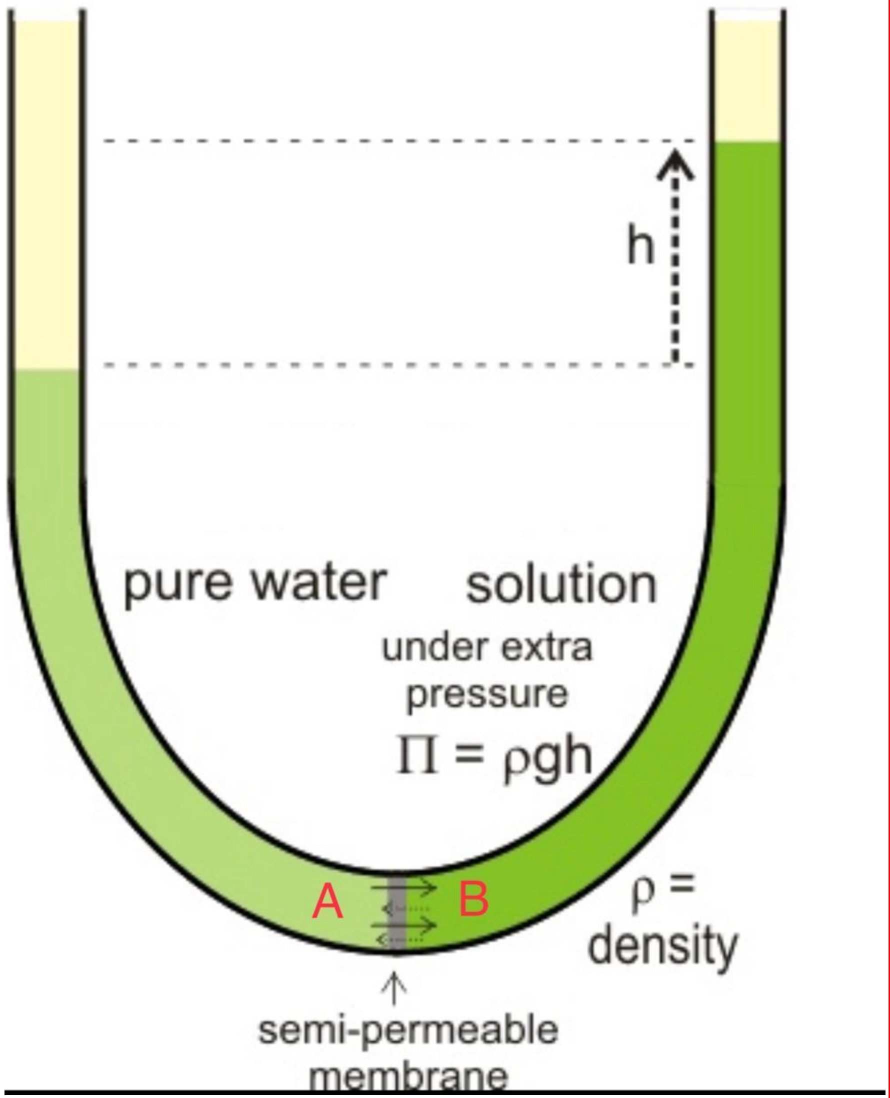
Reverse Osmosis Technology

إهداء الي منتدي خبراء تكنولوجيا المياه

1- Osmotic Pressure and Membrane History

The phenomenon of osmosis occurs when pure water flows from a dilute saline solution through a membrane into a higher concentrated saline solution .Assume that this membrane is permeable to water, but not to salt. Then, place a salt solution in one compartment B and pure water in the other compartment A As a fundamental rule of nature, this system will try to reach equilibrium. That is, it will try to reach the same concentration on both sides of the membrane. The only possible way to reach equilibrium is for water to pass from the pure water compartment to the salt-containing compartment, to dilute the salt solution.That transportation cause a rise in the height of the salt solution this height expressed as pressure .



$(P = \rho\ g\ h)$

This height will increase until the pressure of the column of water (salt solution) is so high that the pressure of this water column stops the water flow.The equilibrium point of this water column height in terms of water pressure against the membrane is called osmotic pressure.

From Van’t Hoff Equation

$$\pi = i\,C\,R\,T$$

Where,

π is the osmotic pressure

i is the van’t Hoff factor

C is the molar concentration of the solute in the solution (Mole/L)

R is the universal gas constant

T is the temperature

From previous Equation

$$\pi = 1.12(273+T)\sum mi$$

$$mi = = \frac{Ci}{1000\ X\ MW} \quad \text{(Mole/Kg)}$$

MW = molecular weight

Ci= concentration of ion ppm

Chemical Analysis Of Feed Water		
Ca	410	ppm
Mg	1310	ppm
Na	10900	ppm
K	390	ppm
CL	19700	ppm
SO4	2740	ppm
HCO3	180	ppm
TDS		ppm

ion	ppm	MW	mi
Ca	410	40	0.01025
Mg	1310	24.3	0.05390
Na	10900	23	0.4739
K	390	39	0.01
CL	19700	35.5	0.5549
SO4	2740	96	0.0285
HCO3	180	61	0.00295
		∑ mi	1.13449

$$\pi = 1.12(273+T)\sum mi$$

At 25 C° $\pi = 1.12 \times (273+25) \times 1.13449 = 378$ Psi

At 30 C° $\pi = 1.12 \times (273+30) \times 1.13449 = 385$ Psi

$$\pi = 0.0104 \times TDS$$

Question ? Relation Between T and π

The first work on RO membranes was initiated by

- 1957 Breton put first disscution of Ion , water flow mechanism through membrane
- 1957 CE Reid, EJ Breton when they successfully fabricated an active cellulose acetate membrane to remove salt from water.
- 1959 CE Reid, EJ Breton -announced that in Journal of applied polymer science .The membrane exhibited efficient desalination (salt rejection: 96%), but water flux through the membrane was low.
- 1962 Researches continued at the University of California, Los Angeles, with the concern of improving water flux without sacrificing salt rejection
- 1963 California university published the progress report by Loeb, S (Sea Water Demineralization by Means of a Semipermeable Membrane)
- 1964 Sourirajain , enhanced membrane flux by increasing cellulous film porosity (using pore-forming monomers)
- 1969 DuPont made the hollow-fiber B-9, the first Permasep permeator commercially available,
- 1974 DuPont introduced the B-10 permeator, the first permeator to make seawater desalination commercially feasible(1992, DuPont introduced the B10 Twin. The Twin reduced operating costs and was more efficient than the standard B-10)
- 1977 Porter, M.C ,Belfort, G. Shuval pupplished the analysis report (cellulose acetate membrane has limited applications due to its weak chemical resistance and low thermal stability)
- 1970,1975 Cadott start R&D on Polyamid polymer instead of AC , as experimental phase
- 1977 J.K. Beasley The Evaluation and Selection of Polymeric Materials
- 1979, Burns and coworkers suggested the use of aromatic polyamide (PA) membrane but water permeability by this membrane is less than that of cellulose acetate membrane, their salt rejection is higher
- 1981 Cadott announce the first commercial PA membrane as Patent however, flux was enhanced

In the past 30 years, different approaches have been exploited to produce the TFC membrane with the following features

1- high water flux,

2- excellent salt rejection,

3- better chlorine resistance

4- better chemical resistance

5- better fouling resistance

6- better thermal stability

By classify the techniques that have been utilized to improve the RO-TFC membrane properties into 4 categories:

(1) Using alternative monomers to prepare the active layer;

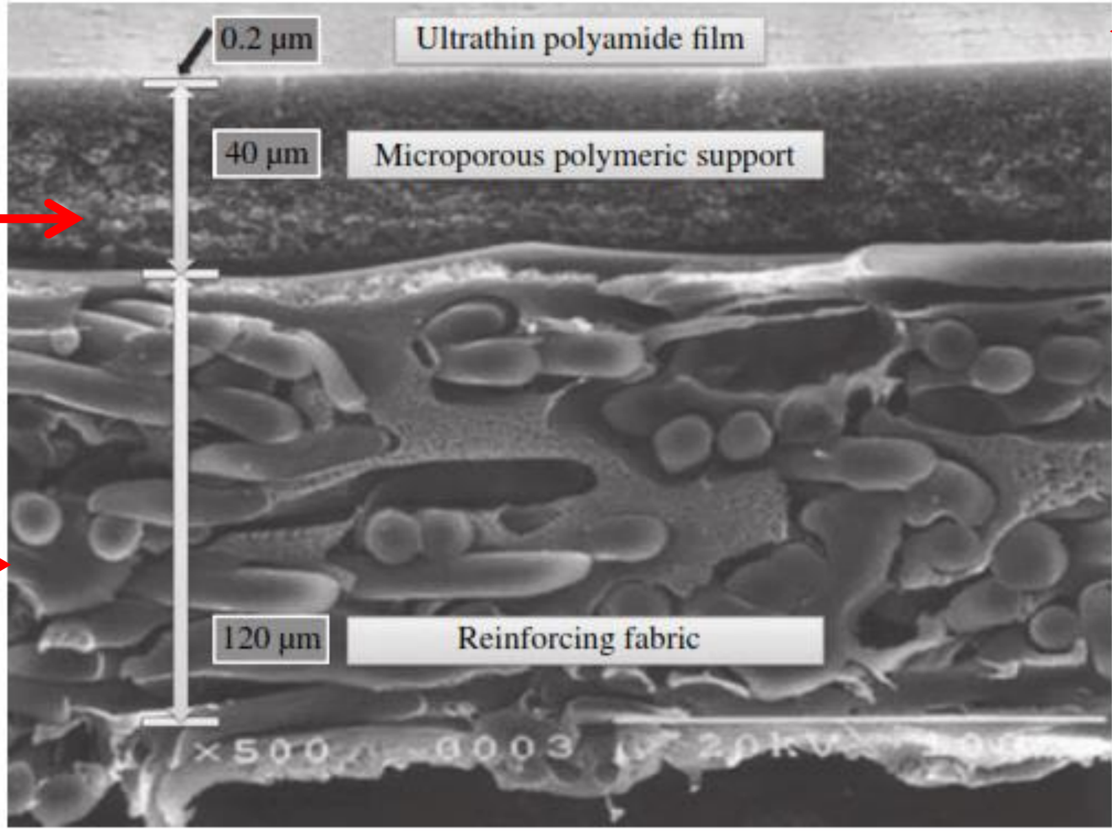
(2) Modification of membrane surface;

(3) Optimization of polymerization reactions;

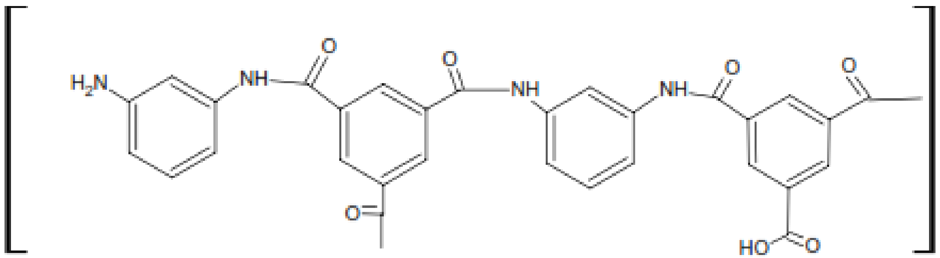
(4) Incorporation of nanoparticles (NPs) into the membrane PA layer.

2- Memebrane Structure

Plysulfone Layer provide chemical resistance and controlled the Thin layer porous



The major structural support is provided by the Polyster non-woven web, which has been calendared to produce a hard, smooth surface free of loose fibers. Since the polyester web is too irregular and porous to provide a proper substrate for the salt barrier layer



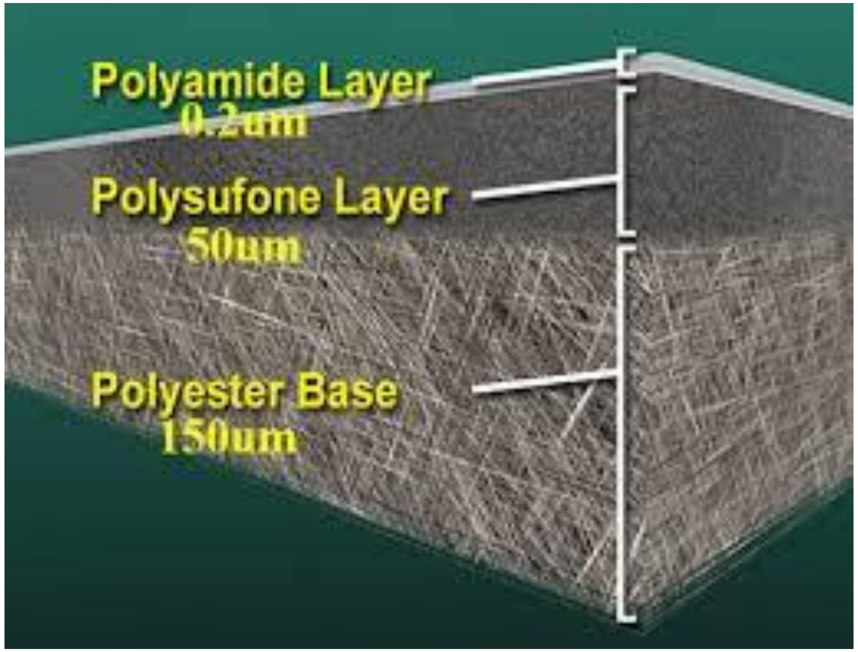
Free Amine

Carboxylate

PS
Phase Inversion Polymerization

MPD – TMC

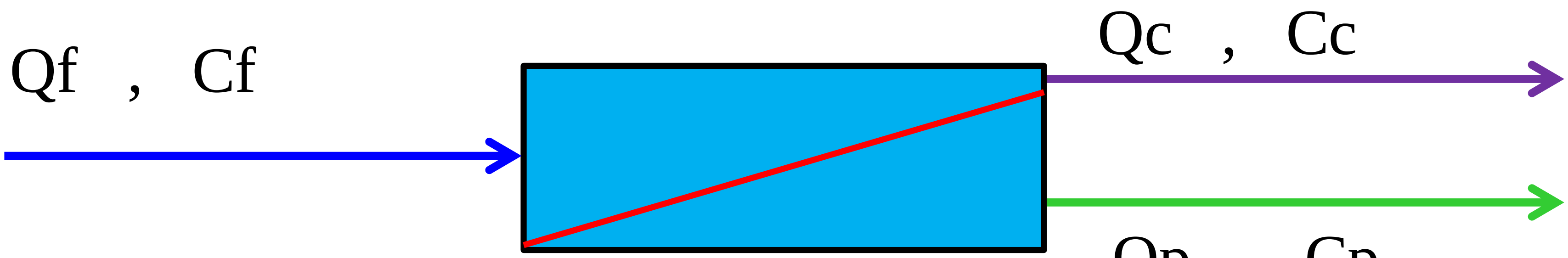
Interfacial Polymerization



Water Flux	Permeability factor	Hydrophilic of PA	PS Characteristic
Salt Flux	Diffusion factor		
Salt Rejection	Size Exclusion	Repulsion Electrostatic force PA characteristic	PA charge

Hydrophobic Hydrophilic

3 – Mass Balance Equation



Y = Qp/Qf

If feed flow 100 m3/hr , Feed Salinity 35,000 ppm , Product flow 40 m3/hr

Y= 40/100=0.4=40%

Cf = 35,000 g/m3 = 35 Kg/m3

Mean Feed salt amount = 3,500 Kg /hr ???

Qf x Cf = (Qc x Cc) + (Qp x Cp) by Divid (Qf)

$$Cf = \frac{Qc}{Qf} Cc + \frac{Qp}{Qf} Cp$$

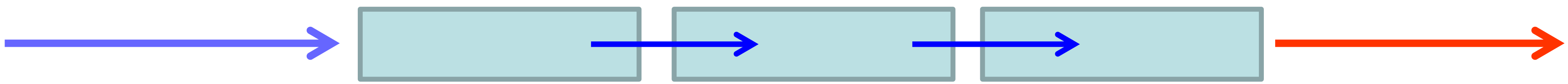
$$Cf = \frac{Qf - Qp}{Qf} Cc + Y\,Cp$$

$$Cf = (1-Y)Cc + Y\,Cp$$

$$Y = \frac{Cc - Cf}{Cc - Cp} \quad \text{neglect Cp} \quad Y = 1 - \frac{Cf}{Cc} \qquad Cc = \frac{Cf}{(1-Y)}$$

If feed 2000 ppm recovery 60 % find Cc

4- Recovery System Vs Recovery Element



First Element Recovery = 1.3/8 = 16.25 %

Second Element Recovery = 1/ 6.7 = 14.9 %

Third Element Recovery = 0.7/5.7 = 12.28 %

System Recovery = 3/8 = 37.5 %

Ys = 1- (1-Y1)(1-Y2)(1-Y3) ….. = 1- (1-0.1625)(1-0.149)(1-0.1228)= 37.5 %

Element Average recovery :

(Y1+Y2+Y3) / 3 = (16.25+14.9+12.28) /3 = 14.48 %

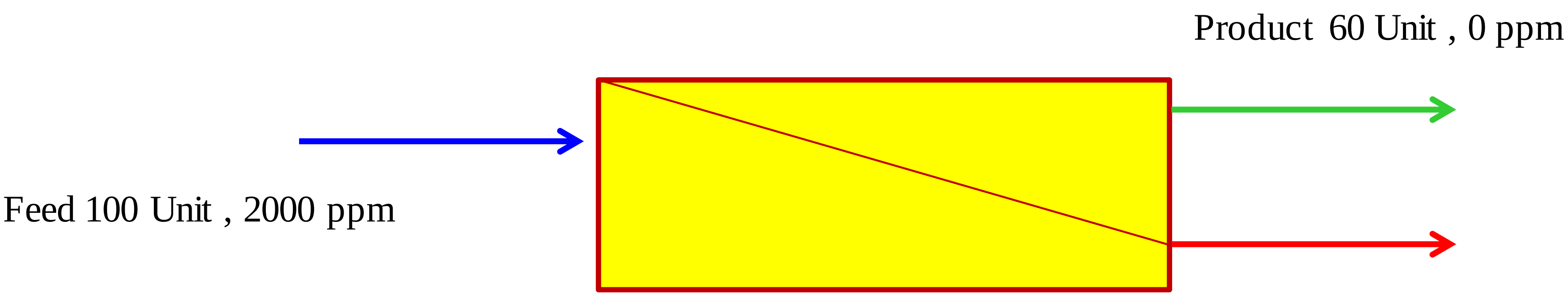
$$Ya = 1-(1-Ys)^{1/n}$$

5- Thinking

1- In the following Plant , the feed flow = 100 unit with salinity 2000 ppm . The product flow = 60 unit with salinity = 0 ppm (permeate salinity neglected) . The scaling will be happen if the recovery exceed 55 % with feed salinity range (2000 : 3000 ppm) .

Calculate :

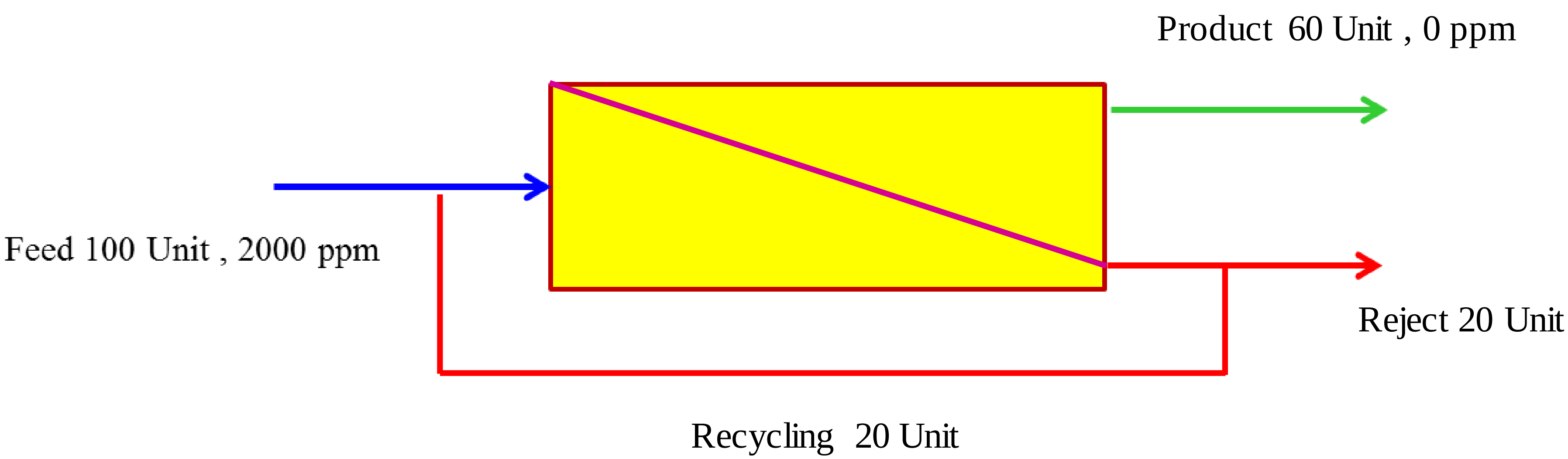
a) System Recovery
b) Reject salinity
c) Is scaling will be happen ?



2- In the Pervious Plant , Mr John make reject circulation by 20 unit added to feed flow , with mentioned fixed production rate 60 unit and still product salinity = 0 ppm

a) Do you think the plant will run in stable mode ?

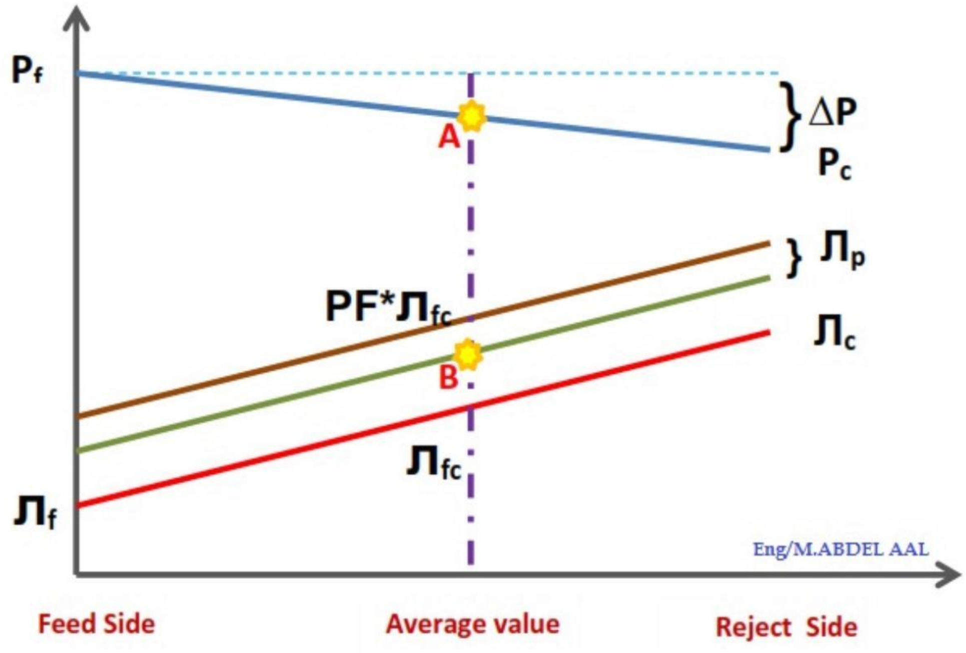
b) Is scaling will be happen ?



6- RO Membrane Equation

Pressure AT (A) Point = $P_f - \frac{\Delta P}{2}$

Pressure At (B) Point = $л_{fc} x\ PF - лp$



$$NDP = P_f - \frac{\Delta P}{2} - л_{fc}\ x\ PF + л_p$$

$$PF = e^{0.7\ Ya}$$

$$Л_{fc} = л_f\ x\ (C_{fc} / C_f)$$

Designer Vs Operation ????

$$Q_p = N_E \times S \times A \times TCF \times FF \times NDP$$

$$\overline{A}(\overline{\pi}) = 0.125; \overline{\pi} \le 25$$

$$\overline{A}(\overline{\pi}) = 0.125 - 0.011\left(\frac{\overline{\pi} - 25}{35}\right); 25 \le \overline{\pi} \le 200$$

$$\overline{A}(\overline{\pi}) = 0.070 - 0.0001(\overline{\pi} - 200); 200 \le \overline{\pi}$$

$$TCF = EXP\left[2640\left(\frac{1}{298} - \frac{1}{273+T}\right)\right]; T \ge 25^{\circ}C$$

$$TCF = EXP\left[3020\left(\frac{1}{298} - \frac{1}{273+T}\right)\right]; T \le 25^{\circ}C$$

$$\Delta P_{fc} = 0.01 n \overline{q}_{fc}^{\ 1.7}$$

What Is q_{fc}

Design plant with capacity 1000 m3/day and feed Salinity 35,000 ppm

Q_p = 1000 m3/day =264200.8 gpd

The average Flux 9 : 9.1 gpd/ft2

Membrane Required Area = 264200.8/ 9.1 = 29033.05 ft2

If we Use Membrane with 400 Ft2

Number of elements = 29033.05/400= 72 Elements

If We Use 6 Elements PV

Number of PV = 72/6 = 12

Given Data : C_f = 35,000 ppm Feed Temperature = 25 C°

Assume Recovery = 40 %

π_f = 378 Psi Cc = Cf/(1-0.4) = 58333.3 ppm C_{fc} = (Cf+Cc)/2 = 46,666 ppm

$\pi_{fc} = \pi_f \times (C_{fc}/C_f)$ = 509 Psi

$Ya = 1-(1-0.4)^{1/6} = 0.15656$

$P.F = e^{0.7 * 0.15656} = 1.1158$

A= 0.07 – 0.00001 (509 X 1.1158 -200) = 0.03320

???? Why In low Salinity 0.125

Qp = 264200.8/24 = 11008.3 gph = 183.4 gpm

qp = 183.4 /12 = 15.2 gpm

qf = 15.2/0.4 = 38.22

qc = qf-qp = 23 gpm

qfc = (38.2+23) / 2 = 30.6 psi

$\Delta P = 0.01 \times 6 \times (30.6)^{1.7} = 20$ Psi

264200.8 = 72 x 400 x 0.0332 x 1 x 1 x (Pf – 20 – (509*1.115)+ 5)

276 = Pf - 20 – 567.5 + 5

Pf = 276 +567.5 +20 – 5 = 858.5 Psi

7- Normalization

Start up Data		
Ca	200	ppm
Mg	61	ppm
Na	388	ppm
CL	633	ppm
SO4	552	ppm
HCO3	152	ppm
T	15	Cº
Pf	363	Psi
Pp	14.5	Psi
ΔP	44	Psi
Qp	150	M3/hr
Cp	83	ppm
Y	75	%
Feed TDS = 1686 ppm		

After 3 months		
Ca	200	ppm
Mg	80	ppm
Na	480	ppm
CL	850	ppm
SO4	530	ppm
HCO3	152	ppm
T	10	Cº
Pf	406	Psi
Pp	29	Psi
ΔP	58	Psi
Qp	127	M3/hr
Cp	80	ppm
Y	72	%
Feed TDS = 1900 ppm		

What is Normalization mean ? Imagine your Car Example

ion	ppm	MW	mi
Ca	200	40	
Mg	61	24.3	
Na	388	23	
K	0	39	
CL	633	35.5	
SO4	552	96	
HCO3	152	61	
		∑ mi	0.050453

Лf = 1.12 x (273+15)*0.050453= 16.274

Cc = 1686 / (1-0.75) = 6744

Cfc = (1686 +6744) / 2 = 4215

Л fc = 16.274 x 4215 / 1686 = 40.685

TCF = 0.7

What is Normalization mean ? Imagine your Car Example

ion	ppm	MW	mi
Ca	200	40	
Mg	80	24.3	
Na	480	23	
K	0	39	
CL	850	35.5	
SO4	530	96	
HCO3	152	61	
		∑ mi	0.06118

Лf = 1.12 x (273+10)*0.06118= 19.39

Cc = 1900 / (1-0.72) = 6785.7

Cfc = (1900 +6785) / 2 = 4342.8

Л fc = 19.39 x 4342.8 / 1900 = 44.32

TCF = 0.58

$$Q_S = \frac{P_{fs} - \frac{\Delta P_s}{2} - P_{ps} - \pi_{fcs}}{P_{fo} - \frac{\Delta P_o}{2} - P_{p0} - \pi_{fco}} \cdot \frac{TCF_s}{TCF_o} \cdot Q_o$$

$$= \frac{363 - 22 - 14.5 - 40.685}{406 - 29 - 29 - 44.32} \times \frac{0.7}{0.58} \times 127$$

$$= 144 \text{ m3/hr}$$


Thank you