# REVERSE OSMOSIS PROCESS AND SYSTEM DESIGN

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**Summary**

Reverse osmosis process is widely used to remove salts from seawater or brackish water throughout the world. The key to the successful operation of a reverse osmosis plant is the establishment of an appropriate pretreatment system for the feed water conditioning. It is most important to clear the component of feedwater for the process design with optimum parameter to prevent membrane fouling or degradation.

Membrane systems should be equipped with continuous close monitoring and control devices to adjust the system performance variable to maintain operation within safe ranges.

## 1. General Considerations

The following are typical examples of the important items to be considered when designing a seawater reverse osmosis process.

### 1.1. Applied Pressure

As the salt concentration of seawater is normally between 32 000–35 000 mg $l^{-1}$, osmotic pressure (Π) is approximately 2.45 Mpa, and the applied pressure (P) of RO equipment is 5.6–6.0 Mpa, the effective pressure (P-Π), is, in this case 3.1–3.5 Mpa. Although membrane permeation rate increases proportionally to effective pressure, the highest recommended applied pressure of commercial membranes presently available is 7.0 Mpa, beyond which compaction will start to occur due to the fact that RO membranes are made of polymers. Current research is however being carried out to develop membranes which can withstand higher applied pressures. As the salt concentration of seawater in the Middle East is relatively high, osmotic pressure is also proportionally high, thus lowering effective pressure (P-Π).

### 1.2. Concentration Factor

When fresh water is separated from seawater, concentrated seawater which is called brine is retained on the surface of the RO membrane. The osmotic pressure (Π) of the concentrated seawater increases proportional to the salt concentration, thus the effective pressure is reduced. As the upper limit of applied pressure (P) is fixed, this means that there is also an upper limit to the concentration of the brine which normally is between 1.6 and 2.5 times that of normal seawater.

### 1.3. Recovery Ratio

One of the performance indexes for RO equipment is the recovery ratio (production volume/feedwater volume). In the case of a seawater RO unit, as there is an upper concentration limit, the recovery ratio of normal seawater is limited to $4\times10^{-1}$ – $6\times10^{-1}$.

### 1.4. Feed Temperature

The water flux of RO membranes increases as water viscosity is lowered, and water viscosity decreases as water temperature is raised. Thus the higher the temperature, the better the flux. However, the RO membrane is made of polymers and the membrane becomes more compact due to applied pressure as temperature rises. In order to reduce the effects of temperature to a minimum, the acceptable upper limit is 40°C. RO systems are usually designed to operate at 25°C and water flux falls by 20–25 per cent when water temperature is lowered by 10°C.

### 1.5. Removal of Suspended Matter

One of the most important factors in maintaining the stable performance of RO membranes is to remove suspended matter in feed water as much as possible. Normally, the treated seawater by coagulation-filtration is supplied to RO equipment and the upper limit of suspended matter content is considered to be 4 on the Silt Density Index. (SDI).

### 1.6. pH Range

The pH of normal seawater is 8–8.5, but in order to reduce chemical deterioration of the RO membrane and scaling on the surface, pH is regulated at 5–7.

### 1.7. Disinfectant Dosing Rate

Chlorine gas, NaOCl, or $Ca(OCl)_2$ is added to feedwater in order to attain a residual chlorine content of 0.5–1.0 mg $l^{-1}$ for sterilization purposes. Alternatively, 0.5 mg $l^{-1}$ of $CuSO_4$ may be added in place of chlorine. If the amount of disinfectant is too little, sterilisation effect is minimal; however, on the other hand, if too much is added, then membrane materials may deteriorate through oxidation. So the regulation of disinfectant quantities is extremely important.

As some kinds of membrane material are not resistant to chlorine, a reducing agent, such as sodium bisulphite ($NaHSO_3$), should be added in the pre-treatment stage in order to remove the residual chlorine.

### 1.8. Feed Flow Rate and Brine Flow Rate

If the linear velocity of seawater supplied to the RO membrane module is high, then the concentration polarization on the surface of the membrane can be held at a low level and the salt rejection rate of the membrane can be maintained at a high level. However, pressure loss in the membrane module increases due to high velocity and energy efficiency is reduced. Therefore, feedwater supply volumes are determined according to the size of each membrane module. Normally, each module consists of 3–6 membrane elements and the linear velocity of the downstream elements is respectively reduced.

Normally the minimum brine flow rate of the latest membrane module is fixed. If this lower limit cannot be maintained, the concentration polarization on the surface of the membrane will increase and lead to damage such as scaling on the surface of the membrane.

## 2. Basic Reverse Osmosis Plant Construction

The typical reverse osmosis plant, particularly for seawater desalination as shown in Figure 1, is composed of the following facilities:

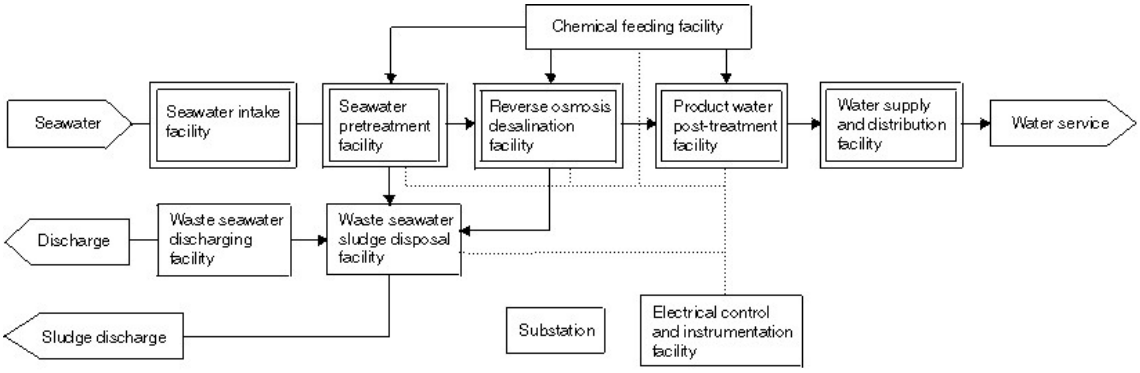


Figure 1. Seawater RO desalination system flow diagram.

### 2.1. Feedwater Supply Facility

The feedwater supply facility may include an intake port off the seacoast other than supply pipe network. In this case, more attention must be paid to the location of the intake port for stable supply of feedwater and to prevent earth and sand from entering. In order to inhibit the growth of shellfish within the intake pipe a limited amount of chlorine is also routinely injected into the pipeline.

### 2.2. Pre-treatment Facility

When suspended matter has accumulated on the surface of the reverse osmosis membrane, separation performance declines, i.e. the membrane permeation flux and salt rejection rate gradually decrease. In order to prevent these phenomena, suspended matter and microorganisms in feedwater are removed by coagulation-filtration in the pre-treatment facility.

### 2.3. Reverse Osmosis Facility

The reverse osmosis facility is the hub of the whole plant. From the typical seawater desalination RO system shown in Figure 1, the clean pre-treated seawater is pressurized to 5.5–7.0 Mpa and sent to the reverse osmosis module where 30–45 per cent of the feedwater passes through the membrane as fresh water while 55–70 per cent is released with a salt concentration increase of 1.4–1.8.

This concentrated seawater, which is still under a pressure of 5.2–6.7 Mpa, then passes on to an energy recovery facility.

## 2.4. Post Treatment Facility

The fresh water that has been provided from the reverse osmosis module has a salt content of less than 500 ppm; however in some cases, various minerals are added to make it suitable for potable use.

The pH is adjusted to prevent corrosion in water supply pipes and chlorine is injected for sterilization.

## 2.5. Water Supply and Distribution Facility

Post-treated fresh water is then distributed to the required areas. Other important facilities which provide smooth operation of the reverse osmosis plant include the chemical feeding facilities, electrical facilities, and waste water sludge disposal facility.

## 3. Basic Principles Involved in Reverse Osmosis Process

The followings are basic principles which must be kept in mind when designing a reverse osmosis plant.

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**Bibliography and Suggestions for further study**

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