

Time: 3 Hrs

Marks 80

- (1) Question No. 1 is compulsory.
- (2) Attempt any three questions out of remaining five questions.
- (3) **Figures** to the right indicate full marks.
- (4) **Assume suitable data wherever necessary.**

- Q1
- |    |  |           |
|----|--|-----------|
| a) | Explain process integration activities in detail?        | <b>05</b> |
| b) | What are the optimum stream rerouting strategies?        | <b>05</b> |
| c) | Explain hierarchy of mass integration strategies.        | <b>05</b> |
| d) | Explain sink composition and source prioritization rule. | <b>05</b> |
- Q2
- Vinyl acetate monomer “VAM” is manufactured by reacting acetic acid with oxygen and ethylene. 10,000 kg/h of acetic acid “AA”(Acetic Acid) along with 200 kg/h of water are evaporated in an acid tower. The vapor is fed with oxygen and ethylene to the reactor where 7000 kg/h of acetic acid are reacted and 10,000 kg/h of VAM are formed. The reactor off-gas is cooled and fed to the first absorber where AA (5100 kg/h) is used as a solvent. Almost all the gases leave from the top of the first absorption column together with 1200 kg/h of AA. This stream is fed to the second absorption column where water (200 kg/h) is used to scrub acetic acid. The bottom product of the first absorption column is fed to the primary distillation tower where VAM is recovered as a top product (10,000 kg/h) along with small amount of AA which are not worth recovering (100 kg/h) and water (200 kg/h). This stream is sent to final finishing. The bottom product of the primary tower (6800 kg/h of AA and 2300 kg/h of water) is mixed with the bottom product of the second absorption column (1200 kg/h of AA and 200 kg/h of water). The mixed waste is fed to a neutralization system followed by biotreatment.

The following technical constraints should be observed in any proposed solution:

#### Neutralization

$$0 \leq \text{Flowrate of Feed to Neutralization (Kg/h)} \leq 11000$$

$$0 \leq \text{AA in Feed to Neutralization (w t\%)} \leq 85\%$$

#### Acid Tower

$$10200 \leq \text{Flowrate of Feed to Acid Tower (kg/hr)} \leq 11200$$

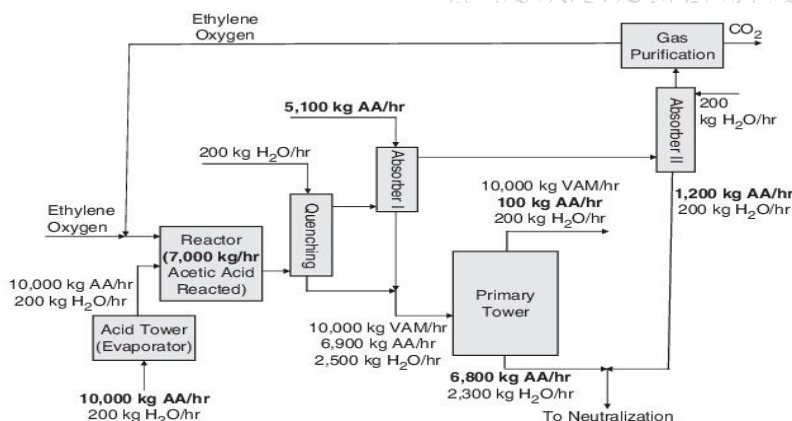
$$0 \leq \text{Water in Feed to Acid Tower (wt\%)} \leq 10$$

#### First Absorber

$$5100 \leq \text{Flowrate of Feed to Absorber I (Kg/h)} \leq 6000$$

$0 \leq \text{Water in Feed to Absorber I (wt\%)} \leq 5.00$

It can be assumed that the process performance will not significantly change as a result of direct-recycle activities. What is the target for minimum usage (kg/h) of fresh acetic acid in the process if segregation, mixing, direct-recycle are used? Can you find more than one strategy to reach the target?



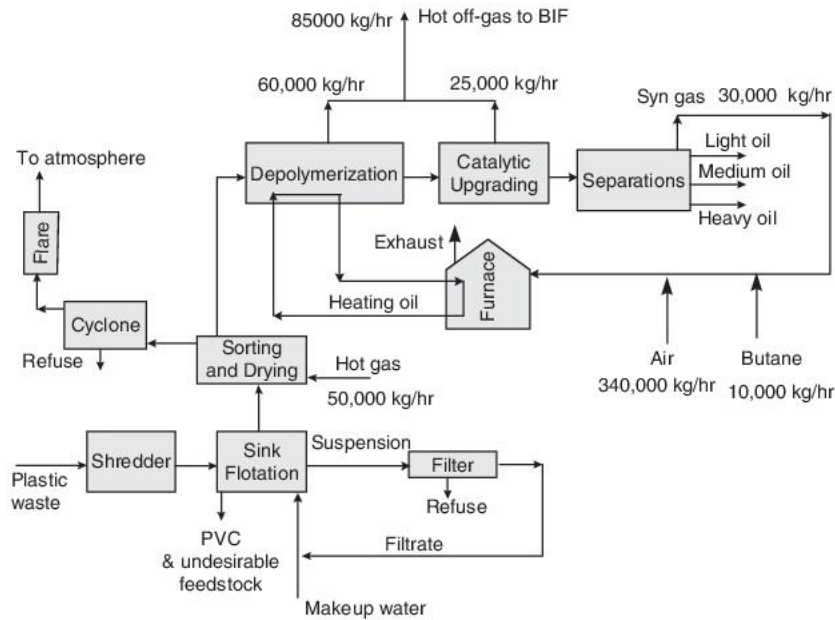
Q3 20

A schematic process flowsheet is given in Figure. Plastic waste (feedstock) is first shredded then sorted in a sink/flotation unit to remove polyvinyl chloride (PVC) and undesirable feedstock. The suspension from the sink flotation unit is filtered. The refuse from filtration is rejected and the filtrate is recycled to the sink flotation unit. The remaining feedstock is sorted and dried using 50,000 kg/h of hot gas. At present, this hot gas contains no butane. Also, no butane is formed in sorting and drying. The hot gas leaving the sorting and drying process is passed through a cyclone to remove suspended solids as refuse. The cyclone is followed by a flare where any organics are burned. The sorted/dried feedstock enters a depolymerization unit where a butane-laden gaseous stream (total flow rate of gas is 60,000 kg/h and it contains 7200 ppm w% butane) is generated. The slurry leaving the depolymerization unit is upgraded in a catalytic unit then separated into various hydrocarbon cuts. The off-gas leaving the catalytic upgrading unit has a flowrate of 25,000 kg/h and contains 80,000 ppmw of butane. The depolymerization unit is heated using a recirculating heating oil coming from a furnace. The feed to the furnace consists of 30,000 kg/h of syngas (composed primarily of butane), 10,000 kg/h of butane, and 340,000 kg/h of air. The exhaust from the furnace contains almost no butane. Until recently, the gaseous streams from the depolymerization and catalytic units were mixed and fed to a boiler/industrial furnace (BIF). Due to economic, safety, and environmental concerns the BIF operation is to be discontinued and the mixed off-gas is to be rerouted in the plant.

- What is current flowrate (kg/h) of purchased fresh butane?
- What is the total amount (kg/h) of butane generated by chemical reaction in the process?
- How much (kg/h) butane is depleted by chemical reaction in the process?.



d. What is the target (kg/h) for minimum purchase of fresh butane?



Q4 Benzene is to be removed from a gaseous emission by contacting it with an absorbent (wash oil, molecular weight 300). The gas flow rate is 0.2 kg-mole/s (about 7700 ft<sup>3</sup>/min) and it contains 0.1% mol/mol (1000 ppm)of benzene. The molecular weight of the gas is 29, its temperature is 300K,and it has a pressure of 141 kPa (approximately 1.4 atm). It is desired to reduce the benzene content in the gas to 0.01% mol/mol Benzene is first absorbed into oil. The oil is then fed to a regeneration system in which oil is heated and passed to a flash column that recovers benzene as a top product. The bottom product is the regenerated oil, which contains 0.08 % mol/mol benzene. The regenerated oil is cooled and pumped back to the absorber. What is the optimal flowrate of recirculation oil that minimizes the TAC of the system? **20**

Data

- 1) Assume Raoult's law
- 2) Vapor pressure of benzene 14.101 Pa

**Absorber Sizing Criteria**

The overall-gas height of transfer unit for the packing is 0.58 m.

The superficial velocity of the gas in the absorber is taken as 1.5 m/s to avoid flooding.

The mass velocity of oil in the absorber should be kept above 2.7 kg/m<sup>2</sup> s to insure proper wetting.

**Cost Information**

The operating cost (including pumping, oil makeup, heating, and cooling) is Rs.40/kg-mole of recirculating oil.

The system is to be operated for 325days/annum. The installed cost of the absorption column (including auxiliaries, but excluding packing) is given by

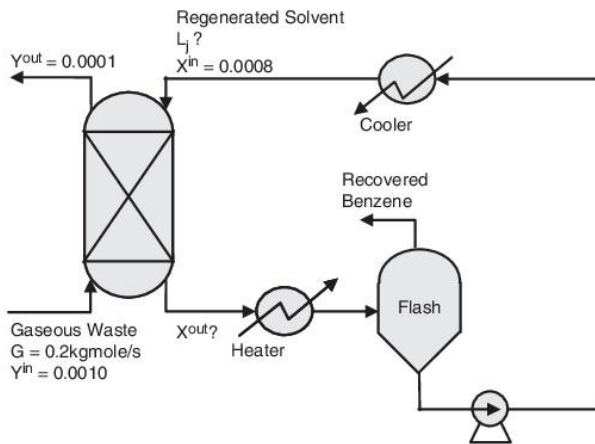
$$\text{Installed cost of column} = 2290 H^{0.85} D^{0.95}$$

where H is the packing height (m) and D is the column diameter (m).

The packing cost is Rs 47500/m<sup>3</sup>

The oil-regeneration system is to be salvaged from a closing unit in the plant. Hence, its fixed cost will not be accounted for in the optimization calculations.

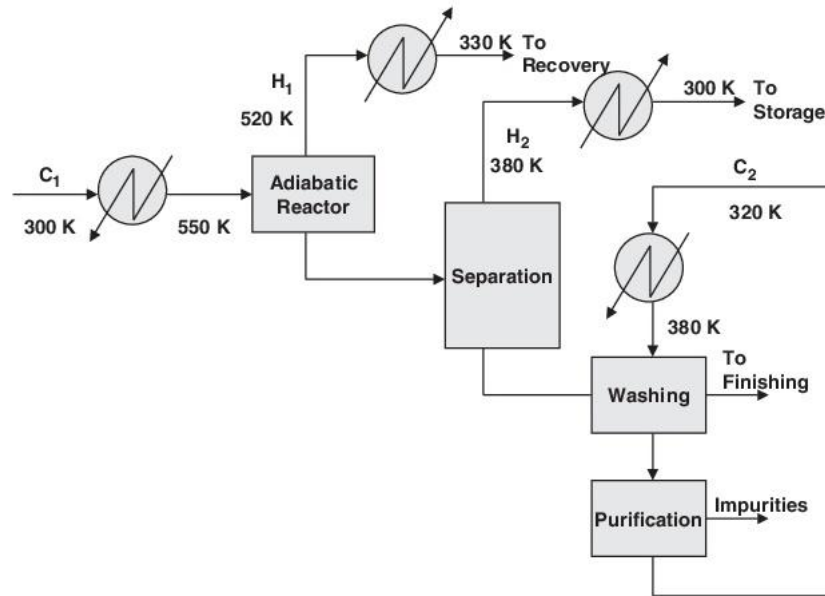
The absorber and packing are assumed to depreciate linearly over five years with negligible salvage values.



**Q5** In the pharmaceutical processing facility as per fig. The feed mixture (C1) is first heated to 550 K, then fed to the adiabatic reactor where an endothermic reaction takes place. The off-gases leaving the reactor(H1)at 520 K are cooled to 330 K prior to being forwarded to the recovery unit .The mixture leaving the bottom of the reactor is separated into a vapor fraction and a slurry fraction . The vapor fraction (H2) exits the separation unit at 380 K and it is also cooled to 300 prior to storage . The slurry fraction is washed with a hot immiscible liquid at 380 K . The wash liquid is purified and recycled to the washing unit..During purification , the temperature drops to 320 K, Recycled liquid (C2) is heated to 380K.Two utilities are available for service HU1 and CU1. The cost of heating and cooling utilities are 3 and 5 (Rs/10<sup>6</sup>Kj)respectively. Stream data are given below. **20**

A value of  $\Delta T^{\min}=10\text{K}$  is used .Using pinch analysis , determine heating and cooling utilities for the process.

Stream	Flow rate	Supply Temp. (K)	Target Temp.(K)	Enthalpy change (KW)
H1	10	520	330	1900
H2	5	380	300	400
HU1	?	560	520	?
C1	19	300	550	-4750
C2	2	320	380	-120
CU1	?	290	300	?



Q6 In the magnetic tape manufacturing process, coating ingredients are dissolved in 0.09 kg/s of organic solvent and mixed to form a slurry. The slurry is suspended with resin binders and special additives. Next, the coating slurry is deposited on a base film. Nitrogen gas is used to induce evaporation rate of solvent that is proper for deposition. In the coating chamber, 0.011 kg/s of solvent are decomposed into other organic species. The decomposed organics are separated from the exhaust gas in a membrane unit. The retentate stream leaving the membrane unit has a flowrate of 3.0 kg/s and is primarily composed of nitrogen that is laden with 1.9 wt/wt% of the organic solvent. The coated film is passed to a dryer where nitrogen gas is employed to evaporate the remaining solvent. The exhaust gas leaving the dryer has a flowrate of 5.5 kg/s and contains 0.4 wt/wt% solvent. The two exhaust gases are mixed and disposed off. It is desired to undertake a direct-recycle initiative to use solvent-laden nitrogen (gaseous wastes) in lieu of fresh nitrogen gas in the coating and drying chambers. The following constraints on the gaseous feed to these two units should be observed: 20



Coating

$3.0 \leq \text{flowrate of gaseous feed (Kg/s)} \leq 3.2$

$0.0 \leq \text{wt\% of solvent} \leq 0.2$

Dryer

$5.5 \leq \text{flowrate of gaseous feed (Kg/s)} \leq 6.0$

$0.0 \leq \text{wt \% of solvent} \leq 0.1$

It may be assumed that the outlet gas compositions from the coating and the dryer chambers are independent of the entering gas compositions. Using segregation, mixing and direct-recycle, what is the minimum consumption of nitrogen gas that should be used in the process? What are the strategies leading to the target?

