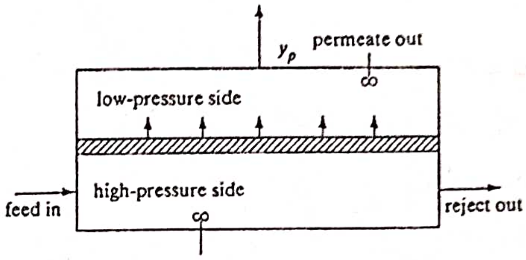
BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE, PILANI
Second Semester 2022-2023
CHE F423 Membrane Science and Engineering
Date: 06.05.2023, FN — Comprehensive Examination — Max Marks: 80

PART-A (Closed Book) Marks: 30

Note: All answers must be technical. General and vague statements will be not given marks. Write and justify any assumptions made. All nomenclature is to be written in words.
Data: Universal Gas Constant, R= 0.0821(L.atm)/(mol.K), Atomic weights: Na = 23, Cl = 35

Q.1 [6+4=10 M]

a. It is proposed to separate binary gases A and B using a membrane separator (shown in the figure). Derive an expression for permeate concentration (y_p) in terms of membrane selectivity (α) and ratio of absolute pressures on low pressure side (P_2) to high pressure side (P_1). Also, an expression to calculate the membrane area (A) for a given flux through the membrane.



b. It is proposed to use membrane for separation of CO_2 from biogas (CO_2 = 40 mol% and CH_4 = 60 mol%). A membrane has a selectivity of 5 for CO_2/CH_4, determine the maximum CO_2 concentration that can be obtained for a single stage device shown in the (a).

Q.2 [8 M]

An experiment is being conducted to determine the suitability of a cellophane membrane for using it in Hemodialysis process. The membrane is 0.025 mm thick. In the experiment, conducted at 36°C using common salt (NaCl) as the diffusing solute, the membrane separates two components containing stirred aqueous solutions of NaCl. The bulk liquid phase concentration of diffusing solute in the upstream is 1.0×10^{-4} mol/cm^3 and 5.0×10^{-7} mol/cm^3 in the downstream. The mass transfer coefficients on either side of the membrane are same which are calculated as 5.24×10^{-5} m/s. Experimental data obtained gave a flux of 8.11×10^{-4} (mol NaCl)/(m^2.s) at quasi steady state condition. Calculate (i) The permeability in m/s, (ii) Diffusivity in m2/s if the distribution coefficient is 0.75, (iii) Calculate the percentage resistance to diffusion in liquid film.

Q.3 [6×2=12 M]

a. Explain the Cake Enhanced Concentration Polarization in Nanofiltration and Reverse Osmosis.

b. What is Silt Density Index?

c. The water-gas-shift reaction is given by $CO + H_2O \leftrightarrow CO_2 + H_2 \quad \Delta H_{298K} = -41$ kJ/mol. The reversibility of the reaction sets a thermodynamic limit to the conversion of CO to H_2. Explain how the thermodynamic limitation can be overcome with a schematic.

d. Explain the characterization tools and their working principle to determine the pore size, pore size distribution, and surface roughness of a membrane.

e. Explain with a neat schematic the pervaporation process and give two industrial applications.

f. Explain the tools which can be used for morphological characterization of membranes. Give neat diagram and explain the cases of polysulfone membrane prepared using phase inversion with additive of low molecular weight PEG and high molecular weight PEG.

#All The Best#

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PART-B (Open Book) Marks: 50

Note: Write and justify any assumptions made. All nomenclature is to be written in words.

Q.1 A laboratory experiment is carried to study the microbial population of wastewater using microfiltration membrane setup at 25°C. A polymer membrane is used for the purpose. The thickness of the membrane used is 100 micron and the average pore size is 1 micron. The porosity of the membrane is 0.4. The data obtained for pure water flux through the membrane is as follows:

ΔP, kPa	40	60	80	100	200
Flux, kg/m^{2}h.	500	750	1020	1220	1500

The density of water of water at 25°C is 1000 kg/m^3 and viscosity is 1 centi Poise.

(a) Determine the tortuosity of the membrane.

(b) Determine the membrane resistance offered to the flow of pure water.

[10 Marks]

Q.2 An aqueous macromolecular solution is ultrafiltered under crossflow over an asymmetric membrane of average pore size 20 nm, tortuosity of 1.7, porosity of 35%, and a permselective skin thickness of 0.45 micron. A plate-and-frame module of 7 mm channel depth is used.
The following data is available: Reynolds number of the liquid is 6500, bulk solute concentration is 1.3%; solution viscosity is 9.5×10^{-3} Pa. s, density is 1030 kg/m^3; solvent (water) viscosity is 8.8×10^{-4} Pa. s ; diffusivity of the solute is 3.5×10^{-7} cm^2/s; transmembrane pressure drop is 3 bar, the temperature is 27°C. Molecular weight of the solute is 5000; The solute rejection is 99%. The gelation of the solute known to occur at a concentration of 12%. The diameter of the particles in the gel is 20 nm, the average porosity of the gel is 50%. At the flow conditions the correction is applicable: $\mathrm{Sh} = 0.025(\mathrm{Re})^{0.75}(\mathrm{Sc})^{\frac{1}{3}}$. The channel depth can be taken as the characteristic length for the calculations. Determine: (i) the thickness of the gel layer, (ii) the pressure drop at which the formation of a gel layer on the membrane starts. **[20 Marks]**

Q.3 A polyamide membrane with an area of 4.0×10^{-3} m^2 is used at 25°C to determine the permeability constant for reverse osmosis of a feed salt solution containing 12.0 kg NaCl/m^3 (density = 1005.5 kg/m^3). The product solution has a concentration of 0.468 kg NaCl/m^3 (density = 997.3 kg/m^3). The measured product flow rate is 3.84×10^{-8} m^3/s and the pressure difference used is 56.0 atm. Calculate the permeability constants for water and salt. Also calculate the solute rejection. **[10 Marks]**

Q.4 An equimolar mixture of CO_2 and N_2 permeates through a composite membrane consisting of a 10 micron thickness of PDMS on a 1 micron thick skin (dense) layer of an assymetric cellulose acetate membrane. The literature gives the following data: the permeability of PDMS is 4550 Barrer for CO_2, 350 for N_2. The permeability of CO_2 in Cellulose acetate is 4.75 Barrer and for N_2 is 0.2 Barrer. Calculate the ideal selectivity of CO_2 over N_2 at 35°C for the composite membrane using resistance-in-series model. **[10 Marks]**

#All the Best#