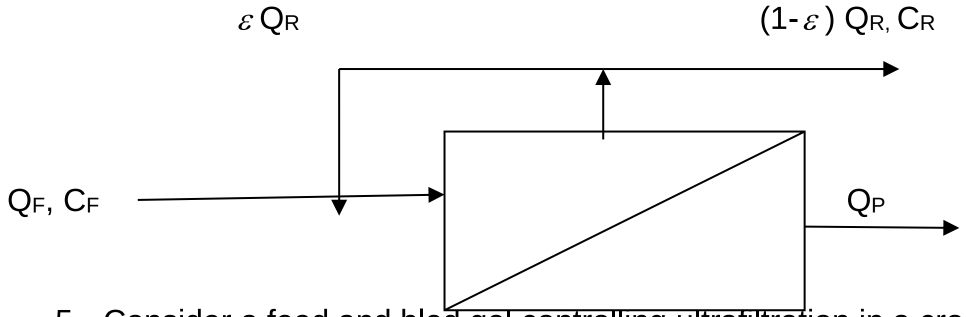
1. A membrane gas separation unit is working under complete mixing mode. Feed contains oxygen (A) and nitrogen (B). The feed flow rate is 400 m^3/h. Mole fraction of A in feed is 0.21, membrane thickness is 0.1 μm. Membrane permeability for nitrogen (B) is 2.43×10^{-16} $m^4/N.s$. $\alpha = P_A / P_B$ =6. P_h=12 bar; P_l=1.2 bar. For having the mole fraction of A in permeate as y_A=0.25, find the membrane area required. Also find the stage cut of this system. (10)

2. A solution of protein A in 0.05 (M) NaCl and 30^0C is ultrafiltered in a rectangular channel of half height 1 mm, length 100 cm, cross flow velocity 0.5 m/s and diffusivity 3 x 10^{-11} m^2/s under gel layer controlled filtration with gel concentration 200 kg/m^3. Protein has surface charge 40e under its natural pH and radius 3 nm. What external electric field strength is applied so that the permeate flux is 1.5 times to that without electric field.
Sh=1.86 $(Re\ Sc\ d_e/L)^{0.33}$ for laminar flow and Sh=0.023 $(Re)^{0.8}$ $(Sc)^{0.33}$ for turbulent flow. ΔP=400 kPa, k_B=1.38×10^{-23} J/K, D=dielectric constant for water=80, ε_0=8.85×10^{-12} C/V.m, N_{Av}=6.023×10^{23} and e=1.6×10^{-19} C.

3. A solution is flowing through an ultrafiltration spiral wound module. It is assumed that the permeate flux is proportional to transmembrane pressure drop and osmotic pressure of solution is negligible. The channel width is 4 cm, half height 1 mm, module length 10 m. Inlet flow rate is 40l/h. Solution viscosity is 0.001 Pa.s. Membrane permeability is 5×10^{-11} m/Pa.s. Find the inlet transmembrane pressure drop so that the fractional recovery of feed is 0.8?

4. A hollow fiber counter current dialyzer contains 7000 fibers with internal diameter 200 μm and wall thickness 45 μm and length 20 cm. The feed and dialysate flow rates are 200 and 600 l/min, respectively. The feed urea concentration is 620 mg/l and it needs to be reduced to 375 mg/l. Dialysate is fresh distilled water. Bulk diffusivity of urea is 2×10^{-9} m^2/s. Dislysate mass transfer coefficient is twice that of feed side. Mass transfer coefficient can be calculated from Sh=1.86 $(Re\ Sc\ d_e/L)^{0.33}$. Find the diffusivity of urea in membrane phase?

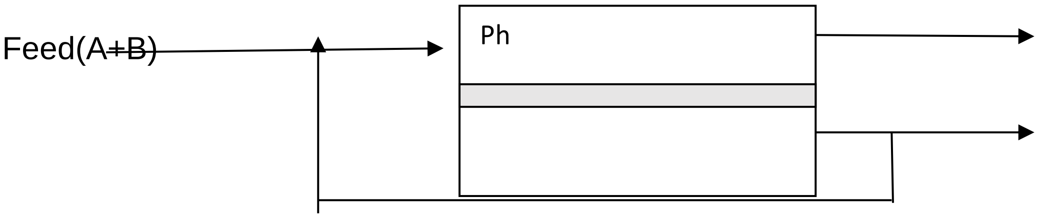
Instructions: Closed notes and book. Clearly state any assumed data



5. Consider a feed and bled gel controlling ultrafiltration in a cross flow cell as shown in the figure. Q_F=100 L/h; Area of filration=1 m^2; C_F=10 kg/m^3; C_g=100 kg/m^3; Area of filtration is 1 m^2. $\theta = \frac{Q_R}{Q_F + \varepsilon Q_R} = 0.6$. All the symbols have usual meaning.
   Find (i) the retentate concentration, C_R; (ii) fractional recycle ratio of retentate, ε; (iii) permeate flow rate in L/h.
   (10)

6. Consider a countercurrent hemodialysis cartridge having 8000 hollow fibers, each having ID 200 μm, wall thickness 40 μm and length 25 cm. The feed and dialysate flow rates are 200 and 600 ml/min, respectively. Consider the feed and dialysate side mass transfer resistances are negligible. Inlet feed concentration of urea is 800 mg/l. Pure distilled water is used as dialysate. Find the concentration of urea at the outlet of dialyzer. Urea diffusivity in the membrane phase is 10^{-10} m^2/s.
   (10)

7. A protein solution with 0.1 (M) NaCl at 30^{0}C is ultrafiltered in a rectangular channel of half height 0.5 mm, length 100 cm, cross flow velocity 0.5 m/s and the protein diffusivity is 5x10^{-11} m^2/s. The filtration is under gel layer controlling and at steady state. Feed concentration of solute 5 kg/m^3. Gel concentration is 100 kg/m^3. Charge on a protein particle is 15e, where "*e*" is the electronic charge. Radius of the protein molecule is 5 nm. N_{av}=6.023x10^{23}; $\varepsilon = \varepsilon_0 D = 80 \times 8.88 \times 10^{-12}$ SI unit; k_B=1.38x10^{-23} J/K and $\mu = 0.001$ Pa.s. An external power source is used to apply 0.7 V across the top and bottom of the UF cell. Find the permeate flux.
   (10)



8. A mixture of A and B is separated by a gas separation membrane. Q_F=300 m^3/h; y_A=0.25; x_{AF}=0.21; $\theta = \dfrac{Q_p}{Q_F + \varepsilon Q_p} = 0.5$; $\varepsilon = 0.6$; *l*=membrane thickness=0.1 μm;
   P_B=32x10^{-10} (cm^3/ cm^2.s)(cm/cm of Hg); $\alpha = 6.2$; P_h=12 bar; P_l=1.2 bar. Find the membrane area required.

   (10)

9. Aniline is removed by SDS micellar solution of surfactant concentration of 10 kg/m^3. Feed concentration of aniline is 5 mg/l. The solubilization isotherm is aniline in the micelles is represented as $S = \dfrac{Qbc_p}{1+bc_p}$, where, c_p is the aniline concentration in the permeate, *Q* = 5 mg/g and *b*=0.09 l/mg. CMC of SDS is 2.3 kg/m^3. Gel concentration of SDS is 280 kg/m^3. The filtration is carried out in a cell with mass transfer coefficient 5x10^{-5} m/s. Find the permeate flux and rejection of aniline.

   (10)

10. Explain the chromatographic separation process using solute movement theory assuming the solute can be in three states, i.e., in the bulk liquid, in stationary liquid and in adsorbed state.

11. Urea is removed from 650 mg/l to 400 mg/l in a hollow fiber counter-current dialysis cartridge. The feed and dialysate flow rates are 260 and 550 ml/min, respectively. The dialysate at the inlet is pure water. The bulk diffusivity of urea is $8x10^{-10}$ m^2/s and that in the membrane is 10^{-10} m^2/s. The flow inside the fiber is laminar and the mass transfer coefficient is estimated from $Sh=1.85(Re\ Sc\ d/L)^{0.3}$. The symbols denote the usual meaning. The wall thickness of the hollow fiber is 40 micron and internal diameter is 220 micron and length is 20 cm. Considering the mass transfer resistance in the feed side and membrane only, find how many fibers are needed for such a dialyzer. (20)

12. In an Electric Field Enhanced UF, the filtration is gel layer controlled with gel concentration C_{gel}, feed solute concentration C_0, mass transfer coefficient k, flow channel equivalent diameter d_e, cross flow velocity u_0 and solute diffusivity D, strength of external electric field E, particle zeta potential ξ, solution viscosity μ and solution permittivity ε. Consider a thin electric double layer and laminar flow inside the channel with $Sh=1.85\ (Re\ Sc\ d_e/L)^{0.3}$. The symbols denote the usual meaning. V_e ($\varepsilon\ \xi$ E/μ) is the electrophoretic velocity, where, E is the electric field strength.

(i) Find an expression of the length of the channel (L) so that the contribution of mass transfer and external electric field towards the total permeate flux is equal. (10)

Find L, if $C_{gel}/C_0=10$, $u_0=0.5$ m/s, d_e=1mm, $D=10^{-11}$ m^2/s, $v_e=10^{-6}$ m/s. (3)

(ii) Prove that under the above conditions, $L \propto E^{-1/3}$. (5)

(iii) Under above conditions, what is L if E is increased by a factor of 2. (2)

13. Consider a cake layer controlling unstirred batch filtration system with initial volume V_0 and solute concentration C_0. The solute is completely rejected by the membrane forming the cake layer. Membrane area is A, cake density is ρ_c, cake porosity ε_c, α is specific cake layer resistance and membrane resistance is R_m. ΔP is the transmembrane pressure drop and v_w^0 is the pure water flux at this pressure. If the filtrate volume is significant compared to feed volume, the feed bulk concentration and feed volume will be function of time of filtration. Under this condition, obtain an expression of V (cumulative volume of filtrate) as function of time. Show that if filtrate volume is small compared to feed volume, the V vs t follows a quadratic relationship.

Hint: The cumulative mass of cake deposited on the membrane at any point of time is $\int C_b(t)dV$, where C_b(t) is the bulk solute concentration at any time point.

(20)

14. Consider, a gas separation system as shown in the figure and we can assume a completely mixed system. Oxygen (A) and nitrogen (B) are separated. The feed flow rate is 300 m^3/h; mole fraction of oxygen in the feed is 0.22. The ratio (r) of pressure in the permeate to the feed is 0.1. The P_A/P_B =6, where, P is the permeability of a species through the membrane. The permeate recovery is 0.6. Permeate recovery is defined as the ratio of permeate flow rate to total flow rate going into the membrane (feed+recycled permeate). If the recycle ratio is 0.2, find the

Permeate flow rate and mole fraction of A in permeate. (10)

Retentate flow rate and mole fraction of A in retentate. (5)

What is the area of the membrane required, if permeability of through membrane is 4.75×10^{-10} $\frac{cm^3}{cm^2}\frac{cm}{cm\,Hg.s}$. Membrane thickness is 0.15 micron. Pressure in feed side is 10 atmosphere. (5)

15. A mixture of phenol and aniline is treated by micellar enhanced ultrafiltration. The concentration of phenol and aniline in the feed is 40 mg/L and 60 mg/L, respectively. The surfactant (SDS) concentration in the feed is 20 g/L and CMC of SDS is 2.3 g/L. The mass transfer coefficient in the UF cell is 2×10^{-5} m/s. The gel concentration of SDS is 210 g/L. The solubilisation isotherm of solutes in the micelles is given as:

$$q_i^e(mg/g) = \frac{q_i^m k_i C_{ei}}{1+\sum_{i=1}^{2} k_i C_{ei}}$$

Here, *i* indicates the solutes 1(phenol) and 2 (aniline) and C_{ei} indicates the unsolubilized solute concentration.

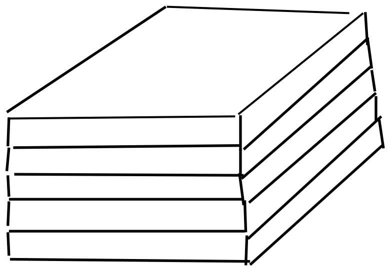
$q_1^e = 60.2\ mg/g$; $k_1 = 0.007\ L/mg$

$q_2^e = 47\ mg/g$; $k_2 = 0.008\ L/mg$

Find the steady state permeate flux. (5)

Find the permeate concentration of phenol and aniline. (15)

16. There is a stack of rectangular dialysis cells placed one above another as per the following schematic. Feed and dialysate chambers are identical and arranged alternatively.



The cell dimensions are: Length (L)=0.5 m; Width (W)=0.1 m and height (H)=1 mm. Total feed and dialysate flow rates (counter-currently) to the system are 200 and 600 ml/min. The solute concentration in the feed is reduced from 650 to 300 mg/l. The mass transfer coefficient in the dialysate side is 1.5 times that of the feed side and pure water is fed to the system as dialysate. The solute diffusivity in the bulk and in the membrane phase are 10^{-9} and $8x10^{-11}$ m^2/s. The membrane thickness is 40 micron. The mass transfer coefficient in the feed can be calculates from $Sh=1.85(ReScd_e/L)^{1/3}$.

(i) What is the solute concentration at the outlet of dialysate? **(3)**

(ii) How many feed chambers are there in the stack to achieve this? **(7)**

17. A protein solution is filtered in a tubular membrane and the cross sectional average velocity is given as $u = \frac{R^2}{8\mu}\left(-\frac{dP}{dx}\right)$, where R is radius of the tube, μ is the water viscosity, P is the pressure in the feed side at any location x. The osmotic pressure of the solution is negligibly small compared to transmembrane pressure drop (ΔP). Find out the length of the tube required for 60% water recovery in the permeate. Following data are provided: R=5 cm; ΔP =414 kPa; L_P=membrane permeability=$2x10^{-11}$ m/Pa.s; Q_{in}=flow rate at the module inlet=40 l/h; solution viscosity can be considered as 0.001 Pa.s.

(10)

18. Consider a steady state gel layer controlling electro-UF system in a rectangular channel at 300K. The gel concentration is 5 times the bulk concentration of the solute. The feed flow rate is 30 L/h. The channel dimensions are 50 cm length,

5 cm width and half height h such that width (W)>> 2h. The feed consists of colloidal particles of radius 5 nm in 0.05 (M) NaCl solution. The charge on the colloidal particle is 10e, where, e is the electronic charge. The voltage of the external power supply is 1 V. If the permeate flux at 300 kPa TMP is 9×10^{-6} $m^3/m^2.s$, find the height of the channel. The solute diffusivity is 10^{-11} m^2/s. The mass transfer coefficient can be calculated from the Sherwood number expression in Q2. For water, dielectric constant is 80 and permittivity in vacuum is 8.85×10^{-12} C/V.m. Boltzman Constant is 1.38×10^{-23} J/K. **(10)**

19. Consider, a well mixed gas separation system. Feed consists of 10% CO_2 (A) and 90% CH_4 (B). The feed flow rate is 5 m^3/h at STP. The permeate recovery is 40% of the feed. Feed pressure is 45 atm and the permeate pressure is negligible compared to that in feed. The permeability (P_A) of CO_2 through the membrane is 4.75×10^{-10} $cm^2/(cm\ Hg.s)$. The ratio of P_A to P_B is 30.

    (i) Find the CO_2 concentration at the outlet of retentate and permeate. **(7)**

    (ii) Find the membrane area required if the membrane thickness is 20 micron. **(3)**

20. In a MEUF process, phenol (feed concentration 10 mg/l) is removed using surfactant SDS (CMC: 2.3 g/L) with concentration 15 g/L. The solubilization isotherm is given as $S(\mathrm{mg/g}) = \dfrac{QbC_p}{1+b_1C_p}$, where, Q=2 mg/g and b_1=0.05 l/mg. Mass transfer coefficient is 2×10^{-5} m/s and gel concentration for SDS micelles is 210 g/L. Find the permeate flux and permeate concentration. **(5)**

21. In a cloud point extraction process, dye is removed from 10^{-4} M to 10^{-5} M using TX-100 at 70^0C. The solubilization isotherm is $q_e(moles\,dye/moles\,surfactant) = \dfrac{mnC_e}{1+nC_e}$, where C_e is the dye concentration in filtrate in Molar unit. At 70^0C, $m=10^{-2}$ and $n=10^4$ in appropriate units. The fractional coacervate phase volume is related to the concentration of surfactant as $F_c = ac_s^b$ where, a and b are 2 and 1 in appropriate units.

    Find the surfactant concentration needed for this purpose. **(5)**