OLI Tips #74

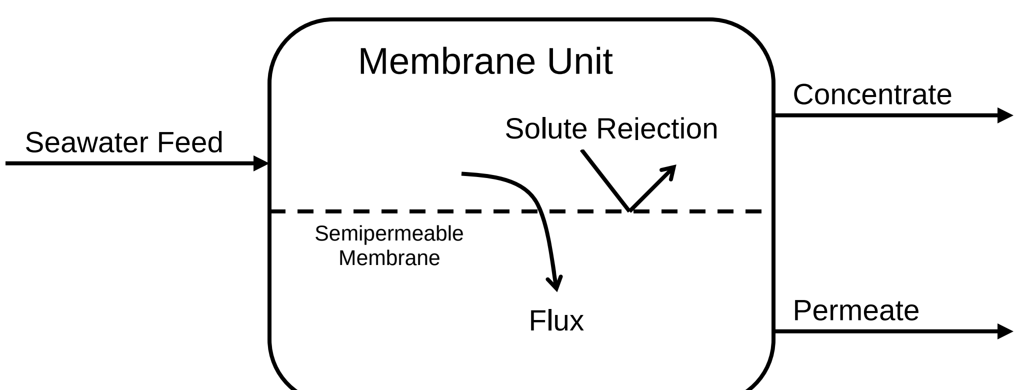
ESP Case Study: Membrane Separation – Sulfate removal from Seawater

Overview

For a high-sulfate seawater stream:

	Seawater Feed (1000 grams of H_2O)
	Moles
H_2O	55.5087
$CAOH_2$	0.0114093
HCl	0.605596
$KMgCl_3$	0.0107542
$MgOH_2$	0.0484974
$Na_6(SO_4)_2CO_3$	0.00251521
NaOH	0.496398
$Na_3(HSO_4)_2$	0.0131326

Temperature 25 ºC
Pressure 11 to 36 atm (depending upon hydraulic pressure drop of the Membrane)



The operating Parameters of the Membrane Unit include:

1. Total membrane area (m^2)
2. Membrane hydraulic pressure differential (atm)
3. Membrane permeability for water ($gm/hr/m^2$-atm)
4. Cation/Anion control of solute flux
5. Membrane permeable solutes and permeability (m/hr)

In base case will use the following:

Total membrane area = **2 m^2**
Membrane hydraulic pressure differential = **10 atm**
Membrane permeability for water = 40 $gm/hr/m^2$-atm
Cation/Anion control of solute flux = Cation control
Membrane permeable solutes and permeability:

	Permeability (m/hr)
OHION	5.00000E-05
CAION	5.00000E-05
CAOHION	5.00000E-05
CLION	5.00000E-05
CO3ION	5.00000E-05
HCO3ION	5.00000E-05
HION	5.00000E-05
HSO4ION	**5.00000E-06**
KION	5.00000E-05
KSO4ION	**5.00000E-06**
MGHCO3ION	5.00000E-05
MGION	5.00000E-05
MGOHION	5.00000E-05
NACO3ION	5.00000E-05
NAION	5.00000E-05
NASO4ION	**5.00000E-06**
CAHCO3ION	5.00000E-05
SO4ION	**5.00000E-06**

(Note that the permeability for all of the sulfate-containing solutes is smaller than the permeability of the other solutes. This is a reflection of the selective sulfate permeability of the membrane.)

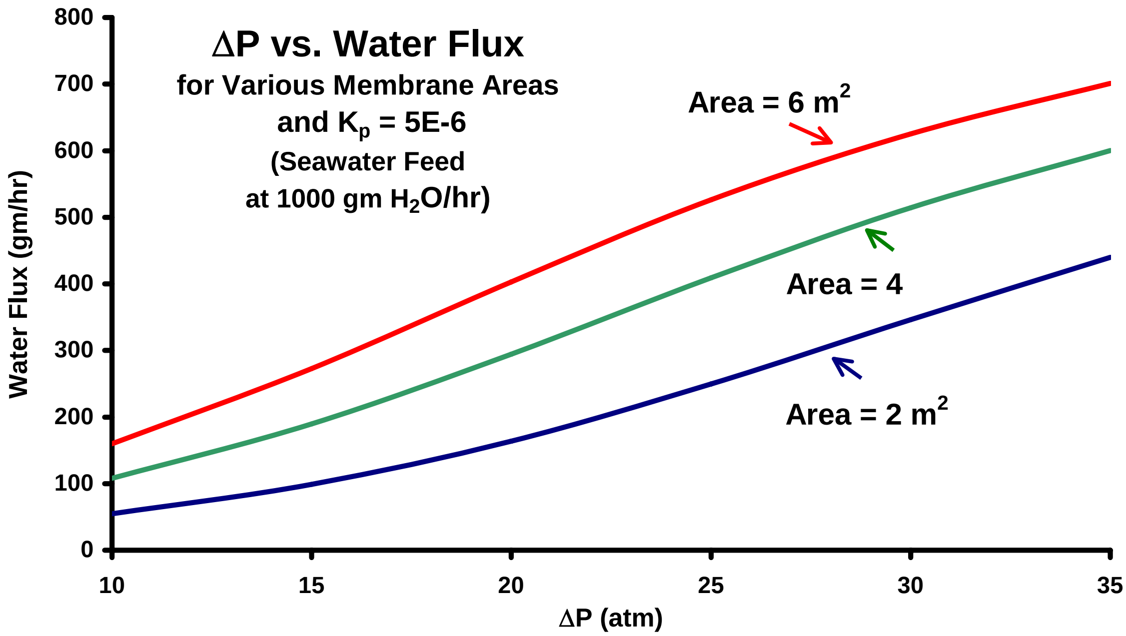
The three operating parameters varied in this study are those in bold in the above summary:

Total membrane area (2, 4, 6 m^2)

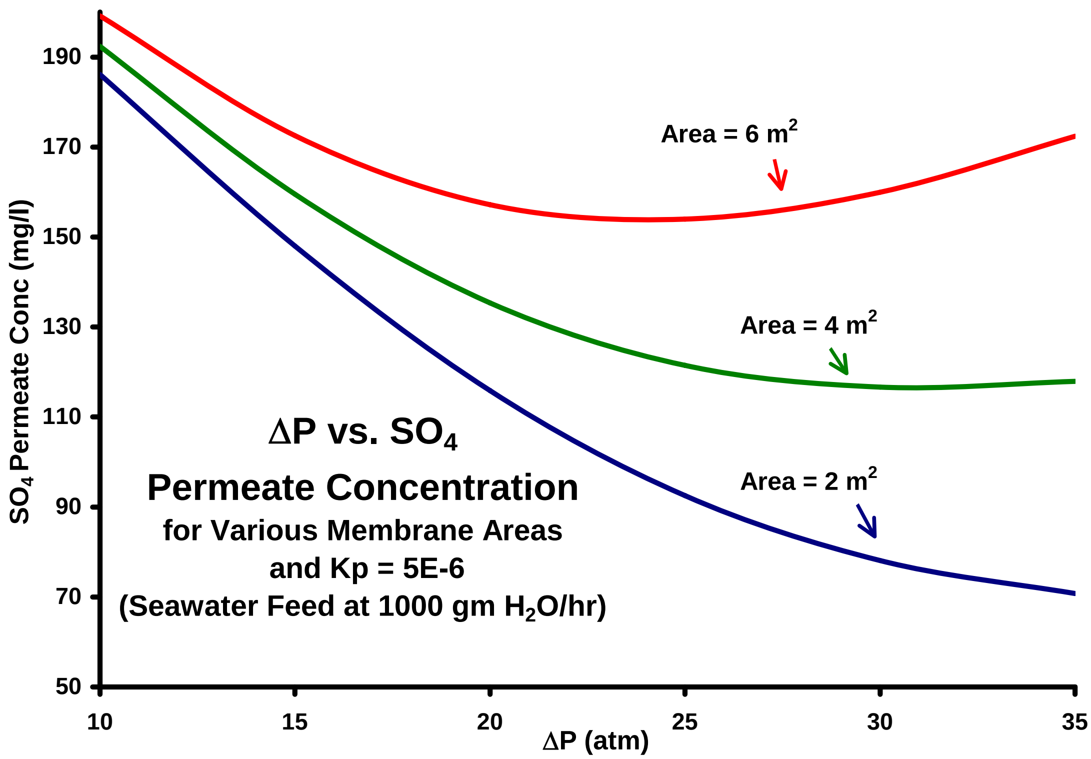
Membrane hydraulic pressure differential (10, 15, 20, 25, 30, 35 atm)

Sulfate membrane permeability (5E-06, 3E-06, 1E-06, 5E-07 m/hr)

The relationship of these parameters to water flux and sulfate permeate concentration is shown in the following graphs.

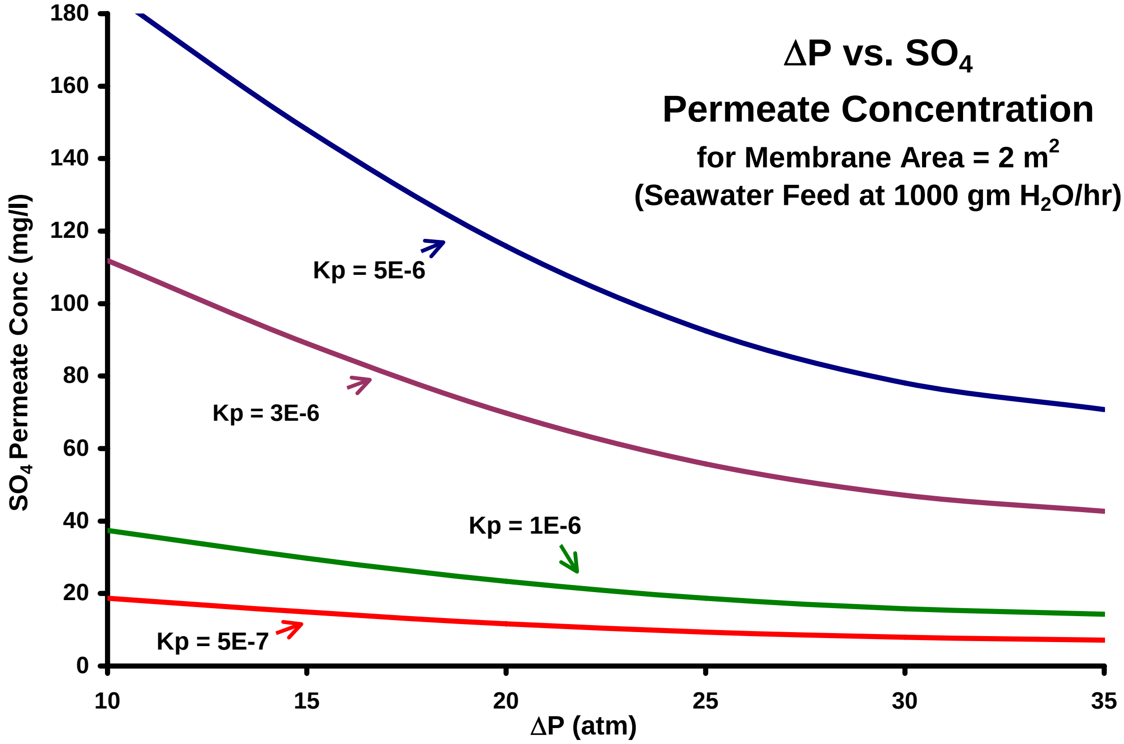


It can be seen that, as the hydraulic pressure differential (P) increases, the water flux increases. Likewise, increasing the membrane area also increases the water flux. (In all cases, the solute permeabities are constant.) Thus, both the hydraulic pressure differential and the membrane area can be manipulated to achieve a desired water flux.



For a given membrane area, the SO_4 permeate concentration decreases to a minimum and then begins to increase. For a given hydraulic pressure differential, the SO_4 permeate concentration increases as membrane area increases. (Again, in all cases, the solute permeabities are constant.)

However, if the membrane area is held constant (in this case, 2 m^2), the variation in SO_4 concentration as a function of sulfate membrane permeability can be seen in the graph shown below. (The bottom curve in the above graph is the top curve in the graph shown below.) For a given membrane pressure differential, as the sulfate membrane permeability decreases the sulfate permeate concentration decreases.



The membrane permeability for water can also be used to achieve desired results, but the water flux and solute permeate concentration is generally less sensitive to changes in this parameter. Thus, a desired water flux and solute permeate concentration can usually be achieved by adjustment of one or more OF the following:

1. hydraulic pressure differential
2. membrane area
3. solute membrane permeability

Example Case

For the specified seawater feed stream, two consecutive membrane units are used to create a combined permeate stream. The Membrane parameters are as follows:

For both Membrane Unit 1 and Membrane Unit 2:

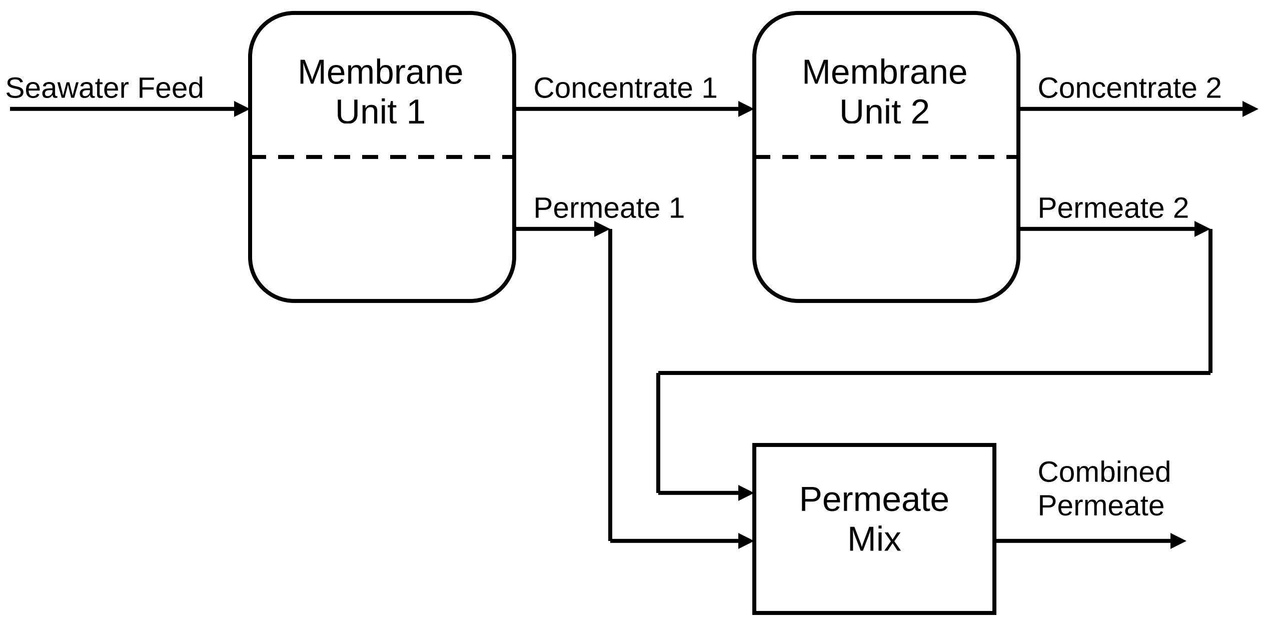
Hydraulic pressure differential:	25 atm
Permeability for Water:	40 gm/hr/(m^2-atm)
Permeability for all *sulfate species*:	7.0E-07 m/hr
Permeability for all other species:	5.0E-05 m/hr

Membrane Unit 1 area: 6 m^2
Membrane Unit 2 area: 4.5 m^2

Membrane permeable solutes:

OHION	**KSO4ION**
CAION	MGHCO3ION
CAOHION	MGION
CLION	MGOHION
CO3ION	NACO3ION
HCO3ION	NAION
HION	**NASO4ION**
HSO4ION	CAHCO3ION
KION	**SO4ION**

Note: The species in boldface are the *sulfate species* having lower permeability.



The seawater feed:

	moles/hr
H_2O	55.5087 (1000 gm/hr)
$CAOH_2$	0.0114093
HCl	0.605596
$KMgCl_3$	0.0107542
$MgOH_2$	0.0484974
$Na_6(SO_4)_2CO_3$	0.00251521
NaOH	0.496398
$Na_3(HSO_4)_2$	0.0131326

Temperature 18 ºC
Pressure 26 atm

The results are as follows[1]:

	Total Flow (gm/hr)	Total SO_4 (mg/l)	Solid Flow (gm/hr)
Seawater Feed	**1052**	**2940**	**0.0011**
Permeate 1	548	22.6	0.0
Concentrate 1	504	6223	0.0034
Permeate 2	214	62.8	0.00054
Concentrate 2	290	10915	0.092
Combined Permeate	762	33.8	0.0

The seawater feed contains 1052 gm/hr at a sulfate concentration of 2940 mg/l. The first Membrane Unit produces permeate containing 55% of the feed at a sulfate concentration of 23 mg/l. The second Membrane Unit produces permeate containing 21% of the seawater feed at a sulfate concentration of 63 mg/l. The resulting combined permeate represents 76% of the seawater feed at a sulfate concentration of 34 mg/l.

[1] These results were originally obtained using version 6.6 of the ESP software. Current results may be different.