**BIRLA INSTITUTE OF TECHNOLOGY & SCIENCE, PILANI, PILANI CAMPUS**
**CHEMICAL ENGINEERING DEPARTMENT**
COMPREHENSIVE EXAMINATION

Course Title: Process Design Principles - I | Nature of Exam: Closed Book
Course No.: CHE F314 | Date: 05/12/2016
Marks: 80 | Time: 2 hr

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**Note:**

- **Make the suitable assumptions by clearly stating them, if necessary.**
- **Q.No. 1 to 15 carry one mark each. Q.No. 16 to 20 carry three marks each. Q.No. 21 and 22 carry 20 and 30 marks, respectively.**
- **Q. No. 1 to 15 should be answered in first page of answer sheet. Write correct answer in Capital letters only.**

1. To determine the phase of a reactor effluent, we can use sharp split approximation procedure. If the distribution coefficients of a given mixture $K_i$<<1, then:
   (a) $V = \sum f_i$ (b) $L = \sum f_i$ (c) $Vy_i = Fz_i$ (d) $V = \sum f_i$ and $Vy_i = Fz_i$
2. In order to avoid the separation of close boiling point mixtures, reactors are operated at high conversions. The high equilibrium conversions in case of exothermic reactions can be achieved by:
   (a) increasing the molar ratio at the reactor inlet
   (b) decreasing the molar ratio at the reactor inlet
   (c) keeping molar ratio constant as it has no significance in obtaining high equilibrium conversions
   (d) increasing the reactor temperature
3. For vapor-liquid processes, if the reactor effluent is all vapor, we cool the stream to ______.
   (a) $35^oF$ (b) $35^oC$ (c) 100 K (d) $100^oC$
4. If the materials that are deleterious to the reactor operation is present in the vapor stream, then vapor recovery system should be placed in the__________.
   (a) Flash vapor stream (b) Purge stream
   (c) Gas recycle stream (d) Reactor effluent stream
5. In which case, we would eliminate the phase splitter and feed the reactor effluent stream directly into the distillation column
   (a) Small amount of vapor in the stream (b) Only vapor in the stream
   (c) Small amount of liquid in the stream (d) Mixed liquid and vapor stream
6. The gas recycles and purge stream is used in a process, if the light reactant is boiled at boiling point lower than the boiling point of _________.
   (a) Ethylene (b) Propylene (c) Propene (d) Ethene
7. Normally the cost of a distillation column is specified in terms of the________.
   (a) Column diameter (b) Number of plates in the column
   (c) Length of the column (d) a & c
8. If the equilibrium constant of reversible byproduct is small, then the byproduct is small. Hence, the byproduct stream should be:
   (a) Removed (b) Recycled (c) Purged (d) Recycled and Purged
9. Which is the most suitable heuristic for column sequencing?
   (a) Remove corrosive components in the last column
   (b) Remove corrosive components as soon as possible
   (c) Remove corrosive components as distillate
   (d) Remove corrosive components as bottoms

10. Kremser-Brown equation is used for calculating number of trays for designing isothermal dilute gas absorber. What is the effect of increasing temperature on liquid flow rate ($L$) and on number of absorber trays ($N$)?
    (a) $L$ increases and $N$ remains the same
    (b) $L$ decreases and $N$ remains the same
    (c) $L$ increases and $N$ decreases
    (d) Both $L$ & $N$ decrease
11. For exothermic reactions, if the adiabatic temperature rise exceeds 10-15% of the inlet temperature and reactor heat load is greater than $6x10^6$ to $8x10^6$ Btu/hr, we generally:
    (a) use direct cooling
    (b) either introduce a diluent or heat carrier
    (c) use jacketed reactor
    (d) use packed bed reactor
12. During the removal of light ends in LSS side-stream scheme, if the desired product is having intermediate boiling point and the waste or a fuel by-product is much heavier than the product,
    (a) recover the product as side stream below the feed
    (b) recover the product as side stream above the feed
    (c) recover the product from the top of the LSS
    (d) use separate azeotropic distillation column
13. Liquid recovery system comes under which hierarchy of decisions in conceptual design
    (a) Input-output structure
    (b) Recycle structure
    (c) Batch Vs. Continuous
    (d) General structure
14. The pinch design method says that cold utility can be placed above the pinch. **(True/False)**
15. For a minimum utility target to meet that should not be any heat flow through pinch. **(True/False)**
16. The relative volatilities of four components (A, B, C and D) of a mixture are given below:

| Component | Relative Volatility |
|---|---|
| A | 4.7 |
| D | 2.58 |
| B | 3.7 |
| C | 2.6 |

    For the separation of given components, draw all possible alternatives of distillation train with reference to column sequencing.
17. The fresh feed of toluene in HDA process is 100 mol/hr. The conversion of toluene in the reactor is 50%. The unconverted toluene is completely recovered in the separator and recycled back to reactor. What is the total feed to the reactor?
18. If the selectivity is defined as moles ketene at reactor exit per mole of acetone converted, write the selectivity in terms of extent of reaction for the following reactions:

    Acetone $\longrightarrow$ Ketene + Methane (1)
    Ketene $\longrightarrow$ $CO + 0.5\,H_2$ (2)
    Ketene + Acetic Acid $\longrightarrow$ Acetic Anhydride (3)

    The extent of reaction for reactions (1), (2) and (3) are $\xi_1$, $\xi_2$ and $\xi_3$, respectively.
19. Phosgene is produced by the following reaction scheme:

    $CO + Cl_2 \longrightarrow COCl_2$

    Discuss the design guidelines with respect to decision making at level-3 corresponding to the use excess amount of reactant.
20. In the given reaction system, assume the second reaction is reversible. The main product is 2-butanol which produces MEK as a by-product. The reactions are as follows:

    **Step 1:** 2-butene + $H_2O$ $\longrightarrow$ 2-butanol
    **Step 2:** 2-butanol $\rightleftharpoons$ MEK + $H_2$

    Discuss the decision for recycling or recovering the byproduct (i.e. MEK).

21. A storage tank is purged continuously with a stream of nitrogen. The purge stream leaving the tank is saturated with the product (low boiling point organic compound, soluble in water) stored in the tank. To recover the product from purge stream, draw the flow sheets of various process alternatives and choose the best one. **Justification is needed for each of the process alternatives**. Perform the material balances to calculate the composition and total flow rate of each stream using the following data:

| | |
|---|---|
| Total flow rate of purge stream | = 800 lb/h |
| Mass fraction of product in purge stream | = 0.5% |
| Fugacity of product and water system at 25$^o$C and 1 atm | = 6.8 |
| Vapor pressure of product at 25$^o$C | = 230 mm Hg |

22. For the problem given with minimum approach temperature difference, $\Delta T_{min}$ = 10 $^o$C, carry out the Energy Integration Analysis using Pinch Technology by determining the following:
(a) Number of heat exchangers based on I law analysis.
(b) Number of heat exchangers based on II law analysis.
(c) Hot end design.
(d) Cold end design.
(e) Heat exchanger network for the maximum energy recovery (MER).
(f) Number of loops crossing the pinch.
(g) Identification of the loops.
(h) Final heat exchanger network after breaking all the loops and restoring $\Delta T_{min}$ as and when there is a violation.

| **Stream No** | **Condition** | ***FC*$_p$ (kW/$^o$C)** | ***h* (kW/m$^2$ $^o$C)** | **Source Temperature ($^o$C)** | **Target Temperature ($^o$C)** |
|---|---|---|---|---|---|
| 1 | Hot | 8 | 0.4 | 120 | 60 |
| 2 | Hot | 10 | 0.55 | 160 | 40 |
| 3 | Cold | 2 | 0.75 | 10 | 100 |
| 4 | Cold | 60 | 0.65 | 80 | 115 |

Assume the supply temperature of hot & cold utility are 300 $^o$C and 15 $^o$C respectively. Heat transfer coefficient of hot utility and cold utility is 0.5 kW/m$^2$ $^o$C. Pinch temperature is 90 $^o$C (based on hot temperature scale), 80 $^o$C (based on cold temperature scale) and 85 $^o$C (based on an average). The minimum hot and cold utility requirements are 1200 and 600 kW.

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Course No.: CHE F314 — Date: 05/12/2016
Marks: 40 — Time: 1 hr

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**Note: Make the suitable assumption by clearly stating them, if necessary.**

1. **(20 Marks)**
   It is usual practice in an industry to estimate the minimum number of trays in a distillation column for a binary mixture by taking the sum of the boiling points and dividing by three times their difference. **Show that the back-of-the-envelope model is essentially equivalent to Fenske's equation for the minimum number of trays**? Assume ideal, close-boiling mixture, the Classius-Clayperon equation, Trouton's rule, and we want to obtain 97% purities. According to Trouton's rule, the molar heat of vaporization in calories divided by the normal boiling point on the absolute scale has the approximate constant value of 21 cal/mol.K.
   **Fenske's Equation**:
   $$N_m = \frac{\ln\left[\left(\frac{x_D}{1-x_D}\right)\left(\frac{1-x_W}{x_W}\right)\right]}{\ln\alpha}$$
   Where, $N_m$ = minimum number of trays required for distillation operation at total reflux; $x_D$ = mole fraction of more volatile component in distillate; $x_w$ = mole fraction of more volatile component in bottom product and $\alpha$ = relative volatility.
   **Classius-Clayperon Equation**:
   $$\log_{10} p^* = -\frac{\Delta H_v}{2.303RT} + B$$
   Where, T = distillation temperature.

2. **(20 Marks)**
   80 mol/hr of Butadiene sulfone is produced by the following reaction:
   $$\text{Butadiene} + SO_2 \Leftrightarrow \text{Butadiene Sulfone}$$
   The reaction takes place in the liquid phase at 90$^o$F and 150 psia. Boiling point of $SO_2$ at 1 atm is -10$^o$C and assume $SO_2$ is pure. The costs are: $SO_2$ = \$0.064/mol, butadiene = \$6.76/mol, and butadiene sulfone = \$8.50/mol. **Develop the recycle structure for the process. Estimate the flow rates of all streams in terms of design variables in the recycle structure. Estimate the EP2 in terms of design variables.** Use the following assumptions: $SO_2$ is supplied in excess and Plant operated for 8150 h/yr.

## ALL THE BEST

**Solution (Closed Book):**

1. (B)
2. (A)
3. (B)
4. (C)
5. (A)
6. (B)
7. (D)
8. (B)
9. (B)
10. (A)
11. (B)
12. (A)
13. (D)
14. False
15. True
16. Solution:

17. Total feed of toluene to the reactor, $F_T = F_{FT}/x$
    Where, $F_{FT}$ = 100 mol/hr (fresh feed of toluene) and $x$ = 0.5 (conversion)
    So, $F_T$ = 100/0.5 = 200 mol/hr

18. No. of moles of acetone converted: $\xi_1$
    No. of moles of ketene exit from first reactor = $\xi_1 - \xi_2$
    Selectivity = $(\xi_1 - \xi_2)/\ \xi_1$

19. Phosgene must be free from chlorine. Hence, we ensure complete conversion of $Cl_2$ by using excess amount of CO, so that total chlorine is consumed by the reaction.

20. Since the second reaction is reversible, we can recycle the MEK back to the reactor and let it build up in the recycle loop until it reaches to an equilibrium level. But, in turn we must increase the size of the equipment. However, if we remove it from the process, we need to pay an economic penalty because increased raw material cost of 2-butene. So, there is an economic trade-off between these two.