

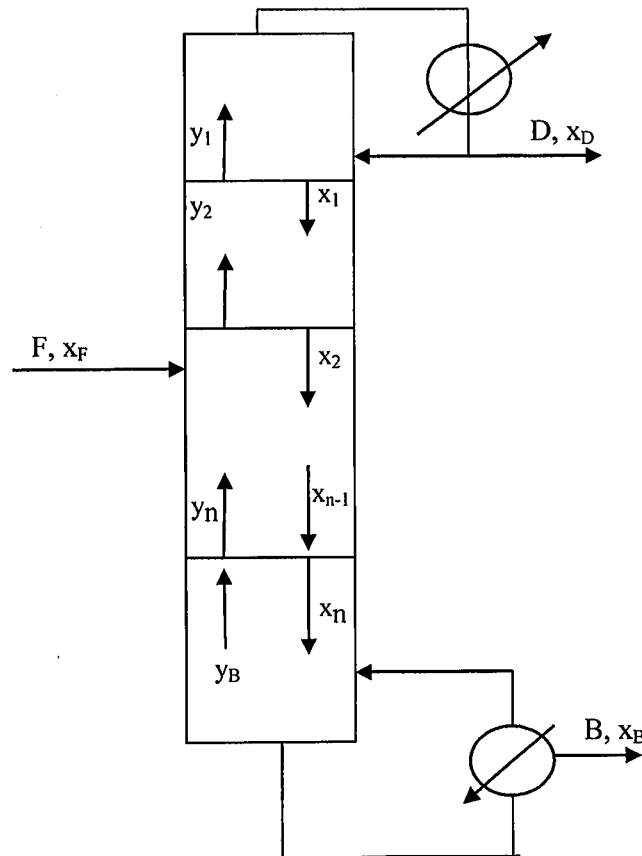
**B.E. CHEMICAL ENGINEERING FOURTH YEAR FIRST SEMESTER - 2019**4<sup>th</sup> Year, 1<sup>st</sup> Semester**SEPARATION PROCESSES-III**

Time: Three Hours

Full Marks: 100

Answer any Two questions**Q1. Multicomponent Distillation: Basics + Approximate methods [4+15+5+14+12=50]**

- a) Explain the following terms with examples in the light of multicomponent distillation: Light Non-Key (LNK); Heavy Non-Key (HNK).
- b) Consider a multicomponent distillation column operating at total reflux as shown in Figure A. Assuming all the stages are equilibrium stages, derive *Fenske's equation* to calculate the minimum number of trays in terms of the fractional recovery of light key in the distillate, fractional recovery of the heavy key in the bottoms and average relative volatility.

**Figure A**

- c) Explain (*with a rough diagram*) **separate 'Pinch Points'** in the rectifying and stripping sections of a rectification column undertaking multicomponent distillation.
- d) The presence of non-distributing heavy non-keys results in a pinch point of constant composition at minimum reflux in the rectifying section whereas due to the presence of non-distributing light non-keys, a pinch point will occur in the stripping section. Considering the pinch point is in the rectifying section, derive *Underwood's equation for minimum reflux* in two widely acceptable forms, i) first Underwood's equation and ii) second Underwood's equation for constant molar overflow and constant relative volatilities.
- e) A feed 150 kmol/h of saturated liquid containing 10 mole % LNK, 55 mole % LK, and 35 mole % HK and is to be separated in a distillation column. The reflux ratio is 1.4 times the minimum. It is desired to have 99.5 % recovery of the light key in the distillate. The mole fraction of the light key in the distillate should be 0.75. Equilibrium data:  $\alpha_{LNK}=4.0$ ,  $\alpha_{LK}=1.0$ ,  $\alpha_{HK}=0.75$ .
- Find out
- Minimum number of stages required by Fenske's method.
  - Minimum reflux ratio by Underwood method.
  - Number of ideal stages at  $R = 1.4 R_{min}$  by Gilliland's equation.
  - Number of ideal stages at the rectifying and stripping sections at an operating reflux ratio and the location of feed stage.

Gilliland's equation:

$$\frac{(N - N_{min})}{N + 1} = 1 - \exp \left[ \left( \frac{1 + \frac{54.4(R - R_{min})}{R + 1}}{11 + \frac{117.2(R - R_{min})}{R + 1}} \right) \left( \frac{R - R_{min} - 1}{R + 1} \right) \left( \frac{R - R_{min}}{R + 1} \right)^{0.5} \right]$$

Kirkbride's equation:

$$\frac{N_R}{N_S} = \left[ \left( \frac{x_{HK,F}}{x_{LK,F}} \right) \left( \frac{x_{LK,B}}{x_{HK,D}} \right)^2 \left( \frac{B}{D} \right) \right]^{0.206}$$

**Q2. Multicomponent Distillation: Rigorous methods** **[20+2+28=50]**

- a) Hengstebeck's Principle: In a typical distillation the flow-rates of each of the light non-key components approaches a constant, limiting rate in the rectifying section and the flows of each of the heavy non-key components approach limiting flow-rates in the stripping section.

Hengstebeck shows how the method can be extended to deal with situations where the relative volatility cannot be taken as constant, and how to allow for variations in the liquid and vapor molar flow rates. Based on this principle, enumerate:

- Lewis-Sorel material balance equations, for any  $i^{\text{th}}$  component,
- The equilibrium relationships in terms of the individual component molar flow rates,

- iii. Estimate the combined flows of the key components, assuming Hengstebeck's Principle,
  - iv. Apply Jenny's method, to estimate the limiting flow-rates,
  - v. Draw operating lines using estimates of the flows of the combined keys for the equivalent binary system. (Rough sketch)
  - vi. What is the particular equation of equilibrium line used in this method?
- b) What are i) Rating methods and ii) Design methods in multicomponent distillation. Give one example for each.
- c) A mixture of ortho, meta, and para mononitrotoluenes with the following composition is to be continuously distilled to give a top product of  $x_{do}=98\%$  mole ortho and the bottom is to contain  $x_{wo}=12.5\%$  mole ortho.

Component	Mole (%)
ortho-mononitrotoluene	60
meta-mononitrotoluene	4
para-mononitrotoluene	36

The mixture is to be distilled at a bottom temperature of  $T_B=410\text{K}$ , requiring a pressure in the boiler of about  $P=6.0\text{ kN/m}^2$ . If a reflux ratio of  $R=5$  is used, what will be the approximate compositions of the product streams? Apply Lewis –Matheson method. The volatility of ortho relative to the para isomer may be taken as  $\alpha_{op}=1.70$  and that of meta as  $\alpha_{mp}=1.16$  over the temperature range of  $380\text{--}415\text{ K}$ .

- i. Perform an overall mass balance.
- ii. Assuming McCabe-Thiele conditions to hold good, derive the equations of operating lines for the rectification and stripping sections.
- iii. Find out the liquid and vapour phase compositions of the still and the first and second plates, as counted from bottom. As a first estimate, assume that the distillate contains 0.6% meta and 1.4% para.

**Q3. Novel Separation Processes: Basics + RO [2+2+10(2+2+3+3)+2+6+3+15+10=50]**

- a) Explain Homogeneous and Microporous barriers w.r.t pore size and the modes of transport.
- b) Mark the correct answers:
  - i. In case of permeation/Knudsen diffusion/convection mean free path is longer than the pore diameter of the membrane.
  - ii. Convective transport is common in reverse osmosis/ultrafiltration/micro and ultrafiltration both.
- c) Explain w.r.t membrane transport:
  - i. Observed retention
  - ii. Real retention
  - iii. Molecular Weight Cut-Off
  - iv. Membrane permeability
- d) Name four factors on which the gradient of electro chemical potential of species depends.
- e) Differentiate (schematically): passive, facilitated and active transport considering electro chemical potential as the driving force of transport of species.

- f) Explain solution-diffusion imperfection model in the light of RO. (*No-derivation please*)
- g) Design an RO Module where a fraction of water in the feed is recovered as the product and most of the salts leave the unit with the reject stream. *Specification*: Feed flow rate ( $Q_f$ ), salt concentration in the feed ( $C_f$ ), permissible salt concentration in the product and the desired fractional recovery of water as product. Derive expressions for retentate concentration ( $C_m$ ) in terms of salt concentration in the feed ( $C_f$ ), rejection  $R'$  and the fractional recovery of water ( $\theta_w$ ).
- h) It is required to design an RO module for the production of 2000 m<sup>3</sup>/day potable water containing not more than 250 ppm salt from sea water containing 44 g salt per litre. An asymmetric cellulose acetate membrane with an inherent salt rejection ability of 98% is to be used. Water permeability coefficient is 0.045 m<sup>3</sup>/m<sup>2</sup>.day.atm. The recovery of the feed water should be 35% and an operating pressure of 70 atm (*guage*) is prescribed. Permeate is essentially at atmospheric pressure. If spirally wound modules of 5 m<sup>2</sup> effective membrane area each is used, how many modules in parallel are required? What fraction of the input power can be recovered from the retentate if a turbine of 70% efficiency is used for energy recovery? The osmotic pressure of 5% brine (linear in salt concentration) is 39.5 atm.

**Q4. Novel Separation Processes: Basics+ UF+ Dialysis [7+2+2+8+4+4+8+7+4+4=50]**

- a) Using film theory, describe the method of estimating real retention experimentally using *velocity variation technique*.
- b) How is *Kedem-Katchalsky* equation different from the *osmotic pressure model*?
- c) How many ways permeate concentration,  $C_p$ , can be expressed in terms of solute concentration at the membrane surface,  $C_m$ .
- d) Derive the implicit form of **Kedem-Katchalsky** model for permeate flux through an ultrafiltration (UF) membrane.
- e) Write down two advantages and two disadvantages of using UF membranes.
- f) How do the following factors affect the performance of an UF membrane:
- i. Trans-membrane flow
  - ii. Salt concentration
- g) Considering mass transfer in dialysis, develop an expression for solute flux through a dialysis membrane in terms of the bulk concentrations in the first ( $c_1$ ) and the second ( $c_2$ ) liquid phases, mass transfer coefficients in the first ( $k_{c1}$ ) and the second ( $k_{c2}$ ) liquid phases, thickness of the membrane,  $\delta$ , the equilibrium distribution coefficient,  $K_s$ , and the diffusivity of the solute through the membrane,  $D_{sm}$ .
- h) Calculate the rate of removal of urea (MW=60.06 g/mol) in g/h from blood in a cellophane membrane dialyser at 37°C. The membrane is 0.025 mm thick and having an area of 2.0 m<sup>2</sup>. The mass transfer coefficient on the blood side is 1.25x10<sup>-5</sup> m/s and the same on the aqueous side is 3.33 x10<sup>-5</sup> m/s. The membrane permeability is 8.73 x10<sup>-6</sup> m/s. The concentration of urea in blood is 0.02 g urea per 100 ml and that in the dialysing fluid can be assumed.
- i) Explain briefly the principle of operation of a Hemodialyser with a schematic diagram.
- j) Explain the Gibbs-Donnan effect w.r.t the transport of solute across a dialysis membrane.