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Large Seawater Reverse Osmosis Installations in Gulf Waters and a Process Comparison With Multi Stage Flash Distillation

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1.0 Introduction

1.1 Over the last few years the Reverse Osmosis Sea Water Desalination process has been criticised, particularly in the Arabian Gulf region, for not meeting the Client's expectations [1]. The Reverse Osmosis process has been promoted, as having a lower capital cost than an equivalent capacity thermal plant [2, 3 and 4]. Whilst first cost is an important factor, other considerations have to be taken into account when assessing through life cost, in particular, the reliability of the process, basic design criteria, operating costs and not least, the experience of both the Consultant and the Desalination Contractor.

The Authors have been responsible for the design, supply, installation and operation of various types of water treatment plant to numerous industries throughout the world. These range from desalination plants producing potable water and boiler feedwater, and water for industrial services through to offshore sea water injection packages which produce low sulphate sea waters for enhanced oil recovery from subsea reservoirs. The technologies utilised have been membrane/nanofiltration and thermal processes (M.S.F and TCD).

This Paper presents the Authors' views on the two main processes and highlights areas within the Reverse Osmosis process design that require careful attention within the Specification, at the design stage and during operation of the plant. The Multi Stage Flash process is already well documented with respect to design and operation, therefore further detailed analysis is not covered in this Paper although certain important aspects are highlighted for comparison purposes.

2.0 Comparison of Processes

Comparisons between different processes for a given water requirement are primarily carried out by considering Capital and Running Costs, Plant Availability, Delivery Periods, Process and Service requirements, Energy availability and occasionally Plot Area constraints. Seldom is the relative suitability of the process to the environmental conditions brought into the considerations, although, in the case of Desalination by Reverse Osmosis this is probably the most important aspect of the selection.

Whilst the M.S.F plant can be considered for sea water desalination on almost any site without a detailed knowledge of the raw sea water composition, the same does not apply to the R.O. process.

With R.O. a full knowledge of the seasonal changes to the raw water quality is mandatory, but seldom immediately available. Ideally small prototype pilot installations should be built on all sites intended for large R.O. installations at least 1½ years before the full size plant design is required. This would then be used to test and optimise the adequacy of conventional pretreatment options to handle the large swings in water quality that can occur in shallow, warm, coastal sea waters particularly in the Gulf. In addition to studying the pretreatment systems, the performance of different membrane types under the varying environmental conditions could also be studied and an optimum selection made for the specific application. Realistic membrane replacement rates and design fouling factors could and should be established.

Comparisons of different desalination processes never really compare like with like. M.S.F. plant costs and design are governed by different variables from those governing the R.O. process.

For example, M.S.F. plant design is strongly influenced by performance ratio and the flash range of temperature. Sea water quality, temperature, and salinity are relatively unimportant. The product water quality desired has virtually no influence on the design as the product quality is predetermined by the process.

By contrast, for R.O processes, feed water quality, temperature and salinity, and the desired final product TDS, are the most important of the design variables. For instance a 1% drop in temperature, results in a 3% drop in product flow.

Figure 1 shows the wide annual variation in temperature and TDS of sea water in the Gulf Region, over a typical one year period.

Optimum designs for each process are the only meaningful basis for comparison which can be made, as they compare the best design for each process to meet a given specified requirement and that is the approach which is recommended.

The following sections compare some the merits and demerits of each process.

2.1 Reverse Osmosis

2.1.1 Advantages

Some of the features of Reverse Osmosis that can be beneficial in a direct comparison with Thermal Distillation are:-

- The Reverse Osmosis process requires a significantly lower feed water quantity when compared with the summertime requirements of the Multistage Flash process which is typically 70% higher. Hence, it offers reduced civil costs for the sea water intake, the outfall and the pumphouse. Sea water flowrates are constant providing stable intake conditions and constant header supply pressure.

- As the Reverse Osmosis process operates at ambient sea water temperature, scaling and corrosion potential, which is exacerbated at higher temperatures, is minimised.

- Reverse Osmosis has the ability to operate stably over a wider turn-down ratio than multistage flash by the simple action of taking sections out of service.

- Start-up to on line time interval is shorter than for M.S.F. and load changes can also be made quicker.

- The plot site area required is generally smaller for a given plant output.

- The initial capital cost is normally lower for Reverse Osmosis than for M.S.F. Distillation.

- Potable water Post-treatment is simpler than that for M.S.F. distillate.

- The delivery time is shorter. Typically on a fast track project, 18 months for R.O. compared with M.S.F. which could be 30 months.

2.1.2 Disadvantages (R.O.)

- The reverse osmosis process is susceptible to significant swings in performance if the raw water quality changes.

- Membranes of the Polyamide type are intolerant to chlorine, which must be chemically removed.

- It is generally not normal practice to continuously monitor incoming sea water quality and first indication that conditions have worsened is when membrane performance has deteriorated and a biofouling regime is established within the bundles. To deal with this factor frequent manual monitoring of biological activity is required.

- Reverse Osmosis Plant performance declines progressively with time due primarily to irreversible fouling and/or membrane compaction in the element bundles. Allowance is made for this by applying flux reduction factors and by specifying membrane replacement rates. The adequacy of replacement rates currently recommended by membrane suppliers is questionable

- In biologically active sea water areas, membrane cleaning can be required as frequently as every 6 to 8 weeks. Since the specific type of foulants may initially be unknown, cleaning operations are largely speculative and are likely to have to vary from season to season. Seasonable bloom periods seriously affect R O. Plant operation causing rapid fouling of the membranes (Fig.2), however, given good monitoring and operational practices plant output can be maintained.

- Due to the larger margins provided for fouling in the plants design, Multi Stage Flash, off-load plant cleaning is only necessary at 1½ to 2 year intervals.

- Relatively elaborate membrane element performance monitoring systems are necessary to satisfy the manufacturer's warranty requirements. No such requirements are necessary for the multistage flash system.

- Assessment of the pre-treatment chlorine, coagulant and coagulant aid dosing levels is an imprecise science and the levels require to be seasonally adjusted to match the changing sea water quality. Routine small scale determinations by "jar testing" are necessary to optimise filtration performance. Figure 3 shows the variability of the optimum coagulant dose rate. Chemical additions on multistage flash plants are virtually constant.

- Measures to keep the feed system bio-activity under control must be rigidly observed with Reverse Osmosis. In the Multi Stage Flash Process, however, sterility is thermally achieved automatically in service.

2.2 Multistage Flash

The long established multistage flash process has proven to be a reliable means of producing freshwater from saline waters.

2.2.1 Advantages (M.S.F.)

- The product water is inherently of high quality (< 5 ppm) and is unaffected by variations in sea water salinity. Thus it is suitable for mixing with locally available brackish water to produce increased wholesome quantities of drinking water, and with minimal polishing can supply directly the make up demands of the steam raising equipment

- In wintertime as the sea water temperature reduces, the flash range can be increased; the system becomes more efficient and more fresh water can be produced. In the reverse osmosis system, as the water temperature reduces, the system becomes less efficient and a greater pressure has to be applied to maintain production.

- Multistage flash is unaffected by normal levels of suspended or biological matter in the raw sea water and the product water is rendered sterile by the recirculating brine being heated above 70°C. By comparison probably the greatest problems to be addressed in reverse osmosis plant design are removal of suspended solids and control of biological activity in the sea water.

- The use of improved scale control additives and on-load tube cleaning on Multi Stage Flash Plants can allow operational periods of 1½ to 2 years between off load acid cleans giving much improved availability levels e.g. 90% v 80% for Reverse Osmosis.

- The multistage flash process is more tolerant of maloperation and less than adequate maintenance.

- The Contract Consultant's Specification imposes the process limitations - not the membrane supplier's warranty constraints.

2.2.2 Disadvantages (M.S.F.)

- Requires more sea water than reverse osmosis and hence more expensive offshore and onshore civil works.

- Requires more energy than reverse osmosis although low grade heat can be efficiently utilised.

- Higher installed capital cost.

- Can be more susceptible to corrosion although this factor can be controlled by use of improved materials. This requirement is probably the main contribution to the capital cost difference between M.S.F. and R.O. Whilst present day constructional materials will give complete protection at the vast majority of sites, there are still some constituents like ammonia and hydrogen sulphide which can give problems.

- Larger plot area is required for a given plant capacity.

- M.S.F. Distillate temperature (typically 43°C) is higher than R.O. permeate temperature.

2.3 Economic Comparison

An in-house study of the two processes for a 15 MGPD capacity plant located in the Arabian Gulf shows the following:-

	SWRO	MSF
Availability	80%	90%
Operation Labour and Maintenance	3.40 p/m³	2.65 p/m³
Membrane Replacements	2.46 p/m³	N/A
Chemicals and Consumables	2.27 p/m³	1 08 p/m³
Electric Power	23.53 p/m³	12 03 p/m³
Steam	N/A	33.55 p/m³
Fixed Charge for Capital Recovery	43.8 p/m³	44 63 p/m³
Total Cost in UK Pence	75.5 p/m³	93.94 p/m³

Table 1: Typical Product Water Costs for a 15 MIGD Plant

Economic assessment is only one factor to be considered in the best selection of desalination process. Local conditions can negate and override the purely financial factors. Such intangibles include the proposed geographical location and its proximity to centres of supply for chemicals and power, widely variable climatic conditions and availability of skilled operation personnel, coupled with simplicity of the process for ease of maintenance.

The appropriate choice is not always immediately obvious but in the authors' opinion the overriding priority must be reliability, i.e. to select a process which in areas of scarcity will ensure the reliable supply of fresh water on a continuous basis. In this context redundancy of plant will not necessarily satisfy that criterion - the fundamental requirement is that of reliability of the basic process itself for a specific application.

3.0 Guidelines for the Successful Design and Operation of Reverse Osmosis Plants

In order for the Reverse Osmosis process to be successfully applied, in particular to surface sea water, it is recommended that the following guidelines are adhered to.

3.1 Contract Specification

1. The Specification should specify the total range of feed TDS and temperature over which the plant has to maintain its output and quality.

2. The method for determining the feedwater TDS should be clearly stated, since this can have a significant effect on apparent plant performance. We recommend a series of tests carried out at an evaporation temperature of 103°C, [5] with the corresponding conductivity being measured. This approach could show a difference of up to 2000 mg/l in TDS levels compared to tests at 180°C. Thus providing a conservative basis for plant design and recognising that standard test solutions are used for membrane characterisation.

3.2 Design

1. Realistic fouling factors should be used, preferably based on either pilot trials.

2. The pre-treatment system should be designed to facilitate on-line and off-line sterilisation and minimise biological growth.

   For surface sea water plants the number of stages of filtration should be considered with disinfection/sterilisation facilities provided in addition to backwash and air scour.

3. The highest feed flow rates possible through the elements should be selected, to ensure maximum shear to reduce the growth of bio-films.

4. Conservative and realistic media filter run-times should be catered for.

5. The mechanical design of an R.O. Plant should provide for start-up and operation of the pre-treatment plant and the associated high pressure S.W. feed pumps as a whole, prior to admitting conditioned sea water to the R.O. membranes.

6. Admission of S.W. feed to the membranes should be controlled in such a manner as to avoid the sudden application of pressure to the membrane bundle, e.g. by slow closure of the by-pass valves or by variable speed control, or by the feed control valve.

7. On large plant, where there could be significant pressure drops in the H.P. feed system, ensure that the membrane feed pressure is monitored/recorded in a representative position. This can be of significance when extended plant guarantees are required, when small margins could be critical.

3.3 Operation

1. On large sea water plants ensure that performance monitoring of the membranes is maintained and reviewed as an operational routine so that if a deterioration of performance is found, effective action may be timeously implemented.

2. Pre-treatment chemical dose rates should be varied as necessary following jar tests to suit the variable feed conditions. This will ensure optimum feed conditions to the membranes, and reduce membrane cleaning down-time

3. Routine biological monitoring should be carried out, so that effective control measures can be taken at an early stage, i.e. sterilisation or replacement of cartridge filters, sterilisation of media filters, etc.

4. Attention to detail, such as flushing of system dead-legs will maximise membrane on-line time.

5. Review media filter run-times to optimise feed water quality at regular intervals.

4. Conclusions

1 For large multi million gallon installations in the Gulf, it would appear that for combined power and water schemes, thermal plant currently offers the optimum solution

2. On the basis of present methods of assessment, R.O. has the lowest apparent capital and operating costs however RO Plants operating in the Arabian Gulf Region are subject to some of the most arduous feedwater conditions to be found Worldwide Design criteria applied to plant located in areas such as the Caribbean and the Mediterranean, are not applicable to the Gulf Region.

   Successful and reliable performance can, however, be achieved provided conservative design is employed and process management is effective.

3. System design should consider the requirement for regular system sterilisation and should include permanent facilities for this purpose.

4. Membrane suppliers must address the "Non User Friendly" aspects of the warranty guidelines imposed on contractors/end users. This can only be done by further product and process developments.

5. Design Flux Reduction Coefficients/Fouling Factors are less conservative for membranes than the equivalents used in thermal plant design where the fouling resistance to heat transfer amounts to 50% of the overall heat transfer coefficient. Comparable figures in R.O. design are typically 20%-30%. However, the R O. system does not lend itself well to generalisation of these types of variables due to the unique nature of every plant and its environment. Pre project pilot trials are advisable to establish the necessary design factors.

More realistic replacement rates of membranes based on actual operational experience must be considered when evaluating product water costs at the early stages of a project, and to ensure plant output is sustained throughout plant life.

This is a factor influencing through life cost assessment.

6. To ensure product water quality is sustained throughout the plant lifetime, it may be worthwhile giving consideration to providing a Two Pass Product Staged plant.

   Additional margin is then available to guarantee that product quality is within specification. This could also result in a reduction of the replacement rate of first Pass Membranes.

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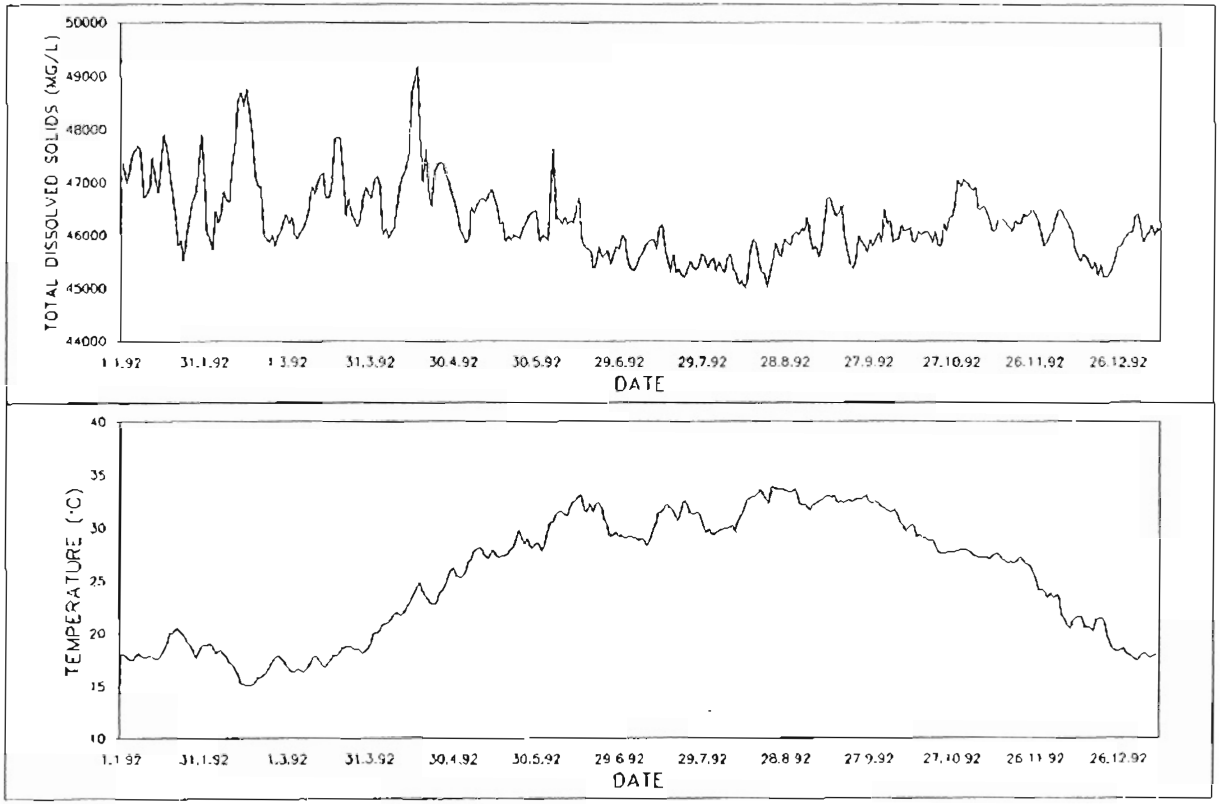

Figure 1: Typical Arabian Gulf Seawater TDS and Temperture Profiles

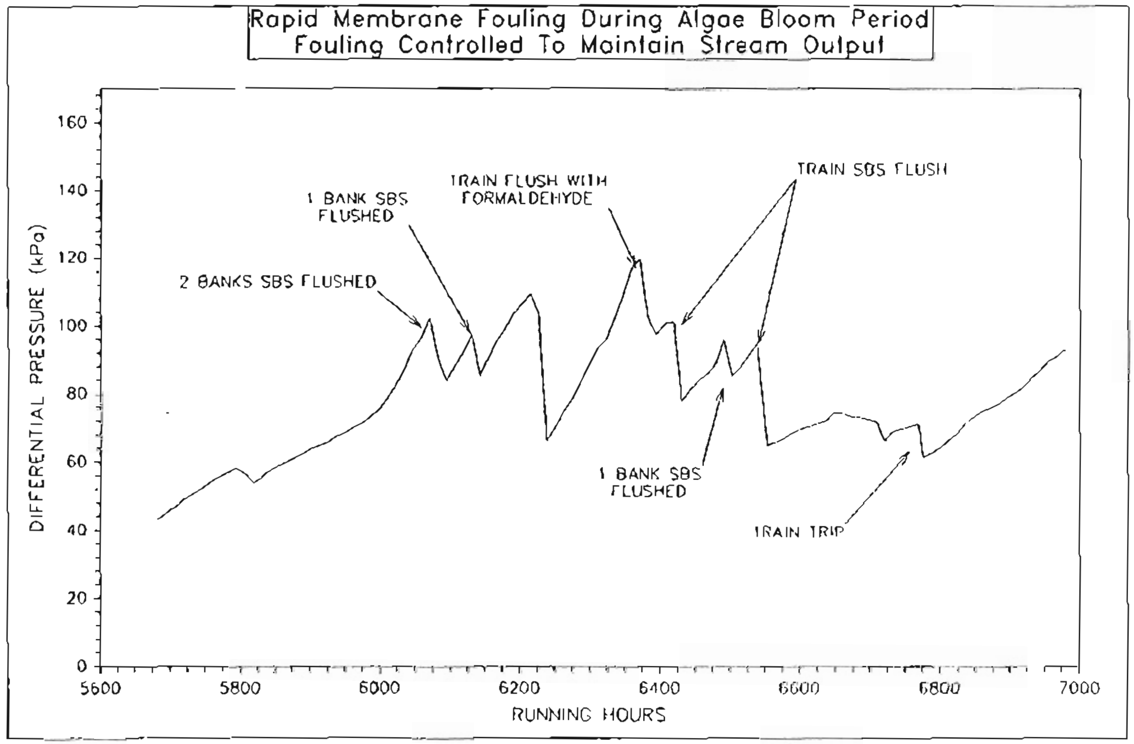

Figure 2: Rapid Membrane Fouling During Algae Bloom Period

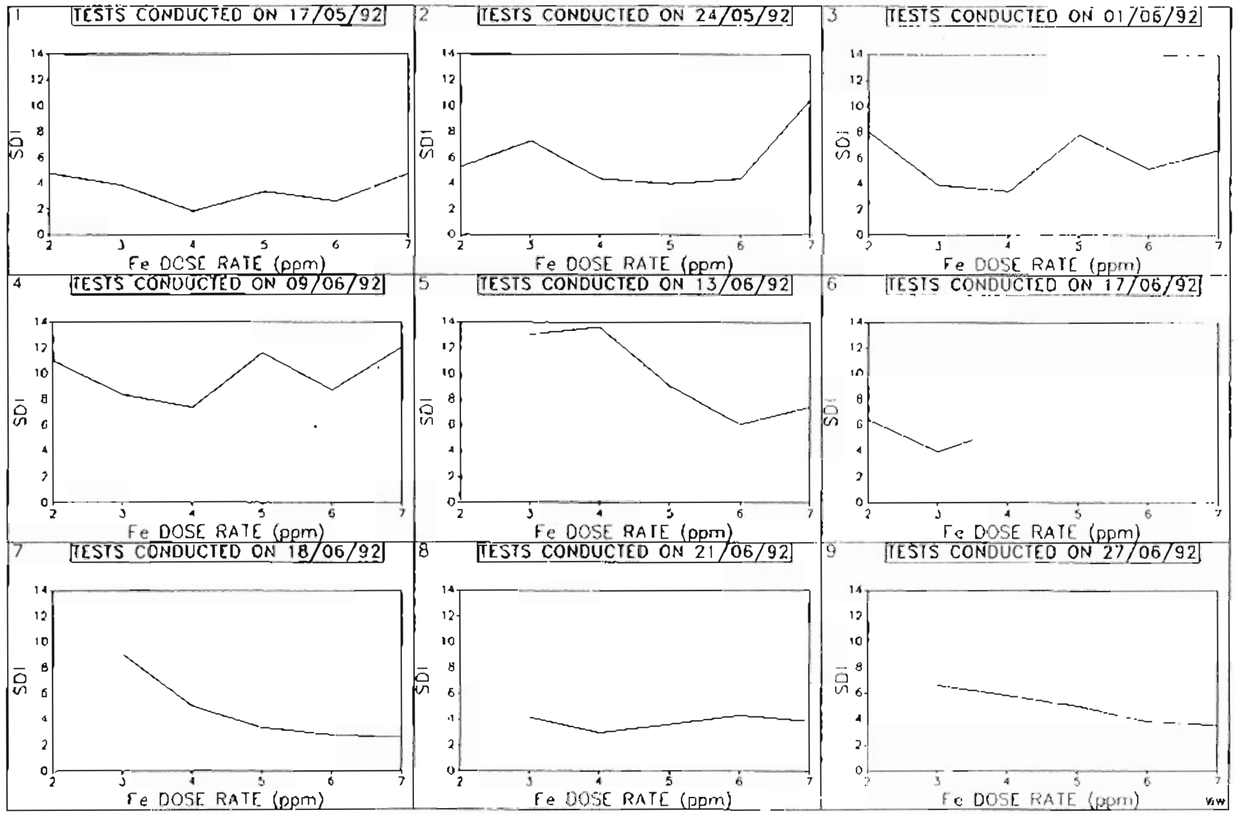

Figure 3: Variation of Optimum Coagulant Dose Rate