FILMTEC Membranes

System Design: The Steps to Design a Membrane System

The Steps to Design a Membrane System

The following steps are taken to design a membrane system:

Step 1: Consider feed source, feed quality, feed/product flow, and required product quality

The membrane system design depends on the available feed water and the application. Therefore the system design information according to Table 3.1 and the feed water analysis according to Table 3.2 should be collected first.

Step 2: Select the flow configuration and number of passes

The standard flow configuration for water desalination is plug flow, where the feed volume is passed once through the system. Concentrate recirculation is common to smaller systems used in commercial applications, as well as in larger systems when the number of elements is too small to achieve a sufficiently high system recovery with plug flow. Concentrate recirculation systems can also be found in special applications like process liquids and wastewaters.

An RO system is usually designed for continuous operation and the operating conditions of every membrane element in the plant are constant with time. In certain applications, however, a batch operation mode is used, e.g., in treating wastewater or industrial process solutions, when relatively small volumes (batches) of feed water are discharged non-continuously. The feed water is collected in a tank and then periodically treated. A modification of the batch mode is the semi-batch mode, where the feed tank is refilled with feed water during operation. See also *Batch vs. Continuous Process (Section 3.2)*.

A permeate staged (double pass) system is the combination of two conventional RO systems where permeate of the first system (first pass) becomes the feed for the second system (second pass). Both RO systems may be of the single-stage or multi-stage type, either with plug flow or with concentrate recirculation. The production of water for pharmaceutical and medical use are typical applications of permeate staged systems. As an alternative to a second pass, ion exchange may also be considered.

Step 3: Select membrane element type

Elements are selected according to feed water salinity, feed water fouling tendency, required rejection and energy requirements. The standard element size for systems greater than 10 gpm (2.3 m^3/hr) is 8-inch in diameter and 40-inch long. Smaller elements are available for smaller systems.

The characteristics of FILMTEC™ elements and their use in specific applications are described in *Element Characteristics (Section 1.8)*. An interactive product selection guide is also available for a range of different applications in our web site.

For high quality water applications where very low product salinity is required, ion exchange resins are frequently used to polish RO permeate.

The Steps to Design a Membrane System (cont.)

Step 4: Select average membrane flux

Select the design flux, f, (gfd or l/m^2-h) based on pilot data, customer experience or the typical design fluxes according to the feed source found in *Membrane System Design Guidelines (Section 3.9)*.

Step 5: Calculate the number of elements needed

Divide the design permeate flow rate Q_P by the design flux f and by the membrane surface area of the selected element S_E (ft^2 or m^2) to obtain the number of elements N_E.

$$N_E = \frac{Q_P}{f \cdot S_E} \qquad \text{Eq. 6}$$

Step 6: Calculate number of pressure vessels needed

Divide the number of elements N_E by the number of elements per pressure vessel, N_{EpV}, to obtain the number of pressure vessels, N_V – round up to the nearest integer. For large systems, 6-element vessels are standard, but vessels with up to 8 elements are available. For smaller and/or compact systems, shorter vessels may be selected.

$$N_V = \frac{N_E}{N_{EpV}} \qquad \text{Eq. 7}$$

Although the approach described in the following sections apply for all systems, it is especially applicable for 8-inch systems with a larger number of elements and pressure vessels, which then can be arranged in a certain way. Small systems with only one or a few elements are mostly designed with the element in series and a concentrate recirculation for maintaining the appropriate flow rate through the feed/brine channels.

Step 7: Select number of stages

The number of stages defines how many pressure vessels in series the feed will pass through until it exits the system and is discharged as concentrate. Every stage consists of a certain number of pressure vessels in parallel. The number of stages is a function of the planned system recovery, the number of elements per vessel, and the feed water quality. The higher the system recovery and the lower the feed water quality, the longer the system will be with more elements in series. For example, a system with four 6-element vessels in the first and two 6-element vessels in the second stage has 12 elements in series. A system with three stages and 4-element vessels, in a 4:3:2 arrangement has also 12 elements in series. Typically, the number of serial element positions is linked with the system recovery and the number of stages as illustrated in Table 3.7 for brackish water systems and Table 3.8 for seawater systems.

Table 3.7 Number of stages of a brackish water system

System recovery (%)	Number of serial element positions	Number of stages (6-element vessels)
40 - 60	6	1
70 - 80	12	2
85 - 90	18	3

One-stage systems can also be designed for high recoveries if concentrate recycling is used.

In seawater systems the recoveries are lower than in brackish water systems. The number of stages depends on recovery as shown in Table 3.8.

Table 3.8 Number of stages of a seawater system

System recovery (%)	Number of serial element positions	Number of stages (6-element vessels)	Number of stages (7-element vessels)	Number of stages (8-element vessels)
35 - 40	6	1	1	—
45	7 - 12	2	1	1
50	8 - 12	2	2	1
55 - 60	12 - 14	2	2	—

Step 8: Select the staging ratio

The relation of the number of pressure vessels in subsequent stages is called the staging ratio R.

$$R = \frac{N_V(i)}{N_V(i+1)}$$

For a system with four vessels in the first and two vessels in the second stage the staging ratio is 2:1. A three-stage system with four, three and two vessels in the first, second and third stage respectively has a staging ratio of 4:3:2. In brackish water systems, staging ratios between two subsequent stages are usually close to 2:1 for 6-element vessels and less than that for shorter vessels. In two-stage seawater systems with 6-element vessels, the typical staging ratio is 3:2.

The ideal staging of a system is such that each stage operates at the same fraction of the system recovery, provided that all pressure vessels contain the same number of elements. The staging ratio R of a system with n stages and a system recovery Y (as fraction) can then be calculated:

$$R = \left[\frac{1}{(1-Y)}\right]^{\frac{1}{n}}$$

The number of pressure vessels in the first stage $N_v(1)$ can be calculated with the staging ratio R from the total number of vessels N_v.

For a two-stage system (n=2) and a three-stage system (n=3), the number of pressure vessels in the first stage is

$$N_V(1) = \frac{N_V}{1 + R^{-1}} \qquad \text{for } n = 2$$

$$N_V(1) = \frac{N_V}{1 + R^{-1} + R^{-2}} \qquad \text{for } n = 3, \text{ etc.}$$

The number of vessels in the second stage is then $N_V(2) = \frac{N_V(1)}{R}$ and so on.

The Steps to Design a Membrane System (cont.)

Another aspect for selecting a certain arrangement of vessels is the feed flow rate for vessel of the first stage and the concentrate flow rate per vessel of the last stage. Both feed and concentrate flow rate for the system are given (from permeate flow rate and recovery). The number of vessels in the first stage should then be selected to provide a feed flow rate in the range of 35-55 gpm (8-12 m^3/h) per 8-inch vessel. Likewise, the number of vessels in the last stage should be selected such that the resultant concentrate flow rate is greater than the minimum of 16 gpm (3.6 m^3/h). Flow rate guidelines for different elements are given in *Membrane System Design Guidelines (Section 3.9)*.

Step 9: Balance the permeate flow rate

The permeate flow rate of the tail elements of a system (the elements located at the concentrate end) is normally lower than the flow rate of the lead elements. This is a result of the pressure drop in the feed/brine channel and the increase of the osmotic pressure from the feed to the concentrate. Under certain conditions, the ratio of the permeate flow rate of the lead element and the tail element can become very high:

- High system recovery
- High feed salinity
- Low pressure membranes
- High water temperature
- New membranes

The goal of a good design is to balance the flow rate of elements in the different positions. This can be achieved by the following means:

- Boosting the feed pressure between stages: preferred for efficient energy use
- Apply a permeate backpressure only to the first stage of a two-stage system: low system cost alternative
- Hybrid system: use membranes with lower water permeability in the first positions and membranes with higher water permeabilities in the last positions: e.g. high rejection seawater membranes in the first and high productivity seawater membranes in the second stage of a seawater RO system

The need for flow balancing and the method can also be determined after the system has been analyzed with ROSA.

Step 10: Analyze and optimize the membrane system

The chosen system should then be analyzed and refined using the Reverse Osmosis System Analysis (ROSA) computer program.

Example

- Feed source: brackish surface supply water, SDI < 5
- Required permeate flow = 132 gpm (720 m^3/d)
- Six-element pressure vessels to be used

1. Brackish surface supply water with SDI < 5; total permeate flow = 132 gpm (720 m^3/d)

2. Select plug flow

3. BW30-365 (BW element with active membrane area of 365 ft^2 (33.9 m^2))

4. Recommended average flux for surface supply water feed with SDI <5 = 15.0 gfd (25 L/m/h)

The Steps to Design a Membrane System (cont.)

5. Total number of elements =

$$\frac{(132\,\text{gpm})(1440\,\text{gpd/gpm})}{(15\,\text{gfd})/(365\,\text{ft}^2)} = 35 \quad \text{or} \quad \frac{(720\,\text{m}^3/\text{d})(41.67\,\text{L/h})/(\text{m}^3/\text{d})}{(33.9\,\text{m}^2)/(25\,\text{L/m}^2/\text{h})} = 35$$

6. Total number of pressure vessels = 35/6 = 5.83 = 6

7. Number of stages for 6-element vessels and 75% recovery = 2

8. Staging ratio selected: 2:1. Appropriate stage ratio = 4:2

9. The chosen system must then be analyzed using the Reverse Osmosis System Analysis (ROSA) computer program. This program calculates the feed pressure and permeate quality of the system as well as the operating data of all individual elements. It is then easy to optimize the system design by changing the number and type of elements and their arrangement.

FILMTEC Membranes
For more information about FILMTEC membranes, call the Dow Liquid Separations business:
North America: 1-800-447-4369
Latin America: (+55) 11-5188-9222
Europe: (+32) 3-450-2240
Pacific (ex. China): +800-7776-7776
China: +10-800-600-0015
http://www.filmtec.com

Form No. 609-02055-1004