**OBJECTIVE:** Be able to correctly identify the equipment connections, array, and positioning of FIC's and PCV's within an RO unit.

**GLOSSARY:**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Array</td>
<td>The number of pressure vessels in the first stage, second stage, and third stage (if present) expressed as a ratio, for example 4 (one stage), 4:2 (two stages), or 4:2:1 (three stages).</td>
</tr>
<tr>
<td>ATD</td>
<td>Antitelescoping Device. A retaining piece placed at each end of an RO element to keep the element from unraveling when the high pressure feed pump is energized.</td>
</tr>
<tr>
<td>Brine Seal</td>
<td>A seal around each RO element which prevents the flow of feed water around the outside of the element.</td>
</tr>
<tr>
<td>Element</td>
<td>The component which houses the RO membrane.</td>
</tr>
<tr>
<td>End Cap Adaptor</td>
<td>The component which connects and seals the elements at each end of a pressure vessel with the end cap.</td>
</tr>
<tr>
<td>FCV</td>
<td>Flow Control Valve.</td>
</tr>
<tr>
<td>FIC</td>
<td>Flow Indicating Controller.</td>
</tr>
<tr>
<td>HPP</td>
<td>High Pressure Pump. The pump which pressurizes the feed water and forces it into the pressure vessels and elements, and through the membrane.</td>
</tr>
<tr>
<td>Interconnector</td>
<td>The component which connects and seals the permeate tubes of the individual elements within a pressure vessel.</td>
</tr>
<tr>
<td>% Recovery</td>
<td>The percentage of feed water that is recovered as permeate.</td>
</tr>
<tr>
<td>PCV</td>
<td>Pressure Control Valve.</td>
</tr>
<tr>
<td>Pressure Vessel</td>
<td>The component which houses individual elements and allows pressurized feed water to flow through RO elements.</td>
</tr>
</tbody>
</table>
## REVERSE OSMOSIS

### Chapter 28: Reverse Osmosis Unit - Equipment

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RO Unit</td>
<td>The pressure vessels and other components fed by one high pressure pump.</td>
</tr>
<tr>
<td>Segmented Ring</td>
<td>The component which constrains the end caps when a pressure vessel is pressurized.</td>
</tr>
<tr>
<td>Shims</td>
<td>Circular pieces of plastic pipe used to fill any spaces left in a loaded pressure vessel in order to reduce the motion of RO elements during operation.</td>
</tr>
<tr>
<td>Stage</td>
<td>Parallel pressure vessels fed by a common feed source. There are generally two stages in most RO units. The first stage receives feed water from the high pressure pump. The second stage receives feed water from the first stage.</td>
</tr>
<tr>
<td>Thrust Collar</td>
<td>The component which is put at the downstream end of a pressure vessel in order to reduce forward motion when the high pressure pump is energized.</td>
</tr>
</tbody>
</table>
Chapter 28: Reverse Osmosis Unit - Equipment

PURPOSE: The purpose of this chapter's material is to thoroughly understand the equipment and connections within an RO unit.

INTRODUCTION

From the previous chapters, we understand:

1. The process of osmosis
2. The process of reverse osmosis
3. That both osmosis and reverse osmosis require a semipermeable membrane
4. What semipermeable membranes are and how they work
5. The various configurations that semipermeable membranes are placed in, such as tubular, plate & frame, hollow fiber, and spiral wound
6. The characteristics (specification sheet information) of the majority of spiral wound and hollow fiber elements sold in the US

But an RO element can’t do anything by itself, of course. It must be placed into a system which includes piping, instrumentation, pumps, and other process equipment. In this chapter we will look at the equipment into which elements are placed, and the equipment needed to place multiple elements in series. In the following chapters we will look at some design criteria and what happens to pressure, flow, and salt concentration within an RO unit.

PRESSURE VESSELS

We know that in order to force water through a semipermeable membrane, we must have net driving pressure (NDP). We must have an applied pressure which will overcome the feed water's osmotic back pressure and also the permeate back pressure. The required feed water applied pressure is generated by a high pressure pump. For RO membranes, the applied pressure is generally around 200 psi (13.8 bar) for thin films, and around 400 psi (27.6 bar) for cellulosic types.

Since 200 - 400 psi (13.8 - 27.6 bar) is a significant pressure, the RO elements must be housed in a system that can withstand pressure in this range. The piece of equipment which houses RO elements is called a pressure vessel. A pressure vessel is a hollow tube (Figure 28.1).

Figure 28.1
The tube is generally made of fiberglass although stainless steel is sometimes used for smaller systems. Under-the-kitchen-sink, low-pressure home RO units generally have plastic pressure vessels.

The inner diameter (ID) of the pressure vessel will be around the size of the outer diameter (OD) of the element. So, if the OD of the element is 7.9" (20.1 cm), the ID of the pressure vessel will be 8" (20.3 cm).

The thickness of the wall of a pressure vessel is determined by the pressure of the system. A 100 psi (6.9 bar) nanofiltration membrane system may have a wall thickness of less than 1/2" (1.3 cm), whereas a 1000 psi (69 bar) seawater RO system may have more than 2" (5.1 cm) thick walls.

There are different pressure vessel (pv) designs. Some membrane manufacturers sell pressure vessels which they either manufacture themselves, or have them manufactured under their specifications. They all function the same, though they may have a different appearance. The difference in appearance is generally due to differences in the way that the two open ends of the pressure vessel are sealed (described later). Figure 28.2 provides three examples of PVs.

Pressure vessels can be manufactured to house a single element or multiple elements. The only difference is the length of the pressure vessel. The most common number of 40" (1.02 m) elements per pressure vessel is six (for larger RO units). The range is from 1 - 7 elements per pressure vessel.
PRESSURE VESSEL INTERNALS

We will now look at the elements and their connections within a pressure vessel (PV). We'll first look at a two-element PV (Figure 28.3), then a six element PV.

Elements and Brine Seals

Elements are placed into a PV. In Figure 28.4, two elements are placed into a PV.

Elements must be loaded into the feed water end of a PV because each element has a brine seal on one end (usually on the feed water end). The purpose of the brine seal is to provide a seal between the outer surface of the element and the inner surface of the PV. If this area is not sealed, some feed water will BYPASS the elements by flowing around them instead of through them. This will reduce the RO unit’s performance and cause problems (discussed later).
The brine seal is placed into a groove in one of the antitelescoping devices (ATD). It is most common to place the brine seal in the feed water-end ATD (Figure 28.5). The rationale is that less suspended particles will be lodged between the element and PV by putting the seal there.

![Diagram of Brine Seals](Image)

**Figure 28.5**

The brine seals act as a “check valve” in a way. The “flap” of the brine seal will “open” with flow in one direction, and “close” with flow in the opposite direction (Figure 28.6).

![Brine Seals Diagram](Image)

**Figure 28.6**

Because of the construction of the brine seals, the elements must be loaded and removed in one direction. If the elements are pushed in “backwards”, the brine seals will open and make it impossible to load. Therefore, the elements are loaded into the feed water end of each PV and removed from the concentrate (downstream) end of each PV. By doing it this way, the brine seals are “closed” when loading and unloading elements, and “open” when the flow is started (Figure 28.7).

![Diagram of Pressure Vessel](Image)

**Figure 28.7**
Permeate Tube Connections

The elements must be connected to each other and to the permeate piping. The elements have an interconnector between them which connects and seals the internal permeate tube of each element (Figure 28.8). Interconnectors may have one or two o-rings on both ends.

![Figure 28.8](image)

Some elements have their permeate tubes sticking out past the ATDs. For other elements, the permeate tubes are flush with the ATDs. If the permeate tubes stick out, an external interconnector is needed, which goes on the outside of each tube. If the permeate tubes are flush, an internal interconnector is required (Figure 28.9).

### Interconnectors

![Internal Connector](image)

![External Connector](image)

The elements' permeate tubes must also be connected to and sealed to the end caps. An end cap adaptor is the piece that connects the end cap with an element. It has o-rings to seal at the end cap and at the element (Figure 28.10).

![Figure 28.10](image)
The performance of an RO unit is not affected significantly by which end of the PV permeate is removed. Permeate is removed from whichever end requires the least amount of piping. Whichever end is NOT used, is sealed (Figure 28.11).

![Figure 28.11](image)

**End Caps**

At each end of a PV there is an *end cap*. The end caps seal the two open ends of the PV so it can be pressurized (Figure 28.12).

![Figure 28.12](image)

Feed water enters a PV through a port in an endcap. Permeate and concentrate exit a PV through ports in an endcap. (Figure 28.13).

![Figure 28.13](image)
REVERSE OSMOSIS

Chapter 28: Reverse Osmosis Unit - Equipment

The end caps must be kept from "blowing out" when the system is pressurized. The end caps are secured differently for different PV designs. The most common method is by segmented rings (Figure 28.14). Another method is the use of a "clam-shell" lock. "Vicatuc"-type couplings are common on smaller diameter units.

With the segmented ring design, a groove is manufactured into the inner surface on either end of a PV. After the end caps are installed the segmented rings slip into the groove and provide an end-cap stop when the system is pressurized.

![Diagram of pressure vessel with segmented rings and flow directions](image)

Figure 28.14

Thrust Collars and Shims

When the high pressure pump starts there is a surge of flow and pressure. This pushes the elements forward. The elements will move to whatever extent that the fittings and clearances allow. Figure 28.15 provides an exaggerated movement of elements..

Element Movement
Grossly Exaggerated

![Diagram of element movement](image)

Figure 28.15

At the downstream (concentrate) end of each PV, a thrust collar is installed in order to minimize the forward movement and also to take the load off of the end cap adaptor (Figure 28.16). This limits the forward movement.

Element Movement
with Thrust Collar

![Diagram of element movement with thrust collar](image)

Figure 28.16

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When the high pressure pump is turned off, movement in the reverse direction occurs. The elements snap back if there are any spaces allowing this. In order to reduce the amount of movement of the elements when a system is shut off, shims are added at the feed water end of the permeate tube if there is any space there after loading the elements.

In Figure 28.17, we can see that when the high pressure pump is energized, the elements will be pushed forward. When the pump is turned off, the elements will snap back because there is space between the end cap adaptor and the end cap. This will cause wearing of the o-rings every time the system is turned on and off. This will eventually cause leaking problems.

To correct this, shims of PVC (usually) pipe are cut in sixteenths, eighths, and quarters of an inch. These shims are placed in the end cap/end-cap adaptor space so that when the high pressure pump is turned off, the backward movement is limited.

**Shims**

![Shims Diagram](image)

**RO UNIT**

An RO Unit is generally considered the equipment (piping, instrumentation, valves, and PVs) fed by one high pressure pump (HPP). Only very small RO units have only one pressure vessel. It is more common to have several PVs in an RO unit. Pressure vessels are arranged in stages. A stage consists of a number of PARALLEL PVs with a common feed source.

Two stages is the most common configuration. In a two-stage system, the feed water from a high pressure pump feeds one set of pressure vessels. This is the first stage. The concentrate from the first stage is manifolded and becomes feed water to a second set of parallel PVs. This is the second stage. Figure 28.18 illustrates a two-stage RO unit.

![Two-Stage RO Unit Diagram](image)
Chapter 28: Reverse Osmosis Unit - Equipment

In Figure 28.18, we see that there are two PVs in the first stage, and one PV in the second stage. The number of PVs in the first and second stages is called the array. An RO unit with two PVs in the first stage and one PV in the second stage has a 2:1 array. If there had been 5 PVs in the first stage and 3 PVs in the second stage, the unit would have a 5:3 array.

The majority of larger RO units have an array which is a multiple of 2:1, such as 4:2, 6:3, 8:4, 10:5, etc. We’ll discuss the reason for this in the next section.

Each pressure vessel in a given stage performs essentially the same. In other words, whatever is happening in one PV in a stage, is happening in all the other PVs in that stage (Figure 28.19).

Notice that the feed water from the HPP is divided equally into the number of PVs in the first stage. The feed water enters the first element of each PV. Feed water passes through the first element and enters the second element. Feed water passes through the second element and into the third, and so on. Due to Net Driving Pressure supplied by the HPP, a portion of the feed water passes through the membrane, as permeate, and exits the unit through the permeate piping.
Chapter 28: Reverse Osmosis Unit - Equipment

After passing through 6 elements with a portion of the feed water passing through the membrane, the feed water is now more concentrated. In a 6-element PV, usually around 50% of the feed water passes through the membrane. The concentrate leaving the first stage, then, is around twice the concentration as the feed water going in.

The concentrated feed water leaving the first stage is manifolded and fed to FEWER PVs in the second stage. After passing through another 6 elements in series, around 50% is again removed. This results in 75% of the feed water passing through the membrane (75% Recovery). The remaining 25% is the waste stream (concentrate) which generally goes to drain (Figure 28.20).

![Figure 28.20](image)

**RO UNIT CONTROL**

We know that takes a certain Net Driving Pressure (NDP) in order to produce a certain amount of permeate. Let’s look at how this is controlled.

RO Units may have manual or automatic controls. Many RO units are controlled by computers, with operators sitting at control room monitor screens and making manual adjustments only as required.

We have to control two things, though, whether manually or automatically. We must control FLOWS and PRESSURES. We will discuss more of the reasons for the controls in later sections. At this point we just need to understand the equipment.

There are generally (but not always) two valves in an RO unit. There is generally a valve on the feed water piping between the HPP and the first stage. There is generally a valve on the concentrate piping just downstream of the second stage. The ONLY valve that should be on the permeate line is a three-way valve which is ALWAYS open to one place (drain) or another (storage tank). The reason for this is that the permeate line should never be valved closed. This will be explained in a later chapter. Figure 28.21 provides a simplified illustration of an RO unit.

![Figure 28.21](image)
The two valves work together to provide the correct pressures and flows. The feed valve is frequently called the flow control valve (FCV). The concentrate valve is frequently called the pressure control valve (PCV). We can’t change pressure without changing the flow, and vice versa, so the two valves have to work together.

There are different control schemes. A common control scheme is to control the permeate flow rate at a set amount. A desired permeate flow rate is determined. The set point is entered into a flow indicating controller (FIC) on the permeate line. The FIC sends a signal to the PCV to supply enough pressure (NDP) to produce the desired amount of permeate. Pressure is changed by the PCV opening (causing lower RO unit pressure) and closing (causing higher RO unit pressure).

The permeate FIC also sends a signal to the feed water FCV (by way of a feed water FIC) telling it to open or close to supply a given amount of feed water. The amount of feed water required is that amount which will allow a certain % Recovery. Remember that % recovery is the amount of feed water recovered as permeate. If an RO unit is designed for 75% recovery, and the permeate desired is 75 gpm (17 m³/hr), then the signal will tell the FIC to maintain a flow rate of 100 gpm (22.7 m³/hr). The FIC will control the FCV to accomplish this (Figure 28.22).

![Diagram](Figure 28.22)

There is generally a flow indicator (FI) on the concentrate line to measure the flow going to drain. It is also not uncommon for an RO unit to have only permeate and concentrate flow meters. The feed flow rate is the sum of the permeate and concentrate flows.

**MONITORING**

In order to effectively monitor an RO unit, we must have instrumentation. We will discuss monitoring and troubleshooting in later sections. At this point, we only need to understand the equipment needs.
Not all RO units have all of the instrumentation illustrated below. What is provided is optimal, however.

As shown, we have conductivity meters (C), to tell us the salt concentration in and out of the unit. We have pressure gauges (P) to tell us the pressures in and out of the unit. We have flow meters (F) to tell us the flow rates in and out. We have pH and temperature (T) measuring devices. These are all required for optimal monitoring. Again, we will discuss these in detail in later sections. Note: The subscripts are \( f = \text{feed} \), \( i = \text{interstage} \), \( p = \text{permeate} \), and \( c = \text{concentrate} \).
1 - 5. What's missing in the following picture?

1. _______  a. End Cap Missing  e. Thrust Collar Missing
2. _______  b. O-ring (s) Missing  f. Interconnector Missing
3. _______  c. Brine Seal Missing  g. Permeate Plug Missing
4. _______
5. _______

6 - 8. What is the array in each of the following RO units?
6. 6 first stage PVs and 4 second stage PVs
   Array _______
7. 18 first stage PVs and 9 second stage PVs
   Array _______
8. 7 first stage PVs and 4 second stage PVs
   Array _______

9 - 11. What will you set the permeate FIC to read in each of the following RO units if you have 100
gpm (22.7 m³/hr) of feed water to work with?
9. 50% recovery
   _______ gpm
10. 75% recovery
    _______ gpm
11. 80% recovery
    _______ gpm
12-14. What will the concentrate flow rate be in each of the following RO units if there are 500 gpm (113.6 m³/hr) of feed water to work with?

12. 50% recovery
   ________ gpm

13. 75% recovery
   ________ gpm

14. 80% recovery
   ________ gpm

15-17. What will the permeate FIC tell the concentrate PCV to do if we want to make 75 gpm (17 m³/hr) of permeate?

15. 

16. 

   a. Open
   b. Close
   c. Stay the Same
17. What will the feed FIC tell the feed FCV to do if we want 75% recovery and the permeate flow rates are where we want them?

- a. Open
- b. Close
- c. Stay the Same

18-20. What will the feed FIC tell the feed FCV to do if we want 75% recovery and the permeate flow rates are where we want them?

18. What will the feed FIC tell the feed FCV to do if we want 75% recovery and the permeate flow rates are where we want them?

- a. Open
- b. Close
- c. Stay the Same

19. What will the feed FIC tell the feed FCV to do if we want 75% recovery and the permeate flow rates are where we want them?

- a. Open
- b. Close
- c. Stay the Same
20.

a. Open
b. Close
c. Stay the Same
Chapter 28: Practice Exam Answers

1 - 5. What's missing in the following picture?

![Diagram of reverse osmosis system]

1. _f_
2. _a_
3. _d_
4. _c_
5. _g_

6 - 8. What is the array in each of the following RO units?

6. 6 first stage PVs and 4 second stage PVs
   Array 6:4

7. 18 first stage PVs and 9 second stage PVs
   Array 18:9

8. 7 first stage PVs and 4 second stage PVs
   Array 7:4

9 - 11. What will you set the permeate FIC to read in each of the following RO units if you have 100 gpm (22.7 m³/hr) of feed water to work with?

9. 50% recovery
   50 gpm (11.4 m³/hr)

10. 75% recovery
    75 gpm (17 m³/hr)

11. 80% recovery
    80 gpm (18.2 m³/hr)
12-14. What will the concentrate flow rate be in each of the following RO units if there are 500 gpm (113.6 m³/hr) of feed water to work with?

12. 50% recovery
    250 gpm (56.8 m³/hr)

13. 75% recovery
    125 gpm (28.4 m³/hr)

14. 80% recovery
    100 gpm (22.7 m³/hr)

15-17. What will the permeate FIC tell the concentrate PCV to do if we want to make 75 gpm (17 m³/hr) of permeate?

15. [Diagram showing the flow of water through two stages of a reverse osmosis system, with flow rates and pressures indicated.]

   a. Open
   b. Close
   c. Stay the Same

16. [Diagram showing similar stages with different flow rates and pressures.]

   a. Open
   b. Close
   c. Stay the Same
17. a. Open  
b. Close  
c. Stay the Same

18-20. What will the feed FIC tell the feed FCV to do if we want 75% recovery and the permeate flow rates are where we want them?

18. a. Open  
b. Close  
c. Stay the Same

19. a. Open  
b. Close  
c. Stay the Same
20.

a. Open
b. Close
c. Stay the Same
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If your score is below 70% we recommend that the chapter be reviewed and that you retake the
exam. Exams are allowed to be submitted only twice.

<table>
<thead>
<tr>
<th>Score Range</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% - 93%</td>
<td>A</td>
</tr>
<tr>
<td>92% - 85%</td>
<td>B</td>
</tr>
<tr>
<td>84% - 77%</td>
<td>C</td>
</tr>
<tr>
<td>76% - 69%</td>
<td>D</td>
</tr>
<tr>
<td>68% - 0%</td>
<td>F</td>
</tr>
</tbody>
</table>

Minimum requirements: Processor - P233 Mhz; Memory - 32 MB RAM; Operating System - Windows 98 or later; CD Player - 4X or
higher; 256 Color Video Display (16 bit or higher recommended) MCI compatible video card.