Assignment 2

Deadline : 2 April 2021

Overview

- Consider all the mixtures/solutions to be ideal unless otherwise mentioned.

- The ambient conditions are assumed to be at NTP (20 °C and 1 atm).

- During grading, least importance will be given to accuracy in the end values. Therefore try to answer using sufficient concepts and equations. Keep your answers short, but don't miss out the key words.

- This is an educational exercise. Therefore, we tried to keep it as practical as possible.

- You can send your completed report to NagarajNMT2021@gmail.com. Also for setting up meetings, doubts, etc.. you are welcome to mail to this id.

Question 1

Did you wash your hands before starting this assignment?

Question 2

Imagine you are an engineer in the boiler maintenance department at a Thermal Power Plant. It has been brought to your attention that the presence of salts in the boiler feed water is inducing corrosion within your boiler. You therefore start making an action plan to regulate your feed water.

You try to establish a purification process with 2 containers - A and B. (throughout this assignment, for your group, you can take the saturation concentration values of NaCl from Table 1).

a. As the first step you try to validate the existing equipments you have at your plant. Therefore, you fill in the container A with a demineralised water and seal it completely. Later you heat it to 100 °C and check the barometer for the reading. If the container was free from damages and barometer was fully functional, what is the pressure that you will record? (for pressure in bar and temperature in K, the component-specific constants in Antoine equation for water are A=6.20963, B=2354.731, C=7.559 - the values are for $\log_{10}$)

b. Now you fill in the container B with the salt water and heat it up to the same temperature (100 °C). Will the barometer show a different value compared to the container A? If yes, then will it be high or low? Should you increase or decrease the temperature of container B inorder to match the pressure value of container A.

c. From your previous knowledge of crystallization, you are aware that beyond the saturation limit a salt is more prone to phase separate (crystallize). However, for the container B, when inspected at ambient temperature you dont see any crystal deposited at the bottom. What does this mean?

d. The analysis of the water composition of container B states that it contains NaCl. However, you have no clue of the amount present, and therefore try to estimate it using the barometer value. What is the maximum and minimum value of the barometer value that you can expect (you can use diluted system formula).

e. Now you have decided to add antisolvent (a liquid) to your container B to reduce the solubility of the salt in water. If we assume that all the salt has been removed, what is the maximum and minimum value of the barometer value that you can expect for this water+antisolvent mixture? (component-specific constants for your antisolvent is given in Table 2)

f. If the solution was non-ideal, what is the additional coefficient(s) that you should consider for your calculations? How will they deviate from your ideal case?

Question 3

You team is not comfortable with you adding antisolvent to treat the water, and moreover you have to come up with a temporary solution as to ensure that the boiler continues to run. Therefore you come up with a simple but effective way, where you decide to mix the demineralised water with the salt water inorder to dilute the system. Hence, in the following question, containers B and A is filled with salt and pure water respectively as before.
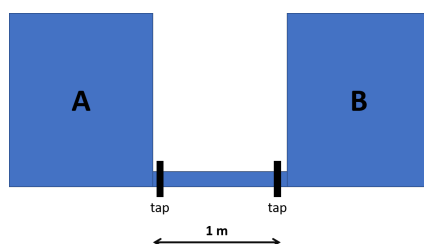
Figure 1: Containers A and B linked to each other

a. Now both the containers are brought to ambient temperature. Later, you establish a link between the containers as shown in the Figure 1 (the link is filled with demineralised water). Roughly calculate how long will it take for for the first solute/salt molecule to reach A from B.

b. Assume that question 3(a) takes place at $100\,°C$. What is the newly calculated time?. (tip: for water, $\mu = 2.414 \times 10^{\left(\frac{247.8}{T-140} - 5\right)}\,$Pa s, where T is in Kelvin)

c. Assume that question 3(a) is performed with container A only filled with half its total volume. What is the additional phenomena that will come into picture? Will it increase or decrease the solute/salt mass transfer rate from B to A? What is the dimensionless number that you can use to model your process?

d. Assume that in question 3(a) the container B has a saturated salt concentration. Calculate the time taken to achieve half the container B concentration near the tap of container A. (for this calculation, you can consider the concentration of container B and A to remain constant at all times)

e. In the current setup, mention atleast one additional design parameter that can be changed to make the transfer of salt from B to A faster? (do not consider directly pouring liquid from one container to another, nor using any water pump)

Question 4

However, for future, you are left with enough time to design an effective process that can produce water with relatively high purity. You decide to employ a continuous process that uses membrane for separation.

In you plant store you find 2 types of membranes. Based on the purchase history you come to know that while both membranes allow water to permeate through them, one membrane doesn't allow the passage of salt through it while other does (in real case NaCl ions are smaller than water molecules, but for this assignment consider this hypothetical membrane)

a. In an effort to check the membrane type, you place it inbetween the containers A and B containing the pure and salt water respectively (both containers have the same amount of liquid). After sufficient time you notice that the water level in the salt solution container has risen. Which type of membrane was it? Why would that happen? If container B had saturated concentration initially, calculate the final height of the liquid rise in container B when equilibrium has been established in the system (only for this case assume that the concentration in both the containers do not change due to solvent flux)

b. Somehow you manage to figure out the following values for the membranes, let the solvent permeability and membrane thickness be $5 \times 10^{-10}\,\mathrm{kg\,m\,s^{-1}\,m^{-2}\,bar^{-1}}$ and $1\,\mathrm{\mu m}$. In the previous question, what and when would you have the maximum flux? why?

c. Lets say at the initial state of the question 4(a) (before the water starts to raise) you supply twice the osmotic pressure greater than the ambient on the side of salt water container . What is the direction and maximum possible magnitude of the new flux?

d. Using the solution from container B, you decide to make this a continuous process. In order to do so you roll the membrane into the shape of a tube with diameter $1\,\mathrm{m}$ and pass the solution through it with demineralised water on the exterior side of the tube. The flow velocity of the solution is $1\,\mathrm{m\,s^{-1}}$. Taking the calculated value of the flux from the previous question to be constant along the length ($50\,\mathrm{m}$) of the membrane tube, can you calculate the final concentration of the solution exiting the tube?

e. (**bonus question**) In a real case there should be a pressure drop across the tube in order to make the solution flow. Lets say you supply twice the osmotic pressure at the inlet compared to the outlet. Can you expect the reverse osmosis to happen through the length of the tube? If yes/no, then when/why? For this question you don't need to calculate any numeric values. Just mention and balance the equations. (tip: Hagen–Poiseuille equation)

The end :)

Table 1: Saturation Concentration Values of NaCl

(a) EHMT Groups

Group	$C_{\textbf{sat}}$ [**Kg/Kg**]
1	0.475
2	0.438
3	0.432
4	0.488
5	0.393
6	0.464
7	0.463
8	0.407
9	0.435
10	0.361
11	0.358
12	0.430
13	0.467
14	0.490
15	0.369
16	0.435
17	0.420
18	0.352
19	0.401
20	0.374
21	0.469
22	0.397
23	0.429
24	0.375
25	0.440
26	0.389
27	0.448
28	0.453
29	0.462
30	0.418
31	0.363
32	0.384
33	0.487
34	0.373
35	0.474
36	0.431
37	0.499
38	0.362
39	0.416
40	0.366

(b) SPDO Groups

$C_{\textbf{sat}}$ [**Kg/Kg**]
0.351
0.466
0.473
0.480
0.363
0.410
0.389
0.470
0.415
0.487
0.377
0.390
0.372
0.370
0.385

Table 2: Question 2 Values

(a) EHMT Groups

Group	Anti-Solvent		
	A	**B**	**C**
1	5.030	2221.537	7.423
2	5.087	2227.431	7.077
3	5.361	2218.885	7.049
4	5.401	2262.177	7.004
5	6.439	2362.527	6.131
6	5.886	2302.712	6.460
7	6.691	2373.295	6.234
8	5.780	2396.097	7.980
9	6.675	2265.331	6.141
10	6.497	2243.923	6.120
11	6.168	2303.645	7.323
12	5.321	2270.601	6.688
13	6.058	2371.895	6.257
14	5.925	2252.004	7.274
15	5.759	2368.744	7.493
16	5.186	2316.560	7.611
17	5.518	2343.881	6.538
18	5.672	2268.705	6.868
19	5.750	2201.855	6.804
20	5.293	2238.489	7.216
21	5.634	2301.478	7.540
22	5.562	2204.848	7.882
23	6.640	2310.008	6.263
24	5.684	2255.237	6.511
25	6.744	2339.248	6.757
26	5.536	2376.271	7.987
27	6.551	2204.936	6.682
28	6.218	2268.241	7.799
29	5.036	2284.281	6.475
30	6.403	2216.002	6.440
31	5.032	2215.871	7.982
32	6.368	2214.475	7.902
33	6.756	2380.068	7.276
34	5.864	2393.862	7.008
35	6.263	2278.261	6.716
36	6.172	2262.717	7.537
37	5.455	2310.663	7.569
38	6.569	2358.410	6.058
39	5.575	2359.663	6.105
40	6.849	2372.652	6.647
41	5.597	2359.592	7.599
42	6.073	2201.275	7.260
43	5.667	2383.980	7.966
44	5.475	2203.592	6.316
45	6.090	2205.883	7.233

(b) SPDO Groups

Anti-Solvent		
A	**B**	**C**
5.607	2228.587	7.082
6.215	2234.284	6.833
5.558	2325.169	7.034
6.599	2205.903	7.772
6.592	2294.466	6.299
6.908	2335.689	6.869
5.889	2222.958	6.118
5.914	2247.213	6.762
6.200	2257.816	7.445
6.685	2234.551	6.190
5.062	2264.741	7.334
5.375	2360.222	6.593
6.887	2259.927	7.197
6.896	2355.125	6.304
5.906	2310.554	6.873