INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR
Mid-Spring Semester Examination 2024-25

Date of Examination:20.2.25 Session: (FN/AN):AN Duration: 2 hrs. Full Marks: 40

Subject No.: CH 62008 Subject: Novel Separation Processes

Department/Center/School: Chemical Engineering

Specific charts, graph paper, log book etc., required : No

Special Instructions (if any): Assume any relevant data; Since all relevant formulae are given , calculation mistake will not be considered.

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1. A 10 kg/m^3 protein solution is ultrafiltered in a hollow fiber module with 6000 fibers, each having length 30 cm and internal diameter 600 micron. The filtration is steady state under gel layer controlling with gel concentration 250 kg/m^3. The protein diffusivity is 10^{-11} m^2/s. The feed flow rate is 50 L/h. Find the filtration rate in L/h. What is recovery of feed in permeate? The flow inside a fiber is laminar and $Sh = 1.62\left(\mathrm{Re}\,Sc\frac{d}{L}\right)^{\frac{1}{3}}$. Use film theory. **(10)**

2. For an osmotic pressure controlled UF in a rectangular channel of length 1m, half height 1 mm, the membrane is placed at the bottom and top surface. The solution osmotic pressure is $\pi(\text{in Pa}) = 1.5\times10^4 c\,(\text{in}\,kg/m^3)$. The membrane permeability is 2.5x10^{-11} m/Pa.s. The solute concentration in feed is 10 kg/m^3 and its diffusivity is 6x10^{-11} m^2/s. The average cross flow velocity in the channel is 0.11 m/s. Find the width of the channel so that the permeate flow rate is 10 L/h. Use stagnant film theory. Assume the membrane is a perfectly rejecting one (Rr=1). The transmembrane pressure drop is 500 kPa. Use $Sh = 1.85\left(\mathrm{Re}\,Sc\frac{d}{L}\right)^{\frac{1}{3}}$ **(10)**

3. In a steady state gel controlling UF, the solute diffusivity is $D = D_0\left(1+k_0 c\right)$, where, D_0=10^{-11} m^2/s and k_0 is 0.02 m^3/kg. The gel concentration is 200 kg/m^3. The solute concentration in feed is 10 kg/m^3 and mass transfer coefficient is 10^{-5} m/s. Use stagnant film theory. (i) Find the permeate flux; (ii) the permeate flux, when k_0=0; (iii) what is the membrane area required to process 100 L/h permeate in both the cases.

(3+3+2+2)

4. In a steady state UF, the filtration is osmotic pressure controlling initially and after that it becomes gel controlling. The transmembrane pressure drop is 800 kPa. The molecular weight of the solute is 20 kDa. The gel layer density is 1020 kg/m^3. The solute feed concentration is 1 kg/m^3. The solution osmotic pressure is $\pi(\text{in Pa}) = 1000c + 80c^2$, where c is in kg/m^3. The membrane is a perfectly rejecting one (Rr=1) and its permeability is 10^{-11} m/Pa.s. The steady state flux in gel controlling regime is 10^{-6} m^3/m^{2}s.

(i) Find the gel layer concentration. (Hint: gel layer starts when the osmotic pressure controlling regime theoretically gives a nil flux). (2)

(ii) If diameter of solute molecule is 5 nm, find the gel porosity. (2)

(iii) Find specific gel layer resistance. (1)

(iv) Find the gel resistance in gel controlling regime at the SS (2)

(v) What is the steady state gel layer thickness? (2)

(vi) Find out the mass transfer coefficient in the gel controlling regime. (1)

The relation between gel porosity and solute molecular diameter is $\varepsilon_g = 1 - 1000\left(\frac{c_g}{MW}\right)N_{Av}\left(\frac{\pi}{6}d_p^3\right)$. The Kozney Equation for specific gel resistance is $\alpha_g = \frac{180(1-\varepsilon_g)}{\varepsilon_g^3 d_p^2 \rho_g}$.

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End-Spring Semester Examination 2024-25

Date of Examination: 23.4.2025 **Session: (FN/AN) AN** **Duration: 3 hrs.**

Full Marks:75

Subject No.: CH 62008 **Subject: Novel Separation Processes**

Department/Center/School: Chemical Engineering

Specific charts, graph paper, log book etc., required : No

Special Instructions (if any): Assume any required data and mention

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1. Consider a membrane module of rectangular cross-section of width 10 cm, half height 1 mm. The transmembrane pressure drop at the inlet is 500 kPa and flow rate at inlet is 100 L/h. Consider, the water viscosity as 0.001 Pa.s and membrane permeability 10^{-10} m/Pa.s. The osmotic pressure of the solute is negligible compared to the transmembrane pressure drop.

   (i) Find the module length to have 70% recovery of feed in permeate.

   (ii) What is the axial pressure drop?

   (iii) What is the pump wattage considering 30% pump efficiency?

   (iv) If the pump runs for 12 hours a day what is the pumping cost per month, assuming there are 25 working days in a month, if the cost of energy is Rs.15/unit (1 unit=1kW-h). (3+3+2+2)

2. In a counter-current, continuous dialyzer, the feed and dialysate flow rates are 200 and 400 ml/min. Urea concentration in the feed inlet is 600 mg/l. In the dialyzer, there are 8000 hollow fibers with internal diameter 200 micron, wall thickness 40 micron and length 30 cm. Urea has a bulk diffusivity 4×10^{-9} m^2/s and that in the membrane phase is 5×10^{-10} m^2/s. The feed side mass transfer coefficient is calculated using the relation $Sh=1.62(Re\ Sc\ d/L)^{0.333}$. The dialysate side mass transfer coefficient is 1.2 times of that in the feed side. Dilysate is pure distilled water at the inlet.

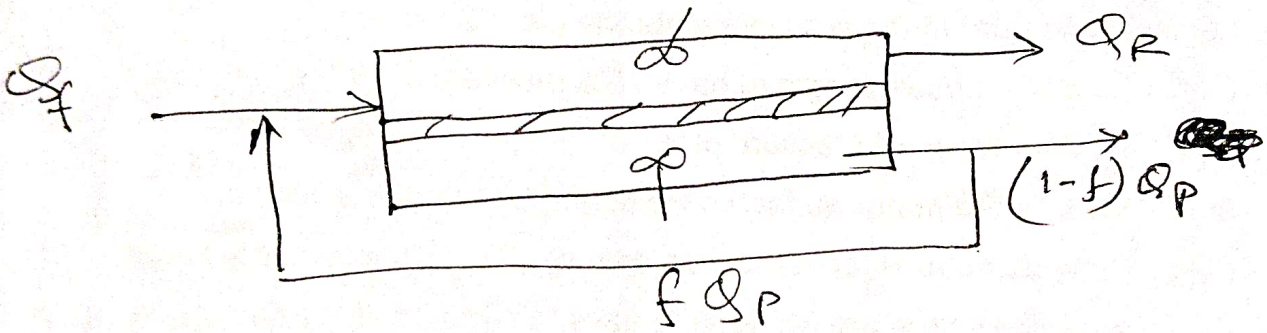
   Find out the urea concentration at the exit of the feed side. (10)

3. A protein in 0.15 M NaCl is separated at 25^{0}C by electric field enhanced gel controlling UF with rectangular cross section. The charge on the spherical

protein is 10e with radius 2.5 nm. The length of filtration cell is 1 m, width 10 cm, height 2 mm; The feed concentration of the protein is 30 kg/m^3 and gel concentration is 150 kg/m^3. The feed flow rate is 10 L/h. The voltage of external power source is 0.5 Volt. The mass transfer coefficient is calculated using the relation $Sh=1.85(Re\ Sc\ d/L)^{0.333}$. The protein diffusivity is 6×10^{-11} m^2/s. 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.

(i) If the throughput of the filtration is 5 l/h, what is the length of the membrane?

(ii) If we the external electric circuit is off, what is the length of the membrane required to realize the same throughput? (7+3)



4. A mixture of A and B is separated by a gas separation membrane and desirable component is A in the permeate. Recovery of feed in permeate is 50% (Q_P/Q_f=0.5). A part of the permeate (f) is recycled to the feed to increase its purity. Following data are given: P_A/P_B=6, X_{Af} =0.2, Pp/Pf=0.1.

(i) Plot the variation of mole fraction of A in in permeate with f.

(ii) For, f=0.75, if *l*=membrane thickness=0.1 μm; $P_B=32\times10^{-10}$ (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. (7+3)

5. In a MEUF process, phenol (feed concentration 8 mg/l) is removed using surfactant SDS (CMC: 2.3 g/L) with concentration 50 g/L. The solubilization isotherm is given as $S(\text{mg/g}) = \frac{QbC_p}{1+bC_p+b_1C_p^2}$, where, Q=10 mg/g, b=0.05 l/mg and b_1=0.008 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. (3+7)

6. Answer the following in one or two sentences:
   (i) Why chromatographic columns are enclosed in an oven? (1)
   (ii) Name a possible mobile phase in a chromatographic column. (1)
   (iii) Name a typical adsorbent used in a gas chromatography. (1)
   (iv) Name two desirable criteria of solid phase in Gas Liquid Chromatographic column. (2)
   (v) What is the common stationary phase in HPLC? (1)
   (vi) What is typical pressure in HPLC? (1)
   (vii) Why joule heating is undesirable in electrophoresis? Give 2 reasons. (2)
   (viii) Why electroosmosis is avoided in in electrophoretic separation processes? How it is avoided? (2)
   (ix) Name 4 reasons why CO2 is used as a supercritical fluid. (2)
   (x) Why co-solvent is used in supercritical fluid extraction? Name one such co-solvent. (2)
   (xi) Why water is not used as supercritical fluid? (2)
   (xii) Why there is a phase change beyond cloud point for non-ionic surfactants? (2)
   (xiii) What are cloud point temperatures for TX-100 and TX-114? (2)
   (xiv) What is the effect of pH and salt concentration on cloud point extraction? (2)
   (xv) Explain type 1 and type 2 facilitation in liquid membrane. (2)

Best Wishes