

Effective Management System for Protection of Desalination Plants Against Corrosion and Scaling

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Abstract :

Corrosion, scales formation and microbiological activities are the common problems encountered in desalination plants . The effective management system to prevent these problems requires an effective quality control laboratory enabling to predict the quality of feed and produced waters . The analysis of water helps to predict the corrosion and scaling problems . The data of analytical measurements also help the management to select the appropriate type of treatment chemicals and their optimum doses required . This paper describes the methods for preventing membrane damage and/or membrane scaling and fouling in the reverse osmosis type of desalination plants . This paper also describes the procedures for calculation the amount of chemicals required for protecting the plant against corrosion and scaling . The implementation of International Quality Management System (ISO 9000) related to desalination plants has also been discussed .

1. Introduction :

The process of producing fresh water from sea water is called desalination process. Of the physical possibilities for producing fresh water from sea water, evaporation and crystallization involve a phase change of the water during the separation process and in membrane processes no phase change occur (Table-1)

Table 1 : Classification processes :

Processes including a phase change		Processes without a phase change
Evaporation processes	Crystallization processes	Membrane processes
* Multi-stage flash (MSF) evaporation	* Freezing processes	* Reverse osmosis
* Membrane distillation	* Hydrate processes	* Electrodialysis
* Multi-effect evaporation		
* Evaporation with vapour compression		

At present, most of the fresh water derived from sea water is produced by evaporation and it probably the alternative (RO or ED) in case of brackish water^{1,2} whereas crystallization processes will have no chance at all . This paper will discuss methods of preventing membrane damage and/or membrane scaling and fouling and the procedures for calculating the required amount of chemicals .

2 . Reverse osmosis type of desalination plants :

It has been stated in the literature³ that reverse osmosis (RO) is the alternative to distillation, and this treatment is corroborated by new plants which are under construction or which have been commissioned recently. Modules successfully employed in these plants are of either the 'spiral wound' configuration or the 'hollow fiber ' type .

Symmetrical cellulose triacetate hollow fibers (Hollosep, Toyobo) or asymmetric polyamide hollow fibers (Dupont, B10, B10T) are used for the hollow fiber modules for sea water desalination . Cellulose triacetate or composite membranes such as Film Tec FT 30 membranes or Toray REC 1000 are used for spiral wound modules . Composite membranes have high flux and such excellent selectivity that potable water (< 500 ppm TDS) and reasonable recovery rates (RC 30%) can be

achieved in a single stage, even in cases of very high feed concentrations (ca. 42000 ppm TDS)⁴. Attention has to be paid to the concentration of free chlorine which is necessary for the pre-treatment of the feed since some membranes, such as the PEC 1000 and polyamide membranes, are very sensitive to free chlorine . Reverse osmosis plants are, however, much more sensitive than thermal plants to adequate feed water pre-treatment . For this reason, it is the accepted technology, where possible, to use well water distillation, some data for a plant erected on our neighbouring country, Malta, is discussed earlier⁶ and summary of data is presented in Table-2 . The entire plant, consisting of ten trains of hollow fiber modules (Dup ont B 10Permeators) , produces 2000 tons/day of fresh water at a specific power consumption of 6.3 kWh⁻¹ of fresh water . This very low figure includes the power consumption for the feed pre-treatment and is a direct consequence of the energy recovery system installed (Guinard integrated turbo-pumps) . It should be noted that product water quality is achieved in one stage .

3 . Optimization of Reverse Osmosis type of desalination plants :

It should be noted that the product of any one-stage reverse osmosis sea water plant contains about 300 – 500 ppm of total dissolved solids, i.e., much more than the distillate from thermal desalination plants . Higher product purities, for chemical processes or for boilers, can only be achieved by a (two-stage) RO cascade . The second stage can be equipped with a different type of membrane (high flux, low selectivity) than the first stage and certainly must be operated at a different trans membrane pressure difference . The module arrangement in each stage, i.e., the number of modules in series and/or in parallel, is determined for a given type of module by the desired recovery of the stage and necessity to maintain optimum flow conditions in the modules . In general these requirements lead to a so-called ‘tapered design ‘ .

Table-2 : Initial operating data of Malta sea-water reverse osmosis plant :

Item	Units	Actual Data*	Design Basis
Feedwater :			
Total dissolved solids	ppm	3650	39200
Temperature	°C	17	21
Pressure	bar	70	70
Recovery	%	33	35
Silt density index #	-	2-4	0-3
Product :			
Flow-rate	m^3d^{-1}	18600**	20000
Total dissolved solids	ppm	380	500
Consumables :			
Electricity	kWhm ⁻³	6.30	6.12
Sulphuric acid	ppm	6.6	6.6
Caustic soda	Ppm	3.2	3.2
Chlorine	Ppm	1.0	1.0

*Source : reference 6

Before cartridge filter

**80% permeators installed

4. Measurement of Feed Water Pre-treatment :

The essential steps of feed and permeate treatment have been discussed in previous sections . In this section methods of preventing membrane damage and/or membrane scaling and fouling are discussed . The procedures for calculating the required amount of treatment chemicals have also been described .

The method and the degree of the necessary pre-treatment de[end essentially on :

- Membrane material .
- Module system .
- Required recovery and permeate quality
- Feed water composition .

Essentially, two classes of water ingredients can be distinguished which could effect the membrane : substances capable of damaging the membranes and components tending to fouling or scaling (Fig. 1) . Substances of the first kind can change irreversibly the physical and chemical structure of the membrane . The very commonly cellulose acetate and polyamide membranes and also some composite membranes react very differently to the various membrane-damaging conditions such as free chlorine, free oxygen, bacteria and pH level (Table-3) . The may exceed the indicated range briefly during module cleaning .

Table -3 : Normal working conditions of different kind of membranes :

	Cellulose acetate membrane	Polyamide Membrane	Composite Membrane
PH	3-7	4 – 11	3 – 11 (4-6)
Free chlorine	< 1 mg/1	PH < 8;<0.1mg/1	Non-resistant
Bacteria	Non-resistant	PH > 8;<0.25mg/1	Resistant
Free oxygen	Resistant	Resistant	Partly resistant

Table-3 Clearly indicates why cellulose acetate membranes are advantageous for sea water desalination, despite their limits : apart from their acceptable performance figures with respect to flux and selectivity their main advantage is that they are highly chlorine resistant . Chlorine can be dispensed in sea water pre-treatment for controlling organic growth, hence chlorine resistance is advantageous . Particularly when the quality of the plant operators is questionable . In contrast to the damaging substances, which are membrane-specific to some extent, the substances tending to cause scaling or fouling will affect all membranes in about the same way . ‘ Scaling ‘ is the crystallization of dissolved water components (after exceeding the solubility limits) at the membrane surface and ‘ fouling ‘ is deposition of suspended or colloidal dissolved particles at the membrane surface .

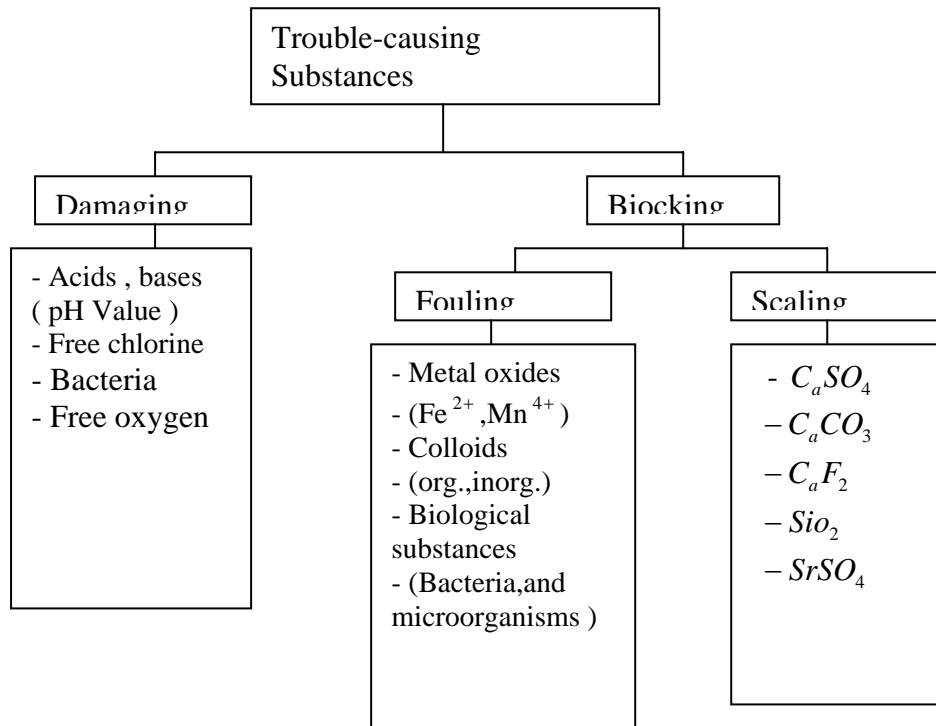


Fig.1 : Substances damaging or blocking membranes

5. Prediction of the fouling potential (fouling index, F1)

A common measure of the fouling potential of the feed of a reverse osmosis plant is the fouling index (colloid index) . The fouling index is a parameter summarizing the concentration and the filtration properties of the suspended or colloidal particles present in the feed .

A 500 mL (100 mL) volume feed water is forced through a standard filter under specified test conditions After 15 min. (5 min .) the test is repeated using the same filter . The filtration times t_1 and t_2 serve to determine the fouling index as described below :

$$F1 = \frac{(1 - t_1/t_2)}{T_{15(5)}} [\% \text{ min.}^{-1}]$$

Where :

$(1 - t_1/t_2)$ 100(%) degree of fouling

t_1 (s) filtration time for volume V_1

t_2 (s) filtration time for volume V_2

$T_{15(5)}$ (min.) filter cake filtration time

(time elapsed between start of first test and start of second test)

Test conditions :

$$V_1 = V_2$$

$$V_{1,2} = 500 \text{ mL for } T_{15} = 15 \text{ min .}$$

$$V_{1,2} = 100 \text{ mL for } T_{15} = 5 \text{ min .}$$

Applied pressure difference $\Delta p = 2$ bar filtrate side : atmospheric pressure filter;

Membrane filter, 0.45 μm pore diameter .

Filter area : 1350 mm^2

From the definition of the fouling index follow the limiting values for highly contaminated feed water (filtration time $t > \alpha$) of $F1 = 6.66$ ($T = 15$ min.) or $F1 = 20$ ($T = 5$ min.) .

6 . physico-chemical analysis of feed water :

Feed water analysis of important, especially with respect to the solubility limits of salts contained in the feed . Usually, the properties and concentrations listed in Table-4 are sufficient for prediction of the scaling potential . The standard methods for measurement are given in ASTM and ISO books . Accurate and practical field instruments have been developed for measuring temperature, pH and conductivity on site . The concentrations of dissolved gases such as CO_2 , O_2 and Cl_2 must be determined directly at the source since the concentration will change during transport and storage .

Table-4 : physico-chemical parameters required for feed water analysis :

Temperature (minimum) in °C

PH

Conductivity ($\mu S cm^{-1}$)

Chemical analysis of the following dissolved components :

<i>Cations (mg/L)</i>	<i>Anions (mg/L)</i>
Na^+	Cl^-
K^+	SO_4^{2-}
Ca^{2+}	NO_3^-
Mg^{2+}	PO_4^{3-}
NH_4^+	HCO_3^-
Fe^{2+}	F^-
Mn^{4+}	CO_3^{2-}
Sr^{2+}	

Methyl orange alkalinity

Phenolphthalein alkalinity

Sio2(mg/L)

Free carbon dioxide (mg/L)

Free chlorine (mg/L)

Total dissolved solids, TDS (mg/L)

7. Pre-treatment methods against membrane fouling

If the feed water contains large amounts of fouling components (suspended particles, colloids, etc.) then pre-treatment measures are mandatory in order to ensure that the fouling index is within the limits recommended by the module manufacturer .

Conventionally water treatment methods are generally used for this . Filtration is used to separate non-dissolved water components, in combination with flocculation agents if necessary . Usually, the filtration step is designed as deep bed filtration . Deep bed filters may be single or multi-layered, the layers consisting of gravel, activated carbon or anthracite . The thickness of the filter layer is about 1-3 m and compressed air or water is used for back flushing . The particle size of the filter material is normally between 0.5 and 3 mm. For low impurity levels and high purity requirements, pre-coat filtration is generally preferred. A cartridge filter is mandatory in front in front of the modules of any reverse osmosis plant. The cartridge are readily exchangeable filter elements with a nominal pore size about 5 μm .

Of chlorine required is determined by the amount of organic degradable matter in the feed water and by the water temperature . For safe plant operation, a slight excess of chlorine, corresponding to a concentration of free chlorine after treatment of about 0.2 mg/L, is advisable . A disadvantage of chlorine dosing is that many membrane materials used for reverse osmosis are sensitive to free chlorine .

Removal of excess chlorine – Especially for reverse osmosis plants equipped with polyamide membranes, practically chlorine-free feed water at the module inlet is mandatory . The removal of excess chlorine after a pre-treatment step against biological fouling can be achieved with activated carbon or by adding a chlorine scavenger such as sodium hydrogen sulphite (NaHSO_3) . Activated carbon absorbers are reliable and guarantee with high purity feed water . NaHSO_3 is almost totally rejected by polyamide membranes⁹ .

(b) Shock treatment – This is carried out with sodium hydrogen sulphite, ozone or hydrogen peroxide .

(c) UV radiation – UV radiation can be an elegant solution to the problem, but is economical at present only at a very low bacteria levels .

8 . Pre-treatment methods against scaling

Pre-treatment against CaCO_3 scaling – The precipitation of calcium carbonate within the modules of a reverse osmosis plant must be avoided at all costs . A measure for estimating whether or not CaCO_3 is likely to precipitate is the difference between the actual pH and the saturation pH value in the concentrate . The saturation pH value can be derived from lime-carbon dioxide equilibrium taking into account of temperature, ionic strength and concentration of Ca^{+2} and HCO_3^- . In general, the Langelier-Strohecker relationship is used for the calculation in the case of brackish waters and tap water and the Stiff-Davis relationship in the case of more concentrated solutions such as sea water¹⁰ . Usually, one of the following methods is employed as a counter measure against CaCO_3 precipitation .

(i) Acid dosing – Acid dosing is an excellent method for reducing the actual pH level and thus preventing CaCO_3 precipitation . Sulphuric or hydrochloric acid is usually employed for this purpose . It should be noted that the dosing of Sulphuric acid will increase the content of sulphate ion in the feed water and consequently the risk of CaSO_4 precipitation . Sulphuric acid, however, is not as expensive as HCl and is safer to handle .

(ii) Softening by ion exchange – The Ca^{2+} and Mg^{2+} hardeners can be removed economically by cation exchange . Synthetic resins are strong cation exchange resins and are commonly used for water softening .

(b) pre-treatment methods against CaSO_4 scaling - CaSO_4 crystallizes in aqueous solution in the following modifications : $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ (dihydrate), CaSO_4 (anhydrous) or $\text{CaSO}_4 \cdot 1/2\text{H}_2\text{O}$ (hemihydrate) . With respect to reverse osmosis plants which operate at temperatures up to $^{\circ}\text{C}$, the precipitation of the dihydrate is critical . The influence of temperature on the solubility of the dihydrate is only marginal in the temperature range 0-42 $^{\circ}\text{C}$. The maximum allowable CaSO_4 concentration for a reverse osmosis plant can be derived from the solubility product, accounting for temperature and ionic strength .

Measures for preventing CaSO_4 scaling in membrane plants are the following :

(i) Addition of polyphosphates or polycarboxylates . Many module manufacturers and plant designers recommend the addition of sodium hexametaphosphate to prevent precipitation of CaSO_4 .

(ii) Softening by ion exchange .

(iii) Precipitation .

(iv) Lowering the recovery rate .

(c) Pre-treatment methods against BaSO_4 and SrSO_4 scaling – The BaSO_4 / SrSO_4 solubility is calculated analogously to that of CaSO_4 . Solubility products as a function of ionic strength and temperature are given elsewhere¹¹.

(d) Pre-treatment methods against SiO_2 scaling – Silica (SiO_2) in the feed water may cause great problems for reverse osmosis processes. The solubility of silica can be increased by adjusting the pH. Methods of preventing SiO_2 precipitation are (i) design (lowering of recovery rate), (ii) heating, (iii) pH adjustment, (iv) heat treatment of the feed for silica removal and (v) reducing of SiO_2 content by precipitation of hardening constituents¹⁰.

9. Application of Quality Management System (ISO 9000)

For quality management purposes a desalination plant should use ISO 9000 family of International Standards in order to develop, implement and improve their quality system. Throughout the ISO 9000 family emphasis is placed on the satisfaction of the customer's need, the establishment of functional responsibilities, and the importance of assessing (as far as possible) the potential risk and benefits. All these aspects should be considered in establishing and maintaining an effective quality system, and its continuous improvement. The following standards will help to establish an effective quality management system.

ISO 9000 – Parts 1 to 4 : Quality Management and Quality Assurance Standards
ISO 9003 : Quality system-Model for Quality Assurance in final inspection and test.

ISO 9004 – Parts 1 to 4 : Quality Management and Quality Assurance Elements

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