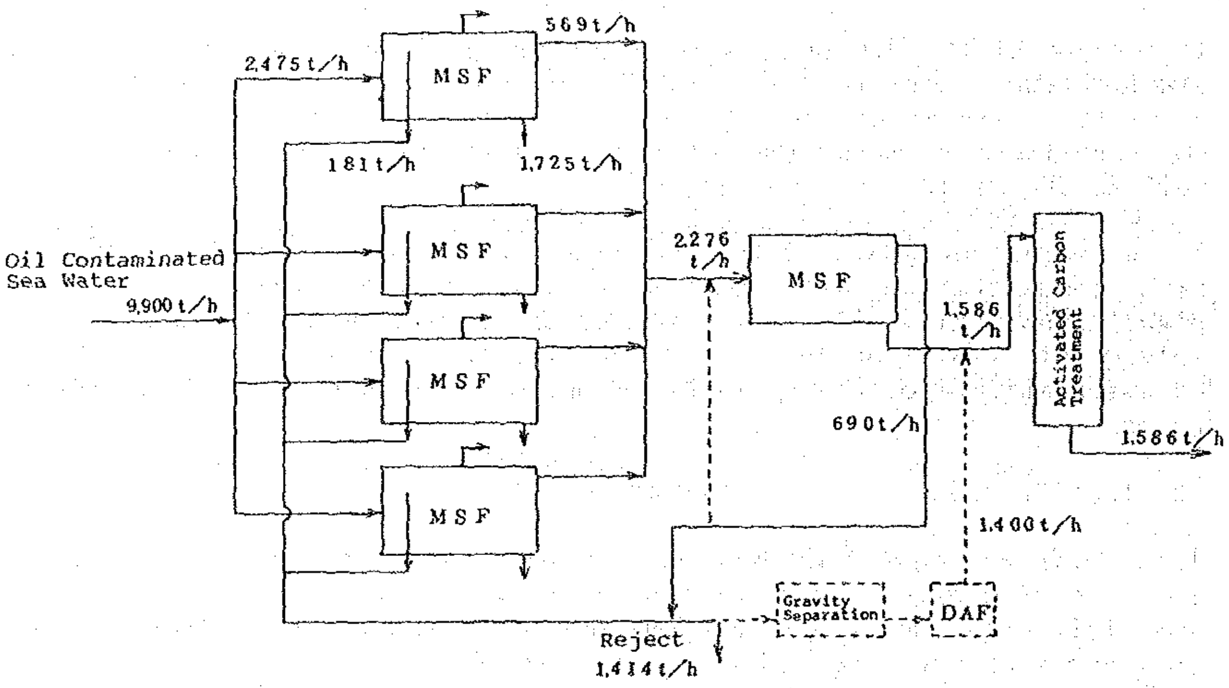


Fig. 6. 1. 15: Material Balance of Case 2

(4) Conclusion

Oil components in product water can be removed by taking the following measures, depending on the effect of pollution on the product water, or the rate of mixing of oil into raw sea water.

1) Case 1

In the case of the oil concentration at the inlet of the subject plant being about 100 mg/l or less, product water from 0 (deaerator) to 4 stages will be discharged, and product water from 5th to 18th stages will be treated by activated carbon.

2) Case 2

In the case of the oil concentration at the inlet of the subject plant being higher than the above value, product water from 0 to 4th stages will be discharged, product water from 5th to 18th stages will be again distilled in the desalination plant, and the produced blow down water will be recovered and treated by activated carbon.

### 3) Product Water

Since the product water from 0 to 4th stages has a high oil concentration, if the product water is treated by activated carbon after oil content have been removed by gravity separator or DAF, the water to be supplied as city water can be recovered, and discharging of useless oily product water can be avoided.

### 6.2 Removal of THM in Product Water

As a method of removing trihalomethane mixed with the product water, the following four items can be conceived of:

(a) Boiling
(b) Aeration
(c) Adsorption
(d) Oxidation and decomposition

Of the above four, the oxidation and decomposition method was reported to be ineffective according to overseas experiments and in Japan, the study made by City Water Department of Chiba Prefecture has revealed ineffectiveness of oxidation by ozone. Although a report says that the combined use of ultraviolet rays and ozone is effective, but this result has not been proven.

#### 6.2.1 Boiling Method

According to the experiment of heating city water 5), chloroform in the water starts increasing with the rise in temperature as indicated in Fig. 6.2.1, and increases rapidly when temperature approaches to 100 °C, and when boiling begins it decreases rapidly, and is finally reduced to about 1/5 in 10 min and almost zero after 30 to 40 min boiling.

In the city water used in this experiment, chloroform and its intermediate not unreacted precursor, and free residual chlorine are contained. Now, when heating starts, chloroform begins to decrease due to evaporation, but the rate of hydrolysis of the intermediate becomes faster by heating, and chloroform is newly produced.

Moreover, new reaction between free residual chlorine and precursor matters is accelerated, and chlorine is produced. Thus, quantity of newly produced chloroform exceeds the quantity reduced by evaporation, resulting in rapid increase in the quantity of chloroform before the temperature reaches 100 °C. When boiling starts by further heating, most of the intermediates become chloroform, residual chlorine decreases, and the quantity of chloroform vanishing by evaporation becomes greater than that of the newly produced, resulting in rapid reduction in its quantity. (Fig. 6.2.2).

THM other than chloroform indicates entirely the same tendency as that of chloroform as indicated in Fig. 6.2.2. However, looking at the reduction rate in concentration after 10 min boiling from the maximum concentration at 100 °C, while chloroform is reduced by about 1/6, bromodichloromethane is reduced by about 1/4 and dibromochloromethane is also about 1/4, which indicates these two have difficulty of evaporation compared to chloroform.

The bromoform produced by chlorination of sea water has a high boiling point, and while its evaporation is more difficult, it can be removed by 50 to 60 min boiling like other THM.

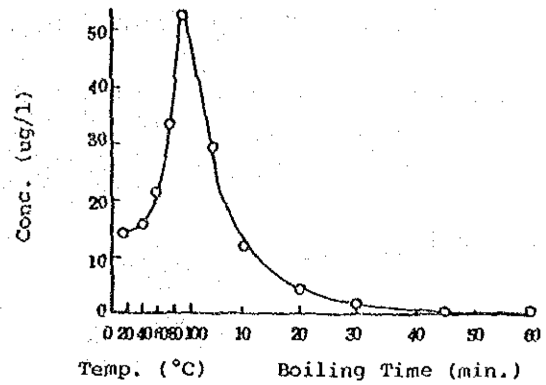


Fig. 6.2.1: Chloroform Concentration by Boiling

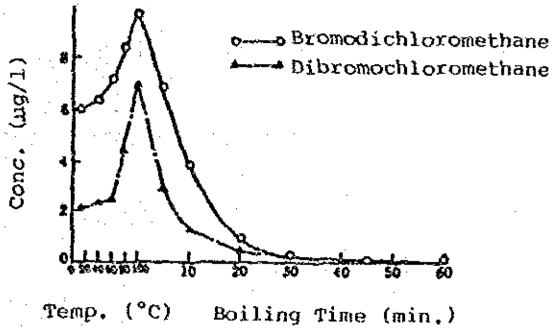


Fig. 6.2.2: Concentration of Bromodichloromethane and Dibromochloromethane

### 6.2.2 Aeration Method 5)

In the removal of THM in the product water by aeration, assuming that entire THM in water is transferred into air, that concentration in inflow water is Cw (mg/l), and its volume is Vw (l), concentration in discharged air is Ca (mg/l), its volume is Va (l), and that Henry's law is applicable between solutes in the liquid phase and gaseous phase, the following equations can be formed:

$$Cw \cdot Vw = Ca \cdot Va$$

$$H = Ca/Cw$$

$$Va/Vw = Cw/Ca = 1/H$$

Henry's constant (H) of chloroform, bromodichloromethane, dibromochloromethane, and bromoform is 0.152, 0.095, 0.035, and 0.024 respectively. According to an experimental result, it is reported that a compound having 0.05 or more as Henry's constant can relatively easily be removed by aeration. 6) Assuming that the above H values are used in an ideal contact layer, the gas liquid ratio between the volume of air and quantity of water is 6.6 for chloroform, 10.5 for bromodichloromethane, 28.6 for dibromochloromethane and 41.7 for bromoform. Fig. 6.2.3 indicates relations between the gas liquid ratio and the removal rate of THM.

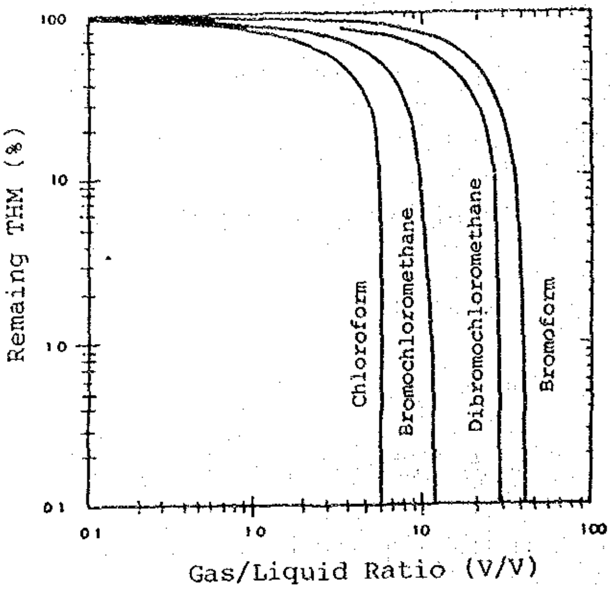


Fig. 6.2.3: THM Removal by Ideal Contact Tower

However, this is the case in an ideal counter-flow tower, and actual measurement values of removal rate in case of chloroform are indicated in Fig. 6.2.4. As the distance from the curve of ideal counter-flow tower becomes larger, efficiency of the apparatus becomes worse. In other words, in order to obtain the same efficiency, it is necessary to enlarge the gas-liquid ratio. Practical value obtainable by this system should be about 30 in gas liquid ratio and about 80% in removal rate.

Fig. 6.2.5 indicates the result of experiment in which city water is dechlorinated by ascorbic acid and then deaerated with air diffuser in the presence of argon gas. Chloroform is reduced to about 1/4 by aeration time of about 10 minutes and by air with volume of 10 to 20 times.

Bromodichloromethane is reduced to 1/3 and dibromochloromethane is reduced to only about 1/2 under the same conditions. Removal rate of bromoform is worse and employment of aeration system does not give any advantage.

Examples of the estimation of treatment cost for the air-dispersing type aeration system (a system in which air is dispersed into the product water in storage tank through a porous diffuser) which incurs relatively low treatment cost are indicated in Fig. 6.2.6, Table 6.2.1, and Table 6.2.2. The treatment volume of 37,800 m³/h used in this estimation nearly corresponds to the treatment volume of two units lines in the subject plant.

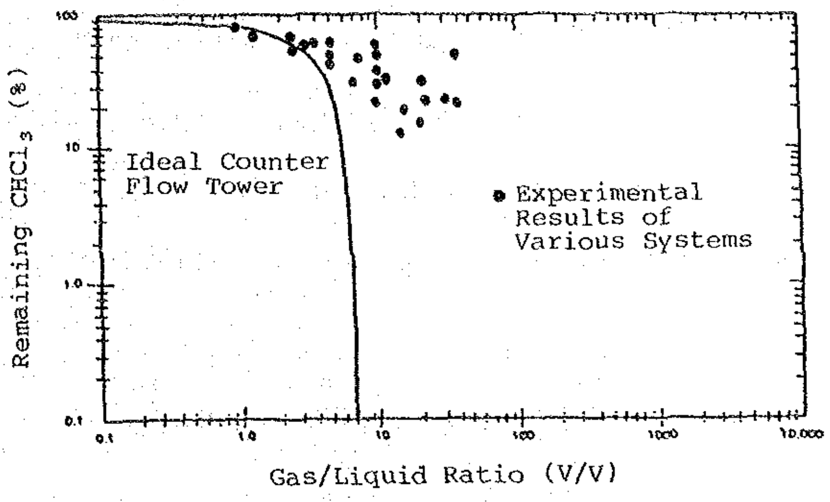


Fig. 6.2.4: Experimental Result of Chloroform Removal

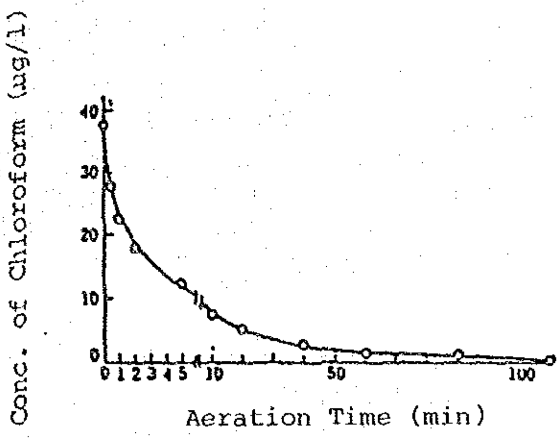


Fig. 6.2.5: Chloroform Removal by Aeration

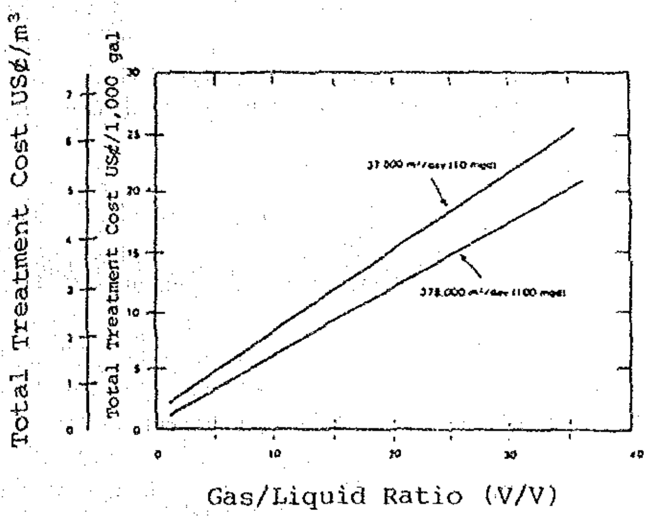


Fig. 6.2.6: Total Treatment Cost of Air Diffusing System

Table 6.2.1: Design Value of Air Diffusing System

| Item | Design Value |
|---|---|
| Depth of Water | 3.3 m (10 ft) |
| Quantity of Air | 1.52 $sm^3/m^2$ (5 $scf/ft^2$) |

Table 6.2.2: Running Cost of Air Diffusing System
(Load: 70%; Gas/Liquid Ratio: 20:1)

| Item | Treatment Capacity | | | |
|---|---|---|---|---|
| | 37,800 $m^3/d$ (10 MGD) | | 378,000 $m^3/d$ (100 MGD) | |
| | c/$m^3$ | c/1,000 gal | c/$m^3$ | c/1,000 gal |
| Running Cost | 2.0 | 8.2 | 1.1 | 4.5 |
| Capital Cost | 1.8 | 7.11 | 1.8 | 7.3 |
| Total Treatment Cost | 3.8 | 15.3 | 2.9 | 11.8 |

### 6.2.3 Activated Carbon Adsorption Method 7)

Fig. 6.2.7 indicates the isothermal curve of THM adsorption by activated carbon. As is clear from this Figure, adsorption capacity of bromoform is larger than that of other THM, and therefore, the method is advantageous when the existing ratio of bromoform is large as in this case.

When the flow rate, THM concentration, and temperature of liquid is constant, the size of activated carbon adsorption apparatus is primarily determined by the adsorption capacity.

Table 6.2.3 indicates theoretical time required for saturation in THM adsorption. This is an example of calculation for the granular activated carbon adsorber when its superficial contact time is 10 min and flow speed 5 m/h.

For example, if the quantity of treating water is 750 t/h (=18,000 t/d) and bromoform concentration is 100 $\mu g/l$, loading rate of bromoform will be 18,000 t/d x 100 $\mu g/l$ = 1,800 g/d. Also, if cross sectional area of adsorbent is 3.14 $m^2$, its depth is 4 m, and its density is 490 $kg/m^3$, the volume of adsorbent will be 12.56 $m^3$ or 6,154 kg by weight of adsorbent.

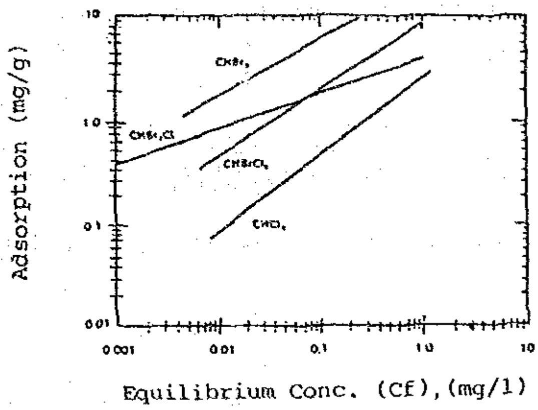
Therefore, the number of days for this much of adsorbent to reach adsorption equilibrium will be; operation days = 6,154 x 6/1,800 = 20.5 days, or in other words, 20.5 days will be needed for this adsorption bed to become saturated. The saturation time largely differs depending on inflow concentration of THM.

The next shows an example in which the activated carbon adsorption is applied to actual removal of THM in city water.

Fig. 6.2.8 indicates difference in activated carbon filtration between chloroform, bromodichloromethane, and dibromodichloromethane which constitute the THM. Chloroform, for which adsorption by activated carbon is most difficult, first appears in the filtrate. Then bromodichloromethane is filtered out in the order of difficulty in adsorption by activated carbon. Therefore, although it is not included in this experiment, adsorption of bromoform should be much easier.

Table 6.2.4 indicates a record of experiments on THM filtration of city water in several cities by activated carbon, which were conducted for 3 years from 1979 to 1981. THM in filtered water can be detected in 1 day at the earliest and 30 days at the latest, and concentration in filtered water becomes equal to that in inflow water in 22 to 70 days, while the maximum ratio of outflow concentration to inflow concentration becomes as much as 1.2 to 3 times.

From the above, it is clear that when activated carbon filtration is used for removal of THM, its effective period is only about 2 months.



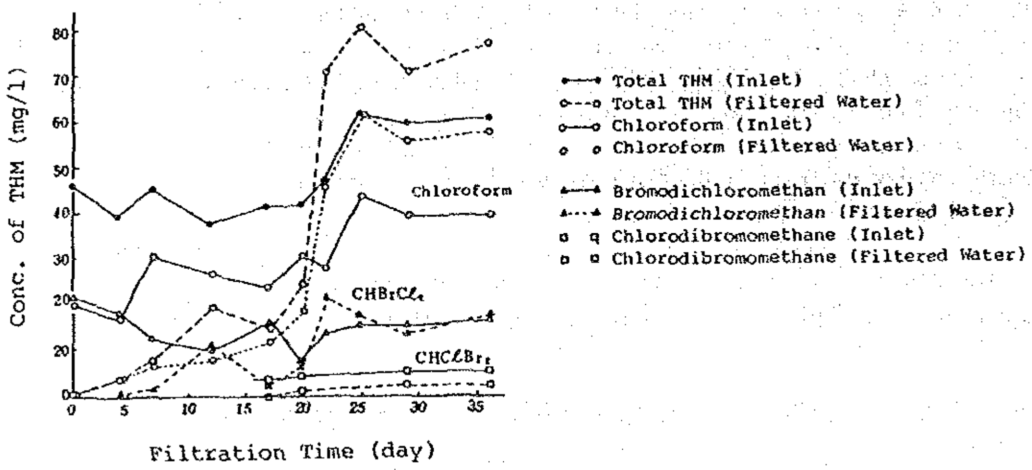
$$* \text{ Adsorption} = \frac{\text{Adsorbate (mg)}}{\text{Activated Carbon (g)}}$$

Fig. 6.2.7: Isotherm Curve of THM

Table 6.2.3: Theoretical Saturation Time of THM Adsorption

| Item | Inlet Concentration (ug/l) | Quantity of Adsorption (mg/g) * | Saturation Time (B) |
|---|---|---|---|
| CHCl3 | 75 | 0.35 | 15 |
| CHBrCl2 | 50 | 1.3 | 87 |
| CHBr2Cl | 25 | 1.4 | 189 |
| CHBr3 | 1 | 1.8 | 608 |

Note: * EBCT 10 min, Velocity 5 m/h (2 gpm/ft²)
GAC Density 490 kg/m³



Activated Carbon Filter
Vessel dia.: 50 mm; Velocity: SV 15
Media depth: 1 m ; A.C.: Pittsburgh Coal Base

Fig. 6.2.8: THM Removal by Activated Carbon Tower

Table 6.2.4: Experimental Result of THM Removal in Japan

| Place | Filtration Bed | Filtration Velocity | Temp. (°C) or Season | Inlet Total THM (μg/l) | Filtration Days | | | *3 Max. Conc. Ratio |
|---|---|---|---|---|---|---|---|---|
| | | | | | First Leak | *1 Out = In | *2 Max. THM | |
| Tokyo | φ 52 mm × H 300 mm | SV 5 | 24 - 8 | 37 - 5.8 | 15 | - | - | - |
| | | SV 10 | | | 10 | 31 | 35 | 2 |
| | | SV 5 | 11 -4 | 28 - 17 | 10 | - | - | - |
| | | SV 10 | | | 10 | 50 | 50 | 1.2 |
| Yokohama | H 900 mm | 5.5 m/h | 11 - 5 | 6 - 3 | 1 | 25 | 35 | 1.5 |
| | H 800 mm | 5 m/h | Summer | 10 - 30 | 20 | 65 | 80 | 1.5 |
| Kita Kyushu | φ 100 mm × H 700 mm | SV 10 | Winter | 15 - 2 | 16 | 45 | 52 | 2.4 |
| | | | | 16 - 5 | 23 | 52 | 66 | 1.7 |
| Chiba | Fludized Bed | SV 10 | Winter | 10 - 80 | 14 | 70 | 112 | 1.7 |
| | φ 50 mm × 1 m | SV 10 | 3 - 10 | 12 - 32 | 6 | - | - | - |
| | | SV 15 | 20 - 26 | 39 - 61 | 4 | 22 | 28 | 1.3 |

Note: *1 The day: Outlet THM Conc. = Inlet THM Conc.
*2 The day: Indicate Max. THM Conc.
*3 Max. Conc. Ratio of Outlet/Inlet THM at *2

### 6.2.4 Conclusion

(1) Boiling is effective for removal at home.

(2) Aeration may be applicable to small-scale treatment, but difficult to say it is effective, because the ratio of air volume to quantity of water is too large.

(3) Powdered activated carbon is not considered effective since greater amount is required compared with its ordinary use for removal of odor generated by mold. However, it can be used temporarily as emergency counter-measure.

Granular activated carbon is generally thought to be effective for removal of organic matters, but for removal of THM, its effective period is shortened and it requires frequent regeneration. However, its performance can satisfy allowable water quality and it can be used for commercial application.

Further, since the activated carbon method shows different function depending on the type of AC and the function varies depending on the existence of other oil components, it should be necessary to decide its employment after confirming by pilot tests or otherwise.

## 6.3 Improvement of Sterilizing Method

In order to prevent the formation of THM in sea water desalination, it is necessary to study improvement of the present chlorination process for intake raw sea water and product water, or to study new sterilizing methods to substitute chlorination.

### 6.3.1 Alteration of Chlorination Method for Raw Sea Water

#### (1) Control of Amount of Chlorine Injection

THM is hardly formed if free chlorine does not exist. When the concentration of free chlorine increases, formation of THM also increases by the following reaction formula, though its effect is not so great. In other words, even if concentration of free chlorine is increased by 10 times, both quantity and speed of THM formation do not reach 2 times. The reaction formula suggests that pH, concentration of precursor, and time factor have greater effect on formation of THM than concentration of chlorine has.

$$[\mathrm{THM}] = 0.83 \times 10^{-3} [\mathrm{pH}-2.8][\mathrm{Humic\ Acid}][\mathrm{Chlorine}]^{0.25} t^{0.35}$$

Where concentration of matters is in mg/l, time is in hour.

In other words, even if concentration of chlorine is controlled, its effect on prevention of THM formation cannot be expected much. Therefore, it is not advisable to reduce the quantity of chlorine injection for control of THM, because it rather causes fouling by marine organisms.

#### (2) Intermittent Chlorine Injection Method[7)]

According to the result of the experiment conducted by Yamazaki et al., on intermittent chlorine injection (Fig. 6.3.1), no attachment of organisms, were observed on the completely cleaned surface during the almost 5 month experimental period by repeating injection of 0.3 ppm residual chlorine for 18 hours and non-injection for 4 hours.

Quantity of THM formation in the case of intermittent injection of 0.3 ppm residual chlorine 4 hours injection, 4 hours non-injection, 14 hours injection during the night) and in the case of continuous injection of 0.1 ppm residual chlorine was compared and studied.

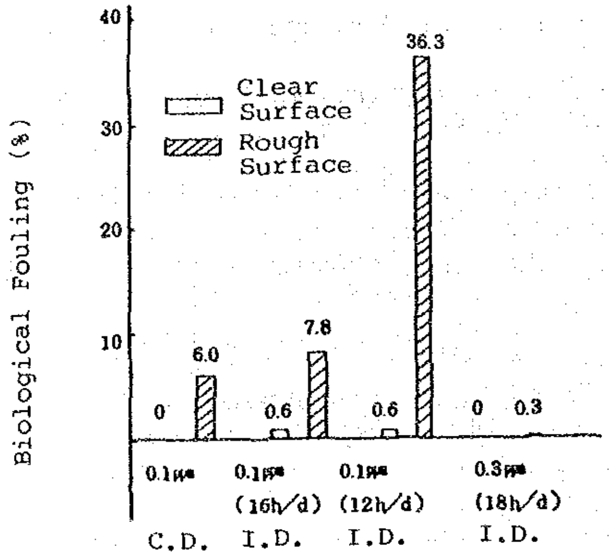
When chlorine is injected at the tip of water intake, THM concentration formed during 3 minutes until it enters the plant is calculated according to the preceding formula, and then the ratio of THM produced by intermittent injection to that by continuous injection is obtained. The result indicates that intermittent injection becomes 1.3 times that of continuous injection as indicated by:

$$(\mathrm{THM})\ \mathrm{intermittent}/(\mathrm{THM})\ \mathrm{continuous} = (0.3)^{0.25} / (0.1)^{0.25} = 1.316$$

However, if the ratio of quantity of THM formation during one day is obtained, the result indicates almost no difference is found since:

THM at *intermittent injection* / THM at continuous injection
$= 0.30^{0.25} \times 18h / 0.1^{0.25} \times 24\ h = 0.988$

In other words, it can be said that the intermittent chlorine *injection* method is not very effective for control of THM formation.



$$* \text{ Biological Fouling} = \frac{\text{Foulant with Chlorine}}{\text{150 Days Foulant without Chlorine}} \times 100$$

* C.D.: Continuous Dosing
I.D.: Intermittent Dosing

Fig. 6. 3. 1: Experimental Result of Intermittent Chlorination

### 6. 3. 2 Substituting Method for Chlorination of Raw Sea Water

Various *methods* to prevent fouling by marine organisms other than the chlorination method are now under study. Advantages and problems of these methods are described in Table 6. 3. 1. Although there are some chemicals effective to prevent fouling by organisms, they have not been commercialized due to inadequacy for the use in sea water and shortage of experimental data.

As for anti-fouling paint, its use is controlled because of the problems such as toxicity, accumulation on environment and organisms, etc., and non-pollution type paints have a limited life of only one year or so, hence it has not been commercialized yet. Other physical methods such as ultrasonic waves, electric shock, etc., have not passed beyond research because their effects are still not constant.

Recently, a method to add bacteriophage to sea water in the area of sea water intake and sterilize harmful microorganisms present in sea water is under way, but has not reached the commercial stage yet.

Also combined use of hydrogen peroxide and ferrous sulfate has been demonstrated as effective for prevention of damages by organisms, and its commercialization is under planning.

As methods which seem to be applicable to the subject plant, there are the combined hydrogen peroxide/ferrous sulfate method, ozone, chloramine, chlorine dioxide and surface treatment, and other physical treatments but most of them except combined the hydrogen peroxide/ferrous sulfate method are not very effective for prevention of adhesion of marine organisms or they are under development.

The effective method from a view point of sterilizing raw sea water without THM formation, is the hydrogen peroxide/ferrous sulfate combined method. However, this method costs more than chlorination, and in Japan this method has not been used on large-scale, and examples of application are not many.

Table 6.3.1: Disinfection and Marine Fouling Prevention Methods

| Method | Outline & Advantage of Method | Problems and Future Subjects |
|---|---|---|
| Chemical Treatment<br>Ozone | Reduction in adhesion of organisms and control of their growth by intermittent injection of ozone | According to a report, continuous injection is necessary. Ozone cannot substitute for chlorine for sea water. Reacts with Br ion in sea water and forms relatively stable hypobromite ion. |
| Hydrogen Peroxide | Reduction in adhesion of organisms and contol of their growth by continuous injection of hydrogen peroxide | Less examples of research |
| Chloramine | Less formation of THM | eactivity is extremely weak compared with chlorine and preventive effect against fouling by organism is also weak. |
| Chlorine Deoxide | Main reaction is oxidation and less formation of THM. No fluctuation by effect of pH. | Stimulus and toxity are stronger than chlorine. |
| Hydrogen Peroxide Ferrous Sulfate | Continuous injection of 0.5 ppm H2O2 and 0.25 ppm ferrous sulfate, Cost is slightly higher than chlorine. | Examples of practical application are a few cases at present. |

Table 6. 3. 1: (Continued)

| Method | Outline & Advantage of Method | Problems and Future Subjects |
|---|---|---|
| Others | Test result of herbicide PCP and insecticide dipterex is available. | Injection of more quantity than chlorine is necessary, therefore, uneconomical. Less examples of research. Use of these chemicals is discouraged due to noxious property. |
| Surface Treatment & Others | | |
| Copper<br>Copper Alloy | No adhesion on copper coating and less on copper alloy because of poisonous effect of copper | Passive film is formed on surface in natural corrosion, hence corrosion rate is reduced. Thus, solubility of copper ion is reduced and organisms can adhere. Economy is a problem. |
| Anti-Fouling Paint | Adhesion of organisms is prevented by dissolultion and extraction of noxious matters | There is a problem of environmental pollution. In case of having no bad effect on environment, their effective time is short. |
| Surface Treatment | Adhesion of organisms is prevented by lowering surface tention without using biological toxic substance. Even if organisms adhere, it can be easily removed. | Development is still under way and gathering of field tests is needed. |
| Physical Treatment | | |
| Increase of Flow Speed inside Tube | Adhesion of organisms is controlled by increasing flow speed in pipe. | Flow speed near wall surface must be increased. Unevenness on the wall surface reduces flow speed. |
| Audible Sound | Adhesion of organisms is controlled by audible sound. | Sometimes effective and sometimes ineffective, therefore evaluation of effect is unstable. Less examples of research. |
| Ultra Sonic Wave | Adhesion of organisms is controlled by ultra sonic. | Damping of ultra sonic wave is fact depending on distance from oscillator, and its effect is spotty. |
| Electric Shock | Adhesion of organisms is controlled by electric shock. | A report says that sea water application is difficult because its consumes much electricity. Adhesion test utilizing electrotaxis of organism is necessary. |

Table 6.3.1: (Continued)

| Method | Outline & Advantage of Method | Problems and Future Subjects |
|---|---|---|
| High Frequency | Adhesion of organisms is controlled by high frequency. | Less examples of researched. A literature says the effect is pessimistic. |
| Light & Color | Adhesion of organisms is controlled by utilizing phototaxis. | Some effects are observed at place in sunshine and no effect without sunshine. |
| Ultraviolet Ray | Adhesion of organisms is controlled by utilizing ultraviolet ray. | Ultraviolet rays are irradiated on film made of sea water. Effect on large quantity of thick water layer seems to be small. |
| Sponge Ball | Adhesion of organisms is controlled and stain is cleaned by sponge balls. | Must be considered in design stage. Measures against corrosion is necessary. |
| Treatment by Bacteria | Initial adhesion is prevented by making use of bacteriolysis of bacterium. | A subject for future study. |

### 6.3.3 Substituting Method for Chlorination of Product Water

The chemicals presently used as disinfectant in the world are liquid chlorine, sodium hypochlorite, bleaching powder, ozone, chlorine dioxide and chloramine. Of these chemicals, liquid chlorine, sodium hypochlorite, and bleaching powder form free chlorine in water and when combined with precursor matters, it forms THM.

Neither of ozone, chlorine dioxide or chloramine react on precursor matters to form THM. This has been confirmed by many studies in laboratories and actual plants. Table 6.3.2 indicates advantages, disadvantages and evaluation of these three kinds of disinfectants. Also Fig. 6.3.2 indicates disinfection cost for each kind of disinfectant 1 m 3 quantity of treating water.

When totally evaluating each kind of disinfectant based on the above figure and table, ozone is most favorable from the view of no formation of THM, but its cost is very high. For example, the disinfection cost (gross expense) for 100,000 $m^3$ treating water is 0.4 yen/$m^3$ by chlorine, while 3.8 yen/$m^3$ by ozone.

Effectiveness of disinfection by chloramine is the lowest, but since it has other better points, disinfection by chloramine is desirous when there is a possibility of pollution of product water by oil.

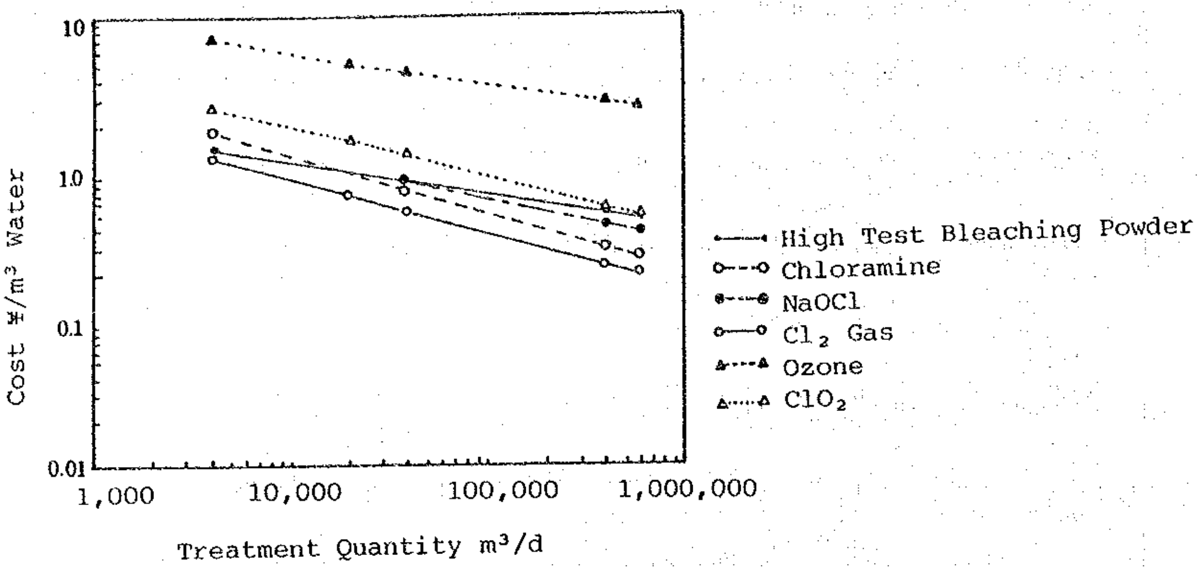


Fig. 6.3.2: Total Disinfection Cost

Table 6.3.2: Comparison of Chlorine Substituting Disinfectants

| Disinfectants | Merits | Demerits | O | T | P | D | C |
|---|---|---|---|---|---|---|---|
| Chloramine | Disinfection by chloramine is done in the form of compound residual chlorine produced by reaction between chlorine agent and ammonium. Order of injection does not matter.<br>(1) THM is not formed. (If chlorine is first injected, THM is reduced by 30-40%.)<br>(2) Residual effect is high.<br>(3) Odor proper to chlorine is not left in water. | (1) Disinfection capacity is weaker than chlorine, and injection of more quantity than free residual chlorine is required.<br>(2) It leaves more residual nitrogen oxide in water. | c | b | b | c | a |
| Ozone | (1) Mold-odor substance, chromatility component, THM-forming substance, etc., can be removed.<br>(2) Most effective as disinfectant of city water.<br>(3) Removability of odor and bad taste, land chromatility is good.<br>(4) No odor or bad taste is left in water.<br>(5) Variability is weaker than chlorine.<br>(6) No formation of THM.<br>(7) Iron removal performance is good. | (1) Residual capacity can not be expected.<br>(2) Ammonia cannot be removed.<br>(3) Installation cost as well as operation and maintenance costs are high.<br>(4) In Japan, it cannot be used for other than odor and chromatility, and in principle, activated carbon treatment is obligated. | d | a | b | a | c |

Table 6.3.2: (Continued)

| Disinfectants | Merits | Demerits | O | T | P | D | C |
|---|---|---|---|---|---|---|---|
| Chloride Dioxide | (1) No formation THM. If chlorine is present as impurity, THM is formed.<br>(2) Disinfection effect is stronger than chlorine. In case of alkaline, chlorine forms hypochlorite and its disinfection is reduced, but disinfection effect of chlorine dioxide shows almost no change.<br>(3) Since chlorine dioxide does not react with chlorine, it does not form chloramine, hence disinfection effect is not reduced.<br>(4) Disinfection effect lasts longer.<br>(5) It reacts with amine and has superior decolorizing effect. Since its oxidation capacity is weak, removal of THM substance is not effective.<br>(6) It will not form chlorophenol even if it reacts with phenol and will not leave odor and bad taste. | (1) Being chemically unstable, it is not applicable to storage and transportation, and place of application is limited.<br>(2) In case much amount of nitrogen compound is contained in water, nitrite is formed as by-product, and if it combines with hemoglobin in brood, it is possible that methohemoglobin symptoms. EPA of USA proposes to control total amount of chlorine dioxide, chlorine dioxide ion and chlorine peroxide ion in water at 0.5 mg/l or less. | d | b | d | b | b |

Remarks: O = Operation and Maintenance
T = THM Formation
P = Preservation
D = Disinfecting Effect
C = Cost

a = Excellent
b = Good
c = Acceptable
d = Not Acceptable

## 6.4 Restarting of Plant Contaminated by Oil

### 6.4.1 Countermeasures against Restoration of Plant Contaminated by Oil

If a plant is contaminated with spilled crude oil, proper and prompt action must be taken for the plant restoration. The practical restoration method will differ depending on the shape and material of the polluted section. For this reason, the cleaning methods that are considered adequate for each piece of the equipment, precautions during cleaning, and specific cleaning, are described in the following.

### (1) Cleaning Method for Equipment

Table 6.4.1 shows the cleaning method for each piece of equipment. Sea water free of oil contamination can be used for cleaning but there are some cases where fresh water is necessary for specific parts of the plant.

The cleaning methods include mechanical (hand cleaning, jet cleaning, pig cleaning (6 to 55), ball cleaning etc.,) and chemical means. Either the mechanical or the chemical cleaning will be more effective dependent on the degree of pollution; selection of the most proper method for the actual situation of the plant is necessary.

Table 6.4.1: Cleaning Method for Each Equipment

| Equipment | Part | Cleaning Method | Remarks |
|---|---|---|---|
| Sea Water Intake & Piping (Curtain Wall Type) | | Drain<br>Scraping<br>Jet cleaning | Cleaning with detergent, if necessary |
| Bar Screen (Bar Rake) Traveling Band Screen | | Scraping<br>Jet cleaning<br>Net replacement | Cleaning with detergent, f necessary<br>In case of light contamination, apply jet cleaning with detergent (consider material) |
| Intake Basin | | Drain<br>Scraping<br>Jet cleaning | Cleaning with detergent, if necessary |
| Intake Pump | | Disassembling & hand cleaning | Cleaning with detergent, if necessary |
| Piping | Intake Pump to Evaporator | Hand cleaning<br>Flushing | Cleaning with detergent, if necessary |
| Surface Condenser for Power Station | Water Chamber | Hand cleaning through manhole<br>Afterwards, flushing with clean sea water (until no sign of oil in water) | |
| | Cooling Tubes - Inside | Flushing with clean sea water (until no sign of oil in water)<br>Afterwards, assure complete removal of oil under operation of Taproge system | Cleaning with sea water or distilled water in circulation, if necessary |
| Service Water Cooler & Turbine Oil Cooler | Cooling Tubes - Outside | Flushing with clean sea water (until no sign of oil in water) | |

Table 6.4.1: (Continued, 2/4)

| Equipment | Part | Cleaning Method | Remarks |
|---|---|---|---|
| Generator Air Cooler | Cooling Tubes - Inside | Flushing with clean sea water (until no sign of oil in water) | |
| Deaerator | Shell Inside | Hand cleaning<br>Jet cleaning | Use detergent, if necessary |
| Evaporator | Shell Inside (Flash Chamber) | Hand cleaning<br>Jet cleaning | Use detergent, if necessary |
| | Demister | Jet cleaning after removal | Use detergent, if necessary |
| | Distillate Tray | Hand cleaning<br>Jet cleaning | Use of detergent should be avoided. (If it is unavoidably used, sufficient rinsing with water is required.) |
| | Heat Transfer Tube Outside | | Use detergent, if necessary |
| | Heat Transfer Tube Inside | Jet cleaning | Use detergent, if necessary |
| | Water Box | Hand cleaning<br>Jet cleaning | Use detergent, if necessary |
| Brine Heater | Shell Inside (Heat Transfer Tube Outside) | | Almost no oil pollution may occur |
| | Heat Transfer Tube Inside | Jet cleaning | Use detergent, if necessary |
| | Water Box | Hand cleaning<br>Jet cleaning | Use detergent, if necessary |

Table 6.4.1: (Continued, 3/4)

| Equipment | Part | Cleaning Method | Remarks |
|---|---|---|---|
| Vent Condenser<br>Ejector Condenser | Shell Inside (Heat Transfer Tube Outside) | Jet cleaning | Use of detergent should be avoided. (If it is unavoidable, sufficient rinsing with water is required.) |
| | Heat Transfer Tube Inside | Hand cleaning with polyurethane foam or brush<br>Jet cleaning | Use detergent, if necessary.<br>No cleaning is required, depending on the degree of oil pollution |
| | Water Box | Jet cleaning or hand cleaning after removal | Use detergent, if necessary<br>No cleaning is required, depending on the degree of oil pollution |
| Piping | Sea Water Line | Hand cleaning | Use detergent, if necessary |
| | Brine Recirculating Line | Hand cleaning | Use detergent, if necessary |
| | Small Piping in Sea Water/ Brine System | Flushing | Use detergent, if necessary |
| | Distillate Line | Flushing | Use of detergent should be avoided. (If it is unavoidable, sufficient rinsing with water is required.) |
| | Brine Blowdown Line | Flushing | Use detergent, if necessary.<br>No cleaning is required, depending on the degree of pollution. |
| | Vent Line | Flushing | Use of detergent should be avoided. (If it is unavoidable, sufficient rinsing with water is required.) |
| | Condensate Line | | Almost no oil pollution may occur. |
| | Steam Line | | |

Table 6. 4. 1: (Continued, 4/4)

| Equipment | Part | Cleaning Method | Remarks |
|---|---|---|---|
| Pump | Brine Recirculating Pump | Hand cleaning<br>Jet cleaning | Use detergent, if necessary<br>It is more effective to disassemble the pump for cleaning, depending on the degree of pollution. |
| | Distillate Pump | Hand cleaning or Jet cleaning after disassembling | Use of detergent should be avoided. (If it is unavoidable, sufficient rinsing with water is required.) |
| | Condensate Pump | | Almost no oil contamination may occur. |
| | Other Pump | Hand cleaning or Jet cleaning after disassembling | Use detergent, if necessary |
| Others | Instrument Sensor | Cleaning with detergent or organic solvent after removal | Prompt action is required.<br>Use detergent, if necessary. |
| | Ejector | Hand cleaning or Jet cleaning after disassembling | Almost no cleaning may be required. |

### (2) Simultaneous Cleaning Method of Entire Evaporator

When pollution with crude oil is not so serious, or after cleaning is carried out to some extent by the methods shown in Table 1 for each piece of the equipment, it is efficient and effective to wash simultaneously the entire evaporator with the alkali cleaning that is used to eliminate oil content from the boiler.

The method is shown in the followings:

1) Equipment Applicable

* Evaporator shell inside (Flash chamber)
* Evaporator heat recovery section, water box
* Evaporator heat recovery section, heat transfer tube inside
* Deaerator shell inside
* Brine heater water box
* Brine heater heat transfer tube inside
* Brine recirculating pump
* Brine recirculating line

2) Cleaning Process

(a) Fill the evaporator shell inside (flash chamber) with fresh water. Sea water should not be used; it may cause scaling.

(b) While circulating freshwater with the brine recirculating pump, feed caustic soda. (The concentration of caustic soda will be approx. 0.2% to the circulating water, pH > 13)

(c) Put steam into the brine heater to increase the circulating water temperature. (A greater effect could be expected if the temperature is higher, but it should be between 60 and 80 ℃ in consideration of possible damage to the material)

(d) While maintaining the temperature and pH, (add caustic soda or increase the temperature as needed), continue circulating cleaning for 2 days.

(e) After completion of the washing, neutralize water with acid.

(f) While diluting with sea water, discharge little by little.

It is considered to be difficult to clean the water boxes and the inside of the heat transfer tubes in the evaporators of the heat rejection system. Therefore, after connecting the discharge of the brine recirculating pump to the pipe of the cooling water by an appropriate method, such as temporary piping, the hot alkaline washing solution from the heat rejection section is to be put into the sea water pipes and water boxes of the heat rejection section. Then, the pipes and water boxes are cleaned by recirculation with the sea water recirculation pump.

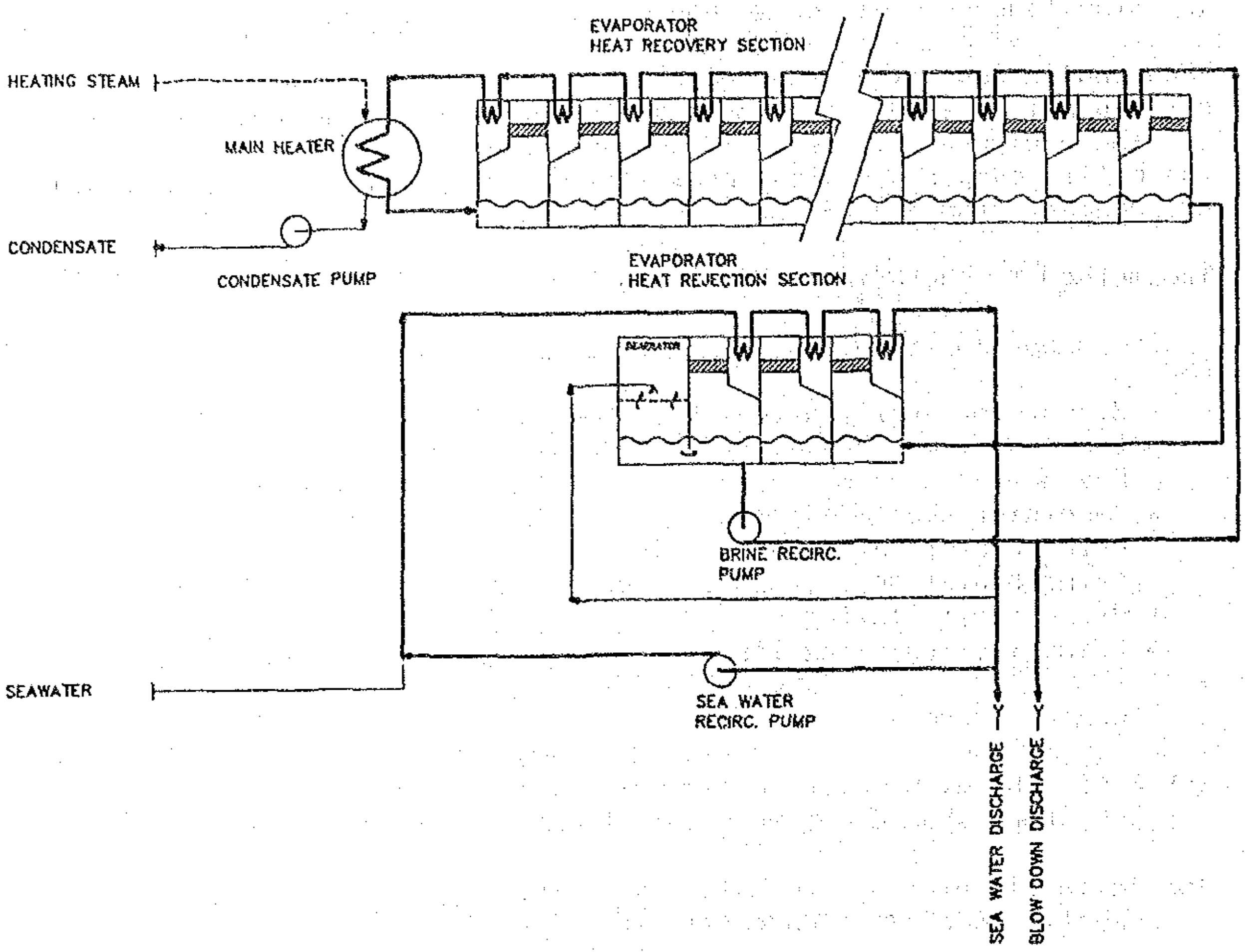


Fig. 6.4.1: Cleaning Cycle of MSF Plant

### (3) Precaution for Restoration

Gaseous oil can exist inside the evaporation chamber if the plant is *polluted with oil. The concentration range of a gas explosion is 5% or* more. Therefore, the possibility of an explosion is considered to be quite low. However, since an unexpected accident may occur due to the oil polluted condition of the plant, cleaning should be carried out with special caution. The points are as follows:

1) Operate the start up (hogging) ejector and purge the gas sufficiently from the evaporation chamber, then take a smell of the odor of the gas discharged from the vent pipe and measure the gas concentration with a gas content detector if possible.

2) Take special care so that no worker suffers from oxygen deficiency. When entering the manhole ensure sufficient ventilation, using, for *example, a fan.*

3) The worker should carry a portable oxygen meter.

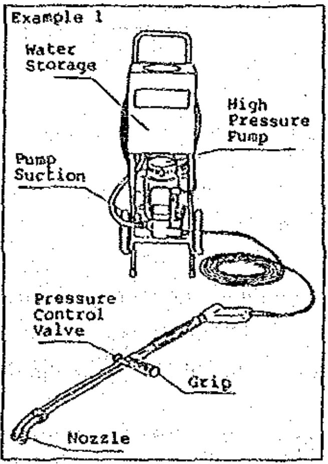
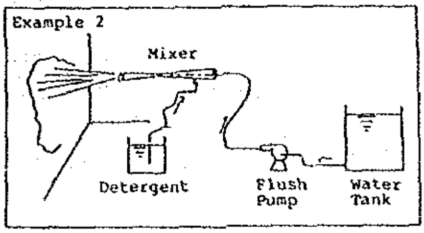
### (4) Practical Cleaning Method

The practical cleaning includes mechanical and chemical methods as mentioned before. The outline of these methods is given below.

#### 1) Mechanical cleaning

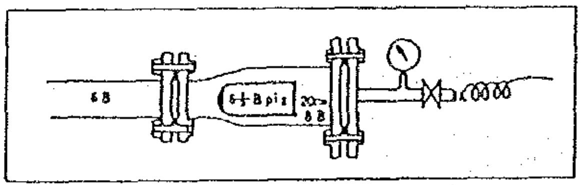
Various mechanical methods are shown in Table 6. 4. 2

Table 6. 4. 2: Outline of Various Mechanical Cleaning Methods

| Cleaning Method | Description | Merit | Remarks |
|---|---|---|---|
| Hand cleaning | - The worker eliminates oil directly (within the equipment) with a scraper, brush, or mop. | - This method is the most effecttive to remove deposits directly.<br>- While visually checking, this work can be carried out with no waste.<br>- No special tool is required. | - The work range is restricted.<br>- It is more efficient to carry out using a portable oil content detector "Black Light" (Fluorescent substance).<br>- This method is effective if detergent is used together. |
| Flushing | - Foreign matter is washed away by flushing a large quantity of water. | - A wide range of section can be washed at a time.<br>- Cleaning in an unaccessible place is possible.<br>- No special equipment is required.<br>- It is less dangerous for working since no worker enters the equipment. | - It takes long hours to remove conglutinating oil contents.<br>- A large amount of water is required.<br>- This method is more effective if hot water and detergent are used together. |
| Jet cleaning | - Jet high-pressure water from the nozzle as jet water flow and remove scales and foreign matter by the impact and dissolving power water has.<br><br> | - Even oil contents heavily sticking can be removed.<br>- While visually chekcing, this work can be carried out with no waste.<br>- The work is easier and more efficient than in hand cleaning.<br>- Scales and foreign matter even in a narrow, unaccessible place can be eliminated. | - The cleaning effect becomes better in the order of a higher temperatures: water — hot water — steam, but this method must be selected with consideration given to the strength of equipment, heat resistance of materials, and safety work.<br>- This method is more effective if jet cleaning is carried out with detergent charged.<br>- Pay special attention to safety during the work.<br><br> |

(Continued)

Table 6. 4. 2: (Continued)

| Cleaning Method | Description | Merit | Remarks |
|---|---|---|---|
| Pig cleaning | - For the cleaning of internal surface of piping, run a bullst type resin sweeper called "pig" within the piping by the air or water pressure and remove scales or foreign matter within piping. | - This method is employed for pipeline cleaning.<br>- This method permits the inside cleaning of piping no person can enter.<br>- The compressed air for pushing a pig can use the plant service air (pressure 6 - 7 kg/cm$^2$G). | - Special equipment such as pig launcher, receiver, etc. is required for this cleaning method.<br>- This pig can be used only for the same diameter piping. (Equipment according to the diameter is required.)<br>- This method cannot be used for a large aperture diameter piping. (Approx. 500mm dia. Max.)<br>- This method cannot be used when a valve, reducer or sharp bend is present midway in the piping.<br>- When coating or lining is applied to the internal surface piping, this pig cleaning may damage it.<br>- A resin piping cannot withstand this cleaning in strength. |
| Ball cleaning | - This ball cleaning system (Taprogge) is equipped to eliminate scales or deposits within the brine heater and evaporator heat transfer tube by passing a sponge ball<br><br> | - This system is used to remove scales during operation, but it is also possible to eliminate even oil if impregnated in scales. | - To operate this system normally, the brine flow rate cannot be reduced so much from normal operating conditions. Consequently, this system can be used only during plant operation.<br>- Since this system is designed so that a ball flows within the heat transfer tube by a small differential pressure, if a foreign matter, such as tar balls deposits within the heat transfer tube, the ball will hang up therein, clogging the heat transfer tube, and also leading to deposit attack. Special care should be given to this point. |

2) Chemical cleaning

A chemical cleaning is one using detergents in general. A detergent has its own features according to the type, and the use of some detergents may not be desirable, depending on the material in the part of each process. Therefore it is necessary to select a proper type of detergent with due consideration given to the effect and adequacy of the detergent, and to discuss sufficiently the safety of the waste water treatment method with detergent manufacturers.

In addition to that, since the water produced in a sea water desalination plant is used for drinking water, the detergent to be used should be determined only after a thorough study regarding safety to humans, with sufficient consideration given to how much detergent is remaining within the evaporator after cleaning, rather than to only its effectiveness as a cleaning agent.

Table 6.4.3 shows the features of the detergent classified chemically.

Table 6.4.3: Characteristics of Detergent

| Type of Detergent | Deoiling Effect | Problem for Materials | Remarks |
|---|---|---|---|
| Solvent type detergent | Substantially effective for thick and solid deposits | It is not preferable to use this detergent for resin coating and rubber lining. | Handle this detergent with special care : it is volatile and flammable. Avoid using it within the evaporation chamber. |
| Alkali type detergent | Effective for normal oil pollution | It is not preferable that ammoniac alkali type detergent is used for copper alloy. | |
| Neutral type detergent | Effective for normal oil pollution | Applicable to any material | Safety is higher, compared with other types of detergent. |

## 6.4.2 Treatment of Waste Water Used for Cleaning

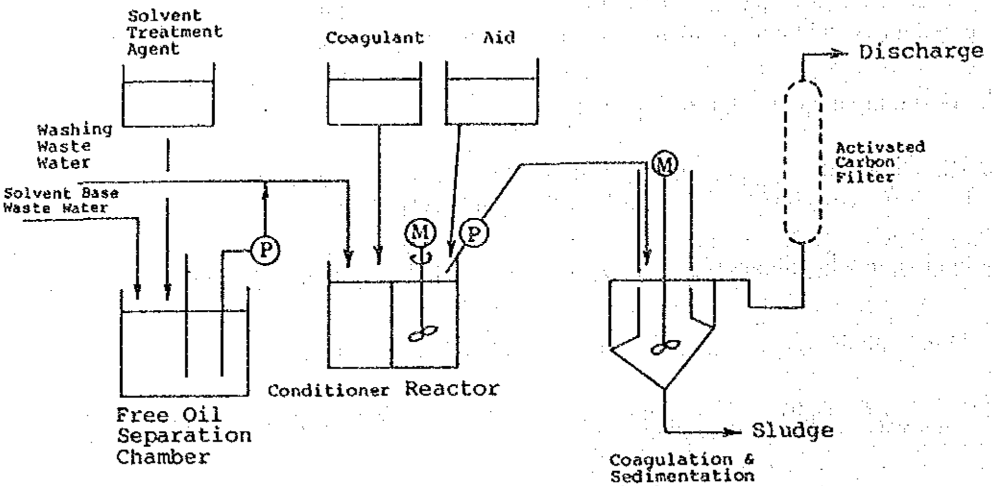
The cleaning of the plant polluted by oil may be accompanied by a large amount of waste water, and the discharge of this waste water into the sea without treatment is undesirable in view of ocean safety, since oil and detergent are mixed together in the waste water.

Detergent used for cleaning, which is low in toxicity has been developed, but oil may exert a harmful influence on the ecosystem.

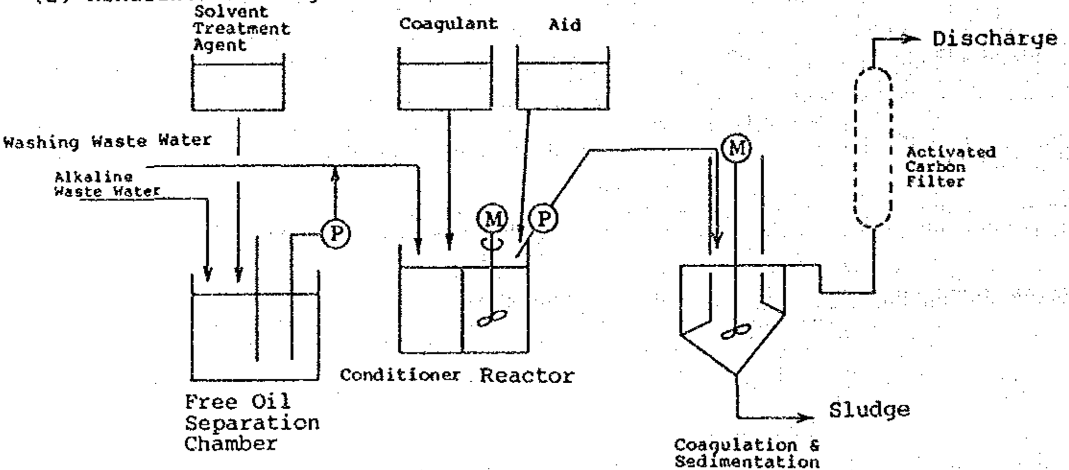
If the detergent is discharged into a sea zone polluted by oil, it may accelerate the diffusion and emulsification of the spilled oil and may exert a harmful influence on the intake sea water of the desalination plant. Therefore, The waste water containing oil and detergent should be discharged into the sea after treatment, or it should be treated in the inland waste oil disposal facilities.

For reference, one example of waste water treatment flow by the system is shown in Fig. 6.4.2. In actual water treatment, it is important to consider a specific treating method according to the conditions of the oil pollution.

(1) Solvent Base Cleaning Waste Water Treatment



(2) Alkaline Cleaning Waste Water Treatment



(3) Neutral Cleaning Waste Water Treatment

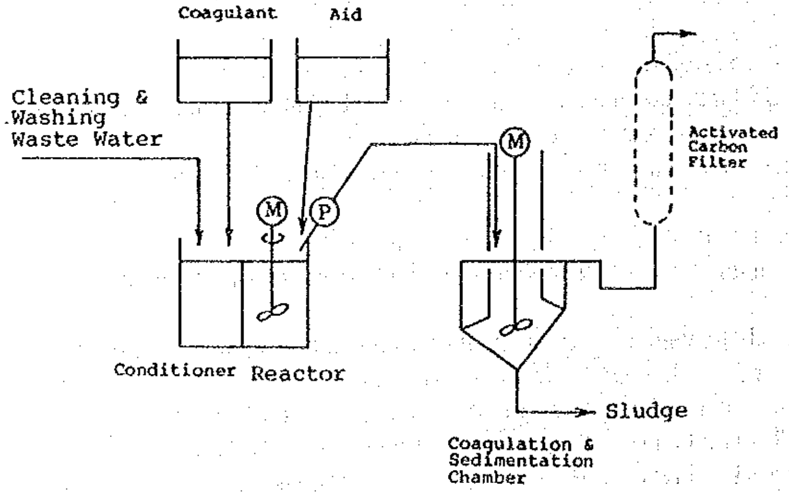


Fig. 6.4.2: Various Cleaning Waste Water Treatments

### 6.4.3 Restoration of Plant

#### (1) Items to be Considered at and after Restarting of Plant Operation

When drifting crude oil is removed and the sea water quality around the sea water intake for the plant has returned to the oil-free state, the plant will naturally then be able to resume operation. However, regarding the oil content, which is particularly important with regards to the quality of the sea water, the detection limit is nearly 1 mg/l with the existing instruments at their best performance. Therefore, it is considered that checking the water for odor is the most practical and appropriate method. (Odor is sensed even when the oil content concentration is approx. 0.002 mg/l).

The actions listed below should be taken after plant operation resumes, because it will take quite a long time before the surrounding sea area of the plant to become clean again as solid oil sunk to the seabed may rise to the sea surface and drift near to the sea water intake.

1) An oil fence and aeration equipment should be provided so that no polluted sea water flows directly into the sea water intake facility, and equipment for the removal of the oil content should also be provided, such as an oil skimmer.

2) Constant measurements should be taken by an oil content monitoring system. (The measurement point will also include the offshore area of the sea water intake facility).

3) Visual monitoring should be carried out at all times.

4) Monitoring by smelling for odor should be carried out appropriately.

5) The arrangement and preparations for the emergency shutdown of the plant should be made so that the plant operation can be stopped quickly.

#### (2) Operational Control System for Problem Control

A system effective in countering problems such as sea water oil pollution by controlling the operation of the power station, is described herein.

Umm Al Nar Power Station has numerous units as shown in Table 6.4.4.

Table 6.4.4: Unit Numbers of Umm Al Nar Power Station

| | West No. 1-6 | West No. 7. 8 | West No. 9. 10 | East No. 1 | East No. 2 |
|---|---|---|---|---|---|
| Boiler Unit | 6 | 2 | 2 | 6 | 4 |
| Steam Turbine Generator Unit | 6 | 2 | 2 | - | - |
| Gas Turbine Generator Unit | - | - | - | 2 | 2 |
| Total | 12 | 4 | 4 | 8 | 6 |

In order to ensure the output of steam volume for the desalination plants, and the supply of electric power depending on external demand at the time, for the efficient operation of such numerous units, an able coordinator is needed in the Umm Al Nar Power Station.

This coordinator is a computerized control system which decides economically and instantly each load level for the boilers, steam turbine generators and gas turbine generators, and controls the separate units as if they were all part of the one bigger unit, while taking into account each unit's operational characteristics.

This system is called in Japan a "Joint Operation System by Computer Optimal Management - JOSCOM", now being used for industrial power stations which have many units, to supply for a fluctuating demand for electric power, and steam for manufacturing processes.

The control system can decide instantly which units should be loaded up and which units should have loads lightened or shut down, depending on the particular problem, such as sea water oil pollution or a similar incident, as well as being able to adjust for a suitable operating load for each unit.

It is recommended that the system be introduced to Umm Al Nar Power Station with a view to the daily optimal operational management and provision for suitable countermeasures against incidents in the plant.

The WED data "Directorate - 1987" shows that the production cost of energy increased from Dh. 0.1377/kWh to Dh. 0.1471/kWh in 1987. The system would also enable the station to decrease the production cost as well as to upgrade operational management.

## 6.5 References of Chapter 6

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# Chapter 7

## Summary

by
Yoshio Murayama

## Chapter 7 Summary

Measures and further investigation desired to be taken by the Water and Electricity Department of the Abu Dhabi Emirate with respect to monitoring of sea water pollution, prevention of oil contamination, countermeasures to be taken when oil-contaminated sea water is used, steps to be taken in case of an emergency shutdown of the plant, etc. based on the results of the current study, are as follows:

### 7.1 Oil Pollution Prevention Systems

#### (1) Prevention of Oil Inflow at Intake with Oil Fence

The biggest effect on the sea water intake of Umm Al Nar Station is the tidal current which flows in from Mina Zayed, goes south along Ashuoom Island, passes between Assamaliyah and Qassr Esall and reaches Umm Al Nar Station. Discharged sea water from outfall of Umm Al Nar Station also affect the intake to some degree. Also when there is a strong south wind, drift current from the Maqta Channel east of the Abu Dhabi Island too has some influence.

Therefore, in order to prevent the inflow of spilled oil into the sea water intake of Umm Al Nar Station, the most effective way is to install an oil fence in the position shown in Fig. 5.1.1. It is desirable that an oil fence extension boat be ready at all times exclusively to string the oil fence promptly in time of urgency.

#### (2) Monitoring System

The most suitable points from which to monitor oil spillage are points 1 to 8 shown in Fig. 5.2.20 for the following reasons (5.4.6):

1) Tidal currents that affect the intake mainly pass points 1, 2 and 3. Point 5 was in consideration of possible oil spillage from vessels berthed at the pier and point 4 to watch for ingress of oil from Channel W. Points 6, 7 and 8 are to take care of oil flowing over the oil fence and into the intake.

2) As it takes oil spillage from points 1, 2 and 3 more than 5 hours to reach the spot in the south basin of the Umm Al Nar Station where the oil fence is to be strung, the installation of the oil fence can be completed during this time.

3) A reliable monitoring will be possible as waves, tides and other sea conditions will be calm.

4) Maintenance administration will be easy.

Also, as even the shortest time that it takes at maximum flood tide for oil spillage from the Baghal Channel to reach Umm Al Nar Station is 18 hours, a spot on the Baghal Channel could be considered for monitoring large-scale oil spills from the Arabian Gulf. However, since the waves are high and the tidal current fast at the entrance of the channel, the accuracy and reliability of the sensors and the monitors are low.

(3) Improvement of Intake System

As the present intake facility of Umm Al Nar Station is constructed so that sea water from the surface layer at low tide also flows in, the entry of oil spillage when it reaches the intake cannot be fully prevented. Also, the depth of the water at the quay wall in which the current intake is located is shallow so that even if a curtain wall was to be provided it would still be difficult to achieve full middle layer intake.

For these reasons it is desirable that the present facility be improved into an offshore intake system by submerged intake pipe so that both the inflow of oil spillage floating in the surface layer and the ingress of sand and mud around the bottom layer can be prevented. (5.4.4)

(4) Countermeasures against Oil Spillage off Abu Dhabi Island

Against oil spillages off the Abu Dhabi Island, movable oil fences which prevent oil spills from spreading and which allow the oil to be recovered are more suitable than a fixed oil fence preventing oil from entering the lagoon. In such a case, it is desirable that oil fence boats and oil recovery boats be stationed so that an oil fence can promptly be installed at the scene of oil spill accident. (5.4.2)

(5) Maintenance System

It is important not only to prepare the oil pollution protection facilities and monitoring system, etc. of (1) to (4), but also to become skillful in the operation and maintenance of those facilities.

(6) Confirming with Hydraulics Model

The tidal current that has a big effect on the Umm Al Nar intake is affected largely by changes in the topography around the Abu Dhabi Island, so it is necessary that new land reclamation and excavation plans for this area be studied in advance, using hydraulics models at the hydraulics research laboratory, to see the effect they will have on the tidal current.

(7) Monitoring of Marine Environment (3.9.2)

In order to monitor marine environment pollution it is desirable that studies be made at regular intervals of the water quality, sediment, planktons, and benthos and coastal organisms.

## 7.2 Effect of Oil-Contaminated Sea Water on Power and Sea Water Desalination Plant

No report could be found on a plant being actually operated with oil-contaminated sea water. In this study, documentary studies and analyses were carried out but the following future research is desirable:

### (1) Formation of Trihalomethane (THM) by Chlorination of Oil-Contaminated Sea Water

Reports of studies on whether or not THM can be formed by chlorination of oil dissolved or emulsified in sea water are extremely scarce. As it is known that the amount of THM generated by the interaction of organic compounds and chlorine varies considerably depending on the reaction time, it is necessary that a definite conclusion be obtained by carrying out tests in which oil is added to Abu Dhabi sea water and the quantity of chlorine input and the reaction time are matched to the operating conditions of the Umm Al Nar sea water desalination plant.

### (2) Corrosion of Plant Materials by Oil Pollution

There is a possibility that oil-contaminated sea water will promote hydrogen sulfide pitting corrosion, stress corrosion cracking of stainless steel and deterioration of epoxy and phenol resins and synthetic rubber. Although estimations of corrosion trends of plant materials were made in this study, competent evaluation were unable to be reached.

It is desirable that statistical research under the operating conditions of the Umm Al Nar power generation and sea water desalination plant be carried out by a material testing laboratory.

## 7.3 Treatment of Oil-Contaminated Desalinated Water and Measures for Securing Subsistence Water during Plant Emergency Shutdown

### (1) Treatment of Oil-Contaminated Desalinated Water

*It is possible to eliminate the oil from desalinated water,* depending on the quantity of oil mixed in the original sea water, by the following treatments. (6.1.1 and 6.1.2)

1) When the oil in the feed sea water is 100mg/l or less, throw away the desalinated water of stage 1 (deaerator) through stage 4 and treat the water of stages 5 through 18 with activated carbon.

2) When the oil in the raw sea water exceeds 100mg/l, throw away stages 1 through 4, distill stages 5 through 18 again in another desalination plant, recover the blowdown water as production water and give it the activated carbon treatment.

In executing the above methods, it is necessary to carry out further tests under actual plant conditions and check out the effectiveness of the treatments.

### (2) Elimination of THM from Product Water

THM formed by the chlorination of feed sea water, the precursors of the trihalomethane in the oil, etc. are transferred from the sea water to the production water. (4. 5. 4) The following arc methods for eliminating the trihalomethane transferred from sea water and generated by the chlorination of production water. (6. 2. 4)

1) Boiling

THM is practically almost vaporized when water is boiled for 40 minutes so this is an effective household method.

2) Activated Carbon Treatment

THM can be eliminated to within tolerable limits by the granular activated carbon treatment which can be adapted to practical use. However, treatment capacity is greatly affected by the type of activated carbon and the other dissolved matters present. Therefore, if this method is to be applied, it is necessary to confirm its proficiency, reclaiming process and time by pilot tests, etc.

### (3) Alternate Method for Chlorination of Production Water (6. 3. 3)

As a method for sterilizing production water without forming THM, the chloramine treatment is suitable. This method has the ability to maintain its sterilizing effect and the cost is comparatively inexpensive.

### (4) Measures for Securing Subsistence Water during Plant Emergency Shutdown (5. 7. 5)

It is conceivable that when excessive oil contamination occurs, etc., the sea water desalination plant will have to undergo an emergency shutdown. In such a case, there are the following countermeasures that can be taken.

1) The storing of production water against such an emergency.

2) Water conservation.

3) Cooperation with desalination plants in other areas.

4) Conversion of raw water.

### (5) Emergency Transportation of Water from Other Areas

Of the above 5 countermeasures for securing subsistence water during a shutdown, water conservation, especially requires immediate study and planning of practical execution methods under the current facilities. Also, it will be necessary to study the ways and means of notifying the water consumers of drops or stoppage in the water supply so as to prevent confusion from occurring.

With regard to cooperation with sea water desalination plants in other areas, since the Taweelha plant 70 km away from the the Abu Dhabi Island is to be completed in 1989, coordinated use with the Umm Al Nar Plant will become possible.

With regard to the other countermeasures, as a large investment will be necessary for the construction of additional storage tanks, the securing of a water supply tanker, the digging of brackish water wells and beach wells, etc., their execution should probably be considered only after complete studies are carried out.