The International Tanker Owners
Pollution Federation Ltd

Effects of Oil Pollution on Major Municipal and Industrial Sea Water Abstractions

Final Report to the Commission of the European Communities
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EFFECTS OF OIL POLLUTION ON MAJOR MUNICIPAL AND INDUSTRIAL SEA WATER ABSTRACTIONS

ABSTRACT

This study considers the effects of oil pollution on industrial plants which employ sea water, either as a coolant or as a source of potable water, in particular electricity generating stations and desalination plants utilising multi-stage flash distillation and reverse osmosis.

The study revealed a lack of recorded information, both in the published literature and on the basis of questionnaires sent to plant operators world-wide. Consequently, basic engineering principles were used in order to predict likely detrimental effects. Various types of sea water intakes are described and the susceptibility of these and individual components of power plants and desalination units are considered. The economic consequences of these effects are compared with the costs of various preventive and protective measures. The general conclusions reached are that except in the case of major spills close to sea water intakes, the effects on heat exchanger performance are unlikely to be serious. However, effects on desalination plants are potentially more severe both with regard to contamination of produced water and damage to the plants themselves.

Recommendations are made regarding future research requirements.

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SUMMARY

Introduction

1. The project involves the study of the effects of oil spills at sea upon industrial works in which sea water is used. The principle uses of sea water are as coolant for power stations and feed water to desalination plants.

2. Specifically included in the study are reviews of the characteristics of oils reaching sea water intakes, the design of intakes and their protection systems, the works in which sea water is used, and the effects of oil spills. In addition the potential of additional protective measures has been evaluated together with the relative economics of protection methods vis-a-vis the costs associated with spills.

3. As foreseen a review of published literature was not rewarding and therefore direct approaches were made by telephone, personal visits, questionnaire and finally by a visit to installations in the Arabian Gulf.

Oil Characteristics

4. Oils transported by sea include crudes, low density, highly volatile refined products, light medium and heavy fuel oils and the very heavy bitumens and asphalts.

5. Once spilled at sea, oils weather due to a range of processes, including the rapid loss of volatile materials and the mixing created by wind and waves. The oils become denser, more viscous and often form emulsions.

Sea Water Intakes

6. Sea water intakes are of three basic types:

Foreshore intakes	Used where steeply shelving beaches permit access through the entire tidal range.
Extended intakes	Channels or pipes are used where beach shelving is slight to ensure access through the tidal range.
Beach wells	Used in only a few cases where sea water flows required are low.

The location of an intake in relation to local currents is important.

7. The sea surface intakes vary widely in design but in almost all cases pumping plant is protected by bar screens and fine screens of the drum or band type.

Uses of Sea Water

8. Sea water is used in power stations as cooling water for the condensation of steam from low pressure turbines. The major effects of oil pollution are likely to be fouling of the heat transfer surface with consequent raising of the condensation temperature and loss of power output.

9. With light medium and heavy oils and when the viscosity is little changed by weathering, the effects on performance are likely to be small. This analytical conclusion is confirmed by a case where fuel oil caused little deterioration in performance and cleaning was found to be easier than expected. The plant was off line for only 30 hours.

10. The main cause for concern at power stations is the ingress of very viscous oils or tar balls which are likely to have much more serious effects. When the risk of such pollution occurs the general philosophy is temporarily to close down the plant.

11. Multi-stage flash distillation (MSF) is the most widely used desalination process and these plants typically use sea water at a rate equal to 7 to 10 times the product rate.

12. Oil pollution is of concern for two reasons:

    - Volatile oil components can be evaporated and pass into the product distillate.
    - Heat transfer surfaces can become fouled.

13. The carry-over of volatile matter is, in principle, of importance since only very small concentrations of specific components in the sea water are sufficient to raise levels in the product drinking water above the recommended quality standards.

14. In practice the severity of such effects is reduced as follows:

    - Much of the volatile matter in a spill is rapidly lost at sea due to the exposure to air;
    - Exceeding the standard for the short duration and rare frequency of oil spills is unlikely to have an effect upon health.

15. The main objection to volatile carry-over is the presence of objectionable tastes and odours in drinking waters.

16. As with power stations, the deterioration in heat transfer performance resulting from pollution of sea water feed water by light, medium or heavy oils is likely to be minor. However, clean-up will be more time consuming due to the ingress of oils into flash chambers and this may create the need for manual cleaning.

17. The sea water desalination process involving reverse osmosis (RO) is becoming widely used. Fresh water, from a pressurised, pretreated, sea water feed passes through a semi-permeable membrane to give a salt free product water.

18. Even small traces of insoluble oils will cause major irreversible fouling of reverse osmosis membranes which are expensive to replace. The flow of sea water to such plants is typically 3 to 4 times the product flow rate.

Protective Measures

19. The use of bubble barriers and floating booms with and without net skirts is common as a means of limiting the ingress of spilled oils into sea water intakes. Such systems are by no means completely effective particularly in rough seas and where wind and tides create fast currents, and where oils are weathered to a state of neutral buoyancy and will float below the surface.

20. A combination of barriers in series together with facilities for oil removal appears to offer the best results for 'sea-side' protection.

21. Intakes should be designed to minimise the intake of water from either the surface or the bottom.

22. Bar screens have little or no influence on the ingress of oils.

23. Fine screens of the drum or band type are effective in removing large tar balls but can become overloaded due to excessive tar loads adhering to the screens. Design modifications could well improve the performance of such screens.

24. A number of processes used to treat oily refinery wastes have been considered as possible means of land based treatment of sea water.

25. Due to the very large flows involved the use of such processes for treatment of power station cooling water is very expensive. Since in most cases national power grids exist it appears that the most sensible protection for power station intakes is the use of 'sea-side' protection and screens alone and to adopt the following operating policy:

    (1) Shut down in the event of likely heavy contamination of the sea water intake.

    (2) Installation of a ball cleaning system for surface condensers.

    (3) The holding of solvents/detergents in preparation for cleaning operations.

26. For MSF desalination plants a relatively minor design change will allow the separation of the make-up water (2 x product rate) and cooling water (5 to 8 x product rate). Additional land based treatment of make-up water appears economically justified where the risk of pollution is high, as in the Arabian Gulf. Alternatively, where possible, beach well intakes might be used.

27. The BP filtration process which is used to treat oily wastes appears to be a promising way of limiting the concentration of insoluble oils to 2 to 3 mg/l in the make-up water to MSF evaporators and reverse osmosis plants. It is recommended that the process be investigated and modified if necessary to treat oil-polluted sea water.

28. Flotation may be effective in the removal of both tars and oils and should also be studied.

29. Where MSF evaporators are at risk from oil spills the use of activated carbon adsorption might be considered for all or part of the distillate in order to be able to maintain a minimum taste-free supply of drinking water.

30. In locations where plants are at serious risk from oil spills the feed water to reverse osmosis plants must be protected from pollution.

If technically possible the abstraction of sea water from beach wells should be used.

If such an approach is not feasible pre-treatment must be used to protect reverse osmosis systems.

31. Again a study of the BP process as a pre-treatment for reverse osmosis is recommended. It may well be possible simply to modify the filters normally used as a part of the reverse osmosis pre-treatment facility.

32. The use of activated carbon adsorption for the removal of the last traces of oil from reverse osmosis feed water appears justified where the works is strategically important. Otherwise reverse osmosis plants should be shut down in the event of local sea water contamination.

33. In view of the lack of quantified data experimental work should be conducted to investigate the effects on heat transfer efficiency of different levels of contamination by a range of oils and to also study the effects of contamination on MSF and RO plants.

CHAPTER 1

INTRODUCTION

1.1 General

The Terms of Reference for this study were formulated jointly by Sir M. MacDonald & Partners and the International Tanker Owners Pollution Federation. They were formalised in the MMP letter to ITOPF of February 4th, 1986 and amended according to the ITOPF reply of April 9th, 1986. The study was funded by the Commission of the European Communities.

In general terms the work involves a study of the effects of oil spills upon industrial works which employ sea water. The most important of such works are power generating stations which employ sea water as a coolant in surface condensers and sea water desalination works which produce high quality drinking water.

The effects of oil spills upon the performance of such works are naturally dependent upon the types and characteristics of the oils reaching the intake, the types of intake and 'sea-side' protection measures, the types of screens employed and any land-based protection measures. Therefore, the work has been carried out and presented under the following general headings:

Properties of oils
Uses of sea water
Sea water intakes
Effects of oil contamination
Protection measures
Economic aspects
Conclusions and recommendations

In the course of the work it was agreed with ITOPF that a visit to installations in the Arabian Gulf would be useful since recent events have created more problems in this area than elsewhere in the world and the area contains the largest concentration of sea water desalination plants. Major technical aspects which came to light during these visits have been included under the subject headings above, whilst specific report summaries have been included as appendices.

1.2 The Approach to the Work

A preliminary study of the published literature showed that relatively little information has been published and it was further suspected that the effects of the oil spills have never been well quantified and hence good data are not available. It was therefore clearly stated in the Terms of Reference that it would be necessary to base assessments upon engineering considerations and judgements of likely effects of spills and the likely effectiveness of the various means of protection against spills which could be used.

In the search for information many organisations and individuals have been directly approached. In several cases these organisations had their own databases and a number of searches were made for relevant data. These included the following:

Water Research Centre, Aqualine, Water Resources Abstracts, and Pollution Abstracts;

Heat Transfer and Fluid Flow Service, AERE Harwell, HTFS Data Base;

Central Directorate of Environmental Pollution, Infoterra Data Base, (United Nations Environment Programme);

Heriot Watt University, Edinburgh;

IRS Dialtech.

As a preliminary indication of not only the small amount of published information, but also of actual experience of problems resulting from oil in sea water intakes, it may be noted that in the UK an Institution of Mechanical Engineers international conference on 'Cooling with Sea Water', in 1979 made no mention of this potential problem.

In making the enquiries in the UK by telephone some 250 calls were made to over 100 organisations and in some cases calls were made to several different divisions within the same organisation. In addition to these approaches, the Confederation of British Industry kindly circulated the enquiry to its Regional and Environmental Committees, representing some 200 industrial firms.

As an additional approach, a standard letter was also formulated to explain the type of information required and this was intended generally as a back-up to the initial telephone enquiry. This letter is given as Appendix 2.

A questionnaire was also produced to assist contacts in recording detailed information. The questionnaire is reproduced as Appendix 3. As in the case of the standard letter, the questionnaire was intended as a follow-up to initial contact by telephone.

These forms of enquiry showed that there was virtually no experience in the UK of oil contamination of intakes resulting in damage or loss whilst some information was obtained from other European countries. The approach was therefore extended by a visit of limited extent to the Gulf States.

As foreseen at the outset, the study relies heavily upon good engineering judgement as to the likely effects of pollution and suggestions are presented as to modifications to the present approach to protection which appear justified from approximate cost analyses.

CHAPTER 2

PROPERTIES OF OILS

2.1 Introduction

Until the development of large refineries at the sites of the worlds major oilfields, oil was in general shipped as crude oil. It is only in the last 20 to 30 years that significant quantities of refined products have been transported by sea tanker. Thus today, oil pollution can arise from spillage of a range of crude oils or indeed a range of refined or partially refined products.

2.2 The Characteristics of Oils

Crude oil or petroleum consists of a range of hydrocarbons associated with very small quantities of nitrogenous and organic sulphur compounds. The hydrocarbons may be paraffinic, olefinic, naphthenic or aromatic in character and the proportions of the individual groups define the character of the crude oil.

Typical characteristics of a range of crude oils are quoted below in Table 2.1. In this table the specific gravity (sg) is quoted together with the API gravity calculated as follows:

$$°API = \frac{141.5}{sg} - 131.5$$

TABLE 2.1

Characteristics of a Range of Crude Oils

	USA Pa	Iran	Venezuela	USA Cal.	Mexico	Kuwait
Type	Paraffinic	Intermediate paraffin	Intermediate asphalt	Naphthenic	Naphthenic very asphaltic	Intermediate paraffin
Specific gravity	0.811	0.845	0.850	0.975	0.988	0.86
°API	43	36	35	14	12	33
Initial boiling point °C	45	30	58	60	125	75
% volatile to 150°C	45	18	17	4	2	16
% volatile to 150-300°C	28	31	36	36	13	28

The data presented illustrates well the variability in characteristics of different crude oils. For example the paraffinic oil has a low specific gravity 0.811 (43° API) and 45% volatile to 150°C. At the other extreme, the Mexican naphthenic oil has a specific gravity of 0.988 (12° API) with only 2% volatile at 150°C. The intermediate paraffinic and asphaltic crudes fall between these two extremes.

By comparison petrol (or gasolene) and naptha have specific gravities below 0.8 and 100% is volatile at 200 °C. The nature of a specific oil will significantly affect its weathering characteristics following a spill and will also influence very greatly the effect on particular installations where sea water is abstracted for industrial use.

2.3 Classification of Oils

The properties of oils which are particularly important with regard to spillages at sea are as follows:

Specific gravity

Pour point °C (the temperature below which an oil will not flow)
Viscosity cSt at 15°C
Volatility - % boiling below 200°C
Volatility - % boiling above 370°C

Oils have been conveniently divided into four groups and the classification, as presented by ITOPF in its Technical Information Paper Nr 11, is reproduced here as Table 2.2.

The nature of the oils exhibited in Table 2.2, together with the weathering processes which occur following their release into the sea, affect the nature and characteristics of the oils reaching a sea water abstraction intake. It is useful therefore to summarise in general terms the weathering processes which occur following the release of oils to the sea.

2.4 The Weathering Processes

(a) Spreading

A large instantaneous discharge of oil will spread by gravitational forces more rapidly than a slow discharge. At this first stage of spillage, spreading is as a coherent slick and the rate is largely governed by the viscosity. High viscosity oils, which have high specific gravities tend to spread slowly.

A few hours after discharge the slick starts to break up and from this point on viscosity becomes less important since the degree of spreading becomes controlled by the turbulence of the sea. Some 12 hours after a spill oil can be scattered within an area of up to 5 km^2, with large variations in thickness occurring within the slick.

(b) Evaporation

Evaporation is a major factor in the weathering of spilled oils. It is the volatility of the oil which is the major factor influencing evaporation. Class 1 oils (see Table 2.2) evaporate very rapidly and can be completely evaporated

TABLE 2.2

Classification of Oils According to their Specific Gravity

Group 1

Specific gravity < 0.8 (°API > 45)
B Viscosity cSt at 15°C : 0.5-2.0
C % boiling below 200°C : 50-100%
D % boiling above 370°C : 0%

	B	C	D
Gasolene	0.5	100	0
Naphtha	0.5	100	0
Kerosene	2.0	50	0

Group 2

Specific gravity 0.8-0.85 (°API 35-45)
A Pour point °C
B Viscosity cSt at 15°C : 4 - solid average 8 cSt
C % boiling below 200°C : 10 - 48% average 35%
D % boiling above 370°C : 0 - 40% average 30%

High pour point >5°C*

	A	B	C	D
Argyll	9	11	29	39
Amma	18	s	25	30
Arjuna	27	s	37	15
Auk	9	9	33	35
Bass Straight	15	s	40	20
Beatrice	12	32	25	35
Bunyu	18	s	29	12
Cormorant	12	13	32	38
Dunlin	6	11	29	36
Escravos	10	9	35	15
Es Sider	9	11	31	37
Gippsland Mix	15	s	40	20
Lucina	15	s	30	34
Nigerian Light	9	s	35	27
Ninian	6	13	29	40
Qua Iboe	10	7	37	8
Rio Zulia	27	s	34	30
San Joachim	24	s	43	20
Santa Rosa	10	4	34	27
Sarir	24	s	24	39
Seria	18	s	37	15
Thistle	9	9	35	38
Zuetina	9	9	35	30

Low pour point

	B	C	D
Abu Dhabi	7	36	31
Berri	9	36	35
Beryl	9	35	34
Brass River	4	45	17
Brega	9	38	32
Brent Spar	9	37	32
Ekofisk	4	46	25
Kirkuk	11	35	36
Kole Marine	11	34	35
Montrose	7	36	31
Murban	9	36	30
Murchison	7	36	20
Qatar Marine	9	36	33
Saharan Blend	4	48	23
Sirtica	7	44	27
Statfjord	9	35	32
Zakum	7	34	31
Gas Oil	5	-	-

Note: * These oils would only behave as Group 2 at ambient temperatures above their pour points. At lower temperatures treat as Group 4 oils.

TABLE 2.2 (cont.)

Group 3

Specific gravity 0.85-0.95 (°API 17.5-35)
A Pour point °C
B Viscosity cSt at 15°C : 8 - solid average 275 cSt
C % boiling below 200°C : 14 - 34% average 25%
D % boiling above 370°C : 28 - 60% average 45%

High pour point >5°C*

	A	B	C	D
Bakr	7	1 500	14	60
Belayim (marine)	15	s	22	55
Cabinda	21	s	21	52
El Morgan	7	30	25	47
Mandji	9	70	21	53
Soyo	15	s	21	48
Suez Mix	10	30	24	49
Trinidad	14	s	23	28
Zaire	15	s	18	55

Low pour point

	B	C	D
Arabian Light	14	30	40
Arabian Medium	25	29	45
Arabian Heavy	55	25	49
Buchan	14	31	39
Champion Export	18	15	26
Flotta	11	34	26
Forcados	12	18	34
Forties	8	32	36
Iranian Heavy	25	29	44
Khafji	80	25	49
Kuwait	30	29	46
Maya	500	25	49
Nigerian Medium	40	14	40
Santa Maria	250	22	54
Tia Juana Light	2 500	24	45
Medium fuel oil	1 500 3 000	-	-

Note: * These oils would only behave as Group 3 at ambient temperatures above their pour points. At lower temperatures treat as Group 4 oils.

TABLE 2.2 (cont.)

Group 4

Specific gravity > 0.95 (°API < 17.5)
or pour point > 30°C

A Pour point °C
B Viscosity cSt at 15°C : 1 500 - solid
C % boiling below 200°C : 3 - 24% average 10%
D % boiling above 370°C : 33 - 92% average 65%

	A	B	C	D
Bachequero Heavy	-20	5 000	10	60
Bahia	38	s	24	45
Boscan	15	s	4	80
Bu Attifil	39	s	19	47
Cinta	43	s	10	54
Cyrus	-12	10 000	12	66
Duri	14	s	5	74
Gamba	23	s	11	54
Handil	35	s	23	33
Heavy Lake Mix	-12	10 000	12	64
Jatibarang	43	s	14	65
Jobo/Morichal	-1	23 000	3	76
Lagunillas	-20	7 000	9	73
Merey	-23	7 000	10	66
Minas	36	s	17	53
Panuco	2	s	3	76
Pilon	-4	s	2	92
Quiriquire	-29	1 500	3	88
Shengli	21	s	9	70
Taching	35	s	12	49
Tia Juana Pesado	-1	s	3	78
Wafra Eocene	-29	3 000	11	63
Heavy fuel oil (Bunker C)		5 000 30 000	-	-

in temperate climates. This can be seen by reference to gasolene and naphtha which are 100% volatile at 200°C. The influence of wind will allow complete evaporation even at lower ambient temperatures. In temperate conditions the entire range of components volatile below 200°C will be completely evaporated within 24 hours.

The proportions of oils evaporated within 24 hours is typically as follows:

Class 1	:	100%
Class 2	:	35%
Class 3	:	25%
Class 4	:	10%

In terms of a sea water intake, one would only be concerned about a Class 1 oil spillage if it was relatively close to the intake and if it were impractical to close down the intake for a period of 2 to 3 days.

(c) Dispersion

During the evaporation process lighter, less viscous components of an oil are lost to the atmosphere and the oil remaining in the slick becomes more viscous and the specific gravity increases. Dispersion occurs as a result of the turbulence created by wind and waves and has the effect of breaking up the slick and mixing oil in smaller droplets within the bulk of the sea water. The degree of dispersion is largely dependent upon the conditions at sea and the viscosity of the oils. Oils which remain fluid despite other weathering processes may disperse completely in moderate seas within a few days. The use of chemical dispersants can assist in the dispersion process. Following dispersion, oils present a large surface area to the surrounding sea water and can weather more rapidly by other processes such as biodegradation and sedimentation.

(d) Emulsification

Many oils when mixed with water under a high degree of turbulence tend to form stable emulsions. These emulsions comprise small water droplets suspended within the bulk of the oil. The creation of the emulsions is dependent upon the concentration of asphaltenes within the oil. Oils with less than 0.5% asphaltenes tend to disperse whilst those with higher contents form viscous, bulky emulsions often increasing the volume of pollutant by 3 to 4 times. The resultant emulsions, sometimes referred to as "chocolate mouse", can be readily identified due to the change in colour of the oil from black to brown, orange or yellow.

The formation of emulsions in asphaltenic oils is more rapid with low viscosity oils. At wind speeds greater than Beaufort Force 3 volumes can increase by 60% to 80% in 2 to 3 hours with low viscosity oils whereas for viscous oils it may take several days to reach maximum increases of 30% to 40%.

It is the emulsification of light and medium oils which accounts for their persistence on the sea surface.

(e) Dissolution

Heavy crude oils are almost insoluble in sea water but lighter fractions particularly aromatic hydrocarbons such as benzene and toluene are slightly soluble. Whilst these compounds are extremely volatile and losses due to evaporation are considerably greater than losses by dissolution in water, concentrations of dissolved hydrocarbons may reach 1 ppm which is a significant level in terms of feed to a sea water evaporator producing drinking water.

(f) Oxidation

Some hydrocarbons can react with oxygen, albeit at very slow rates. Whilst this may be of assistance in dispersion of thin films, in the case of thick layers oxidation probably contributes more to persistence than degradation because the oxidation tends to assist in the formation of the high molecular weight compounds which form the outer protective skin of tarry deposits.

(g) Sedimentation

Most crude oils have a specific gravity of less than 0.9 and therefore will not settle in sea water. Sinking usually occurs due to the combined effects of weathering and the adhesion of fine particles suspended in sea water.

Clearly the Mexican naphthenic crude (see Table 2.1) with a specific gravity of 0.988 would need to take up few high density particles for it to become more dense than sea water. The same would apply to most heavy fuel oils and also to emulsions where the specific gravity approaches 1.0. The adhesion of high density particulate matter to oils is much more prevalent in shallow waters whereas in the deeper ocean waters relatively little dense suspended matter is normally present.

(h) Biodegradation

Oils present in water will biochemically degrade by serving as an organic feed for bacteria, moulds and yeasts. This is without doubt the slowest of the degradation processes, occurring over months if not years.

2.5 The Overall Effects of Weathering

The combined effects of weathering are not precisely understood nor can they be accurately depicted. It is, however, useful to consider the typical effects of weathering for the four classes of oil shown in Table 2.2. When considering these effects one must take care in that a Group 3 oil may dissipate in a manner similar to that shown for Group 2 oils in very rough weather whilst in calm cold conditions the persistence is more likely to approach that shown for Group 4 oils. With such reservations in mind, the following three figures are presented from TIP Nr 11.

Figure 2.1 reflects the relative importance of the general weathering processes and their respective time scales. Spreading, evaporation and emulsification are relatively short-term effects with the weathering complete in days/weeks. Sedimentation tends to take weeks/months whilst biodegradation can take several years.

Figure 2.2 illustrates typical volumes of floating oil (plus oil/water emulsions) in relation to the volume of oil spilled as a function of time after the spill. It is notable that the volumes of light (Group 2) and medium (Group 3) oils increase rapidly during the first day of the spill due to emulsification whilst the long-term effect is far more severe for the Group 4 heavy oils.

In Figure 2.3 the typical effects of weathering upon the viscosities of the various oils are illustrated. The increasing viscosities are of significance in two respects:

(i) Chemical dispersants are ineffective as viscosities approach 5 000 cSt to 10 000 cSt and it can be seen that rapid decisions are necessary, following a spill if chemical dispersion is to be of assistance.

(ii) Physical clean-up methods must be selected to suit the viscosity experienced. Weir, Vortex, oleophilic rope and disc skimmers are effective only at viscosities up to 10 000 cSt. Screw, belt or air conveyor systems can be used with Group 2 and Group 3 oils up to 100 000 cSt. Mechanical grabs must be used for the heavy Group 4 oils unless it is possible to take action within the first 5 to 6 hours following a spill.

2.6 Oil Reaching Sea Water Intakes

From the foregoing sections it can be seen that a whole range of oils at various stages of weathering could reach a sea water intake.

The time of travel is dependent upon the wind and current strengths and directions. The velocity of travel is normally the vector sum of 100% of the current speed and 3% of the windspeed. Under these circumstances the combined effect of a 0.3 m/s current and a 47 km/h wind would be at the worst a travel speed of 0.85 m/s corresponding to a travel distance of 60 km/d. Under the less severe conditions of a current at 0.2 m/s and a cross-wind at 30 km/h the slick travel speed would be 0.32 m/s equivalent to a travel distance of 28 km/d.

In most cases evaporation of Group 1 oils would be almost complete in 3 hours. For the two conditions above it would be necessary for a spill to be within 7.5 km and 4.5 km respectively, of the intake for a Group 1 oil to cause significant problems.

For light oils dispersing typically within 4 days, the intake would be at risk from spills 120 km to 240 km distant. The intakes would be even more vulnerable to the persistent medium and heavy oils.

All oils entering a sea water distillation plant are likely to create carry-over of volatile organics, giving rise to taste and odour problems. Even 1 ppm of soluble aromatics such as benzene and toluene would be stripped in a multistage flashplant and could form in the distillate creating taste and odours as would many of the paraffins and olefines. The light fractions are likely to cause less problem than heavier tarry components in terms of heat exchange performance.

Clearly the weathered medium and heavy oils can cause problems in the operation of intakes, screens and pumps as well as heat transfer equipment due to their very high viscosities which will cause adhesion to surfaces and blocking of fine apertures.

Figure 2. 1

The Weathering of Crude Oils

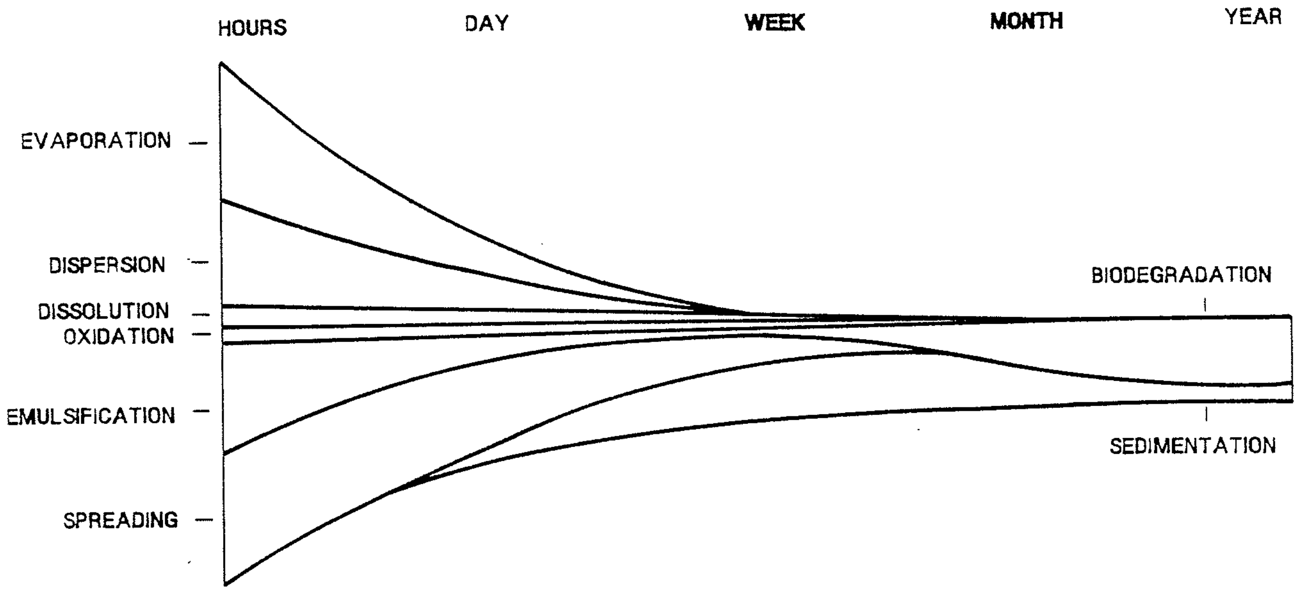


Figure 2. 2

The Rate of Removal of Oils from the Sea Surface

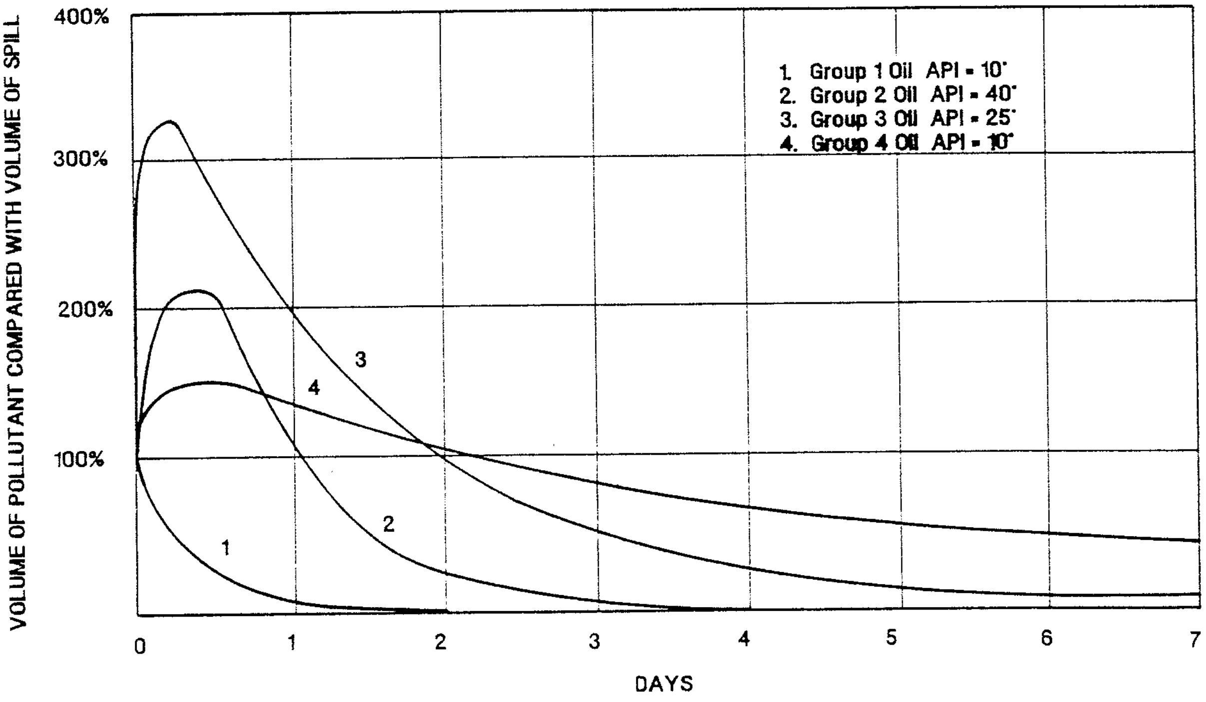
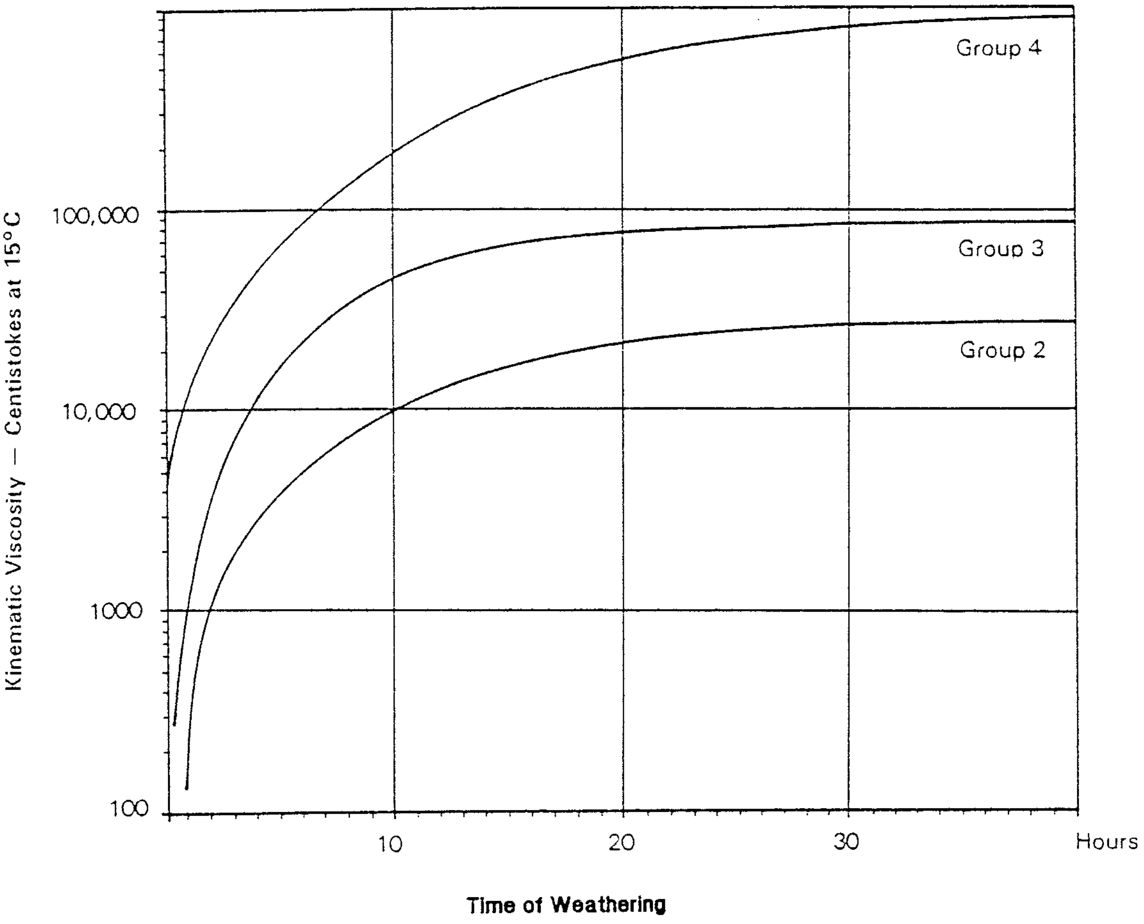


Figure 2. 3

Typical Rates of Viscosity Increase in Moderate to Rough Seas



CHAPTER 3

USES OF SEA WATER

3.1 General

There are a number of specific industrial processes which use sea water as a feed stock. For example sea water is used to produce salt, caustic soda and chlorine. Similarly the sea acts as a source of some chemicals such as bromine. However, there are very few abstractions for such use.

By far the greatest use of sea water is as an industrial coolant. Thermal power stations and industry both employ vast quantities of sea water as a coolant and after use it is returned to the sea. Of the 53 000 MW of thermal power generating capacity installed in the UK, 24 000 MW of plant employs sea water or saline estuary water for cooling.

A second use of sea water is as feed water to desalination plants. Whilst this is a smaller use of sea water it is of particular importance because in a number of locations the life of whole communities is sustained with desalinated sea water as it is the sole source of drinking water.

In view of the importance of sea water in these two applications this study concentrates upon the effects of pollution on desalination and cooling systems.

Two desalination processes are in wide use for the production of drinking water from sea water:

Multi-stage flash distillation (MSF)
Reverse osmosis (RO)

Whilst other distillation processes are in use MSF supplies some 90% of the world's output of distilled sea water. Reverse osmosis has been used for almost thirty years to treat the less saline, brackish groundwaters but now is being widely employed for sea water treatment. It is therefore these two processes which must be considered.

The largest use of sea water as a coolant is for the condensation of steam in power station surface condensers. For other industrial applications sea water is used as a coolant in liquid/liquid heat exchangers as well as vapour condensers. In terms of oil contamination the effects are independent of the fluid to be cooled or condensed. The study can therefore be simplified by examination of condenser and heat exchanger performance without the need to consider in detail the fluid being cooled or condensed.

In the sections below the major uses of sea water are described under the above categories.

3.2 Multi-stage Flash Distillation

3.2.1 Background

Distillation of sea water to produce drinking water has been used for centuries, particularly on board ship. The use of large land based units is much more recent. In 1867 two evaporators with an output of 160 t/d were constructed at

Zula on the Red Sea in support of General Napier's expedition into Ethiopia. Until the late 1950s the type of plant used was submerged tube evaporators. Following the invention of multi-stage flash distillation by Silver and Frankel the process rapidly replaced the submerged tube process because capital costs were typically halved and energy requirements were reduceo by a factor of about 4.

The size of individual units rose from about 400 m^3/d in 1955 to 5 000 m^3/d in 1960 to maximum sizes of about 30 000 m^3/d today. These developments were largely due to the rapid growths of communities in the arid oil states of the Arabian Gulf, Kuwait, Saudi Arabia, Bahrain, Qatar and the United Arab Emirates.

3.2.2 The Process

In an MSF plant a preheated salt water (brine) stream composed of sea water and return brine is further heated in a steam-fed heat exchanger. The heated brine is passed into the first of a series of flash chambers when the pressure is reduced permitting part of the brine to flash to a salt-free vapour which is condensed on a bank of condenser tubes to give the product water. In condensing the vapour gives out its latent heat preheating the recycle brine stream. The brine then passes to additional stages, each of which operates at a slightly lower pressure than the preceding chamber with the result that further flashing to salt-free vapour occurs in each chamber, providing additional product water.

The MSF process can be illustrated as shown in Figure 3.1. Cooling water, M_C, is fed to the condensers of the heat rejection section of the plant. On emerging, a portion of the cooling water, M_F, is separated and, after chemical treatment, is passed to the inlet of the recycle pump where it is mixed with flashing brine withdrawn from the final stage (stage 7 in the works illustrated). After discharge of the concentrated waste stream, M_B, the recycle flow M_R is passed through the condensers of the heat recovery section where it is successively heated by condensing steam. On emerging from the condensers of stage 1 the recycle stream is heated to its highest temperature, T_{Fo}, by heat exchange with feed steam in the brine heater.

The heated brine then enters the flash chamber of stage 1 which is held at such a pressure that a portion of the brine stream flashes off thereby cooling the flashing stream to its boiling point at the stage pressure. As the flashing brine stream passes from stage to stage it is successively cooled with a portion of the flow flashing off, to be condensed as distillate in each stage.

The temperature distribution is shown in Figure 3.2. Mass and heat balances can readily show that the performance ratio R approximates to the following:

$$R = \frac{\text{The flashing temperature range}}{\text{Temperature rise across brine heater}} \qquad (3.1)$$

$$R = \frac{T_{FO} - T_{FN}}{T_{FO} - T_{RI}} = \frac{\Delta T_T}{\Delta t + a + \Phi} \qquad (3.2)$$

where: T_{FO} = temperature of recycle brine as it leaves the brine heater.

T_{FN} = temperature of flashing brine as it leaves the last stage (Stage N) of the plant.

Figure 3.1

Simplified Flowsheet MSF

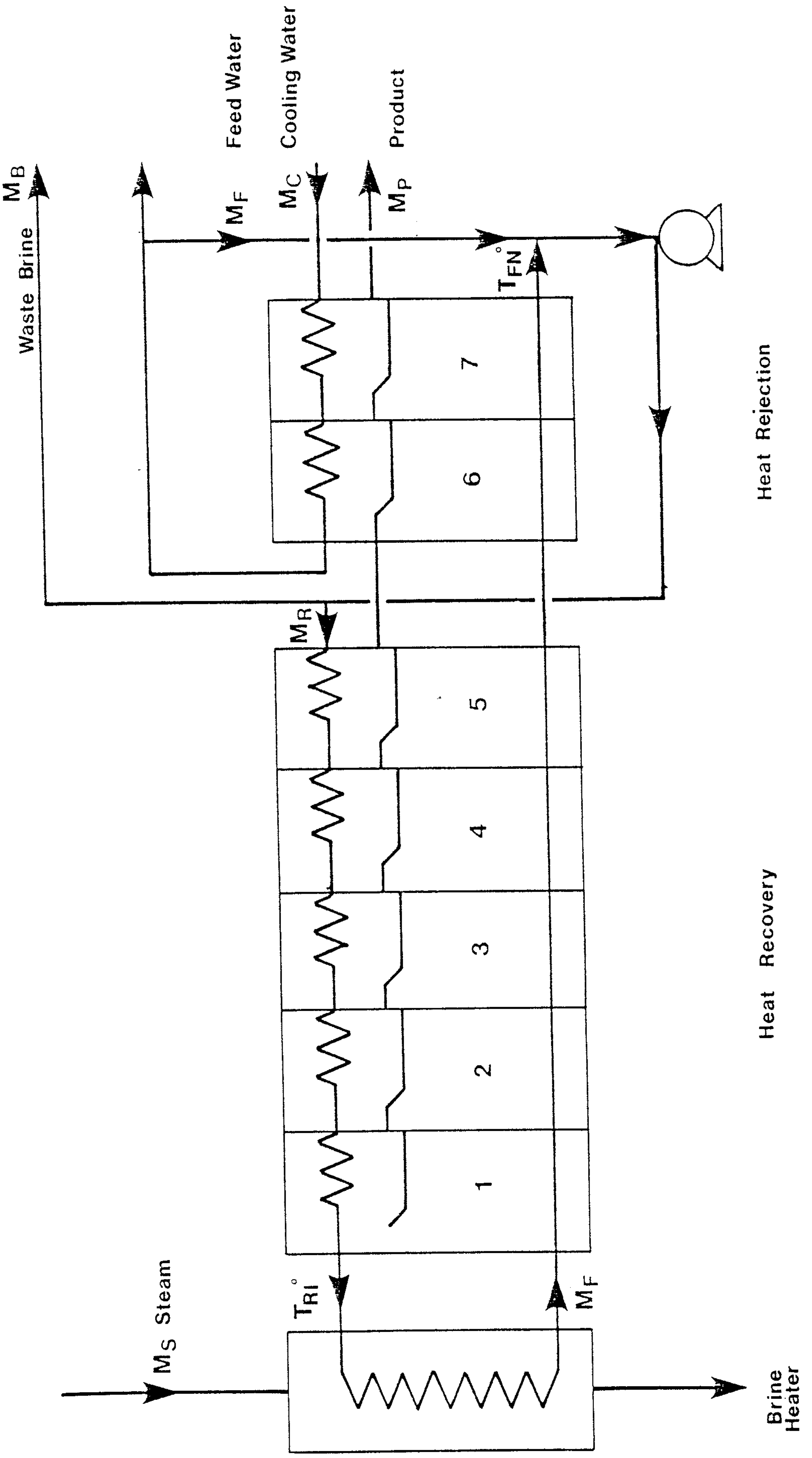
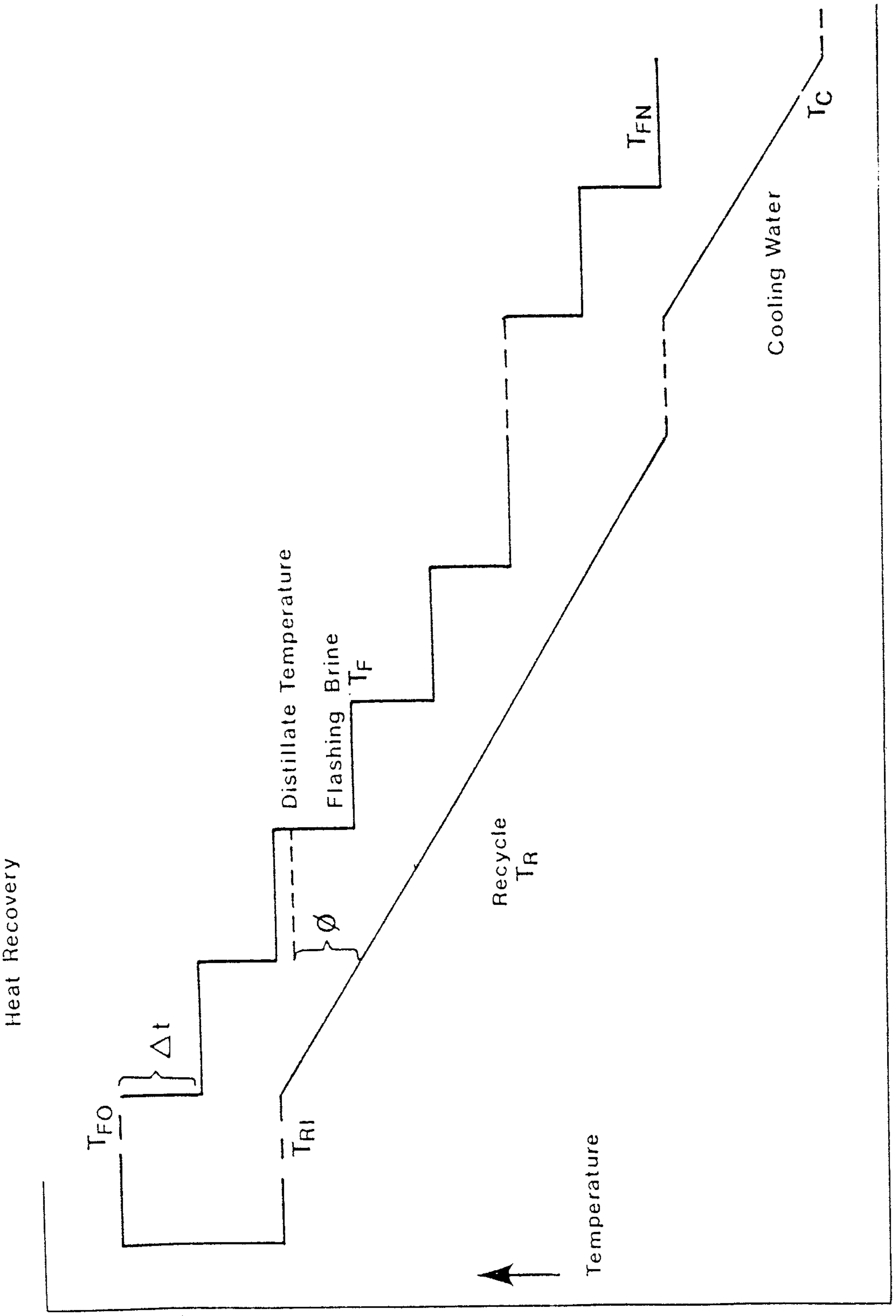


Figure 3.2

Temperature Distribution MSF



Δt = the temperature drop of the flashing brine in one single stage.

Φ = the approach temperature of the stage condenser.

a = irreversible temperature losses and includes:
- the boiling point elevation of the brine
- demister losses
- flashing equilibrium losses.

Thus the energy consumption can be reduced by the following means:

(i) Increasing ΔT_T the total flashing range.

Since the lower temperature T_{FN} is fixed by the temperature of the sea, ΔT_T can only be increased by raising the top temperature T_{FO}. Developments in scale control have been aimed at increasing the top temperature whilst avoiding undue corrosion.

(ii) Reducing the Stage Temperature Drop Δt

This can only be achieved by increasing the number of stages employed and hence increasing the capital cost of the plant.

(iii) Reducing the value of Φ, the stage approach temperature (the temperature difference between recycle brine leaving the stage and condensing steam).

This can be achieved by use of more heat transfer area in each stage or increasing the heat transfer coefficients.

Any material which causes fouling of the heat transfer surface will reduce the heat transfer coefficient and hence increase the power requirement. Moderate to heavy oils would be expected to cause such effects.

a is the temperature difference between flashing brine and condensing distillate and is the sum of the boiling point elevation and the temperature difference caused by pressure losses. Little can be done to reduce the value of a.

From points (ii) and (iii) above it is clear that plant design can be optimised to achieve a lowest water cost by balancing capital with fuel costs (or balancing heat transfer area and number of stages with performance ratio). This is shown by the following approximate relationship.

$$A_s = \frac{n\lambda}{U\Delta T_T} \log \left[\frac{n}{n - R} \right] \qquad (3.3)$$

where: A_s = the specific heat transfer area, represents the heat transfer area per unit of product water output.

λ = the mean latent heat of evaporation over the flashing temperature range.

U = the mean heat transfer coefficient.

ΔT_T = the flashing temperature range.

n = the number of stages.

R = the performance ratio.

Using typical values, this relationship has been plotted as shown in Figure 3.3.

From equation 3.3 and Figure 3.3 it can be seen that costs of MSF distillation can be reduced by the following means:

(i) Increasing the flashing range ΔT_T.

(ii) Increasing the heat transfer coefficient U.

(iii) Use of cheaper heat transfer and shell materials.

(iv) Use of improved designs to permit smaller flash chamber.

(v) Use of cheaper energy sources.

It is therefore of value to consider the developments in distillation in terms of their effects upon these factors.

3.2.3 Scale Control

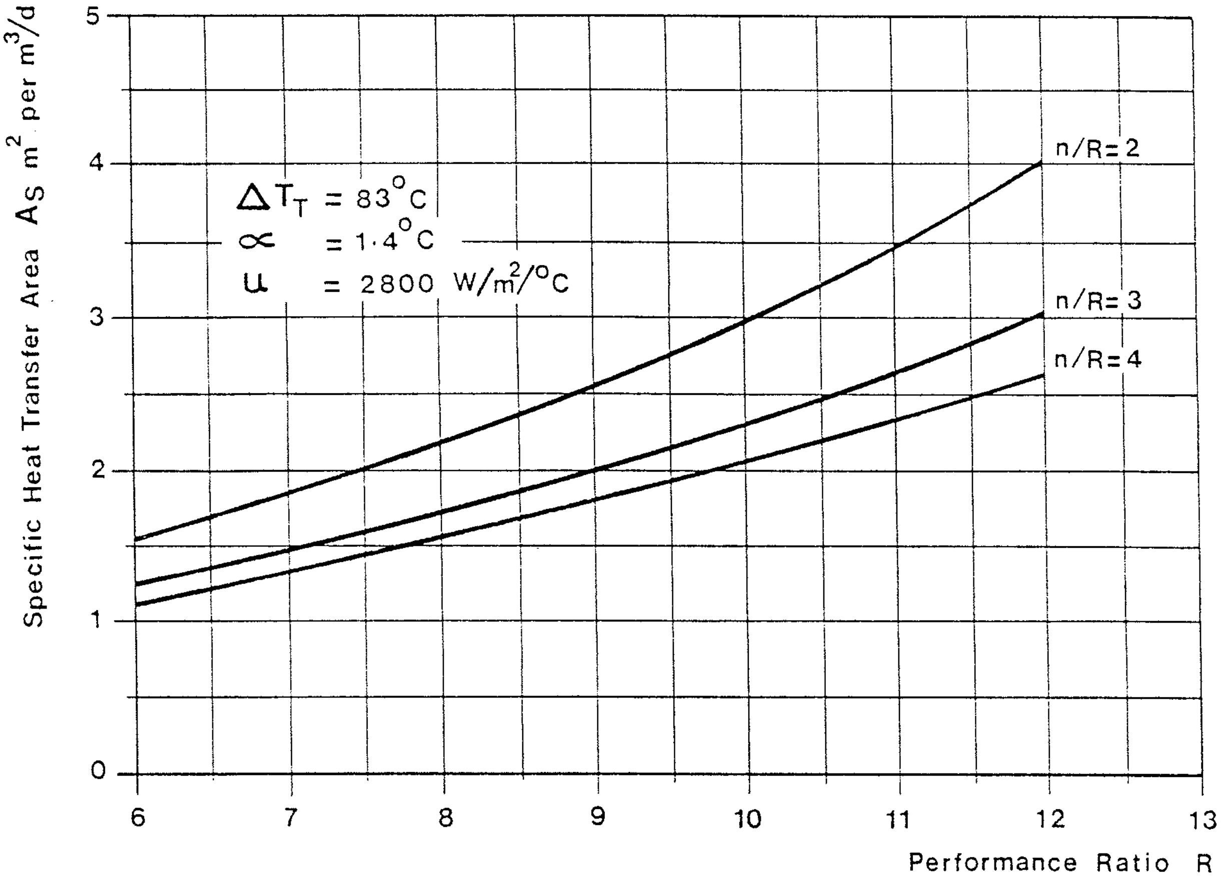
The flashing temperature range is limited by the maximum brine temperature at which scale formation can be satisfactorily controlled. Alkaline scale formation, caused by the breakdown of bicarbonates in sea water to deposit calcium carbonate and magnesium hydroxide scales, has traditionally been controlled by one of two alternative means:

(a) The dosing of polyphosphates at low levels, 5 to 10 mg/l, does not completely eliminate scale formation but rather causes scales to form as sludges which do not adhere strongly to the heat transfer tube surfaces. The use of these materials limits the top temperature to about 90°C since at higher temperatures the phosphates break down and become ineffective. Periodically it is necessary to acid flush the condenser tubing in order to remove the sludge build-up which will otherwise cause a deterioration of plant performance.

(b) Pretreatment of the feed water by dosing of acid, at a concentration of about 120 mg/l, effectively removes the scale-forming bicarbonates with evolution of carbon dioxide. The gas is removed by air or steam stripping prior to entry of feedwater to the plant, otherwise severely corrosive conditions will be created within the evaporators. Even so, the negligible buffering capacity of the recycle brine makes the control of pH difficult and therefore the risk of corrosion will always be present where acid dosing is used for scale control.

Figure 3.3

Heat Transfer Requirements MSF



By the use of acid, top temperatures of 110 to 115°C can be achieved without serious scale formation.

The benefit of this higher temperature can be illustrated as follows. If the temperature of sea water controls the bottom flashing temperature to 38°C, the total flashing range with acid treatment will be 77°C (= 115 - 38) as compared with 52°C (= 90 - 38) for operation with polyphosphates. Substitution of these values in equation (3.3) will show that the heat transfer area can be reduced by about 47% by the use of acid dosing while still retaining the same number of stages and performance ratio.

A rigorous evaluation will show the difference in costs between polyphosphate and acid dosed plants to be greater at high performance ratios. The approximate relationship is shown in Figure 3.4.

This capital cost saving led many users to select acid dosed plant in preference to the more expensive polyphosphate dosed works. In a number of cases poor pH control and the use of unsuitable materials has caused premature failure of heat exchange tubing and steelwork, so much so that the cost of replacements and repairs has outweighed the initial benefits. The Ministry of Electricity and Water, Kuwait, is typical of several authorities who have deliberately avoided the use of acid and in so doing have maintained a high standard of reliability.

Belgarde for Scale Control

One of the most significant improvements of recent years is the development of additives which effectively control scale at high temperatures without the creation of corrosive conditions. Whilst many of the chemicals developed have shown only marginal benefits over the traditional polyphosphates the Belgarde range of chemicals, developed by Ciba-Geigy Ltd. have been found to be most effective. Top temperatures of 105 to 110°C have been successfully achieved over many months of operation with insignificant rates of fouling of heat transfer surfaces and with iron and copper dissolution rates typically 10% and 30% of those experienced in acid dosing plants.

Trials with Belgarde at Qatar are typical of many uses of the chemical. In this case the plant, 9 000 m^3/d capacity, had previously been operated with polyphosphates at a maximum temperature of 85°C and intermittent acid cleaning at 6-monthly intervals. Dosing with 7.5 mg/l of Belgarde over a 5-week monitored test period showed no increase in fouling factor with a top temperature of 110°C and an output of 11 800 m^3/d, an increase of 30% above that for polyphosphate operation. Extended operation of 150 days at a top temperature of 105°C and a Belgarde dose of 6 mg/l showed the fouling factor to remain constant whilst the output was maintained at 10 900 m^3/d, an increase of 21% over the production rate when polyphosphates were employed.

Without doubt the high maintenance cost often associated with high temperature plant is minimised by the use of scale control polymers such as Belgarde.

3.2.4 Materials for Evaporators

The early MSF plants followed normal marine practice, with the use of copper-base alloys for heat exchanger tubing and, in general, this practice has continued. Thus the Kuwait MSF plants normally use 70/30 cupro-nickel tubing for the heat reject, brine heater and high temperature stages with aluminium brass used elsewhere. Approximately 25% of the tubes are cupro-nickel and the remainder aluminium brass. The cupro-nickel alloy used in the first plants was the 2% iron 2% manganese version. This practice has continued and has spread to most other areas, apart from the USA, where standard 70/30 cupro-nickel has been specified. Tube plates for the plants are usually Naval brass or 90/10 cupro-nickel.

In contrast to the above practice for polyphosphate dosed plants, there has been a tendency to use 90/10 cupro-nickel instead of aluminium brass in acid dosed plant, and some units have been built with this alloy in all sections. Overall, therefore, there has been an increase in usage of 90/10 cupro-nickel at the expense of aluminium brass. Some data showed the overall picture of about 65% aluminium brass in 1971 and about 35% in 1975.

Data from the A D Little Survey (1972) shows 90/10 cupro-nickel to perform significantly better than aluminium brass in acid dosed plants so that this switch to 90/10 cupro-nickel was probably based on an increased usage of acid dosed plants during the 1971 to 1975 period.

There has been no significant usage of titanium for tubing apart from Jubail I. However, as Jubail II has reverted to 90/10 cupro-nickel this does not seem to represent a breakthrough for titanium. For ejector condensers, where vapour side conditions are unfavourable to copper-base alloys titanium has often been used, but as this represents less than 0.5% of the market it does not affect the overall trends. Aluminium bronze is the usual tube plate material where titanium tubes have been used.

Water-Boxes

Experience has shown that bare carbon steel water-boxes, even in polyphosphate plants, suffer severe corrosion and most plants now employ protection of some kind, the most common being 90/10 cupro-nickel (either as solid or clad plate). Some linings of 70/30 cupro-nickel have been used but this is much less common and seems to be declining.

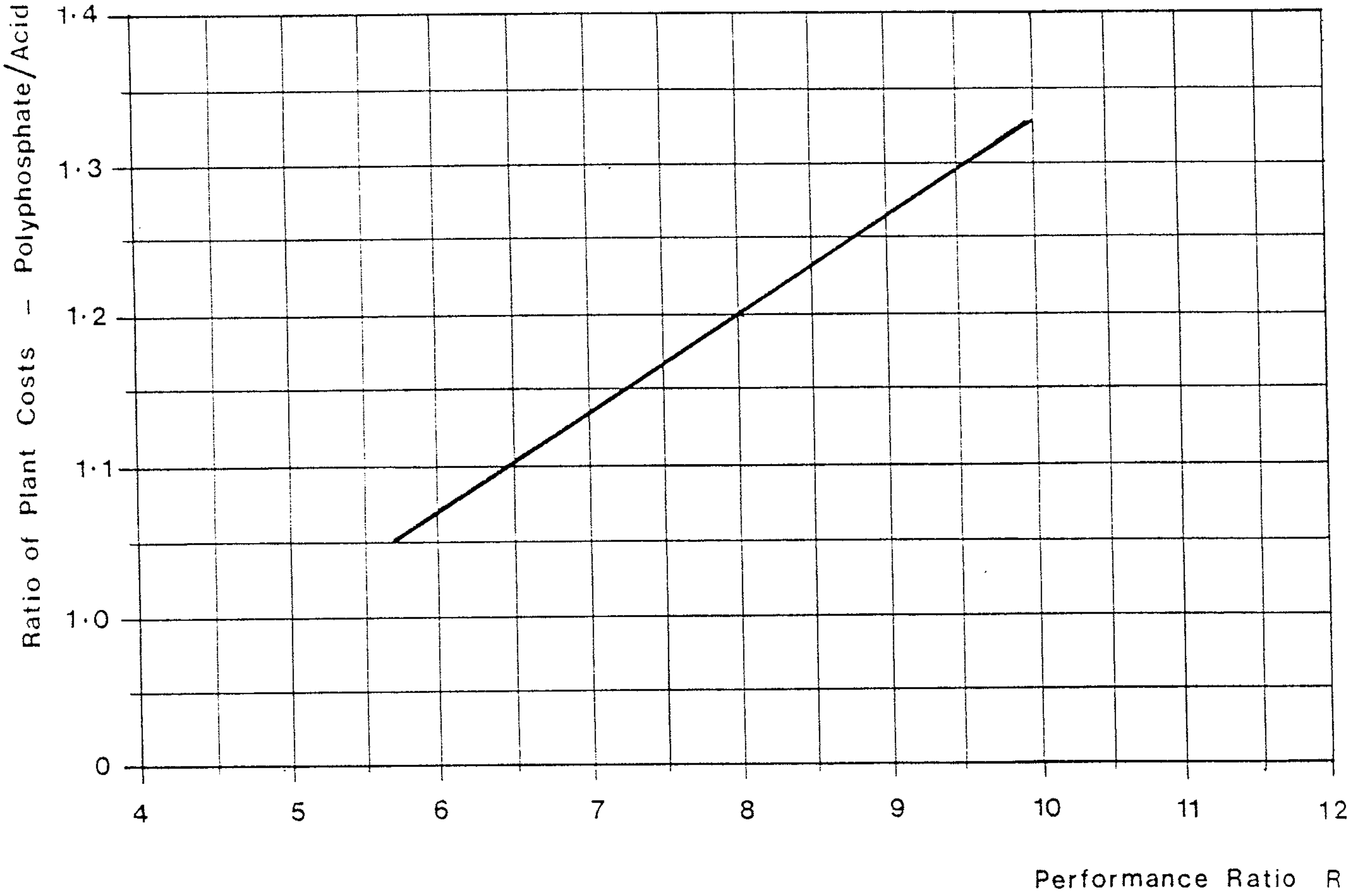
In some cases all water-boxes have been metal lined, but elsewhere only the raw sea water and high temperature boxes have been protected. Rubber linings are sometimes used for raw sea water but epoxy and similar coatings which, in general, have performed poorly are no longer widely used.

Flash Chambers

Following the trend in water-boxes many acid dosed plants are now lined with corrosion-resistant material. The two commonly used materials are 90/10 cupro-nickel and stainless steel, usually type 316L. Both appear to perform satisfactorily but experience with completely lined stainless steel chambers is sparse and time is needed to be sure that this alloy can withstand the varying conditions and in particular oxygen levels to be expected in MSF plant. In low oxygen conditions, stainless steel can be expected to perform well; however, at high oxygen levels pitting and perhaps cracking may occur. 90/10 cupro-nickel is not prone to these problems but is more expensive than stainless steel, hence the use of both materials for this application. For smaller units, where the shell thickness is low, cupro-nickel is the normal choice where an alloy material is specified, as stainless steel would suffer problems externally.

Figure 3. 4

Plant Capital Costs - Polyphosphate/Acid



For large plants clad steel plate is used for economic reasons and this circumvents external corrosion problems where stainless steel is specified.

For polyphosphate plants alloy linings are not normally used apart from local areas around weirs and nozzles. Elsewhere deposits of carbonate and hydroxides on the steel surface seem to markedly reduce corrosion of the underlying metal. This trend towards the use of alloy lined chambers is probably the most significant change in material usage in desalination in recent years.

It can, in general, be concluded that over the last 10 years no new materials have been employed in evaporators but rather the practice has been to upgrade materials used and consequently fewer problems tend to be experienced.

3.2.5 Cost of Sea Water Evaporation

Capital Costs

The capital costs of sea water evaporator installations are comprised of three elements:

(a) The evaporators.

(b) The feed steam system - self-contained boilers or, more commonly, the supply system from combined power generation plant.

(c) Ancillary works - civil works for the evaporators, post-treatment or blending facilities, storage and distribution works.

Typical costs for high temperature, acid or Belgarde dosed evaporators are shown in Figure 3.5. The costs are presented in terms of pounds sterling per unit of plant size and performance ratio. It can be seen that a typical evaporator of 10 000 m^3/d capacity with a performance ratio of 10 will cost about £7.0 million. Clearly such costs can only serve as a guide since site conditions and the state of the market as well as specific design details will influence the precise cost in an actual case. Costs of polyphosphate dosed plant are higher, as shown in Figure 3.4.

The civil works directly associated with the evaporator typically added 15% to the cost of the installation but if post-treatment works to artificially harden the distillate prior to distribution are employed higher additional costs will be incurred.

The total cost of self-contained, low pressure, water-tube boilers installed together with auxiliary equipment has been taken as £35 per kg/h of steam raising capacity.

Thus typical capital costs for a 10 000 m^3/d installation are shown in the following table. For the fuel costs assumed, the performance ratio for a single purpose plant is optimised at 12 whilst that for corresponding dual plant is 10.

Operating Costs

The major items contributing to the running costs of evaporators are as follows:

- fuel for steam raising;
- auxiliary power;
- chemicals;
- maintenance and operation.

Steam Supplies

The largest single operating cost is that of fuel for generating feed steam. This cost is extremely variable, being dependent upon the source of energy. The highest values are those associated with the raising of steam in self-contained boilers where the effective cost of the steam is directly related to the world market rate for energy. Such a case is shown in Table 3.1 with oil priced at $20 per barrel and a boiler efficiency of 85% assumed.

The lowest values quoted in the literature tend to be based upon the use of free or very low priced gas which would otherwise be flared off. An authority may wish to set a low price for such a fuel but this can only be considered as a subsidy and does not reflect a realistic value. Similarly 'waste heat' from incinerators or the exhausts from gas turbines or diesels cannot be realistically valued at zero cost.

TABLE 3.1

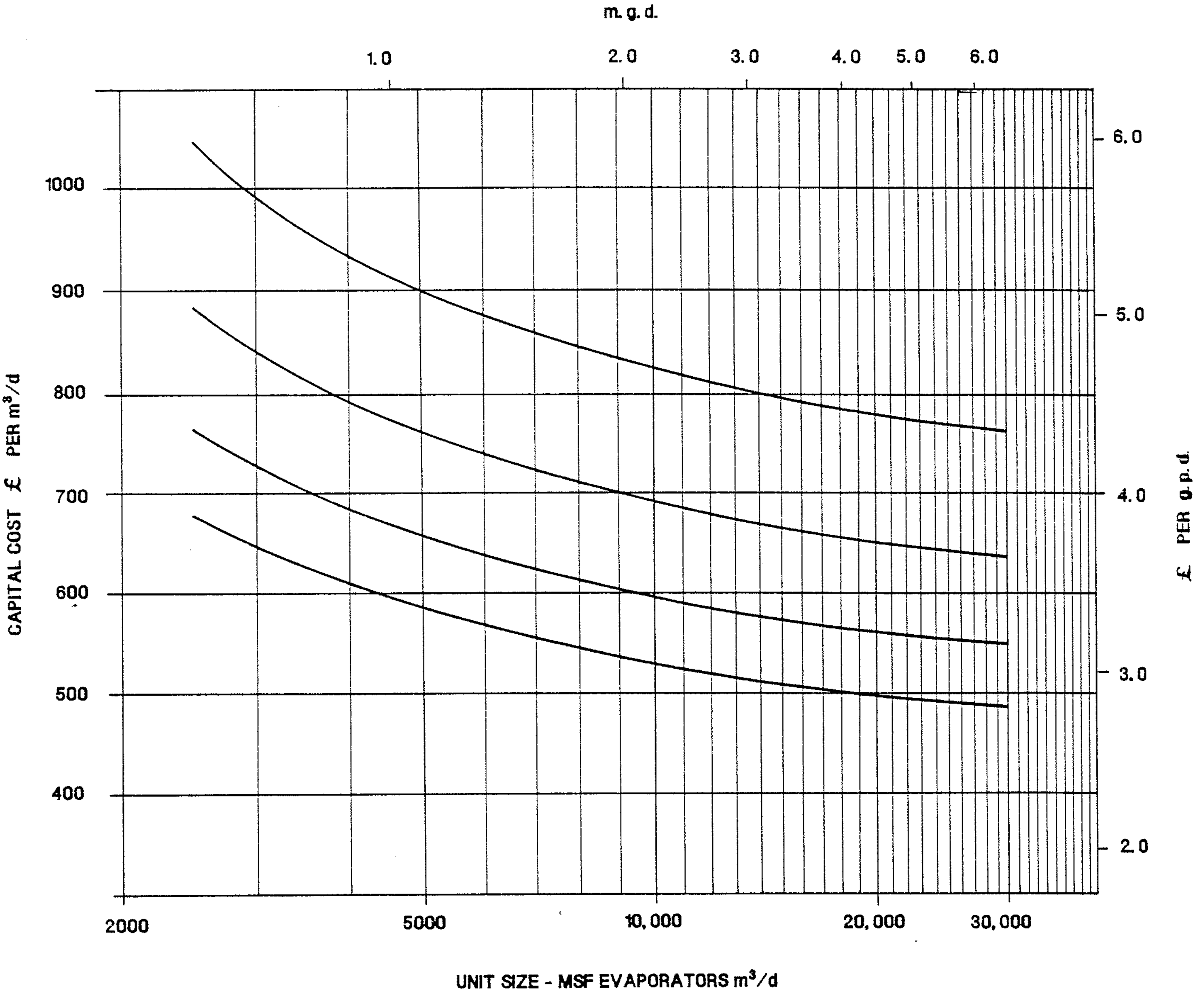
Costs of MSF Distillation (70% Load Factor)

	Single purpose	Dual purpose
Capital Costs (£ million)		
Opt. performance ratio	(12)	(10)
Distiller cost	8.30	6.96
Boiler cost	1.44	1.77
Civil cost	1.24	1.04
Total capital	10.98	9.77

	£ M pa	£/m^3	£ M pa	£/m^3
Operating costs (£ million pa and p/m^3)				
1. Fixed charges 11.75% (10% interest, 20 years)	1.29	0.507	1.19	0.450
2. Fuel at $25 per barrel (half cost for dual purpose)	1.04	0.406	0.63	0.244
3. Chemicals - Polymer £2 000/t, 7 mg/l	0.09	0.034	0.09	0.034
4. Auxiliary power (at 2p/kWh)	0.20	0.079	0.20	0.079
5. Maintenance operation, staff and materials	0.25	0.100	0.25	0.100
Total annual cost (£ M)	2.87	-	2.36	-
Total water cost (£/m^3)	-	1.126	-	0.926

Figure 3.5

Capital Costs MSF Evaporators (Acid Dosed) 1979



Probably the lowest economic value which can be placed on feed steam is that part of the costs associated with generation of steam which can be attributed to low pressure use after expansion from high pressure in the generation of electricity. In such cases the allocation of fuel costs between electricity and power is somewhat arbitrary. In the second case, quoted in Table 3.1, 50% of steam raising costs have been allocated to the low pressure steam employed for desalination.

The variation in fuel price for the two cases would lead to the selection of different performance ratios. With a 10% interest rate and repayment over the 20 years' life of the plant and an average load factor of 70% of the optimum performance ratios become 12 for the single purpose plant and 10 for the dual purpose plant. Capital costs and capital charge rates quoted reflect these different efficiencies.

Auxiliary Power

Major power consumption includes the pumping of recycle brine, the running of distillate, blowdown and condensate pumps and site instrumentation and services. This, for a 10 000 m^3/d plant will approximate to 1 600 kW, being slightly lower for the lower performance ratio plants.

Chemicals

Prices for chemicals for scale control are extremely variable, dependent upon the location of the works. Typical costs are:

- polyphosphates	£500/t
- polymer	£2 000/t
- acid	£120/t

With typical doses of 7 mg/l for polymer and 120 mg/l for acid there is little between the costs of these two chemicals for high temperature operation.

The polymer cost quoted in the table of operating costs is based upon the use of a feedwater rate 2.4 times that of the product, thereby limiting the concentration of the brine blowdown to 1.7 times that of the feed sea water.

Maintenance and Operation

The annual cost of maintenance typically contributes some 1.5% of the capital cost of the distiller whilst operation is approximately double this value for a plant of 10 000 m^3/d. Thus the combined cost contributes about 0.10 £/m^3 to the cost of water.

Water Costs

It can be seen that for the conditions assumed total water costs range from 0.93 £/m^3 for the dual purpose works to 1.13 £/m^3 for the single purpose case. The selection of steam turbine drives for major pumps for single purpose plant can save up to about 0.04 £/m^3 on the cost quoted by raising steam at an adequate pressure to drive the turbines before being employed as feed to the brine heater.

3.3 Reverse Osmosis

3.3.1 Background

It was in 1957 that Loeb and Souririjan developed the first semipermeable membranes that would allow passage of water through them but restricted the transfer of dissolved ions to very low rates. These were asymetric cellulose acetate membranes which have a thin dense surface layer supported upon a porous backing layer. The development of these membranes immediately spurred the development of engineering systems to allow their use of reverse osmosis for desalination.

Numbers of different means of supporting these membranes to withstand the high pressures necessary to obtain practical production rates were developed. These included tubular, plate and frame and spirally wound support systems. It was not until 1970 that the DuPont Company introduced self-supporting membranes based upon the use of polyamide. These membranes are in the form of minute hollow fibres which could withstand external operating pressures up to 2 800 kN/m^2 (400 psi). At this pressure reverse osmosis treatment of brackish waters is possible but the high osmotic pressure of sea water 2 450 kN/m^2 precluded their use for treatment of sea water.

It was not until 1977 that membranes were developed to treat sea water in a single pass. The important criteria are the strength to withstand operating pressures of 5 500 to 7 000 kN/m^2 (800 to 1 000 psi) and the integrity to limit the passage of salts to 1%.

Nowadays a number of membrane systems are available including the following:

DuPont	Hollowfibre
Filmtech	Sheet
Hydranautics	Sheet

In addition a number of Japanese membrane systems are now appearing on the market.

3.3.2 The Reverse Osmosis Membranes

The reverse osmosis process operates under ambient temperature conditions by pumping feed water to a pressure which exceeds the osmotic pressure and is sufficient to force water through the membrane. The semipermeable characteristics of the membrane limit the passage of the chemicals in solution to very low rates.

The distinction between osmosis and reverse osmosis is explained by reference to Figure 3.6.

The three basic forms of membranes are as follows:

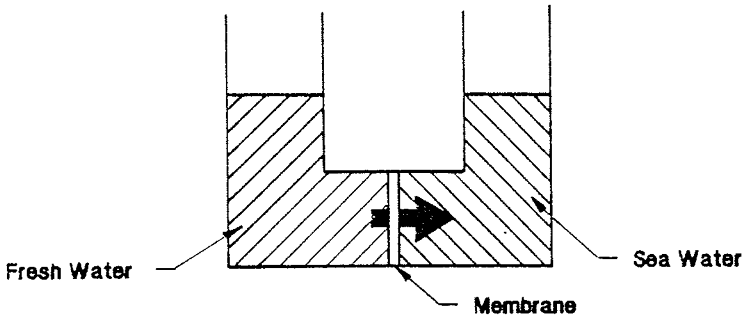
(i) Forms of cellulose acetate (CA).

(ii) Polyamide (PA).

(iii) Thin Film Composite (TFC). Composite membranes employing a thin film of polyamide or similar desalting layer formed upon a porous substrate of a material such as polysulphone.

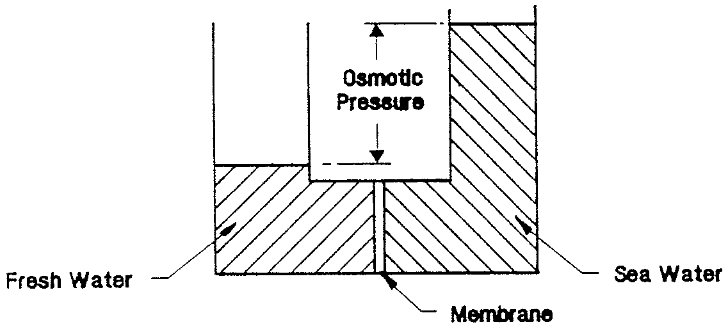
Figure 3.6

Basic Principles of Reverse Osmosis



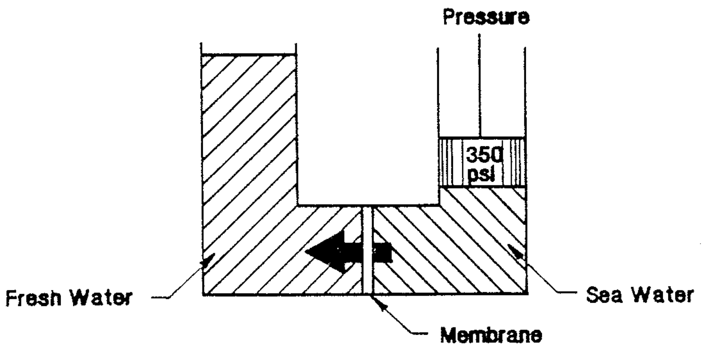
OSMOSIS

When fluids of different concentrations in a vessel are separated by a membrane, water from the dilute solution will flow through the membrane into the concentrated solution.



OSMOTIC PRESSURE

The level of the dilute solution drops and the level of the concentrated solution rises until an "equilibrium" is reached. The pressure difference between these two levels is the "osmotic pressure".



REVERSE OSMOSIS

If a pressure in excess of the osmotic pressure is applied to the concentrated solution, the flow is reversed from the concentrated solution to the diluted solution. This is "reverse osmosis".

Both the cellulose acetate and polyamide membranes are asymmetric. This means that the membrane is formed in a one stage process with an outer, thin dense active layer, typically 0.1 to 1μm thick for desalination, supported by a thicker porous layer of the same material. The cellulose acetate membrane is cast onto a supporting fabric to provide mechanical strength for handling. The polyamide hollow fibres of DuPont are no thicker than a human hair and are self-supporting.

The thin film composite membranes consist of a very thin active layer of polymer deposited onto a porous support of a different polymer and thus fabrication is a two stage process. The construction details of all three membrane types are shown in Figure 3.7.

The fabrication advantages of composite membranes include the independent selection of polymers from which to optimise the properties and fabrication of each layer, plus the ability to vary the layer thicknesses for different applications. They are dry processed and can be wet-dry cycled with no effect on membrane performance. Hydranautics Water Systems offer a form of this property with dry ship, dry store for their cellulose acetate membranes.

Typical performance characteristics of reverse osmosis membranes for sea water and brackish water applications are shown in Table 3.2.

TABLE 3.2

Typical Characteristics of Reverse Osmosis Membranes (2 800 kN/m^2 (400 psi) for Brackish Water and 6 000 kN/m^2 (850 psi) for Sea Water)

Membrane type	pH range	Maximum tempera-ature (°C)	Inorganic salts rejection (%)	Flat sheet flux (m^3/m^2/d)	Allowable free Cl in feed (mg/l)
Cellulose acetate					
(a) Brackish (several types)	3-8	40	98 95	0.73 0.85	0.5 above 25°C 1.0 below 25°C
(b) Sea	3-8	35	98	0.6	0.5 above 25°C 1.0 below 25°C
Polyamide hollow fibre					
(a) Brackish	4-11	35	95		0.1
(b) Sea	5-9	35	98.5		0.1
TFC					
(a) Brackish	2-12	45	98	0.7	Nil
(b) Sea	2-12	45	98.5	0.7	Nil

Note: These data refer to plant performance of 75% recovery for brackish water and 30% recovery for sea water.

It can be seen from the data presented that membranes have pH and temperature limitations and none of the materials is particularly resistant to attack by free residual chlorine.

Similarly all membranes compact under the high operating pressures to which they are exposed and with compaction, the production rate (flux in m^3 per unit area per unit pressure per unit time) will also reduce. A loss of output under standard conditions of 25% over three to five years is normal.

Typical performance of reverse osmosis plant on sea water applications is shown in Table 3.3 below.

TABLE 3.3

Performance Sea Water Reverse Osmosis

		Jeddah		South Caicos	
		Feed	Product	Feed	Product
Temperature	°C	32	-	-	-
pH	unit	8	7.5	7.4	6.5
Total Dissolved Solids (TDS)		41 200	800	42 000	635
Ca		520	20	600	8
Mg		1 460	-	1 118	1
Na				16 000	133
HCO_3(as $CaCO_3$)		125	65	190	20
Cl		22 000	600	25 000	210
SO_4		2 960	20	2 900	1
Membranes		TFC		Polyamide	

3.3.3 Process Engineering

Whilst there are some exceptions, the major membrane system used for potable water production are of two types:

Hollow fine fibre:

The polyamide hollow fine fibre membranes are mounted in a form similar to a heat exchanger. Membranes are cast into a tube sheet with the opposite ends sealed.

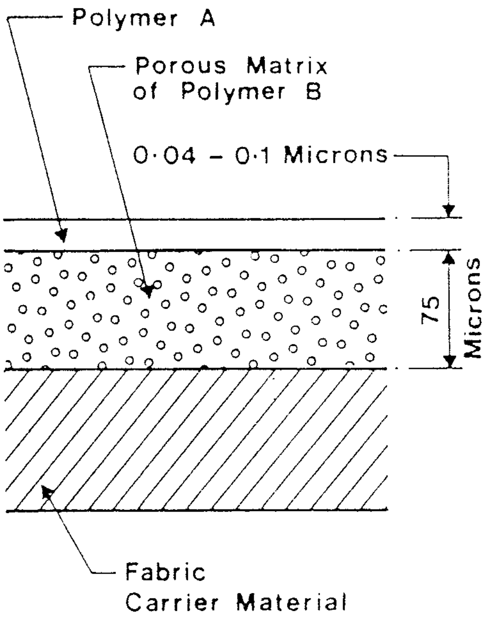
The tube bundle is then mounted in a pressure vessel and the complete unit is referred to as a module.

Modules of this type range in size from 4 inch to 8 inch diameter and lengths of 0.5 m to 1.5 m.

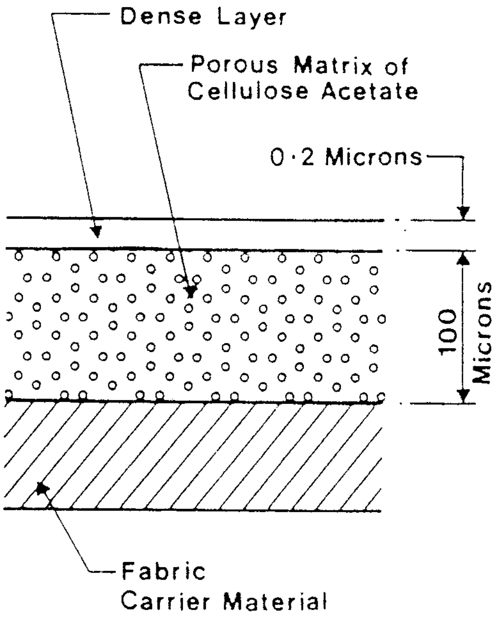
In sea water applications one module may have nominal outputs ranging from 1 to 21 m^3/d.

Figure 3.7

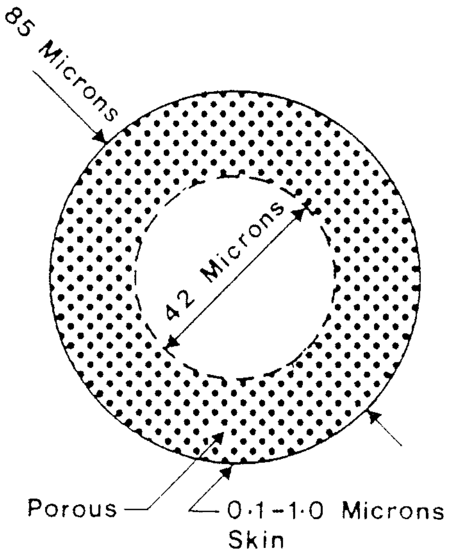
Membrane Configurations



ASYMMETRIC MEMBRANE



COMPOSITE MEMBRANE



HOLLOW FIBRE MEMBRANE
(Asymmetric Aramid)

Spiral Wound:

Both the asymetric and thin film composite membranes are produced in thin sheet form. Basically a number of sheets are used together and are separated by feed channel spacers and product spacers. One end of such a sandwich is sealed into a tube and the whole assembly is rolled up into a 'swiss roll form', with appropriate edges sealed, and mounted in a pressure vessel.

Feed sea water is fed between membranes from one end of the roll. Permeate passing through the membranes is collected in the central tube.

Whichever system is employed membrane modules are mounted in racks with a system of interconnecting pipework as illustrated in simple form in Figure 3.8.

Most modules are mounted in parallel but in some cases the reject from the Stage 1 array is fed to a second stage and similarly the reject from a second stage may be fed to a third stage.

This staging of membrane modules is carried out in order to maintain adequate hydraulic flow through each individual module for the particular value of overall product recovery for which the works is to be designed.

As can be seen two streams leave the plant:

(1) The almost pure product water;

(2) The reject stream which carries away the dissolved salts for discharge.

If the product flow on a works is designed to be R% of the feed flow, then the water recovery is said to be R%.

Hence $$R = \frac{Q_P \, 100\%}{Q_F} \qquad (3.4)$$

Clearly if the concentration of dissolved solids in the feed is C_F mg/l and if the product was completely pure the concentration in the reject would be:

$$C_R = C_F\left[\frac{Q_F}{Q_F - Q_P}\right] = C_F\left[\frac{100}{100-R}\right] \qquad (3.5)$$

The concentration on the product side of the membranes therefore becomes an average of the feed and reject concentrations:

$$\frac{C_F + C_R}{2} = \frac{C_F}{2}\left[\frac{200-R}{100-R}\right] \qquad (3.6)$$

If the membrane characteristics are such that the salt rejected is 98% for example, then the salt passage is 2% and for this case the concentration in the product water becomes:

$$C_P = \frac{2}{100}\;\frac{C_F}{2}\left[\frac{200-R}{100-R}\right] \qquad (3.7)$$

For a sea water with 35 000 mg/l TDS and with a water recovery of 40% it can be seen that:

$$Cp = 933 \text{ mg/l} \tag{3.8}$$

If the water recovery was raised to 50% the product quality would deteriorate to 1 050 mg/l whilst at a 30% water recovery the product quality would improve to 850 mg/l.

When one bears in mind a usual target of 500 mg/l TDS it becomes clear that with present membrane performance one has to design for water recoveries in the range 25% to 30%, the particular value selected being dependent upon the quality of the sea water.

The sea water varies in total dissolved solids from typically 35 000 mg/l for ocean water to 42 000 to 45 000 mg/l in enclosed areas such as the Arabian Gulf.

These factors have a large effect upon the design of plant and in particular the measures adopted to avoid or at least minimise fouling.

It is clear from the above that to produce 10 000 m^3/d it is necessary to abstract and pretreat 33 000 to 40 000 m^3/d of sea water. Similarly it becomes necessary to discharge 23 000 to 30 000 m^3/d of water to waste. Significant costs are associated with these operations.

Pretreatment of Feed Water for Reverse Osmosis

Reverse osmosis membranes can become fouled on their surface or can become chemically or biologically attacked in which case design performance cannot be maintained. Pretreatment is necessary to avoid these effects and particular requirements are to some extent dependent upon the type of membranes employed.

All membranes can be subject to physical fouling which has a similar effect to the blocking of a filter. To prevent such effects it is common to provide filtration as a pretreatment.

Sand or anthracite sand in pressure filters is the most common means with hydraulic loading rates ranging from 12 to 18 m^3/h per m^2. Thus for our example 10 000 m^3/d plant with 30% water recovery a filter area of 115 to 170 m^2 is required. Very small colloidal particles cannot be removed by filtration alone and therefore it is common to dose the water with an inorganic coagulant such as ferric salts or synthetic organic polymers.

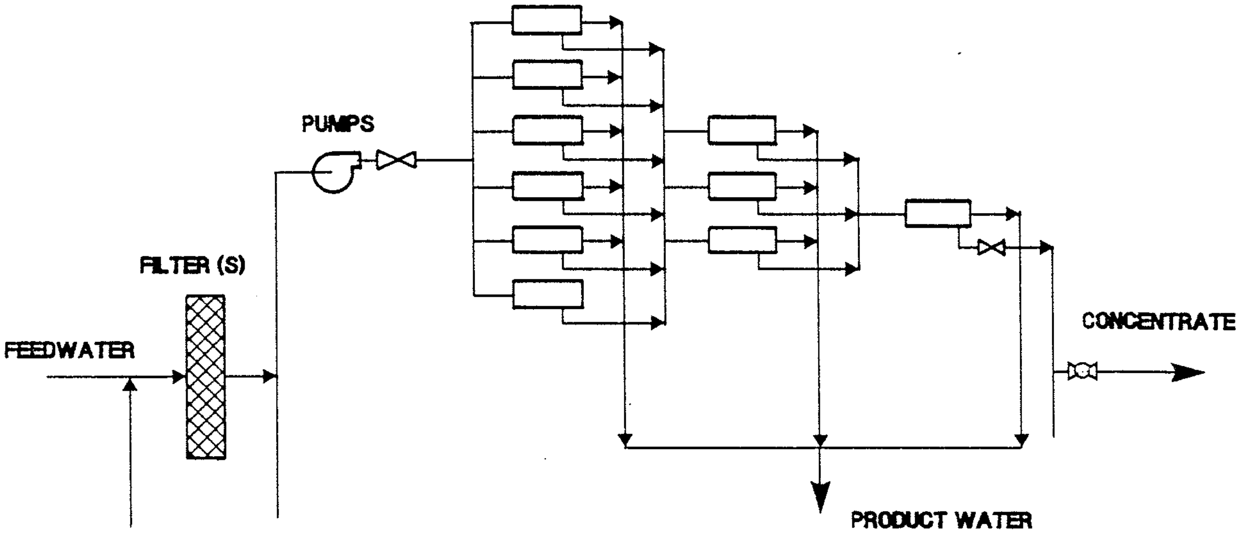
All membranes are subject to fouling by chemicals which precipitate within the system. This can include the following:

Oxidised iron and/or manganese
Calcium deposited as carbonate
Magnesium deposited as hydroxide
Calcium deposited as sulphate

The solution to these problems is either to remove the objectionable materials (e.g. iron and manganese) or to chemically treat the water to ensure that the solubility of the products are not exceeded as the solutes become concentrated in the reject stream.

Figure 3. 8

RO Arrays



All membranes are subject to biological attack. If bacteria are allowed to grow within the modules they will start 'feeding' upon the organic membrane materials. Chlorine is one of the most effective disinfectants but unfortunately chlorine also attacks membrane materials. It is common therefore in sea water systems to prechlorinate feed water at or near the intake and then, immediately before entry to the modules, to dechlorinate.

None of these methods of pretreatment is particularly effective in situations where sea water is contaminated with oils.

For sea water desalination the feed water must be pumped to high pressures. The pumps employed, multipiston reciprocating units or multistage centrifugal pumps, are protected against damage by the installation of cartridge filters immediately upstream; 5 to 10 micron units are commonly employed.

3.3.4 Costs of Sea Water Reverse Osmosis

It is difficult to generalise upon the costs of reverse osmosis because of the variability in designs to meet local requirements. The intake, delivery and pretreatment systems and reject discharge pipework are the aspects which cause significant variation in costs. Similarly some plants incorporate energy recovery systems so that energy can be recovered for the high pressure brine and used to assist in sea water pumping.

In Table 3.4 some guideline figures are quoted. The costs for electricity employed are rather low by UK standards but are fairly representative of situations like the Middle East where the basic fuel, oil or gas is free or heavily subsidised. The effects of alternative tariffs can be readily calculated.

3.4 Power Station Cooling

3.4.1 General

Electricity generating stations are primarily of two types:

(a) Thermal - steam expansion through turbines.

(b) Diesel or gas turbine.

The latter units are considerably smaller in output and use considerably less water. The main sea water users are the steam power stations. For example, in Kuwait some 8 000 MW of generation plant is installed with sea water used in every case for surface conductor cooling.

This is also the largest use of sea water in the UK and indeed Europe.

3.4.2 Thermal Power Generating Cycle

A simplified flowsheet of the thermal power generation system is illustrated in Figure 3.9.

TABLE 3.4

Typical Reverse Osmosis Costs for a 90% Load Factor

(for a sea water feed with 35 000 mg/l total dissolved solids, product water with 500 mg/l total dissolved solids, 860 psi operating pressure, 25°C sea water temperature and 30% conversion)

	4 Ml/d		20 Ml/d	
Capital costs (£ million)	2.08		9.94	
Operating costs (£ million pa and £/m^3)	£M pa	£/m^3	£M pa	£/m^3
1. Fixed charges 11.75% (10% interest, 20 year plant life)	0.24	0.186	1.16	0.178
2. Power (at 3.2 p/k Wh)				
(a) Brackish (1.8 kWh/m^3)				
(b) Sea (8.0kWh/m^3)	0.34	0.256	1.70	0.256
3. Chemicals Acid Polyphosphate Chlorine Detergent Formaldehyde				
(a) Brackish				
(b) Sea	0.041	0.031	0.20	0.031
4. Membrane replacement 3-year life	0.32	0.244	1.53	0.244
5. Maintenance, operation, staff and materials	0.042	0.031	0.17	0.026
Total annual cost (£ million)	0.98		4.76	
Total water cost (£/m^3)		0.774		0.735

Figure 3.9

Steam Power Generation Simplified Flowsheet

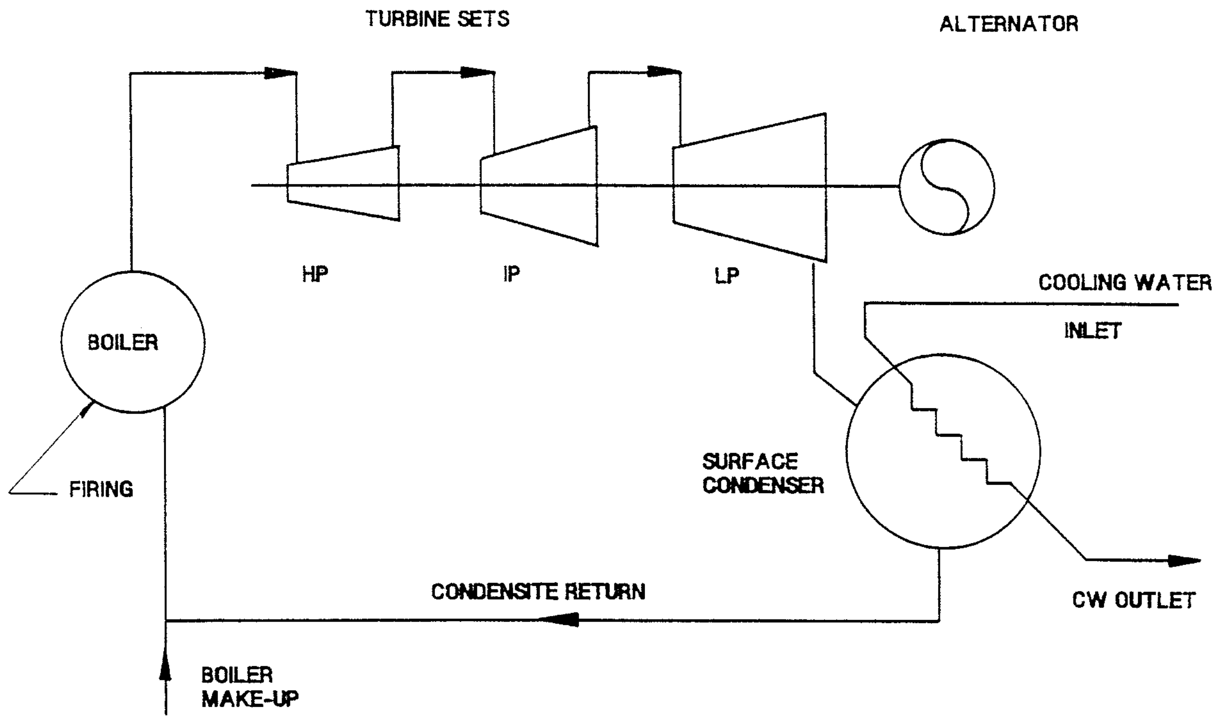
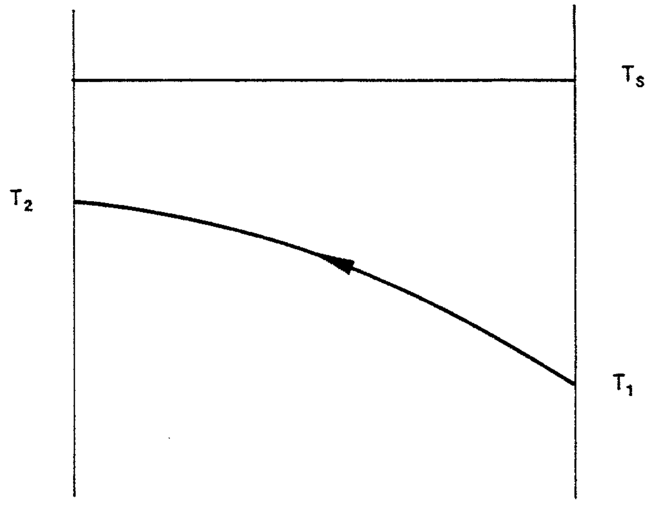


Figure 3.10

Temperature Distribution in Condenser



Steam is raised in boilers at high pressure and with high superheat. This is fed into a steam turbine train. In small low pressure installations this may comprise a single turbine but in large high pressure units it is common to employ either two or three turbines in series. In principle a single turbine could be used in all situations but a limitation exists to the physical size of turbines and housings.

From the high pressure turbine steam is fed to the intermediate pressure unit and then to the low pressure (LP) machine. In practice some steam may be extracted from intermediate points between machines for use in preheating. Similarly turbines can be mounted on separate shafts with individual alternators.

The one thing that is common to all systems is that steam exhausted from the LP set has to be condensed and returned. The condensate is returned for reuse in order to take advantage of the very high quality necessary for feed to the boilers.

Overall water losses of water in the entire cycle are very small and therefore the demands for high quality boiler feed water are minute compared with the demands for cooling water.

In the steam cycle, only the sensible heat is converted to mechanical energy, the latent heat of the steam has to be discarded in the cooling water. Thus these power stations have an efficiency of typically 30% and for each megawatt of power generating capacity some 100 t/d of steam has to be condensed.

Thus the 8 000 MW of generation capacity in Kuwait require cooling water for the condensation of some 800 000 t/d of steam.

3.4.3 Surface Condensers

(i) Temperature Distribution

The distribution of temperature with a steam condenser is illustrated in Figure 3.10.

If the condenser is fed with saturated steam the temperature on the outside of the heat exchange tube bundles will be constant and equal to the condensation temperature of the steam (the boiling point of the water). Sea water entering at temperature T_1 will be heated to temperature T_2.

The driving force for the transfer of heat is the temperature difference between the condensing steam and the cooling water. The shape of the cooling water temperature curve is such that the average temperature difference is as follows:

$$\Delta Tm = \frac{\Delta T_1 - \Delta T_2}{\ln \frac{\Delta T_1}{\Delta T_2}} \qquad (3.9)$$

where $\Delta T_1 = T_3 - T_1$

$\Delta T_2 = T_5 - T_2$

hence $$\Delta Tm = \frac{T_2 - T_1}{\ln \frac{T_3 - T_1}{T_5 - T_2}} \qquad (3.10)$$

(ii) Mass and Heat Balances

The heat load on the condenser is as follows:

$$Ms \; x\lambda s = Qs \tag{3.11}$$

where Ms = mass steam flow

λs = latent heat of steam.

A heat balance across the condenser will show for a specific heat of unity:

$$Ms \; \lambda s = Mc \, (T_2 - T_1) \tag{3.12}$$

Hence the flow of cooling water is related to the temperatures as follows:

$$Mc = \frac{Ms \lambda s}{T_2 - T_1} \tag{3.13}$$

The equation above will be used to evaluate requirements for the following case:

(i) For 1 MW generating capacity

Ms = 100 t/d

(ii) For a condensing pressure of 28 in. mercury vacuum

Ts = 38.7°C = 101.7°F

λs = 576 cal/g = 1 036 Btu/lb

(iii) T_1 = 15°C

(iv) T_2 = 28.7°C

Under these conditions the flow of cooling water required is 4 200 m^3/d. Hence for a large 2 000 MW power station the cooling water flow will be about 8 million m^3/d, or 100 m^3/s.

(iii) Heat Transfer

The rates of heat transfer in the surface condenser are covered by the following equation:

$$Q = U \, A \, \Delta Tm \tag{3.14}$$

where Q = heat load kcal/h (Btu/h)

A = heat transfer area m^2 (ft^2)

ΔTm = temperature driving force °C (°F)

U = overall heat transfer coefficient kcal/h/m^2/°C (Btu/h/ft^2/°F)

From the analysis above the heat load and temperature distribution can be identified. The remaining factor necessary to establish the area of heat transfer tubing necessary for a specific case is the overall heat transfer coefficient U.

The majority of costs associated with surface condensers lies in the large area of heat transfer surface required. In practice the cost is almost directly proportional to the heat transfer surface.

The factors which govern the value of the overall heat transfer coefficient U will now be examined.

(iv) Heat Transfer Coefficient

The resistance to heat transfer can be evaluated by reference to the two-film theory which is presented in all standard texts ((1) Kern, Process Heat Transfer, Coulson and Richardson, Chemical Engineering Vol. I).

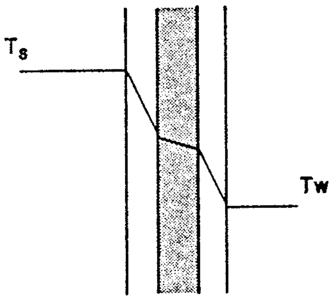


Figure 3.11 Film Effect on Heat Transfer

In the main bulk of the two fluids, separated by a heat transfer surface, turbulence is so great that the resistance to heat transfer is negligible. However, a thin film forms on each side of the surface and this film is relatively static and creates significant resistance to heat transfer (Figure 3.11).

The combined resistance to heat transfer (1/U) can be calculated by summing individual resistances.

$$\frac{1}{U} = \frac{1}{h_o} + \frac{1}{h_m} + \frac{1}{h_i} \tag{3.15}$$

where h_o = the outside coefficient

h_i = the inside coefficient

h_m = the metal coefficient.

The term h_m can be shown to be equal to k/x where k is the thermal conductivity of the metal surface and x the thickness of the metal. For the non-ferrous materials used k is typically 180 ft Btu/h/ft^2/°F and x is 0.0625 in.

hence h_m = 30 000 Btu/h/ft^2/°F

This is so small that it represents only some 2% of the total resistance to heat transfer.

(a) Outside Coefficient h_o

For horizontal tubes the film heat transfer coefficient can be represented by the Nussett equation:

$$h_o = 0.72\left(\frac{k^3 p^2 g \lambda}{d_o \mu \Delta T_f}\right)^{0.25} \qquad (3.16)$$

where k = thermal conductivity of condensate

p = density

g = gravitational constant

λ = latent heat

d_o = outside diameter of tubes

μ = viscosity of condensate

ΔT_f = temperature difference across condensate film.

(b) Inside coefficient h_i

The inside coefficient can be expressed by the Sieder Tate equation:

$$\frac{h_i D}{k} = 0.27\,(Re)^{0.8}\,(Pr)^{0.33}\left[\frac{\mu}{\mu s}\right]^{0.14} \qquad (3.17)$$

where D = inside diameter of tube

k = thermal conductivity of the coolant

Re = Reynolds Nr = $\frac{Dv\mu}{k}$

V = velocity

Pr = Prandtl Nr = $\frac{Cp\mu}{k}$

Cp = specific heat

μ = viscosity of bulk fluid

μs = viscosity at temperature of the tube surface.

By the use of these relationships and typical values for film and overall heat transfer coefficients, the likely effects of oil contamination of cooling sea water can be examined.

When film coefficients as calculated above are employed to calculate the overall coefficient, a factor (f) is normally included to allow some margin for fouling of the surface.

$$\text{Thus} \quad \frac{1}{U} = \frac{1}{h_m} + \frac{1}{h_o} + \frac{1}{h_i} + f \qquad (3.18)$$

In surface condensers fouling from steam on the outside is minimal, the factor being typically 0.0003 ft^2 h °F/Btu. Similarly the factor for clean sea water is also low at 0.0005. However, in refinery heat exchangers where fuel oils are handled fouling factors are high, typically 0.006 and for tars 0.01.

Thus, if average film coefficients as quoted by Coulson and Richardson (Table 6.13, page 214) are used for clean water/steam the overall coefficient can be calculated as shown in Table 3.5 to be 454 Btu/ft^2/h/°F. By comparison use of a river water gives U = 345 Btu/ft^2/h/°F.

If the quoted fouling factor for fuel oils is added to that of water the heat transfer coefficient of a sea water cooled surface condenser would fall from 454 to 357 Btu/ft^2/h/°F.

	h_o	h_i	h_m	f_o	f_i	U
Steam/water	2 000	1 150	30.000	0.0003	0.0005	454
Steam/river water	2 000	1 150	30.000	0.0003	0.0012	345
Steam/water and oil	2 000	1 150	30.000	0.0003	0.0011	357
Steam/water and tar	2 000	1 150	30.000	0.0003	0.0105	82

In the extreme if tars were present the heat transfer coefficient could fall to below 80 Btu/ft^2/h/°F.

These losses are very approximate estimates but probably represent the extremes of performance deterioration which could be expected in a steam condenser where the cooling water is polluted with unweathered oils. When weathered oils enter condenser tubing the effects are likely to be more severe, eventually leading to complete blockage and complete failure of heat exchange.

(v) Summary

The effect of oil in cooling water is to reduce the rate of heat transfer by fouling of the metallic surfaces. The effects can be quantified by examination of the changes in the overall heat transfer coefficient U.

TABLE 3.5

Typical Overall Heat Transfer Coefficients

Heating media	Cooling media	U Btu/ft^2/h/°F
Condensers		
Steam (press)	water	350 - 750
Steam (vac)	water	300 - 600
Low boiling HC (atm)	water	80 - 200
High boiling HC (vac)	water	10 - 30
Heaters		
Steam	water	250 - 750
Steam	light oils	50 - 150
Steam	heavy oils	10 - 80

These are the effects which might be expected following entry of unweathered oils into heat transfer equipment. The entry of weathered oils, tars or emulsified oils would cause more serious problems and could eventually lead to complete failure of the units. It is for this reason that plants tend to be shut down when the risk of entry of viscous oils occurs.

3.5 Industrial Cooling

3.5.1 General

Sea water is used in industrial applications as cooling water. Probably the largest single facility of this type is the Jubail industrial complex on the eastern coast of Saudi Arabia. A wide range of industries is served including steel and petrochemicals and the total design flow of the system is 2.16 million m^3/d (25 m^3/s).

On a much smaller scale sea water is frequently used for indirect cooling of diesel engines used in turn for small scale power generation. In order to avoid corrosion of engines by sea water a secondary circuit is used so that high quality fresh water is used as the primary coolant and this is cooled in shell and tube coolers by sea water. An example of this type of use is the power generating facility of the BBC on Ascension Island where diesel engines are used to generate 8 MW for radio transmission and the power supply of the island.

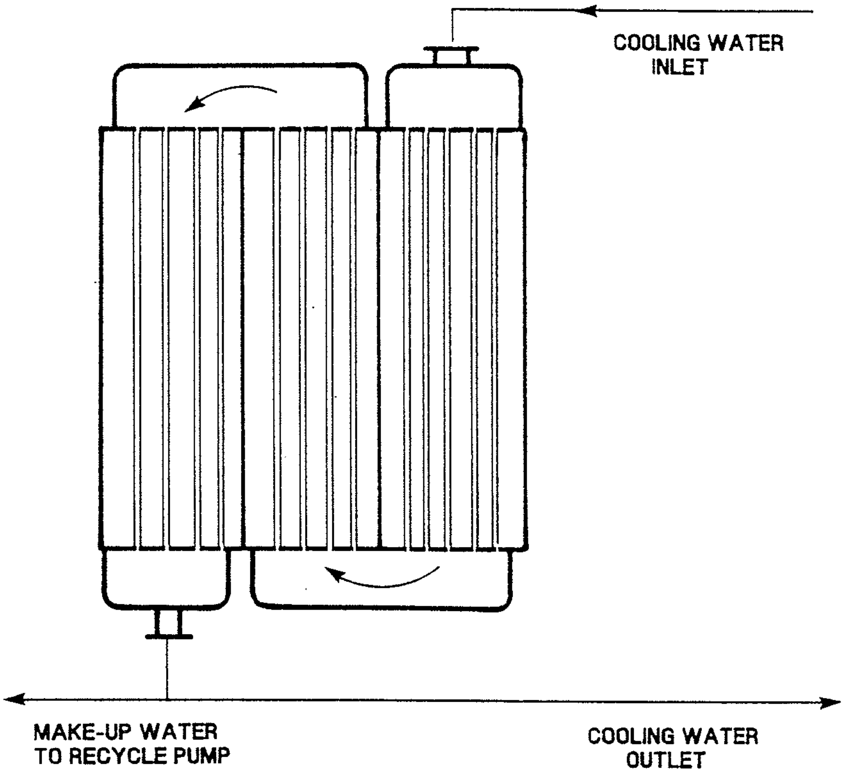
3.5.2 Heat Exchangers

Almost all of these types of installation use shell and tube type heat exchangers as illustrated in Figure 3.12.

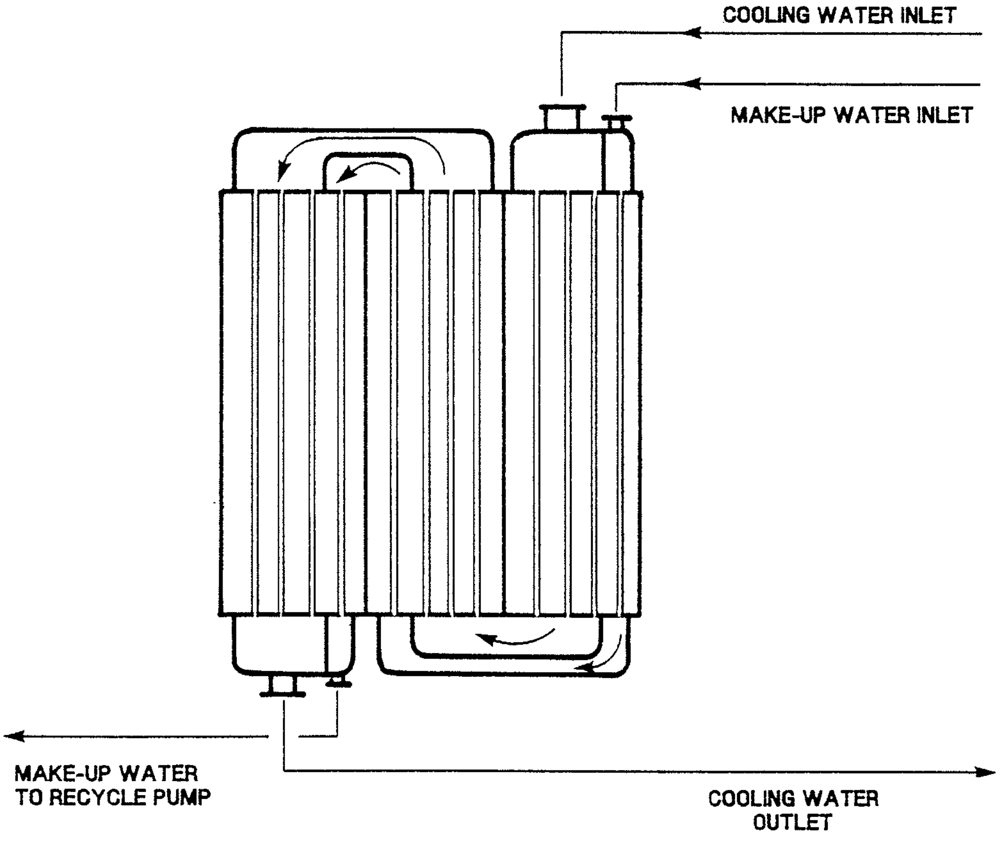
The fluid which passes through the tubes enters and leaves through the domed end cover whilst the second liquid enters and leaves through shell ports.

Figure 3. 12

Heat Rejection Condensers (MSF Distillation)



a) Typical flow in heat rejection condensers



b) Modified water boxes for separation of make-up and cooling water in heat rejection condensers

Heat transfer analysis of these types of units are again presented in standard texts. Equations of the type of (3.18) above are used to calculate both tube and shell side film coefficients and again the overall heat transfer coefficient is calculated as follows:

$$\frac{1}{U} = \frac{1}{h_o} + \frac{1}{h_i} + \frac{x}{k} + f$$

The effects of pollution or fouling of the heat transfer surface can again be determined by measurement of reductions in the overall heat transfer coefficient and hence the increase in fouling factor can be calculated.

Typical overall coefficients for heat exchangers where no change of state occurs are taken from Coulson and Richardson and reproduced below:

	U
Water/water	150 - 300
Water/light oils	60 - 160
Water/heavy oils	10 - 50

Whilst these data relate to the cooling of light and heavy oils, it is clear that pollution of water with oils will result in a reduction in overall heat transfer coefficient due to the nature of the fluid and in addition deposits from the oils will cause fouling.

The figures above indicate the order of performance deterioration to be expected when oil pollution of cooling water occurs. Again the presence of very viscous weathered oils will be considerably more serious leading ultimately to blockages.

CHAPTER 4

INTAKES FOR SEA WATER UTILISATION

4.1 Introduction

Many types of intake are used for supplying various sea water utilities. There are no specific classes of intake applicable to a particular operation, as there are many differences in water demands and physical and meteorological conditions between particular situations.

Major power stations and industrial complexes require very large volumes of cooling water and there are many technical considerations not associated directly with the intake which govern site selection. These considerations include depth of water at the foreshore, ground conditions for foundations, wave, current and tidal regimes, environmental factors, relative costs of dredging, shore protection and intake and pump station costs, effects of cooling water abstraction and discharge on fisheries, the costs of supply, installation and operation of pumping plant, etc. The design of intakes to such utilities are therefore usually compromise solutions to a wide range of engineering, economic, ecological and political problems.

Although this report will consider mainly the requirements and conditions affecting major utilities such as large power stations and desalination plants, consideration should be given to smaller utilities also. Although the range of intakes is large it is possible to identify intakes as a series of basic types, such as open channels, offshore, foreshore and riverine, infiltration, and whether they are directly screened, unscreened, floating or fixed.

4.2 Major Intakes

4.2.1 Open Channel Intakes

Open channel intakes are often used where water is a reasonable depth close inshore but the intake and pump station can be economically located away from the foreshore. Such an intake channel is sized to draw in the full flow requirement of the utility at a low velocity and its orientation will be designed to minimise siltation, current and wave effects.

This type of intake offers considerable advantages in terms of pollution control, as the length of channel enables a number of pollution control measures to be deployed against slicks.

4.2.2 Offshore Intakes

This class of intake is often employed where there are shallows close inshore, or, for example, where potential circulation problems require wide separation of inlet and discharge.

A typical arrangement of this type (Figure 4.1) was selected for the sea water pumping station for the Al Khobar II power and desalination plant, where the intake is situated about 700 m offshore in about 7 m depth of water. The intake is connected to the pumping stations onshore by three large reinforced concrete culverts. At the downstream ends of the culverts there is a screening plant consisting of one bar screen and one travelling band screen in each of 8 screening lines with a design capacity of about 40 000 m^3/h, about 1/6th of the total capacity of the pumping station. The pumping station at Al Khobar lifts the sea water into a distribution channel running parallel to the coast from which pumping stations for desalination, power generation (5 units each), chlorine plant and auxiliary cooling water all draw their supplies. This provides an additional possible line of defence against pollution, as compared with smaller and more conventional schemes which would not have the distribution channel and second pump stages.

4.2.3 Foreshore Intakes

This class of intake will often see the intake and pumping station in a combined structure, as with the channel intake type, and is only suitable in a situation where there is sufficient depth of water available inshore. This type of intake requires particular attention with regard to the effects of tides and currents. It is a type often used in riverine situations, where there are often risks particularly due to small spills from bunkering and discharge activities.

A major potential problem with foreshore intakes is wave action, which can amplify level oscillations in forebays and screen chambers, with consequential effects on pump action. Their performance is also dependent on cross current effects, and such intakes often require careful hydraulic modelling for proper design. An example of a foreshore intake is shown in Figure 4.2, located at Heysham power station in UK. In this case there were no particular wave or tidal problems and no hydraulic modelling was undertaken.

4.2.4 Intakes at Power Stations in UK

(a) General

In the UK by far the major users of sea water are the power stations. Roughly 25%of the power stations in England and Wales use sea water for cooling purposes and this includes 8 of the 9 operational nuclear stations. A power station condenser consists essentially of a large vessel containing many thousand tubes, each typically 25 mm in diameter. The sea water is pumped through these tubes at a velocity of about 1.7 m/s to condense steam in the vessel. In the case of stations on the sea or lower estuaries the sea water is returned directly to the source after use. A power station generating 2 000 MW of electricity requires about 63.2 m^3 of water per second for cooling and this applies equally to nuclear as to conventionally fired power stations.

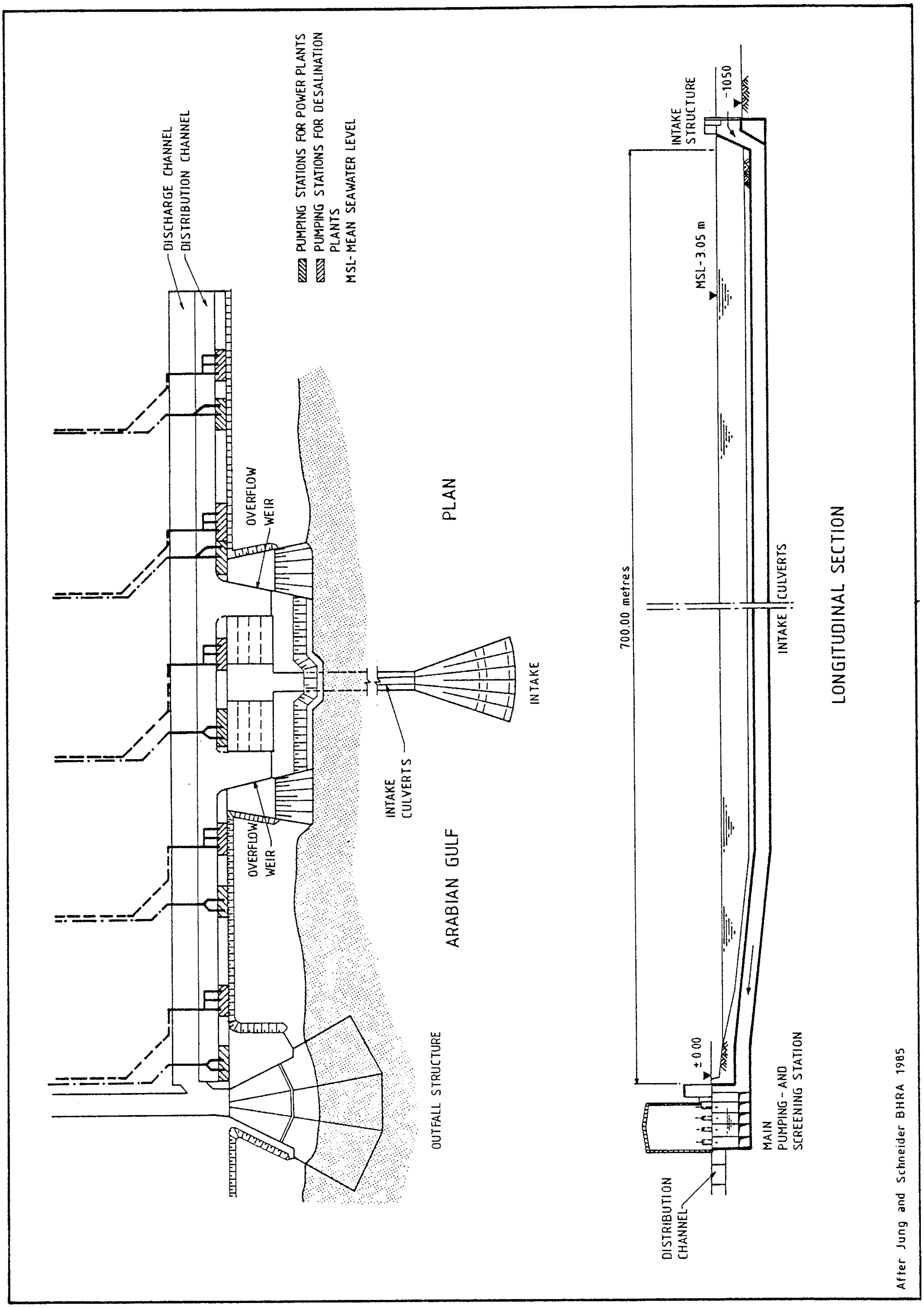
The 8 nuclear power stations with a total gross capability of nearly 5 000 MW will together use sea water at a rate of 153 m^3/s and the remaining conventional stations with a total gross capability of over 15 000 MW will use over 480 m^3/s. The steam undergoing condensation is at about 100°F and the tubes may typically be made of cupro-nickel, nickel aluminium bronze with aluminium brass or of titanium.

(b) Effect of Oil Contamination

If heavy oil in the intake water should foul the inside of the tubes, it will reduce the rate of heat transfer to an extent depending on the surface area fouled and the thickness and persistence of the oil. Should the oil persist, it can harden to form a scale which would be difficult to remove. It might be expected that the oil would be more likely to persist in a situation where some scale already existed on the tubes.

Figure 4.1

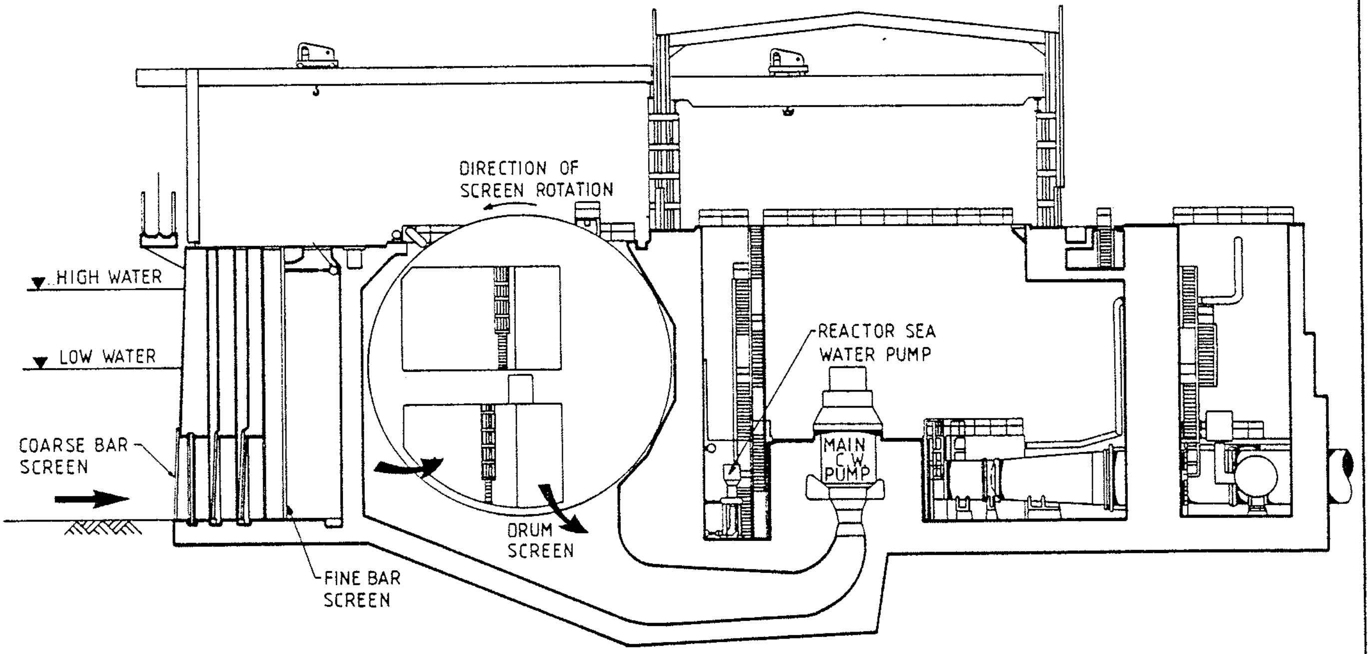
Al Khobar Complex Sketch Layout



After Jung and Schneider BHRA 1985

Figure 4.2

Heysham Power Station Intake



(c) Protective Measure

Power stations have to contend with various types of debris in their intake water, such as seaweed and mussel shells and the protective measures already required to keep such material out of the condenser tubes might be expected to provide some protection from oil. Although this would be inadequate for operational purposes, visual inspection of screens and free water surfaces in holding tanks would quickly reveal any small amounts of oil present.

A typical power station intake system comprises coarse bar screens in many cases, with spacings between about 50 and 150 mm. The water is commonly received into a forebay which in some circumstances, as on an estuary, may provide storage for 6 hours or more operation at low tide. The forebay may house screens which will typically have either plastic or metal screen plates with holes which may vary between about 6 and 12 mm. The screens are of the drum or belt type and in some situations include facilities for recovering and returning fish to the sea or estuary. In a few cases it has been found unnecesssary to run the screens continuously; in one case they were on a time switch to reduce the running time, but in another they were operated as stationary screens.

In a few cases permanent booms are deployed, but these may be partly or wholly to keep out floating branches and other debris, rather than oil. In several other cases booms were stored in readiness for deployment if required.

(d) Experiences with Oil Contamination

Seventeen major power stations in the UK employing sea water for cooling were contacted. None of these had experienced any problem with oil although in a few cases they had narrowly escaped. Port Authorities and County Council emergency pollution schemes keep a close watch on the oil pollution situation and give early warning of any threat.

4.3 Minor Intakes

Small communities with limited water demands in remote areas or on islands are often served by small desalination plants. The intakes required for such small utilities are small and simple and two examples are shown in Figures 4.3 and 4.4. The intake in Figure 4.3 for an island community in Oman is a solid concrete structure protected against anchor or collision damage by rockfill, and abstracting water through valved intake pipes in the front chamber. Thus the system is protected against ingress by surface oil, and tar balls or other pollutants will adhere to the rock cover or be intercepted by the downstand wall across the chamber.

The second type of chamber shown in Figure 4.4, located in shallow waters off Abu Dhabi, is more vulnerable to pollution as it is a more open structure. This type of intake is relatively inexpensive.

4.4 Groundwater Intakes

As an alternative to direct intakes as described above, beach wells and wells into aquifers infiltrated by sea water are alternative approaches, appropriate in some situations. In locations where there is a particularly high risk of oil pollution it may be that an on-shore wellfield is an economic and technically viable approach. An example of such a scheme for the east coast of Bahrain is described below. In Bahrain a groundwater investigation was carried out in 1983, complementary to a more extensive groundwater study in Saudi Arabia of the Umm er Radhuma formation. The hydrogeological section through the relevant aquifer in Bahrain is shown in Figure 4.5. As a result of the site investigation work, together with the detailed computer model studies, development recommendations were formulated for the east coast area, in which wells were proposed for supplying water for reverse osmosis desalination plants which have been built subsequently on the basis of a Japanese design.

During the study it was not possible to accurately assess certain parameters, such as the leakance coefficient in the central core area and thus a cautious approach to the development has been adopted until a more accurate assessment can be made.

(a) Water Quality

The two main constraints on water quality were intrusion of sea water and oil pollution due to the oil development company oilfield wastewater injection. The general conclusions and recommendations for this particular case are summarised below.

The effects on other aquifers of developing Aquifer C would be as follows:

(i) Large scale abstraction in the east coast area will assist in reducing the effects of saline intrusion to the fresher Aquifer B.

Predictive runs of the models have established that the upward leakage of saline water in the Ali-Salamabad area will be reduced. In addition, a small decline in the Aquifer B watertable in the Sitra area is predicted. At this location Aquifer B is almost completely invaded by sea water and the introduction of a small watertable decline will contribute to the stabilisation of the advancing saline front.

(ii) No serious detrimental effects on the fresher water areas of Aquifer B are anticipated.

Until careful long-term observations for at least 5 years of wellfield operation have been made to obtain more definitive values for the database, it was recommended that large scale development of Aquifer C is held at the levels necessary to feed a 46 500 m^3/d reverse osmosis plant. Under the worst conditions the 46 500 m^3/d plant would have over 25 years of operation before the feed water quality reached that of sea water. Under better conditions it could be nearer 40 to 50 years.

In comparison to the values of the leakance coefficients the quantity of Aquifer C water which is abstracted is not so critical. Consequently, should the leakance coefficient be observed to tend towards the better estimates, consideration of increasing abstraction for a further 23 000 m^3/d reverse osmosis plant could be given, without appreciably altering the rate of deterioration of water quality.

Figure 4.3

Kuria Muria Intake

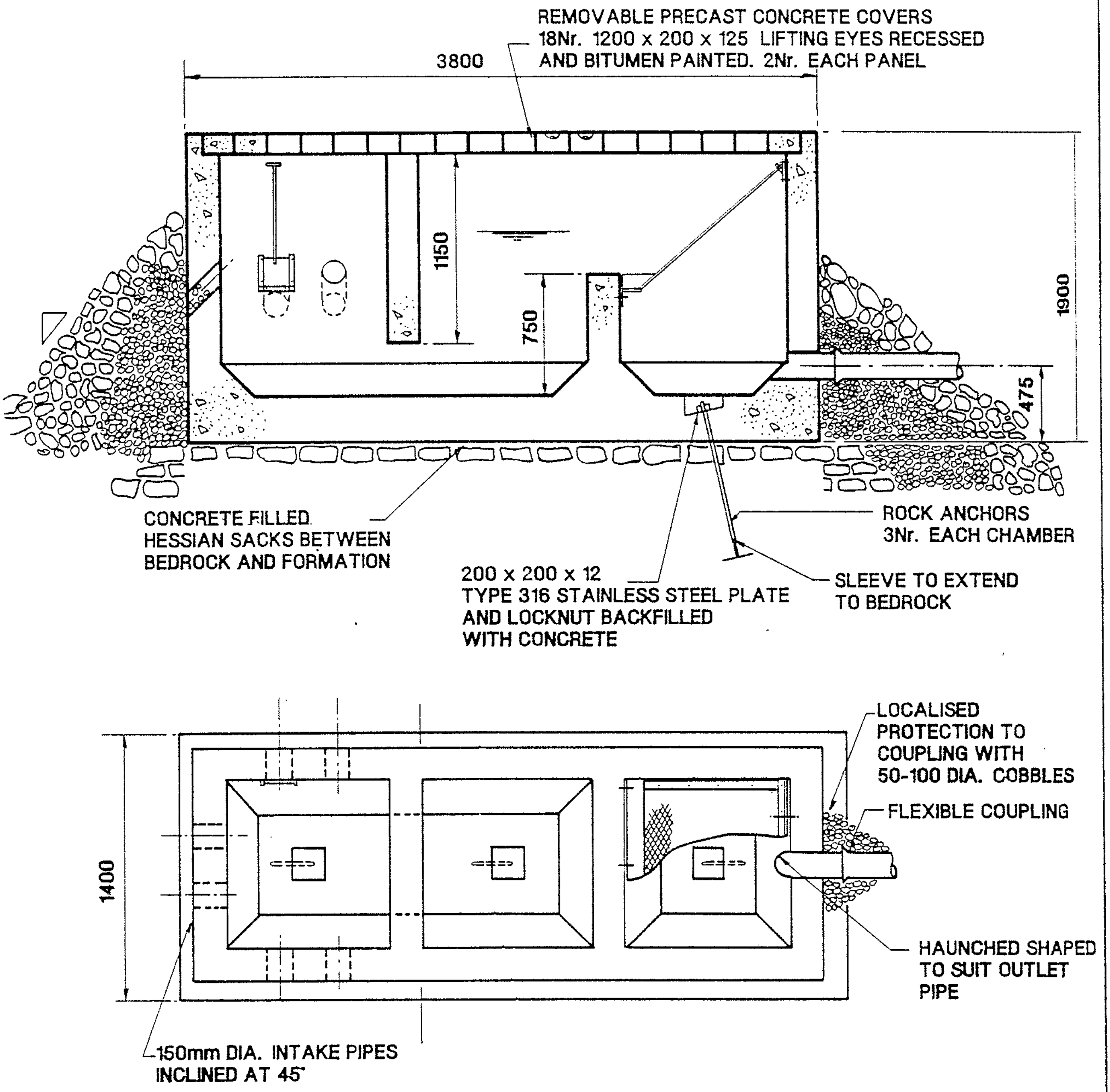
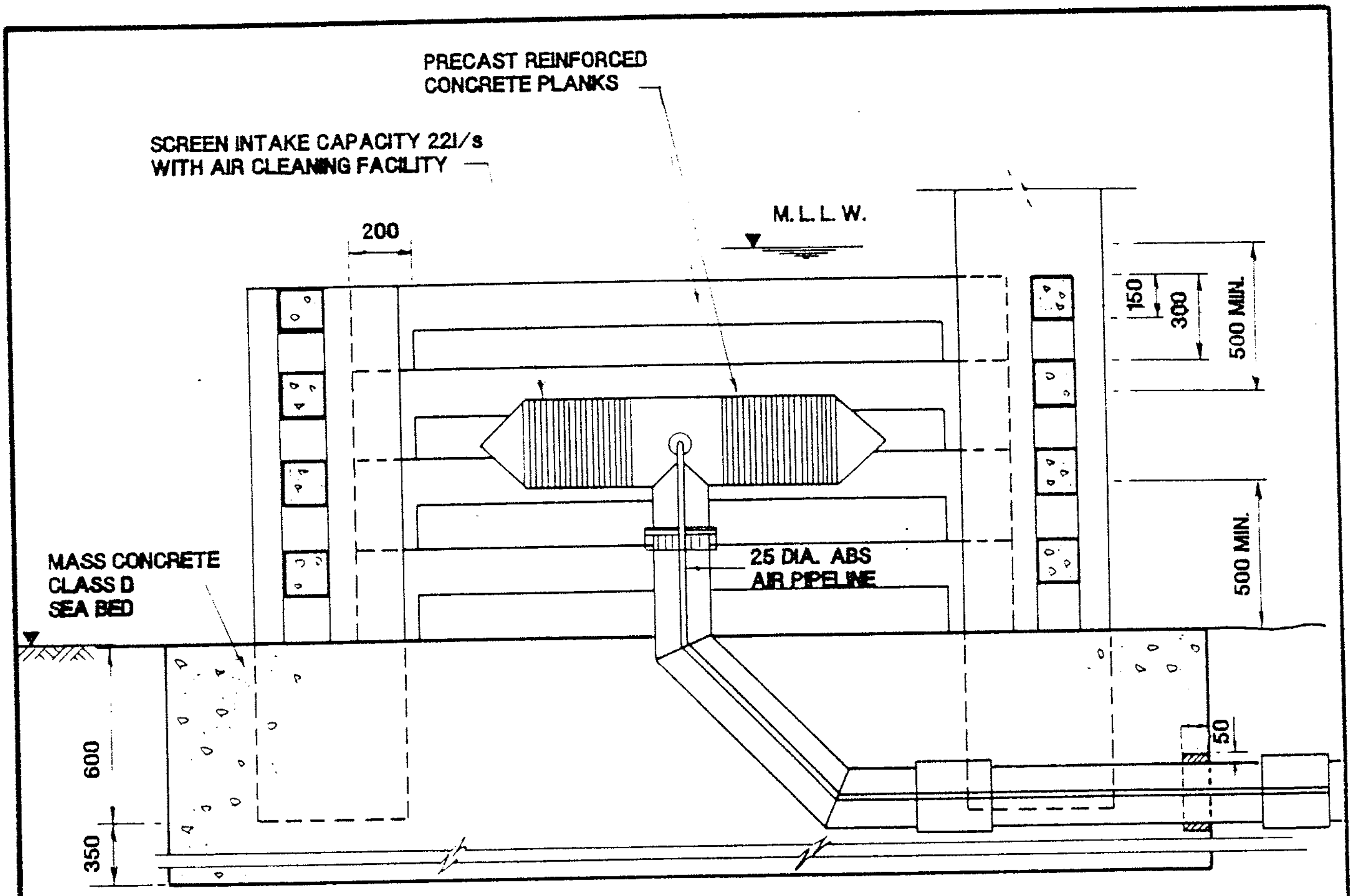
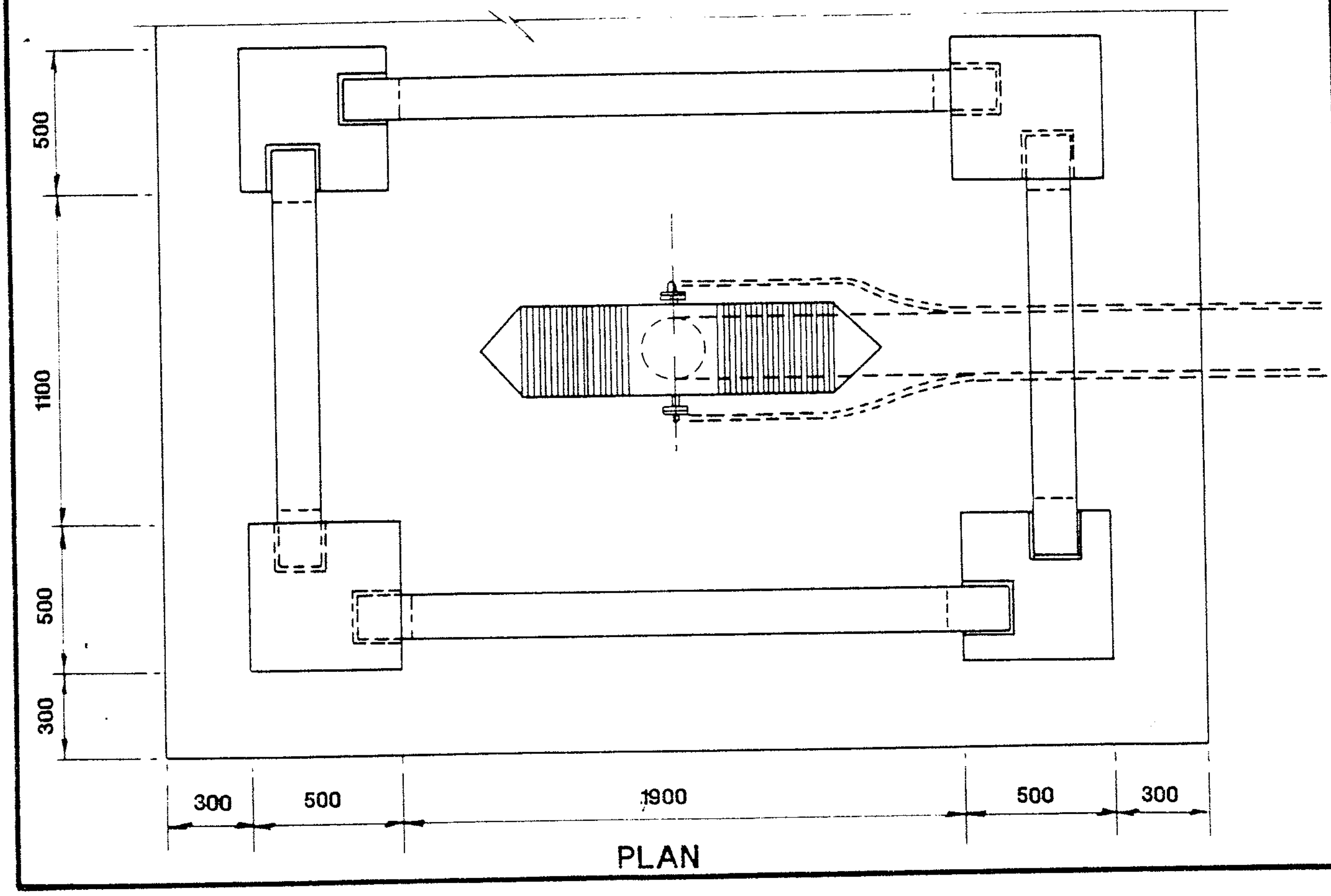


Figure 4.4

Small RO Plant Intake



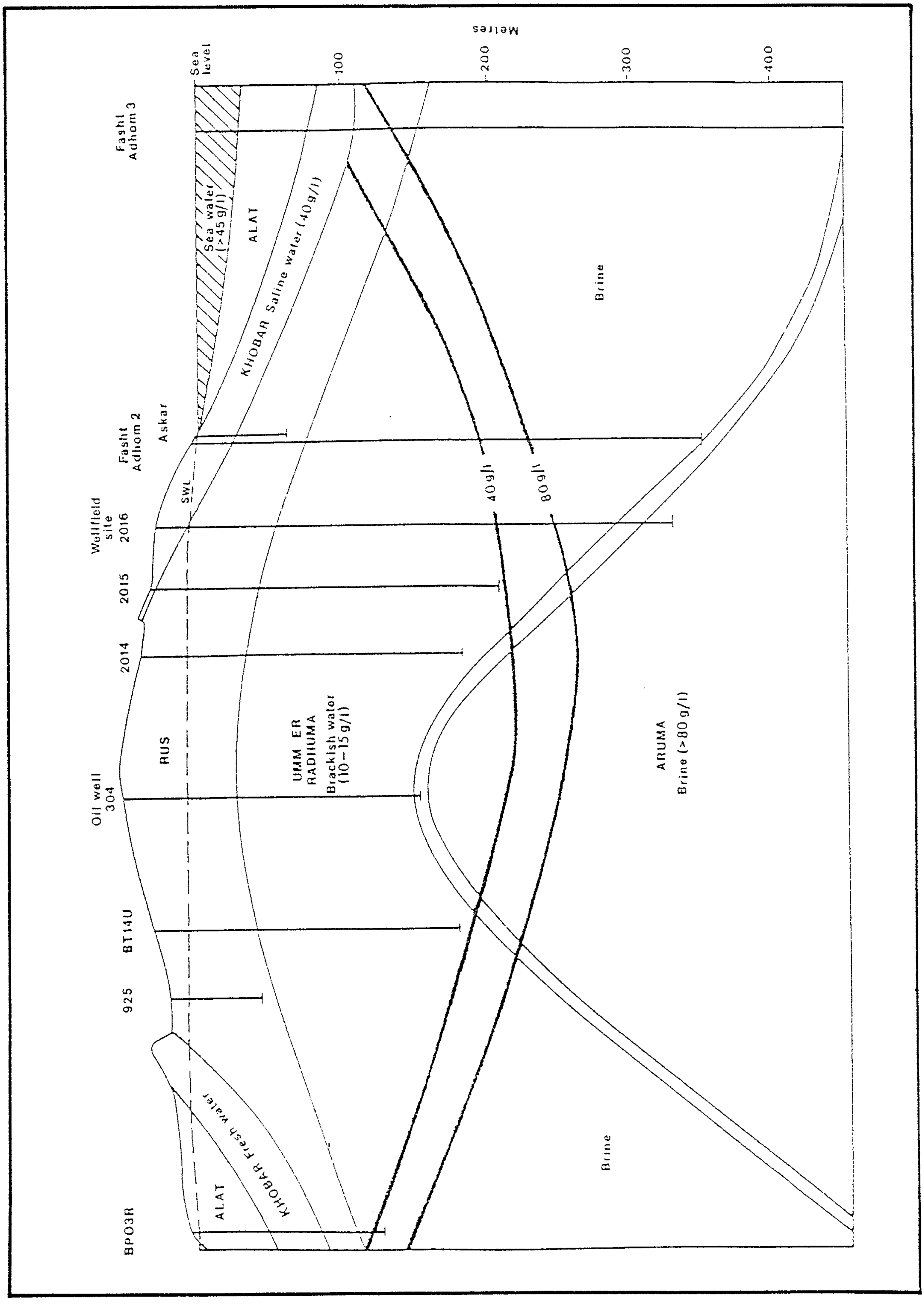
SECTION



PLAN

Figure 4.5

Simplified Salinity Distribution



In determining the recovery rates of the reverse osmosis process the chemical constitution of the water is as important as the overall salinity. However, for Aquifer C, the chemical constitution is only significant in the earlier years and, as the salinity increases, this becomes the predominant criterion for recovery rate determination.

Levels of hydrocarbons in 1983 as determined from the analysis of groundwater samples taken during the investigation, were considered unlikely to cause major problems. However, the installation of activated carbon filters was strongly recommended and has been adopted. It is difficult to simulate the movement of oil/water mixtures in a fissured carbonate aquifer but the high transmissivity of Aquifer C in the area along and around the proposed wellfield does suggest that movement could be rapid. Although the effect of continuing with the present discharge arrangements cannot be defined, it was recommended that the oilfield wastewater injection would be only allowed to continue provided that the injected water was cleaned to a residual level of less than 30 mg/l of oil.

(b) Well and Wellfield Design

In order to minimise local drawdown it was recommended that, initially, individual well output is restricted to 70 l/s. The proposed production well design is based on the hydrogeological section shown in Figure 4.6. Nominal 360 mm casing was specified to allow the pump capacity to be increased should future conditions permit.

The Rus section of the borehole is screened over its lower portion to derive some benefit from the better quality water present in the Rus formation. Although the transmissivity of this section is relatively low, its inclusion as a direct contributor to the well discharge will delay the onset and rate of deterioration of the water quality.

Screening the complete Rus section was not recommended as the upper section of the Rus was likely to have slightly higher hydrocarbon levels through migration of the injection water oil content to the free water surface. However, it must be noted that no evidence was obtained in the 1983 investigation to show that the floating layer of oil which exists in the central dome area extends as far as the wellfield and casing-off upper Rus section was considered an additional safety measure.

Consideration has been given to the method of supplying the additional raw water requirements of either the 46 500 m^3/d plant as the quality of feed water deteriorates or an increase in plant capacity should the rate of quality deterioration permit. Hence, it was recommended that a well spacing of 250 m be provided to enable the well pump capacity to be increased, as a first stage, to 100 l/s and possibly higher. A smaller well spacing at these higher discharges would result in more rapid water quality deterioration and the well interference effects would increase the wellfield drawdown.

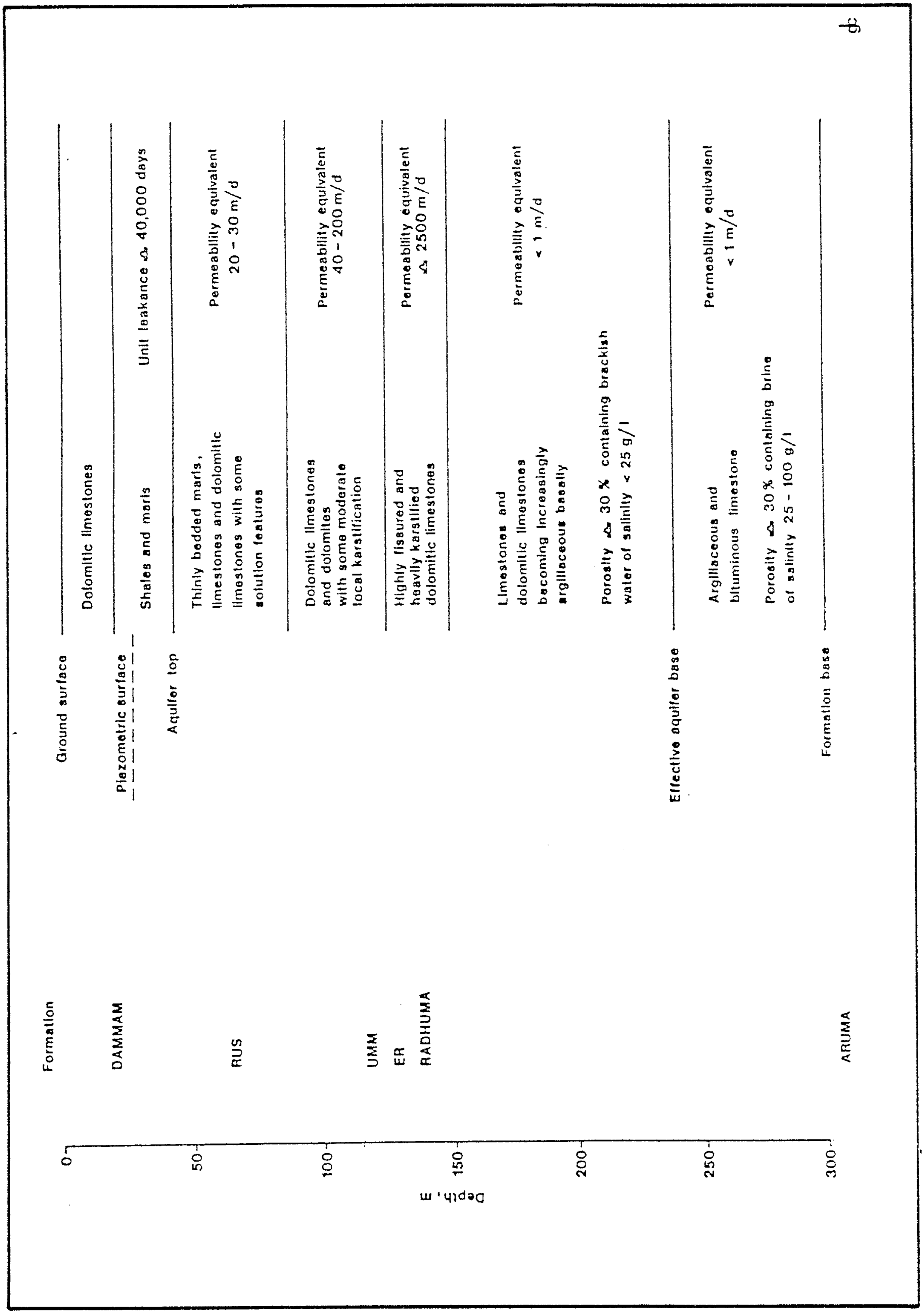
(c) Overall Development of Aquifer C

It is not possible to comment fully on the overall development of Aquifer C until the studies are all complete and the scheme has been operated for some time to give an indication of quality trends. However, it was considered essential that development of Aquifer C was carried out in a controlled manner, not only in the location and quantity of abstraction but also in the inevitable brine disposal problems associated with desalination of this aquifer water.

Aquifer C is a limited resource and the proposed development greatly exceeded present recharge. Priorities for development must therefore be clearly established, and it is particularly important when using this approach to infiltration intakes to carry out a thorough prior investigation and to monitor changes in the aquifer water after implementation.

Figure 4. 6

Hydrogeological Section of Aquifer C on the East Coast of Bahrain



CHAPTER 5

THE EFFECTS OF OIL CONTAMINATION

5.1 Screens

In any oil pollution incident the first items of plant to be affected are the mechanical screens. Screening arrangements vary from facility to facility, but in general screening will be in two stages. The first stage screen would normally be a static bar screen typically with an opening of about 50 to 100 mm to intercept large debris, and provided with means of manual or mechanical raking to dispose of large trash.

The second stage would be a drum screen or travelling band screen as indicated in Figure 5.1. Other configurations are possible, including pressure strainers upstream or downstream of the pumps.

Static bar screens are not affected by oil contamination to any great degree, although there may be some build-up of tar balls, depending on current velocity, trash bulk and other factors. Generally, however, the polluting oil products will pass through a coarse screen except for minor adhesion of sticky particles.

There are potentially serious problems with the mechanical screens with finer meshes (from 10 mm down to say 2.5 mm opening), either because of mechanical loading, or due to blockage. The majority of mechanical screens used in large plants are equipped with torque limiting clutches between the screens and driving motors. Should the screens become overloaded with oil products and other trash, the clutches normally automatically disengage, freeing the motors which will then cut out. The clutches can be manually re-engaged and the screens restarted after cleaning and there is little risk of major mechanical damage to the equipment.

In the case of screens with drive equipment fitted with shearing pins, there is a risk of damage necessitating dismantling the drive motor to replacing the pins, should there be significant overloading. This can prove time consuming, particularly if no spares are available at the plant.

The CEGB in the UK specifies that power station cooling water intakes have drum screens which are designed to withstand the full hydraulic head which could occur with completely blocked screens. This provides an additional safety factor to that provided by torque limiting clutches.

Screens are normally cleaned by water jets washing debris off the screens into a trash channel as shown in Figure 5.1. The trash channel will discharge to a rubbish pit hopper from which clear water will be recirculated and the rubbish discharged to landfill waste, or in some cases back into the sea, depending upon the local situation.

In Algeria in 1986 15 tonnes of bitumen were spilt close to a power station cooling water intake. Much of the bitumen went into the intake and blocked the drum screens, burning out the drive motors and shutting the plant for a short time. If these screens had been fitted with torque limiting clutches or been designed to withstand the full hydraulic head when blocked, the incident would have been of a less serious nature and the clean up would have been easier.

Consultations with utility operators and with drum and band screen manufacturers have not identified any incidents except the Algerian case where tar balls or other oil pollution products have reportedly blocked or damaged screens, and there are no reported modifications carried out to the normal screen washing facilities described above. This might indicate that either tar balls have been taken out by booms upstream of the screens or by amalgamation with other trash on raked screens upstream of the drum screens, a screen configuration often used in UK conditions in large power stations. Other possibilities are that early shutdown of plant in pollution incidents and diversion of the pollutant has been effective in avoiding the problem, or that the designs of washing equipment are adequate to cope with such a problem.

Washing systems for screens fall into two categories, one of which involves high velocity washing jets with relatively low wash water requirement, the other using a lower jet velocity but larger quantities of wash water and relying on the mass of wash water for cleaning action. Should tar ball build-up on the screens prove a potential problem under closer investigation, since there are generally large volumes of hot water available at these utilities, consideration should be given to using high temperature wash waters for emergency cleaning.

5.2 Heat Exchangers

Discussions with users of sea water for cooling have revealed that plant is normally shut down when an incident resulting in large scale oil pollution of sea water has occurred. When only minor pollution has occurred the user is often unaware of the problem and has not been meticulous in attempting to measure the effects of pollution on heat transfer efficiency.

In Chapter 3 a fairly detailed analysis has been presented and data on overall heat transfer coefficients (U), film coefficients (h) and fouling factors are presented. The data are based upon the experience which exists in the heating and cooling of oils in the petroleum industry and does not directly relate to the handling of a contaminated sea water. Some engineering judgement is therefore necessary in attempting to relate such data to the pollution situation.

Clearly the magnitude of the effects of oil pollution upon heat transfer are dependent upon the type of oil and the degree of weathering experience between the time of the oil spill and abstraction.

Light oils have a lower viscosity and hence are more readily 'washed' from heat transfer surfaces. In contrast tar will tend to stick to surfaces and create more significant effects.

In order to attempt to quantify effects, data from Chapter 3 are repeated below for condensers:

TABLE 5.1

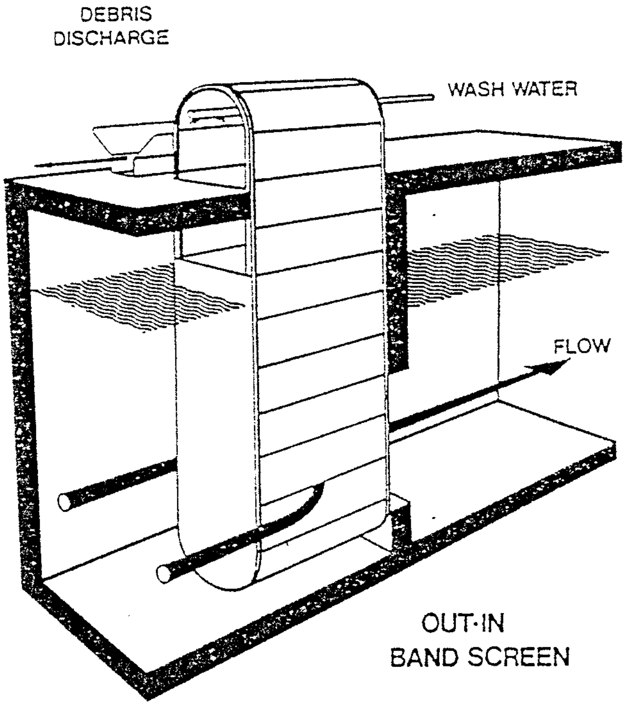
Typical Heat Transfer Coefficient Condensers

Media	Typical U Range	Mean
Steam/water	250 - 750	500
Steam/light oil	50 - 150	100
Steam/heavy oil	10 - 80	45

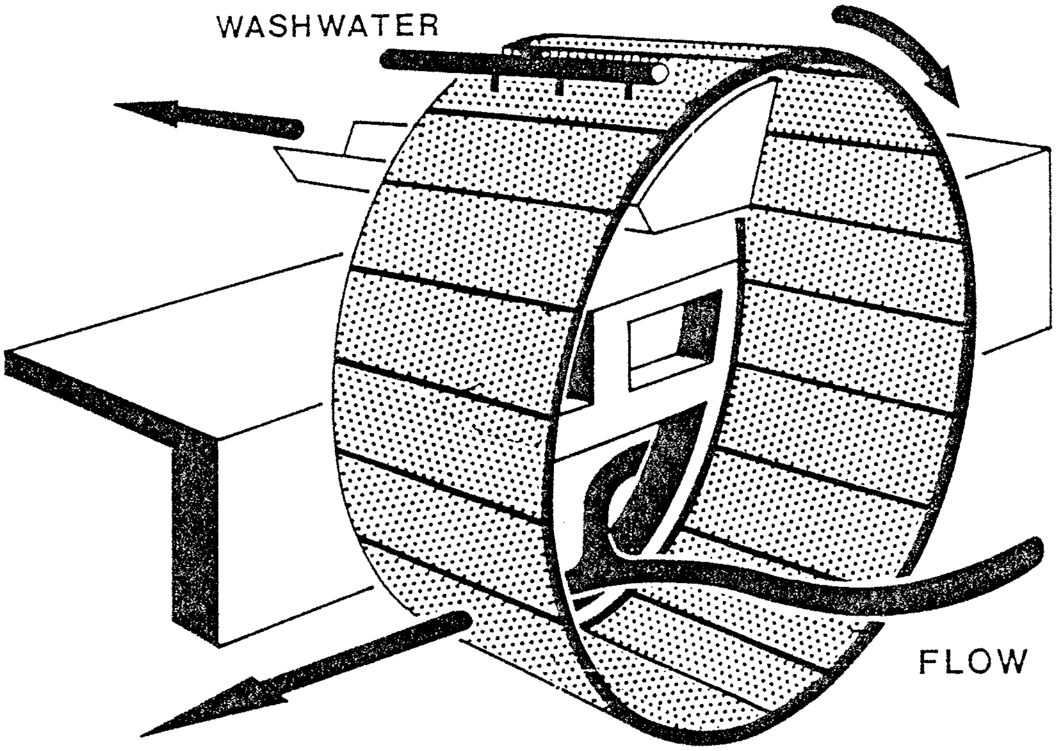
Figure 5.1

Drum and Band Screens

(a) Band Screens.



(b) Drum Screens.



These data relate to the heating of water, light and heavy oils by steam where the whole of the tube side flow is water or oil as indicated. The reductions of U for water contaminated by unweathered oil are likely to be less than those indicated unless highly viscous weathered oils are involved. In the section below the effects of reductions in heat transfer coefficient are examined.

The likely range of effects are judged to be reductions in U of 0 to 50% for light oils and 0 to 70% for heavy oils.

Values of heat transfer coefficients considered are as follows:

TABLE 5.2

Possible Effects of Pollution on Heat Transfer

		Heat transfer coefficient
Clean steam/water		500
Steam/water-light oil	(a)	400
	(b)	250
Steam-heavy oil	(a)	325
	(b)	150

In the case of a power station designed for clean water use the effect of reduced heat transfer efficiency is for the steam condensing temperature to rise.

For the example quoted in Chapter 3 where steam condenses at 38.7°C and the cooling water temperature rises from 15°C to 28.7°C the log mean temperature difference (ΔTm) can be calculated by equation (3.10) to be 15.9°C.

Heat transfer is defined as follows:

$$Q = U A \Delta Tm$$

Hence $Q = 500 A.15.9 \times 1.8$

Hence $A = 0.00007 Q$

In order to handle the same heat load with the lower heat transfer rates the ΔTm must rise.

$$\Delta Tm = \frac{14\ 300}{U\ 1.8}$$

Thus for the four heat transfer conditions quoted above the condensing temperature will be as shown below.

TABLE 5.3

Possible Effects of Pollution on Power Generation

	U	ΔTm	ΔTs	Loss power (%)
Steam/water	500	15.9	38.7	0
Steam/water-light oil	400	19.9	43	2.5
	250	31.9	54	12.0
Steam/water-heavy oil	325	24.5	47	4.5
	150	53.0	75	16.5

The percentage loss in generated power for the case where turbines are fed with steam at 100 bar pressure and 500°C with a normal turbine efficiency of 80% is also shown.

It can be seen that losses are high if the condensing temperature rises much above 45°C.

These reductions are those to be expected if significant quantities of unweathered oils are present in the cooling water. It is not possible without experimental work to predict the effect of oil concentrations upon performance deterioration but due to the relatively high viscosities of all but very light oils such deterioration in performance is to be expected if as little as a few 100 mg/l of free oil is present in the water.

As stated above the presence of highly viscous weathered oils, emulsified oils or tar balls is likely to be catastrophic with irreversible fouling and blocking of heat exchange surfaces.

It is no doubt the fear of such conditions which leads operators to shut plant down when major risks occur and this explains the lack of information on practically measured effects.

In the case of process coolers of the liquid/liquid type, it is not possible to quantify loss of efficiency without reference to the specific process. It is, however, possible to describe the inefficiency in terms of additional heat exchange surface required due to lower heat transfer coefficients since the heat transfer area required is inversely proportional to the overall heat transfer coefficient.

Reference to Coulson and Richardson shows average heat transfer coefficients as tabulated below. The corresponding size of cooler required for each case is shown by reference to the area for water/water exchangers.

TABLE 5.4

Additional Heat Transfer Area Requirements to Maintain Performance with Severe Pollution

	U	Area
Water/water	225	1
Water/light oil	110	2.05
Water/heavy oil	30	7.5
Water/water-light oil		
(a) 20% deterioration	180	1.25
(b) 50% deterioration	112.5	2.0
Water/water-heavy oil		
(a) 30%	158	1.4
(b) 70%	68	3.3

It should be noted that the above effects involve a judgement as to the possible effects of heat transfer deterioration due to severe pollution of cooling water with oils.

The lack of convincing data as to measured effects would indicate that some experimental work is justified to quantify the effects for different concentrations and types of oils.

5.3 Sea Water Distillation Plant

5.3.1 General

The effects of oil pollution on the performance of distillation plant are two-fold:

(i) Heat transfer performance deteriorates.

(ii) Volatile components are distilled in the flash chambers and are condensed in the distillate.

No evidence exists of the practical effects of attempting to distil heavily polluted sea water. On occasions when oil slicks have approached distillation facilities the plants have been closed down. This policy is adopted for good reason since it is quite likely that the output of a plant could be seriously affected and the necessary cleaning programmes could well be protracted in view of the vast areas of tubes involved. In the case of light pollution loads where unweathered light oils are present at up to about 50 mg/l in sea water abstracted the heat transfer problems are not believed to be very severe but the carry-over of volatile matter causes taste problems in the drinking water.

As in the case of power and industrial heat exchangers, the potential decline in performance is related to deterioration in heat transfer performance and is presented below so that an understanding of the factors can be obtained.

5.3.2 Heat Transfer Fouling

The following approximate expression is useful in presenting an understanding of the effects of heat transfer deterioration in flash evaporators:

$$M_d = \frac{A\ U\ \Delta T_T}{n\ \lambda \ln\left[\frac{n}{n-R}\right]} \qquad (5.1)$$

where M_d = distillate production rate

A = heat transfer area

U = average heat transfer coefficient

ΔT_T = Flashing temperature range

λ = average latent heat of steam over flashing temperature range

n = number of stages

R = performance ratio (production rate/feed steam rate).

For a typical case:

U = 600 Btu/h/ft^2/°F

ΔT_T = 64°C = 115°F

λ = 1 000 Btu/lb

Values of U and R are optimised for a particular case; but, for the sake of example, 25 stages and a performance ratio of 10 will be considered.

For a 10 000 m^3/d plant the heat transfer area can be shown to be about 19 000 m^2. This is equivalent to 196 miles of $\frac{1}{4}$ in. tubing.

If allowance is made at the design stage for oil fouling by the installation of additional heat transfer area, a 20% reduction in the design value of U would create the need for an additional 50 miles of tubing.

If one considers a normally designed plant and then evaluates the reduction in performance with a 20% fall in heat transfer rates the matter is rather more complex.

The output could almost be maintained if more steam is used.

First the effect on the flashing temperature range will be examined. In order to reject the required quantity of heat with a lower heat transfer coefficient the temperature difference across the heat rejection condensers must be increased.

A typical ΔT_m of 10°C would rise to 12.5°C and hence the flashing range ΔT_T would be cut by 2.5°C. Similarly in the brine heater a typical ΔT_m of 10% would again rise to 12.5°C. Hence the total effect on the flashing temperature range would be a reduction of 5°C which would inevitably lead to an 8% reduction in output.

The performance ratio (R) of the works would fall.

R = product output per unit feed steam

$$R = \frac{\lambda s\,(1 - e^{-a})}{\Phi t + \alpha + \Delta T_x} \qquad (5.2)$$

where λs = latent heat of feed steam = 950 Btu/lb

Φt = terminal temperature difference in heat recovery section

λ = irreversible temperature losses = 1.4°C

ΔT_x = interstage temperature difference = 2.56°C

a = $\Delta T_T/\lambda$ = 0.115

Solving the above equation for R = 10 shows Φt to be 1.8°C (3.25°F).

The log mean temperature difference in the heat recovery section with clean brine will be 2.9°C (5.22°F).

With a 20% reduction in the overall heat transfer coefficient in the heat recovery section the ΔTm will rise from 2.9° to 3.6°C (6.5°F). This in turn will increase the heat load on the brine heater by the factor (3.6 + 1.4 + 2.56)/(2.9 + 1.4 + 2.56), i.e. by a factor of 1.10 and create an increase in the steam feed of 10%.

In summary, therefore, if oil pollution reduced the heat transfer coefficients in a sea water evaporator by 20% the following effects would be expected:

(i) The output would fall by 8%.

(ii) The energy input would rise by 10%.

If these effects were related to the costs of water from the dual purpose installation costed in Table 3.1, the water cost would rise from 92.6 to 100.3 p/m^3: a rise of 8.3%.

In a 10 000 m^3/d installation this would amount to £5 400 per week and of course subsequent cleaning operations would create additional costs.

In practice the effects would be more serious than this if viscous weathered oils were allowed to enter the evaporators.

5.3.3 Taste Problems

When sea water contaminated with volatile components is fed into a sea water distillation plant, parts of the volatile constituents are evaporated and pass with vapourising steam into the condensers. Then they will be condensed and will form part of the product water stream.

The degree of carry-over depends upon the volatility of the particular chemical.

In the case of multi-stage flash distillation evaporators, the evaporation of the constituent occurs stage by stage. The degree of evaporation for benzene and toluene which are both soluble in water, has been calculated by a stage-by-stage calculation.

The same effect will occur if insoluble oils are present with water entering a plant, in that steam stripping of the components will occur. A simplified approximate calculation has been carried out to determine the concentration of a range of hydrocarbons in the distilled product water. Results are presented in Table 5.5.

The concentrations of individual hydrocarbons in distillate from an MSF evaporator when the concentration of the individual component in the feed water is 1 mg/l has been plotted as a function of boiling point in Figure 5.2. It can be seen that a linear relationship exists between log concentration and boiling point and this is almost independent of the class of hydrocarbon present.

TABLE 5.5

Concentrations of Specific Hydrocarbons which will Appear in Distillate of MSF Evaporator with a Concentration in the Feed of 1 mg/l

Chemical	Molecular weight	Boiling point (°C)	Concentration in distillate (mg/l)	Solubility (mg/l)
Paraffins				
Octane	114	126	0.53	20
Decane	142	174	0.09	i
Dodecane	170	216	0.02	i
Pentadecane	212	271	0.003	i
Aromatics				
Benzene	78	80	1.5	700
Toluene	92	111	0.9	500
Xylene	106	144	0.3	i
Ethyl benzene	106	136	0.4	100
Trimethyl benzene	120	165	0.1	i
Cyclohexane	84	80	2.5	i
Naphthalene	130	218	0.02	30

As one would expect, constituents with boiling points less than that of water concentrate in a flash evaporator whilst constituents with higher boiling points appear in the distillate at lower than the feed concentrations.

It is useful to attempt to put these results into context. To establish precisely the significance of particular constituents which will carry-over under practical conditions one needs to know the concentrations entering an evaporator and the health effects of the constituent found in the distillate.

No particular levels are quoted for paraffins in the various drinking water standards other than the general requirement that no free oil shall be present.

Standards are, however, set for benzene and lower alkylbenzenes which include toluene, xylene, ethyl benzene and trimethyl benzene.

Exposure to benzene causes aplastic anaemia, a ~~fatal disease, and there is~~ concern regarding association between the occupational exposure to benzene and leukaemia. This has led to the categorisation of benzene as a carcinogen by a working group convened by the International Agency for Research on Cancer.

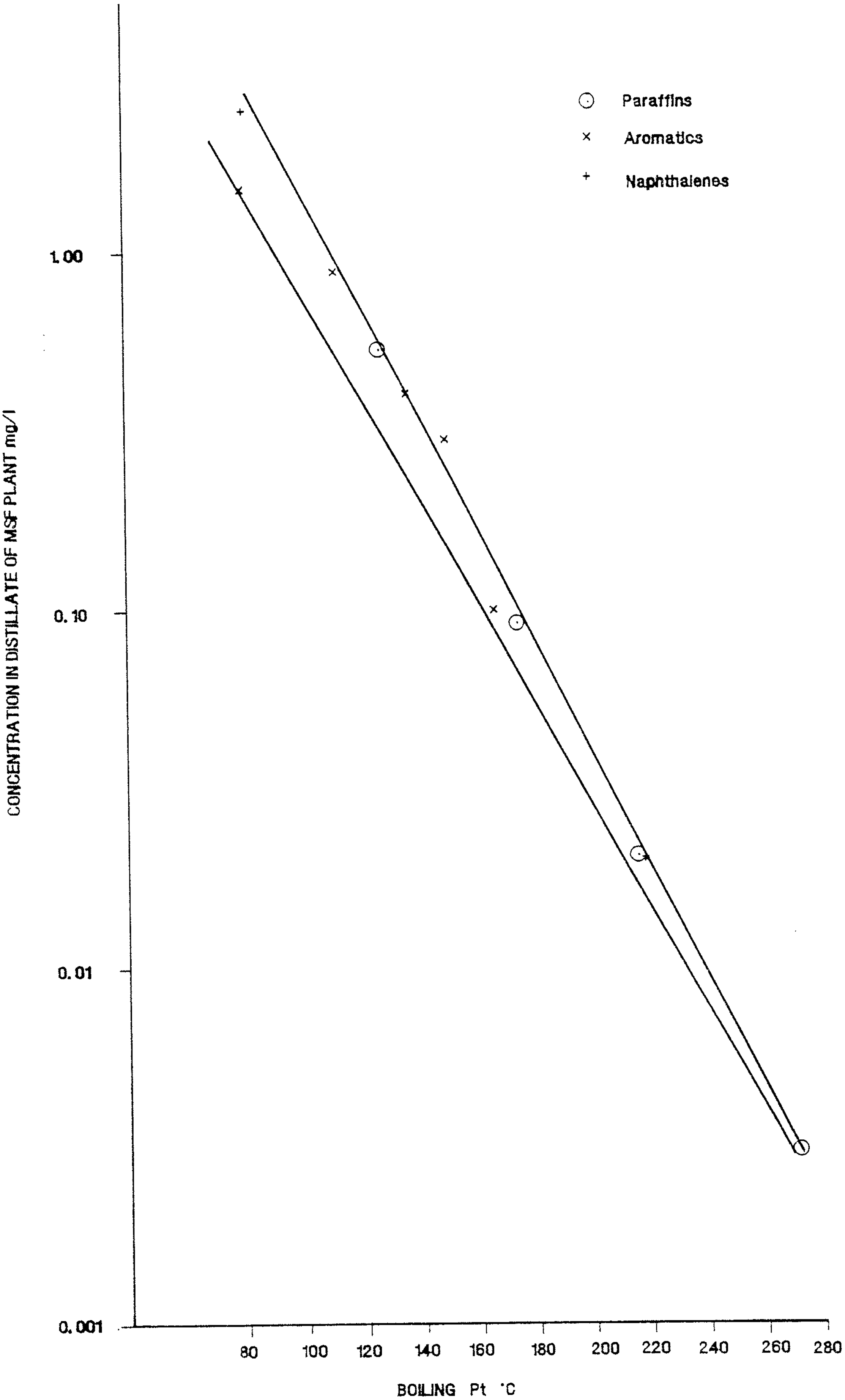
Toluene adversely affects the central nervous system but does not appear to be carcinogenic. No guideline level has been set for tolerance but a 10 µg/l guideline level has been set for benzene.

This implies that the concentration of benzene in the feed to an evaporator should be kept below 6.6 µg/l = 0.0066 mg/l.

The solubility of benzene in water is 700 mg/l but exposure of water to air under turbulent wave conditions will mean that in practice levels are very much lower than this. The World Health Organization (WHO) in their 1984 Guidelines

Figure 5.2

Concentration of Hydrocarbons in Distillate of MSF Plant with 1mg/l Feed Concentration



for Drinking Water Quality quote a half life of 37.3 minutes for benzene in surface waters at 25°C. This implies that benzene would be evaporated to a level of 0.066 mg/l in 8.3 hours. It also implies that there is unlikely to be a problem with benzene in most cases but with a combined current wind effect of 0.5 m/s contamination could still cover some 15 km in 8.3 hours and hence some risk of excessive contamination could occur.

Polynuclear aromatic hydrocarbons (PAH) are a large group of organic compounds which contain two or more benzene rings. They include naphthalene, anthracene and fluoranthene. They are relatively insoluble in water and are readily adsorbed on to particulates in water.

PAH have been found to cause skin tumours and mutagenicity in bacterial systems. The individual chemicals are seldom found singly and interactions have been found to occur which increase the potency of the constituents. The WHO 1974/71 standards set at limit of 0.2 µg/l for the total of six PAH in drinking water. These indicator PAH were fluoranthene, benzopyrene, benzoperylene, benzo fluoranthene (b), benzo fluoranthene (k), and indopyrene.

The 1984 WHO guideline was set at 0.010 µg/l for benzo (a) pyrene.

Conventional treatment of river waters to remove turbidity is sufficient to ensure adequate removal of PAH.

Sea water distillate is not treated for suspended solids (turbidity) removal and therefore some risk of contamination from oil spills will occur.

As can be seen from Table 5.5 the quantity of naphthalene which will pass to the product water is only about 2% of that fed to an evaporator but at the very low levels of PAH acceptable for drinking water it would only need some 10 µg/l of PAH in the feed water to exceed the 1971 standards. Whilst the PAH are relatively insoluble the presence of small quantities of insoluble oils may be sufficient to cause these limits to be exceeded.

In preparing drinking water quality standards the levels are set based upon the health effects which result from continuous long term exposure to the contaminants. Where such contamination is of an intermittent nature, as in the case of oil spills where, at the worst, exposure is only likely to be for a few days per year, exposure to levels of 10 to 100 times the values set in the standards is unlikely to cause problems.

Whilst it is not possible to reliably quantify acceptable levels for such short duration exposures it would be unrealistic to attempt to maintain the very low levels called for in continuously supplied drinking water.

The full effects of oils in sea water intakes cannot at present be quantified due to lack of knowledge as to the presence and concentrations of specific components which may be present following various stages of degradation/ dispersion of oils.

In view of this lack of knowledge it is not surprising that plant operators are concerned about pollution from oil spills and tend to shut down evaporators when there is a serious risk of spills.

In the course of our enquiries, no direct evidence has been collected to establish quantitatively the pollution of distillate by organics although unquantified tastes and odours have been referred to following chlorination of distillate.

In later sections various measures are considered for the reduction or elimination of such problems.

5.4 Reverse Osmosis Desalination

As explained in Chapter 3, water passes through reverse osmosis (RO) membranes whilst the flow of dissolved constituents through the membrane is very much slower. Hence in terms of desalination some 99% of dissolved inorganic ions are rejected by normal sea water membranes.

The performance of such membranes in the treatment of organic constituents is poorly documented despite the fact that the processes have been used in the concentration of alcohols and fruit juices. In general, the data available relate to a limited range of water soluble compounds and no data have been identified to indicate performance with insoluble hydrocarbons.

However, the general behaviour of membranes is a useful indication of likely performance.

In general, it is found that high molecular weight organics are highly rejected. If an oil, immiscible with water, was fed with sea water into an RO system one would expect to see some passage of light fractions through the membrane and the more viscous higher molecular weight fractions retained by the membrane. This would create an oil boundary layer at the membrane surface which would blind the surface and limit the flow of water. This is apparently what happened at the Jeddah sea water reverse osmosis plant. Whilst no details are available, private communications with staff who were operating the works at the time, revealed that oil entered the sea water intake on a number of occasions. No heavy oils were present but a thin layer of light fractions was seen to be present in the feed water. Despite pretreatment by sand filtration, oil entered the RO units and membranes became fouled. The output of the works fell rapidly to about 50% of the design value. However the membranes did not have to be replaced. After removal from service and repeated washing with sodium tripolyphosphate the performance completely recovered.

On occasions when large spills were observed, the plant was shut down in advance in order to avoid problems.

A secondary factor gives cause or concern when handling organic materials. If the materials are readily biodegradable bacterial colonies can become established within the membrane system and these can attack the membrane materials. Whilst such problems can be overcome by the use of bactericides, precautions may be necessary in the event of oil spills.

Clearly the entry of viscous oils or tars into an RO plant will cause problems. Tar balls will be removed in pretreatment plant as will the majority of oils but nevertheless some oil may be expected to penetrate the sand filters.

BP has developed a process for treatment of oily refinery wastes. This involves filtration through beds of conventionally sized sand. Filter cleaning is by means of air scour and backwashing with water heated to an approriate temperature. It is, however, notable that 3 to 5 mg/l of oils are reported to pass through such filters with feed oil concentrations of 50 to 200 mg/l.

All of the evidence therefore points to the possibility of some oils passing through pretreatment filters. This is even more likely in cases where pretreatment filters are designed at very high ratings as is the case at many works. Often filtration rates of 15 to 18 m/h are used, compared with rates of 6 to 10 m/h in conventional water treatment filters.

The feed water to a 46 000 m^3/d RO plant at Ras Abu Jarjur, Bahrain, is drawn from groundwater. The sea is interconnected to the particular aquifer and the feed water quality will be initially dominated by the quality of aquifer water but will eventually approach that of sea water as more sea water enters the system due to increases in aquifer drawdown.

It is notable that this plant includes pretreatment both by rapid gravity filtration and by activated carbon adsorption. The reason for inclusion of activated carbon adsorption is that oils have been detected in the groundwater. These oils, however, do not arise from spillages at sea but rather because for many years wastewater from the refinery has been discharged to deep groundwater. Due to the large number of wells on the island, which are not grouted as they pass through the water-bearing strata, it is possible, indeed likely, that oil contaminated water can be fed to the desalination plant.

The specification for these works, prepared by VBB Consulting Engineers, calls for the works to cater for up to 10 mg/l of soluble oils. The works were supplied and constructed by Sasakura Engineering of Japan.

These data have been presented in some detail since they represent possibly the only fully designed/engineered approach to reverse osmosis desalination of water contaminated by soluble oils.

Clearly such an approach could be adopted to any beach well type intake with great confidence and indeed following physical protective measures could be applied to surface abstractions.

Major reverse osmosis membrane manufacturers have been contacted with regard to the effects of oils upon their membrane systems.

Both Dupont and Film Tech, the two largest sea water membrane suppliers state that immiscible oils have a disastrous effect on membrane performance and that their guarantees of performance become null and void if any immiscible oils are present in the feed water to the membrane systems. No quantified evidence has been presented to show the effects of oil contamination but experiences, such as that referred to above for the Jeddah works, are sufficient for the manufacturers to take this action.

CHAPTER 6

PROTECTIVE MEASURES

6.1 Introduction

Various measures have been adopted for the protection of cooling and desalination installations from the effects of oil pollution. The overall emphasis has so far been placed upon the protection of sea water intakes from pollution by the use of such techniques as booms, bubble barriers and screens. Far less attention has been paid to the use of on-shore facilities, mainly because they are much more expensive and their effectiveness has not been fully tested or evaluated.

In this section information collected from questionnaires and our visit to Arabian Gulf installations is presented together with the expected performances of on-shore protective measures. In the latter respect, the technical processes and their likely efficiencies are developed from use in situations other than sea water pollution. The data presented must therefore be considered as somewhat speculative rather than positively proven. Nevertheless the ideas presented may prompt owners or designers to consider in more detail protective measures which could be adopted.

The problems in considering protective measures centre on the wide range of forms in which the pollution could appear at the intake. For example:

(i) weathered oils can be presented as highly viscous floating liquids or floating or settling tar balls;

(ii) refined products can have low viscosity and be highly volatile;

(iii) certain toxic components can be present in a soluble form.

This range of forms renders no single type of protection effective in all cases, and therefore, for full protection a range of protective measures is necessary.

In considering protective measures this section is divided into two basic parts:

(i) Sea Intake Measures

These include dispersion of oils at sea, the use of floating booms with and without net skirts, bubble barriers, design of intakes.

(ii) On-shore Measures

These include the use of gravity oil separators, coagulation and flotation, filtration, activated carbon adsorption, plant design modifications.

In designing any system of sea intake protective measures, it is necessary first of all to establish the probability of oil spillage affecting a particular intake. In the case of intakes near to or within a harbour the oil spill risk is high, as most spills occur during routine operations of loading, discharging and ballasting (70% of spills), and bunkering (11%). Most of the spills occurring at berths are small, less than 50 m^3, and 73% of reported spills during the period 1974 to 1979 were of less than 1 m^3 (ITOPF).

The other two main factors involved in assessing risk in a particular location are the oil behaviour (discussed in Chapter 2) and the direction of movement of the spillage, which is governed by wind, wave and current effects at the sea surface.

Intakes sited in a critical hydrometeorological situation relative to main shipping channels are also particularly subject to risk from large spills resulting from a major navigational accident.

Following the identification of the extent and nature of the risks, consideration can be given to the types of protection to be provided. These will be considered under four categories as follows:

- chemical dispersion;
- physical containment upstream of the intake;
- physical containment upstream of the intake pumps;
- design of the intake to minimise pollution effects.

6.2 Chemical Dispersion

The mechanics and chemistry of dispersion at sea are generally well documented elsewhere, and have been summarised in Chapter 2. The natural dispersion of oil slicks can be assisted by the addition of chemical dispersants, particularly in the early stages of a spillage event. These dispersants break down the oil into small droplets, which increases the rate of which the slick can be dispersed by hydrometeorological effects, and by biodegradation and volatility effects.

However, particular considerations apply to the use of chemical dispersants adjacent to an intake, and what are beneficial effects on an oil slick in the open sea, are disadvantageous adjacent to an intake. A compact oil slick can be contained by booms or bubble barriers or other types of controlling barrier, and collected by skimmers or other collection machinery for disposal. Breaking up an oil slick in this situation by chemical dispersants will only produce an uncontrollable mass of emulsified material, some of which is bound to enter the intake and the plant with consequential deleterious effects.

Thus it is recommended that chemical dispersants not be used in or immediately adjacent to sea water intakes.

The UK Government Warren Spring laboratory has a list of approved chemical dispersants for use in dispersing oil spillage. These dispersants are approved as practically non-toxic to marine life, and if spills are being dealt with by experienced people, no problems of product water quality should be expected.

However, there are a number of industrial degreasants on the market which are toxic, and in an emergency situation responded to by unexperienced people, there may be some risk of toxic materials being used, with subsequent risk of a toxic product water, and thus any use of chemical dispersants should be checked to confirm that products from the approved list only are used.

6.3 Booms - General

Physical containment systems fall into two categories, floating booms and bubble barriers. There are many different types of design and materials produced, but the principle of operation is the same in every case, to contain the oil slick so that it can be physically collected and safely disposed of. Adsorbent floating booms are also available which are useful in situations where it is difficult to move in collection machinery and only small quantities of oil are present.

In the case of intakes the prime objective is to exclude the oil slick from the intake, collection or dispersion being only a second consideration.

Booms have generally proved of useful effect in service in a number of spill events. There are a number of different types of booms available on the market, and in emergencies booms comprising SBM floating hoses or similar materials are sometimes used.

In its simplest form a protective boom may be regarded as a floating fence supported by one or more buoyancy units. For present purposes only booms designed to deflect oil, rather than to collect it, will be considered.

6.3.1 Fence and Curtain Booms

The 'fence' type of boom presents a vertical screen against the oil floating on the water and may be made of rigid or semi-rigid material. Buoyancy may be provided by plastic-filled compartments or blocks of plastic foam and weights are attached to the base of the screen. The construction of some booms of this type is such that the main component or screen may be rolled up and compactly stored.

The 'curtain' type of boom consists essentially of long and sometimes continuous buoyancy tubes carrying a pendent skirt with chains or other metal weight ballast attached to the base. Such booms are commonly inflated with air before deployment and deflated after use, so that storage space is reduced, but some form of inflation device has to be included as additional equipment.

In order to keep the skirt down in high-current conditions, the ballast weight must be increased and this must be matched by an increase in buoyancy. If the buoyancy tube is of the 'lay-flat' variety more air can be pumped in to restore the initial level of flotation. The submerged portion of a boom may be subjected to high drag forces due to currents; these forces are proportional to the square of the velocity.

Tests have been made in the UK on a number of booms of different types, which have shown that performance of vertical screens is far below that of some of the heavier curtain-type booms. Apart from the increased windage of most vertical-fence booms, they rarely have sufficient buoyancy to overcome their tendancy to dive below the water surface in currents, or if moored from a point near the waterline have sufficient stability to remain vertical. The performance of a curtain boom under similar conditions is much more satisfactory.

These two types of boom constitute at least 80% of all known commercial types.

The floating boom operates on the principle of physically blocking progress of the oil along the surface of the water and it is vulnerable to certain types of failure as indicated in Figure 6.1. Oil can be forced under the boom in conditions where the depth of slick built up by the combined effects of water current and wind exceeds the draught of the boom. It can also be forced under the boom in droplet form when the water current velocity is excessive relative to the oil slick velocity. In this case oil droplets become entrained by the water.

The actual conditions under which these types of failure occur depend on the physical dimensions of the boom, and its behaviour in the hydrometeorological conditions at site. Hydraulic modelling work has been done on examples of booms for particular sites, a project for Yanbu in Saudi Arabia by Delft Hydraulic Laboratories being a particular reference. It is possible to determine design dimensions by modelling techniques in cases where the size and importance of the project justify such expenditure. This particular study also determined that for high viscosity oils drainage failure occurs at a velocity difference between boom and current of greater than 0.15 m/s due to build-up of the oil slick in front of the boom.

The other problem with floating booms is that they do not deal with the problem of tar balls floating at varying depth, which pass beneath the boom, generally to be caught on the band or drum screens of large intakes or passing into the plant if no other measures are taken.

A device frequently used to minimise this particular problem is to suspend nets below the floating booms in order to extend the draught. This is often effective, but care is required to maintain and replace the nets on a regular basis, and there is a risk of the net becoming overloaded by too many tar balls adhering to it, and consequently breaking and going to the bottom. A mesh size 5 mm square has been found to be effective in picking up tar balls, but smaller particles will pass through.

6.3.2 Other Types of Boom

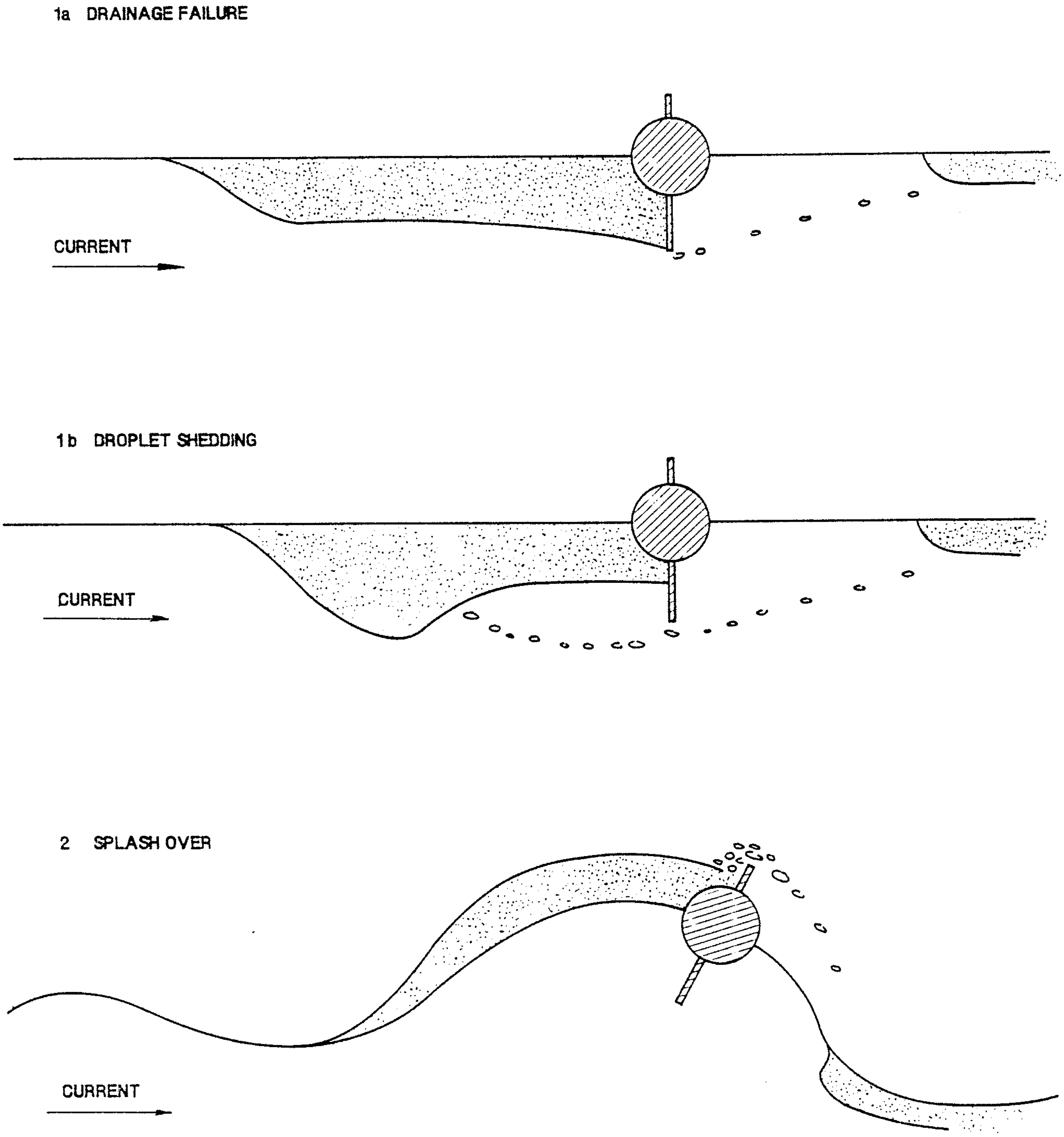
Other types of boom work on the principle of absorbing the oil into oleophilic absorbents. Such materials may be in the form of random-packed plastic capable of absorbing up to 20 times its own weight of oil and contained in sleeves of net or other permeable material. The absorbent units clearly require replacement when saturated with oil, but such disposable units require handling with considerable care to prevent expulsion of oil due to over-compression. Absorbent booms are therefore of restricted value except for limited spills on enclosed waters where complete removal of the floating oil is required.

In the case of a sea water intakes such booms might be expected to have a role as a second or third line of defence where highly vulnerable desalination plants are involved. A simplified form of this type of boom may be made up in an emergency by wrapping quantities of loose straw in a fish net, although this will have limited capacity for absorption and sinks after prolonged use.

A similar device known as the Oil Mop consists of a rope of oleophilic fibres woven into a polypropylene core to form an efficient oil-absorbing device with a density of 0.9. Although primarily designed as a pick-up device, intended to be passed between rollers to expel the oil, it may also be described as a floating absorbent boom.

Figure 6.1

Some Modes of Failure of Oil Containment Barriers



1a DRAINAGE FAILURE

1b DROPLET SHEDDING

2 SPLASH OVER

6.3.3 Design and Construction

An important objective in boom design is to produce a long smooth barrier with the minimum number of protruding appendages and couplings. In practice a compromise has to be reached between convenience of packing and stowing on the one hand and good hydraulic design on the other. For example, long unbroken lengths of tubular boom present less resistance to flow than shorter lengths joined by some means that is convenient to operate, but usually forms an expansion or contraction which in itself hinders the smooth flow along it. If the boom is one long continuous length it is unwieldy to support, handle and repack and it must be broken into sections having smooth connecting pieces at the joints between sections.

Most booms are made of reinforced plastic and some are proofed against the effects of sunlight and oil. Nylon-reinforced neoprene appears to have durable qualities and its long storage life, even when oily, is an essential requirement.

The strength of material used in boom construction is highly important and the couplings and fittings need to have compatible strengths. A boom 300 m long, moored in tidal flow, might be required to withstand a load of several tonnes on its end moorings. If this load is transmitted to the mooring throughout the full length of the boom material there is usually ample strength, but if the points of attachment are reduced to a few separate eye fastenings, then the load is concentrated at the weakest points, and failure can occur.

6.3.4 Air Barriers

A further type of boom is the air barrier, also known as the air curtain or bubble barrier. A perforated pipe layed either on the sea bed or in a shallow trench is used and when air is pumped through this from a suitable compressor a curtain of bubbles rises to the surface. This induces an upward flow of water and owing to the presence of air bubbles results in the sea level rising slightly in a shallow ridge along the line of the curtain. At the same time the upward flow of water spreads out as two horizontal currents at right angles to the line of bubbles. This local current prevents the oil from crossing the barrier. Its effectiveness depends on the amount of air in the curtain and is increased by using small bubbles to keep the rising bubble velocity as small as possible.

The amount of air in the curtain varies between 0.2 and 1.3 m^3/m run of pipe and the air pressure required will clearly depend on the depth of the manifold. The holes are spaced at some 300 mm apart and vary in diameter from 0.5 mm to 0.7 mm according to the depth, the smaller holes being used at the greater depth. This type of barrier is effective in still water, but in currents as low as 0.22 m/s the current can tear droplets from the accumulated oil as is the case with a normal boom. Some of these droplets are swept into the air plume and then move with the surface current onto the wrong side of the barrier, thus transferring the oil. If the air barrier can be placed at a suitable angle to the current, it can be made to operate reasonably well.

Bubble barriers have been developed in various materials and have been installed at a number of locations. Results in use have been variable. In general conditions a bubble barrier will suffer from similar failure modes to a surface boom, the countercurrents set up by the emission of air bubbles shearing off droplets which pass through the barrier in the main current. Bubble barriers appear to be effective only in relatively still waters and currents above about 0.5 m/s and wave motions in excess of about 1 m appear to render them ineffective.

6.3.5 Availability of Oil Booms

Many firms in America, Europe and Japan specialise in the manufacture of booms. Many other firms making rubber and plastic articles, for example hose and inflatables generally can also readily manufacture booms.

Booms are made in a variety of sizes to cope with different spill situations. A small curtain boom with 120 mm inflated tubular flotation unit and a 180 mm skirt is ideal for coping with small spills on calm inland waters. A boom of this type can be light in weight and a man can easily carry a 20 m length.

For more stringent hydraulic conditions, for example, where waves 30 cm to 45 cm in height and currents up to 1 m/s are likely a larger boom having a freeboard of 30 cm to 40 cm and draught of at least 45 cm would be required. The thickness and strength of the material from which such booms are manufactured will depend on whether they are required for permanent or temporary use.

For permanent installation, foam-filled booms are a more appropriate choice than the air-filled version. Unless a heavy boom is required for permanent deployment, it may be conveniently stored in zig-zag fashion on board a raft and this avoids the accumulation of weed growth in the boom and consequent loss of freeboard.

6.3.6 The Limitations of Booms

Although booms have been used successfully, it also has to be recognised that there are probably far more examples of their inadequate use because of oil passing either under or even over them, of booms being carried away by wind and waves and of being completely broken up by the sea. Their placement is a skilled operation which must be carried out with great care.

The ability of a boom to arrest the flow of surface oil is determined mainly by the hydraulic conditions and their physical effect on the barrier. For example, if the water currents are too strong the boom skirt may be deflected upwards sufficiently to allow oil to pass underneath. If the current is at right angles to the boom, oil will start to pass underneath when the flow has reached 0.3 m/s, even when the depth of water is large compared with the depth of the skirt. If the water is shallow, say, only twice the depth of the submerged portion, the speed of the water passing beneath the barrier will be doubled and the limiting velocity in front of the boom will be reduced to 0.15 m/s. Ideally, the depth of water beneath the boom should be at least five times its draught.

Improved boom performance will be possible if it is placed at an angle to the flow. For practical purposes in keeping the total length of the boom required within reasonable limits, the finest angle between the boom and the line of flow should not be less than 14°. The formula $\sin A = 0.3/V_{max}$ may be used to determine the angle the boom makes with the current direction which must not be exceeded. However, as $\sin 14^{\circ} = 0.24$ the maximum current flow must not exceed $0.3/0.24 = 1.2$ m/s.

In order to maintain freeboard and draught in a wave situation, a boom must be flexible. Flexibility and strength tend to be incompatible, so that care in this respect is an essential part of boom design. It has to be accepted that booms are generally not successful in rough waters.

6.3.7 Protection of Intakes

Two typical examples of boom deployment to protect a cooling water intake are shown in Figure 6.2. In the lower sketch the configuration of the intake itself is such as to reduce the water velocity along the outer extremity of the intake and the boom may then be deployed a few metres away where the cross-sectional area is greater. In some cases the cooling water intakes are exposed to long fetches of water and are subjected to considerable wave action. The velocity distribution across the inlet should be measured at low water when the cross-sectional area is least and thus the intake velocities are highest. If possible the boom should be placed some distance away from the intake structure to avoid damage through chafing contact with the piles or screen. The moorings should be of adequate length to allow for tidal rise and fall. A typical configuration is shown in Figure 6.2 in the upper sketch.

6.4 Intake Design

Discussions with various utilities, as detailed in the appendices to this report, have identified a number of common features of intake designs which may be effective in avoiding oil spillage pollution problems.

The first stage of protection would be external to the intake, where consideration should be given to the provision of booms, either permanently deployed in the case of high risk locations, or temporary booms. Adequate duty boats and attendant staff are required. Permanent booms are likely to be cost effective in sheltered locations, but in open water locations the larger sizes of boom required for heavy weather conditions and related anchorage costs are likely to be prohibitive. Regular inspection, cleaning and maintenance is required for permanent booms.

Intakes with approach channels provide the opportunity to deploy a staged boom protection system. For foreshore and offshore intakes, where sea conditions permit, similar staged protection can be provided, as shown in Figure 6.3. This shows the protective layout at Abu Dhabi power and desalination plant, where the booms are deployed sequentially following an alarm signal. The alarm signal is actuated by oil sensors deployed on buoys in advance of the booms. The sensors comprise a membrane and microswitch. The membrane material dissolves in the presence of oil, releasing the microswitch and thus a radio alarm signal.

The bubble-barrier system is started on the alarm signal. Once this is in operation the floating boom is deployed. Within these temporary booms, there is a permanent harbour boom, and the intake is further protected by coarse screens, or settling basin and band screens.

Following the use of sensors and booms, the next stage of protection is simple design measures at the intakes themselves.

Submerged intakes with pillar box type openings, protected by a top beam deep enough to intercept a surface oil slick and to avoid drainage under wave conditions, will limit the ingress of pollutant material.

Top entry intakes can sometimes induce oil by vortexing, and a number of cases have been reported of temporary capping plates being installed successfully during pollution incidents to create safe horizontal intake flow conditions, thus avoiding oil induction. Consideration should be given to designing intakes to function permanently in this manner.

It may often be possible for a small additional cost to provide separate settling basins and/or screen chambers which can be individually isolated for cleaning or provided with temporary nets to intercept tar balls. Providing such separate or additional chambers could assist a more rapid return to operation, the economic implications of this should be considered in detail as part of more detailed studies.

6.5 Gravity Oil Separators

Gravity separators have been in use for many years for the treatment of oily wastes from refinery operations. In principle such units can be used on shore to remove floating oils from water. They are by no means completely effective in that they typically reduce oils to concentrations of 25 to 50 mg/l and they are not designed or intended to cope with settling tar balls. The American Petroleum Institute has issued a manual on 'The disposal of refinery wastes' in which the recommended design of oil/water gravity separators is presented in Chapters 5 and 6.

Whilst circular units can be employed the API design criteria relate to the use of horizontal flow units of the type illustrated in Figure 6.4. The oily waters are normally introduced through trash racks comprising bars at 2.5 cm centres. If such a unit was to be used for treatment of polluted sea water such racks would not be required if installation was downstream of intake screens. Tapered forebays either with separate gates or with facilities for balloon stoppers are included for each separator tank. Water enters each separator through slotted diffuser walls, designed to distribute flow as evenly as possible over the full depth and width of the tank. Tanks are equipped with both sludge scrapers and oil skimmers. Chain or span scrapers move sludge to a discharge hopper at the inlet end of the tank whilst the main skimmers are located at the outlet end. The rotary drum skimmers are the most common type in use for oily waste treatment but, as stated in Chapter 2 these are limited to use with oils of viscosity less than 10 000 cSt. Floating weir oil skimmers are also in use. In all cases an oil baffle board is installed some 300 mm downstream of the skimmer. Skimmers are usually also installed in the forebays to such gravity separators.

Overall sizing of the separators follows the following steps:

(i) Calculation of rise rate, Vt, of droplets based upon specific gravities of oils and sea water, viscosity of sea water and droplet size. Droplets of 0.15 mm are usually adopted as the design criterion.

(ii) Setting of maximum horizontal velocity, Vh, equal to 15 Vt or 54.9 m/h whichever is lowest.

(iii) Calculation of minimum cross-sectional area for flow, width x depth, from Vh and flow and minimum depth to width ratio of 0.3.

(iv) Calculation of plan area (width x length) based upon Vt, a turbulence factor Ft which is a function of Vh/Vt and flow. Ft typically varies between 1.4 and 1.64.

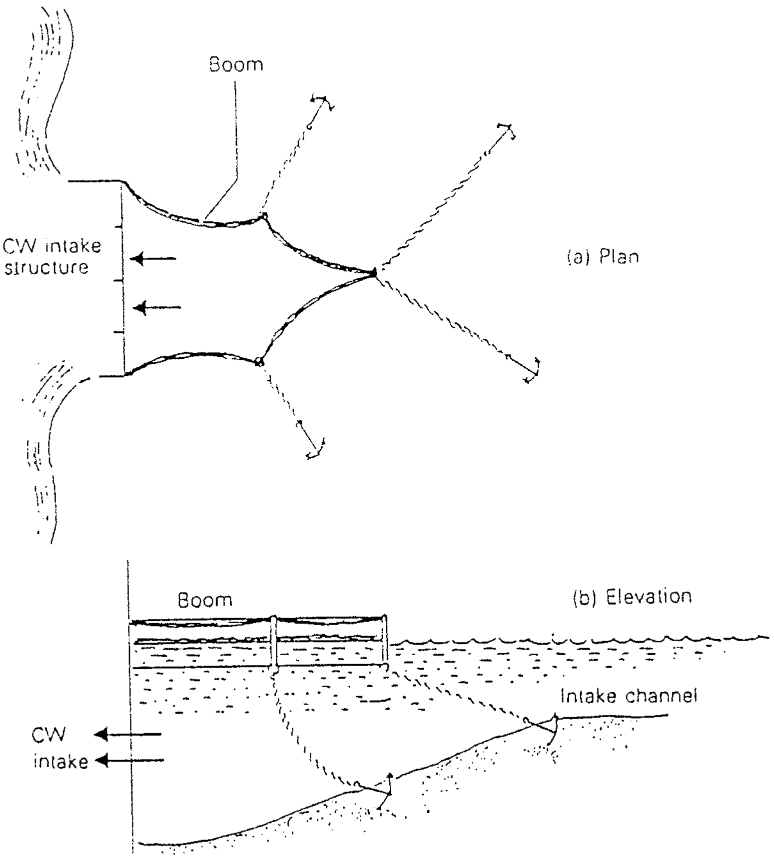
The effect of oil properties upon a separator design is shown in Table 6.1 for 20 to 30° API oils and temperatures ranging from 50 to 90°F.

Taking typical conditions in the Arabian Gulf where many desalination plants are installed, the overall dimensions for a 25° API oil at a sea temperature of 70°F would be as shown in Table 6.2.

Figure 6.2

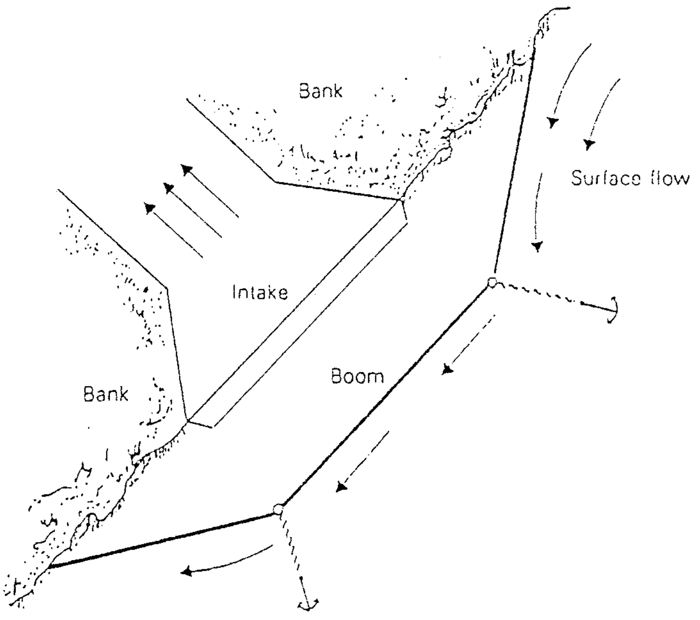
Typical Examples of Boom Deployment

a)



Source: J. Wardley-Smith

b)



Source: J. Wardley-Smith

Figure 6. 3

Protective Layout at Abu Dhabi Desalination Plant

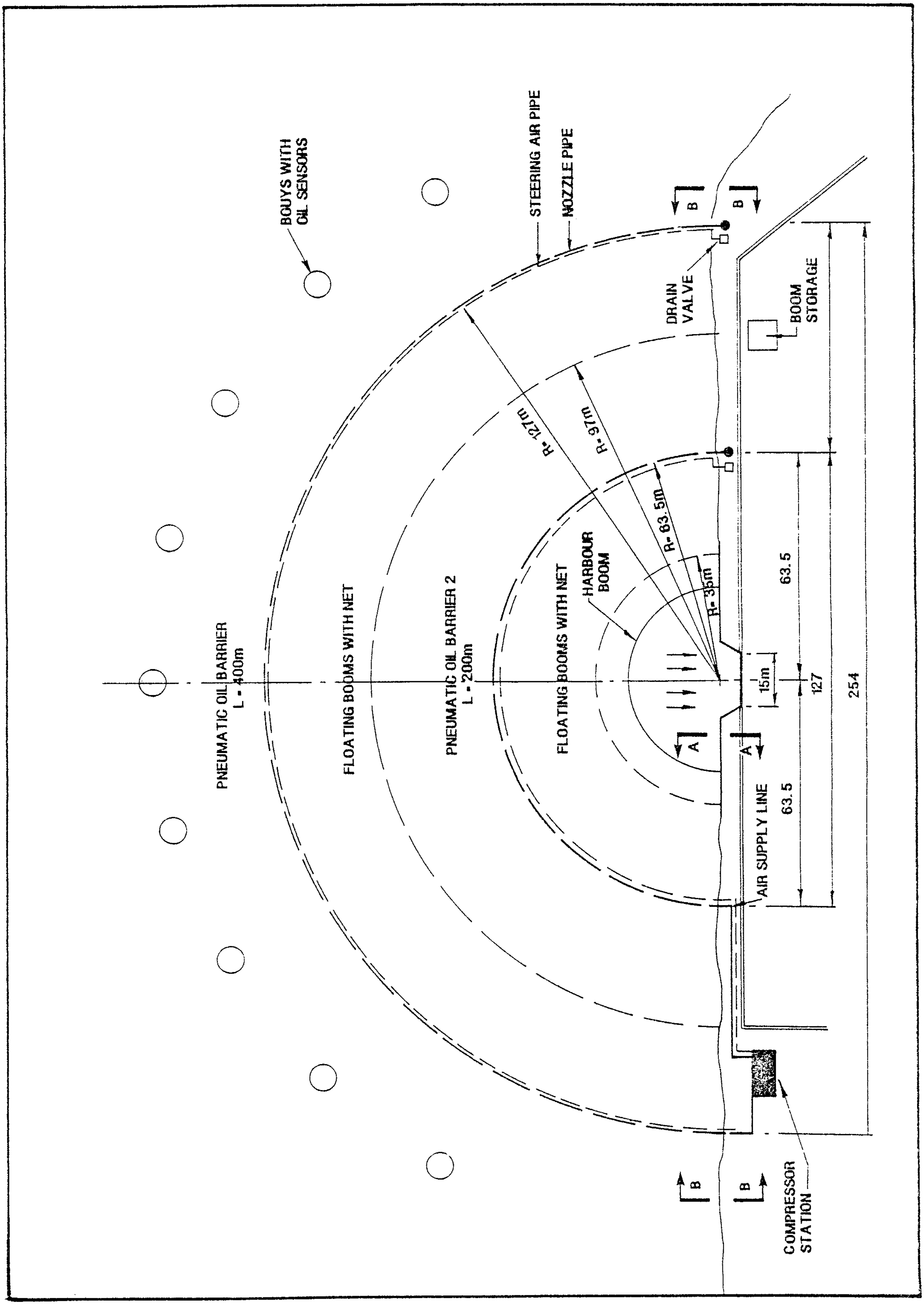


Figure 6. 4

API Oil-Water Separator

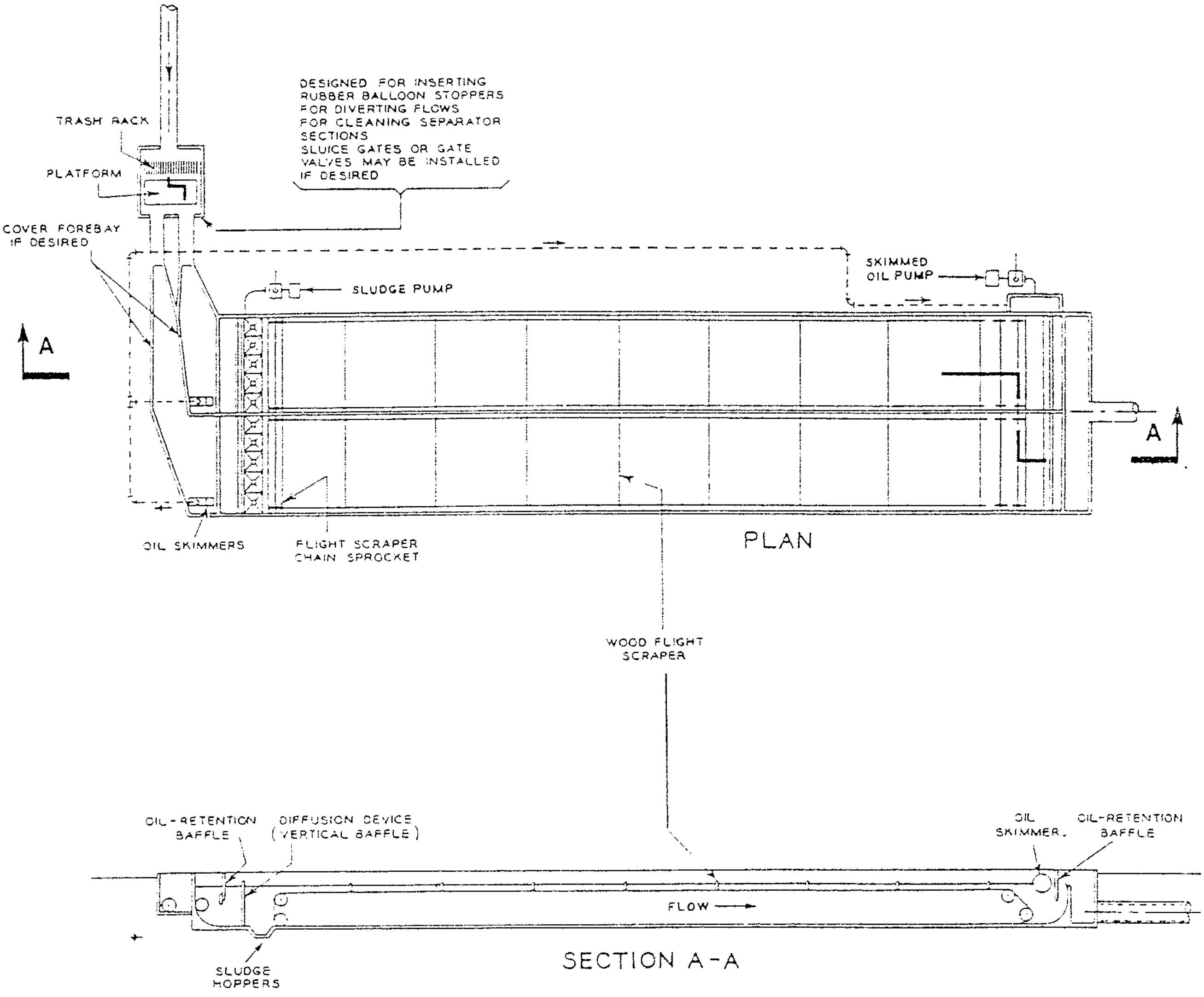


TABLE 6.2

Typical Details of API Gravity Separators for 25° API oil at 70°F

Flow of water (m^3/d)	50 000	500 000
Total plan area (m^2)	615	6 150
Total width x depth (m^2)	38	380
Number of tanks	2	10
Width each (m)	8	11
Depth each (m)	2.4	3.1
Length each (m)	38	56
Volume (m^3)	1 460	19 000
Typical costs (£ million)		
Civil works	0.263	1.70
Plant	0.155	0.76
Total	0.418	2.46

The application of such separators to the onshore treatment of polluted sea water would have a number of limitations:

- Where oils are well weathered and enter a works as a viscous, high specific gravity material modifications would be required. As seen from Table 6.1 with higher density oils larger separators are required and similarly the increased viscosity has a similar effect.

- Alternative forms of skimmer would be required if viscous oils or emulsions are to be handled. It may well be necessary to install screw type oil removal systems.

- Whilst floating and settling components could be removed, tar balls which have a density very close to that of sea water are likely to pass through a gravity separator and therefore one would have to rely on other methods to handle tar balls.

- Units would need to be very large to handle total flows fed to power stations and sea water evaporators. For example a 30 mgd distillation plant (136 000 m^3/d) which is a common size in the Arabian Gulf typically requires about 1 000 000 m^3/d of sea water feed. Separators would cover some 12 000 to 20 000 m^2 and cost £4 to 6 million. In many cases land would not be available. As stated in Section 7.3 MSF evaporators could be designed so that the majority of sea water passes only through the heat rejection section and only 2 x the product rate would pass through the main works. It may be more practical to consider the use of gravity separators for the treatment of this smaller part of the feed.

- Gravity separators are only likely to reduce oil levels to 25 to 50 mg/l. Whilst this would be of great assistance in the event of entry of major quantities of oil into an intake, it is suspected that effective sea protection measures would reduce the need for such treatment to a very short period during a spill.

6.6 Coagulation/Flotation

Coagulation of suspended particles with salts of aluminium or iron is widely used with sedimentation for the treatment of fresh water for drinking use. In this case the particles to be removed have a density significantly greater than water. Where the density of the particles approaches, or is less that of water coagulation and flotation are more appropriate.

Flotation has been used as a treatment for oily wastewaters usually downstream of an API separator. However, there appears to be no case where the process is used as an onshore treatment for oil polluted sea water. This is rather surprising since the process appears to have a number of advantages:

- It is relatively small and compact compared with API gravity separators.
- The capital costs are not excessive and the high operating costs are not a significant disadvantage when the process would be used only rarely when a spill occurs.
- Whilst proven performance does not exist, one would expect the process to be at least partially effective in the removal of small tar particles even if the density is equal to or exceeds that of sea water.

Coagulation and flotation is now widely used in the treatment of oil wastes from refinery operations. The coagulation chemicals required and their doses are strongly influenced by the type of waste treated. At the Saran refinery a Degremont plant treated a waste with 90 mg/l of hydrocarbons to 3 to 5 mg/l hydrocarbon by use of 0.5 mg/l of a polyelectrolyte in combination with ferric chloride. Where aromatics are high (50 to 100 mg/l) performance is not so good with 13 to 20 mg/l of hydrocarbons remaining from a feed containing 110 to 150 mg/l when 100 mg/l of alum and 1 mg/l of an anionic polymer was used.

In general it appears to be possible to achieve hydrocarbon levels of 5 to 15 mg/l by use of this process with flotation rates of 4 to 6 m/h and recycle rates of 15 to 20%.

The process involves two stages:

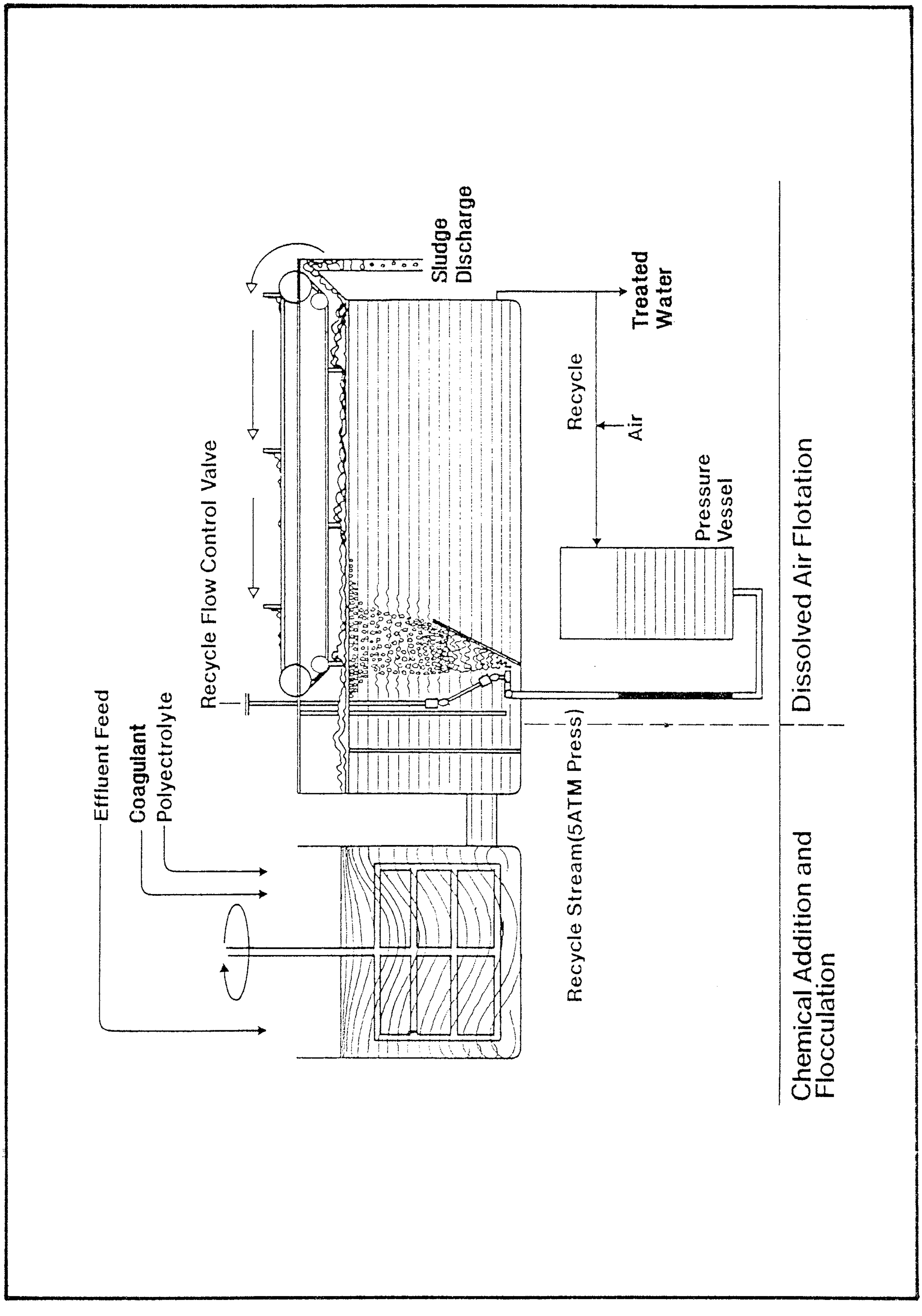
- flocculation
- flotation

Flocculation is best achieved in a chamber with gentle agitation achieved by mechanical or hydraulic mixing. The retention time is temperature-dependent and is likely to be between 5 and 15 minutes. The flotation process is illustrated in Figure 6.5. A portion of the treated water is recycled and fed into a packed column where it is saturated with air at a pressure of about 5 atm. This saturated recycle stream is fed into the water where the pressure is released through valves or purpose designed nozzles so that microbubbles are released. These attach to the coagulated particles and raise sludge to the top of the tank where it is removed by a skimming rake.

In view of the exposure of polluted sea water to wave action the concentration of soluble aromatics in polluted sea water might be low compared with many refinery wastes. It is possible therefore that performance might be at the better end of the refinery treatment range.

Figure 6. 5

Diagram of Dissolved - Air Flotation Plant



Whilst it is not possible without tests to predict coagulation/flotation performance for oil-polluted sea water, approximate cost estimates for flotation plant have been prepared upon the basis of expected design criteria.

Flow of water (m^3/d)	50 000	500 000
Volume of flocculator (m^3)	350	3 500
Overflow rate flotation (m/h)	6	6
Area flotation (m^2)	350	3 500
Depth of flotation (m)	2	2
Recycle rate (15%) (m^3/d)	7 500	75 000
Capital costs (£ million)		
Civil works	0.414	2.90
Plant	0.173	1.80
Total	0.587	4.70

6.7 Rapid Gravity Filters

British Petroleum developed a process for the treatment of oily refinery wastes (I WPC 79, 2, 236-243, 1980) based upon the use of sand filtration. The process is capable of treating wastes with 100 to 150 mg/l of insoluble oils to levels of less than 5 mg/l. By use of polyelectrolytes oil concentrations are normally reduced to 2 to 3 mg/l and often less. Filtration rates normally range from 10 to 20 m/h. Back washing is carried out by air scour and water washing. Hot water is used to assist in the removal of oils from the sand bed.

The use of the process in the treatment of polluted sea water has not been investigated but it is likely to be effective when insoluble oils are in liquid form. Tar balls would foul the surface of the sand bed and might restrict penetration of liquid oils into the bed where it would be held. However, with facilities to backwash with warm water tar balls would probably be removed from the sand bed without causing severe problems.

Approximate costs of the process have been developed based upon the use of a filtration rate of 15 m/h and assuming conventional rapid gravity filtration practice.

Water flow (m^3/d)	50 000	500 000
Number of filters	4	14
Area/filter (m^2)	40	100
Capital cost (£ million)		
Civil works	0.25	1.96
Plant	0.30	1.44
Total	0.55	3.40

6.8 Activated Carbon Adsorption

Activated carbon could be used in two ways in the protection of industrial installations from oil contaminated sea water.

(i) Desalinated water which contains traces of organics can be treated by activated carbon for removal of the organics. In this way taste and odour problems, often associated with chlorinated organics formed after disinfection of the water with chlorine, can be removed.

(ii) Traces of oil remaining in feed water could be removed so that the delivery to reverse osmosis would be essentially oil free. It is in this application that plant was installed for the Bahrain reverse osmosis plant.

Activated Carbon for Taste and Odour Removal

This application requires a retention time of about 5 minutes and under continuous duty a carbon life of about 2 years is normally expected. The regeneration or replacement of activated carbon is a major operating cost under the circumstances. When used as a safeguard against the effects of sea pollution the carbon life may well be extended to 10 to 20 years in which case operating costs become less significant.

Activated carbon is mounted in pressure filter shells with water to be treated passed vertically down through the beds at linear velocities of 10 to 20 m/h.

The typical capital costs of a distillate treatment facility are presented below together with the basic design parameters assumed.

Distillate flow (m^3/d)	50 000	500 000
Number of adsorbers	9	18
Diameter (m)	3	3.6
Carbon depth (m)	3.2	10
Overall depth (m)	5	12
Capital costs (£ million)		
Civil works costs	0.040	0.4
Plant costs	0.450	3.6
Total costs	0.490	4.0

Activated Carbon for Oil Removal

Since the process is relatively expensive it would not be economic to consider its use for cooling water applications but it could be a sensible process for the removal of insoluble oils and the last traces of soluble oils prior to reverse osmosis. In this application a retention time of 20 to 30 minutes would be required. Again carbon would be held in vertical cylindrical shells of the pressure filter type. Design criteria and typical capital costs for this type of use are presented below. When considering these costs it is necessary to take into account that water recovery from reverse osmosis sea water systems is typically only 30% hence the feed water flow is typically 3.3 times the product flow.

Feed water flow (m^3/d)	50 000	500 000
Number of adsorbers	14	70
Diameter (m)	3.6	3.6
Carbon depth (m)	5.0	10
Overall depth (m)	7.0	12
Capital costs (£ million)		
Civil works	0.18	1.2
Plant	1.53	12.2
Total	1.71	13.4

6.9 Distiller Design

6.9.1 Separation of Make-up Water

The sea water feed to MSF distillation plant is typically 7 to 10 times the flow of product water. Most of this water is used solely in the heat rejection section of the plant which typically includes only 10 to 15% of the total heat transfer area. The make-up water flow is only about 2 times that of the product water flow but this passes through the entire heat recovery and brine heater tubing which constitutes the remaining 85 to 90% of the heat transfer surface.

By inexpensive means evaporators could be constructed to keep make-up water and cooling water separate within the plant. This would allow the effects of oil pollution to be limited to the inside of tubes in the heat rejection section of the works if the limited volumes of make-up water required were oil free. For example in sites where flows equal to twice the product flow could be extracted via beach wells or were treated for oil removal by on-shore works such as filtration.

The modifications proposed are illustrated in Figure 3.12. As can be seen water boxes can be constructed to keep make-up water and cooling water separate. With such a design and with protection of the make-up water from oil pollution the effects of oil pollution would be limited to the heat rejection section and the cost of protection/prevention of oil contamination could be limited to the much smaller recycle flow.

6.9.2 Tube Cleaning

It is common practice to incorporate Taprogge into MSF evaporators as a means for removing sludges or scales from the inside of condenser tubing. With Taprogge, foam or abrasive balls are pumped through the tubing as a means of scouring deposits. A similar system is sometimes used in power plant condensers.

During a land based spill of 36 m^3 of fuel oil at the Aabenraa power station in Denmark in 1982 some 27 m^3 of oil entered the condenser of the 600 MW station. The condenser became coated with the heavy fuel oil and the station was immediately shut down. Whilst no quantitative measurements were taken of performance deterioration, the clean-up measures were of interest.

The inlet system was manually cleaned whilst tubes were cleaned by use of rubber balls of the Taprogge type together with the use of a solvent. The station manager states that the clean-up was easier than expected and the cost of clean-up operations was DKr 300 000, equivalent to £26 000.

CHAPTER 7

THE ECONOMICS OF OIL SPILLS AND PROTECTIVE MEASURES

7.1 Introduction

Little information regarding the economic effects of oil spills has come to light from literature searches, from questionnaires issued or from visits to installations in the Arabian Gulf. Seventeen of the major power stations employing sea water for cooling in the UK have been contacted and none of these have experienced the effects of oil pollution of sea water. In the Arabian Gulf there have been a number of oil spills but in no case has oil entered the sea water intakes. In most cases the intakes are favourably located and have been protected from the normal current from north-west to south-east. Sea protection systems have in general coped with small local spills.

7.2 Power Stations

7.2.1 The Costs of Spills

The most useful economic information is that which comes from a land based spill at the Aabenraa power station in Denmark. In this case the 600 MW power station was closed down for a period of 30 hours and cleaning operations, by use of a dispersant, cost £26 000. The loss of power from generation due to plant outage at a rate of 3.365 p/kWh (the cost per unit as quoted by CEGB for 1987) would amount to £485 000 per day for a full output of 600 MW. This would not, however, be the true cost. Where a national grid exists the shutdown of one power station would result in the introduction of a standby station. The CEGB select power stations for operation in accordance with their thermal efficiencies. The 1986/87 year book shows the efficiencies of the top ten stations to range from 35.7% to 37.9% whilst the efficiencies of the older, less efficient stations range typically from 23% to 25%. If one of the higher efficiency stations had to be taken from service and replaced by a low efficiency unit, the efficiency might fall from 36% to 24% in which case 50% more fuel would be required. The cost of such a change at the 600 mW level and with oil at $20 per barrel would amount to £152 000 per day.

In the case of the Aabenraa plant where the shutdown lasted 30 hours and the cleaning cost was £26 000 the total cost of the oil spill would be £216 000 calculated upon the basis described. In the Danish case the total cost was estimated to be £180 000.

7.2.2 The Costs of Sea Protection Systems

The costs of sea intake protection systems can vary enormously according to their complexity. As an example, it is useful to consider the system employed at present by the Water and Electricity Department in Abu Dhabi for the protection of the power station intake. This is quite comprehensive comprising five levels of protection as shown in Figure 6.4. The following are the main features:

(i) Oil sensors permanently mounted on buoys outside of the protection barriers.

(ii) An outer bubble barrier at a radius of 127 m.

(iii) Floating booms with skirt nets at 97 m radius.

(iv) An inner bubble barrier at 63.5 m radius.

(v) A floating boom with skirt nets at 35 m radius.

(vi) An inner harbour boom.

The facilities are served by a compressor station, boom storage and oil skimming and separation facilities.

The intake at the Mina Road power station handles flows of sea water up to 76 000 m^3/h and the cost of the installation in 1983 was about 4.0 million. Abu Dhabi Dh equivalent to £0.70 million. At 1987 prices this is approximately equivalent to £0.85 million.

In Table 7.1 the costs of alternative protections are presented together with a typical penalty for fouling by oil spills.

In studying these figures it must be appreciated that cost estimates are very approximate and also that the protective measures shown are by no means proven and are unlikely to be completely effective. In terms of the effectiveness of the measures shown the following should be taken into account.

Case 1: Intake protection alone. Such protections have been found to be effective for small spills and where weathered oils and tar balls do not create major problems.

Case 2: Intake protection and gravity separators. Where large oil spills occur and are carried to an intake, gravity separators are likely to restrict oil concentrations to about 50 mg/l. However significant, floating tar balls could still cause some problems.

Case 3: Intake protection, gravity separation and flotation. Oil contents are likely to be reduced to 5 to 20 mg/l, however the process is by no means proven.

Case 4: Intake protection, gravity separation, filtration. Oils are likely to be reduced to levels of 2 to 5 mg/l and tar balls eliminated from the power plant. The effectiveness of filter backwashing systems in removing tar from filter beds is not known.

Case 5: Intake protection, filtration. Such a treatment is likely to reduce oils to 2.5 mg/l and remove tar balls when intake protection can keep oil content down to 150 mg/l.

A comparison of costs and penalties shows that the only protection which can be positively justified is the use of sea defences as a means of intake protection. Only when standby power plant is not available would the costs of land based treatment be justified or perhaps in circumstances where there is an unusually high chance of pollution.

TABLE 7.1

Comparison of Costs of the Effects of Oil Pollution with those of Protective Measures (£ million) for 600 MW Power Station Condensers

Approximate costs associated with pollution incident			Costs of protective measures				
4 day outage	8 day outage	Case Nr	Intake protection booms, etc.	Gravity separators	Coagulation flotation	BP filtration	Total
0.634	1.242	1	0.9	-	-	-	0.9
		2	0.9	8.9	-	-	9.8
		3	0.9	8.9	16.9		26.7
		4	0.9	8.9	-	12.2	22.0
		5	0.9	-	-	12.2	13.1

From a comparison of the costs it appears that intake protection followed by the BP filtration process justifies additional study. It is only likely to be in very rare circumstances that the oil content of the filter feed would exceed 150 to 200 mg/l if adequate intake protection is provided. It would therefore be useful to investigate the effectiveness of the BP filter in handling weathered oils and tar balls which pass through screens. It would also be sensible to determine whether hot water or steam jetting is of assistance in prevention of tar balls sticking to screens.

7.3 MSF Distillation

No information has come to light on the deterioration of performance of flash evaporators due to the effects of oil spills. In Section 5.3.2 it was shown that the effects of 20% fouling of heat transfer surface would be to increase the cost of distilled water by 0.08 £/m^3. Thus for an installation of 50 mgd (227 500 m^3/d) the cost penalty would be £18 200 per day plus the cost of cleaning. The cleaning operation would be approximately equivalent to that for a power station and £25 000 has been allowed in comparing costs in Table 7.2. Shutdown for cleaning is likely to be of longer duration than for a surface condenser since manual cleaning is likely to be necessary for the flash chambers. In the comparison of costs of the effects of oil spills with the costs of protection measures. Two separate cases are considered:

(i) Costs to cover the effects of oil spills if a reduced output occurs for one week and cleaning takes 7 days.

(ii) Costs of total water losses associated with 7 days outage plus 7 days for cleaning. In this case costs of fuel for evaporation have not been included since during outage fuel would be saved.

In both cases a 50 mgd (227 500 m^3/d) plant has been considered.

Six different forms of protection have been considered.

Case 1: Intake protection, gravity separators to treat full flow of cooling and make-up water with activated carbon treatment of distillate. By this means oils are likely to be reduced to about 50 mg/l but any tar balls passing screens will enter the plant. Any taste and odours occurring in the distillate would be removed by activated carbon adsorption.

Case 2: Intake protection, gravity separators, coagulation flotation of cooling and make-up water with carbon treatment of distillate.

Oil is likely to be restricted to 5 to 15 mg/l and tar balls could be removed.

Case 3: As above with the BP filtration process used in place of coagulation/filtration. Oils likely to be reduced to 2 to 5 mg/l and tar balls removed.

Case 5: MSF evaporator modified to keep make-up and cooling water separate. Intake protection and gravity separation for the entire feed with filtration limited to make-up water and activated carbon employed for taste and odour control.

TABLE 7.2

Comparison of Costs of the Effects of an Oil Spill with Costs of Preventative Measures (£ million) for 227 500 m^3/d (50 mgd) MSF Evaporator Installation

Costs incurred due to oil spills			Costs of protective measures						
Reduced output and cleaning	Outage and cleaning	Case Nr	Intake protection	MSF design modification	Gravity separators	Coagulation flotation	BP filtration	Act C taste control	Total
		1	0.9	-	9.3	-	-	1.8	12.0
		2	0.9	-	9.3	17.9	-	1.8	29.9
		3	0.9	-	9.3	-	12.9	1.8	24.9
1.29	2.31	4	0.9	-	-	-	12.9	1.8	15.6
		5	0.9	0.36	9.3	-	3.1	1.8	15.5
		6	0.9	0.36	-	-	3.1	1.8	6.2

Case 6: Evaporator modifications as above, intake protection for full flow with filtration limited to evaporator make-up water and activated carbon employed for taste and odour control in the distillate.

Approximate cost estimates of the effects of oil spills on the performance of evaporators and the relative capital costs of preventative measures are presented in Table 7.2.

Again the performances of gravity separators, flotation and the BP filtration processes, as means of cleaning polluted sea water, are not known but rather the likely performances have been assessed by use of engineering judgement with a knowledge of their effectiveness in treating oily refinery wastewaters.

In all cases evaluated the costs of protective measures are small compared with costs of the evaporator installation, approximately £220 million.

It is clear that the costs of intake protection are small compared with the costs of plant outages. However, such measures will not provide protection in the event of heavy spills.

Most of the measures are relatively expensive with costs between £15 and £30 million.

A much more reasonable cost (£6.2 million) is involved if Case 6 is selected. This case refers particularly to new evaporator installations where the plant modifications to separate cooling from make-up water would be minimal. Filtration treatment of make-up water would involve a relatively small cost and in this case any oil fouling would be restricted to the heat rejection section where cleaning is relatively simple and inexpensive.

The inclusion of activated carbon treatment of distillate will eliminate taste and odour problems and allay the fears of those who may be concerned with the health effects of a water which does not meet health standards on the rare occasions of a spill.

It appears to be justified to investigate experimentally the BP filtration process under simulated oil pollution conditions so that a practical knowledge of process performance can be gained.

In areas where beach wells can be used for extraction of sea water it is likely to be sensible to use this as a source of make-up water thereby eliminating the need for filtration and activated carbon treatment while employing sea water from an intake for cooling use.

7.4 Reverse Osmosis

No practical data as to the effects of oils upon reverse osmosis systems have come to light but membrane manufacturers state that more than 1 mg/d would cause major problems. It would therefore be necessary to provide very thorough protection if problems from pollution of sea water feed with oil are to be avoided.

None of the physical treatment processes such as gravity separation, flotation or filtration can be relied upon to consistently reduce oil to such levels. Therefore to be sure of effective protection both filtration and activated carbon treatment would be required. Without such treatment the penalty for pollution is likely to be the complete loss of a membrane system. Bearing in mind that all sea water reverse osmosis systems are preceded by filtration the additional protection involves the installation of the activated carbon system alone. In Table 7.3 the cost of membrane replacement is set against the capital costs of activated carbon adsorption as a guide to the benefit/cost of additional protection.

TABLE 7.3

The Comparison of Costs of Oil Spill Compared with those of Protective Measures (£ million) for 227 500 m^3/d (50 mgd) Reverse Osmosis Installation

Cost of membrane replacement	Cost of protective measures		
	Intake protection	Activated carbon	Total
50	1.4	18.8	20.2

It can be seen that protective measures are well justified as a means of avoiding irreversible membrane fouling. However the costs of activated carbon plant are high and if the subsoil geology is suitable abstraction of sea water from beach wells or underground strata is likely to be economic in cases where the transmissivity of the aquifer is sufficient to make this approach technically feasible. Since a number of reverse osmosis installations are exposed to the risk of pollution, data should be collected on the effects of specific oils on reverse osmosis plant and the effectiveness of cleaning techniques.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

1. Oils transported by sea are of many different types ranging from highly volatile low density refined products to viscous bitumens. Following a spill, viscous emulsions may be formed and weathering to 'tar balls' may occur. Some of these constituents float on the surface of the sea whilst others have neutral or negative buoyancy.

   No single protective measure can effectively protect an industrial cooling or desalination plant from all forms in which the oils may appear.

2. Sea water intakes in use range from foreshore intakes where shelving beaches occur and full tidal effects can be handled to long channel or piped intakes where the beach shelves only slightly. Beach wells are used in some circumstances to provide a sea water supply to reverse osmosis desalination plants and these are believed to provide a high degree of protection.

3. The most important factor in protecting an intake from oil pollution is its location. In a number of cases significant pollution of an intake has been avoided in the Arabian Gulf by the intake being sheltered from the natural currents.

4. The most common means of intake protection is the shutdown of plant when oil spills are seen to approach the intake.

5. A wide range of sea barriers are in use for the protection of intakes. The two principal types are floating booms and bubble barriers. The views of individual users upon the relative merits of the two systems vary widely but it appears that combination barriers offer the best approach. Probably the most comprehensive system is that in use at Abu Dhabi and this comprises five levels of protection.

   Booms and bubble barriers are only effective where velocities at right angles to the boom or barrier are generally limited to less than 0.3 m/s and wave heights are low.

   The use of 'fishing net' skirts is partially effective in reducing the passage of tar balls.

   It is not always clear whether booms have been employed to divert slicks or to collect them. Permanent or temporary facilities to remove collected oil are employed in some cases.

6. Whilst analytical evidence is not available it is almost inevitable that some liquid oils and tar balls will escape through any protective sea barrier. However, sea barriers provide a very useful means of protecting sea intakes from the major effects of spills.

7. Bar screens and fine drum or band screens are used on almost all intakes. Tars and viscous oils can cause damage to such screens by sticking to the screens, creating undue headloss across the screens and by overloading drive mechanisms. Plant operators should be encouraged to specify screens with torque limiting clutches which are designed to withstand the full hydraulic head difference when completely blocked. In the event of oil spills, hot water or even steam jetting may assist in the release of tarry deposits.

8. From the little evidence that exists, short-term contamination of cooling water even with heavy fuel oils has relatively little effect upon power station condenser performance and the cleaning of these oils from the inside of tubes can be effectively achieved by use of solvents, detergents and a foam ball recirculation system such as Taprogge.

Very viscous oils and tars will cause more serious problems but no data have been collected to quantify such effects.

9. Cooling water flows for power station condensers are in general so great that land based treatment methods as used for oily wastewater treatment are not economic.

10. Contact with the CEGB and 17 power stations (including 8 nuclear stations) in the UK revealed that no problems from oil pollution have ever been experienced.

11. Sea water distillation plants are vulnerable to oil pollution in two respects:

(i) fouling of heat transfer surfaces;

(ii) vaporisation of organics and carry-over into the distilled drinking water.

12. The short-term effects on heat transfer of liquid rather than viscous oils is not likely to be very serious but with present designs cleaning of flash chambers is likely to be time consuming.

13. By relatively minor changes, MSF evaporators could be designed to keep make-up water (2 times product flow) and cooling water (5 to 8 times product flow) separate. With such a design fouling could be limited to only about 10% to 15% of the plant if the make-up water was taken from beach wells or was treated by land based plant for oil and tar removal. Such a system appears to be economically attractive and warrants further study.

Investigation of the BP filtration process, used to treat oily wastewaters, as a means of handling polluted sea water is recommended.

14. Most of the volatile constituents of oils will vaporise at sea but nevertheless some carry-over of organics into sea water distillate is to be expected. Soluble aromatics such as benzene and toluene are probably the constituents which give most cause for concern.

Whilst the concentrations of organics carried over into distillate are likely to exceed drinking water guideline standards, the short-term nature of such pollution is unlikely to cause health problems. The most serious objection is likely to arise from tastes and odours in the drinking water.

The use of activated carbon adsorption is likely to be effective in removing such taste and odour problems. The cost of such treatment on an intermittent basis would not be excessive.

It is recommended that investigations be carried out to confirm the effectiveness of activated carbon in such an application.

15. Reverse osmosis membranes are very susceptible to fouling by small traces of immiscible oils. It is recommended that where possible feed water be taken from beach wells or groundwater aquifers. Where such a supply is not possible and where the risk of pollution is high, land based pretreatment of feed water is desirable.

It is recommended that reverse osmosis pretreatment filters be studied for their effectiveness in oil removal and that the need for modifications and for particular forms of coagulation prior to filtration be established.

The installation of activated carbon for the removal of final traces of oils in feed water to reverse osmosis plants is considered justified by the high costs associated with replacement of membranes where a high risk of oil pollution exists.

16. There is a lack of data on the effects of different levels of contamination by specific oil types on heat transfer plant, MSF plant and RO plant. An experimental investigation programme to establish such data and the effectiveness of cleaning techniques should be carried out.

APPENDIX 1

ORGANISATIONS APPROACHED

APPENDIX 1

ORGANISATIONS APPROACHED

1(a) Research and Advisory, Trade Associations

Water Research Centre (WRC)

Heat Transfer and Fluid Flow Service, (HTFS), AERE Harwell

Central Electricity Research Laboratory (CERL)

Oil Pollution Research Unit (OPRU)

Natural Environment Research Council (NERC)

Institute for Environmental Marine Research

Heriot Watt University, Institute of Offshore Engineering

Admiralty Research Establishment (ARE)

Royal Aircraft Establishment (RAE)

University of Aberdeen, Centre of Environmental Management and Planning

EEC, Directorate General XII

International Maritime Organisation (IMO)

Institute of Petroleum

Oil Companies International Marine Forum

Oil Industry International Exploration and Production Forum

Marine Biological Association of the UK

Department of the Environment, Central Directorate of Environmental Pollution

Chemical Industries Association Ltd. (CIA)

Process Plant Association

Scottish Marine Biological Association

1(b) Central Electricity Generating Board and Power Stations

Central Electricity Generating Board (CEGB)

Aberthaw 'A' and 'B' Power Stations

Berkeley Power Station*

Blyth 'A' and 'B' Power Stations

Bradwell Power Station*

Brighton Power Station

Dungeness 'A' Power Station*

Fawley Power Station

Grain Power Station

Hinkley Point 'A' and 'B' Power Stations*

Kingsnorth Power Station

Littlebrook 'D' Power Station

Oldbury-on-Severn Power Station*

Pembroke Power Station

Sizewell 'A' Power Station*

Uskmouth Power Station

Wylfa Power Station*

1(c) Water Industry

Water Authorities Association

Anglian Water

Northumbrian Water

North West Water

Severn-Trent Water

Southern Water

South West Water

Thames Water

Welsh Water

Wessex Water

Yorkshire Water

Forth River Purification Board

Note: * = Nuclear.

1(d) Oil Companies

Amoco Explorations, London

Britoil, Aberdeen

BP International, London

Shell UK Exploration and Production Ltd., London

Shell International Marine Ltd., London

Shell UK Exploration and Production, Aberdeen

1(e) Oil Refineries

Amoco Refinery, Milford Haven

Conocco, Immingham

Esso, Fawley

Gulf Oil and Refining, Milford Haven

Lindsay Oil Refinery, Barrow-on-Humber

Mobil Coryton Refinery, Stanford-le-Hope

Phillips Imperial Refinery

Shell, Stanlow

Texaco, Milford Haven

1(f) Non-Oil Industry

Confederation of British Industry

Babcock-Bristol

Cargill UK (formerly Croda Premier Oils Ltd.), Hull

BP Chemicals, Hull

Anglesey Aluminium, Holyhead

British Alcan, Morpeth

Associated Octal, Amlwch

1(g) Shipping Companies

Mobil Shipping Co.

Texaco Overseas Tankships Ltd.

1(h) Public Bodies with Pollution Control Remit

Department of Transport, Marine Division, UK

British Ports Association, UK

Port of London Authority, UK

Northumberland County Council, UK

Ministere de la Sante Publique et de L'Environment, Belgium

National Agency of Environmental Protection, Marine Division, Denmark

Ministry of Environment, Finland

CEDRE, France

Wasser und Schiffahrtsant, Sonderstelle der Kustenlander Olunfalle, See/Kus, West Germany

Ministry of Mercantile Marine, Greece

Department of the Environment, Ireland

Ministerio della Marina Mercante, Italy

Rykswaterstaat Sante Publique, The Netherlands

Statenus Forurensningstilsyn, Norway

Direccao Geral dos Services de Fouento Marit, Portugal

Direccion General de la Marina Mercante, Spain

Kustbevakningsledningen, Sweden

APPENDIX 2

STANDARD LETTER SENT TO CONTACTS

1599/1/1

Dear Sirs,

EFFECTS OF OIL POLLUTION ON DESALINATION AND POWER PLANTS

We are carrying out a study for the International Tanker Owners Pollution Federation, which is financed by the EEC to look at the effects of oil pollution on major municipal and industrial sea water abstractions.

The object of the study is to identify various uses of sea water (including feed to desalination plant and cooling water to power stations), to quantify as far as possible problems which may be created by oil pollution in the use of the sea water and to suggest methods, and their costs, by which such effects can be minimised.

To this end we are contacting owners of major desalination plants to seek both their experience of oil polluted sea water and its effects and any ideas they have or investigations that have been carried out. In particular we are interested in any experience of oil pollution incidents at your installations.

Obviously the type and design of the sea water intakes used are significant in that some intakes are better suited to minimise the withdrawal of oil contaminated water.

Similarly if any effects of oil pollution have been measured we are most interested. For example any loss of heat transfer performance or, for evaporators, reduction in performance ratio or output, and the quantity and type of volatile organics which may be found in the distillate.

We are also interested in the economic impact of any oil pollution for example loss of water output during the periods of plant shut down during a spill. In this latter respect if you have recent data on installed costs for evaporators and the running labour cost, that data would be helpful.

We are contacting a number of organisations in the hope of gathering together information on this subject and if you are able to help us by filling in and returning to us the enclosed questionnaire I would be most grateful. We will be able to make available to you a copy of the report produced as part of this study and I hope this may be of use to you.

Yours faithfully,
for SIR M. MACDONALD & PARTNERS LIMITED

G. M. Fenton
Director

AK/ld
Enc.

APPENDIX 3

QUESTIONNAIRE SENT TO CONTACTS

Questionnaire on Experiences of Actual or Threatened Oil Pollution of Installations Using Sea Water for Industrial Purposes

1. Name, address and telephone number of organisation supplying information.

2. Name of contact (telephone extension if available).

3. Date of spill or first notification of presence of oil in sea.

4. Location of spill if known and name of any tanker or other vessel involved.

5. Quantity of oil spilled.

6. Type of oil spilled.

7. Was the oil floating, suspended or settled on the sea bed.

8. Measures taken at location of spill to prevent pollution of installations at risk.

9. Degree of success in containing the pollution hazard and problems encountered with these efforts.

10. Type of installation threatened or polluted.

11. Size of installation (m^3 per day water used).

12. Please give details of intake arrangement. A sketch of the intake arrangement would be helpful.

13. Measures taken at threatened installation to prevent pollution.

14. Date when these measures were taken.

15. Comments on success of these measures and on problems encountered.

16. For Desalination Plants

   (i) Distillation Plants: please state the effects of oil fouling on:

      (a) Performance ratios

      (b) Output

      (c) Heat transfer coefficient (if known)

      (d) Water quality

   (ii) Reverse Osmosis Plants: please state the effects of oil fouling on:

      (a) Membrane flux

      (b) Operating pressure

      (c) Water quality

17. For power stations or other cooling applications; please state the effects of oil fouling in terms of:

   (i) Loss in heat transfer coefficient

(ii) Reduction in heat load

(iii) Effects on intake screens

18. Other applications: please detail.

19. Description of any damage caused by pollution of the installation.

20. Description of measures taken to restore satisfactory performance of installation (cleaning, replacement of parts, etc.).

21. Estimation of cost of preventative measures at installation and of any damage caused.

22. Any lessons learned from the incident (such as measures to be taken to deal more effectively with the threat from any future incident).

23. Any other comments.

Notes: (1) Please use additional paper where necessary and indicate relevant question number.

(2) Please return questionnaire to:

Sir M. MacDonald & Partners
Demeter House
Station Road
Cambridge
CB1 2RS
England

APPENDIX 4

RESPONSE TO QUESTIONNAIRES

APPENDIX 4

RESPONSE TO QUESTIONNAIRES

Questionnaires were sent to organisations in the UK, Denmark, West Germany, Abu Dhabi, Dubai, Bahrain, Oman, Saudi Arabia and Kuwait. The response was variable and included informal replies as well as completed questionnaires. In this appendix a selection of responses to the questionnaires are presented.

Response:

(1) Dubai Electricity Company
(2) Ministry of Works, Power and Water, Bahrain
(3) Sonderjyllands Hojspaendings vaerk
Aabenrau Power Station, Denmark
(4) Shell UK Exploration and Production
(5) Mobil Oil Company Ltd.
(6) Mobil Shipping Company Ltd.

شركة كهرباء دبي
Dubai Electricity Company

Cable : KAHRABA DUBAI
Telex : 45838 Kahrba EM
Tel. : 222111 / 5
226216/5
P. O. Box 564 Dubai, U. A. E.

تلغرافيا : كهرباء دبي
تلكس : ٤٥٨٣٨ كهرباء دي اي.ام
تليفون : ٥/٢٢٢١١١
٥/٢٢٦٢١٦
صندوق بريد : ٥٦٤ دبي، الامارات العربيه المتحده

Ref : SM(D)/165/87/V.10 المرجع

Date : June 20, 1987 التاريخ

M/s Sir M. Mac Donald & Partners Limited,
PO Box 7094,
ABU DHABI.

Attn: Mr. J.T. Hancock, Resident Manager

Dear Sir,

EFFECTS OF OIL POLLUTION ON
DESALINATION & POWER PLANTS

Please refer to your letter 1599/1/1/535/87 dated 3/6/87.

We have no experience of oil pollution incidents at our installations of Power and Water Desalination Plants at Jebel Ali.

However, we have oil slick defence facility which will be deployed around the sea water intakes in case any oil pollution hazard is alerted.

Our sea water intake heads are situated at a distance of 650 meters away from the sea shore and at a depth of 4 meters from sea level. The intake heads are side suction type with bottom of the heads at 1.8 meter above sea bed.

As there was no incident of oil pollution at our installation we have no measurement of its effects on Plant performance or economic impact due to force shutdown of

../-

M/s Sir M. Mac Donald &
Partners, Abu Dhabi SM(D)/165/87/V.10 June 20,1987

Desalination Plant. However, in case of severe oil pollution of our sea water intakes causing the force shutdown of our Desalination Plant, a total of 31.7 MGD water production will be interrupted which in turn will affect the 565 MW Steam Power generation also due to non-availability of boiler make up water and fouling up of Turbine condenser tubes.

The installed cost of our 8 Desalination evaporators is approximately UAE Dirhams 519~~,000~~ millions and the approximate running labour costs is Dh.2.7 million per year.

See TLX
24/[illegible]

We are returning herewith the questionnaire duly filled in as desired by you.

We hope the above will serve your purpose. We shall be very glad to receive a copy of your report after completion of your study.

Yours faithfully,
for DUBAI ELECTRICITY COMPANY

(S.P. KIM)
GENERAL MANAGER & CHIEF ENGINEER

SHL/psa

Encs: as above

Questionnaire on Experiences of Actual or Threatened Oil Pollution of Installations Using Sea Water for Industrial Purposes

1. Name, address and telephone number of organisation supplying information.

   Jebel Ali Steam Power Station
   Dubai Electricity Company
   P.O. Box 564, Dubai, U.A.E.

   Tel: 222111 or 237745 Dubai

2. Name of contact (telephone extension if available).

   Mr. Sang Hoon Lee,
   Station Manager,

   Tel: (084) 56272 Ext 201 Jebel Ali, Dubai.

3. Date of spill or first notification of presence of oil in sea.

   April 3 '83 information received about the threat of oil spill reaching Dubai Coast line from damaged Iranian off-shore platform at Nowrouz oil field.

4. Location of spill if known and name of any tanker or other vessel involved.

   Nowrouz oil field at Iran.

5. Quantity of oil spilled.

   Not known

6. Type of oil spilled.

   Not known

7. Was the oil floating, suspended or settled on the sea bed.

   Not known

8. Measures taken at location of spill to prevent pollution of installations at risk.

Not known

9. Degree of success in containing the pollution hazard and problems encountered with these efforts.

Preventive measures taken for sea water intakes by deploying of oil boom and skirt net as a training purpose though not required.

10. Type of installation threatened or polluted.

Sea water intake for power and water desalination plant.

11. Size of installation (m^3 per day water used).

1,920,000 M^3/day (16000M^3/H x 24H x 5 Nos) - Phase I
1,296,000 M^3/day (18000M^3/H x 24H x 3 Nos) - Phase II
Total 3,216,000 M^3/day
================

12. Please give details of intake arrangement. A sketch of the intake arrangement would be helpful.

The intake heads are situated at a distance of 650M away from sea shore and at a depth of 4M from sea level. The intake heads are of side suction type with the bottom of the heads at 1.8M above sea bed.

13. Measures taken at threatened installation to prevent pollution.

1) Deployment of oil boom and skirt net all around the sea water intake.
2) Deployment of oil globules intercepting screens at the pump suction channels.
3) Frequent operation of travelling screen at the pump suction channel to detect any tar balls.
4) Visual inspection of the shores at intake and outfall.

14. Date when these measures were taken.

Ist deployment in April 1983) As a trial
2nd deployment in Sept. 1983) operation

15. Comments on success of these measures and on problems encountered.

These were only precautionary measures.
No real oil spill/hazard was experienced.

16. For Desalination Plants

(i) Distillation Plants: please state the effects of oil fouling on:

(a) Performance ratios	No adverse effects on Plant performance as no oil fouling occurred.
(b) Output	
(c) Heat transfer coefficient (if known)	
(d) Water quality	

(ii) Reverse Osmosis Plants: please state the effects of oil fouling on:

(a) Membrane flux	Does not arise
(b) Operating pressure	
(c) Water quality	

17. For power stations or other cooling applications; please state the effects of oil fouling in terms of:

(i) Loss in heat transfer coefficient : No effect

(ii)	Reduction in heat load	No effect on plant performance as no oil fouling occurred.
(iii)	Effects on intake screens	

18. Other applications: please detail. : Nil

19. Description of any damage caused by pollution of the installation.

Nil

20. Description of measures taken to restore satisfactory performance of installation (cleaning, replacement of parts, etc.).

Nil

21. Estimation of cost of preventative measures at installation and of any damage caused.

			Dhs
1)	Cost of 1000M oil Boom with reel system		1,086,211/-
2)	Cost of Civil work	...	1,628,422/-
3)	Cost of Mechanical works	...	1,111,814/-
4)	Cost of Electrical works	...	92,316/-
		Total -	3,918,763/-

22. Any lessons learned from the incident (such as measures to be taken to deal more effectively with the threat from any future incident).

No incident of oil spill took place.

23. Any other comments.

The oil slick defence system was installed for preventive measurement incase of any oil slick threat to our sea water intakes.

The system is now kept as standby for any emergency.

Notes: (1) Please use additional paper where necessary and indicate relevant question number.

(2) Please return questionnaire to:

Sir M. MacDonald & Partners
Demeter House
Station Road
Cambridge
CB1 2RS
England

STATE OF BAHRAIN
MINISTRY OF WORKS, POWER AND WATER
POWER AND WATER AFFAIRS
ELECTRICITY DIRECTORATE

دولـــة البحـــرين
وزارة الأشغال والكهرباء والماء
شـــئون الكهرباء والمـــاء
إدارة الـكهـربـاء

No.: 23300/20.15/320/87
Date : 8th July, 1987

الرقم :
التاريخ :

13 JUL 1987

Sir M. MacDonald and Partners,
Demeter House,
Station Road,
Cambridge CB1 2RS,
U.K.

Dear Sirs,

EFFECT OF OIL POLLUTION ON DESALINATION AND POWER PLANTS

Thank you for your letter Ref.1599/1/1 dated 8th June 1987 on the above subject, your letter was not received until 29th June, 1987.

I regret to inform you that I am unable to provide you with the information requested. Despite my previous involvement in Power and Desalination (Thermal) Plants the Electricity Diretorate have not recorded any incident of an actual major oil pollution threat to the cooling sea water for the Power Plant or feed make-up for the desalination since early 1976.

However, on one or two occasions, the Electricity Directorate have noticed the presence of traces of light oils in the distillate but for a very short duration and the distillate was dumped to the culvert. No effect on heat transfer coefficient output or even water quality was noticed except for the very slight odour of the product water.

This installation is located at Sitra Island and the intake is normally protected by a permanent oil boom.

The only operational Reverse Osmosis Plant in Bahrain is that of Ras Abu Jarjur using brackish water, hence this installation is not threatened by Oil Pollution.

As discussed with your representative on 4th July, 1987 over the phone you may also contact the Environmental Protection Committee of Bahrain for futher clarifications concerning this topic.

Thank you.

Yours faithfully,

Khaild Bo Rashid
Projects and Development Department
Electricity Directorate

KBR/sh

P.O. Box 2 - Telex 8515 POWASE BN - Tel.: 533133
ص . ب : ٢ - تلكس : ٨٥١٥ بى إن - تليفون

SH
Sønderjyllands Højspændingsværk
Andelsselskab

Aabenraa, 21st August 1987

The International Tanker Owners
Pollution Federation Ltd.
Stable Hall
87-90 Houndsditch
London EC3A 7AX
England
Att.: Mr. T. H. Moller

Our ref: BMJ/rs

Journ.No. 1987000047

Dear Sirs

As agreed with Mr. P. S. Stamp, Commander, National Agency of Environmental Protection I enclose your questionnaire duly filled out.

If you want further information, please contact me by phone.

Yours faithfully
SØNDERJYLLANDS HØJSPÆNDINGSVÆRK
Andelsselskab

Bent Møller-Jensen
(Station Manager)

Encl

Telephone:
Nation. 04 62 42 31
Int. nat. +45 4 62 42 31

Telefax
04 63 09 01

Telex
52140

Bank: Handelsbanken, Aabenraa
Int.nat. Copenhagen Handelsbank A/S
Reg.nr. 4610.
Konto nr. 210 317

Al korrespondance bedes stilet til selskabet, ikke til personer.

J. nr.: 16 - 17/ 400 - 13
- 9 JUU 1987

Questionnaire on Experiences of Actual or Threatened Oil Pollution of Installations Using Sea Water for Industrial Purposes

1. Name, address and telephone number of organisation supplying information.

Sønderjyllands Højspændingsværk
Flensborgvej 185
DK-6200 Aabenraa
Phone No +454 62 42 31

2. Name of contact (telephone extension if available).

Bent Møller-Jensen, Station Manager

3. Date of spill or first notification of presence of oil in sea.

1st September 1982

4. Location of spill if known and name of any tanker or other vessel involved.

Spill caused by overfloading lorry during loading at night due to a sleeping drunken driver.

5. Quantity of oil spilled.

About 36 tonnes

6. Type of oil spilled.

Heavy fuel

7. Was the oil floating, suspended or settled on the sea bed.

The oil was running through the surface water drainage system to the power station inlet cooling canal. Some of the oil was settled in the drainage system, but most of it floaded in the inlet canal.

8. Measures taken at location of spill to prevent pollution of installations at risk.

A wall in the canal reaching 1,5 m down under the water surface for holding back oil on the water surface.

9. Degree of success in containing the pollution hazard and problems encountered with these efforts.

The wall retained 9 tonnes of oil.

10. Type of installation threatened or polluted.

600 MW power plant (condenser part).

11. Size of installation (m^3 per day water used).

75.000 m^3/h = 1.800.000 m^3/day.

12. Measures taken at threatened installation to prevent pollution.

Lorry loading station moved to another location and protected against spillage.

13. Date when these measures taken.

Shortly after spillage.

14. Comments on success of these measures and on problems encountered.

None

15. Description of any damage caused by pollution of the installation.

Condenser contaminated with a layer of heavy fuel oil. The power plant was immediately shut down to minimize contamination of the outside water.

16. Description of measures taken to restore satisfactory performance of installation (cleaning, replacement of parts, etc.).

The very contaminated condenser was cleaned up, in first hand by removing free oil from inlet side and thereafter manual cleaning of each tube with the usual rubber balls together with some oil solvent.

17. Estimation of cost of preventative measures at installation and of any damage caused.

Cleaning cost about 300.000 D.Kr. plus not calculated production loss.

18. Any lessons learned from the incident (such as measures to be taken to deal more effectively with the threat from any future incident).

It is very difficult to prevent oil contamination from major oil spillage if the oil has found its way to a high velocity stream. The cleaning up of condenser was in fact more easy than expected.

19. Any other comments.

Please use additional paper where necessary and indicate relevant question number.

Shell U.K. Exploration and Production
1 Altens Farm Road
Nigg, Aberdeen AB9 2HY

Telex:
Aberdeen 739601
Telegraphic address:
Shellexpro Abn.

Telephone:
direct line (0224) 88
switchboard (0224) 882000

Mr. A. Keiller,
Sir N. MacDonald & Partners,
Demeter House,
Station Road,
CAMBRIDGE.
CB1 2RS

Your ref:

Our ref:

Date: 22nd June, 1987

25 JUN 1987

Dear Mr. Keiller,

ITOPF STUDY

Thank you for your letter and questionnaire on the above.

The depth of our intakes offshore makes it highly unlikely that any surface oil would be drawn in to the systems. To our knowledge there have been no cases of intakes being contaminated with oil. I trust this answers the main point of your enquiry.

Yours sincerely,

James G. Parker.

DR. J. G. PARKER
ENVIRONMENTAL SENIOR SCIENTIST

STP019

Shell U.K. Exploration and Production is a business name of Shell U.K. Limited.
Registered in England: No. 140141. Registered Office: Shell Mex House, Strand, London WC2R 0DX.

Mobil Oil Company Limited
REGISTERED IN ENGLAND NO 70170

REGISTERED OFFICE
MOBIL HOUSE
54/60 VICTORIA STREET
LONDON SW1E 6QB

PLEASE REPLY TO
RESEARCH AND TECHNICAL
SERVICE LABORATORY
THE MANORWAY
CORYTON STANFORD-LE-HOPE
ESSEX SS17 9LN

TELEPHONE STANFORD-LE-HOPE 673355
TELEX 263488

CIRCULATION		
FJM		
IDMB	1	
IRM		
BLD		
JD		
A.H.		
RAP	2	RAP
PJW	3	PJW
[illegible]	4	

Dr. J.D. Swanwick
80, Meadway
Harpenden
Herts AL5 1JQ

30 July, 1987

Please reply to:
R.A. Portsmouth
Environmental Protection Co-ordinator

Dear Dr. Swanwick

Effects of oil in the Thames water on Coryton Refinery Operations
Files: 310/013/702/3, 310/013/702/8

You telephoned R.A. Portsmouth on June 15th 1987 and from this conversation we understand you have been commissioned to undertake a study on behalf of the International Tanker Owners Pollution Federation to establish the effects of oil pollution on the uses of sea water.

At Coryton Refinery, the cooling water is drawn from the Thames and could be affected by a high concentration of suspended oil such as may occur in the event of a substantial oil spill. The intake is normally under water of course, and large quantities of floating oil would not normally be drawn in. However, at low water springs we would expect gross ingress of oil if it was on the water surface.

We have no experience of the consequences of this, but would expect the major effect to be on the turbine power generation plant, where fouling of the heat exchangers would, we believe, lead to a loss of efficiency with the ultimate possible need to shut these units down. This could in turn lead to production restraints through lack of power, but the degree to which this would occur would depend very much on the circumstances of the time.

Yours faithfully,
MOBIL OIL COMPANY LIMITED
R.A. Portsmouth
for
I.D.M. Burns
Manager
Analytical and Environmental Services

RAPortsmouth/reg
SPEC441

b.c.c. T.Bogle
E.C.Hauswald
M.J.Morrant
R.J.Walker
R.Smith

Mobil Shipping Company Limited
REGISTERED IN ENGLAND NO 506593
ULTIMATE HOLDING COMPANY — MOBIL CORPORATION (USA)

PLEASE REPLY TO —
MOBIL HOUSE
54/60 VICTORIA STREET
LONDON SW1E 6QB

TELEPHONE 01-828 9770
TELEX 8812411/9
CABLES MOBILSHIP LONDON SW1

INT. SALES DEPT.
10 JUL 1987
FILE

Mr. R.S. Skinner
Marine Sales
Mobil Oil Company
Mobil House

10 July 1987

PDAR/jar
04.10.01

INTAKE PROBLEMS WITH OIL
POLLUTED SEA WATER

Dear Bob,

Following our recent discussion on the request for information on sea water intakes by the ITOPF via Sir M. MacDonald & Partners I have asked around our operating departments to see whether we have ever suffered from problems of oil polluted sea water in the intakes on our vessels. It would appear that this has not been a problem that anyone can recollect. I telephoned the ITOPF to find out the background to their enquiry. The reason they organised the study was because of the many occasions on which they had been told that in an pollution incident it could have very serious consequences as well as high cost penalties on power stations and desalination plants and ships. Indeed, they were able to quote some instances when large costs had been incurred due to power stations being forced to shut down completely. What ITOPF are trying to establish is any specific damage which has been caused by oil polluted water as there is mostly heresay and not much factual evidence on which to draw conclusions.

ITOPF said that they would welcome negative reports as well as positive ones. Therefore you could advise them that from Mobil Shipping's point of view because ships are able to change from high to low level intakes the effect of oil pollution floating on the surface of the sea can be reduced or eliminated. Furthermore, since the majority of pollution incidents arise in port environments it would be possible for ships to shut down their intakes without too much difficulty. It would, of course, be a problem if they were unaware of the pollution until it had been sucked in by the intake. Fortunately, this has not happened yet to our knowledge.

Please do not hesitate if you would like any further information.

Yours very truly,

P.D.A. ROBSON
Marine Superintendent

REGISTERED OFFICE MOBIL COURT 3 CLEMENTS INN LONDON WC2A 2EB

APPENDIX 5

SITE VISITS IN THE GULF

APPENDIX 5

SITE VISITS IN THE GULF

Abu Dhabi

(1) Abu Dhabi power station
(2) Abu Dhabi villages and outstations

Bahrain

(3) Sitra power generation and distillation plant
(4) Al Dur desalination plant

Dubai

(5) Dubai Electricity Company (DEC)
(6)(Dubai Aluminium Company (DUBAL)

Qatar

(7) Ras Abu Fontas power station