13

RO membrane unit configuration

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Configuration of RO system reflects the subsequent process stages: raw water is delivered to the plant, it is treated to the required feed water quality, feed stream is separated into permeate and concentrate streams, permeate is treated and pumped to the distribution system, the concentrate is disposed through the outfall according to regulations.

Depending on type of feed water treated in the RO plant, the configuration, type of equipment and materials of construction will vary. In most instances the salinity and ions composition of municipal waste water reflects the salinity and composition of potable water in the area. The salinity of influent to the wastewater reclamation system usually is below 2000 ppm TDS. Therefore, the operating parameters of RO system are similar to these of brackish system treating low salinity feed water. The major difference between RO system treating wastewater effluent and the one designed to desalt brackish water, is configuration of the pretreatment unit. In majority of brackish systems, the pretreatment is limited to acidification and/or addition of scale inhibitor, followed by cartridge filtration. In wastewater reclamation system the pretreatment may include similar conditioning of feed water through addition of acid and scale inhibitor. In addition, the pretreatment process includes membrane filtration step. Membrane filtration technology used for pretreatment of RO feed in wastewater reclamation plants is discussed extensively in preceding chapters of this Guidebook.

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13.1 Pressure vessels

Membrane elements operate inside pressure vessels that enable application of high feed pressure and facilitate proper flow distribution. Pressure vessel assembly is configured as a tube with feed and concentrate ports, end plates and permeate ports (Fig. 13.1).

A a spacer, also called trust ring, located inside pressure vessel, is a device that prevents excessive movement of membrane elements during sudden changes of feed flow velocity. In the majority of commercial pressure vessels the vessel body is made of fiber reinforced plastic (FRP) material. Epoxy is usually used as a bonding agent. Some pressure vessels are manufactured from stainless steel tubes of standard dimensions. Feed and concentrate ports are made from high alloy steel. Two permeate ports, that are located at the centers of the two end plates, are made from plastic materials. Because the geometry and dimensions of spiral wound elements are standardized, pressure vessels are standardized also and designed to accommodate commercial membrane elements from any manufacturer. In some cases special permeate port adaptors may be required to connect last and first element permeate tubes to the pressure vessel head assembly. Pressure vessels are designed for a different operating pressure according to applications. For wastewater reclamation, pressure vessels with medium pressure rating of 31 bar (450 psi) are satisfactory.

Pressure vessels are designed to hold from 1 to 8 elements per vessel. Their dimensions vary accordingly as illustrated in Table 13.1.

Low pressure RO systems (brackish and nanofiltration) are designed with 6 or 7 elements per vessel. Seawater systems are designed with 7 or 8 elements per vessel. There is operational and cost advantage of using pressure vessels with 8 elements over the configuration with 6–7 elements. This subject will be discussed in details in Chapter 17.

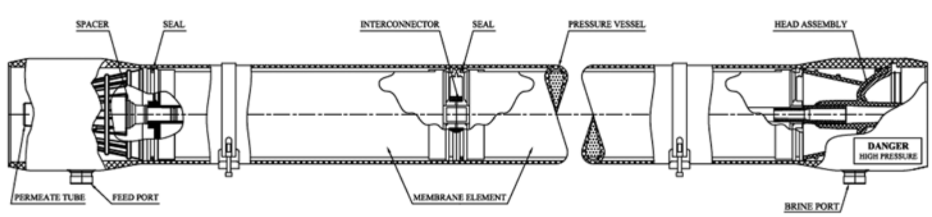

FIG. 13.1 Configuration of sideport pressure vessel with membrane elements (courtesy of Bell Industries).

TABLE 13.1
Dimension of pressure vessels for RO applications

Element type—elements number/PV	Inside diameter, mm (in)	Outside diameter, mm (in)	Length, mm (in)
8040–1	204 (8.02)	259 (10.2)	1478 (58.2)
8040–2	204 (8.02)	259 (10.2)	2494 (98.2)
8040–6	204 (8.02)	259 (10.2)	6558 (258.2)
8040–7	204 (8.02)	259 (10.2)	7574 (298.2)
8040–8	204 (8.02)	259 (10.2)	8590 (338.2)
4040–1	105 (4.13)	127 (5.0)	1194 (47)
4040–2	105 (4.13)	127 (5.0)	2210 (87)
4040–4	105 (4.13)	127 (5.0)	4242 (167)

13.1.1 Pressure vessels configurations: "sideport," "multiports" and "Optiflux"

Pressure vessels were initially configured to have feed and concentrate port located at the end plates (head assembly). In a latter design the feed and concentrate ports were installed directly into the body of the pressure tube, so called "sideport" configuration. Sideport configuration allows the feed and concentrate ports of the pressure vessel to be connected directly, through victaulic coupling, to the feed and concentrate manifold, as shown on Fig. 13.2. Picture of RO train with side port pressure vessels is shown in Fig. 13.3

Introduction of sideport technology enabled design of membrane units with slightly smaller footprint and elimination of piping connectors between pressure vessels, and feed and concentrate distributing manifolds. However, construction of membrane unit with sideport vessels requires precise positioning of outlet ports in the distribution manifold. The sideport technology also opened possibility for having more than one feed and concentrate ports in a pressure vessel. This, so called "multiportt" technology, commercial today, enables connecting pressure vessels to each others, through the feed and concentrate ports (1).

In this configuration the multiple feed and concentrate manifolds, with connections to two pressure vessels at the given level, are replaced with a single manifolds with "strings" of interconnected pressure vessels. The flow hydraulics in multiport configuration is similar to flow conditions in a sideport unit. The pressure vessels in the multiport configuration form a parallel network connecting the single entry and exit points through feed and concentrate ports

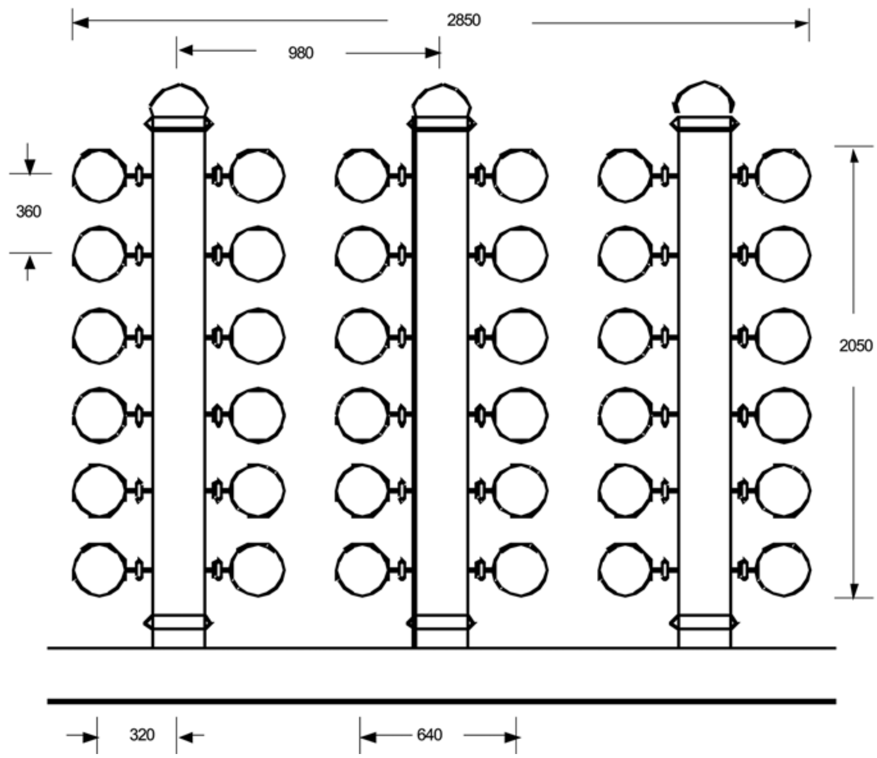

FIG. 13.2 Diagram of a membrane unit with sideport pressure vessels connected to the distribution manifold (measures in mm).

of the pressure vessel. These feed and concentrate ports, of the first pressure vessel, are directly connected to the corresponding feed and concentrate manifolds (Fig. 13.4–13.6). The connected parallel set of pressure vessels could be either horizontal or vertical.

As illustrated in Fig. 13.7, it is evident that multiport technology provides additional reduction of the membrane unit footprint and the quantity of high pressure piping used in unit construction is smaller. The obvious consideration is how many pressure vessels can be connected together in parallel. The recommendations for number of pressure vessels could be connected together are usually provided by the manufactures of pressure vessels. It will be dictated by the feed flow rate, which is a function of recovery rate, flux rate and number of elements per vessel. Accordingly a sizes of feed and concentrate ports are selected. At present the sizes are ranging from 50–100 mm (2–4″). The port sixe is

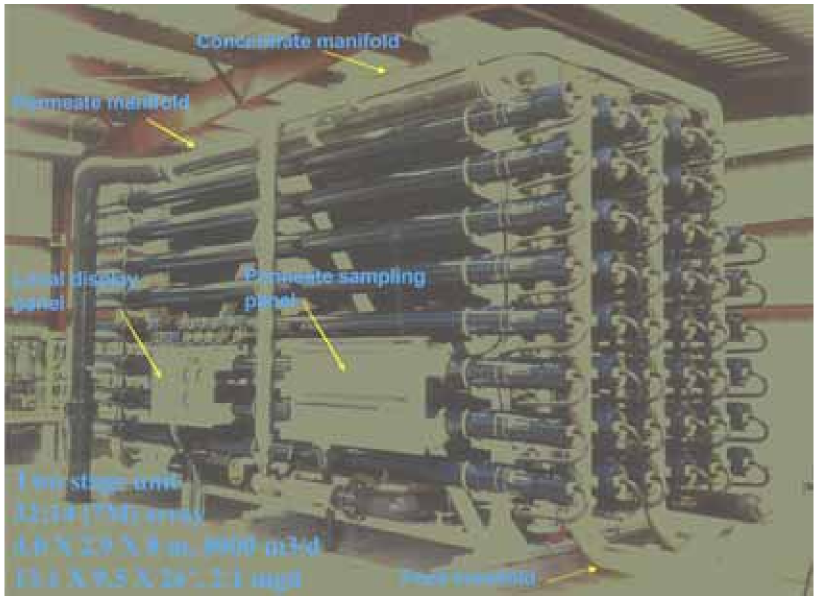

FIG. 13.3 Picture of a membrane unit with sideport pressure vessels.

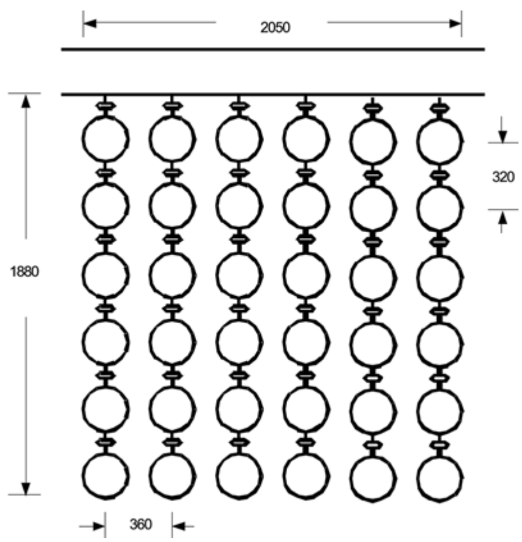

FIG. 13.4 Diagram of a membrane unit with multiport pressure vessels connected to the distribution manifold (measures in mm).

FIG. 13.5 Picture of connected multiport pressure vessels (courtesy Protec Pressure Vessels).

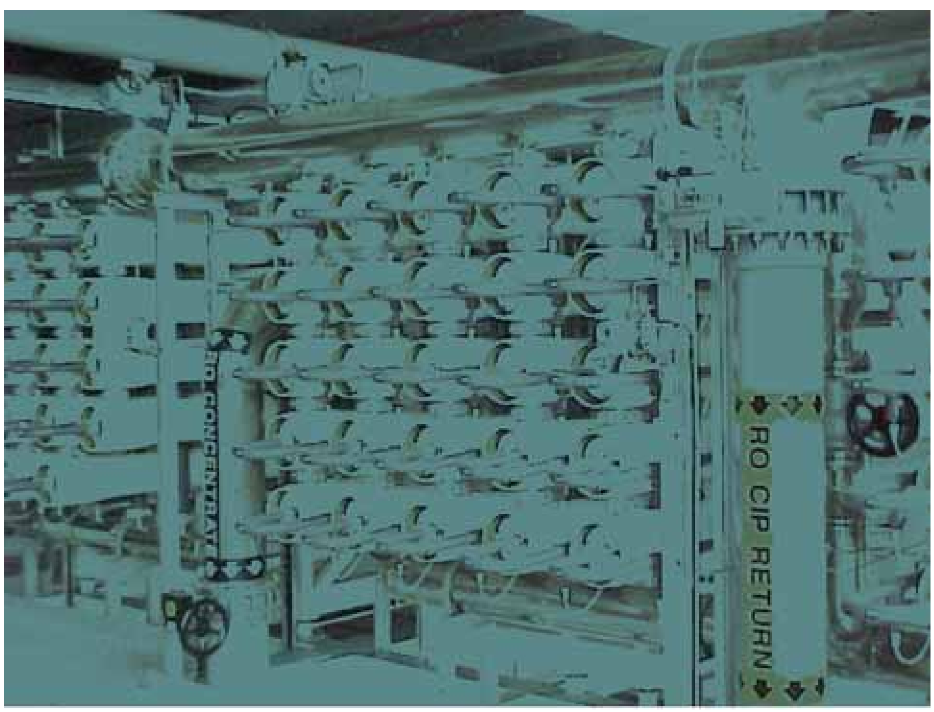

FIG. 13.6 Picture of a membrane unit with multiport pressure vessels.

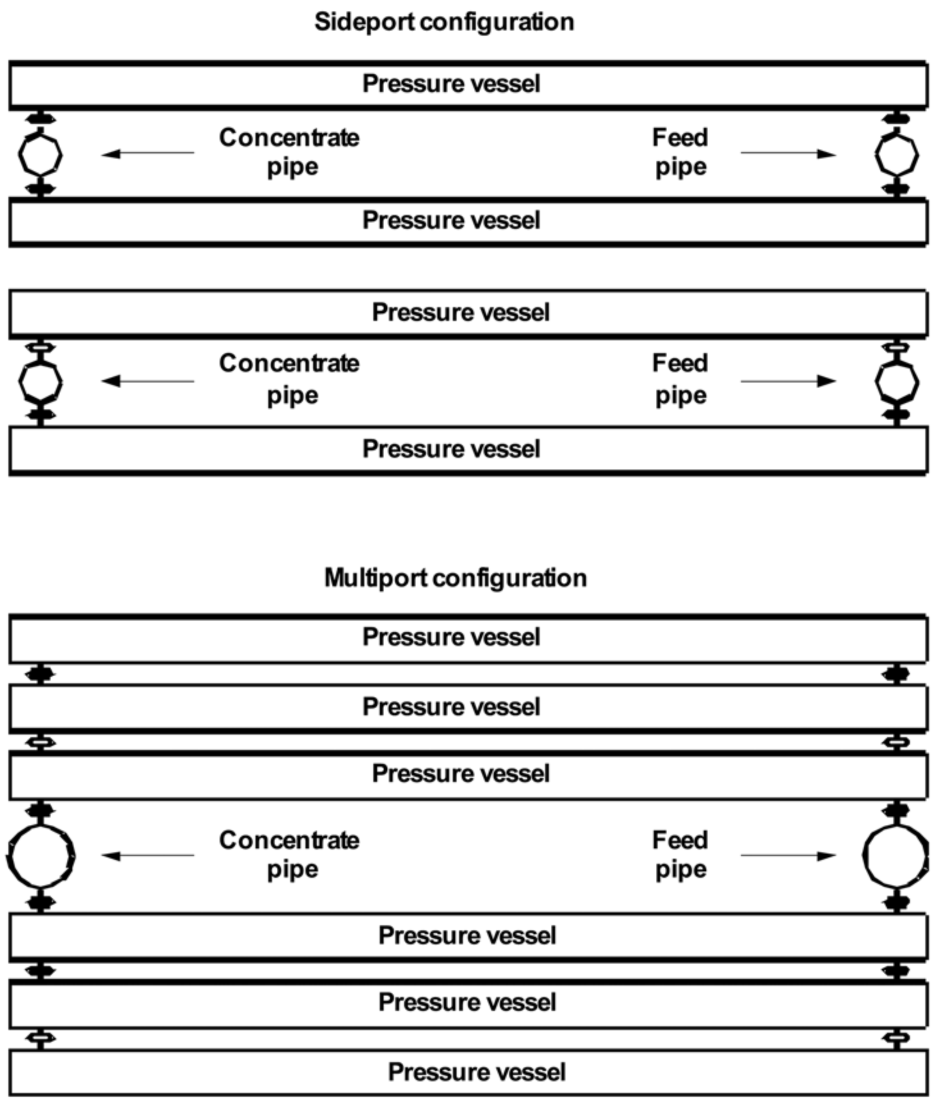

FIG. 13.7 Schematic configuration of a top view of sideport and multiport pressure vessel connections.

selected to keep the pressure drop through the entry/exit port of the first pressure vessel below 10% of the overall feed–concentrate pressure drop in the given stage (5). The pressure drop per stage in membrane unit is usually in the range of 2 bar (30 psi). Therefore, 0.2 bar (3 psi) pressure drop would be the upper limit for entry/exit pressure loses in a multiport configuration.

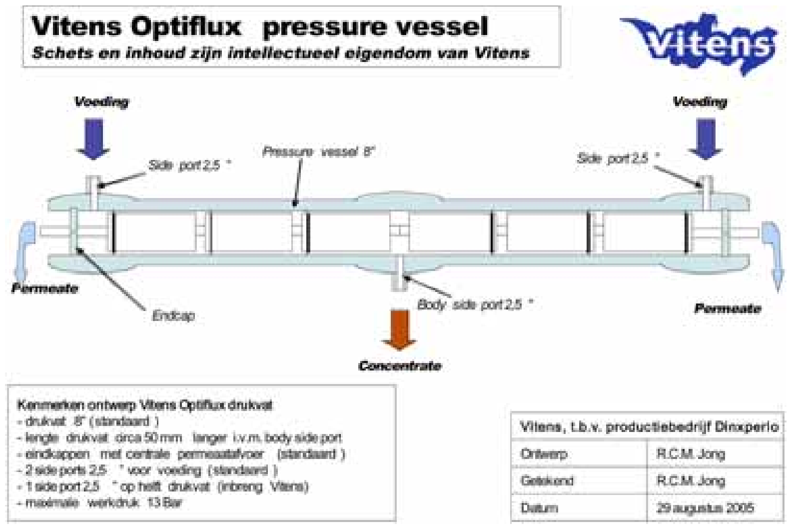

FIG. 13.8 Schematic configuration of Optiflux pressure vessel and corresponding flow path (courtesy Vitens).

Some pressure vessel manufacturers base the selection of port diameter on the flow velocity through the ports. The limit is 3m/sec (10 ft/sec).

One of the new entries to the RO pressure vessel market is "Optiflux" configuration (2). The Optiflux pressure vessels are configured to have short flow path of 3 membrane elements. This is accomplished by providing feed from both ends of pressure vessel. The pressure vessel that holds six membrane elements is divided in the middle. The concentrate from each half of the pressure vessel is collected at the middle of the vessel or at the both ends (Fig. 13.8).

The objective of development of the Optiflux configuration is reduction of internal friction losses, therefore lower feed pressure and energy requirements. This has been achieved through shorter feed–concentrate flow path, as shown in the Fig. 13.8. In the Optiflux configuration the recovery rate per membrane element is significantly higher than recommended by membrane manufacturers. It could be expected that such flow conditions would result in significantly higher concentration polarization. Small number of number of commercial nanofiltration plants, utilizing Optiflux pressure vessels have ben in operation for some time. Stable operation at field condition has been reported (2). It is somewhat questionable if this technology could be applied to other water sources with higher scaling potential.

13.2 Membrane assembly unit

The membrane assembly unit, the RO train, is the "engine" of the RO system. This is where the separation between water and dissolved species takes place. It consists of a frame supporting pressure vessels, interconnecting piping, and feed, permeate and concentrate manifolds, flow and pressure controlling valves. RO train also includes an instrumentation panel with local display of flow pressure and conductivities. In some systems permeate sampling panel is also included. This panel is a collecting point for permeate sampling tubing from individual pressure vessels. Depending on the size of RO train, it could be feed by single or multiple high pressure feed lines. Permeate and concentrate streams exit from RO trains are usually through single pipes. High pressure feed piping manifold, between discharge of high pressure pump and through RO train, is made of stainless steel (SS 316). The same material is used for construction of concentrate manifold, up to the concentrate controlling valve. Product piping could be made from plastic materials (HDPE or PVC) or lower schedule stainless steel piping.

The dimension of the membrane train is dictated by the output capacity, number of elements per pressure vessel, type of pressure vessels used (sideport or multiport) and number membrane elements connected to a single manifold. Incorporation of interstage pressure boosting equipment will result in larger footprint also. The size of RO train is dictated mainly by logistic of plant operation and product water supply, overall system reliability and flexibility of membrane cleaning operation.

RO plant can operate at partial product output, either by reducing feed pressure or by reducing number of RO trains in operation. Operations at lower feed pressure results in lower flux rate therefore in higher permeate salinity. Use of variable frequency convertors, to control operation of high pressure pump motors, is very common today. Therefore, energetic penalty for operation at lower feed pressure is not significant. This method of capacity control could be contemplated is permeate salinity will maintain within limits.

However, the common approach to control desalination plant output is to reduce number of RO trains in operation. If partial capacity has to be maintained for longer period of time (beyond one week), trains are being rotated, in and out of operation, to avoid flushing idle trains with preservative solutions.

Flexibility of membrane cleaning procedure is another consideration in decision of the membrane train size. Recommended flow rate of cleaning solution per vessel is about 9 m^3/hr (40 gpm). One cleaning attempt takes between 4–8 hr to complete. Some cleaning operations require 24 hr membrane soaking period. Therefore, it is desirable to clean a complete train or stage at once. For example, membrane train configured for cleaning of 100 pressure vessels at once, will require cleaning system capable to deliver about 1,000 m^3/hr (4,400 gpm) flow of cleaning solution. Much larger membrane trains that that, my require division of a train into separate segments of pressure vessels, incorporation disconnecting valves, to facilitate cleaning operation.

13.3 Concentrate staging

The membrane unit is divided into groups of pressure vessels, called concentrate stages. In each stage pressure vessels are connected in parallel, with respect to the direction of the feed/concentrate flow. The number of pressure vessels in each subsequent stage decreases in the direction of the feed flow. The configuration is usually in the ratio of 2:1. Thus, one can visualize that the flow of feed water through the pressure vessels of a system resembles a pyramid structure: a high volume of feed water flows in at the base of pyramid, and a relatively small volume of concentrate leaves at the top. The decreasing number of parallel pressure vessels from stage to stage compensates for the decreasing volume of feed flow, which is continuously being partially converted to permeate. Permeate from all pressure vessels in each stage, is combined together into a common permeate manifold.

The objective of the taper configuration of pressure vessels is to maintain a similar feed/concentrate flow rate per vessel through the length of the system and to maintain feed/concentrate flow within the limits specified for a given type of membrane element. Very high flow through a pressure vessel will result in a high pressure drop and possible structural damage of the element. Very low flow will not provide sufficient turbulence, and may result in excessive salt concentration at the membrane surface (concentration polarization). The limits of maximum feed flow and minimum concentrate flow are specified by membrane manufacturers for a given membrane element type depending mainly on combined height of the feed channels in the element and type of feed spacer net used.

A commercial RO unit usually consists of single pump and a multistage array of pressure vessels. A simplified diagram of a two stage RO unit is shown in Fig. 13.9. It is shown as having four, connected in parallel, pressure vessels in the first stage and two in the second stage. Feed enters the four pressure vessels in the first stage. The concentrate from the first stage becomes the feed to

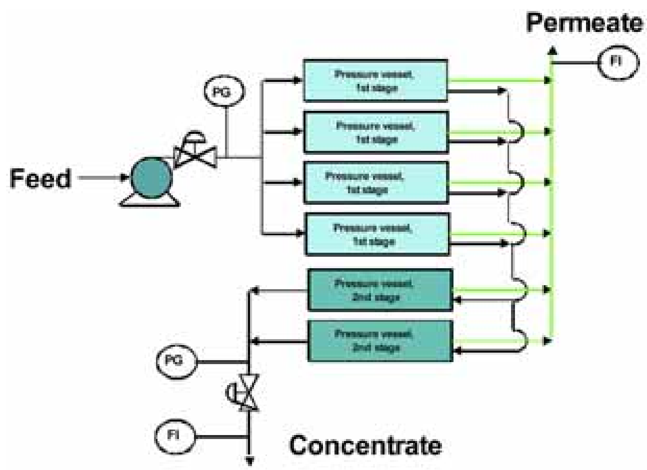

FIG. 13.9 Configuration of two stage RO unit.

the second stage; this is what is meant by the term "concentrate staging." Permeate from both stages are collected together in a common permeate manifold. The flows and pressures in the multistage unit are controlled with the feed and concentrate valves. The feed valve, after the high pressure pump, controls feed flow to the unit. The concentrate valve, at the outlet of RO train, controls feed pressure inside the unit.

For a given RO unit, the number of concentrate stages will depend on the permeate recovery ratio and the number of membrane elements per pressure vessel. In order to avoid excessive concentration polarization at the membrane surface, the recovery rate per individual membrane element should not exceed 18%. It is common engineering practice to design brackish RO systems so that the average recovery rate per 40 inch long membrane element will be about 6–8%. Accordingly, the number of concentrate stages for an RO unit having 6 elements per pressure vessel would be two stages for recovery rates over 60%, and three stages for recovery rates over 75%. With pressure vessels containing seven to eight elements, a two stage configuration would be sufficient for recovery rates up to about 85%.

Fig. 13.10 shows 3-D drawing of an RO train in a two stage configuration. Feed, permeate and concentrate manifold are clearly indicated. The drawing corresponds to system using a multiport pressure vessels. In this unit four pressure vessels are connected as a group to a single feed and concentrate manifold

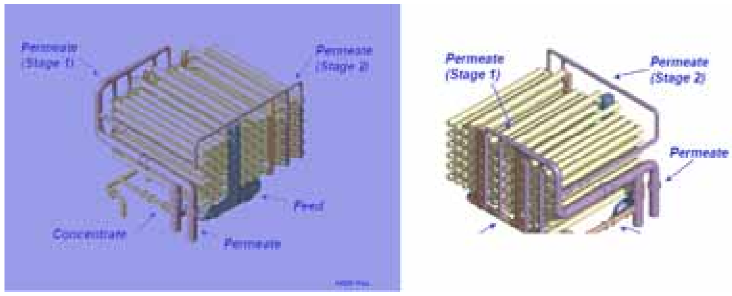

FIG. 13.10 3-D drawing of an RO train in a two stage configuration (courtesy CH2MHill).

ports. Unlikely the feed and concentrate ports, the permeate port from each pressure vessel is connected directly to the permeate manifold.

It is common design approach to have number of pressure vessels in subsequent stage in a 2:1 ratio. The objective is to maintain a similar feed–concentrate flow per pressure vessel through the membrane unit. The assumption is that in each stage about 50% of feed flow is converted to permeate. Therefore, about half of the feed flow leaves the stage as a concentrate and is available as a feed to the next stage.

The Fig. 13.3 shows a picture of a commercial, two stage, brackish train. The array is 32:14 sideport pressure vessels with 7 elements per vessel. The picture shows two parallel feed manifold with 4×8 pressure vessel connected, as a first stage. The two feed manifolds distribute feed water to feed port of first

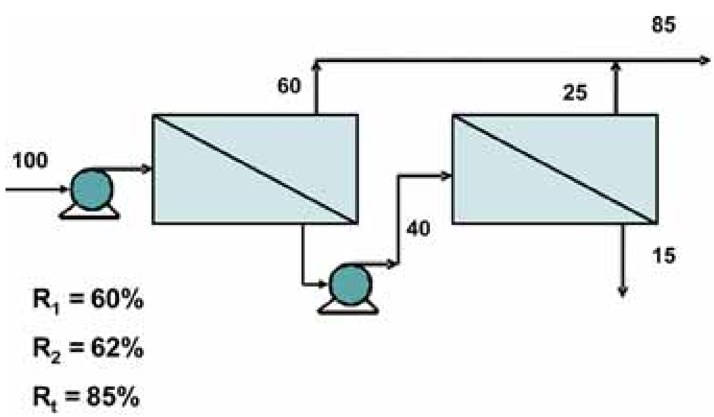

FIG. 13.11 Configuration of a two stage membrane unit with interstage booster pump.

stage pressure vessel. The first stage concentrate is collected from the concentrate ports of 32 first stage pressure vessels into a common manifold, at he back of the unit, and fed to 14 second stage vessels. The concentrate outlets from the second stage vessels are connected to the concentrate manifold. The concentrate throttling valve located on the concentrate pipe is shown as well. The feed and concentrate distribution manifold is made of 316 stainless steel. The vertical, permeate collecting manifolds are made also of 316 stainless steel. They are connected to the permeate outlet pipe made of PVC. The train is equipped with permeate sapling panel, which enables sampling permeate conductivity from individual vessels and local display panel of flow, pressure, feed temperature and conductivities.

The unit shown in Fig. 13.3 contains total of 322 membrane elements, each 200 mm (8″) diameter, 1000 mm (40″) long, and is capable of about 8,000 m^3/day (2.1 mgd) of permeate at recovery rate of 80%.

The unit configuration is eight vessels high and six vessels wide. This translates into unit dimensions of 4.0 m high, 2.9 m wide and 8.0 m long ($13.1' \times 9.5' \times 26'$).

13.4 Permeate flux and flow distribution

It is schematically illustrated if Fig. 11.6 the changes of NDP along the membrane unit. In this figure the changes of NDP are depicted as straight lines for simplicity of presentation. In actual system the NDP changes are more complex, due to nonlinear changes of recovery rate and concentrate salinity along the membrane unit. However, the NDP at the feed and concentrate end would be the same as shown in Fig. 11.6. This is because feed salinity and the recovery rate of the membrane unit determine NDP at the feed entrance and concentrate exit points. Examples of average permeate flux and calculated flux of individual elements at the lead and tail positions in a two stage membrane unit are listed in Table 13.2.

The results in Table 13.2 indicate that in the membrane unit the differences of permeate flux rate between lead and tail elements are quite significant. The flux difference increases with increase of temperature and system recovery rate. There is a concern that high permeate flux in the elements in lead position could accelerate fouling by dissolved organics present in the feed water. Evaluation of elements after field operation usually shows that the lead elements have somewhat higher accumulation of foulants and increased water permeability decline

TABLE 13.2
Flux distribution in a two stage RO unit

Feed salinity, ppm TDS	Feed temp., °C	Recovery rate, %	Avg. flux 1st stage, $l/m^2/hr$ (gfd)	Avg. flux 2nd stage, $l/m^2/hr$ (gfd)	Flux first element 1st stage, $l/m^2/hr$ (gfd)	Flux last element 2nd stage, $l/m^2/hr$ (gfd)	Permeate salinity, ppm TDS
1000	14	85	23.8 (14.0)	13.0 (7.7)	27.5 (16.2)	7.8 (4.6)	23
1000	28	85	26.0 (15.3)	8.7 (5.1)	32.6 (19.2)	4.1 (2.4)	57
1500	14	80	24.1 (14.2)	12.2 (7.2)	28.6 (16.8)	7.5 (4.4)	30
1500	28	80	26.3 (15.5)	8.2 (4.8)	34.5 (20.3)	3.9 (2.3)	75
2000	14	80	24.8 (14.6)	10.9 (6.4))	30.3 (17.8)	5.9 (3.5)	42
2000	28	80	27.0 (15.9)	6.5 (3.8)	36.7 (21.6)	3.1 (1.8)	106
2000	14	75	24.5 (14.4)	11.9 (7.0)	29.4 (17.3)	7.1 (4.2)	37
2000	28	75	26.5 (15.9)	7.8 (3.8)	35.7 (21.6)	4.8 (3.5)	90

(3, 4) but nowhere as significant as one would expect based on the distribution of permeate flux along the membrane unit. The general consensus is that, as long as the average flux is within values appropriate for the feed water quality, the overall permeability decline should not exceed the design values.

However, operation of elements in last positions at very low permeate flux could result in significant increase of permeate salinity. Therefore, in some cases it would be beneficial to equilibrate permeate flow between stages i.e. decrease permeate flow from the first stage and increase permeate flow from the last stage. This can be accomplished in one of two design configurations. One solution is to install a valve on the permeate line from the first stage. By throttling this valve, permeate back pressure will increase, reducing net driving pressure and reducing permeate flux from the first stage (see Equation 11.15). To compensate for lower permeate flow from the first stage the differential permeate flow is produced from the second stage by operating the RO unit at a higher feed pressure then would be required without permeate throttling. The other solution is to install a booster pump on the concentrate line between the first and the second stage (Fig. 13.12). The booster pump will increase feed pressure to the second stage. This configuration will result in lower permeate flow from the first stage and higher permeate flow from the second stage, i.e. more uniform permeate flux distribution. The advantage of the permeate throttling design is simplicity of the RO unit configuration and lower capital cost. However, this design results in additional power losses due to permeate throttling and higher

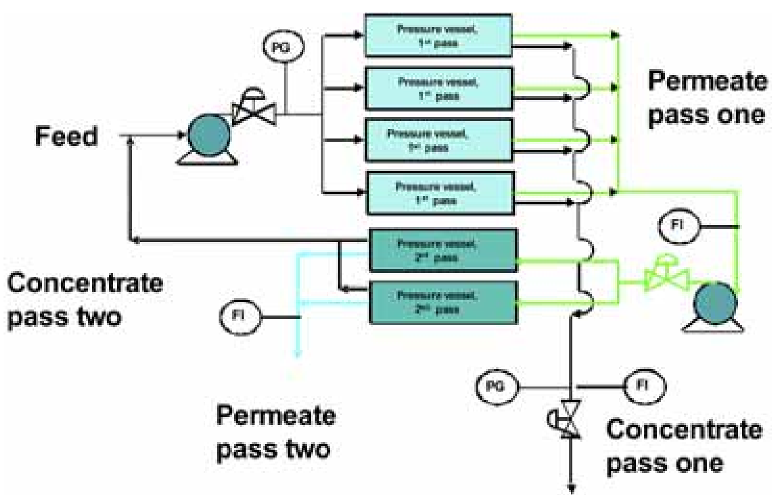

FIG. 13.12 Configuration of a two pass RO unit.

power consumption. The interstage pump design requires modification of the interstage manifold and an additional pumping unit. The investment cost is higher than in the first design configuration, but the power consumption is lower.

Additional configuration alternatives utilizing interstage booster are discussed in Chapter 16.

13.5 Permeate staging (two pass systems)

For some applications, the single pass RO system may not be capable of producing permeate water of a required salinity. Such conditions could be encountered in two types of RO applications:

Seawater RO systems, which operate on a very high salinity feed water, at high recovery ratio and/or at high feed water temperature.

Low pressure RO (brackish or wastewater reclamation) applications which require production of very low salinity permeate such as supply of makeup water for pressure boilers or production of rinse water for microelectronics applications.

To achieve an additional reduction in permeate salinity, the permeate water produced in the first pass is processed again in a second RO system. This configuration is called a two pass design, or "permeate staging." Fig. 13.13 contains schematic diagram of a two pass system.

Example of compositions of feed and permeate in a two pass system is included on Table 13.3. As shown in Table 13.3, salt passage is generally higher in the second pass system. This difference is especially high for passage of total organic carbon (TOC). These results provide some insight into process of rejec-

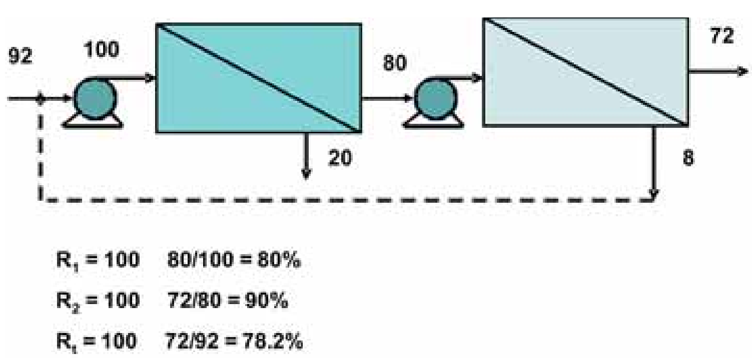

FIG. 13.13 Recovery rate in a two pass unit.

TABLE 13.3
Example of permeate salinity and salt passage in a two pass RO unit.

Constituent	Feed concentration, ppm	Permeate concentration pass 1, ppm	Permeate concentration pass 2, ppm	Salt passage, pass 1, %	Salt passage, pass 2, %
Conductivity	1120	31	2.5	2.8	8.0
Alkalinity	150	11.0	ND	7.3	
Sulfate	168	ND	ND		
Chloride	123	2.2	1.8	1.8	8.1
Calcium	38	0.02	ND	0.05	
Magnesium	17	0.01	ND	0.05	
Sodium	110	2.7	0.2	2.4	7.4
Potassium	15	0.3	ND	2.0	
Silica	25	0.2	ND	0.1	
Ammonia	30	2.0	0.2	6.7	10
TOC	10	0.3	0.2	3.0	67

tion of dissolved organic species in the reverse osmosis process. As the RO membranes in the first and the second pass are the same, this difference in TOC passage indicates that rejection of TOC is most likely base on size exclusion. The fraction of dissolved organic species that passed the first membrane barrier will pass the second barrier at much higher rate due to small molecular size and possibly lack of charges.

Depending on permeate quality requirements, part or all of the first pass permeate volume is desalted again in the second pass unit. The system configuration is known as a complete or partial two pass system according to whether all of the 1st pass permeate or only some fraction is fed to the second pass unit. The first pass permeate is a very clean water. It contains very low concentrations of suspended particles and dissolved salts. Therefore, it does not require any significant pretreatment. The second pass RO unit can operate at a relatively high average permeate flux and high recovery rate without concerns of concentration polarization and scaling. The common design parameters for the second pass RO unit are average flux rate of 34 l/m^2-hr (20 gfd) and recovery rate of 85%–90%.

In a two pass system, the permeate from the first pass flows through a storage tank or is fed directly to the suction of the second pass high pressure pump.

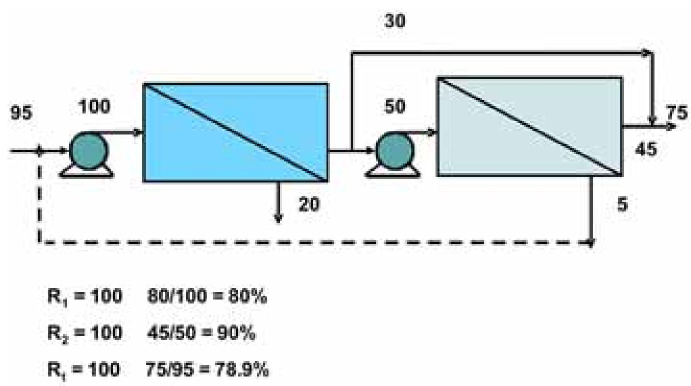

FIG. 13.14 Recovery rate in a partial two pass unit.

It is a common procedure in a two pass seawater RO systems to return concentrate from the second pass unit to the suction of the high pressure pump of the first pass unit. The dissolved salts concentration in the concentrate from the second pass is usually lower the concentration of the feed to the first pass unit. Therefore, blending feed water to the first pass with small flow rate of the second pass concentrate, reduces slightly the salinity of the feed to the first pass, and increases the overall utilization of the feed water (Fig. 13.14).

There are number of possible configuration of the two pass RO units. One configuration, which is a partial two pass system, is shown in Fig. 13.15. In this configuration the first pass permeate is split into two streams. One stream is

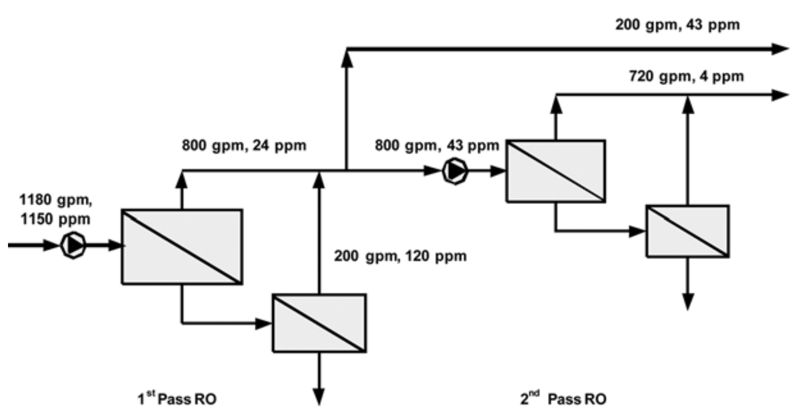

FIG. 13.15 Configuration of two pass system with processing of combined permeate from the 1st pass RO unit.

processed by the second pass unit, and it is then combined with the unprocessed part of the permeate from the first pass.

Provided that the partial two pass system can produce the required permeate quality, this configuration results in smaller second pass unit, therefore lower capital and operating costs, as well as higher combined permeate recovery rate (utilization of the feed water), compared to a complete two pass system.

Another partial two pass configuration, which takes advantage of internal salinity distribution of RO permeate could be processing through second pass permeate from a selected stage of the first pass unit. A two stage first pass system produces about 70–80% of product water in the first stage and the rest in the second stage. The second stage permeate salinity is much higher than salinity of permeate from the first pass, by a factor of 3–5. As shown in Table 13.4 the second stage, having only 20% of the total permeate flow, contributes 55% of salinity to the total permeate.

Depending of the RO system objectives and water demand, it could be beneficial to process permeate from a single stage only. It is obvious from Table 13.4, that processing only of first stage permeate with second pass unit will produce second pass permeate of lower salinity then could be produced by processing of the combined first pass permeate. The other option, processing of

TABLE 13.4
Feed and permeate salinities in a two stage RO unit

Component	Feed, ppm	Stage 1, ppm	Stage 2, ppm	Total, ppm
Ca	77	0.6	3.2	1.1
Mg	23	0.2	1.0	0.3
Na	213	4.8	27.3	9.3
K	5	0.1	0.6	0.2
HCO3	322	7.2	39.3	13.7
Cl	219	4.3	24.7	8.4
NO3	4	1.2	4.3	1.8
SO4	254	1.8	10.0	3.5
SiO2	22	0.4	1.5	0.6
B	0.5	0.4	0.6	0.4
TDS	1160	23.6	118.7	42.7
Flow fraction, %		80	20	
Salt transport, %		45	55	

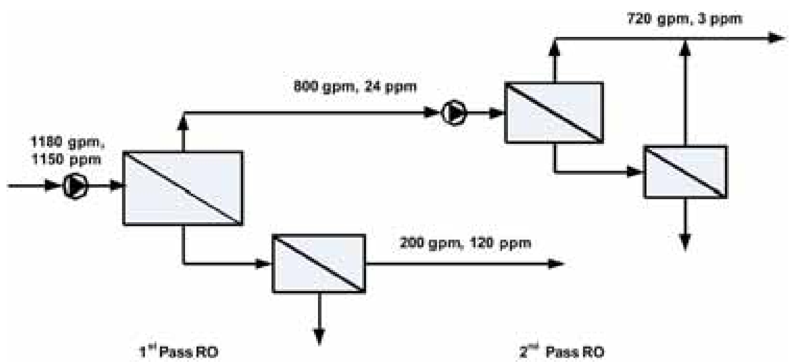

FIG. 13.16 Configuration of two pass system with processing of low salinity permeate (1st stage) from the 1st pass RO unit.

permeate from of the second stage, would result in smaller system size and reduction of operating cost but result in higher permeate salinity. Configuration of two alternatives of partial two pass system is shown in Fig. 13.15 and 13.16.

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