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

Course Title: Process Design Principles - I (CHE F314)

Mid-Semester Test (Closed Book)

Marks: 90 ` **Date: 09/10/23** **Time: 90 minutes**

Note: Make suitable assumptions by clearly stating them, if necessary. Write all steps clearly.

1. **(12+13 = 25 Marks)**
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.
(a) To recover the product from the purge stream, draw the flow sheets for two possible process alternatives and choose the best one. **Justification is needed for each of the process alternatives**.
(b) Perform the material balances in the best-chosen flow sheet to calculate the composition and total flow rate of each stream using the following data:

Total flow rate of purge stream	= 800 lb/h
Molecular weight of organic compound	= 60
Mass fraction of product in purge stream	= 0.5%
Activity coefficient of product and water system at 25°C and 1 atm	= 6.8
Vapor pressure of product at 25°C	= 230 mm Hg

2. **(2+6+6+4+1+10+10+1 = 40 Marks)**
For the problem given with minimum approach temperature difference, ΔT_{min} = 10 °C, carry out the Energy Integration Analysis using Pinch Technology by determining the following:
(a) Net amount of heat available in the streams based on I law.
(b) Shifted temperature scales diagram with net heat in respective intervals.
(c) Construction of cascade diagram, minimum hot & cold utilities requirement, and Pinch temperature.
(d) Number of heat exchangers based on I & II law analysis.
(e) Number of loops crossing the pinch.
(f) Hot-end design.
(g) Cold-end design.
(h) Heat exchanger network for the maximum energy recovery (MER).

S No	Condition	FC_p (kW/°C)	h (kW/m² °C)	Source Temperature (°C)	Target Temperature (°C)
1	Hot	4	0.4	200	80
2	Hot	2	0.55	170	50
3	Cold	3	0.75	40	155
4	Cold	7	0.65	100	160

Assume the supply temperature of hot & cold utility are 330 °C and 15 °C respectively. Heat transfer coefficient of hot utility and cold utility is 0.5 kW/m² °C.

3. **(5+5 = 10 Marks)**
(a) In a given process, reactor effluent contains 5 components (A,B,C,D, and E) having significant differences in boiling point. The objective of the process is to recover pure products D and E. **Name the unit process and process synthesis step** that will be selected for this recovery.
(b) Why is the pressure inside the chlorination reactor kept above the atmospheric pressure and is kept at 500 Psi in the pyrolysis reactor, for the vinyl chloride production process?

4. **(8 + 5 + 2 = 15 Marks)**

Ammonium nitrate, a constituent of many fertilizers, is manufactured as per the following reaction between ammonia and aqueous nitric acid:

$$NH_3(g) + HNO_3(aq) \rightarrow NH_4NO_3(aq)$$

The nitric acid fed to the process is a 59.5 wt% solution that enters a charge tank at a rate of 10,970 kg/h. Also fed to the tank are two recycle streams coming from different parts of the process. Both of these streams contain ammonium nitrate, and one also contains dissolved ammonia. A liquid stream from the charge tank is heated from 24°C to 149°C and fed to the reactor, along with a stream of ammonia vapor at 108°C and 4.5 bar. The total ammonia fed to the reactor is 5% in excess of the amount needed to react completely with the nitric acid in the feed. At the reactor operating conditions, the ammonium nitrate is formed as liquid droplets and most of the water in the acid is vaporized. The reaction goes to completion. The reactor effluent - a gas-liquid mixture - leaves the reactor at a temperature of 238°C and flows into a cyclone separator. The tangential flow of the mixture generates a centrifugal force on the liquid droplets that impels them to the wall. The droplets adhere to and flow down the wall to the base of the unit where they are contacted with hot air, which vaporizes essentially all of the water and a small amount of the ammonium nitrate, leaving the remaining ammonium nitrate in a molten condition. The mass ratio of air to reactor effluent entering the cyclone is 0.045:1. Before entering the cyclone, the air is heated from 24°C to 205°C by exchange of heat with the gases leaving the cyclone. The molten ammonium nitrate stream leaves the separator at 199°C and is air-cooled on a slowly moving belt to a temperature at which it all solidifies. The solid ammonium nitrate is then ground and screened. All but the smallest particles (the "fines") go through a coating process and then to bagging and shipping. The fines, which account for 16.4% of the nitrate fed to the grinding mill, are recycled to a tank where they are redissolved in acid and recycled to the charge tank. The gas stream leaving the cyclone contains hot air, the excess ammonia, water evaporated from the nitric acid solution in the reactor and from the collected liquid in the cyclone, and 3% of the ammonium nitrate in the reactor effluent. The stream leaves the separator at 233°C, passes through the air preheater, and enters a partial condenser where some of the water and ammonia and essentially the entire nitrate is condensed.

Show the following hierarchy of flow sheets:

(a) General structure

(b) Recycle structure

(c) Input-Output structure

ALL THE BEST