

[Time: Three Hours]

[Marks:80]

Please check whether you have got the right question paper.

- N.B:
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

- Q.1. a) Explain hierarchy of mass integration strategies. 05
 b) Explain Mass separating Agent(MSA) selection criterion 05
 c) Explain sink composition Rule, Source prioritization rule. 05
 d) Explain composition interval diagram (CID) 05

Q.2. Consider the magnetic tape manufacturing process shown in Figure. In this 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:

Coating

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

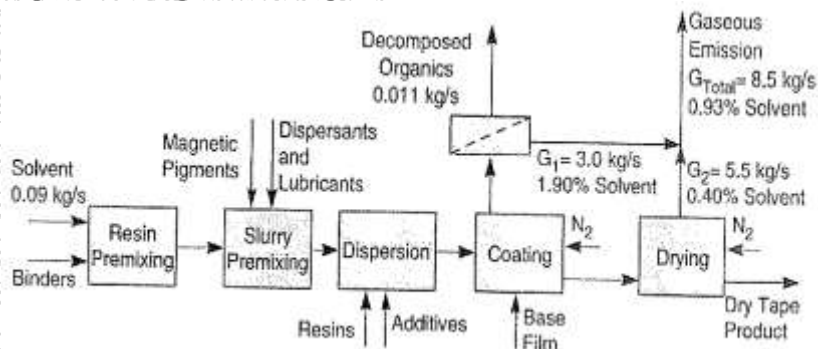
$$0.0 \leq \text{wt\% of solvent} \leq 0.2$$

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?



Q.3. Benzene is to be removed from a gaseous emission by contacting it with an absorbent (wash oil, 20 molecular weight 300). The gas flow rate is 0.2 kg-mole/s (about 7700 ft³/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 (Total Annual Cost) of the system?

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/m²s to insure proper wetting.

Cost Information

The operating cost (including pumping, oil makeup, heating, and cooling) is Rs.30/kg-mole of recirculating oil.

The system is to be operated for 8000 Hr/annum.

The installed cost of the absorption column (including auxiliaries, but excluding packing) is given by Installed cost of column = 2300 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 48000/m³

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

Q.4. A metal degreasing process presented in Figure Currently, a fresh organic solvent is used in the 20 degreaser and the absorber. A reactive thermal processing and solvent regeneration system is used to decompose the grease and the organic additives, and regenerate the solvent from the degreaser. The liquid product of the solvent regeneration system is reused in the degreaser, while the gaseous product is passed through a condenser, an absorber, and a flare. The process produces two condensate streams: Condensate I from the solvent regeneration unit and Condensate II from the degreaser. The two streams are currently sent to hazardous waste disposal. Since these two streams possess many desirable properties that enable their possible use in the process, it is recommended that their recycle/reuse to be considered. The absorber and the degreaser are the two process sinks. The two process sources satisfy many properties required for the feed of the two sinks. An additional property should be examined; namely Reid Vapor Pressure (RVP), which is important in characterizing the volatility, makeup, and regeneration of the solvent.

Property of Loads

Sink	Flow rate (kg/S)	Upper bound	Upper bound RVP ^{1.44}	Max. Property Load
Degreaser	5.0	3.0	4.87	24.35
Absorber	2.0	4.0	7.36	14.72

The mixing rule for vapor pressure (RVP) is given by the following expression:

$$RVP^{1.44} = \sum xi RVP_i^{1.44}$$

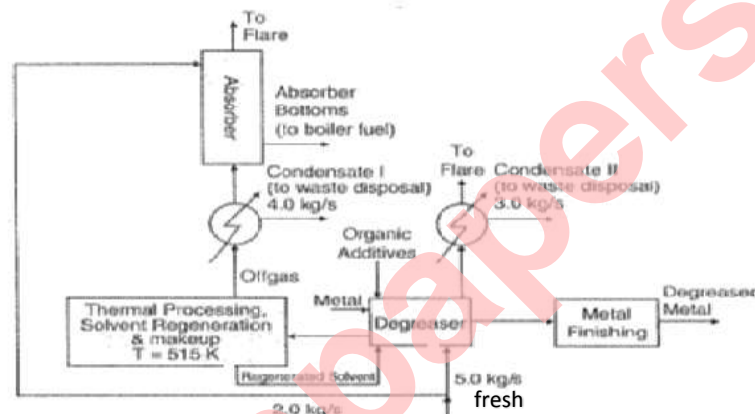
The RVP for condensate I is a function of the thermal regeneration temp as follows

$$RVP_{\text{Condensate I}} = 0.5e^{(T-100)/175}$$

Properties of Process sources and Fresh

Source	Flowrate (Kg/s)	RVP(atm)
Process condensate I	4.0	6.0
Process Condensate II	3.0	2.5
Fresh Solvent	To be determined	2.0

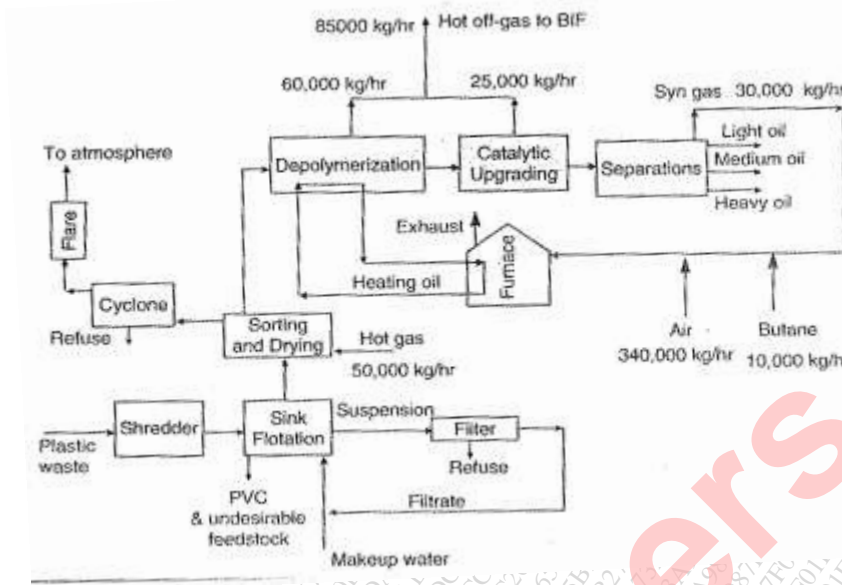
- What is the target for minimum fresh usage when direct recycle is used?
- Of the process is to be modified by manipulating the temp, of the condenser, what is the target for min fresh usage?



Q.5. Every year, significant quantities of plastic wastes are disposed off to landfills, An emerging processing technique for reclaiming plastic waste is to convert it into liquid fuels. Plastic waste (feedstock) is first shredded then sorted in a sink/flotation unit to remove polyvinyl chloride (PVC) and undesirable feedstock. 20

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



Q.6 Consider the chemical process shown in Figure. The reactor consumes 100 kg/s of fresh feed. In order to reduce the consumption of the fresh reactant, two process sources are considered for recycle to the reactor: the top and bottom products of a separation system. The flowrates of the top product is 60 kg/s and it has 10% (mass basis) of impurities. The bottom product has a flowrate of 216 kg/s and its content of impurities is 75% (mass basis). Determine the recycle strategies that minimize the usage of the fresh reactant.

