5.2 Design of Oil Monitoring System

5.2.1 Monitoring Requirements

The fate and behavior of spilled oil at sea are governed by three types of processes more fully described in 4.1:

* Physical Processes

Spreading, transportation, evaporation, emulsification, dispersion, dissolution, direct sea/air exchange, sinking, sedimentation, and tar lump formation

* Chemical Processes

Photochemical oxidation

* Biological Processes

Microbial degradation and uptake by organisms.

The rate at which these three processes affect the disintegration or dispersion oil depends on the type of oil and its chemical and physical characteristics, the elapsed time after a spill, and other environmental conditions.

Based on a review of the existing oil monitoring system at Umm Al Nar Station, it is considered that since the oil sensors are currently deployed only in the vicinity of No.1 intake they cannot effectively monitor a wide area and detect oil in water.

To provide an early response for protection of the electric power and desalination plants from accidental oil spills, it is necessary to not only detect the oil spreading at the sea surface and in the water column but to also provide information on meteorological and oceanographic conditions for preventive action purposes. In addition to monitoring, it is necessary to predict the trajectory of the oil slick once it is detected [1].

To accomplish these recommended requirements, the following parameters should be monitored.

1) Oil Contamination

* Oil slicks or films on the sea surface
* Oil in water

2) Oceanographic and Meteorological Conditions

* Wind speed and direction
* Current speed and direction
* Wave height
* Tide level

5.2.2 Review of Monitors and Sensors for Oil Spills

The current state of technology relative to oil spill monitoring was reviewed as a first step in the selection process of candidate sensors and oil content monitors.

(1) Oil on Sea Surface

A wide variety of sensors have been developed for detection of oil on the water surface as follows:

* Remote sensors

  * Radar
  * Microwave radiometry
  * Infrared sensor
  * Ultraviolet sensor
  * Fluorescence sensor
  * Low light level TV

* In-situ Sensors

  * Surface conductivity sensor
  * Chemical fuse
  * Vapor sensor
  * Mechanical torque sensor
  * Sonar
  * Differential evaporation sensor

1) Remote Sensors

(a) Radar

Detection of oil spills using radar is based on the suppression of wind-driven capillary and small-scale gravity waves due to the presence of an oil film on the water. An oil slick reduces the amplitude of ocean waves. The reduced amplitude, compared to surrounding water, is detected by radar, thereby indicating the presence of an oil slick. 2) 3) 4) 5) 6) 7) This principle is shown in Fig. 5.2.1.

The contrast in radar reflectivity between an oil film and the surrounding water is currently measured from aircraft.

Fig. 5.2.1: Detection by Means of Radar

Two basic methods for sensing oil by radar are used:

Side Looking Airborne Radar (SLAR) and Synthetic Aperture Radar (SAR). SLAR, or real aperture radar, scans an area on the water that is not directly below the aircraft but is off to one side, hence the name Side Looking Airborne Radar. It is used in maritime surveillance systems by the US Coast Guard, Swedish Coast Guard, UK Department of Transport, Dutch Ministry of Transport and Norwegian State Pollution Control Authority. 8) 9) 10) 11) 12)

Sea state affects the minimum detectable oil film thickness, however, a detection value of less than 1 μm has been reported. 13. Synthetic Aperture Radar generates high resolution imagery by using signal processing techniques. 14) 15) The results of an experimental test flight using SAR have shown potential utility for sensing oil slicks. Radar systems can penetrate clouds and fog, and are capable of providing wide surveillance swaths. However, difficulty is recognized in the use of radar for discriminating oil slicks from the surrounding water in calm conditions, or high wind conditions that generate large-scale waves. 16)

(b) Microwave Radiometry

Microwave radiometry is a passive system that measures the natural microwave energy, or brightness temperature, emitted and/or reflected from surfaces. 17) 18) 19) 20) The natural microwave energy is measured as the brightness temperature of the surface. The surface of an oil slick exhibits a higher brightness temperature than the surrounding water, and the higher brightness temperature, the thicker the oil slick.

The minimum detectable oil film thickness is 5 to 100 μm. 13) It is also recognized that advantages of microwave radiometry include its ability to penetrate weather, and its lack of dependence on ambient lighting conditions. A microwave radiometry sensor is currently under development and is being considered for potential application to sense relatively thick oil films.

(c) Infrared Sensor

Infrared sensors can be classified into two types of passive and active sensors.

a) Passive Infrared Sensor

A passive infrared sensor utilizes naturally occurring radiation. Passive infrared sensors measure the temperature differences in thermal infrared between oil slicks and surrounding water. 21) 22) 23) 24) Fig. 5.2.2 shows the passive infrared sensor concept.

Passive infrared sensors mounted on aircraft are currently operated in maritime surveillance systems of the US Coast Guard, the Dutch Ministry of Transport, Swedish Coast Guard, and the UK Department of Transport. 25) 26) 27)

One of the problems with passive infrared sensors is that thin films of oil do not produce significant thermal contrasts, and thus may not be detected. 28) The minimum detectable thickness of oil in a film is reported to be is 10 μm . 13)

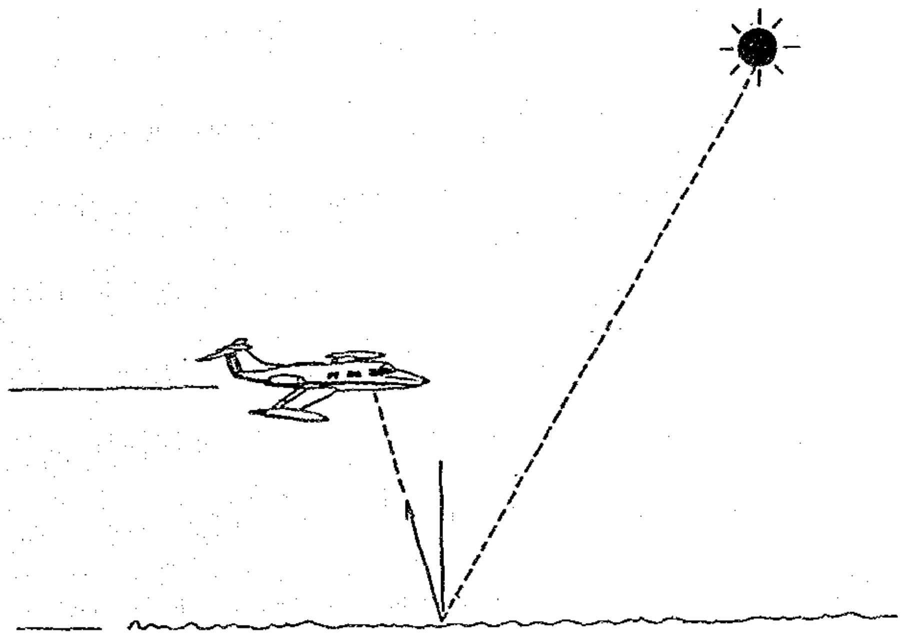


Fig. 5.2.2: Schematic of Passive Infrared Sensor 21)

b) Active Infrared Sensor

An active infrared sensor utilizes radiation from an artificial light source. Active infrared sensors measure the differences in reflective properties of water and oil in the infrared band. The sensor consists of an infrared transmitter and receiver. An active infrared beam is transmitted from a light source to illuminate the water surface. The reflected energy from the water is collected and measured by a receiver. 29) 30) The principle is shown in Fig. 5.2.3. Active infrared sensors installed on fixed structures have been widely used in refineries and manufacturing plants to monitor oil in effluent and cooling water. 31) 32)

A test was conducted to confirm the ability of the active sensor to avoid false alarm when debris or marine algae was detected. It was demonstrated that signatures between oil and other materials of dirt, mud, plywood, paper and algae are different.

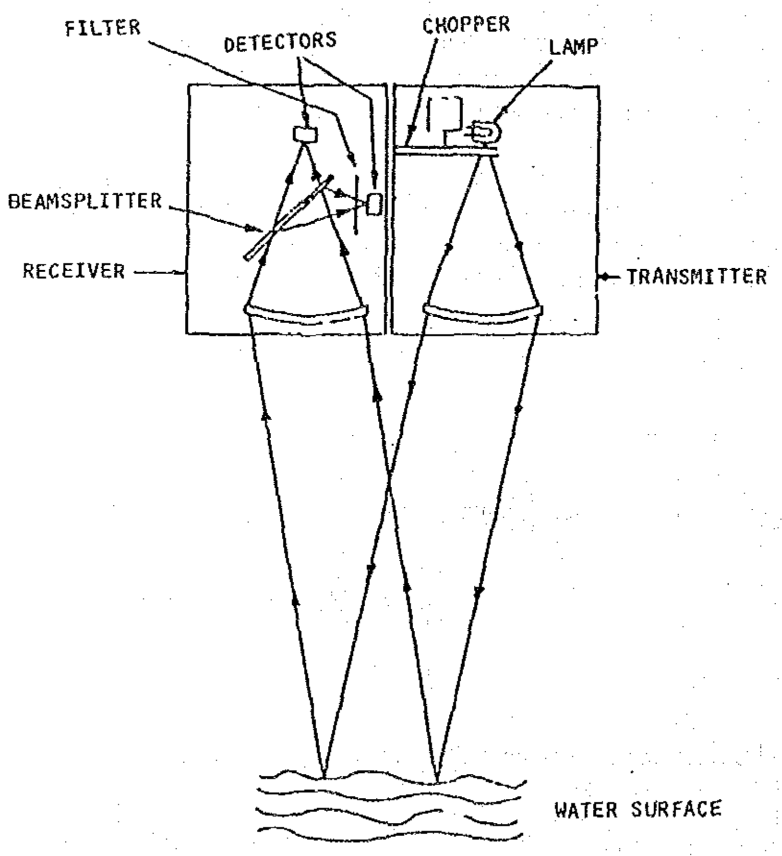


Fig. 5.2.3: Schematic of Active Infrared Sensor 29)

A ratio process that computes the ratio of the reflected signals from two objects with different wave lengths has demonstrated that the sensor can detect oil on wavy surfaces. 23) 32) The minimum detectable oil film thickness is 0.1 μm 32) 34) Both passive and active infrared sensors have the ability to detect oil in both daylight and night conditions.

(d) Ultraviolet Sensor

An ultraviolet sensor is a passive sensor that measures the difference in reflected solar energy from ultraviolet radiation between oil and water; oil is more highly reflective in this portion of the spectrum. 22)

It is recognized that ultraviolet sensors can detect very thin films of oil, as thin as 0.15 μm , compared with passive infrared sensors which have a limited ability to detect relatively thin films. 13) 28) The ability of the two sensors to detect thin films has been demonstrated in a system in which an ultraviolet sensor combined with a passive infrared sensor is mounted on an aircraft.

This system is currently operating in maritime surveillance activities conducted by the US Coast Guard, the Swedish Coast Guard, and the UK Department of Transport, etc. 9) 10) 35) 36) However, it was shown that the use of ultraviolet sensors in dark conditions is very limited because the sensor does not operate in conditions where ambient illumination is weak. Moreover, the sensor responds to seaweed floating on the sea surface.

(e) Fluorescence Sensor

A fluorescence sensor is an active sensor. The portion of ultraviolet absorbed by oil is re-emitted at longer wave lengths. This phenomenon, known as fluorescence, is the basis for operation of a fluorescence sensor. 37) 38) 39) A fluorescence sensor measures the fluorescence the oil excited by ultraviolet energy. An example of this sensor is shown in Fig. 5.2.4.

Since the wave length and intensity of the emitted fluorescence is different for different types of oil and film thickness, the sensor has the potential to classify as well as detect oil. It is reported that the minimum detectable oil film thickness is 10 to 100 μm . 40) 41) A sensor consisting of an ultraviolet lamp and detector has been developed and used to measure oil in the effluent from holding basins and their intakes in various industries.

However, the sensitivity is adversely affected by interference from solar energy and by atmospheric attenuation in the ultraviolet wave lengths when operating from high altitudes. Because the atmospheric attenuation effects in the ultraviolet region are severe, a laser fluorosensor in which a laser is used as the excitation source has been developed for airborne application.

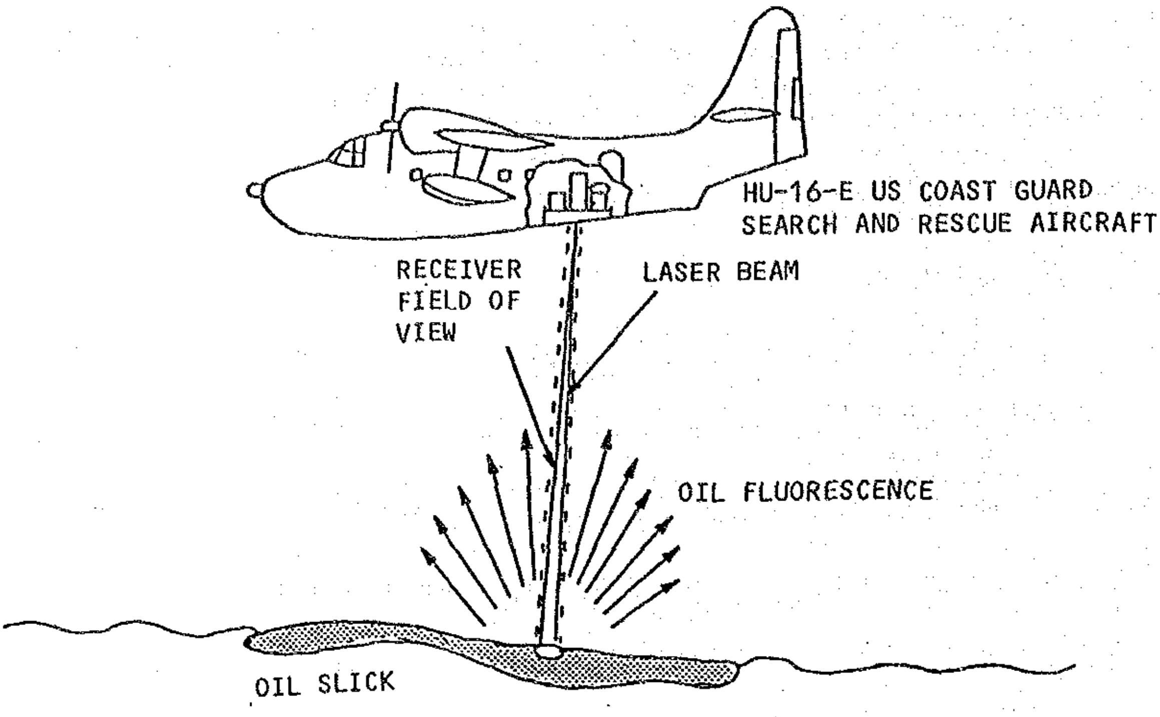


Fig. 5.2.4 The Principle of Fluorescence Sensor 38)

An example of a laser fluorosensor is shown in Fig. 5.2.5. Laser fluorosensors have been extensively tested by laboratory measurements and experimental flights. 42) 43) 44) 45) 46) 47) 48) 49) 50) 51)

(f) Low Light Level Television

A low light level TV produces images of the differences in reflectivity of solar energy between oil and water. 2) 3) The reflectivity difference between oil and water is strongest in the ultraviolet wave lengths. As the low light level TV can immediately scan a relatively wide area in on image, it is thus commonly operated as a auxiliary means of ultraviolet sensor. 13) Usage of the television systems during night time is very limited.

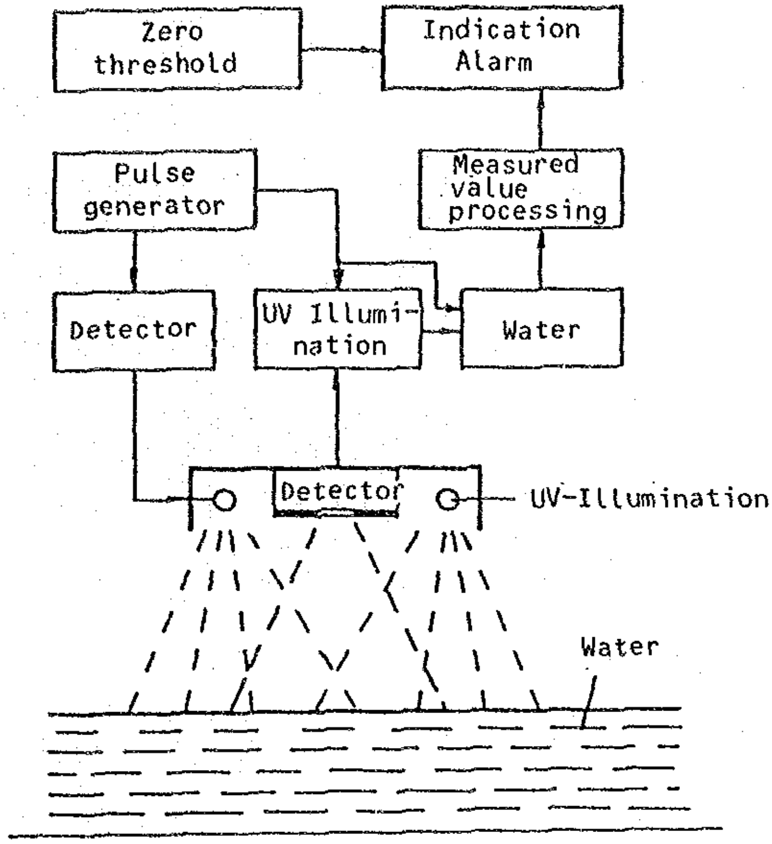


Fig. 5.2.5: Airborne Laser Fluorosensor 45)

2) In-Situ Sensor

(a) Surfaces Conductivity Sensor

This sensor system consists of a floating sensor probe connected to a control box containing instrumentation that continuously measures conductivity at the water surface. When an oil film makes contact with the sensor probe, oil is detected by a change in conductivity. 52) 53) 54) An example of this system is shown in Fig. 5.2.6.

The sensor is useful for detection of relatively thick oil films (minimum detectable oil film thickness is 0.5 to 3 mm 52) and is affected by wave action. It is used to monitor accidental oil spills of effluent from oil separators and oil storage facilities. These type of sensors are deployed at Umm Al Nar Plant.

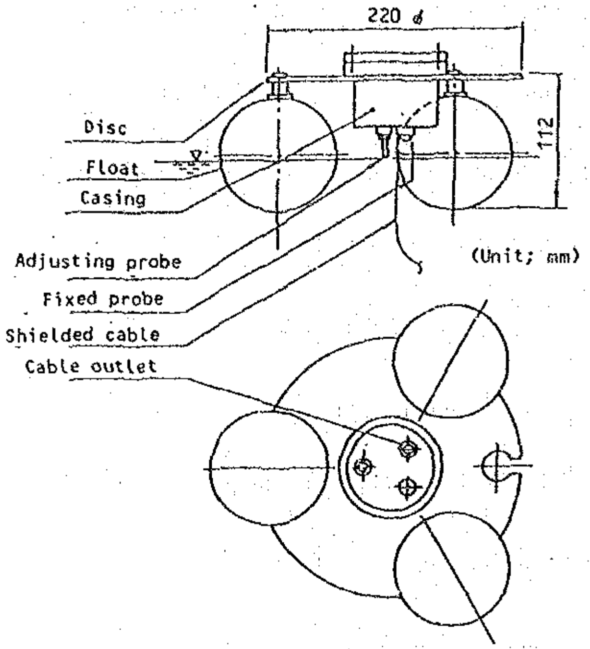


Fig. 5.2.6: Conductivity Sensor 53)

(b) Chemical Fuse Sensor

This sensor consists of a chemical fuse in the form of a membrane which is dissolved by hydrocarbons. The sensor is set by stretching the membrane between two connectors that hold open a circuit breaker. The unit is partially submerged in water. On contact with oil, the membrane dissolves and the presence of oil is signaled when the circuit breaker closes. 56) The sensor is sensitive to relatively fresh oil and light hydrocarbons which have the potential to dissolve the membrane. These sensors have been installed at the intake facilities of the Abu Dhabi power Station.

(c) Vapor Sensor

The vapor sensor detects oil by sensing vapor evaporating from oil on the water surface. 57) Preliminary evaluation of this system indicates that these sensors are capable of detecting a wide range of hydrocarbon vapors in a laboratory environment. However, the results of field tests indicate that sensitivity is not sufficient to detect oil in an open sea environment.

(d) Mechanical Torque Sensor

This sensor consists of a viscometer with a cylinder spinning inside a slightly larger cylindrical shroud partially submerged in water as shown in Fig. 5.2.7. An oil slick causes the spinner to become coated with oil increasing the shaft torque. This increased torque can be measured and indicates the presence of oil. 58)

The applicability of the detection technique has been confirmed by laboratory tests which demonstrated that the minimum detectable oil film thickness is 3 to 30 μm. 58) However, these test results also indicated that a mechanical sensor would not operate in waves, would become clogged with debris and may have difficulty cleaning itself of oil after an initial detection. 34)

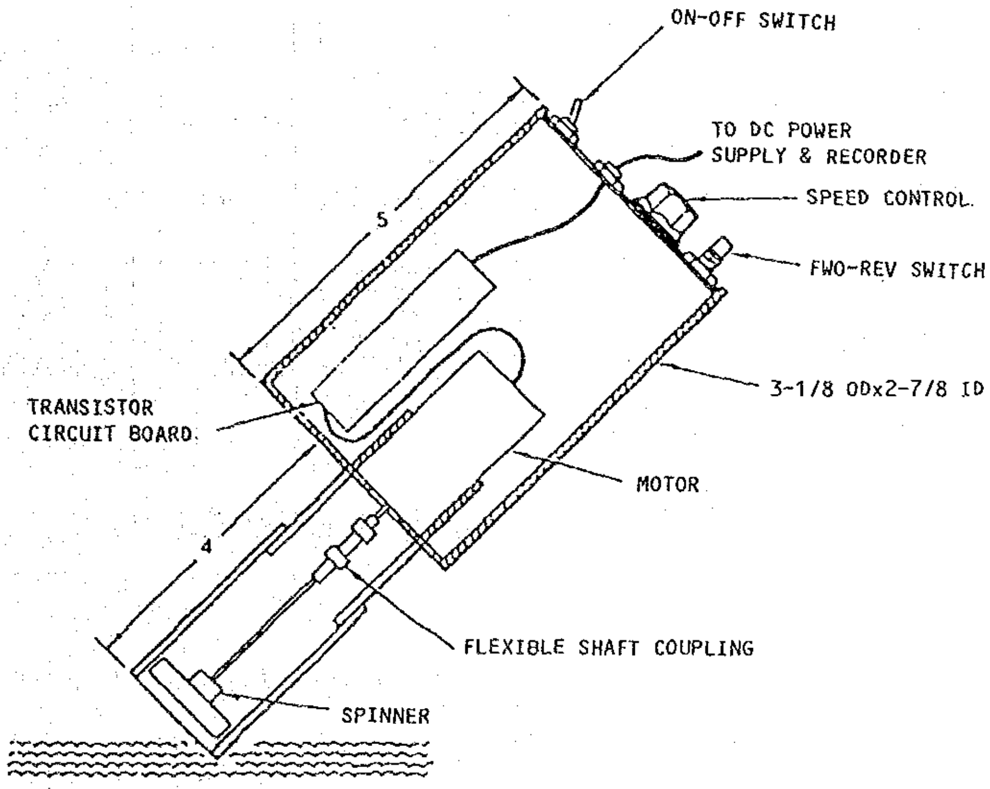


Fig. 5.2.7: Mechanical Torque Sensor 41)

(e) Sonar Sensor

This sensor applies the sonar principle to the measurement of oil thickness on the water surface. Ultrasonic waves are emitted upwards from a transponder installed in the water. Oil film thickness is measured by a signal reflected from the boundary layer of air-oil and oil-water interfaces. 59) This principle is shown in Fig. 5.2.8. A prototype of an oil thickness measuring device has been developed and tested in the laboratory. The minimum detectable oil film thickness reported for this prototype is 3 mm.

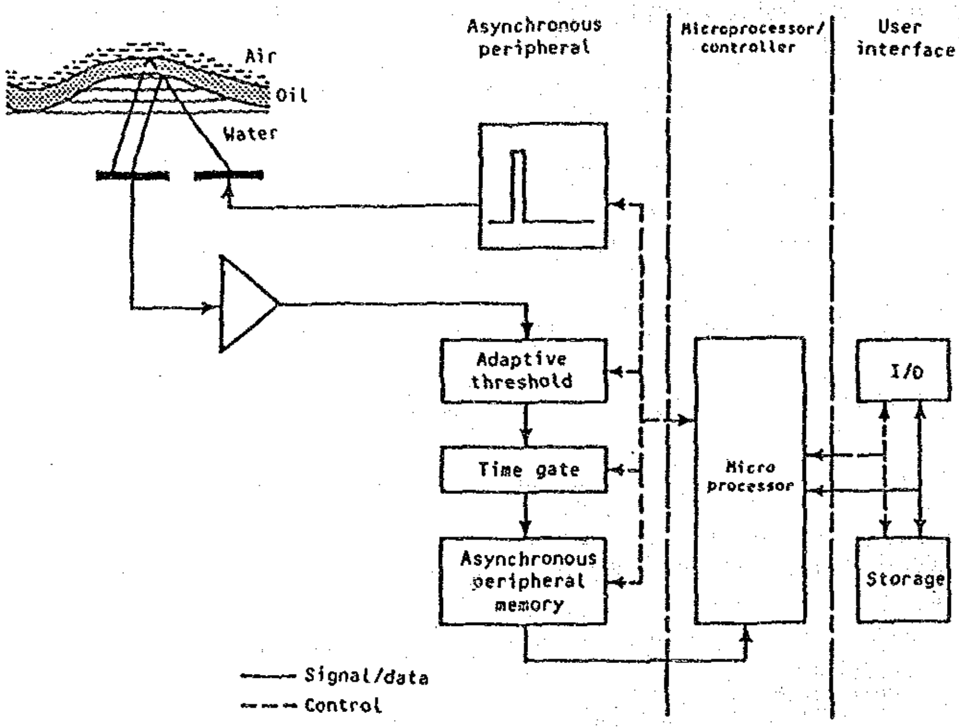


Fig. 5.2.8: The Principle of Sonar Sensor 59)

(f) Differential Evaporation Sensor

This sensor operates on the principle of measuring the difference in evaporation properties between oil and water. The sensor consists of two temperature probes mounted on a buoy and periodically immersed, one into oil free water in a container, and the other into the the water surface being monitored (Fig. 5.2.9).

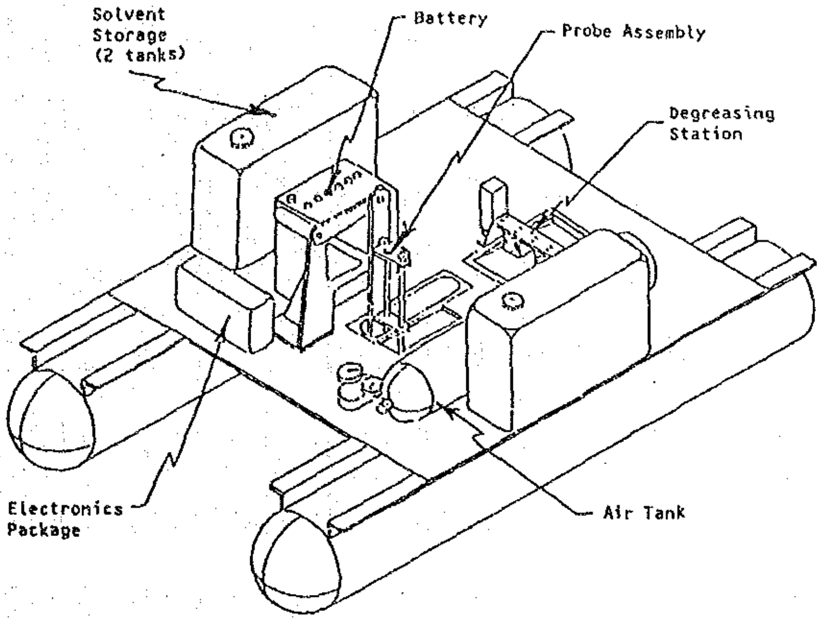


Fig. 5.2.9: Differential Evaporation Sensor

After each immersion, the temperature change of each probe is monitored. If no oil is present, evaporative cooling effect of the water will be the same for both probes. However, if an oil film is present during an immersion, one temperature probe will become coated with oil. Since oil and water evaporate at different rates, the cooling effect will be different for each probe.

The presence of an oil film would be detected by the temperature difference between the two probes. 60) 61) A design for a prototype sensor to demonstrate the detection technique was prepared. Tests showed that the minimum detectable oil film thickness by the prototype sensor is 1 to 3 μm .

However, it became clear that the complex design necessary to implement this detection technique included a buoy configuration, a probe immersion mechanism and a probe cleaning system that would require a solvent and compressed air to clean the probes after each detection. The sensor was not considered suitable for long-term, unattended, in-situ operation. 34)

A summary of the present state of sensors for detecting oil on water is shown in Tables 5.2.1 and 5.2.2.

Table 5.2.1 Remote Sensors

SENSOR	PRINCIPLE	SENSITIVITY	REAL TIME	CONTINUOUS SENSING	NIGHT OPERATION	COVERAGE AREA	OPERATIONAL STATUS
Side looking airborne radar	Difference in radar reflectivity between the oil film and the surrounding water	Doubtful usefulness under calm and high wave conditions	Yes	Yes	Yes	Wide	Operating in maritime surveillance aircraft
Synthetic aperture radar	"	"	Yes	Yes	Yes	Wide	Experimental test flights
Microwave radiometory	Difference of brightness temperature between the oil film & the surrounding water	Applicable in thick oil films	Yes	Yes	Yes	Wide	Currently under development
Passive Infrared sensor	Temperature differences between the oil film and the surrounding water	May not detect thin oil films	Yes	Yes	Yes	Wide	Operating in maritime surveillance aircraft
Active infrared sensor	Reflectance properties of of oil and water	Applicable in wave conditions, based on experimental results	Yes	Yes	Yes	Medium	Operating in refineries and other manufacturing plants
Ultraviolet sensor	Difference of reflected ultraviolet between the oil film and surrounding water	Defects thin oil films under sufficient solar illumination	Yes	Yes	No	Wide	Operating with passive infrared sensor in maritime surveillance aircraft
Fluorescence sensor	Fluorescence excited by ultraviolet lamp	Affected by atmospheric attenuation of ultraviolet from high attitude radiation	Yes	Yes	Yes	Medium	Operating in effluent stilling basins and sewers
Laser fluorosensor	Fluorescence excited by ultraviolet pulsed laser	Applicable for oil classification	Yes	Yes	Yes	Medium	Extensively tested in laboratory measurements and experimental flights
Low light level television	Difference in reflectivity of solar energy between the oil film & surrounding water	Applicable in low light conditions	Yes	Yes	No	Medium	Operates as supplementary sensor of ultraviolet sensor

Table 5.2.2 In-Situ Sensors

SENSOR	PRINCIPLE	SENSITIVITY	REAL TIME	CONTINUOUS SENSING	NIGHT OPERATION	COVERAGE AREA	OPERATIONAL STATUS
Surface conductivity sensor	Change of conductivity by contact with oil	Applicable in thick oil films Affected by wave action	Yes	Yes	Yes	Narrow	Operating in oil separators, oil storage facilities
Chemical fuse sensor	Dissolution of chemical fuse by oil	Depend on dissolution potential of oil	Yes	Yes	Yes	Narrow	Operating in Abu Dhabi Power Station
Vapor sensor	Evaporated vapor detection from bil	Insufficient in open water environments	Yes	Yes	Yes	Narrow	Laboratory and field tests
Mechanical torque sensor	Increased shaft torque from oil coating	Inoperative in waves, clogging with debris	Yes	Yes	Yes	Narrow	Laboratory tests
Sonar sensor	Acoustic impedance difference amongst water, oil and air	Applicable in thick oil films	Yes	Yes	Yes	Narrow	Laboratory tests
Differential vapor sensor	Temperature difference caused by evaporation properties of oil and water	Only the detection technique has been demonstrated	Yes	Yes	Yes	Narrow	Prototype design

Remote sensors measure the characteristics of emission and reflectance of various electromagnetic wave lengths. Therefore, the sensitivity of such sensors is affected by type of oil and oil film thickness, as well as oceanographic and meteorological conditions. These factors must be considered in the use of remote sensors.

Fluorescence sensors and fluorosensors have a potential for classifying as well as detecting oil film. Other sensors primarily detect only the presence of an oil film. In-situ sensors have been developed that measure the various changes in water characteristics caused by the presence of oil, and thus detect the oil. However, at the present development stage, all sensors discussed in this report, except conductivity and chemical fuse sensors, have problems and are not suitable for practical use.

(2) Oil in Water

Detection systems for analyzing oil in water are generally divided into gravimetric, spectrophotometric and other methods.

1) Gravimetric Method

The gravimetric method is a laboratory technique whereby oil contained in test water is extracted by a solvent such as carbon tetrachloride or normal hexane. The solvent is then removed by evaporation and the weight of oil is obtained by weighing the residue. 62)

2) Spectrophotometric Method

This method is divided into three methods: infrared, ultraviolet-fluorescence and turbidity. Water discharged from vessels and industrial sources is continuously monitored by these methods. 52) 63) 64) 65)

(a) Infrared Method

The principle of this method is to extract the oil contained in test water by a solvent such as carbon tetrachloride and then to measure the absorbance of the extraction using an infrared analyzer in the wave length region which stretches vibration in C-H of hydrocarbons (3.4 to 3.5 μm). Oil concentration is calculated based on the relation between the absorbance and concentration of oil. 52) 65)

Fig. 5.2.10 shows the flow scheme of the analyzer. Other solvents such as trichlorotrifluoroethane that are not absorbed in the 3.4 to 3.5 μm wave length region can be used. The measuring range is 0 to 100 mg/l and accuracy is circa 3 to 5%. 62) 66)

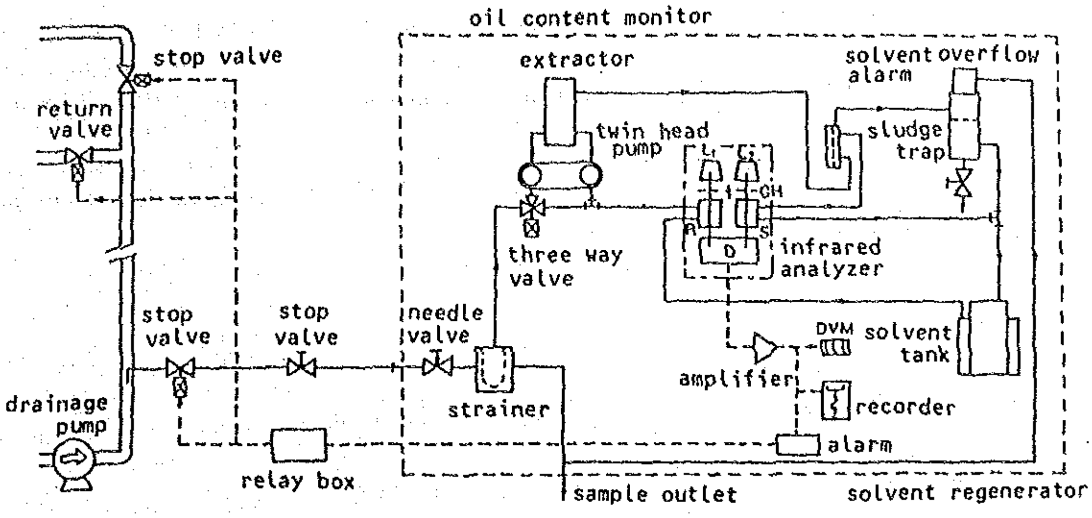


Fig. 5.2.10: Infrared Method Flow Scheme 52)

(b) Ultraviolet-Fluorescence Method

The principle used in this method includes ultraviolet radiation on to test water and subsequent measurement of either ultraviolet absorption or excited fluorescence. Oil content is calculated based on the absorbance or emission strength. 53) 66) 67) 68) The basic principle of the method is shown in Fig. 5.2.11.

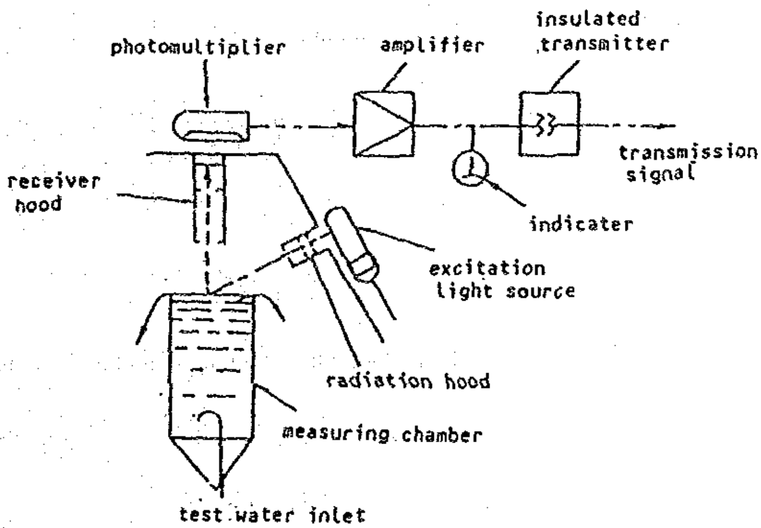


Fig. 5.2.11: Basic Principle of Ultraviolet-Fluorescence Method 52)

Since the test water is measured directly, the structure can be kept simple and response time can also be short. The method measures the ultraviolet absorption or fluorescence by aromatic components and unsaturated double bonds. Since these compounds vary widely from oil to oil, the method is particularly useful for detecting oil when the oil type is known beforehand. The measuring range is 0 to 100 mg/l and accuracy is circa 2 to 5%. 62) 66)

(c) Turbidity

The turbidity of standing test water is first measured, then the turbidity of the emulsified sample is measured using an ultrasonic vibrator, oil concentration is calculated based on the difference of the two measured turbidities. 52) 66)

Fig. 5.2.12 shows a schematic of the method. The method is sensitive to particle size variation, particle color and the build-up of deposits on the photocell window. However, almost the same sensitivity is obtained from petroleum oil as from the above conditions. The measuring range is 0 to 100 mg/l and accuracy is circa 2%. 62) 66)

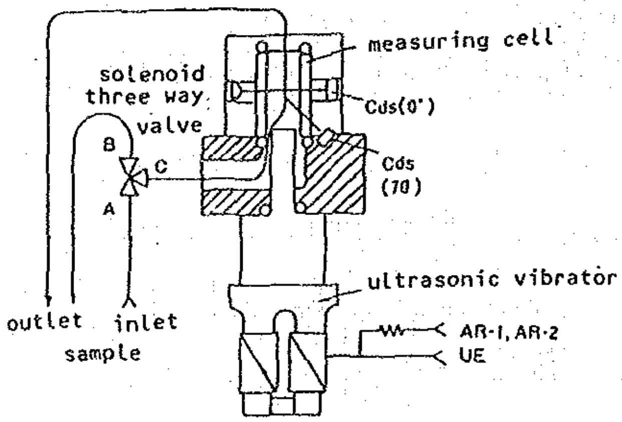


Fig. 5.2.12: Schematic of Turbidity Method 52)

3) Other Principles

(a) Laser Fluorosensor

Several laser fluorosensors have been tested for oil spill detection and identification in water as well as for monitoring chlorophyll and turbidity. 69)

(b) Gas-Liquid Chromatography

This instrument can be used to determine very low concentrations of oil. It is, however, more frequently used as an analytical tool to determine oil type for identification purposes. It could be used quantitatively by summing the area under the detection peaks corresponding to the individual components of oil. 62)

(c) Acoustic Method

The subsurface oil mass can be detected by the use of acoustic waves emitted downward from a sound source at the water surface. The scattered wave indicates suspended solids in the water. The principle is shown in Fig. 5.2.13.

However, it is necessary to use this method in conjunction with other methods for precise identification of oil because particles other than oil (plankton, soil particles, etc.) are also detected by the method. Its applicability has been demonstrated in laboratory tests. 70) This method was also applied to detect subsurface oil from the IXTOC-1 oil well spill in the Gulf of Mexico. 71)

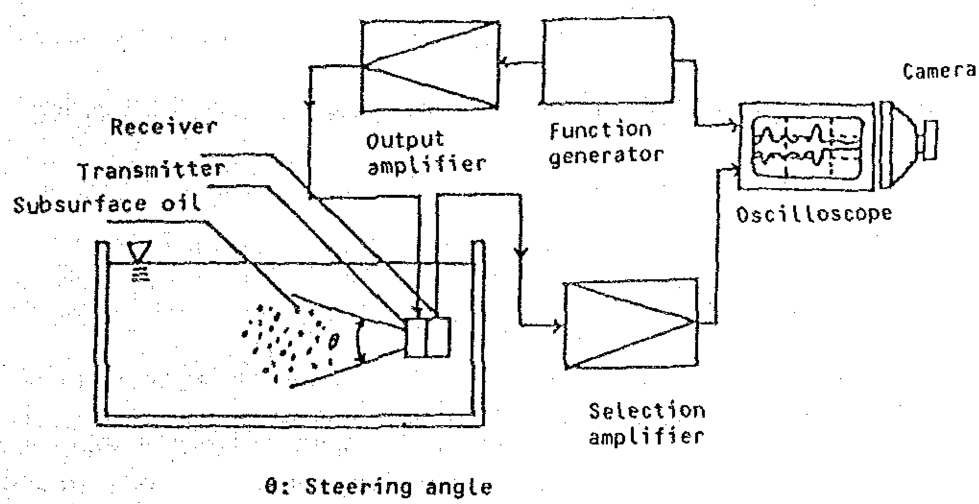


Fig. 5.2.13: Schematic of Acoustic Method 70)

5.2.3 Selection of Monitoring System

To detect oil with certainty and provide an oil spill response after detection, it is necessary to select monitors which are responsive to each of the monitoring parameters. In this section, the monitors are selected based on sensing capabilities, monitoring requirements and existing environmental conditions.

(1) Oil on Sea Surface

The sensors to be used in detection of oil on the sea surface must be capable of:

* Real time response
* Continuous monitoring
* Day and night coverage
* Effective detection under wave conditions
* Effective detection unaffected by ambient conditions
* Experience in field operation

Each of the sensors previously discussed will be evaluated using the above criteria.

1) Remote Sensors

(a) Real Time Response

Each sensor has the capability of real time response for oil detection.

(b) Continuous Monitoring

Each sensor can continuously monitor for the presence of oil.

(c) Day and Night Coverage

Ultraviolet sensors and low light TV are inoperative at night.

(d) Wave Condition

Radar cannot detect oil under high wave and calm conditions.

(e) Ambient Conditions

The fluorescence sensor is affected by atmospheric attenuation and interference from solar energy. Ultraviolet sensors responds to seaweed. Passive infrared sensors cannot be used effectively when significant thermal contrast between oil and surrounding water is not produced.

(f) Experience in Field Operation

Microwave radiometry and laser fluorosensors are currently under development.

2) In-Situ Sensors

(a) Real Time Response

Each detector has the capability of real time response for oil detection.

(b) Continuous Monitoring

The differential vapor sensor is incapable of continuous monitoring since it only samples periodically.

(c) Day and Night Coverage

Each sensor is capable of day and night operations.

(d) Wave Conditions

The surface conductivity sensor and mechanical torque sensor are ineffective when the probe is separated from the water surface.

(e) Ambient Conditions

Mechanical torque sensors can become clogged with debris.

(f) Experience in Field Operation

Vapor sensors, mechanical torque sensors and differential vapor sensors have only been operated in laboratory or field tests. As a result of the above evaluation, the most practical and potential sensors appeared to be:

a) Remote Sensors

* Active infrared sensor

b) In-situ Sensors

* Chemical fuse sensor

(2) Oil in Water

The monitor used to detect oil in water must be capable of:

* Real time response
* Continuous monitoring
* Experience in field operation

Each monitor is evaluated based on the above criteria.

(a) Real Time Response

The gravimetric method and gas-liquid chromatography are not capable of real time response, since the sample preparation and analysis are performed in a laboratory.

(b) Continuous Monitoring

The gravimetric method is not capable of continuous monitoring because an automatic monitor has not yet been developed.

(c) Experience in Field Operations

Infrared, ultraviolet-fluorescence and turbidity methods have been used to monitor oil in discharge water from vessels and industrial sources. The acoustic method has been used in oil well spills. As a result of the above evaluation, the most applicable monitors for detecting oil in water appear to be:

(a) Oil Content

* Infrared absorption method
* Ultraviolet-fluorescence method
* Turbidity method

Although these three methods have been applied practically to oil content metering the ultraviolet-fluorescence method, in which it is unnecessary to pretreat a sample water for solvent extraction, is considered as a candidate for oil content meter in the following section.

(b) Oil Particles in Water

* Acoustic method

As mentioned previously, the acoustic method cannot discriminate oil from other suspended solids. Therefore, to measure the degree of oil concentration in water, it is necessary to design a system that combines the acoustic method with the oil content meter as shown in Fig. 5.2.14.[66)]

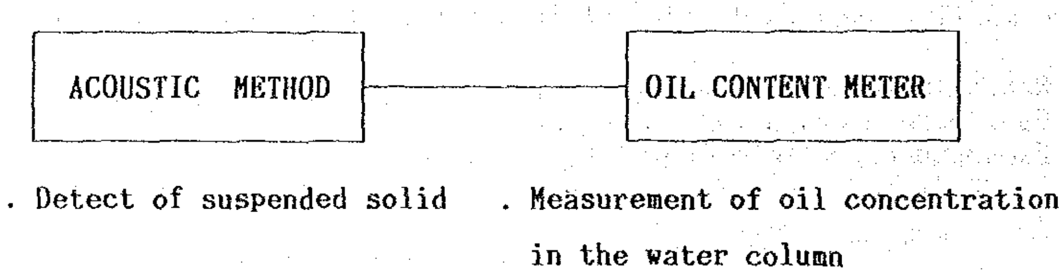


Fig. 5.2.14: Monitoring System of Oil in Water

(3) Oceanographic and Meteorological Parameters

1) Wind Direction and Speed

Knowledge of wind direction and speed are essential for predicting the trajectory of an oil slick on the sea surface and for deployment of countermeasure equipment. A wind sensor as shown in Fig. 5.2.15 has been widely used for the purpose of meteorological observations. This type of wind sensor is sufficient for the measurement of wind direction and speed for the above purposes.

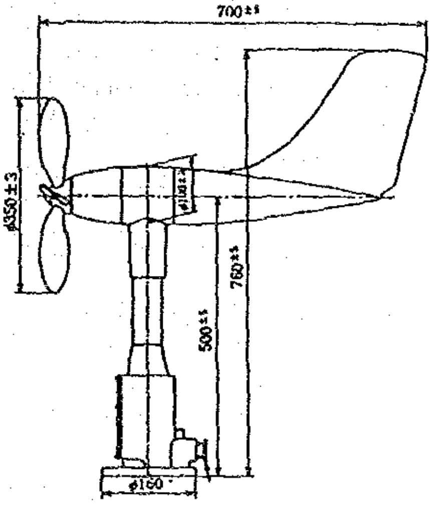


Fig. 5.2.15: Wind Sensor

2) Current Speed and Direction

Speed and direction of sea currents are another environmental factor required for the trajectory modeling of oil slicks and deployment of countermeasure equipment. The following two methods have been generally applied to measure current conditions.

* Current meters
* Hydrodynamic modeling

When measuring sea currents over an extensive area using current meters, it is necessary to deploy a large number of current meters since current speed and direction are influenced by bathymetric and topographic features. Consequently, the use of current meters does not appear to be a practical approach for obtaining data in this case due to the extensive area under consideration. Alternatively, it is recommended the speed and direction of currents be derived from numerical hydrodynamic modeling.

3) Wave Height

Wave action is the primary factor which limits both the sensitivity of the oil sensor on the sea surface and the deployment of response equipment. To compensate data measured by the oil sensor for wave action and to judge the effectiveness of oil spill containment and removal equipment, information on wave height is required. Four main types of wave gauge are considered: ultra sonic, pitch-roll buoy, pressure and wave staff gauges. 49)

(a) Ultrasonic Wave Gauge

With this instrument, ultrasonic pulses are emitted upward from a transmitter installed on the sea bottom. The pulses reflect off surface waves and are received by the transmitter. The wave height is calculated based on the pulse propagation time between the sea bottom and the sea surface. An example is shown in Fig. 5.2.16.

(b) Pitch-Roll Buoy

An accelerometer mounted on the buoy follows the motion of the water surface and obtains wave height. The shape of a surface wave is obtained by double integration of the measured acceleration. An example is shown in Fig. 5.2.17.

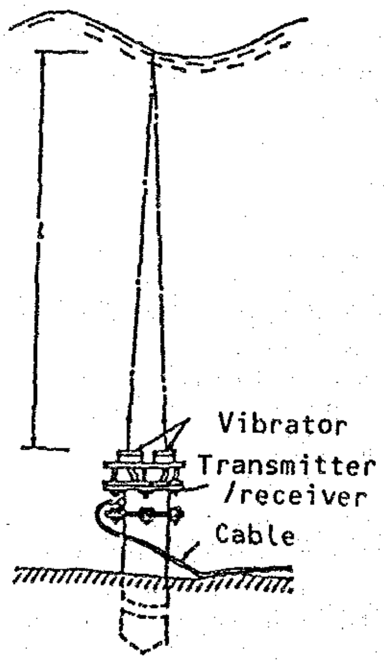


Fig. 5.2.16: Ultrasonic Wave Gauge 72)

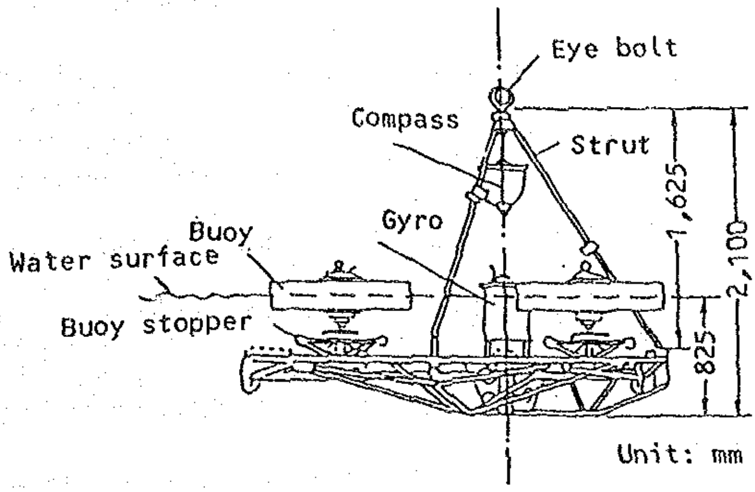


Fig. 5.2.17: Buoy Type Wave Gauge 73)

(c) Pressure Wave Gauge

This method is based on a pressure sensor installed in water at wave height. As the device moves with wave motion, small pressure changes are converted to indicate wave height and period. This principle is shown in Fig. 5.2.18.

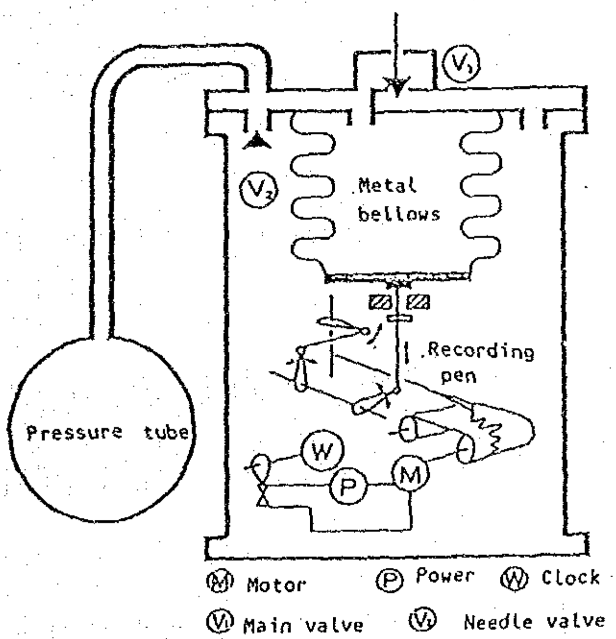


Fig. 5.2.18: Schematic of a Pressure Wave Gauge 73)

(d) Wave Staff

A wave staff is used to measure water levels directly. There are several types of wave staffs, such as graduated sticks for visual observation, step resistance gauges on which electric contact points are attached, and capacitor gauges which measure the change of electric capacity caused by waves.

In summary ultrasonic and buoy wave gauges are sensitive to waves over relatively deep water. A wave staff requires frequent cleaning to maintain sensitivity. A pressure wave gauge is useful in shallow water conditions. Since the water around the Umm al Nar area is relatively shallow, a pressure wave gauge is satisfactory for measuring waves in these conditions.

4) Tide Level

Tide level data would be used for altitude corrections of remote sensors. Tide levels can be derived from the results of harmonic analysis based on field measurements of tide described in 3.3.

5.2.4 Alarm Threshold of Oil Spill

(1) Threshold Value

Detection of oil is based on the comparison of a threshold level and the output signal from an oil sensor or monitor. When the output exceeds the threshold, an alarm is activated. If a low threshold is set, the likelihood of a false alarm increases.

Conversely, a high threshold means that the presence of oil may be missed. The proper threshold level should be based on the balance between reducing the number of missed detections and the likelihood of false alarms. Crude oil and petroleum products are complex mixtures of hydrocarbons.

The light fraction of hydrocarbon is soluble in water. The higher molecular weight components of petroleum are essentially insoluble but can be driven into the water column in the form of tiny droplets by wave action. Therefore, there are two forms in which oil could enter the power and desalination plant through intake water.

Since there are no criteria or standards available on the allowable maximum contaminant levels for oil in sea water passing through power and desalination plants, it is difficult to define the appropriate threshold level for oil in the water column. It has been generally observed that spilled oil on the water, except some kind of crude oil, immediately spreads outward on the water surface.

The observations in the field and from experiments show that oil films do not tend to form homogeneous films of constant thickness. The films are of nonuniform thickness with lenses, striations and other sharp variations in the film thickness over relatively short distances. 74)

This could be due to the distribution of surfactants in the oil which influence the surface tension of oil. It has been reported that the thin region of oil slicks is mostly in the order of 1 to 5 μm .

The thick region is on the order of 1 to 2 millimeter thick and contains most of the total volume. 75) Based on these data and observations, 1 micron appears to be an appropriate thickness for the alarm threshold of oil on the sea surface. The alarm threshold of oil in water is set to be 10 mg/l based on the results of numerical simulation described in 4.4.2 for oil contamination of intake sea water.

(2) Alarm Criteria

1) Oil on Sea Surface

The following two conditions were considered as the triggering criteria of an alarm.

(a) An alarm is triggered whenever the threshold level is exceeded.

(b) An alarm is triggered only if the threshold level is continuously exceeded for a preset period of time T.

Since the output signal fluctuates because of the random noise due to environmental interferences, it was considered that the latter alarm criterion is desirable because there is less probability of a false alarm caused by noise in the output signal.

2) Oil in Water

Oil content meters and acoustic sensors are used to detect oil in water. The alarm criteria based on the signal sent by these equipments are assumed to be as follows:
An alarm is triggered if the detection signal from the acoustic sensor is activated and at the same time the threshold level of the oil content meter is continuously exceeded for a preset period of time T. The two criteria are required since an acoustic sensor cannot discriminate oil from other suspended solids.

5.2.5 Selection of Monitoring Locations

(1) Oil Sensor and Monitor

Several characteristics of the site selected for placement of a monitoring station can affect the sensor and monitor performance. The selection of the monitoring stations should be determined by considering the following factors:

* Anticipated high probability of drifting oil or an oil spill
* Sensor and monitor placement with respect to oil detection
* Stability of oceanographic conditions
* Accessibility for maintenance purposes
* Response time for preventive action

Ideally, a monitoring location should satisfy all the above factors for detection of oil spills. However, it may be impossible to find an ideal location due to the realities of site related factors. Practically therefore, a candidate site that maximizes the detection of oil spill is selected by considering actual site conditions.

It is anticipated that the pathways for spilled oil entering the plant intake facilities are:

* Oil passing the three sections of B, D, and E as shown in Fig. 5.2.19 (derived from the results of oil slick trajectory simulation, 5.1.3)
* Oil passing through the waterway W shown in Fig. 5.2.19.
* Oil spilled from vessels moored at the pier in the vicinity of intake No. 3

1) Oil on Sea Surface

(a) Section B

If an in-situ sensor is deployed, many in-situ sensors would be required to cover Section B due to its width. It is not practical to deploy in-situ sensors along the transect crossing waterway, since the sensors represent an obstacle to vessels and strong currents in the waterway effect both on the sensitivity and mooring of the sensors. In view of the limited applicability of in-situ sensors, it is recommended that a remote sensor should be placed on a purpose-built structure since there are no existing structures available for placement of a remote sensor along Section B.

(b) Section D

Based on the same considerations as for section B, it is recommended that a remote sensor be placed on a new structure in the waterway.

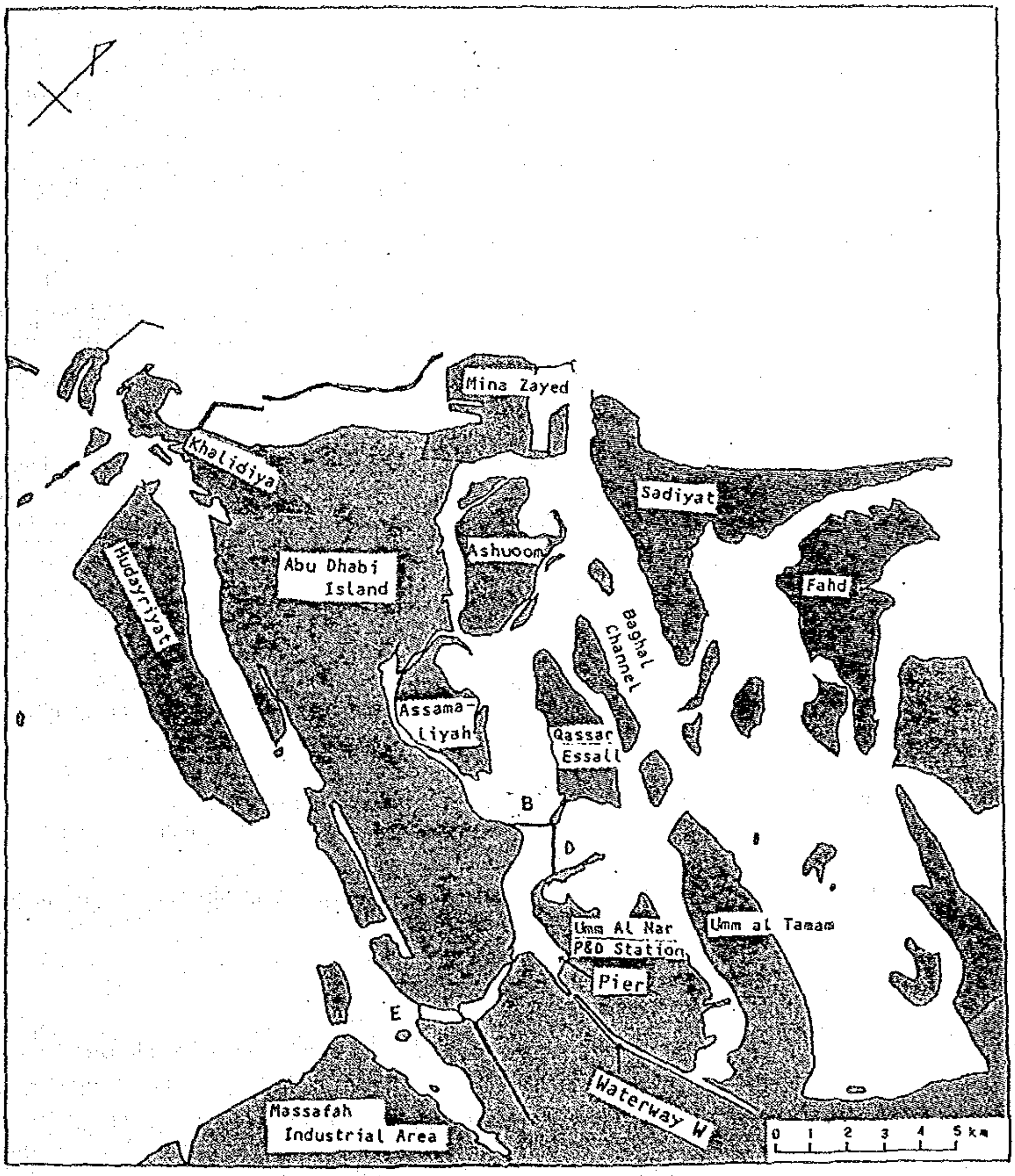


Fig. 5.2.19: Anticipated Path of Oil

(c) Section E

It is recommended that a remote sensor should be installed on an existing structure in the vicinity of Section E, since it is possible that an in-situ sensor might be trapped by vessels passing through Section E. The most practical approach appears to be to utilize the Al Ain Bridge located approximately 1 km northeast of Section E.

(d) Waterway W

It is recommended that a remote sensor be placed on the bridge adjacent to the oil refinery although the results of oil slick trajectory simulation described in 5.1.3 show the low possibility of oil drifting into waterway W.

(e) Oil Spilled from a Vessel

It is reported that an oil spill from a vessel moored at the pier near the No.3 intake occurred as is described in 4.4.3. Consequently, this would appear to be the area which presents the probable location of an oil spill. It would be possible to detect oil from a vessel using a remote sensor installed on the pier.

In addition to the above-mentioned monitoring stations, deployment of a remote sensor at the inlet of lagoon may be useful to increase the time for emergency action, although accuracy and reliability are considered lower than those of sensors installed in recesses of lagoon due to high wave and fast current.

2) Oil in Water

With regard to monitoring oil in water, it is recommended to install the following equipment:

* Strainer and piping system connecting to an oil content meter
* Acoustic sensor for detecting oil particles

These equipments ideally should be placed at the same location as the sensor for oil on the sea surface. However, installation of the equipment at the same location would be impossible since the presence of such equipment interferes with the use of the watercourse for vessels.

An available site avoiding damage to vessels is the area in front of sea water intakes. Equipment placed here would detect oil in water before it entered the plant.

(2) Meteorological and Oceanographic Conditions

1) Wind Sensor

A wind monitoring station ideally should be situated on flat unobstructed terrain. The standard placement of a wind sensor over level open terrain is 10 m above the ground. Where a standard height of exposure is not available, the wind instruments are often mounted at a height greater than 10 m by an amount that depends on the extent, height and distance from obstructions. There are many plants, tanks and buildings in Umm Al Nar which might present obstructions. Considering the following factors:

* Minimum perturbations to the wind field introduced by the structures
* Accessibility for maintenance
* Need of a new tower installation for wind sensing

It is recommended that the top of the turbine building is a suitable place for wind measurement. If the wind speed at a arbitrary height is required, it can be calculated using the following logarithmic formula:

$$Uz_2 / Uz_1 = \ln (Z_2 / Z_0) / \ln (Z_1 / Z_0)$$

Where,

Uz_2: wind speed at height of Z_2
Uz_1: wind speed at the wind sensor height of Z_1
Z_0: roughness length

2) Wave Height

An ideal location for installing a wave sensor should satisfy the following conditions:

* Accessibility for maintenance
* Minimal influence of topographic conditions
* Relatively flat bathymetric conditions
* Minimal effects of reflected waves
* Minimal effects related to vessel navigation

It is appropriate to install a wave sensor near the intake facility considering that preventive action in the event if spilled oil will take place in that waterway. An appropriate location for a wave sensor avoiding the effects of the navigation route is in the area around No.2 Intake.

(3) Central Monitoring Station

A central monitoring station equipped with a processor, display and recording device and alarm indicator is required. This station should be located such that it is easily accessible to the person in charge of the monitoring system and where it will attract immediate attention and facilitate a quick response to the oil spill when an alarm is activated.
From these perspectives, the control room of the power plant is suitable as the location of the central monitoring station.

In conclusion, it is recommended, based on the consideration described above, that the various monitoring stations should be placed as shown in Fig. 5.2.20.

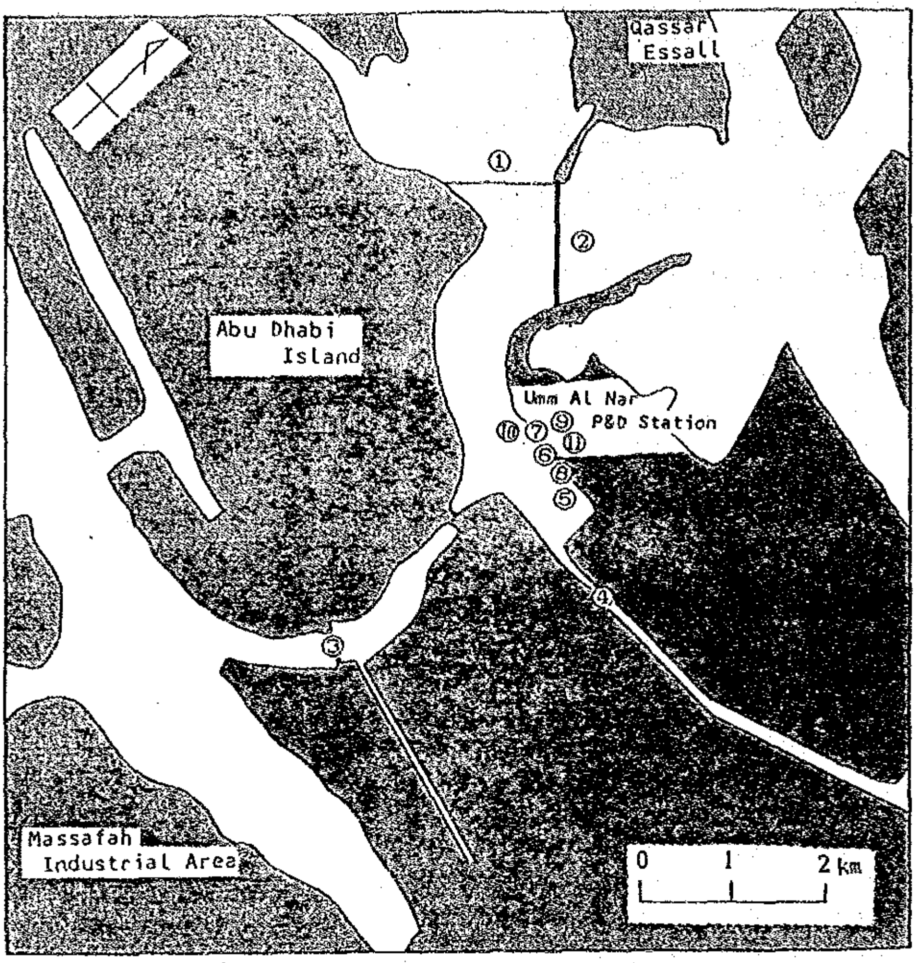


Fig. 5.2.20: Candidate Monitoring Station

Legend

(1) Section B (Active Infrared Oil Sensor)
(2) Section D (Active Infrared Oil Sensor)
(3) Al Ain Bridge (Active Infrared Oil Sensor)
(4) Waterway W (Active Infrared Oil Sensor)
(5) Pier (Active Infrared Oil Sensor)
(6) Intake No. 1 (Acoustic Sensor, Oil Content Meter)
(7) Intake No. 2 (Acoustic Sensor, Oil Content Meter)
(8) Intake No. 3 (Acoustic Sensor, Oil Content Meter)
(9) Turbine Building (Wind Sensor)
(10) Intake No. 2 (Wave Sensor)
(11) Control Room (Central Monitoring Station)

5.2.6: Transmission System

The communications from the remote monitoring stations require a transmission system in which data from the monitoring are carried to a central station for processing and display. The transmission system should be planned so that both the alarm signal and measured data from the monitoring stations can be carried with a low probability of failure.

(1) Transmission Media

Transmissions can be conducted by either radio or direct wire links. Major factors to be considered in selecting the transmission methods are the conditions of monitoring station such as:

* Distance from the central monitoring station
* Existing transmission media available to pass the data
* Location of sensors or monitors
* Terrain
* Installation cost

The selected transmission media based on the above considerations are shown in Table 5.2.3.

Table 5.2.3: Selection of Transmission Media

Sensor / Monitor	Transmission Media
Sensors for oil on the sea	Radio
Oil content meter	Radio
Acoustic sensor	Radio
Wind sensor	Cable
Wave sensor	Radio

The distance of radio signal propagation is mainly dependent on the radio frequency. The VHF or UHF bands, which are utilized over a range from short transmission distances up to several tens of kilometers, are suitable for the radio transmission between monitoring stations and the central monitoring station since the distances are relatively short. (less than 5 km). Radio frequencies are allocated in accordance with rules and regulations pertinent to radio communication. Therefore, a permit must be obtained from the Radio Regulatory Bureau.

(2) Transmission Method

Data transmission procedures are classified generally into three modes: free link mode, basic link mode and HDLC (High Level Data Link Control). The HDCL procedure is most reliable in terms of data error occurrences and has the fastest data transmission speed among these three modes. However, the cost of HDLC hardware compared with the other two modes is expensive. The HDLC procedure is recommended from the point of view of data transmission reliability and high data transmission speed.

The data acquisition system used to transmit data from remote stations (sensor or monitors) to the master station (central monitoring station) can be divided into the three following methods.

* Polling Method

  Master station calls each remote station according to a predetermined sequence and receives data.

* Contention Method

  Data from remote stations are sent to the master station asynchoronously whenever the conditions at a remote station changes.

* Cyclic Method

  Data from remote stations are sent continuously. The polling method has been used widely in environmental monitoring and it is easily capable of handling an increase in the number of remote stations. Moreover, the occurrence of problems in radio transmission and system operation is low, therefore, the polling method is selected.

5.2.7 Conceptual Design of Monitoring System

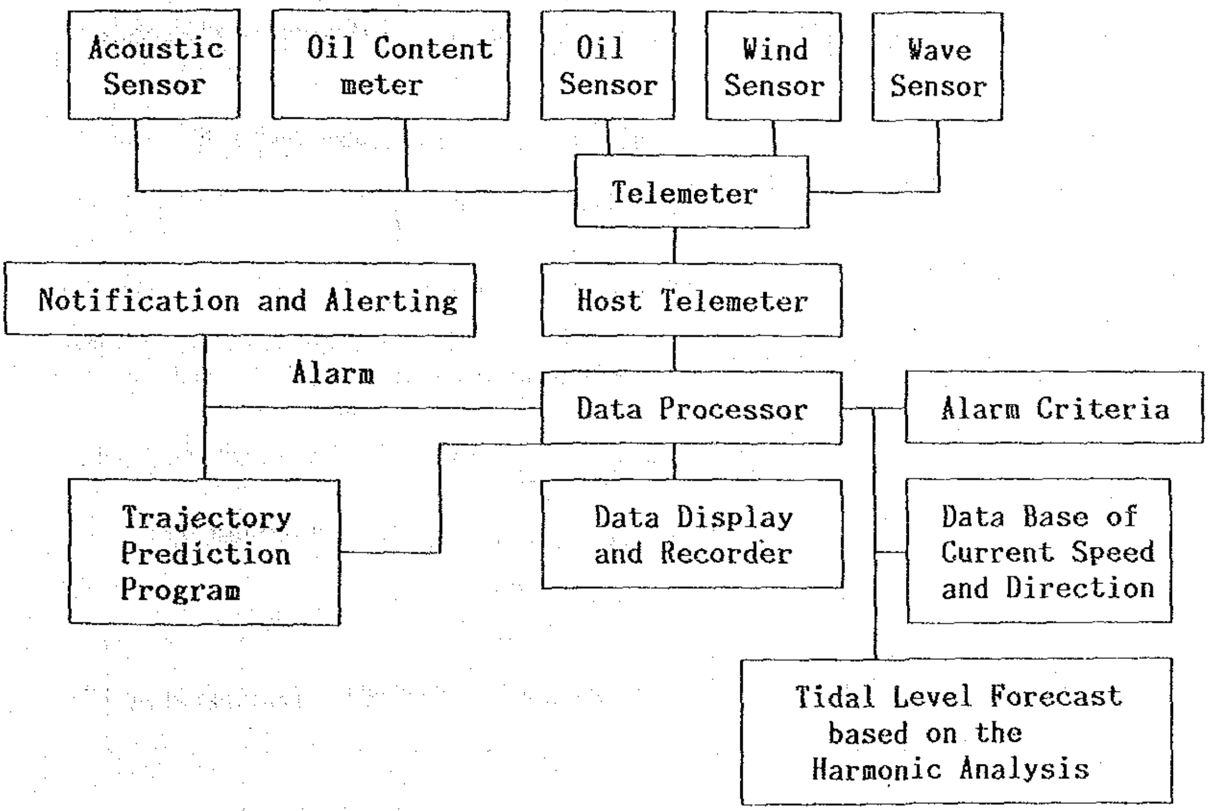
The candidate sensors, monitors, monitoring stations and data transmission systems required for protecting the power and desalination plants from oil spills were selected as described in the above sections. The monitoring system to be developed for the plants should provide automatic and unattended detection and alarm response to an oil spill in real time.

To respond to an oil spill, it is also necessary that the system is capable of providing information on meteorological and oceanographic conditions, and the trajectory of the oil slick after detection. In addition, it should be designed so that the monitoring system is fully operational in the expected deployment environment. The conceptual design of the monitoring system to meet these requirements is described in the following sections.

(1) Total System Configuration

The components required for the monitoring system are shown in Table 5.2.4 and Fig. 5.2.21.

Component	Function
Oil Sensor	Detect oil on the sea surface
Oil Content Meter	Measure oil concentration in water
Acoustic Sensor	Detect oil particles in water
Wind Sensor	Measure wind speed and direction
Wave Sensor	Measure wave height
Telemeter	Transmit a signal
Data Processor	Process the transmitted data
Data Display and Recording Device	Display and record the processed data
Trajectory Prediction Program	Predict the movement of oil slick after detection
Data Base of Current Speed and Direction	Storage of current speed and direction
Tidal Level Forecast	Forecast tidal level based on the results of harmonic analysis



(2) Detection System for Oil on Sea Surface

1) Required Number of Sensors

The coverage area of an active infrared oil sensor, selected as the remote sensor for oil on the sea, is relatively small, although the coverage area is dependent on the height of the sensor above the water surface. For adequate coverage at the monitoring stations, at least the number of sensors shown in Table 5.2.5 should be deployed at each monitoring station.

Table 5.2.5: Number of Sensors

Monitoring Station	No. of Sensors	Remarks
Section B	2	Active infrared oil sensor
Section D	2	Active infrared oil sensor
Section E	2	Active infrared oil sensor
Waterway W	1	Active infrared oil sensor
Pier	1	Active infrared oil sensor
Total	Active infrared oil sensors : 8	

2) System Configuration

The system configuration for detecting oil on the sea surface is shown in Figs. 5.2.22, 5.2.23, 5.2,24 and 5.2.25 and Table 5.2.6.

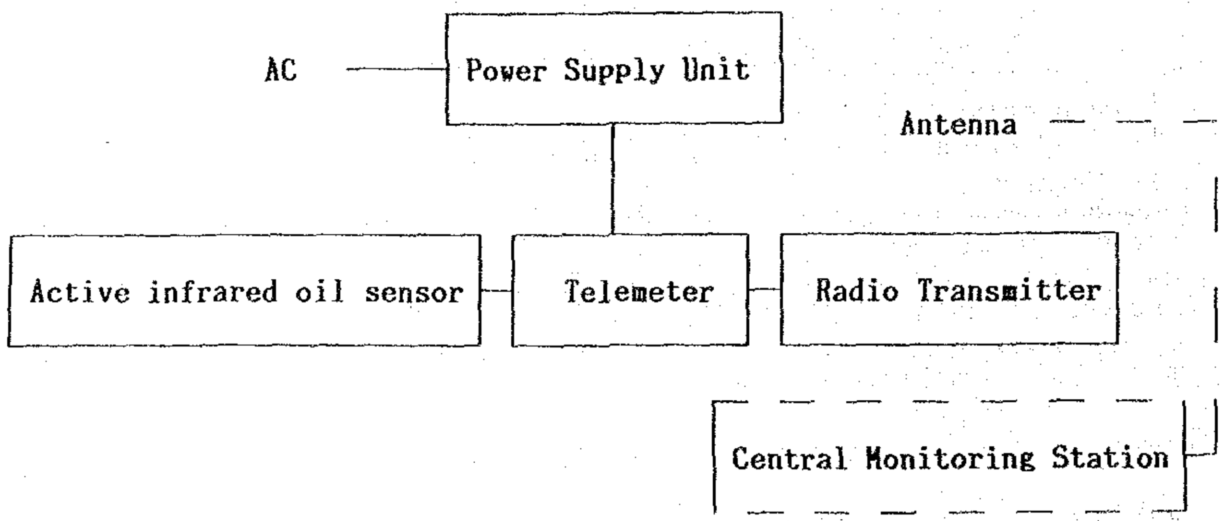


Fig. 5.2.22: System Configuration

Table 5.2.6: Required Equipment

Monitoring Station	Equipment	Quantity
Section B	Active infrared oil sensor Telemeter Radio transmitter Antenna Power supply unit	2 2 2 2 2
Section D	Active infrared oil sensor Telemeter Radio transmitter Antenna Power supply unit	2 2 2 2 2
Section B	Active infrared oil sensor Telemeter Radio transmitter Antenna Power supply unit	2 2 2 2 2
Waterway W	Active infrared oil sensor Telemeter Radio transmitter Antenna Power supply unit	1 1 1 1 1
Pier	Active infrared oil sensor Telemeter Radio transmitter Antenna Power supply unit	1 1 1 1 1

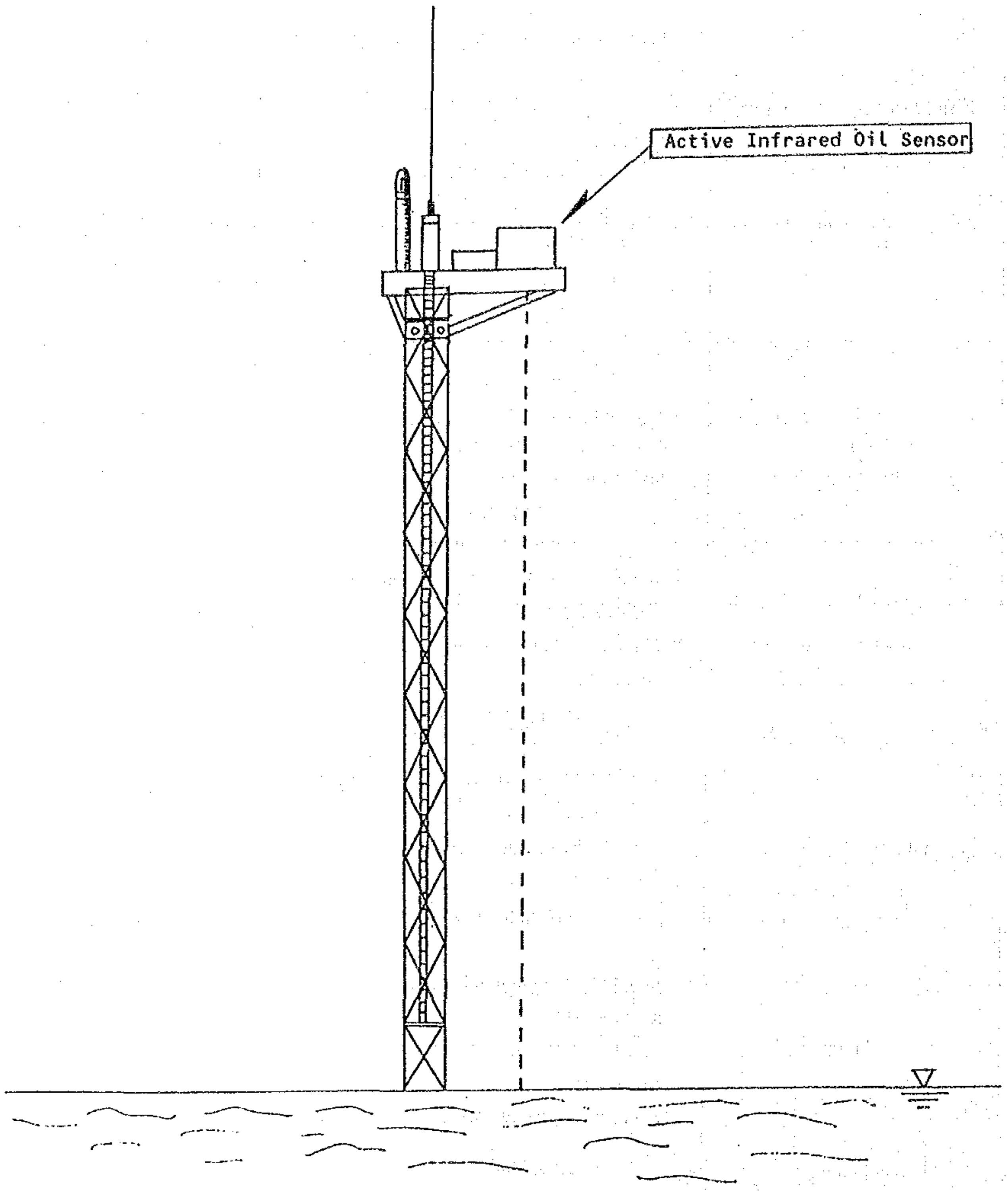


Fig. 5.2.23: Schematic Of Detection System for Oil on Sea Surface
(Sections B and D)

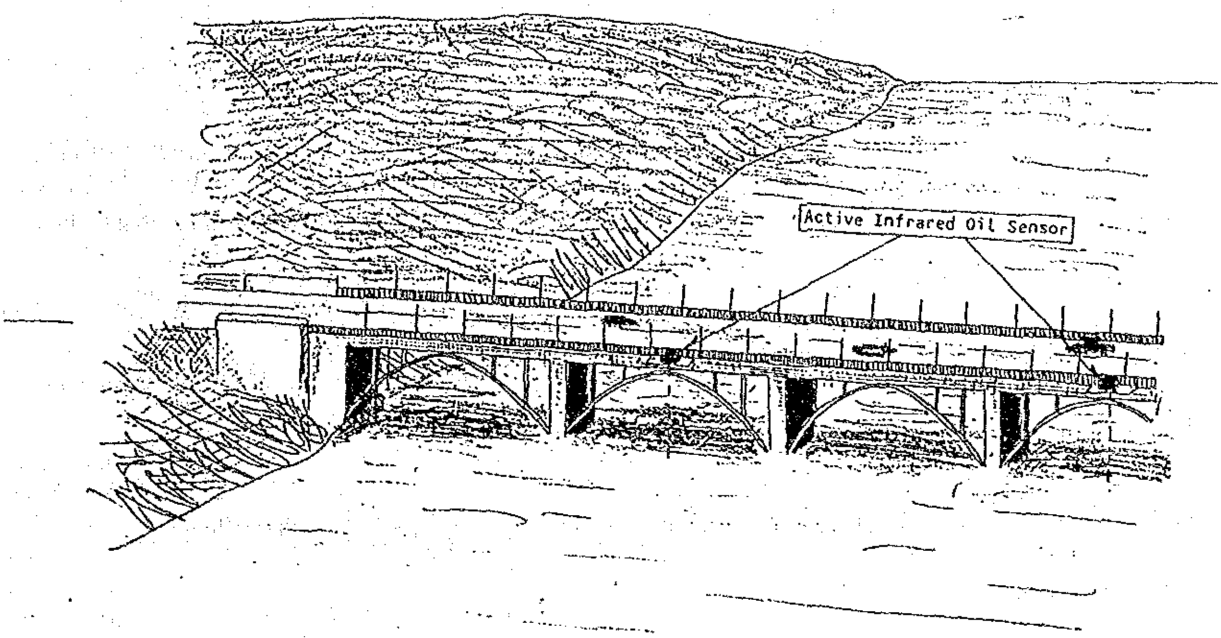


Fig. 5.2.24: Schematic of Detection System for Oil on Sea Surface (Section E and Waterway)

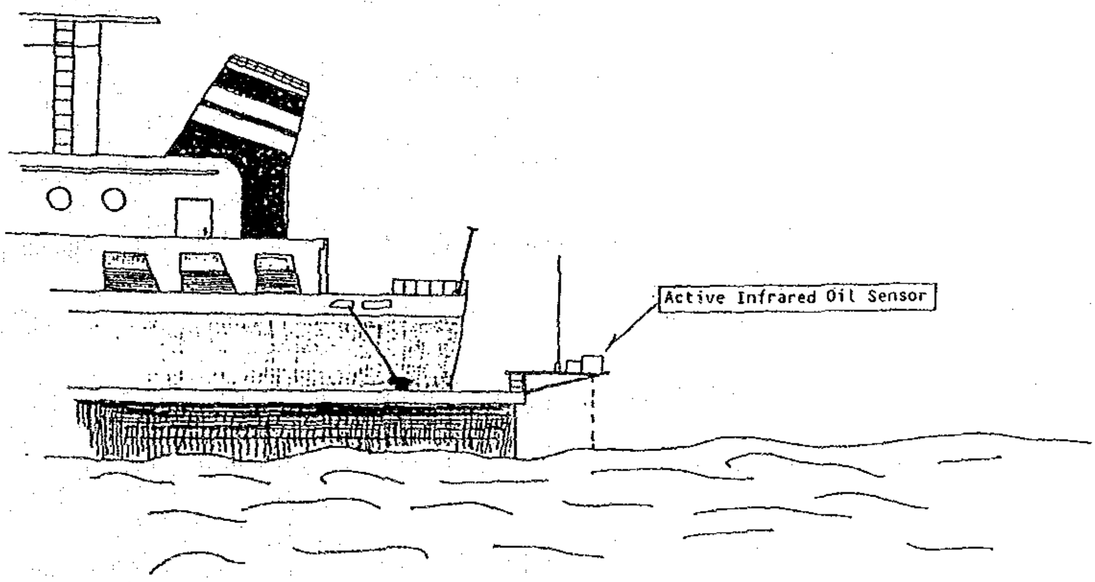


Fig. 5.2.25: Schematic of Detection System for Oil on Sea Surface (Pier)

(3) Detection System for Oil in Water

1) Required Number of Monitors

(a) Oil Content Meters

Because the coverage area of oil content meters can be extended by appropriate arrangement of the water sampling probes, the following number of oil content meters would provide detection of an oil spill.

* Intake No. 1 : 1 (ultraviolet fluorescence analyzer)
* Intake No. 2 : 1 (ultraviolet fluorescence analyzer)
* Intake No. 3 : 1 (ultraviolet fluorescence analyzer)

(b) Acoustic Sensors

The following number of acoustic sensors are required to cover the monitoring area considering the range of the sensor steering angle.

* Intake No. 1 : 1
* Intake No. 2 : 1
* Intake No. 3 : 1

2) System Configuration for oil in water is shown in Fig. 5.2.26, Table 5.2.7 and Fig. 5.2.27.

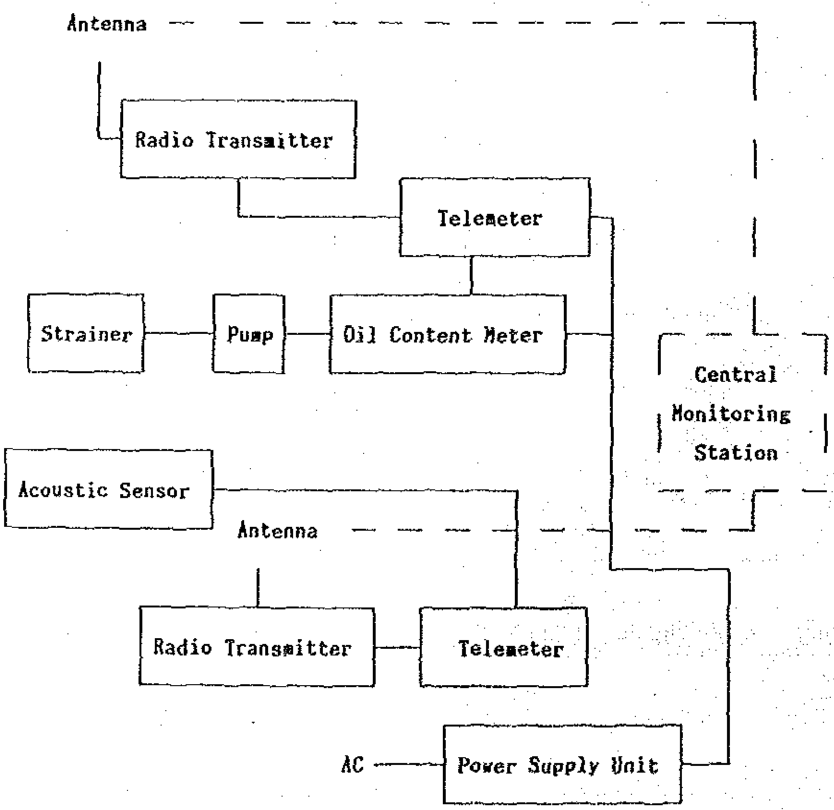


Fig. 5.2.26: System Configuration

Table 5.2.7: Required Equipment

Monitoring Station	Equipment	Quantity
Intake No.1	Oil content meter	1
	Acoustic Sensor	1
	Pump	1
	Radio transmitter	2
	Antenna	2
	Telemeter	2
	Power Supply Unit	1
Intake No.2	Oil content meter	1
	Acoustic Sensor	1
	Pump	1
	Radio transmitter	2
	Antenna	2
	Telemeter	2
	Power Supply Unit	1
Intake No.3	Oil content meter	1
	Acoustic Sensor	1
	Pump	1
	Radio transmitter	2
	Antenna	2
	Telemeter	2
	Power Supply Unit	1

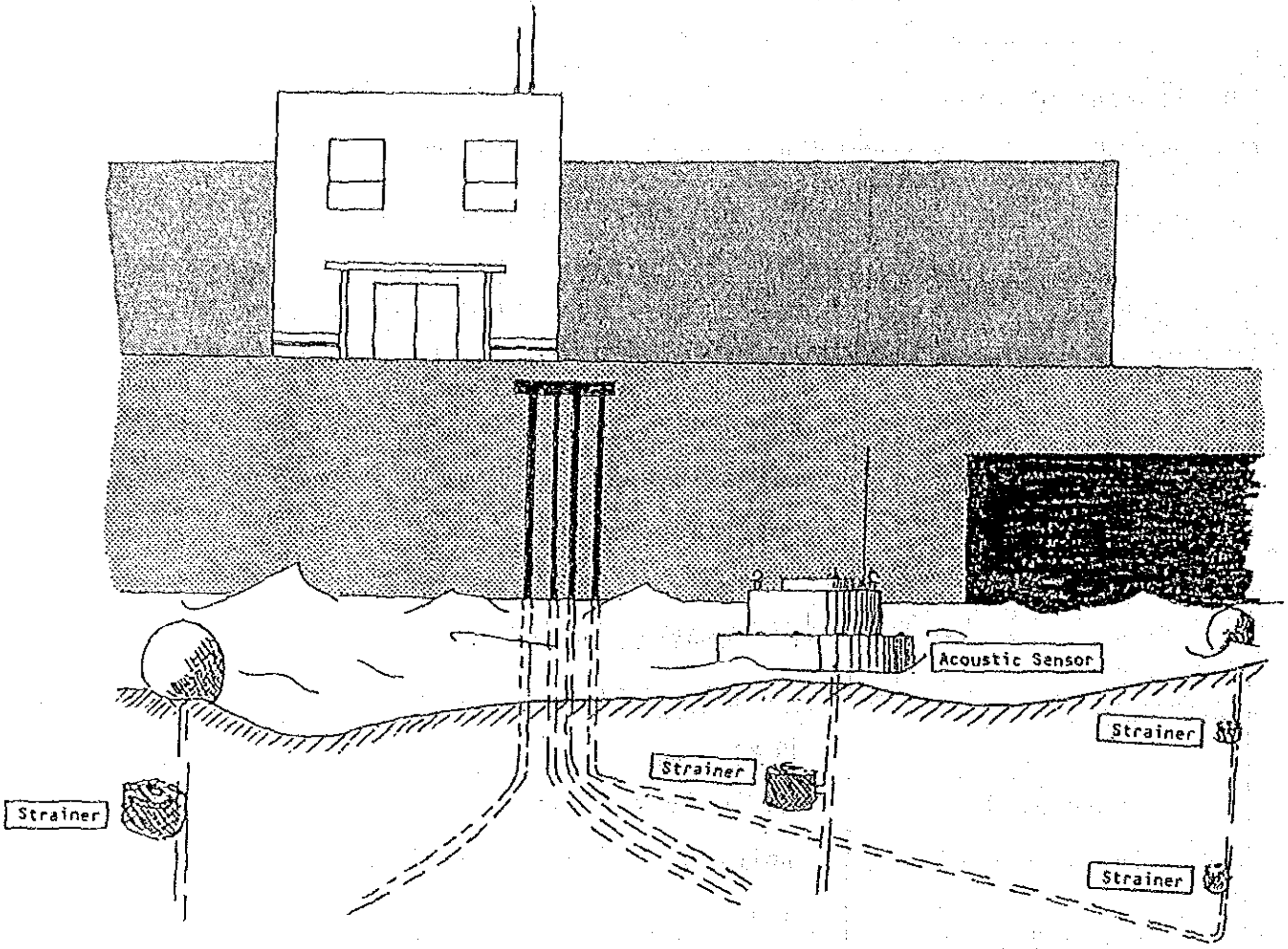


Fig. 5.2.27: Concept of Detection System for Oil in Water

3) Systems Operating Sequence

The detection system for oil in water, consisting of an acoustic sensor and oil content meter, is operated in the sequence shown in Fig. 5.2.28. When a suspended solid is detected by the acoustic sensor, the oil content meter is actuated to discriminate suspended solids from oil.

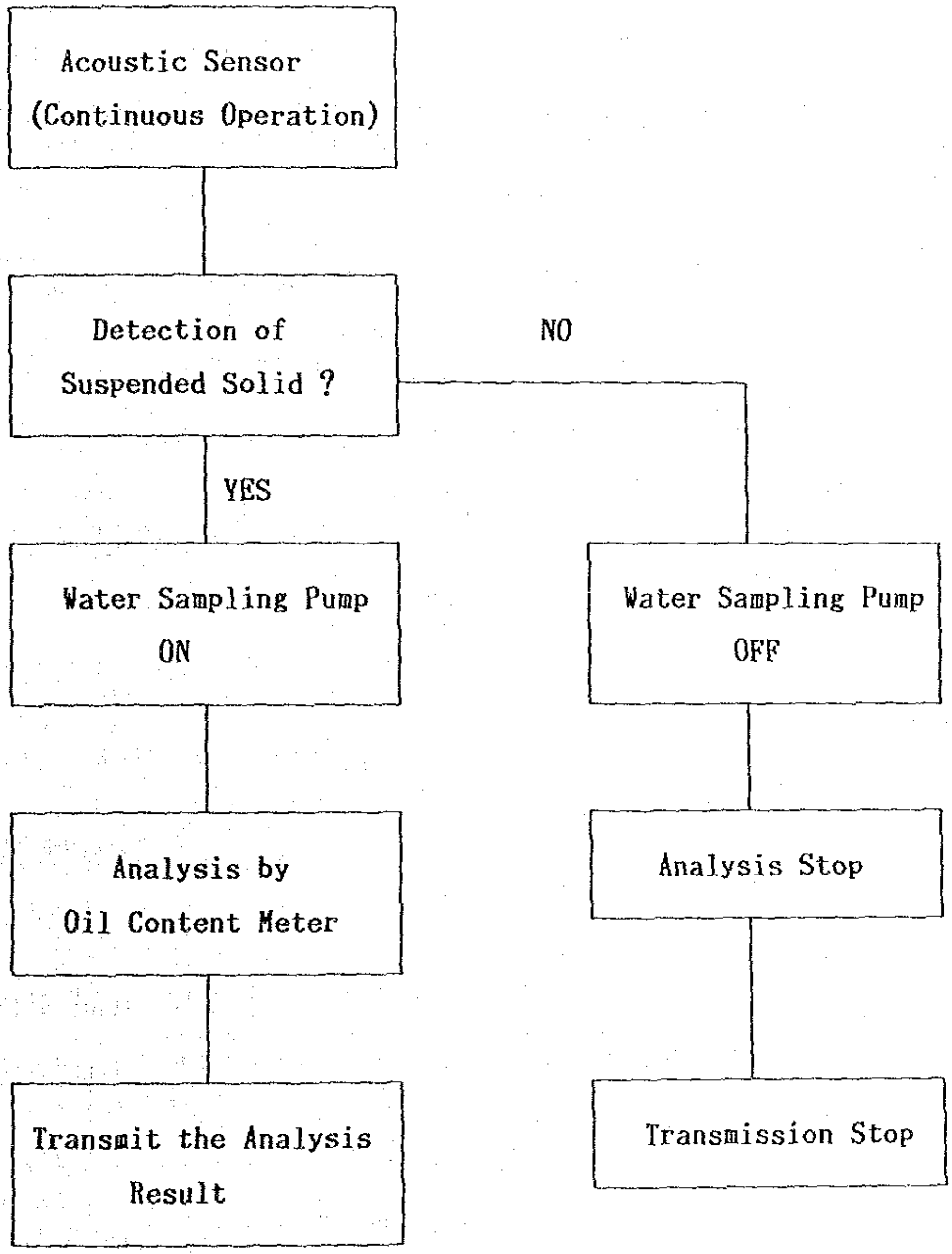


Fig. 5.2.28: System Operating Sequence

(4) Measurement System for Oceanographic and Meteorological Parameters

1) Required Number of Sensors

Representative data and information on environmental conditions can be obtained by the following number of sensors.

* Wind sensor : 1
* Wave sensor : 1

2) System Configuration

The system configuration for oceanographic and meteorological parameters is shown in Figs. 5.2.29 and 5.2.30 and Table 5.2.8.

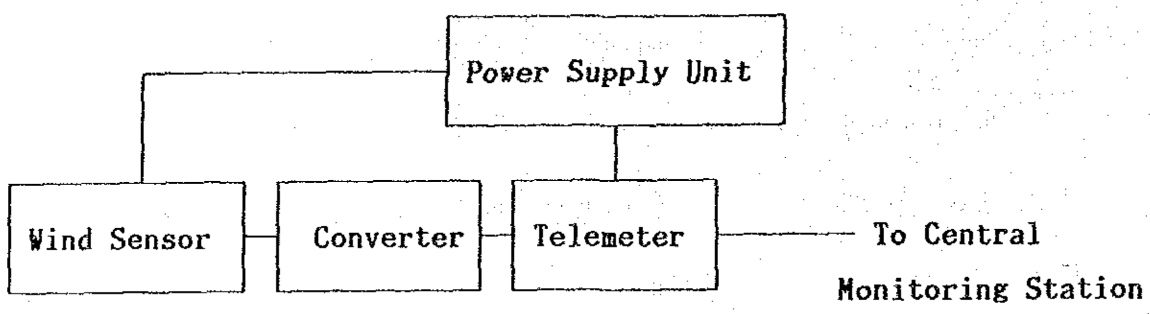


Fig. 5.2.29: Wind Sensor

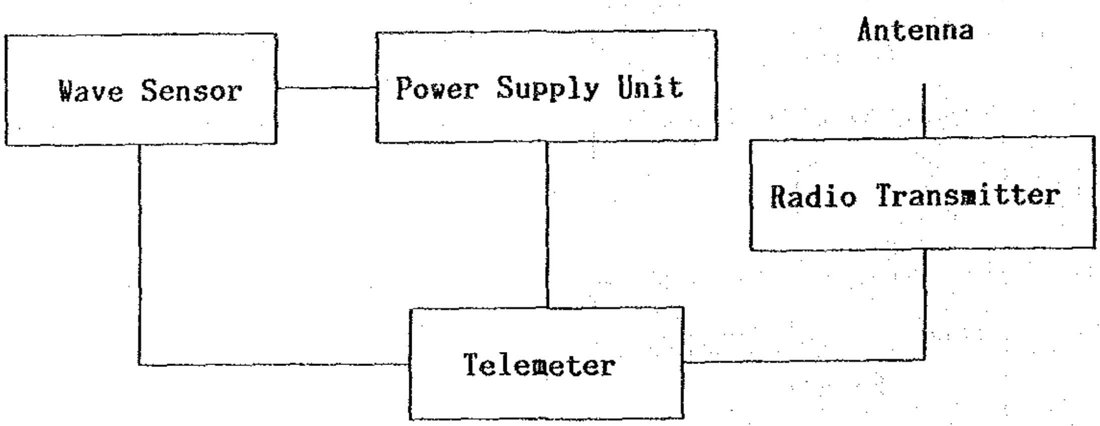


Fig. 5.2.30: Wave Sensor

Table 5.2.8: Required Equipment

Monitoring Parameter	Equipment	Quantity
Wind	Wind Sensor	1
	Power Supply Unit	1
	Telemeter	1
Wave	Wave sensor	1
	Power Supply Unit	1
	Radio Transmitter	1
	Antenna	1
	Telemeter	1

(5) Central Monitoring System

1) Data Processor

The processor is required to receive signals from sensors and monitors at regular time intervals, and process the data on-line and in real-time for automatic and unattended display and recording of the data. A computer is suitable to carry out such data processing. A microcomputer is appropriate for this application because the data processing rate is low.

2) Data Display and Recording

A CRT display screen is suitable for data display. A digital printer, floppy disk and hard disk are required for data recording. Both data display and data recording devices should be connected with the microcomputer for data processing. The basic data should be stored in a form which allows easy retrieval. The data automatically displayed and recorded should include at least the following items:

* Time and date
* Alarm conditions
* Sensor or monitor condition (active, failure)
* Oil concentration
* Wind speed
* Wind direction
* Wave height
* Current speed and direction
* Tidal level

The data should be displayed and recorded at the following frequencies.

* Alarm condition: when an alarm is developed
* Sensor or monitor condition: when a failure condition is developed
* Oil concentration: hourly
* Wind speed and direction: hourly
* Wave height: hourly
* Current speed and direction: when an alarm is activated
* Tidal level: hourly

3) System Configuration

The system configuration for the central monitoring station is shown in Fig. 5.2.31 and Table 5.2.9.

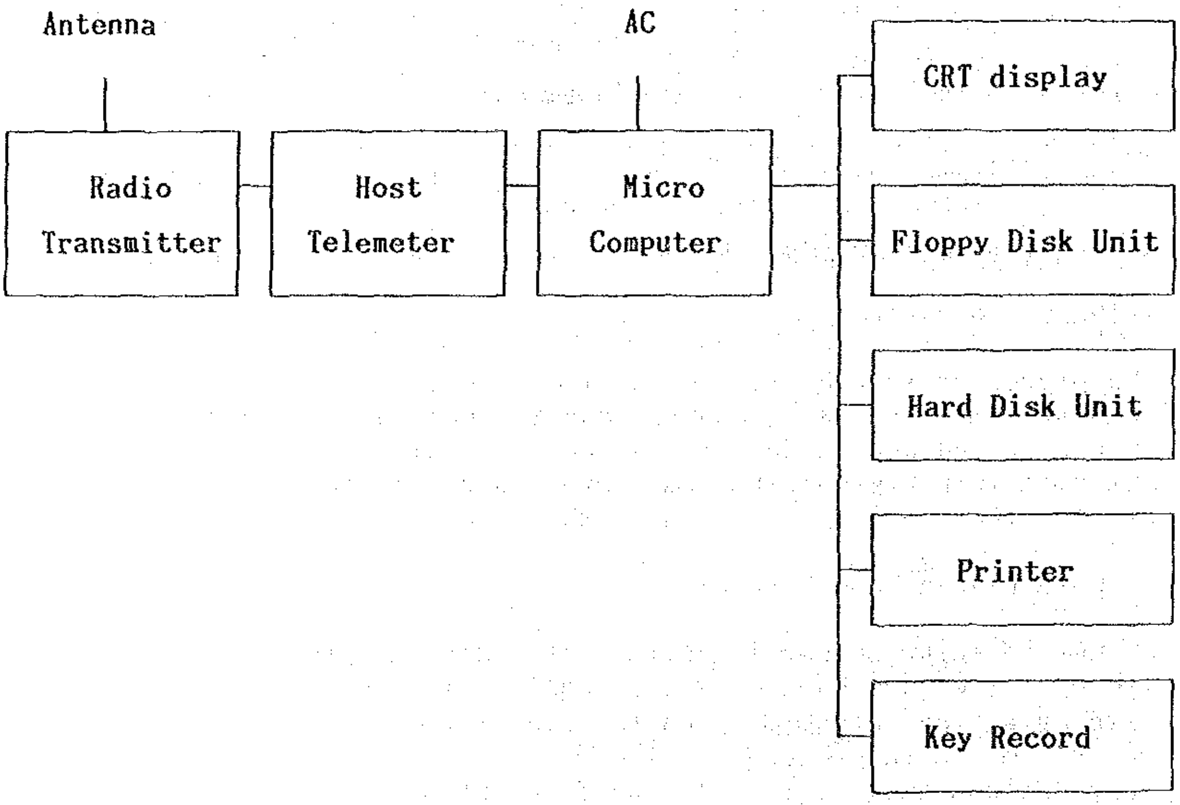


Fig. 5.2.31: System Configuration

Table 5.2.9: Required Equipment

Equipment	Quantity
Micro Computer	1
CRT Display	1
Floppy Disk unit	1
Hard Disk unit	1
Keyboard	1
Printer	1
Host telemeter	1
Radio transmitter	1
Antenna	1

(6) Trajectory Prediction Program

A computer simulation model which is able of predicting the movement of an oil slick is a useful tool for strategizing oil spill response. The role of the simulation program is shown in Fig. 5.2.32.

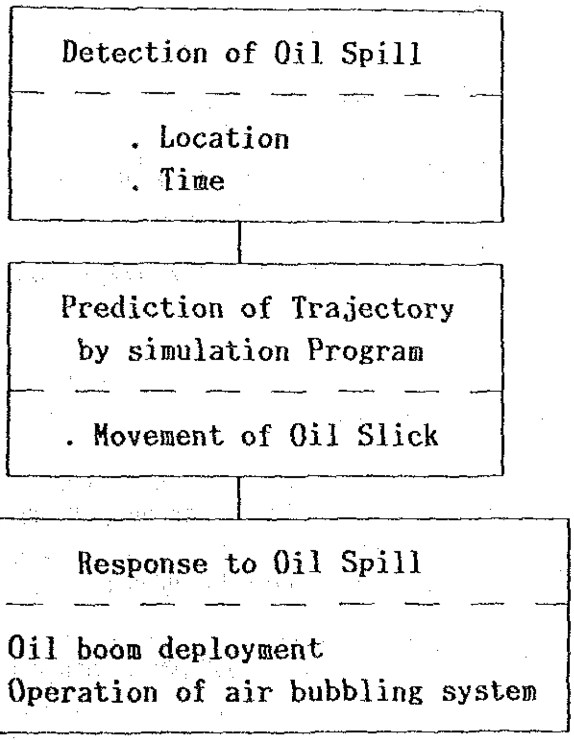


Fig. 5.2.32: Role of Simulation Model

A real-time system should be developed to use the simulation program in emergency situations. The structure of the model to be developed is assumed to be as follows:

(a) Drift Model

Assuming that the primary factors affecting the movement of an oil slick are winds and currents, a superposition theory of wind and current vector may be applied as it is in most drift models. The wind-induced velocity is found by multiplying the wind speed by a wind factor.

(b) Wind Data

Actual wind speed and direction data can be directly obtained from the telemeter data transmitter from the wind sensor.

(c) Current Data

The data file of current speed and direction information should be created using a numerical hydrodynamic model. The data file should be stored in a computer from which the current data can be derived since it requires a great deal of time to prepare the temporal and spatial descriptions of current data.

(d) Input Data

The main keyboard inputs to the simulation program are:

* Location of oil slick
* Tidal phase

(e) Output Data

The main outputs from the simulation program are:

* Present time
* Predicted trajectory of oil slick as a function of time
* Wind vectors
* Current vectors

(f) Computer System

The required size of the computer is a function of the size the computer program. The trajectory simulation program should be developed to meet the size requirements of the computer for monitoring data processing since it is expected that the run frequency of the model will be very low.

(g) Operation

The simulation of an oil spill trajectory is initiated from the keyboard by loading the program and typing in the required input data. The wind data are entered from the telemetry system, and the current data are read from the current data file. The simulation results are displayed on a CRT display or on a digital printer.
The components of the simulation are shown in Fig. 5.2.33.

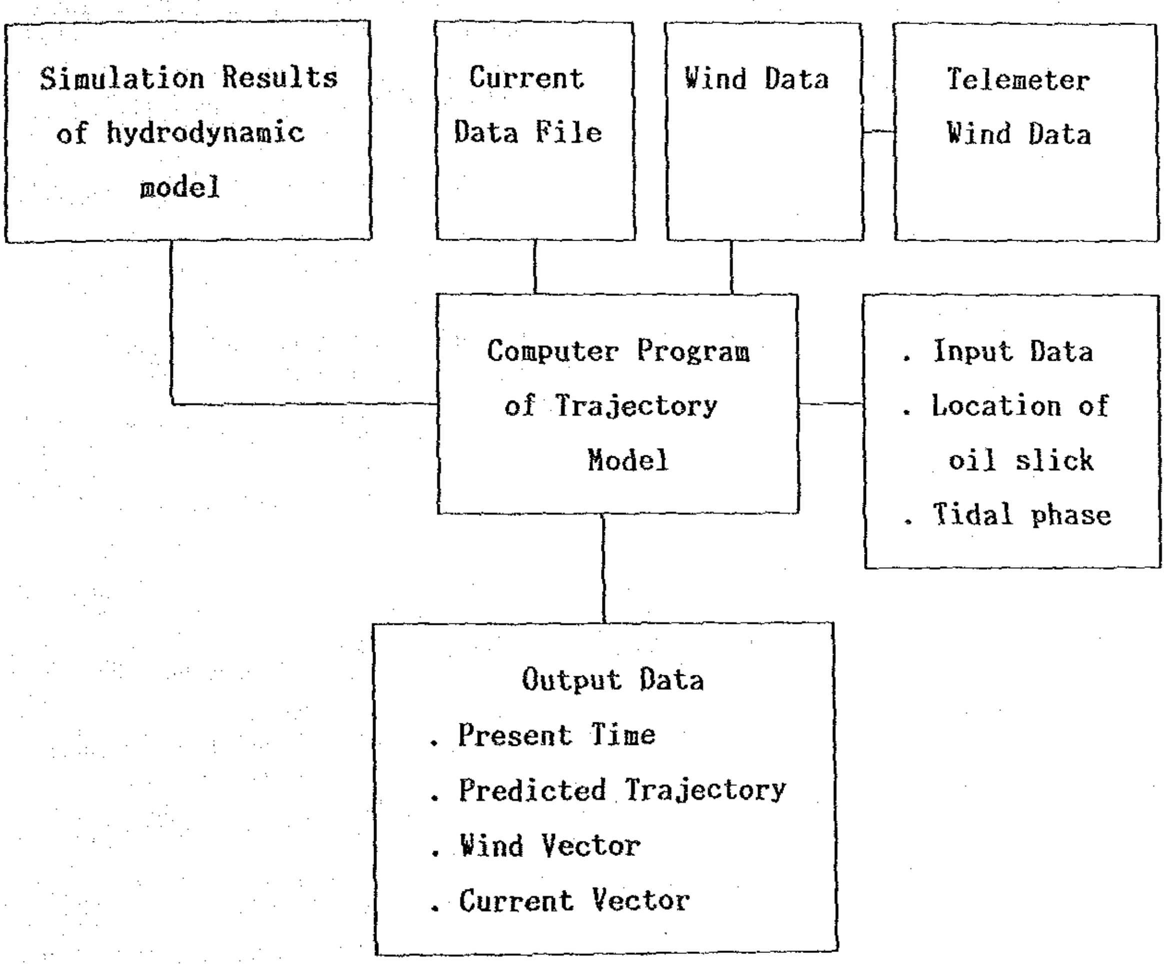


Fig. 5.2.33: Components of the Simulation Model

(7) Specifications of Equipment

The components of the monitoring system need to meet certain requirements in order to operate under the expected deployment environment. These requirements are described in the following subsections.

1) Sensors for Oil on Sea

* Sensing object:	Oil film on the sea surface
* Sensor type:	Active infrared oil sensor
* Operating distance:	Greater than 10 m (above water surface)
* Detectable Minimum oil film:	1 micron thickness
* Ambient temperature:	0 - 60 °C
* Ambient humidity:	20 - 100%
* Environment:	Waterproof, dustproof, explosion proof, corrosion resistant
* Alarm:	Oil alarm, equipment failure
* Power:	AC
* Response time:	within 20 sec.

2) Monitors for Oil in Water

(a) Oil content meter

* Measuring object:	Oil concentration in water column
* Method:	Ultraviolet-fluorescence method
* Range:	0 - 100 ppm
* Reproductivity:	Better than 5%
* Sample water:	Sea water
* Sample temperature:	10 - 40 °C
* Ambient temperature:	0 - 60 °C
* Ambient humidity:	20 - 100%
* Environment:	Dustproof, explosion proof
* Alarm:	Oil alarm, equipment failure
* Power:	AC
* Response time:	within 20 sec.

(b) Acoustic Sensor

* Detecting object:	Oil particle in water
* Method:	Acoustic method
* Frequency range:	100 - 3000 kHz
* Environment:	Waterproof, corrosion resistant tropic-proofing
* Operating water depth:	0 - 20 m
* Alarm:	Oil detection alarm, equipment failure
* Power:	AC
* Response time:	within 10 sec.

3) Meteorological and Oceanographic Sensors

(a) Wind Sensor

* Measuring object:	Wind speed and direction
* Sensor type:	Windmill or propeller anemeter with wind vane
* Range:	0 - 60 m/s, 0 - 360°

* Accuracy: circa 0.4 m/s (wind speed < 10 m/s)
circa 4 % (wind speed > 10 m/s)
* Ambient temperature: 0 - 60 °C
* Ambient humidity: 20 - 100%
* Environment: Waterproof, dustproof, tropic-proofing

(b) Wave Sensor

* Measuring object: Wave height
* Sensor type: Pressure wave gage
* Range: 0 - 10 m
* Accuracy: circa 1%
* Environment: Waterproof, corrosion resistant, tropic-proofing
* Operating water depth: 0 - 30 m

4) Computer System

* CPU: 32 bit microprocessor
* Memory: Minimum 2 MB
* Display: 640 dot x 400 line (RGB)
* Peripheral memory: Floppy disk 1 MB x 2, hard disk 40 MB
* Printer: Digital printer, 136 character / line
* Keyboard: with dust cover
* Power: AC
* Ambient temperature: 0 - 50 °C
* Ambient humidity: 20 - 90%

5) Telemeter

(a) Station Telemeter
* Communication link: 1 : N
* Data acquisition: Polling method
* Transmission rate: 200 BPS
* Transmission mode: HDLC
* Power: AC
* Ambient temperature: 0 - 60 °C
* Humidity: 20 - 90%

(b) Host Telemeter
* Communication link: 1 : N
* Data acquisition: Polling method
* Transmission rate: 200 BPS
* Transmission mode: HDLC
* Power: AC
* Ambient temperature: 0 - 50 °C
* Humidity: 20 - 90%

6) Power Supply Unit

* Type: Uninterruptible power equipment
* Capacity: More than 30 min
* Ambient temperature: 0 - 60 °C
* Humidity 20 - 90%
* Environment: Waterproof, dustproof, tropic-proofing

(8) Complete Conceptual Design

The complete conceptual design is shown in Fig. 5.2.34. Because this conceptual design is primarily based on the available data and a synoptic field survey, basic and detailed designs are required to finalize the conceptual design.

(9) Installation Sequence

The total monitoring system can be divided into four subsystems:

* Detection system for oil on the sea surface
* Detection system for oil in water
* Measurement system for meteorological and oceanographic parameters
* Trajectory prediction system

Two approaches to establishing the total monitoring system were considered.

(a) Simultaneous Installation

Installation of the four subsystems simultaneously. This approach requires a high initial investment but results in a short establishment period for the total system.

(b) Stepwise Installation

Because it has been generally observed that most spilled oil spreads and drifts on the sea surface, the total system is established in four steps which are dependent on the priority related to detection of oil spill. The proposed steps are as follows:

Step 1: Detection system of oil on the sea surface
Step 2: Detection system of oil in water
Step 3: Measurement system of meteorological and oceanographic parameters
Step 4: Trajectory prediction system

The projected installation sequences for these 2 approaches are summarized in Fig. 5.2.35 and Fig. 5.2.36.

(10) Cost Estimation

The current estimated costs for the establishment of the monitoring system are given in Table 5.2.10 to Table 5.2.13. However, these costs do not include the cost of database preparation.

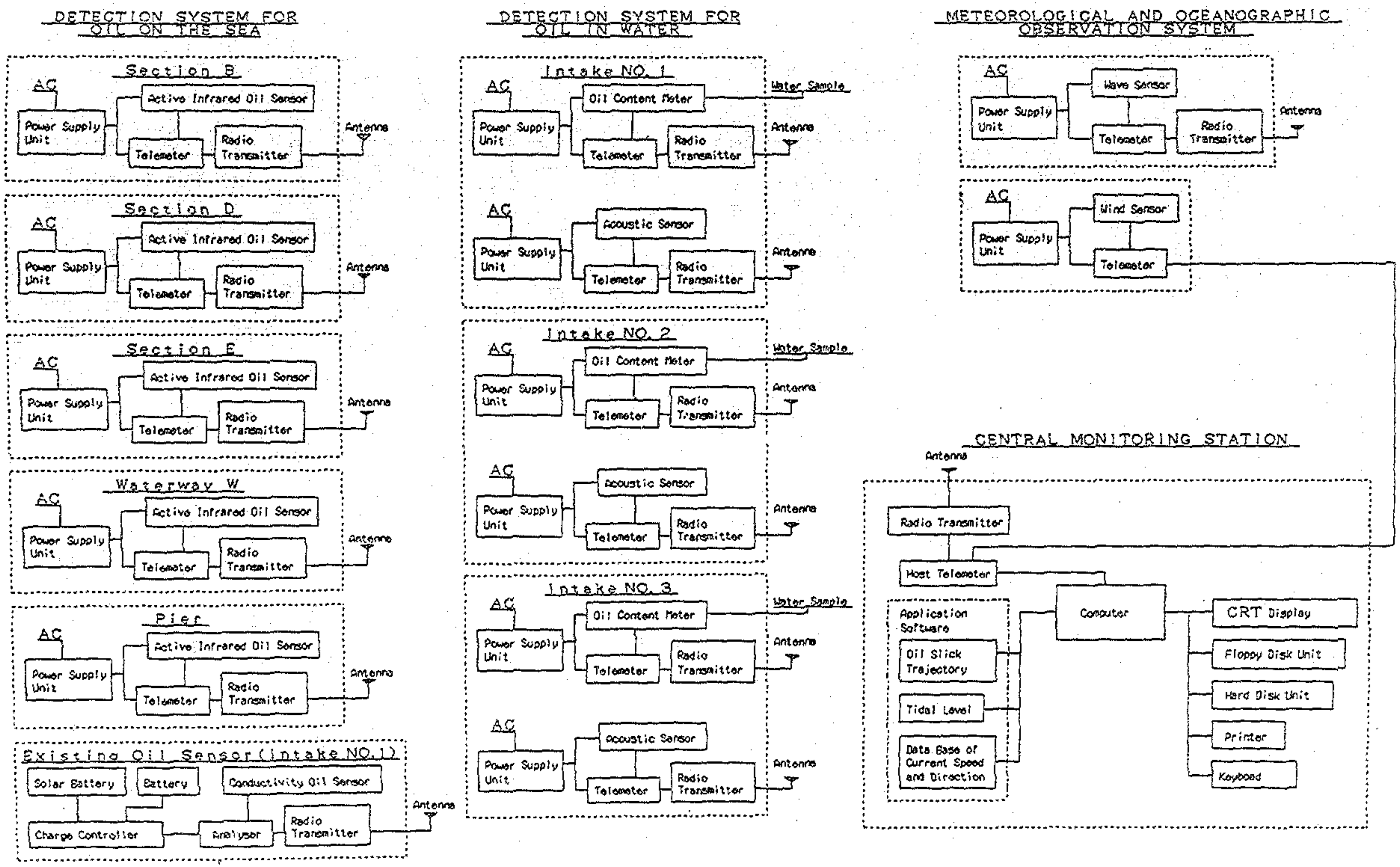


Fig. 5.2.34: Total Conceptual System

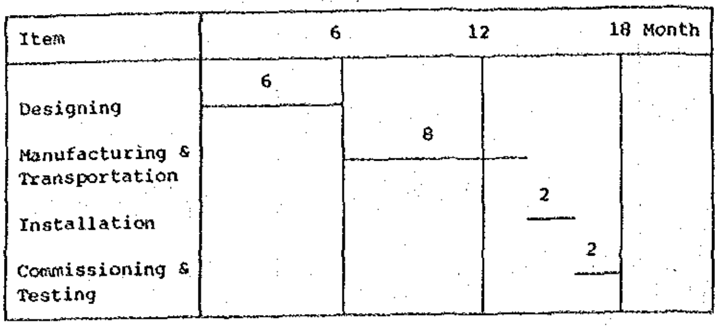


Fig. 5.2.35: Simultaneous Installation

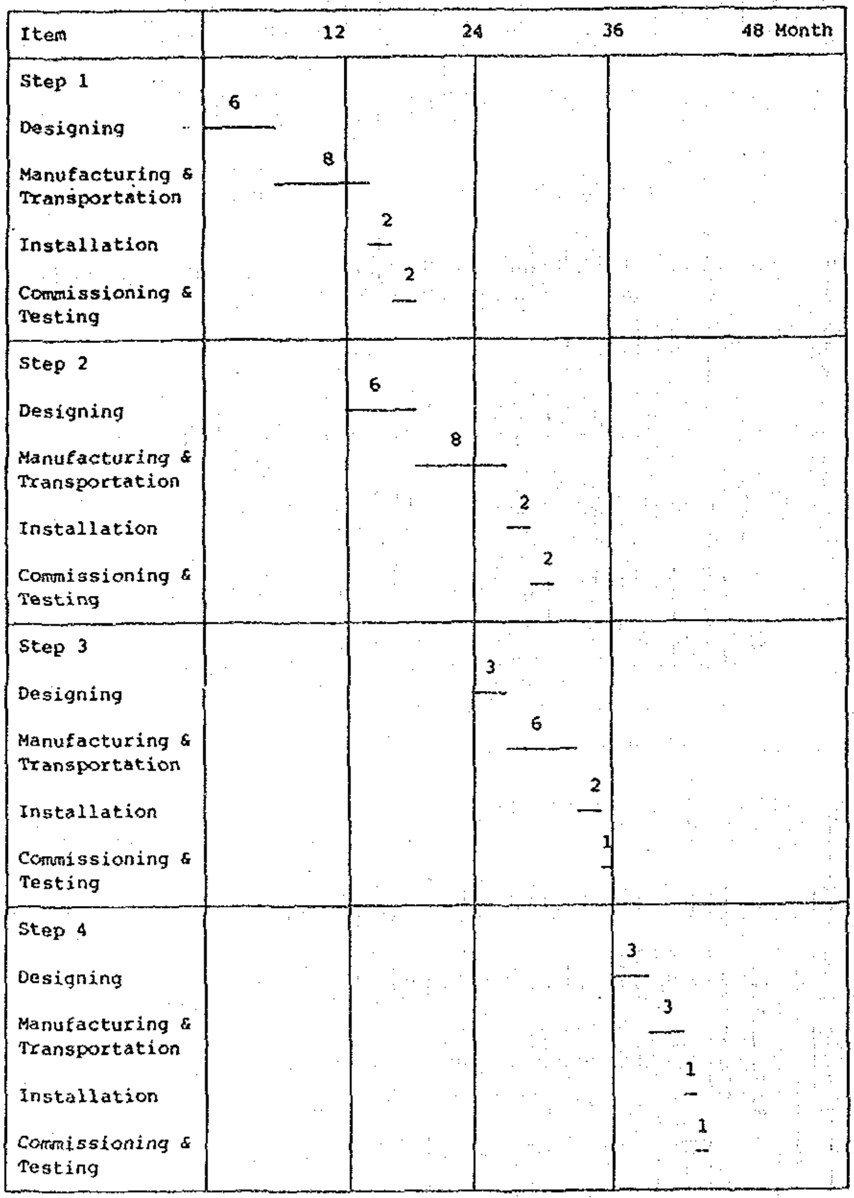


Fig. 5.2.36: Stepwise Installation

Table 5.2.10: Estimated Costs (Detection System for Oil on Sea)

Item	Quantity	Cost	
		Yen Portion (¥1,000)	DH Portion (DH 1,000)
1. Sensor/Equipment			
(1) Active Infrared Oil Sensor	8	24,000	
(2) Telemeter	8	8,000	
(3) Radio Transmitter	8	8,000	
(4) Antenna	8	100	
(5) Power Supply Unit	8	8,000	
2. Sensor Mounting Framework			
(1) Offshore Platform	4	32,000	
(2) Mounting Framework for Bridge and Pier	4	2,000	
3. Packaging and Freight	lump	4,500	
4. Installation	lump		430
5. Electrical & Instrumentation	lump	5,800	280
6. Field Adjustment and Test Operation	lump	3,000	
7. Other Expenses	lump	13,900	110
Total		109,300	820

Table 5.2.11: Estimated Costs (Detection System for Oil in Water)

Item	Quantity	Cost	
		Yen Portion (¥1,000)	DH Portion (DH 1,000)
1. Sensor/Equipment			
(1) Oil Content Meter	3	12,000	
(2) Acoustic Sensor	3	6,000	
(3) Pump	3	6,000	
(4) Telemeter	6	6,000	
(5) Radio Transmitter	6	6,000	
(6) Antenna	6	100	
(7) Power Supply Unit	6	6,000	
(8) Piping Material	3	13,000	
(9) Housing for Monitor	3		80
2. Packaging and Freight	lump	1,000	
3. Installation	lump		2,850
4. Electrical & Instrumentation	lump	5,100	230
5. Field Adjustment and Test Operation	lump	3,000	
6. Other Expenses	lump	9,600	470
Total		73,800	3,630

Table 5.2.12: Estimated Costs (Meteorological and Oceanographic Data Observation System)

Item	Quantity	Cost	
		Yen Portion (¥1,000)	DH Portion (DH 1,000)
1. Sensor/Equipment			
(1) Wind Sensor	1	2,000	
(2) Wave Sensor	1	3,000	
(3) Telemeter	2	2,000	
(4) Radio Transmitter	1	1,000	
(5) Antenna	1	20	
(6) Power Supply Unit	2	2,000	
2. Packaging and Freight	lump	300	
3. Installation	lump		10
4. Electrical & Instrumentation	lump	900	50
5. Field Adjustment and Test Operation	lump	3,000	
6. Other Expenses	lump	2,100	10
Total		16,320	70

Table 5.2.13: Estimated Costs (Central Monitoring Station)

Item	Quantity	Cost	
		Yen Portion (¥1,000)	DH Portion (DH 1,000)
1. Equipment			
(1) Computer	1	1,000	
(2) Peripheral Equipment	1	1,500	
(3) Host Telemeter	1	3,000	
(4) Radio Transmitter	1	1,500	
(5) Antenna	1	50	
2. Database, Software Application Program	lump	20,000	
3. Packaging and Freight	lump	200	
4. Installation	lump		5
5. Electrical & Instrumentation	lump		5
6. Field Adjustment and Test Operation	lump	5,000	
7. Other Expenses	lump	1,800	2
Total		34,050	12

5.2.8 Conclusions

(a) Performance of remote oil sensors are affected by weather and oceanographic conditions, therefore changing weather and oceanographic conditions may alter the reliability of sensors.

(b) There are very few actual applications of in-situ oil sensors to the detection of oil on the sea, since the sensors have been primarily developed for use on land facilities such as holding ponds, drainage pits and sewage lines. If in-situ oil sensors which are now commercially available are applied at sea, the sensitivity is likely to be degraded by waves, fouling debris and corrosion. To use these sensors and to ensure maintenance procedures.

(c) Continuous oil in water monitors have been mainly used to measure the oil content of effluents discharged from tankers and from manufacturing plants. It is believed that the main factor which adversely affects the performance of the monitors installed at sea is interference with the water sampling pipe caused by clogging of debris, algae, jellyfish and corrosion. The pipe therefore should be well maintained or designed to prevent such clogging and corrosion in the marine environment conditions.

(d) It has been demonstrated that the acoustic method can be applied to the detection of oil particles in water. However, the method should be used in conjunction with oil content meters since this method is not capable of discriminating oil particles from other particles in water.

(e) Meteorological and oceanographic instruments have been widely used in field observations. The reliability and stability of such instruments are much higher than that of oil sensors and monitors.

(f) Sensors exposed to the weather are subject to gradual depositional fouling by salt and dirt. Equipment in sea water is affected by clogging, corrosion and biofouling. A scheduled maintenance program is required to minimize these effects and to keep the system reliable in the marine environment.

5.3 Study on Oil Contamination Preventive Facilities

5.3.1 Existing Oil Contamination Preventive Facilities

(1) Prevention of Oil Dispersion

1) Oil Fence

(a) Standard of Oil Fence in Japan

In Japan, only two kinds of oil fence, A and B-type, are provided by an ordinance 78) of the Ministry of Transport. But the effect of these oil fences has been doubtful in cases of strong wind and high wave and being used in the open sea. Large scale oil fences such as C and D-type have been developed and used actually.

The standard and developing target of oil fences in Japan are indicated in Table 5.3.1. Standard design conditions for B-type fixed oil fence are as follows:

Wind velocity: 10 m/s
Wave height: 1 m
Tidal currents: 0.5 knots (≒ 26 cm/s)

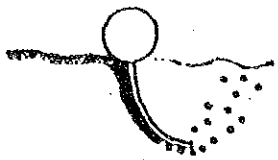
Table 5.3.1: Standard of Oil Fence in Japan

Item \ Type		A-Type	B-Type	C-Type	D-Type
Size	Above the Sea Surface	20cm or more	30cm or more	40cm or more	60cm or more
	Below the Sea Surface	30cm or more	40cm or more	50cm or more	80cm or more
	Length	20m or more	20m or more	20m or more	20m or more
Tensile Strength of Length Direction		6t or more	6t or more	6t or more	6t or more
Note	Materials	vinylon, nylon, so on	vinylon, nylon, so on	synthetic rubber,so on	synthetic rubber,so on
	Weight	about 50kg	about 70kg	about 150kg	about 200kg

(b) Performances and Properties Required for Oil Fence 79)

* Not to be turned up by tidal currents and ocean currents:

If a skirt (the part below water) of an oil fence is turned up, oil will flow *inside at that part*. So a skirt has a reinforcing belt to prevent turning up.



* To have superior flexibility against wave:

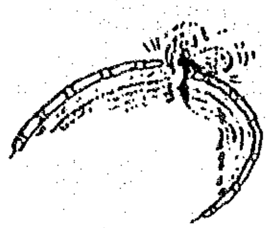
If flexibility against the wave is not so good, oil will flow inside from upper and lower side of an oil fence. Independent *floats installed* with short length will be used for oil fence to prevent oil invasion.

* To have superior stability against wave and wind:

If stability is not good , an oil fence will fall under strong wind and wave. Suitable counterweights can be attached at the lower part of a skirt to prevent it from falling down.

* To be made of weatherproof, oilproof and durable material:

If the material is not good, the oil fence will be damaged during towing and steeping in oily sea water.



* To have good workability:

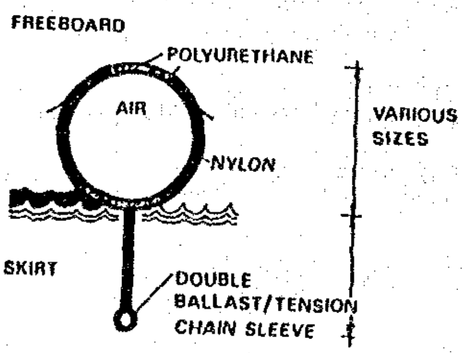
If workability is not good, a lot of time and manpower are necessary for extension and re-winding of the oil fence. And also wide space is necessary for storage of the oil fence.

(c) B Type of Oil Fence

Typical types of oil fence are described as follows:

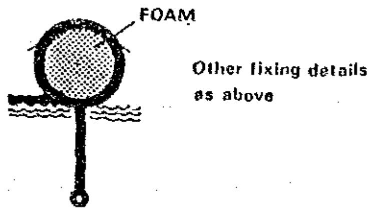
* Expansion float type

Compressed air from an air compressor or carbon dioxide from a cylinder is charged into floats to expand. In this type ,periodical gas charging is necessary to make up for the gas leaking. But storage of the oil fence is easy when not used.



* Foam styrol float type

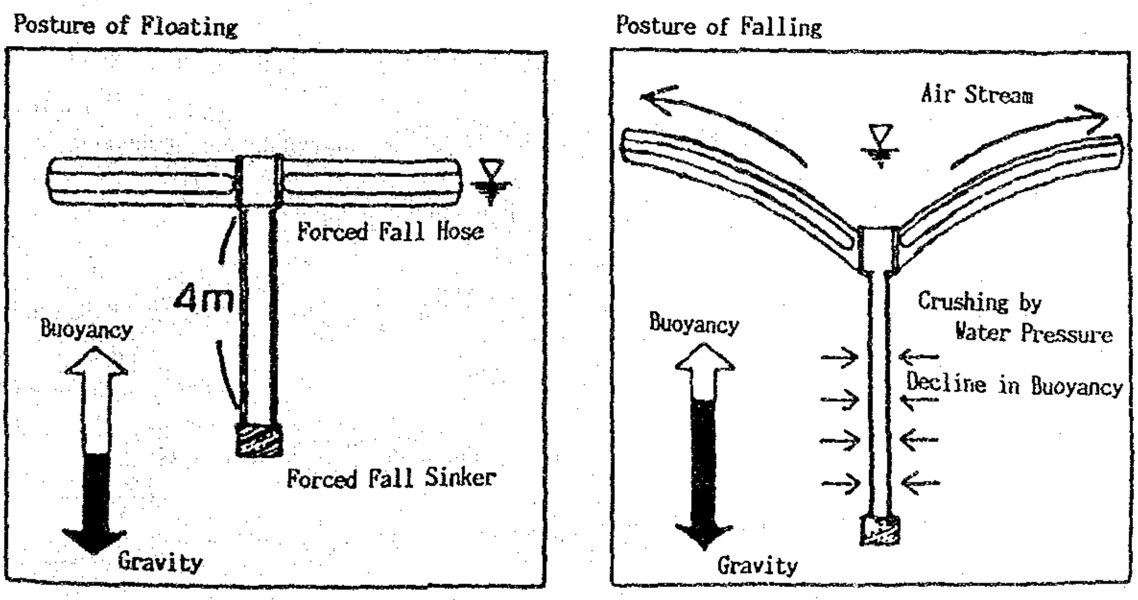
A float is made of foam styrol. In this type, maintenance is easy but a large storage space is necessary. So this is suitable for the fixed oil fence.



* Rise and sink type 81)

The oil fence of this type can be deflated with valve operation when ships are cruising. When an emergency arises, the oil fence can be set up by inflating the floats of the oil fence.

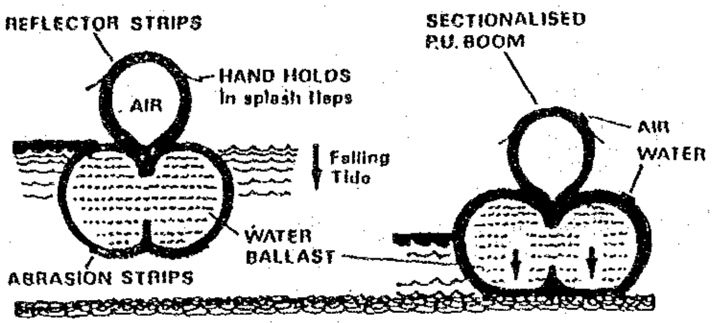
Therefore, it will be able to take measures quickly.



* Beach sealing type 80)

Oil dispersion cannot be sufficiently prevented by conventional oil fences at a seashore which turns dry and wet according to the tide.

The oil fence of this type has a adjustable ballast water tank at its skirt part. Oil dispersion at seashore can be effectively prevented by the oil fence of this type.



(d) Examples of Actual Application of Oil Fence 80)

* In the case of an oil effluent accident in open sea, it is necessary to prevent oil effluence and dispersion by dispatching quickly the maintenance personnel and extending many oil fences of the screen type doubly or triply. This oil fence of expansion float type does not take up much space and so more of them can be stored in limited space. (Fig. 5.3.1)

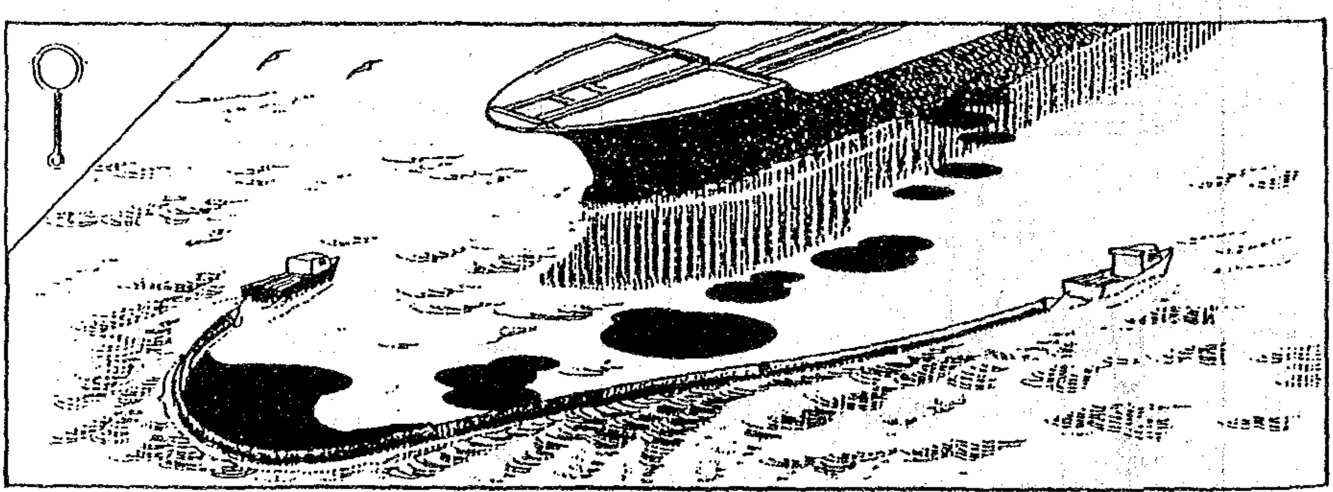


Fig. 5.3.1 Example of Using Enveloped Type Oil Fence at Open Sea

* In the case of an oil effluent accident near the mouth of harbor, prevention for oil invasion into the harbor and oil recovery are carried out by oil fences and oil skimmer (Fig. 5.3.2)

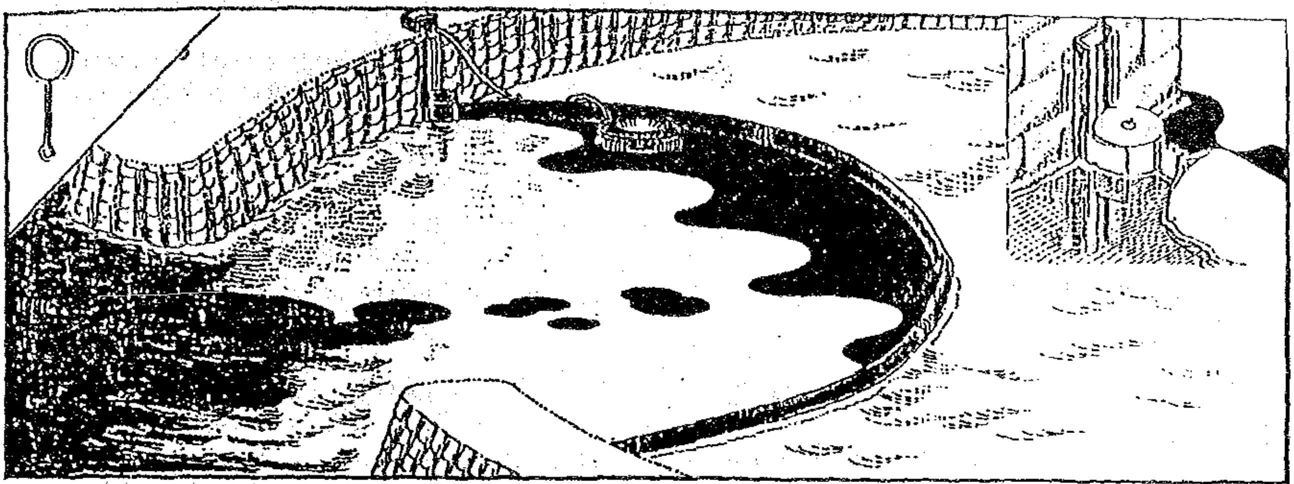


Fig. 5.3.2: Example of Using Semi-fixed Type Oil Fence at Mouth of Harbor

* Oil fence of the above mentioned beach sealing type can be used at rivers where the depth of water changes due to the tides. (Fig. 5.3.3)

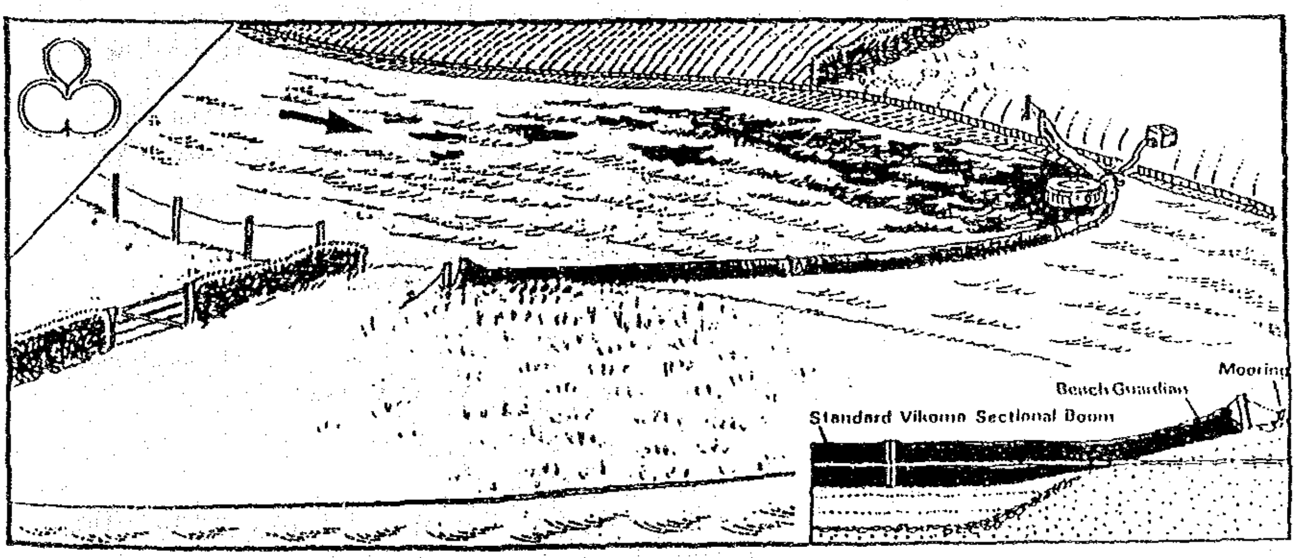


Fig. 5.3.3: Example of Beach Sealing Type Oil Fence at River

2) Oil Gelatinizer

In the case where oil flows out on the sea surface, the oil fence will be extended to prevent oil dispersion. Usually it takes more than 30 minutes to extend a oil fence. And the extension work is only operated at a state of emergency. So the work is not always carried out completely.

There is an oil gathering agent which has a main component of ethylene glycol, additives of higher alcohol. This agent is not so effective when wave is high and viscosity of effluent oil is high.

If oil can be solidified by some gelling agents, oil in a damaged tank will be changed to solid state by these agents and oil effluence can be prevented. Even if the solids flow out to the sea, its dispersion area is small and they can easily be recovered using mechanical method, eg. using net.

There are a few kinds of oil gelling agents, namely, amino acid type gelling agent (main component is a derivative of amino-acid) and sorbital type gelling agent (main component is dibenzylidene sorbital). These agents need long time gelling and are not effective for comparatively low viscosity oils such as A-heavy oil and Mahban crude oil and so on.

According to Hagiwara's report (1975) 82), many kinds of oils can be solidified in a short time by a certain sort of amino-acid type gelling agent regardless of the existence of water. Special features of this gelling agent are as follows:

* Many kinds of oils can be solidified in a short time.

* Gelling time is short for low viscosity oils such as Mahban crude oil and A-heavy oil, but long for high viscosity oils such as Iranian heavy crude oil and C-heavy oil.

* Gelling speed can be controlled by adding n-butanol as gelation delaying agent.

* Strength of gel made with 1% (W/V) of the gelling agent is comparatively large with figure of 25 to 100 g/cm^2 .

* Solid gel returns to liquid state at 60 to 100 °C.

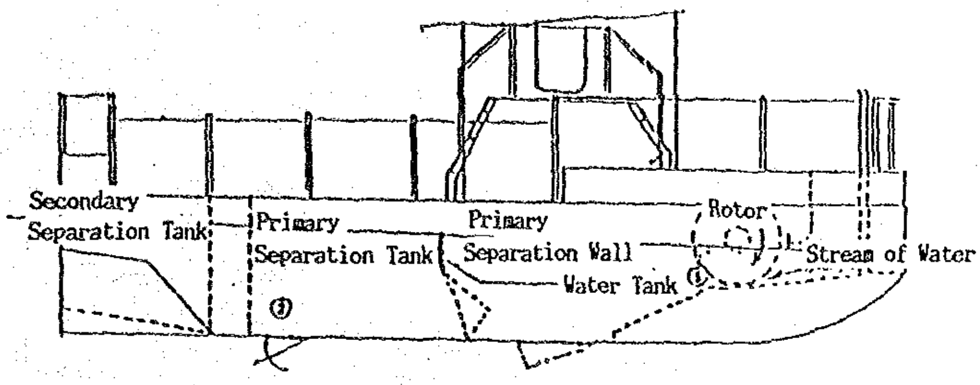
(2) Oil Recovery Ship 83)

Several oil recovery ships have been developed as follows:

(a) "Futaba Maru"

This ship is the first oil recovery ship constructed in Japan in 1968. The outline of the structure of the ship is shown in Fig. 5.3.4.
This ship has a twin-hull structure ,catamaran type and equipped with a

parallel multi-disc and a rotor at the bow. Oil film on sea surface is collected by the rotor and then supplied to the oil-water separator through intermediate channel between the hulls.



Main Specification

Ship Length	8.5m
Width	4.0m
Depth	1.4m
Displacement	≒4.0t
Main Engine	35PS×2
Rotor	15PS×1
Speed	4.59knot

Fig. 5.3.4: Sketch of Oil Recovery Ship "Futaba Maru"

(b) "Kiyozumi"

This ship was constructed in Japan and has a special oil recovery apparatus patented by Standard Oil Corp., U.S.A. The apparatus has a drum coated with foam polyurethane (foam diameter of 3 to 5 mm). The diameter of the drum is 90 cm and length 200 cm. Oil is recovered by squeezing the absorbed oil in the foam on the drum which rotates at 0 to 30 rpm. (Fig. 5.3.5)

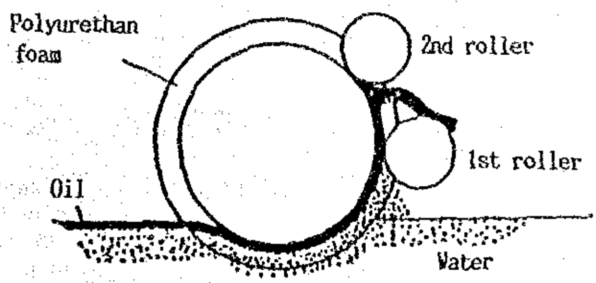


Fig. 5.3.5: Sketch of Twice Squeezing Oil Recovery Drum

(c) DIP (Dynamic Inclined Plane Skimmer)

This ship has been developed by JBF Scientific Corporation. A sloping belt is installed at the intermediate channel of a twin-hull ship (Fig. 5.3.6).

The belt is driven at about the same speed as the inflowing oil. Then oil film is collected and supplied to the oil-water separating tank on the ship.

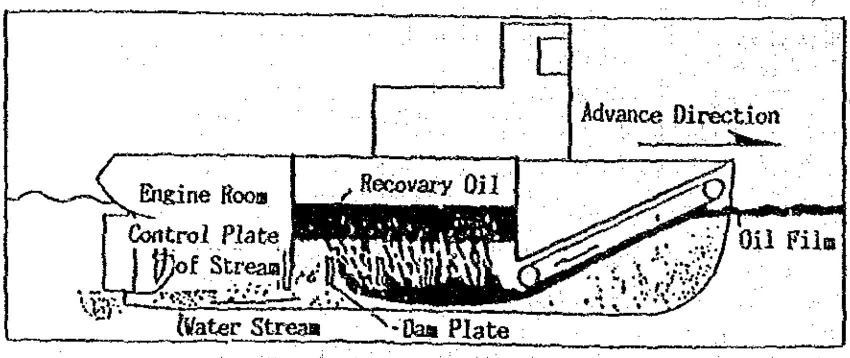


Fig. 5.3.6: Schematic Drawings of DIP Type Oil Recovery Ship

(d) Bridge-Stone Oil Skimmer

This ship has a floating belt having a sag like DIP type belt. Oil film is taken into the upper side of a oil-water separating tank on the ship. The shape of the tank is cylindrical and oil-water is separated by eddy current. (Fig. 5.3.7)

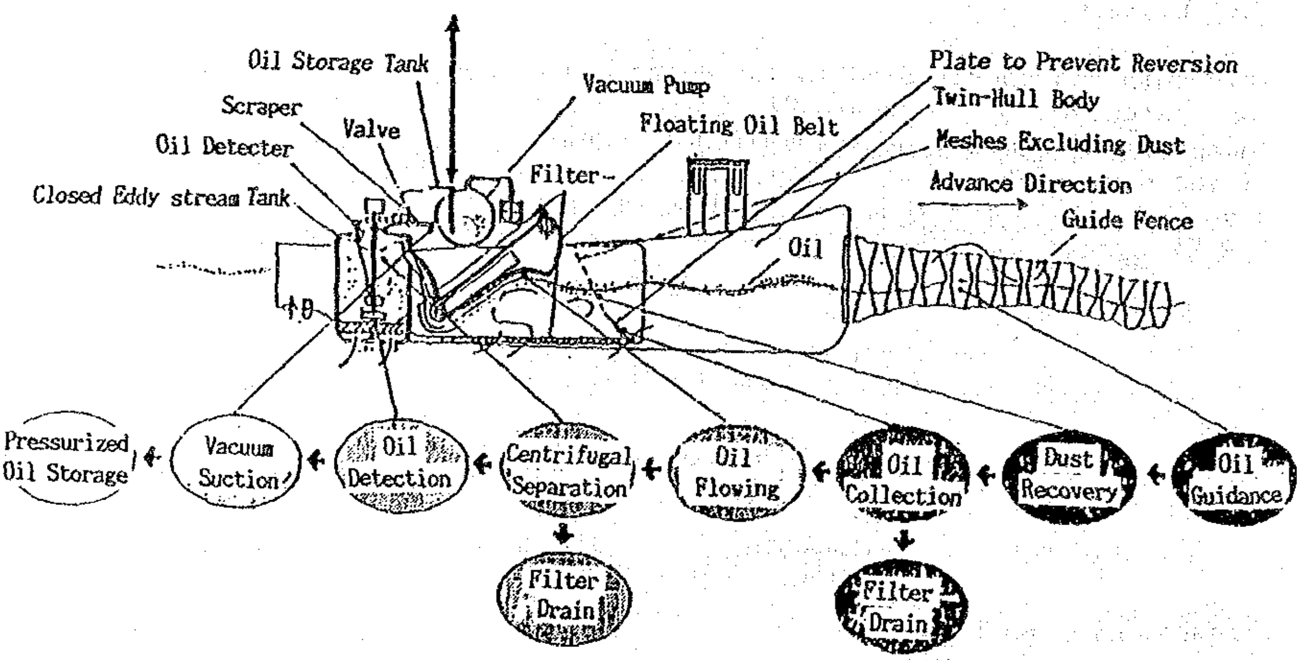


Fig. 5.3.7: Schematic Drawings of BS Oil Skimmer

(e) MIPOS (Inclination Plate Type Oil Recovery Ship)

Oil film on sea surface is recovered by a ship which sails at a speed of about 3 knots.

Oil recovery mechanism is shown in Fig. 5.3.8. Fixed inclined plate is installed at the front of the intermediate channel of the twin-hull ship. Oil is at first intercepted at the entrance of the fixed inclined plate forming oil drops together with sailing of the ship. At least oil is supplied into a oil storage tank at the stern of the ship.

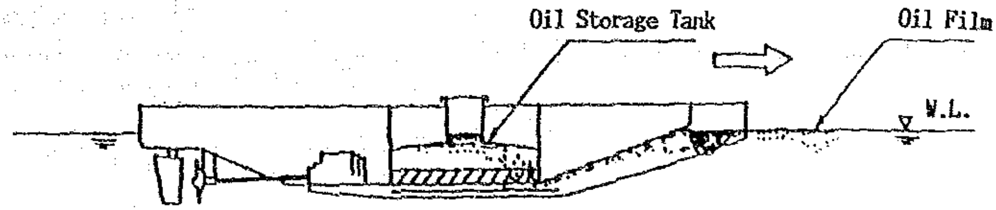


Fig. 5.3.8: Inclination Plate Type Oil Recovery Ship

(f) Clean-Sweep

This ship developed by Lockheed Corp., U.S.A. has a rotating cylinder at the twin-hull to which oil can adhere.

As shown in Fig. 5.3.9, many plates are arranged with one inch pitch. This equipment is rotated on the effluent oil film. Oil stuck on the plates goes upwards and is wiped by the wiper and into a oil transfer pipe which is coaxial with the rotating shaft.

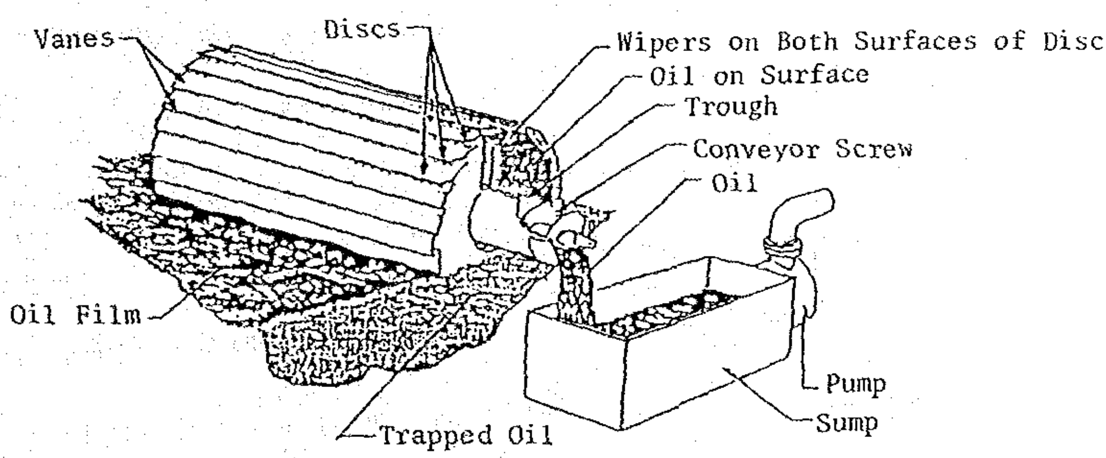


Fig. 5.3.9: Oil Recovery Equipment of Clean Sweep

Kondo's evaluation for the above-mentioned oil recovery ships (1976) 83) is as follows:

* Cost of the ship being supplemental equipment is unreasonably expensive as compared to that of the recovery system of the main equipment.

* Crew members and a wharf for the oil recovery ship are necessary. So maintenance and operation fee are expensive.

* Oil leaked from recovery process must not be dispersed by sailing of the oil recovery ship. So propeller as propulsion is considered to be better than screw.

* When oil surrounded by oil fence is recovered by the oil recovery ship, there is a some possibility that the oil fence is broken down by the ship.

2) Oil Fence and Oil Recovery Apparatus

(a) Oil Enveloping Method

An oil fence is extended at down stream side of effluent oil, and the floating speed of the oil fence is adjusted by using sea anchors etc., so that the oil is enveloped finally by the oil fence.

VICOMA system developed by England Petroleum Co. is one of those typical systems using this method. (Fig. 5.3.10) Generally, floating oil film on sea surface is more influenced by tidal force as compared to wind force, but the oil fence exposed on sea surface is more influenced by wind force. In sea area in which directions of tides and wind are not the same, considerable training and experience of the operation are necessary to envelop effluent oil skillfully.

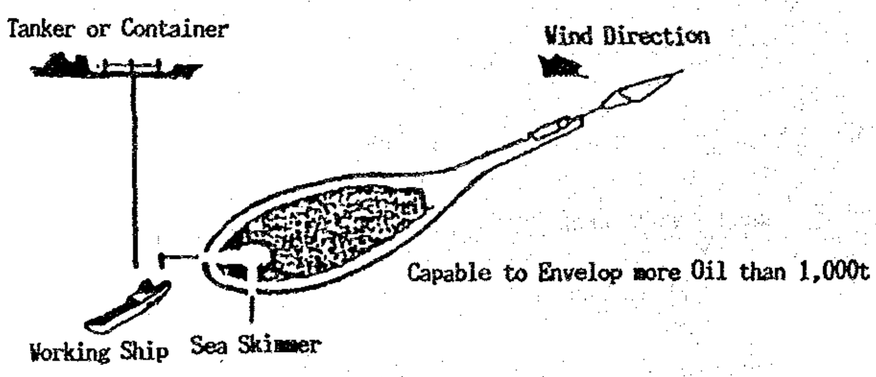


Fig. 5.3.10: Oil Envelopment by VICOMA System

VICOMA skimmer shown in Fig. 5.3.11 is an effective oil recovery equipment using this method.

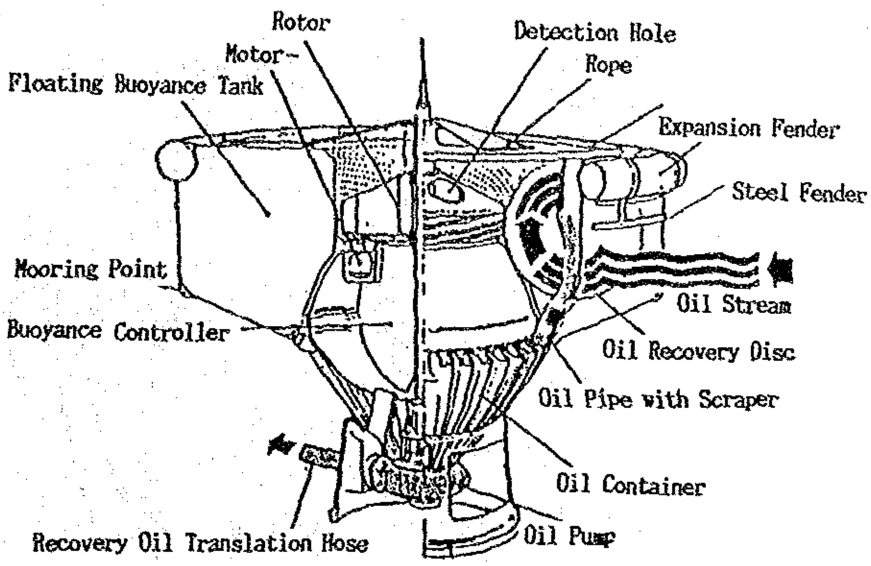


Fig. 5.3.11: Sketch of VICOMA Skimmer

(b) Oil Interception Method

In this method, effluent oil is intercepted by an oil fence extended and moored with circular or parabolic shape at the down stream side of the floating oil. The workability of the oil fence is good and easy. If oil mop method developed by OMI, U.S.A. is used with this method to recover oil film, the combined method seems to be a reasonable and effective method for effluent oil recovery.

3) Oil Mop and Oil Fence

Oil mop machine consists of a oil mop, a mop pressing machine and guide pulleys. As shown in Fig. 5.3.12, shape of the oil mop is just like a rope weaved with polyethylene or polypropylene tapes of 1 mm width or less. The rope has a length of several ten meters forms a large ring. The guide reel has the pulleys floating horizontally. The mop pressing machine presses the mop and at the same time drives the pulleys. Procedure of oil recovery by oil mop method is shown in Fig. 5.3.13.

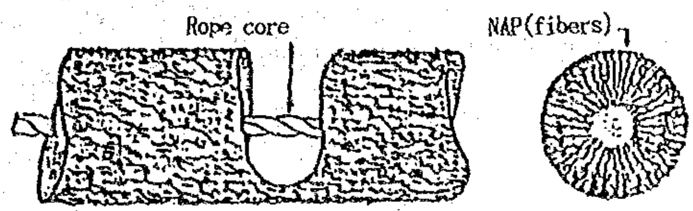
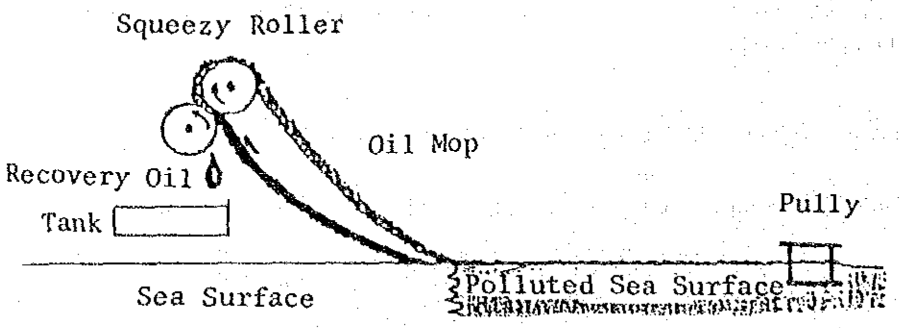


Fig. 5.3.12: Structure of Oil Mop



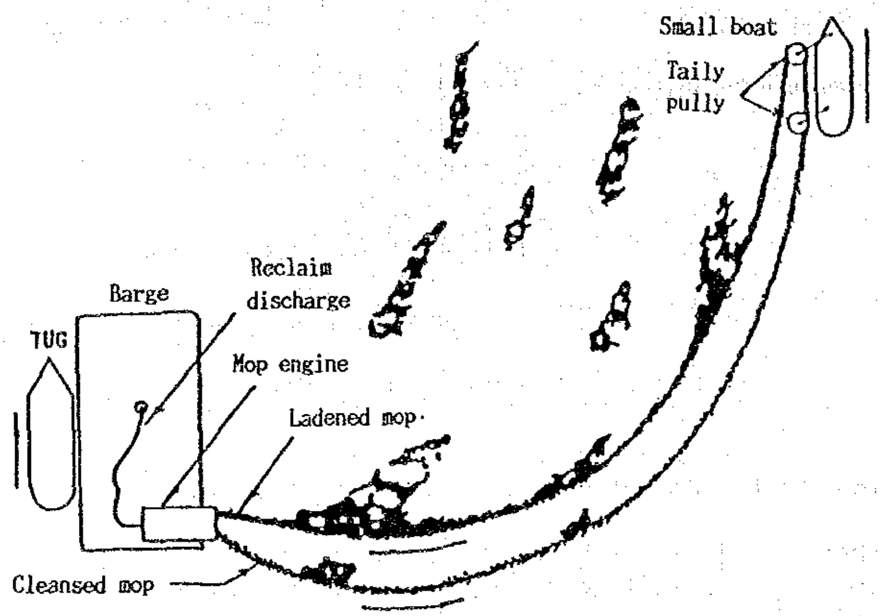


Fig. 5.3.13: Sketch of Oil Recovery by Oil Mop

The oil mop method is very effective for calm sea condition but not for high wave sea condition. In the case of high wave sea condition, oil often gets over the oil mop. According to Kondo's suggestion (1979) 83), the combined system of the oil mop and the oil fences is the most reasonable.

If the oil mop is guided to the thick oil film grown by interception of the oil fence, oil does not get over the oil fence and the length of the oil mop can be shortened. (Fig. 5.3.14)

The oil recovery system is effective so as to utilize many oil fences which have been stored at present. This system does not require any exclusive ship. The workability is comparatively easy and cost of the oil recovery system is about 1/50 to 1/100 times as compared with that of the oil recovery ship.

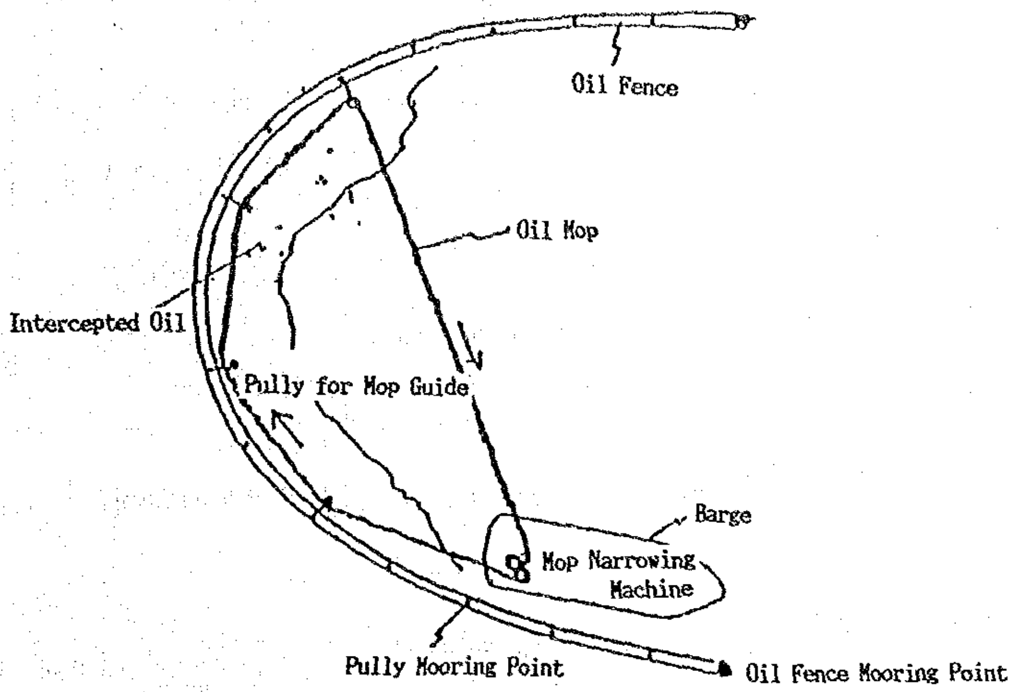


Fig. 5.3.14: Oil Recovery by Combined System of Oil Mop and Oil Fence

(3) Oily Water Treatment

Typical oily water treatment processes are shown in Fig. 5.3.15.

- Oil-Water Separator
  - Floating Separation
    - Natural Flotation
      - API
      - PPI
      - CPI
    - Forced Flotation
      - IAF
      - DAF
  - Filtration Separation
    - Hay Filter
    - Coalescer
  - Coagulation Separation
    - Sedimentation
    - Flotation
- Physical-Chemical Treatment
  - Adsorption Treatment
    - Sedimentation
    - Flotation
- Biological Treatment
  - Activated Sludge
  - Lagoon

Fig. 5.3.15: Typical Oily Water Treatment Process

1) API (American Petroleum Institute)

API method (Fig. 5.3.16), typical example of oil-water separator method has a simple water basin. Normally oil drops having diameters of 0.15 mm or more are separated from water by this equipment. Emulsion oil and oil adhered to suspended solid cannot be separated by this equipment. Hay-Filter made of hay and/or straw is prepared at the outlet of the equipment to adhere and recover residual very small amount of oil.

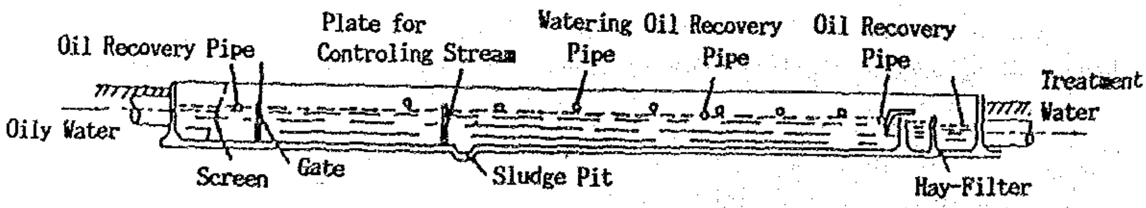
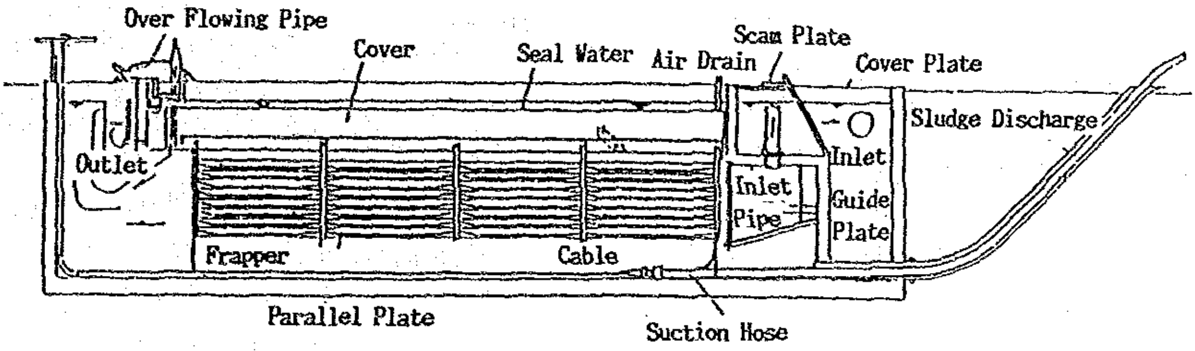


Fig. 5.3.16: API Oil-Water Separator

2) PPI (Parallel Plate Interceptor) 87)

PPI method has been developed as as an improved version of API method (Fig. 5.3.17). Normally oil drops having diameter above 0.06 mm can be separated from water by this equipment. In the case of oil content of 1,000 ppm at the inlet of this equipment, oil content of about 10 ppm can be got at the outlet of this equipment.

The main part of this equipment is just the same as inclined plates. Parallel plates having each 10 cm pitch are prepared and increase effective area and prevent turbulent flow and channeling in the water basin. Separation efficiency of this equipment is about 45% up as compared with that of API. Open area for atmosphere is comparatively small and required installation area is about 1/4 times as compared with API.



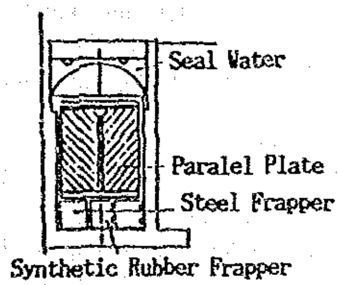


Fig. 5.3.17: PPI Oil-Water Separator

3) CPI (Corrugated Plate Interceptor)

CPI method has again been developed as an improved version of the PPI method. (Fig. 5.3.18) Special feature of this method is the shape of the plate. Parallel corrugated plastic plates having pitches between 2 to 4 cm are dipped in the oily water at an inclination of 45 degrees. Normally oil drops having diameters above 0.06 mm can be separated from water using this equipment just like the PPI method. The required installation area for CPI is about 2/3 times as compared with PPI.

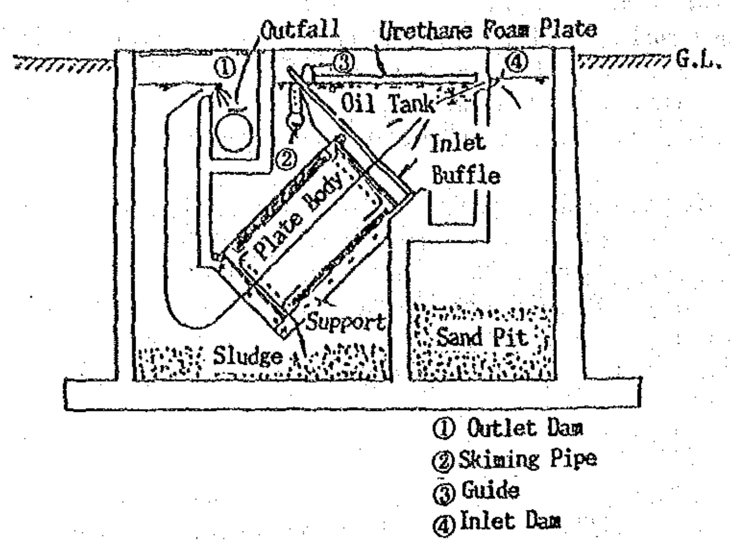


Fig. 5.3.18: CPI Oil-Water Separator

4) Forced Floating Separation

Generally, there is a forced floating separation method known as oil-water separation method using air bubbling. The forced floating separation method can be classified into air flotation method (IAF) and dissolved air flotation (DAF).

Air bubble diameter gained by IAF is from 0.5 to 1.0 mm, but that of DAF is 0.05 to 0.1 mm, 10 times smaller than IAF. In the horizontal stream pressurized floating method shown in Fig. 5.3.19, oily water is pressurized up to 3 to 5 kg/cm² and atmosphere air is introduced at the suction side of the pump.

Introduced air is compressed by pump into a dissolving tank and in about 1 min it dissolved almost perfectly into water. According to Henry's law, solubility of air into water is proportional to pressure and inversely proportional to absolute temperature.

When pressurized oily water is introduced into the floating separating tank through the reducing valve, excess undissolved air is generated in the form of fine bubbles under the atmospheric pressure. Generally, air bubbles are liable to be generated at the interface of solid and liquid. So this method has a merit that air bubbles adhere to oil drops from the outset.

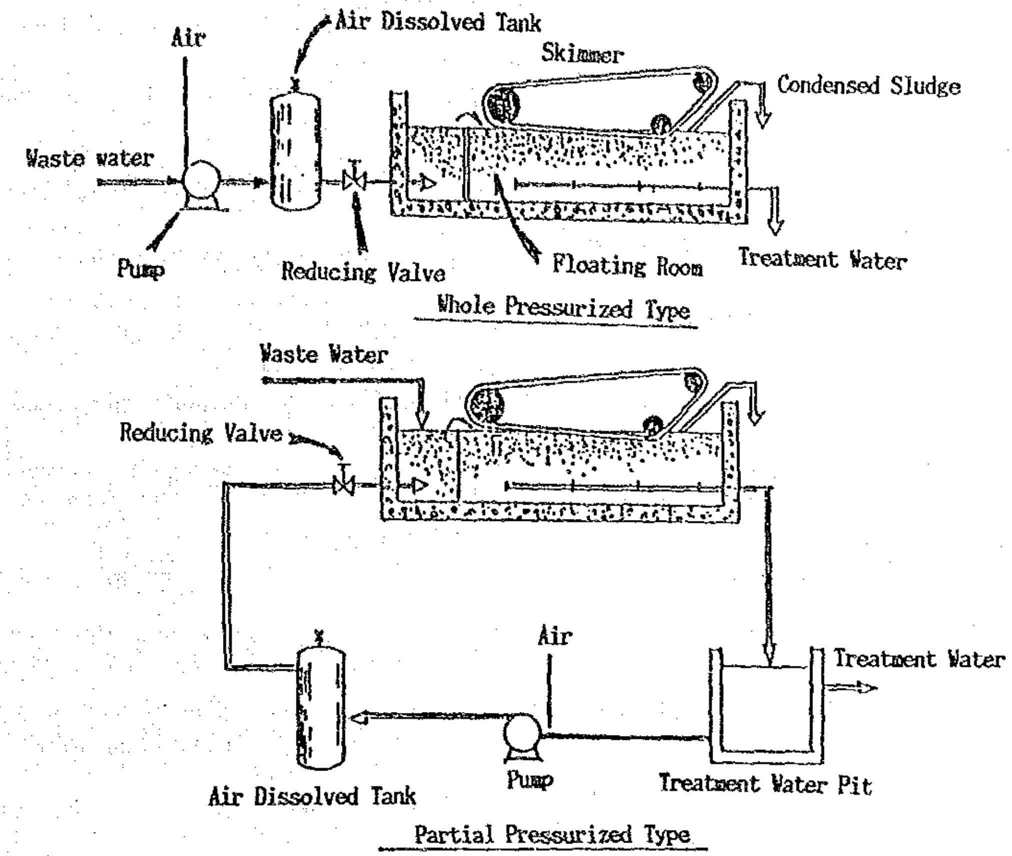


Fig. 5.3.19: Horizontal Stream Pressurized Floating Separator

On the other hand, there are no need of pressurizing equipment, air dissolving tank and so on for IAF method. So the equipment of this method is simple as compared with that of DAF method and applicable to the sea water intake system. Regarding IAF method, priority must be given to the selection of air bubble generating equipment. Main air bubble generating equipment for oil-water separation are as shown in Fig. 5.3.20.

Studies and actually applied examples of forced flotation method are as follows:

* Kondo has developed a so-called "Air bubble meeting method" (1971) 89). This method is a kind of IAF method. Oily water is treated by blowing air bubbles into a bottle. In Kondo's experiment, oily water flowing in the water was continuously treated by air bubbles generated from submerged air jetting porous media having a diameter of 0.5 mm each. This method was called "Horizontal stream air bubble meeting method". According to the result of this experiment, oil elimination of 99% or more was obtained for oil content of 5,700 to 5,800 mg/l after 1 to 3 hours of aeration.

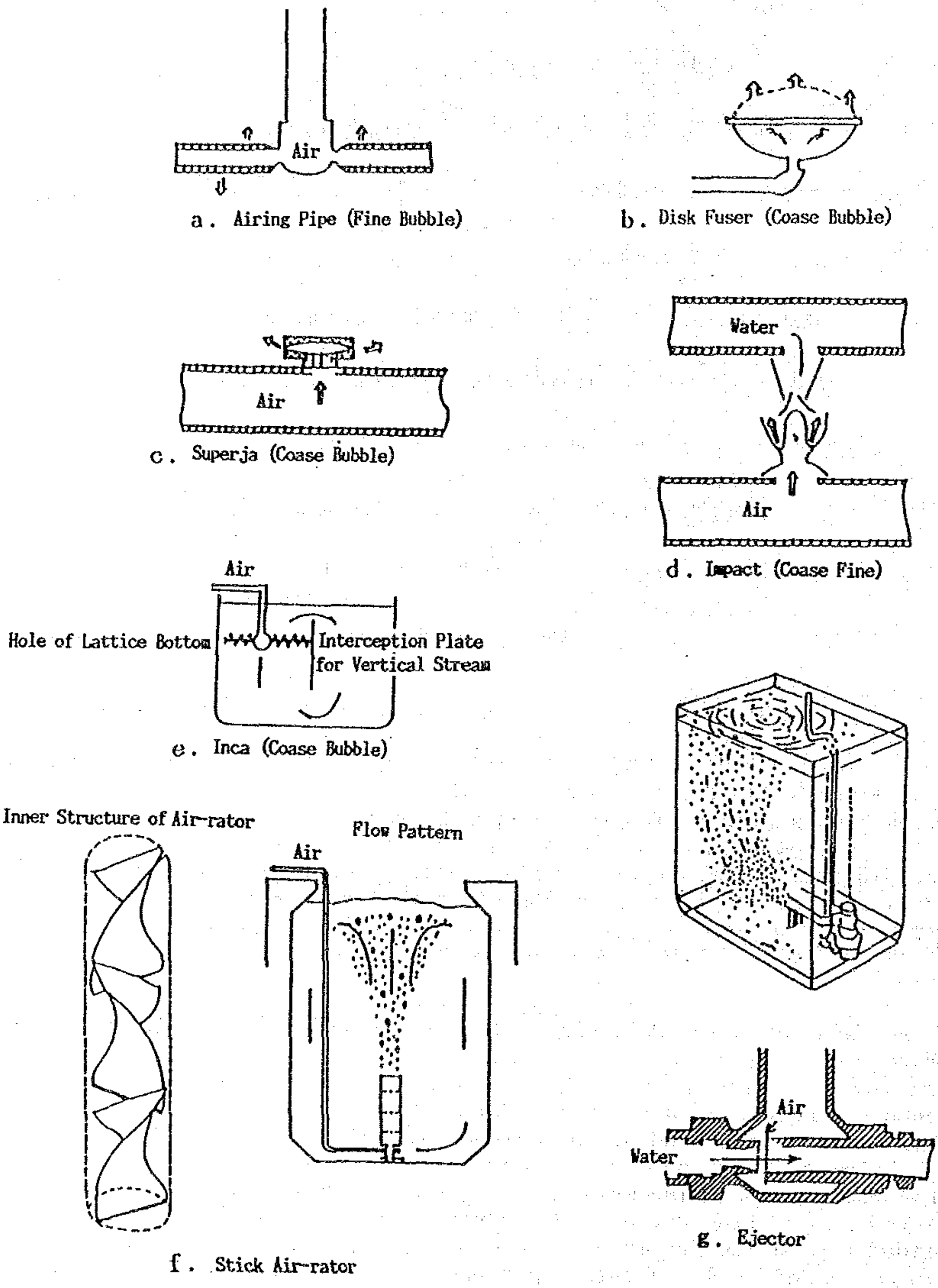


Fig. 5.3.20: Main Air Bubble Generating Equipment for Oil-Water Separation

* Steiner reported (1978) 90) about the oil elimination efficiency by IAF and DAF methods after API oil separating treatment. According to the report, oil elimination efficiency of about 80% was obtained with retention time of 1.4 to 1.8 min under co-existence of a cation electrolyte.

* Bradley reported (1985) 91) about some examples of IAF equipment using rotors at nozzle parts. According to the report, oil elimination of 90% was obtained with retention time of 4 min.

* Burkhard reported (1978) 92) about influential factors for oil elimination effect of IAF method. He suggested that co-existence of high molecular electrolyte and metallic salt gives a great influence for oil elimination effect.

* Tomita reported (1966) 93) that fine oil drops are better eliminated by IAF and DAF method as compared with API, CPI and PPI method.

5) Filtration Separation

The principle of this method is utilization of the difference between wetness. In this method, oily water including fine oil drops is flowed through filtration media such as hay, straw, shavings, synthetic fiber, glass wool and adsorption filtration media such as clay, diatomaceous earth, silic acid and special woven metal net. Fine oil drops are combined with each other when these fine oil drops pass through narrow space. This phenomenon is called "Coalescene".

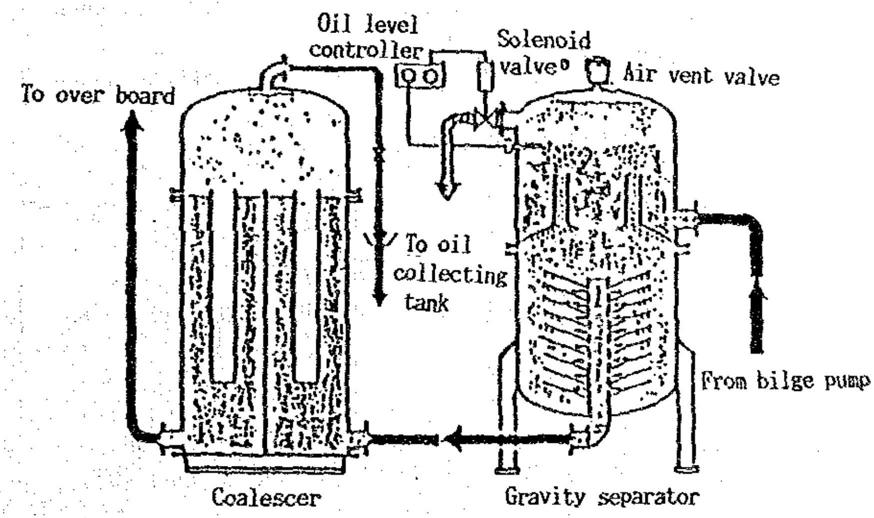


Fig. 5.3.21: Coalescer Combined with Gravity Separator for Oil-Water Separation

The simplest method of this filtration separation is the Hay-Filtration method applied for API which uses hay as filtration media. But this method is not so effective for emulsion oil and fine oil drops.

Plate, glass wool, metal net, synthetic fiber etc. have been used as coalesciment which is the most important part of the oil-water separator. But when plate is mainly used as oil-water separator, it is not effective for emulsion oil elimination. When synthetic fiber is mainly used as oil-water separator shown in figure 5.3.21, it is effective for emulsion oil elimination.

Since agglomeration of fine oil drops of 0.01 mm diameter or less is difficult, quantity of synthetic fiber and packing density must be increased to get high elimination efficiency. But at that time, oily water flow is decreased by friction loss and treatment capacity is also decreased. This oil-water separator shown in Fig. 5.3.21 is not suitable for large capacity oil-water separation but suitable for concentrated emulsion oil treatment.

6) Coagulation and Floating Separation

Pressurized floating treatment equipment with coagulant addition is shown in Fig. 5.3.22. Oily water is separated to three parts, namely oil, water and agglomerated oil, so-called flock, by adding sulfic-acid aluminum, iron salt and high molecular coagulant into oily water to adjust its pH value. This flock is liable to sink.

So oil recovery is carried out by floatation of oil flock and surface oil adhered to air bubbles. Special feature of this method is to make oil flock and float it by air bubbles.

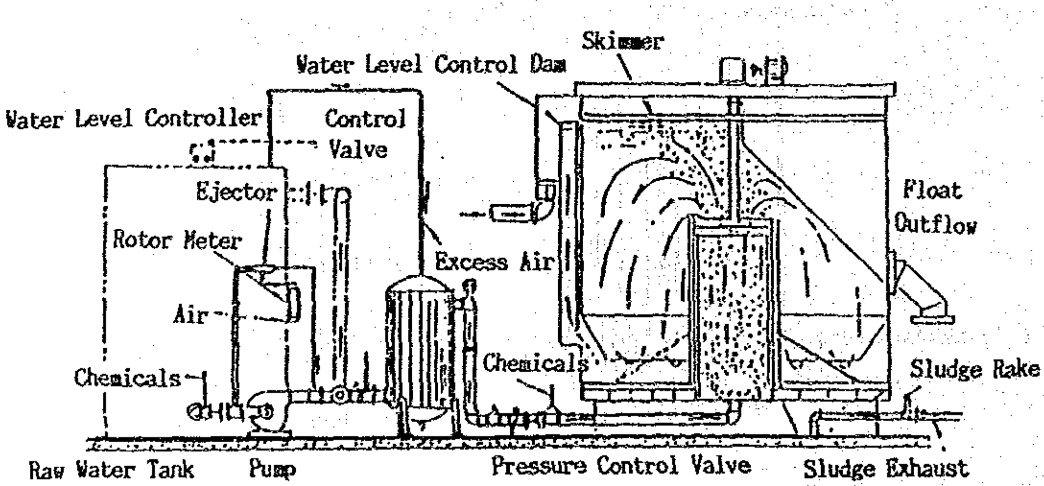


Fig. 5.3.22 Coagulation and Pressurized Floating Separator

In this equipment, coagulant is added into oily water to adjust pH value in the coagulation tank first, then oily water is saturated with dissolved air in the pressurized tank. The dissolved air becomes fine air bubbles and catches oil flocks at the surface, and escapes from the surface later, when pressurized oily water is decompressed up to atmospheric pressure. Then oily scum is formed from the oil flock and recovered in the floating separation tank.

Metallic salts used as coagulants are iron salt, zinc salt, aluminum salt and etc. The most suitable range of pH value is different for each metallic salt and influence of co-existence ion is different too.

7) Adsorption Treatment

In this treatment, oil in oily-water is eliminated by solid adsorption agent.

Powder or pellet of activated carbon, synthetic adsorption agent, natural adsorption agent. There are two kinds of method for adsorption treatment. One is the dispersion contact method which adsorption agent and oily water are mixed and sedimented or separated by filtration. Another is the fixed bed method in which oily water is passed through fixed layer of adsorption agent.

Activated carbon is the most popular adsorption agent for waste water treatment. Activated carbon is mainly used in tertiary treatment and waste water recycling treatment. It has large surface area of 800 to 2,000 m2/g and has a lot of small pores. Solute in waste water is concentrated at the surface of the pores, that is called adsorption. When there is only a small amount of oil in water, and the smell is bad, activated carbon may be used, effectively though in most case uneconomical.

8) Biological Treatment

When ample oxygen is supplied and agitated in sewage, blown lump like water-moss, or so-called sludge is generated. This sludge is different from raw sewage original sludge in color and smell. Being capable to purify sewage , it is called "activation sludge".

A lot of aerobic micro-organisms such as bacterium, bacilli, ferments, molds, protozoa and vermin live in activated sludge. When oil component in oily water adheres on the activated sludge, oil is oxidized by aerobic bacteria. A part of oil is decomposed to carbon dioxide and water and another part of oil is synthesized to cell substance of new activated sludge. Activated sludge treatment is a kind of oily water purification treatment utilizing decomposition ability of organic matter by activated sludge and good sedimented rate of activated sludge.

Regarding activated sludge treatment, there are some demerits that aerobic bacterium are always cultured and this treatment, has not enough flexibility for sudden load change and it needs wide construction area.

9) Other Treatments

(a) Centrifugal Separation Treatment

This treatment has been used for oil recovery from W/O-type oil emulsion and grease recovery from wool washing waste water. Oil elimination efficiency of this treatment is not so good, such as 30% or less. So this treatment is not effective for diluted emulsion oily water.

(b) Electric Treatment

This treatment is based on the idea that oily water including emulsion oil is exposed to high voltage such as 10,000 volt or more between narrow electrodes so that dispersed emulsion oil is agglomerated under the strong electric field. But this treatment is under study and has actually not been used yet.

(c) Supersonic Waves Irradiation Treatment

This treatment utilizes the effect of supersonic waves irradiation to increase and to change interface characteristics of oil emulsion. However, supersonic wave energy is effective both for dispersion and agglomeration of oil particles. Emulsion oil is agglomerated under the specific frequency of supersonic waves, but is dispersed at the same time. So this treatment has actually not been used yet.

(d) Thermal Treatment

Thermal treatment seems to be the most effective treatment among agglomeration treatment. It is said that oil emulsion is destroyed by thermal energy. On the contrary, very stable oil emulsion can be destroyed by freezing at a low temperature. But these treatments are very much expensive and difficult to put into practice.

(4) Sea Water Intake Facilities

The most effective and important oil pollution preventive measures for a sea water desalination plant is to avoid pumping up oily sea water.

Horizontal and vertical distribution tendency of oil discharged to sea shows various forms depending on effluent scale, elapsed time after effluence, climatic and marine conditions at the oil effluent area.

Generally, spilled oil mainly spreads on the surface of the sea due to the difference between density of oil and water. Therefore, measures taken so as not to introduce oil from the sea water intake facilities are as follows:

* To pump up sea water with comparatively low speed from the middle layer of the sea and not from the surface where the oil film is nor from the bottom layer where oil balls are.

* To install sea water intake facilities specially structured so that effluent oil may not stay near these facilities due to the action of wind and current.

From the above mentioned view points, typical sea water intake facilities which are actually operating now for the sea water desalination plants are studied concerning their prevention of oil pollution. The comparison tables are indicated in Tables 5.3.2(1) to 5.3.2(4). Effective sea water intake facilities for prevention of oil pollution are as follows:

* Submerged piping system
* Curtain wall system

Table 5.3.2(1): Comparison Table of Sea Water Intake Facilities Regarding Prevention of Oil Contamination (Submerged Piping System) 94)

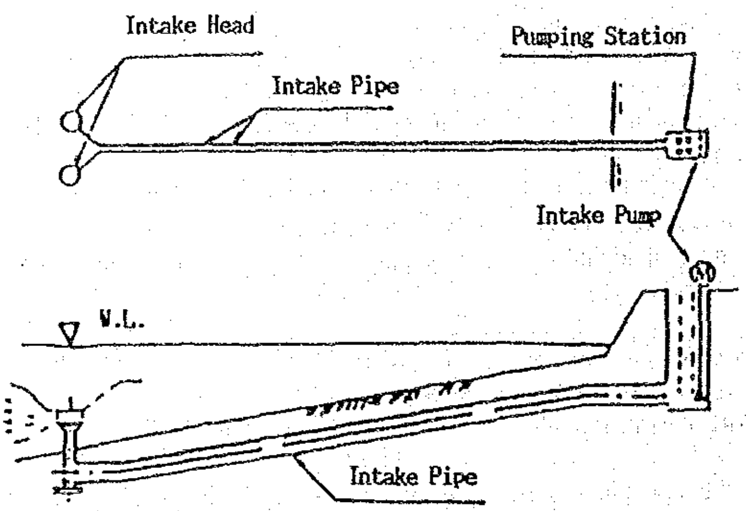
1. Outline	 Intake head is located offing place to be able to keep required sea water depth. Selective sea water intake is carried out. Sea water is introduced to the pumping station on land through the intake pipe constructed at the sea bottom.
2. Merits	• Selective sea water intake can be carried out for dispersion oil being made up of some layer. • There is no trouble of staying of oil around the intake head because of submerged structure. • This system is suitable for the place of sever wind and wave conditions.
3. Demerits	• It will be liable to be late when new oil pollution preventive measures is carried out, because all structures are constructed. • The oil pollution preventive effect by this system is almost same with the other systems, when oil contamination expands all layer from the sea surface to the sea bottom.

Table 5.3.2(2): Comparison Table of Sea Water Intake Facilities Regarding Prevention of Oil Contamination (Pier System) 94)

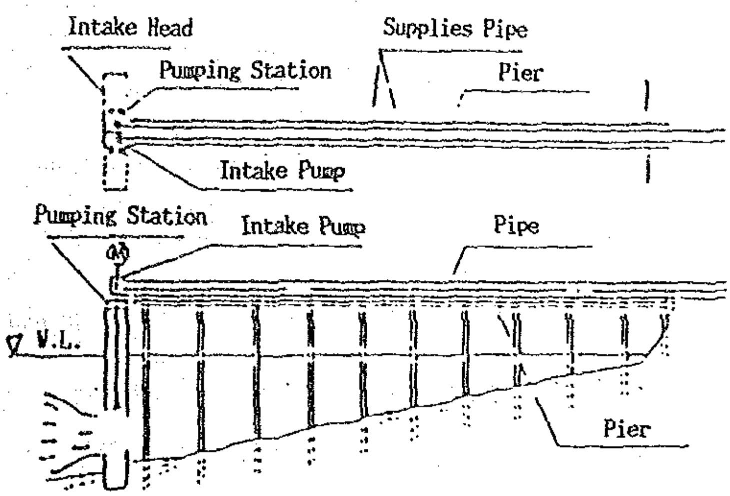
1. Outline	 Pumping station is located offing place to be able to keep required sea water depth. Direct sea water intake is carried out. The sea water is introduced on land through piping on the pier.
2. Merits	• Secondary pollution is very little, because a small part of the structure stands out on the sea surface and oil staying is limitted around the pumping station. • Oil pollution preventive measures can be newly carried out quickly, because some structure such as the pier and the pumping station stand out on the sea surface.
3. Demerits	• At the view point of the structure, selective sea water intake is difficult. • Secondary contamination is liable to occur, because some part of the structure stands out on the sea surface and stream is disturbed.

Table 5.3.2(3): Comparison Table of Sea Water Intake Facilities Regarding Prevention of Oil Contamination (Curtain Wall System) 94)

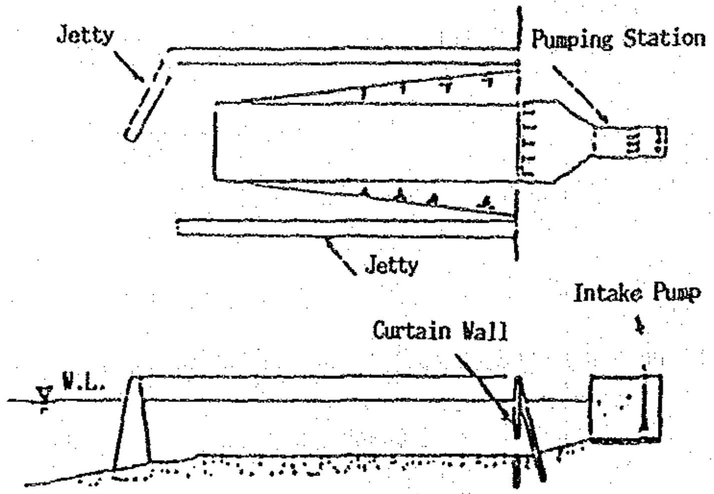
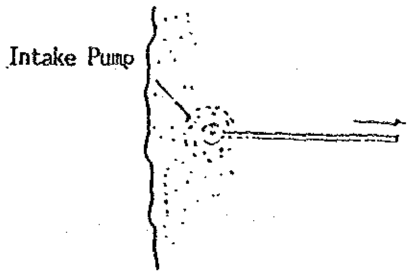
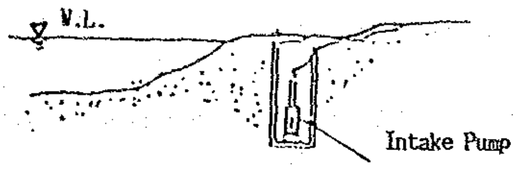
1. Outline	 Curtain wall is located the place to be able to keep required sea water depth and is surrounded by ripraps and sheet piles. Selective sea water intake is carried out. The sea water is introduced to the pumping station on land.
2. Merits	• Selective sea water intake can be carried out for dispersion oil being made up of some layer. • New oil pollution preventive measures can be carried out quickly, because a part of the structure stands out on the sea surface. • This system is suitable for comparatively large scale sea water intake system.
3. Demerits	• Stream of the sea is liable to be disturbed, because a part of the structure stands out on the sea surface. There is some trouble of oil staying around the sea water intake. This causes secondary oil contamination. • This system is not suitable at strong wave place.

Table 5.3.2(4): Comparison Table of Sea Water Intake Facilities Regarding Prevention of Oil Contamination (Beach Well System) 94)

1. Outline	  A well is made near sea shore and the sea water is introduced from the well to the plant by submerged sea water intake pumps.
2. Merits	• The clean sea water can be taken through natural filtration such as coral and/or sand.
3. Demerits	• When the sea bottom around the well is contaminated by oil, there are some troubles of decrease of intake water quality and oil invasion. • This system is not suitable for large scale sea water intake system.

(5) Summary

At the viewpoint of actual use, evaluation on the above mentioned oil contamination preventive methods are as follows:

* Oil enveloping method by oil fence is the most effective method for oil recovery in open sea, but is not so suitable for small oil effluence.

* Oil fence is the most fundamental method which is applicable to many kinds of cases, if application of oil fence is changed depending on the conditions of oil contamination.

* Combined system of oil mop and oil fence is the most effective method in such a case when oil contamination occurs at the sea area of low tidal current and of short distance from seashore, because prevention of oil dispersion and oil recovery can be carried out at the same time and also mop narrowing machine can be installed easily on land nearby.
* Suitable selection of sea water intake facilities is the most fundamental matter regarding measures to prevent oil contamination for sea water utilization system.

* Application of oil gelling agent must be studied carefully depending on the circumstances of the place where oil contamination occurred.

* Application of oil recovery ships must be carefully considered because of high expense of the construction and maintenance.

* Adsorption agents can be applicable as supplemental method of oil dispersion prevention.

* The effect of the combination of air curtain and oil fence is expected to be favorable.

5.3.2 Existing Oil Contamination Preventive System of Umm Al Nar Station

(1) Geographical Conditions

The position of Umm Al Nar Station was decided to be the innermost part of the lagoon so as to protect the sea water intake facilities from storms in the open sea as shown in Fig. 3.1.1. The station has been commercially operated since 1979.

As the station is located at the innermost part of the lagoon, replacement of sea water between the sea area around Umm Al Nar and the Gulf is not so good, and distributions of high temperature and high salinity of sea water around Umm Al Nar are observed. So, once an oil pollution accident occurs around the Abu Dhabi Island, a long lasting influence and difficulty of countermeasures of oil contamination, can be expected.

The wide tidal zone is contaminated during ebb tide period with oil which invade the inner part of the lagoon. Such a process is repeated and the oil reaches the sea water intake of Umm Al Nar Station.

As the depth of water of the surrounding area of tidal zone is shallow, large ships cannot be used to eliminate oil and manpower only seems to be used to effect the elimination.

Therefore, regarding oil contamination preventive measures of Umm Al Nar Station, deteriorated oil, suspended oil in the middle layer and at bottom of sea, and long lasting oil contamination must be considered, in addition to invasion of dispersed oil on the sea surface.

(2) Climatic Conditions

Most of the time throughout the year, the wind direction in Abu Dhabi is NW . Especially in February and March strong NW wind, called "Shamal" blows. The Gulf and Umm Al Nar are connected with Baghal Channel which lies at full length of the NW direction. So oil dispersion is expected to be influenced very much by NW wind.

Contaminated oil will be physically, chemically and biologically changed and will deteriorate in comparatively shorter time because of high atmospheric temperature of 10 to 45 °C in Abu Dhabi City.

(3) Marine Conditions

1) Channel Area

The highest current speeds at most of the sites in the channels around the Abu Dhabi Island are 40 cm/s or more. Speed more than 90 cm/s or was recorded at certain sites. As the geographical feature is very complicated, dispersed oil on the sea surface is considered to be mixed into the sea water at the corners of the channels and near the sea water mass front. Therefore, it seems that oil fence can be used effectively only at limited places and oil dispersion cannot be perfectly prevented by oil fence only.

According to the results of consecutive anchored observation of sea water temperature and salinity, the open sea water reached the middle part of Baghal Channel during the latter flood tide period. Therefore, effluence oil near Mina Zayed will be dispersed to the middle part of Baghal Channel during one flood tide period.

2) Neighborhood of Umm Al Nar Intakes

According to the marine observations, outlines of the marine conditions around Umm Al Nar intakes are as follows:

* The recorded maximum range of tidal level was about 2 m and this value is comparatively large.

* There was no dominant current direction but to some extent the eastward streams were recorded.

* The main current direction was 74 deg. and the average current speed over the observation period was 1.9 cm/s.

* The sea water temperature was comparatively high and the daily range of the temperature was small, but sudden temperature rise was often recorded.

* The salinity was comparatively high and the daily range of the salinity was small.

* Dispersed oil in the neighborhood of the sea water intakes is liable to be gathered around the sea water intake No. 3.

The followings are presumed from the above mentioned records:

* The sea water temperature and salinity around the intakes seem to indicate high distribution, because of the influence of waste water from Umm Al Nar Station (washing water of screens and sand filters) and recirculation of thermal discharge. Once oil is introduced to the station from the intakes, it is considered that the oil will move just same as sea water around it.

Therefore, period influenced by oil pollution is expected to be long.

(4) Oil Invasion Preventive Facilities

Oil invasion preventive facilities have been installed at the sea water intake facilities No. 1 as shown in Fig. 2.2.3. These facilities adopted air curtain as the first barrier. Fine air bubbles are generated at the bottom of the sea.

Oil invasion to the inside can be prevented with up-lift air bubbles from the bottom of the sea and also can prevent approach of oil film with horizontal stream generated by air bubbles nearby the sea surface. As an air bubble generating equipment, "Superja" type generates large air bubbles, and it seems to be difficult to prevent effectively the invasion of fine oil drops floating in the sea.

As the secondary barrier, oil fence has been additionally installed inside the air curtain. This oil fence has dimensions of about 1 m submerged from the sea surface and about 10 cm height on the sea surface. Invasion of dispersed oil on the sea surface can be prevented by this oil fence, but cannot be prevented for suspended oil from the middle and bottom layers of the sea.

(5) Sea Water Intake Facilities

Sea water intake facilities No.1 are made of reinforced concrete and submerged intake type. It has five intake gates, bar screens, traveling screens and sedimentation ponds. A common channel is installed after the above mentioned equipment. The sea water from each gate is gathered at the channel and supplied for each plant through band screens by vertical pumps.

The inlet dimension of the intake is 4.50 m (W) x EL-4.30 to -9.00 m (H). On the other hand, according to the observations of the tidal level in 1987 by Hydraulic Laboratory, the minimum tidal level in 1987 was recorded as ACD+32 cm in December. At this time, therefore, the top of the inlet is submerged about 40 cm from the sea surface. According to the observations of tidal currents near the intake in October, 1988, intake speed was about 40 cm/s. If this speed and the minimum tidal level are combined at the same time, there is some possibility that dispersed oil near the intake is introduced into the intake.

When the acid was put on board a tanker from the electrolysis factory adjacent to Umm Al Nar Station on February 22, 1988, light oil effluent accident occurred. At this time, spilled light oil flowed into the sea water intake facilities No.3, the nearest intake facility from the place where the oil spill happened.

Current velocity distribution and grain size distribution of sediment in the sedimentation pond of sea water intake facilities No.1 were studied in October 1988. According to these results, speed in the pond was about 10 cm/s at 2 m layer below the sea surface and about 30 cm/s at 3 m layer below the sea surface or more.

The range of grain size of sediments in the pond was 0.1 to 5.0 mm in diameter. The grain size of half of them was about 1.2 mm in diameter. As above mentioned, the flow speed in the pond is so high that not much effective separation can be expected between water and oil.

(6) Effective Measures to Prevent Oil Contamination

When measures to prevent oil contamination are applied at Umm Al Nar Station, the following items must be considered:

* There is some possibility of oil invasion to Umm Al Nar Station through Baghal Channel. (by numerical calculation)

* There is rare possibility of direct oil invasion to Umm Al Nar Station through Bateen Channel. (by numerical calculation)

* As current speed is high in Baghal Channel, effective measures to prevent oil contamination cannot be expected in Baghal Channel. (by numerical calculation)

* Taking into consideration of the current speed during flood tide period, semi-fixed oil fence installed at the open sea near the entrance of Baghal Channel must be located in the offing of 5 km. (by numerical calculation)

* There is some possibility of chronic occurrence of oil contamination near Umm Al Nar Station. (by numerical calculation)

Taking into consideration of the above mentioned matters, effective measures to prevent oil contamination at Umm Al Nar Station seem to be as follows:

* To prevent oil invasion from the open sea to Baghal Channel and to recover effluent oil, an enveloped oil fence is used in the open sea.

* To prevent oil invasion in the neighborhood of Umm Al Nar intakes, a semi-fixed oil fence is installed near the entrance of South Basin of Umm Al Nar.

* To prevent unexpected and chronic oil invasion into the sea water intakes of Umm Al Nar Station, the presently used intake facilities should be changed to submerged piping system or curtain wall system.

5.4 Conceptual Design of Oil Contamination Preventive System

5.4.1 Outline of Oil Contamination Preventive System

Subject marine area of conceptual design is shown in Fig. 5.4.1.

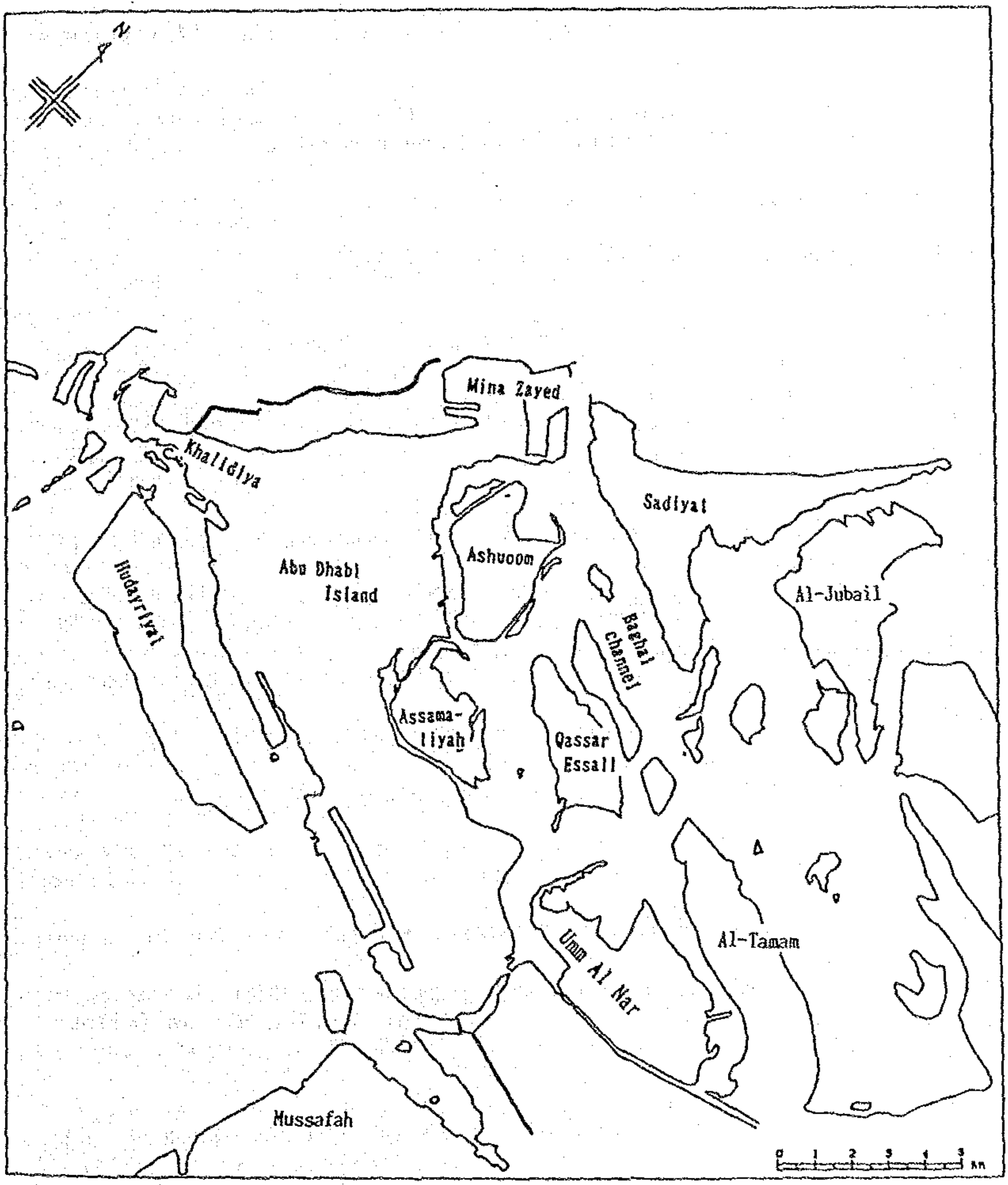


Fig. 5.4.1: Subject Marine Area

As described in 5.3.2, the following countermeasures agaist oil contamination at Umm Al Nar Station are considered to be effective in:

* Prevention of oil effluent from Arabian Gulf to Baghal Channel

* Prevention of oil effluent from the entrance part of South Basin at Umm Al Nar to the sea water intake

* Reconstruction of the presently used sea water intake facilities at Umm Al Nar Station

In this section, conceptual designs for the above mentioned countermeasures against oil contamination will be described.

Fundamental design conditions are as follows:

(1) Marine Conditions and Climatic Conditions

1) Tide

H.H.W.L. : ACD + 2.37 m
H.W.L. : ACD + 1.90 m
M.S.L. : ACD + 1.29 m
L.W.L. : ACD + 0.70 m
L.L.W.L. : ACD + 0.32 m

2) Tidal Currents

Entrance part of Baghal Channel: 40 to 90 cm/s
Entrance part of Umm Al Nar South Basin: 20 cm/s

3) Wave

Negligible near Umm Al Nar Station

4) Wind

Velocity is 15m/s for oil fence design

(e) Sea Water Temperature and Salinity

According to the observation results in October, 1988, sea water temperature and salinity at the front of Umm Al Nar Station are as follows:

Sea water temperature: 31 °C
Salinity: 46

therefore,

Density ρ_o = 1.0297 g/cm³

(2) Density of Effluent Oil

Regarding the density of the effluent oil, it depends on the place of production, effluent scale and marine conditions. So the density of effluent oil is only assumed as follows:

ρ_o = 1.00 g/cm^3 (water content: 80%)

(3) Intake Sea Water Quantity at Umm Al Nar Station

* Sea water intake No.1

Q_1 = 44,000 m^3/h x 5 = 220,000 m^3/h = 61 m^3/s

* Sea water intake No.2

Q_2 = 45,000 m^3/h x 4 = 180,000 m^3/h = 50 m^3/s

* Sea water intake No.3

Q_3 = 55,000 m^3/h x 1 = 15.3 m^3/s

5.4.2 Countermeasures against Oil Effluent from Open Sea to Baghal Channel

According to the numerical calculation results carried out recently, effluent oil near the seashore which is originated from an oil contamination accident in Arabian Gulf, will invade Baghal Channel during the flood tide period. Then, the wide area of the lagoon in Baghal Channel will be contaminated by the effluent oil, once it has gotten into the channel. And gradually the oil diffuses to the innermost part of the channel and at last arrives nearby Umm Al Nar Station.

Therefore, it is necessary to execute countermeasures against oil contamination not only at Umm Al Nar Station, but also at all facilities and in the environment of the channel.

Countermeasures against oil effluent from the open sea to Baghal Channel are as follows:

* Extension of oil fence at the entrance part of Baghal Channel

* Oil recovery in the open sea by oil enveloping method

(1) Extension Method of Oil Fence at the Entrance Part of Baghal Channel

Based on the results of the site investigation and numerical calculation, an extension method of oil fences at Mina Zayed, where the amount of sea water inlets is at a maximum compared to other places, will be studied. The extension method of oil fences at Mina Zayed to prevent oil invasion into the channel is shown in Fig. 5.4.2.

* Case-1 Perfect blockade at entrance of channel

* Case-2 Extension of oil fence in offing

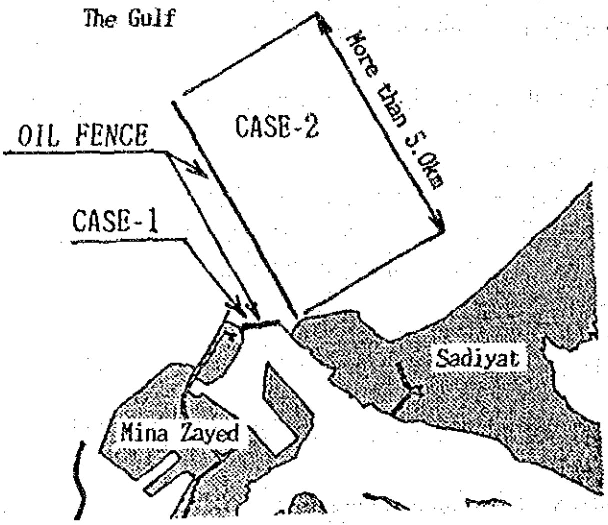


Fig. 5.4.2: Countermeasures against Oil Effluent to Baghal Channel

But these countermeasures are not practical from the view point of preventive efficiency and economy. The reasons for this are as follows:

1) The said area is the most important sea route. Therefore, if the period of oil contamination becomes lengthy, a sea route blockade of the oil like in Case-1 is actually difficult to accomplish.

2) According to the site investigation results, flow velocity at the said area is fast at about 40 to 90 cm/s. But the maximum endurance speed of an oil fence, even of the D-type, is said to be about 50 cm/s. Therefore, not much can be expected from the preventive efficiency of oil fences in this area.

3) According to the numerical calculation, markers flowing near seashore almost flowed into the channel from 5 km offshore from the embankment.

   In Case-2, therefore, an oil fence would have to be extended up to more than 5 km. So, the extension of oil fences is not practical at the said area.

(2) Oil Enveloping Method in Offshore of Abu Dhabi Island

As mentioned above, utilization of semi-fixed oil fence at the said area is not practical from the viewpoint of preventive efficiency and economy.

Therefore, to minimize the invasion of oil into the said channel from an oil contamination accident in the Gulf, the best way is if an oil fence extension ship and an oil recovery ship are always prepared and ready nearby the said place, and prevention of oil dispersion and oil recovery in the Gulf should be carried out by these ships.

According to numerical calculation, an oil mass located 5 km offshore will arrive at the inlet mouth of Mina Zayed within 3 to 5 hours in the maximum spring tide period.

Therefore, the oil fence extension ship and the oil recovery ship should arrive at the said place within 2 hours.

1) Oil Fence Extension Ship

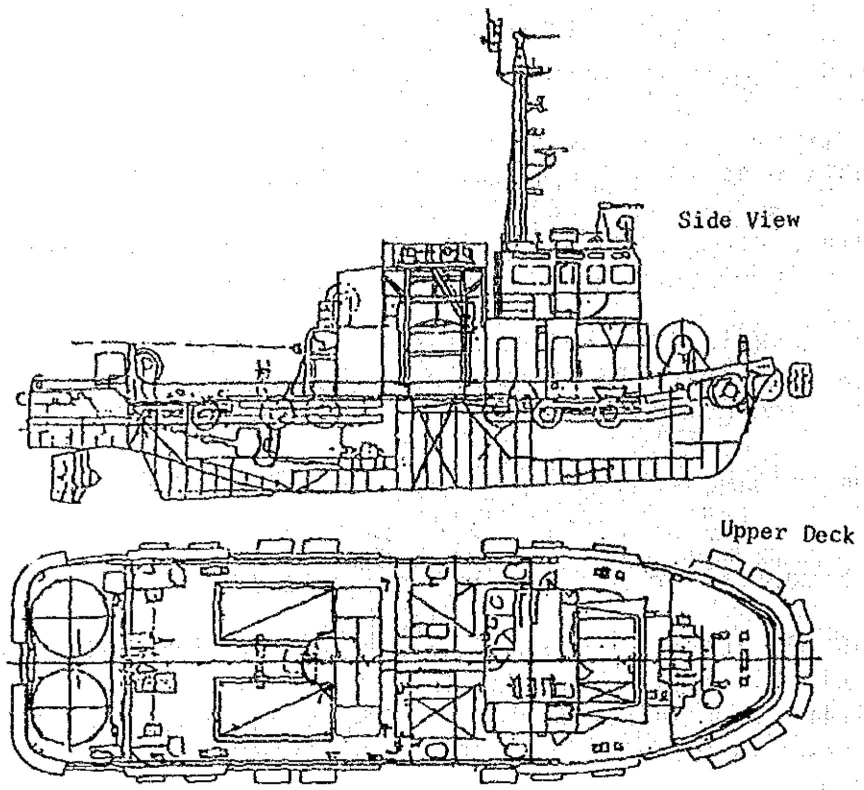
Generally, an oil fence ship drags an already extended oil fence to the site to prevent oil dispersion. But this time, as prompt action is necessary, an oil fence on-board ship which is able to carry, extend and rewind an oil fence is preferable. Such an oil fence on-board ship is shown in Fig. 5.4.3.

2) Oil Recovery Ship

Generally, oil enveloped by an oil fence is recovered by an oil recovery ship. The oil fence on-board ship mentioned above has some kinds of oil recovery equipment on-board. But from the viewpoint of the mobility of oil recovery, the preparation of a professional oil recovery ship is preferable. Such an oil recovery ship is shown in Fig. 5.4.4.

Main specifications:

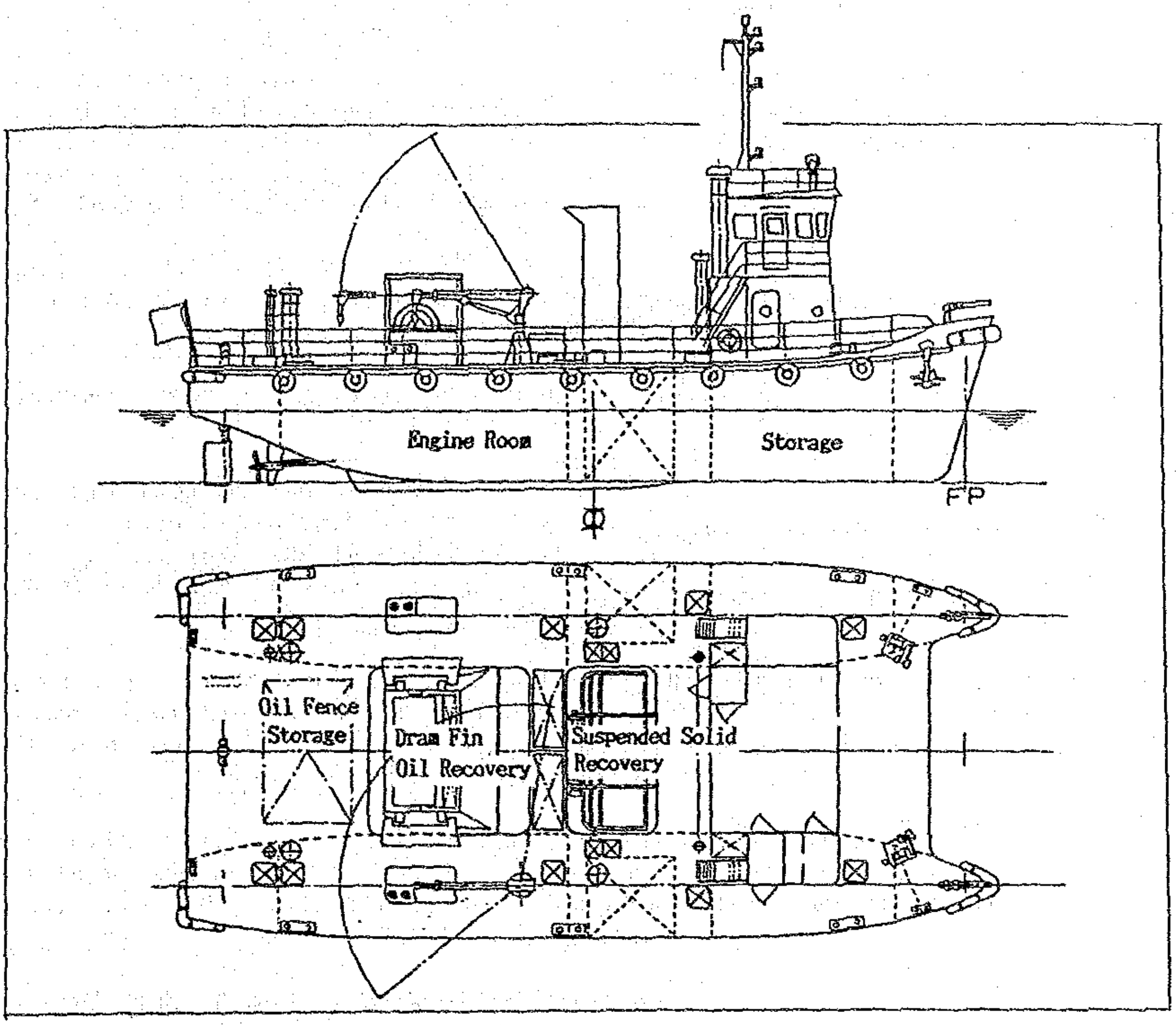
Length of ship:	22.3 m
Width of ship:	9.3 m
Width of single hull:	2.9 m
Depth of hull:	3.2 m
Drought:	2.0 m
Total displacement:	100 GT
Speed:	10 knot
Main engine:	Diesel 350 ps x 2 sets
Oil recovery equipment:	Dram fin type 1 set
Oil recovery capacity:	30 m^3/h



Ship body	
Length	24.70 m
Width	7.00 m
Depth	3.05 m
Draught (plan)	2.20 m
Navigation area	coastal area
Total displacement	128.87GT
Real displacement	51.47T
Maximum speed	11.26 knot

Main engine	2 sets
Water cooling, 4 cycle, high speed diesel engine 6L20AX	
Power*rotation 650ps*860rpm	
Oil recovery equipment	2 sets
Inclinated plate type	
Oil recovery speed	50.3m³/h

Fig. 5.4.3: Example of Oil Fence Extension Ship



Main specification

Length of ship	22.3 m
Width of ship	9.3 m
Width of single hull	2.9 m
Depth of ship	3.2 m
Draught	2.0 m
Total displacement	100 GT
Speed	10 knot
Main engine	diesel 350ps × 2 sets
Oil recovery equipment	dram fin type 1 set
Oil recovery capacity	$30m^3/h$

Fig. 5.4.4: Example of Oil Recovery Ship

5.4.3 Prevention of Oil Inflow at Entrance Part of Umm Al Nar South Basin

According to the results of numerical calculation, inflowing oil to the channel will probably arrive at the sea water intake facilities of Umm Al Nar Station through the canal between Essall and Assamaliyah as shown in Fig. 5.4.1. Also, oil which disperses near Umm Al Nar has higher possibility to inflow into the sea water intake facilities of Umm Al Nar Station.

Considering marine and geographical conditions at the sea water intake of Umm Al Nar Station, conditions of oil contamination are as follows:

* Inflow oil near the sea water intake of the station has some tendency to gather near the intake of the station No. 3.

* Oil, once it passes into sea water intake seems to be recirculated in the station due to the influence of waste water discharged near the sea water intake and/or thermal discharge from Umm Al Nar Station. So the influence of the oil contamination in the station will continue for a long time.

As the surface sea water is supplied into the station by the presently used sea water intake facilities at the time of L.L.W.L of tidal level, oily-water near the sea water intake system will be introduced into the station together with the surface sea water.

Therefore, regarding protection of the station from oil contamination, it would be most effective to prepare an oil inflow prevention system at the entrance of South Basin of Umm Al Nar. The location of the oil fence extension in this sea area is shown in Fig. 5.4.5.

An oil fence is usually wound on a winder located at Umm Al Nar Station side so as not to obstruct sea routes. The oil fence will be extended from Umm Al Nar Station side to the opposite side only when there is some fear of oil invasion. Oil fence and accessories are described hereafter.

(1) Oil Fence (length of 1,300 m)

Marine conditions at this sea area are as follows:

Tidal currents: 20 cm/s
Wave: negligible
Wind Velocity: 15 m/s

According to the above mentioned marine conditions, a normal oil fence would be sufficient. But this time, a B-type oil fence having a long skirt will be adopted. There are many kinds of B-type oil fences approved by the Ministry of Transport, Japan. One example of B-type oil fence having a comparatively long skirt is shown in Fig. 5.4.6.

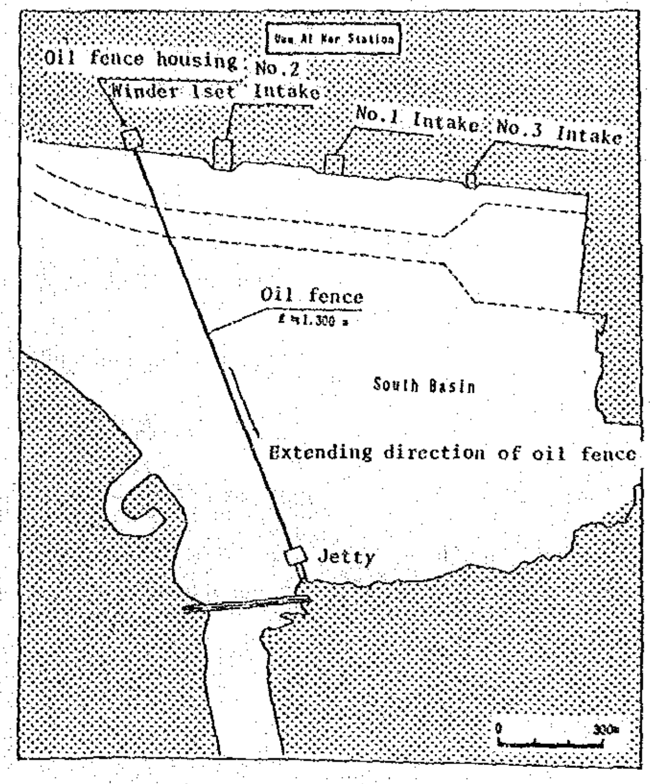


Fig. 5.4.5: Extension Location of Oil Fence

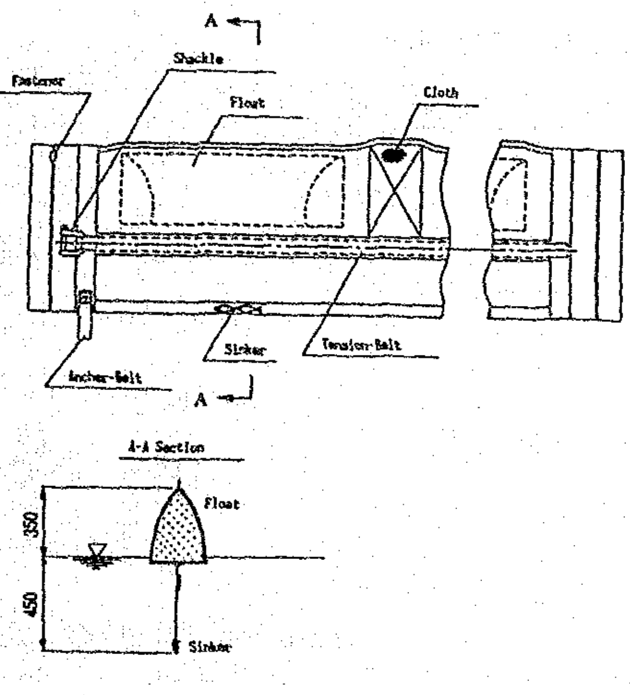
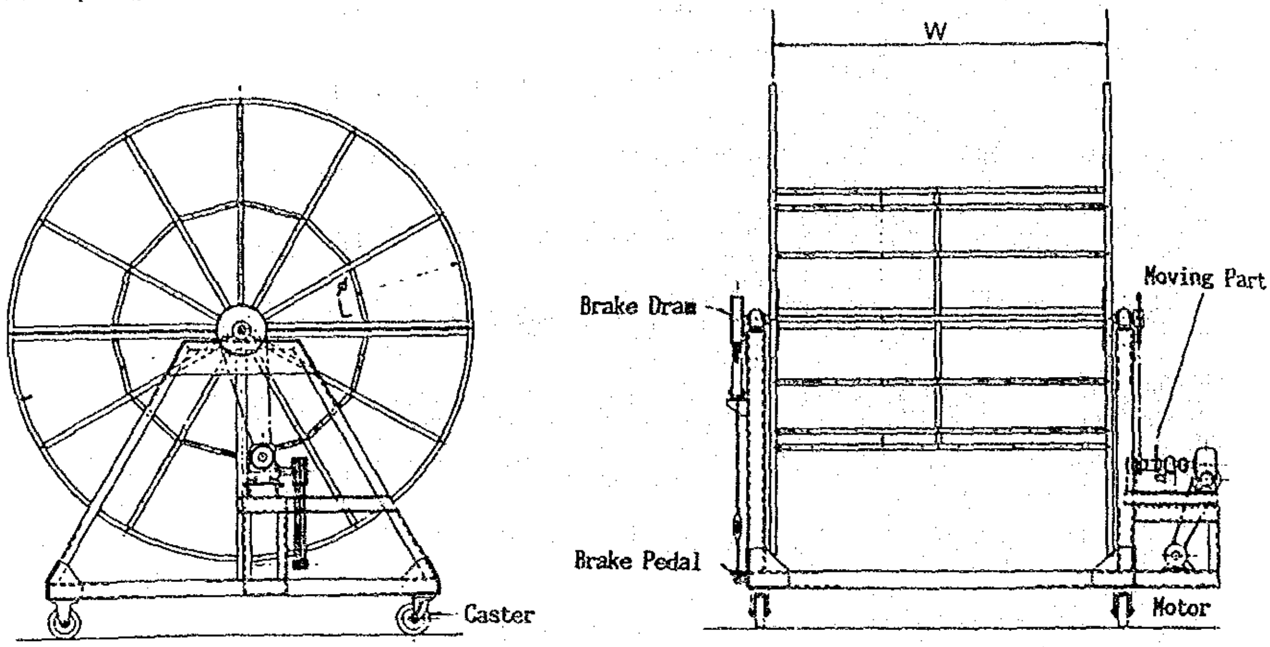


Fig. 5.4.6: Example of B-type Oil Fence

(2) Oil Fence Winder

Installation of an oil fence winder at the embankment of Umm Al Nar Station is necessary for the extension and rewinding of the oil fence speedily in case of emergency. An example of the oil fence winder is shown in Fig. 5.4.7.

Standard Specification



Type	B-type Oil Fence Length of Rewind (m)	Size of Rewinder (m) Width of Dram (W)	Diameter of Dram (L)
TK-1	160	1.8	3.6
TK-2	200	2.5	3.6
TK-3	300	3.2	4.0
TK-4	400	3.75	4.25
TK-5	500	3.75	4.5
TK-6	600	4.15	4.5

Fig. 5.4.7: Example of Oil Fence Winder

(3) Oil Fence Extension Ship

An oil fence extension ship is required to use an oil fence winder effectively and also must always be prepared nearby the winder, ready for an emergency situation. An oil fence extension ship is shown in Fig. 5.4.8. And also the oil fence winder and extension work are shown in Fig. 5.4.9.

In the case of these facilities, about 3 to 4 hours is necessary to fully extend the oil fence of 1,300 m in length. Therefore, an oil monitor system must be located to be able to alarm the oil fence winder in advance, say 5 hours before the oil reaches the station.

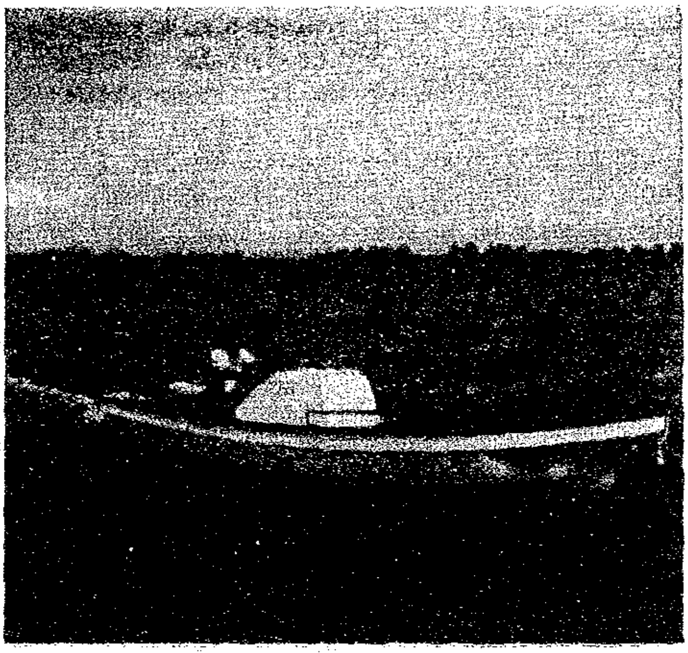


Fig. 5.4.8: Oil Fence Extension Ship

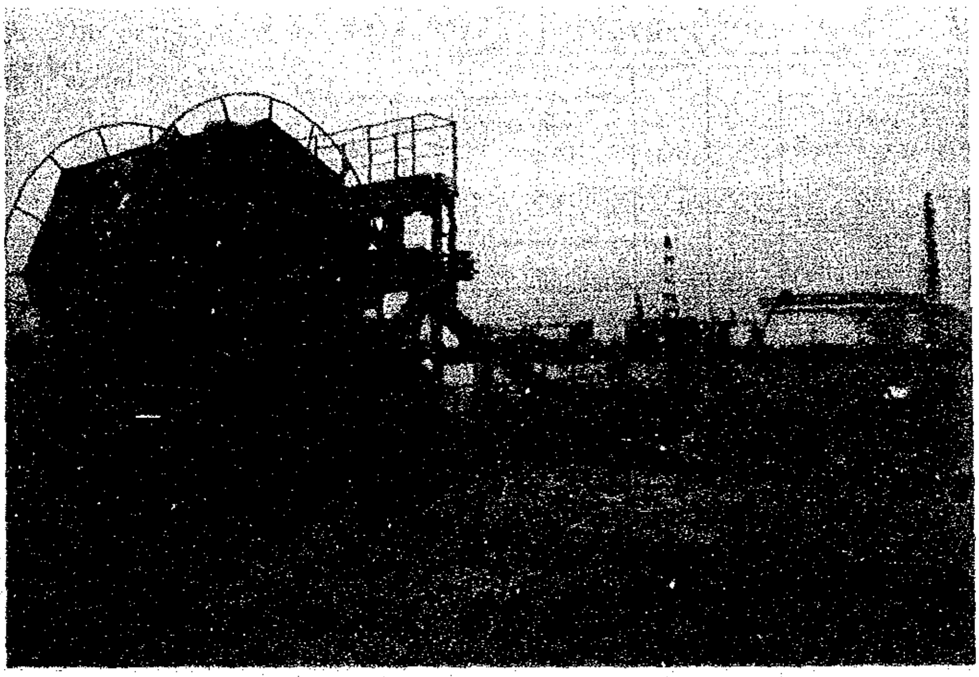


Fig. 5.4.9: Extension Work by Oil Fence Winder

5.4.4 Reconstruction of Existing Sea Water Intake Facilities in Umm Al Nar Station

As mentioned above, the surface sea water is introduced into the station by presently used No. 1 to 3 sea water intakes under certain tidal conditions.

Therefore, it is almost impossible to prevent oil invasion into the station through the presently used sea water intake system if an unexpected oil effluent accident were to occur. So the reconstruction of the presently used sea water intake system to be able to avoid invasion of surface oil into the Umm Al Nar Station, would be an effective measure to prevent oil pollution.

Using the sea water intake head as shown in Fig. 5.4.10, not only the inflow of surface sea water, but also that of contaminated sediments at the sea bottom would be avoided. Abrasion of plant materials caused by sand inflow will also be reduced by the reconstruction.

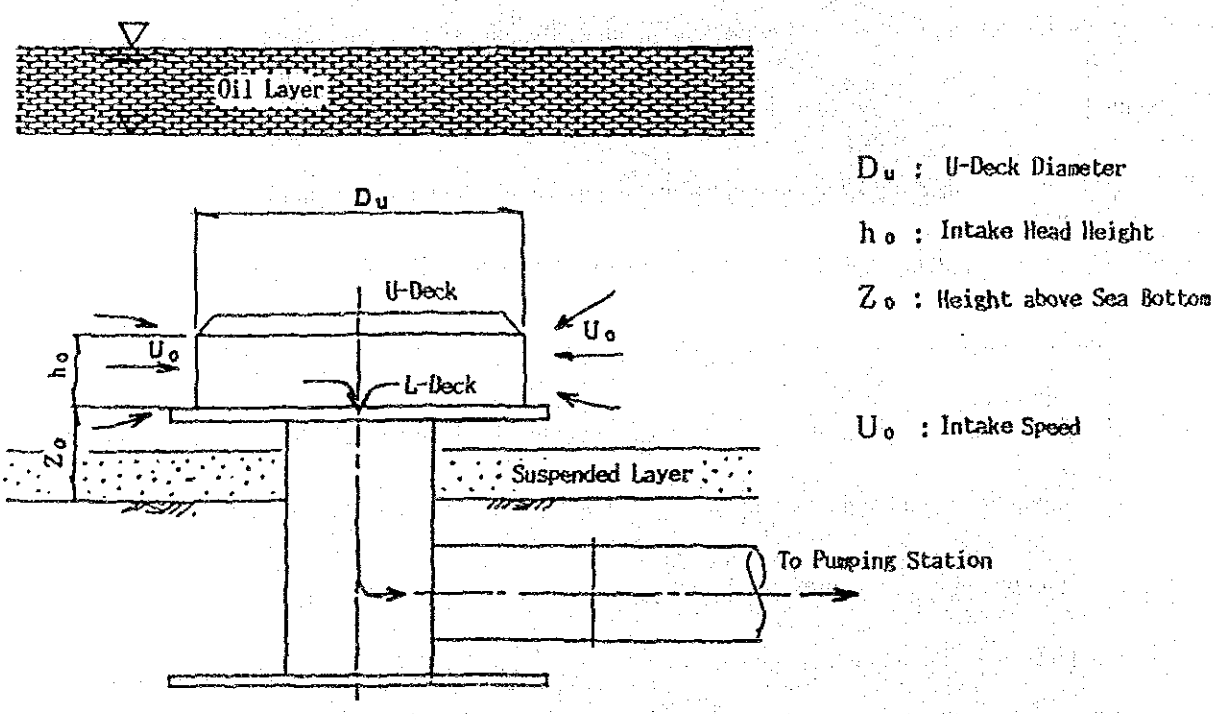


Fig. 5.4.10: Sketch of Selection Intake Introduced from Middle Layer

The above mentioned measures to prevent oil contamination for the presently used intakes including intake head shown in Fig. 5.4.10 are only effective for invasion of surface oil, but are not entirely effective for emulsion oil suspended in the sea water. One method to prevent emulsion oil is an aeration system. Generally, to increase preventive efficiency for emulsion oil, the aeration system becomes very large and uneconomical especially if it were applied to the existing intake system.

But on the contrary, when the aeration system is applied nearby the above mentioned improved intake head, a fairly good preventive effect can be expected.

The conceptual design of this improvement plan, including aeration system are described hereinafter.

(1) Study on Shape of Intake Head

1) Conditions

(a) Water Depth

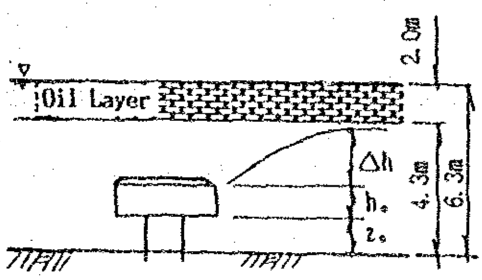
The sea water intake head will be located at the middle point between the embankment of Umm Al Nar Station and offshore sea route. According to the results of the field investigation, the depth in this area is assumed to be about ACD -6.00 m, and then the water depth by L.L.W.L. is h = 6.3 m.

(b) Thickness of Oil Film

Generally, the oil film thickness floating on the sea is about several micrometers to several centimeters. As the aeration system will be constructed around the intake heads to prevent inflowing oil in the sea.

The intake head is designed so as to avoid inflow of the sea water from the thickness of horizontal surface flow which is caused by aeration. And the above mentioned thickness which is called the "friction depth", is assumed to be same with oil film thickness.

According to Nakamura's report 95), friction depth also depends on air quantity. The following formula 96) is applied, when the air quantity is not so great.



$h_d = 0.3\ h$

where,

h_d: friction depth
h: water depth

Friction depth is assumed to be same with oil film thickness.

$h_d = 0.3 \times 6.3 = 1.89 \fallingdotseq 2.0$ m

2) Study on Critical Intake Height

According to the report by WRPC (1985) 98), intake conditions so as not to be contaminated by surface oil film, are given by the following formula:

$$\frac{\Delta h}{h_o} \geqq 0.279\ F_i^{1.47}$$

Where,

Δh: Critical intake height
h_o: Height of inlet
F_i: Internal Froude number
$Fi = Uo / \{g\ (\rho_2 - \rho_1)/\rho_2 \cdot ho\}$
ρ_1: Water density of surface layer (oil layer), about 1.0 g/cm³
ρ_2: Water density of bottom layer, about 1.0297 g/cm³
Uo: Intake velocity
g: Gravitational acceleration

3) Shape of Intake Head

According to the above mentioned formula, each dimension of the intake heads, so contamination by surface oil film would not occur, are shown in Table 5.4.1.

Table 5.4.1: Shape of Intake Head

Sea Water Intake / Items		No. 1	No. 2	No. 3
Total Sea Water Intake Quantity		61.0 m³/s	50.0 m³/s	15.3 m³/s
No. of Intake Heads		2 sets	2 sets	1 set
Intake Quantity per Head		30.5 m³/s	25.0 m³/s	15.3 m³/s
Height above Seabed	Zo	1.5 m	1.5 m	1.5 m
Height of Inlet	ho	2.0 m	2.0 m	2.0 m
U-deck Diameter	Du	15.0 m	12.0 m	8.0 m
Intake Velocity	Uo	0.36 m³/s	0.37 m³/s	0.34 m³/s
Critical Intake Height	h	0.20 m	0.20 m	0.17 m

(2) Diameter of Sea Water Intake Pipe

Sea water is introduced from the new installed intake head to the existing intake through a pipe. The most suitable pipe diameter is decided upon in order to minimize annual costs, including construction cost and running costs, pump electric power costs etc. The procedure to decide the most suitable pipe diameter is carried out by calculation for several kinds of pipe diameters. The calculation results are described in Table 5.4.2.

Table 5.4.2: Most Suitable Pipe Diameter

Sea Water Intake Items	No. 1	No. 2	No. 3
No. of pipe	2 sets	2 sets	1 set
Most Suitable Diameter	34,800 mm	34,400 mm	33,400 mm
Loss Head	38 cm	41 cm	41 cm

(3) Study of Aeration System

1) Location of Aeration System

If the aeration system is installed too close to the intake head, bubbling air is introduced into the intake facilities. Also, if the intake area is under the influence of rising oil with unstable conditions, the above mentioned assumption of critical intake height does not come into being.

Therefore, it is necessary that the aeration system is installed a little away from the intake head. But theoretical calculation formula to decide the distance between the aeration system and the intake head has not been established yet.

Then, the above mentioned distance, in which the surface stream generated by the aeration system would be sufficiently low, is adopted. According to Nakamura's report 95), the distance, with which the velocity of the rising air bubbles and accompanying surface stream decrease up to from 1/50 to 1/100 of their initial velocity, is said to be about 3.5 to 5.5 times that of the water depth.

Therefore, the aeration system is installed 4.5 times the water depth away from the intake head (at radius). Water depth at the site is 7.2 m from M.W.L. (ACD + 1.29 m), so the aeration system is installed 33 m (about 7.3 x 4.5) on the radius away from the intake head.

2) Air Quantity

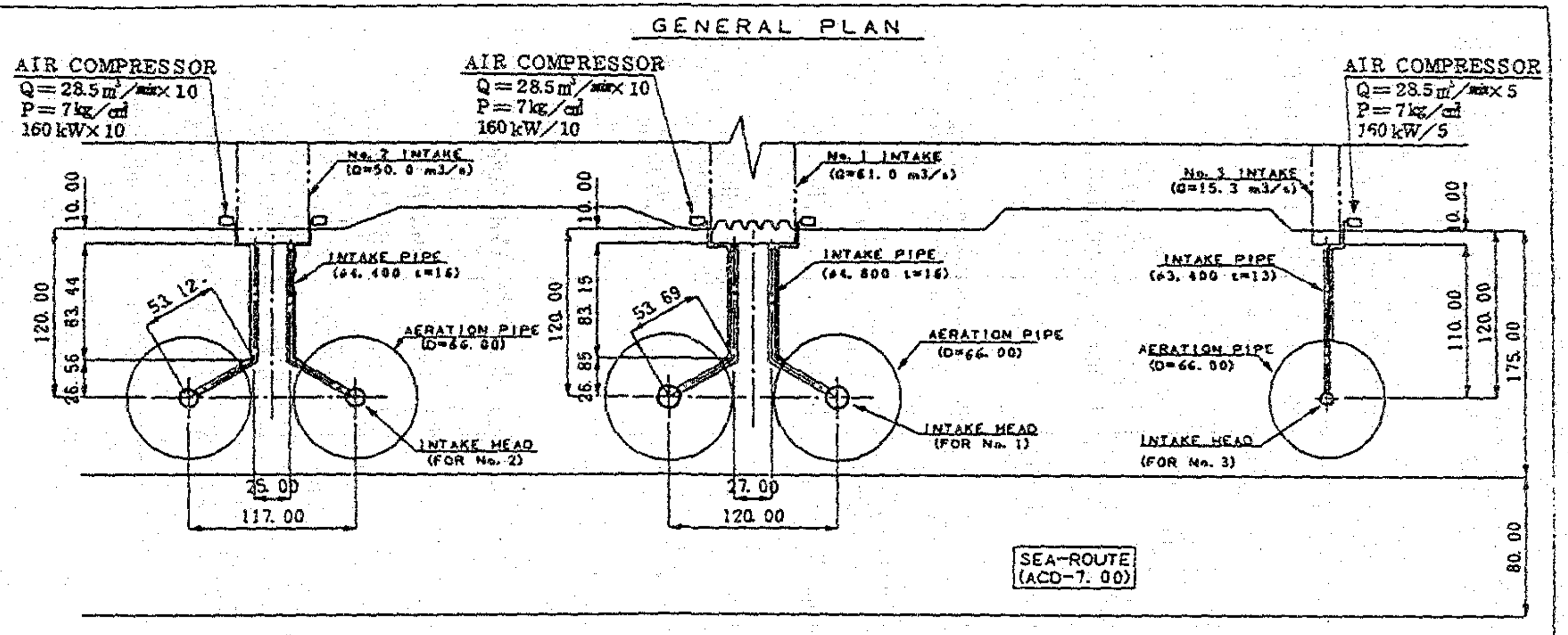
The purpose of the aeration system installation is not to eliminate oil by adsorption into the air bubbles, but to repress invasion of oil into the intake head by the rising action of the stream of water generated by the aeration system.

Therefore, an air quantity enabling the effective amount of up-lift in the stream is necessary. According to Ueda's report regarding the prevention of effluent oil dispersion, it is reported that an air quantity of 0.01 $m^3/s\cdot m$ with stream velocity of about 0.3 m/s in the area is effective for prevention of effluent oil dispersion. Therefore, in this system the total air quantity for the intake each head is;

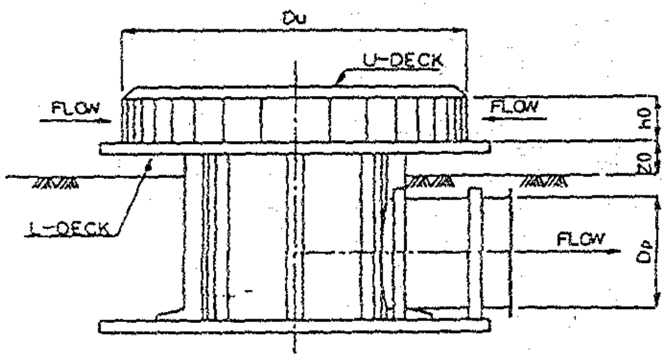
$$2.07\ m^3/s\ (Q = 0.01 \times 2 \times p \times 33 = 2.07),$$

assuming a unit air quantity of 0.01 $m^3/s\cdot m$.

5 sets of the above mentioned aeration systems are necessary for No. 1 to No. 3 sea water intake systems. General arrangement is shown in Fig. 5.4.11.



OUTLINESHAPE OF INTAKE HEAD



	No. 1 INTAKE	No. 2 INTAKE	No. 3 INTAKE
Du (mm)	φ15. 000	φ12. 000	φ8. 000
h0 (mm)	2. 000	2. 000	2. 000
Z0 (mm)	1. 500	1. 500	1. 500
Dp (mm)	φ4. 800	φ4. 400	φ3. 400

Fig. 5. 4. 11: General Plan and Outline Shape of Intake Head

5.5 Rough Estimation of Construction Cost

Rough construction costs of oil pollution preventive systems described in 5.4 at the present moment are as follows. This costs are based on unit cost in Japan.

Table 5.5.1: Rough Construction Cost

Item	Quantity	Cost ¥10,000
1. Preventive measures against oil pollution in the Arabian Gulf		
(1) oil fence extension ship	1 set	50,000-
(2) oil recovery ship	1 set	10,000-
Total		
2. Preventive measures against oil pollution at the entrance part of the of South Basin of UAN		
(1) oil fence 0.9 * 1,400m	1,400m	1,260-
(2) oil fence winder 600 * 3sets	3 sets	1,800-
(3) oil fence extension ship	1 set	1,000-
(4) embankment construction work	1 set	13,000-
(5) transportation and others	1 set	940-
Total		18,000-
3. Preventive measures against oil pollution by rectification of the existing intake system		
(1) manufacturing of intake pipe and head	1 set	128,200-
(2) construction and civil work	1 set	272,100-
(3) aeration system	1 set	69,000-
(4) transportation and navigation	1 set	69,600-
(5) others	1 set	151,100-
Total		690,000-

Notes : Ex-shipyard

5.6 Construction Time Schedule

Construction time schedules of three methods mentioned in 5.5 are as follows:

1) Preventive measures of oil pollution in the Arbian Gulf

Item	1st Year												2nd Year											
			3			6			9						3			6			9			
1) Planning and design	—	—																						
2) Manufacturing of oil fence extension ship		—	—	—	—	—	—	—	—	—	—	—	—											
3) Manufacturing of oil recovery ship		—	—	—	—	—	—	—	—															

2) Preventive measures of oil pollution at the entrance part of South Basin of Umm Al Nar

Item	1st Year												2nd Year											
			3			6			9						3			6			9			
1) Planning and design	—	—																						
2) Manufacturing and transportation			—	—	—	—	—	—																
3) Construction at site									—	—														
4) Test											—	—												

3) Preventive measures of oil pollution by rectification of the existing intake system

Item	1st Year												2nd Year											
			3			6			9						3			6			9			
1) Planning and design	—	—																						
2) Manufacturing and transportation			—	—	—	—	—	—	—	—														
3) Construction at site and civil work											—	—	—	—	—	—	—	—	—					
4) Test																				—	—			

5.7 Emergency Plant Shutdown and Ways to Ensure Water Supply

5.7.1 Rise of Oil Conternt Concentration during Sea Water Intake and Emergency Plant Shutdown

As product water from desalination plants is indispensable to human life in this area, especially in the Abu Dhabi Island and its surrounding areas where the only source of drinking water is this product water, it is necessary that the plants be kept running even though the sea water may be contaminated with oil.

However, a system capable of ensuring complete prevention of oil contamination is not available at present. The plants might have to stop operation due to high oil concentrations not only when oil leaks occur near the plant but also when large quantities of oil are found far from the plant, and when conditions are worsened when strong winds form high waves causing the oil to mix with sea water in the middle or lower layers. Here, the conditions giving rise to emergency shutdown, the actions to be taken during such emergency shutdown, etc. will be investigated. Measures for the storage of product water shall also be studied.

5.7.2 Conditions of Emergency Shutdown

Investigation reveals the followings:

* Actual cases in which existing desalination plants were affected by oil pollution and caused to be shutdown were not found in any reports.

* There are almost no examples of oil contamination affecting plant operation and the product water, except in the case of desalination plants which use sea water.

* Therefore, it seems difficult to settle standards of emergency shutdown based on data obtained from past operation records.

As described in Chapter 4, oil concentration level might be less than 1,000 mg/l because oil in solid form can be eliminated at the entrance of the sea water intake. Therefore, oil contamination of feed sea water does not affect greatly to the short-term operation of desalination plant.

However, continued use of such raw sea water will, in the long run, cause accumulation of oil inside plant machinery, giving rise to a need for cleaning work would be much longer than the period required during an emergency shutdown caused by a sudden oil inflow. Oil separators designed for marine use, are generally able to cope with a maximum oil concentration of 1,000 mg/l. This means, the treatment of raw sea water when oil concentrations exceed 1,000 mg/l may be detrimentally affected.

Therefore, based on levels of oil concentration, one method for plant protection may be to set a standard for emergency shutdown when the oil concentration in the intake sea water exceeds 1,000 mg/l.

In any case, it is still necessary to conduct total and integrated investigations, concerning the treatment methods of oil contaminated product water, the possibility of water quantity improvement and procurement of emergency supplies of water, the affects of a reduction or stoppage in water supply, etc.

5.7.3 Attention and Measures Necessary for Emergency Shutdown

When oil spills occur in the sea surrounding the desalination plant, careful attention to the spread and the direction of oil flow is required. In the event that the oil spill has the potential to damage the plant intake facility, the following actions should be taken:

(1) The desalination plant at Umm al Nar has 3 intake facilities in its east and west sides. It is considered that these 3 facilities do not necessarily have the same oil contamination potential since they are situated in different sea water areas.

Therefore, it may be necessary to adjust the quantity of raw sea water taken from each of the intakes by changing the number of operating units and/or the operation load taking into account the condition of each facility. Further, to avoid the concentration of loads on certain intakes, if there are other intake facilities not in operation it will be necessary to prepare them for start-up operation.

(2) The product water storage tank at the plant should be filled by reducing the water supply. The boiler water supply tank should also be filled after confirming that no oil is present.

(3) If all units are contaminated by oil, and it takes a long time to repair them, new problems may be expected to arise. Therefore, in preparation for the re-start of operation after completion of oil elimination work, the necessary number of units to secure water for living should be shutdown at an earlier time before the oil contamination becomes serious.

(4) When oil mixes into sea water, the more volatile components are vaporized in the deaerator or high temperature evaporation chamber. It is quite possible that some or all of these components are contained in the venting steam in which they are cooled down and condensed by a lower temperature cooling water in the vent condenser and ejector condenser.

Therefore, it is necessary to take whatever action to prevent the drain water from the vent condenser and ejector condenser being drained outside and recovered as product water.

(5) To set the minimum operation load of the desalination plant at 50 to 60%, where plant shutdown due to oil contamination becomes likely, the operation load could be reduced in advance. This would help to reduce the shutdown period.

In addition, during low load operations the amount of sea water intake is similarly reduced. Consequently, the amount of oil mixture entering the intake facilities will also be reduced.

(6) It will be necessary to organize and prepare detergents, jet washing devices, etc. necessary for the elimination of oil during plant shutdown.

5.7.4 Plant Shutdown and Measures during Plant Shutdown

As for measures to be taken during plant shutdown and maintenance, there is no special difference between ordinary shutdowns and emergency shutdowns. Measures to be taken during ordinary shutdown and maintenance periods may be applied in the case of emergency shutdowns. However, since start-up after a period (eg. 1 week to 1 month) of shutdown is expected to be difficult, it is recommended that plant equipment be washed well with pure water to prevent corrosion.

Some of the water stored in the product water storage tank may be used for this washing.

As a summary, the major points concerning the moth ball procedures are as follows:

(a) Intake head, intake pipe and storage facilities-sterilizer to be injected as required.

(b) Intake pump

(b.1) In the event that the shutdown period is expected to be long and the equipment is not resistant to corrosion, the pump should be removed from the intake pit and then washed with fresh water and dried.

(b.2) Routine manual rotation is required after greasing.

(b.3) Any openings around the rotating parts should be sealed by greasing.

(b.4) Machine parts, such as the shaft holder should be well greased to protect against rust.

(c) Piping

Drain out and then wash with fresh water and dry.

(d) Deaerator

Drain out and then wash with fresh water and dry.

(e) Evaporator

(e. 1) Drain out.

(e. 2) Rinse with fresh water using brine recirculation pump.
(e. 3) Dry.

(e. 4) Keep dry.

(f) Brine heater

In tube side, drain out, wash with fresh water and then dry.

In shell side, drain out and dry.

(g) Vent condenser and ejector condenser

The same procedure as that recommended for brine heater should be carried out.

(h) Post treatment system

Drain out and dry.

(i) Others

a) Pumps (other than intake pump)

a-1) Pumps installed in the sea water line, brine line and chemical injection lines.

Drain out, wash with fresh water and dry. b. 2, 3 and 4 above are also carried out.

a-2) Pumps in product line

Drain out and dry.

b) Rotating Parts

Routine manual rotation is required after greasing.

Any openings around the rotating parts must be sealed by greasing.

c) Inlet and outlet of equipment (opening of equipment)

Close with cloth/vinyl sheet.

d) Instrument

d-1) Sensors should be removed and stored after cleaning.

d-2) Air piping

Drain out and dry.

d-3) *Local instrument equipment*

Sealed with vinyl sheet.

e) Central control room

HVAC system should continue to be operated with an emergency power supply.

5.7.5 Measures to Ensure a Domestic Water Wupply during Plant Shutdown

Considering the serious consequences of a shutdown of the sea water desalination plant which is the sole water supply source in this area, it is very important to take measures in advance to ensure the availability of the minimum required quantity of water for domestic use. To this end, measures such as (1) storage of product water, (2) saving on water consumption in an emergency, (3) coordination with desalination plants in other areas, (4) conversion of ground water, and (5) emergency transport of water from other areas, could be considered.

(1) Storage of Product Water

The capacity of the existing storage tanks for product water at the sea water desalination plants in Umm Al Nar is about 180,000 m^3 which is equivalent to approximately 70% of the average daily water supply (or nearly 17 h worth of water supply) to the Abu Dhabi City area.

In case of an emergency, in order to avoid the complete suspension of water supplies, even if this entails drastically reducing the quantity of water supplied, an increase in the water storage capacity is highly desirable. As possible measures to increase the water storage capacity, the construction of large scale reservoirs, underground dams, as well as the additional installation of storage tanks in Umm Al Nar, and storage in water tanks could be considered.

Also a study is necessary to plan for an increase in the capacity of existing water tanks installed to control the water pressure in the districts supplied, which at present have a capacity of several hundred cubic meters, and for their use as water supply stations in case of an emergency.

Furthermore, the installation of emergency water tanks and the stock piling of canned or bottled mineral water in private houses and buildings should always be encouraged.

(2) Saving on Water Consumption in Emergency

At present about 300,000 m³ of fresh water is produced daily in the Abu Dhabi City area (Umm Al Nar), of which 50,000 m³ is supplied to Al Ain, and the remaining 250,000 m³ is supplied to Abu Dhabi. Furthermore, about 50,000 m³ of water from waste effluent is re-used for irrigation.

It is assumed that approximately 50% of the total service water in the city is used for irrigation and sprinkling etc., which in the case of an emergency should be restricted to the minimum, and top priority should be given to its use as water for domestic use only.

In order to restrict non-urgent demands like irrigation and sprinkling etc., the supply lines for water for domestic use should be separated from those for non-urgent use if possible, and valves should be attached to the latter lines so they can be operated to restrict non-urgent water supply in case of an emergency.

When the plants shut down, water will be supplied from the storage source and/or emergency source, but saving on water consumption is indispensable because the quantity of water able to be supplied is limited. Measures should be taken to save on water consumption not only through notification to each household, but also through the restriction of water supply, which may be necessary depending on the circumstances.

There are several methods to enforce these restrictions such as by controlling the water pressure, restricting the supply to certain hours etc., but unfair water supply can be avoided by adjusting pumps, valves and pressure regulators, which should always be kept in good condition, and by operating the restrictions carefully and impartially.

In order to economize more drastically in water consumption in case of an emergency the water supply through the current pipe lines should be stopped as early as possible and a new supply system should be established from water supply stations and/or by the use of water wagons.

Assuming the water demand per capita per day is 10 liters, then the total water demand for the entire city area amounts to 4,000 m³. (Though the minimum water demand per capita is said to be about 3 liters, an ample surplus has been provided for in the above figure.)

This figure means that if 20 water wagons with a capacity of 20 m³ each were available, then the required quantity of water could be supplied by dispatching them 10 times per day. Water supply station equipment and any other accompanying equipment will have to be provided by way of providing water loading facilities etc..

(3) Coordination with Desalination Plants in Other Areas

Although simultaneous occurrences of oil pollution in wide ocean areas are very rare it would be desirable to install sea water desalination plants in several different places so that if sea water in a certain place is polluted then the plants in other locations could cover any water shortage when the pipelines between plants have been completed.

It would also be preferable that not only the plants in Abu Emirate such as Umm Al Nar and Taweela be interconnected but also that they be connected up with other plants in UAE such as Dubai, Sharjah, etc. by pipelines.

In case of water being supplied by other emirates, it would be necessary to put together an agreement on the conditions of mutual accommodation regarding the quantity, price and cost sharing of water supply facilities and so forth.

(4) Conversion of Ground Water

Should the intake of sea water become impossible, one countermeasure would be to desalinate at the Umm Al Nar water obtained from either subterranean sources under Al Ain, nearby saltwater lakes, or wells which should be opened up in the future. According to all surveys undertaken up until now, there are no possibilities for fresh water wells in the area, so further surveys of, and excavation of wells which can supply brackish water are deemed necessary in order to provide water for desalination at the plants in the case of an emergency.

Since there is the possibility that such brackish water contains some substances which cannot be treated in the Umm Al Nar sea water desalination plants, it would be desirable to examine the quality of the brackish water and establish the appropriate countermeasures in advance.

It should also be feasible to dig beach wells to obtain oil-free sea water and use it as a water source for a short period. Although the installation of beach wells is subject to severe regulation and the quantity of intake sea water would be limited, it could be useful as one of the countermeasures if the beach wells are dug beforehand and the supply lines to the plants are made ready.

(5) Emergency Transport of Water from Other Areas

Transport of product water from other desalination plants or underground water from other areas by means of water tankers is a highly feasible countermeasure. If one considers factors such as the required amount of water to be supplied, transport times, and expenses, then the required capacity of the water tankers would be between 10 and 40 thousand m^3 per tanker.

If two tankers could make shuttle deliveries, then they could suffice in an emergency situation. However, ship anchorage facilities, water unloading facilities, and water storage facilities would be needed at both sites where water loading and unloading occurs.

The conversion of an oil tanker into a water tanker is a conceivable means of transporting water, but the water would get mixed with oil unless freshwater ballast tanker were used, and such oily water could only be used for purposes other than drinking. Moreover this would necessitate the installation of oil cleaning equipment and waste oil disposal facilities on the ship.

All of the countries along the coast of Arabian Gulf contend with the possibility of emergency shutdowns of their sea water desalination plants.

Therefore, it would definitely be worthwhile studying the situation to assess the possibility of these countries jointly possessing water tankers and concluding an international agreement for the management and operation of the tankers which would be implemented to mutually accommodate them in case of an emergency.

This would be of benefit to all of the countries as it would improve the security of their water supply and be an effective way of economizing on the cost necessary to do this.

The above 5 measures for living water during plant shut-down, the study and planning of concrete enforcement plan in the existing facilities are required without delay especially for the saving water measure in (2).

Also, it is necessary to study the way to get into communication with the water consumers exactly about decrease of water supply, suspension of water supply, etc. to prevent occurrence of confusion.

As for the connection with sea water desalination plants in other are shown in (3), the desalination plant which has capacity of 100,000 m^3/d is to be completed in 1989 in Taweelha 70 km away from the Abu Dhabi Island and synthetic operation with Umm Al Nar Plant may become possible.

As for other measures, considerable investment in plant and equipment such as installation of more water storage tanks, securing of water supply tankers, installation of brackish water wells and beach wells, becomes necessary. Therefore, comprehensive investigation should be performed prior to the enforcement of the plan.

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