FILMTEC Membranes
System Design: Plug Flow vs. Concentrate Recirculation

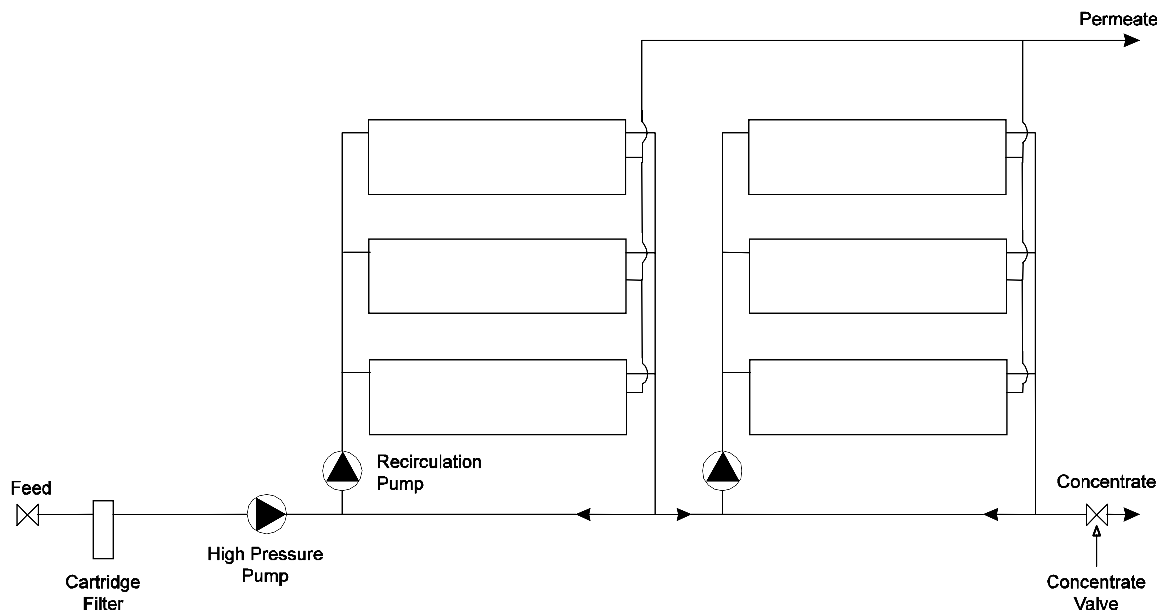
Plug Flow vs. Concentrate Recirculation

The standard RO system design for water desalination applications is the plug flow concept. In a plug flow system, the feed volume is passed once through the system. A certain fraction *Y* of the feed passes across the membrane to produce permeate. The feed is gradually concentrated and leaves the system at a higher concentration.

Concentrate recirculation is employed 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 waste waters. In systems with internal concentrate recirculation, a fraction of the concentrate stream out of the module (or stage) is directed back to the feed side of the module (or stage) and mixed with the feed stream.

Multi-stage systems can also be designed with internal concentrate recirculation for each stage, using a separate recirculation pump. For example, the system shown in Figure 3.5 can be designed with concentrate recirculation instead of plug flow, see Figure 3.6.

Figure 3.6 Two-stage system with internal concentrate recirculation



The main advantage of the recirculation concept is the defined feed flow rate to the modules regardless of the degree of fouling of preceding modules and the changes in feed water composition. Further aspects of the recirculation concept are mentioned in Batch vs. Continuous Process (Section 3.2), and Single-Module System (Section 3.3). A comparative summary is given in Table 3.3.

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Plug Flow vs. Concentrate Recirculation (cont.)

Table 3.3 Comparison of plug flow and recirculation systems

Parameter	Plug flow	Recirculation
Feed composition	Must be constant	Can vary
System recovery	Must be constant	Can vary
Cleaning circuit	More complicated	Simple
Compensating fouling	More difficult	Easy
Membrane pressure from feed inlet to concentrate end	Decreasing	Uniform
Power consumption	Lower	Higher (15 - 20%)
Number of pumps (investment, maintenance)	Lower	Higher
Extension, varying the membrane area	More difficult	Easy
Taking individual stages of multi-stage systems in/out of service	Not possible	Possible
System salt passage	Lower	Higher

The apparent salt passage of the system, SP_s, also called system salt passage, is defined as the concentration of a compound (may be a certain ion, an organic compound or TDS) in the permeate (C_p) related to its concentration in the feed water (C_f):

$$SP_s = \frac{C_p}{C_f} \qquad \text{Eq. 1}$$

In plug flow systems, SP_s is a function of the system recovery Y and the membrane salt passage SP_M:

$$SP_s = \frac{1-(1-Y)^{SP_M}}{Y} \qquad \text{Eq. 2}$$

where the membrane salt passage is defined as the concentration of a compound in the permeate (C_p) related to its average concentration on the feed-concentrate side (C_{fc}):

$$SP_M = \frac{C_p}{C_{fc}} \qquad \text{Eq. 3}$$

In systems with internal concentrate recirculation, however, there is an additional dependence on the Beta number β, which is defined as

$$\beta = \frac{\text{permeate flow leaving the module}}{\text{concentrate flow leaving the module}} \qquad \text{Eq. 4}$$

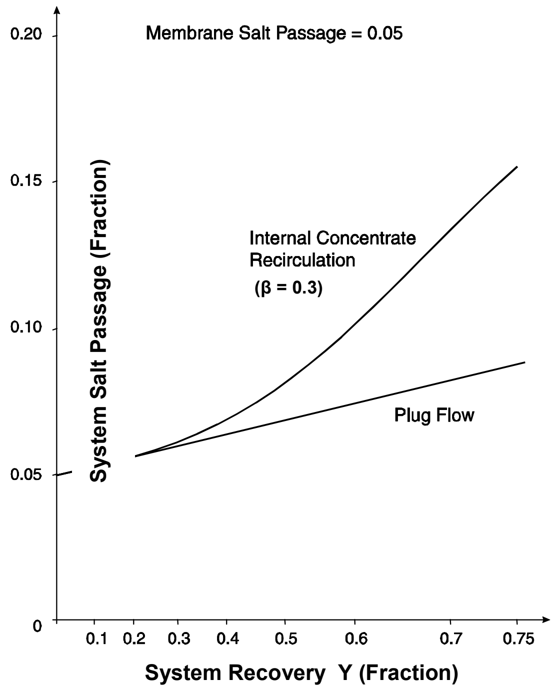
For systems with the concentrate being partly recycled to the feed stream, the system salt passage is

$$SP_s = \frac{(1+\beta)^{SP_M} - 1}{Y(1+\beta)^{SP_M} - Y(1+\beta) + \beta} \qquad \text{Eq. 5}$$

For high system recoveries, the system salt passage of a recirculation system is much higher than that of a plug flow system. This is demonstrated by a sample calculation, see Figure 3.7. The difference is less, however, for multi-stage systems with recirculation loops for each stage. The system salt passage of such a system (for an example, see Figure 3.6) has to be calculated by application of Eq. 5 to each stage.

Plug Flow vs. Concentrate Recirculation (cont.)

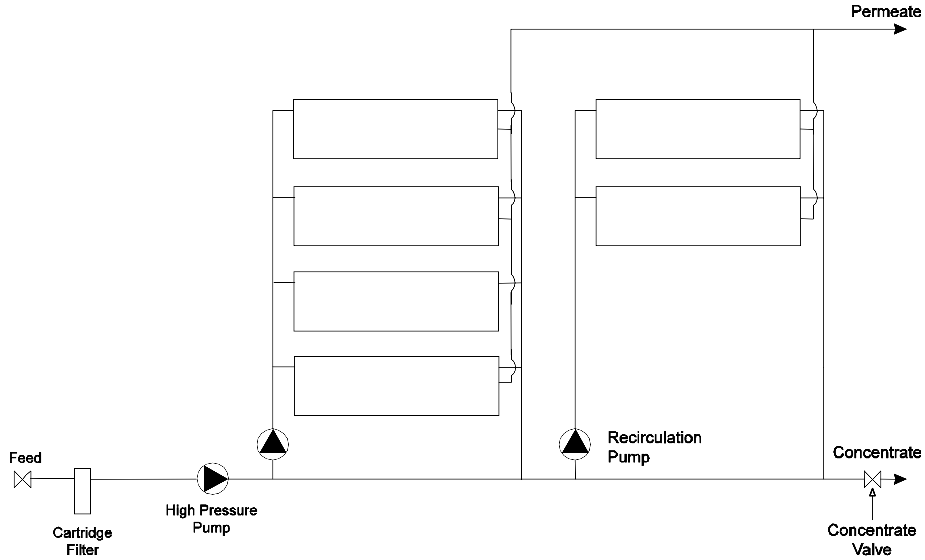
Figure 3.7 System salt passage for a plug flow and a concentrate recirculation system



When the recirculated concentrate stream approaches zero, the β number approaches 1/[(1/Y) –1], and the recirculation system becomes a plug flow system. A compromise between plug flow and recirculation systems is the tapered recirculation system with a declining number of parallel modules per stage when viewed in feed flow direction (see Figure 3.8).

The recirculation pumps can be tailored in such a way that only a minor part of the concentrate leaving the stage is recycled while the major part is flowing to the next stage (or to the concentrate outlet, for the last stage). Then, there are almost plug flow conditions, but the advantages of the recirculation concept are still present.

Figure 3.8 Tapered recirculation system



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