Reference. No.: Ex/ChE/T/221/2017

B.E. Chemical Engineering 2nd year 2nd Semester Examination 2017

Chemical Process Calculation

Time : Three hours | Full Marks : 100

Use a separate Answer-Script for each part

PART - I (50 Marks)

Assume any missing data

Answer any *two* questions

1. (a) Air at 35°C saturated with water vapour is to be dehumidified. Part of the air is sent through a unit where it is cooled and some water is condensed. This air leaves the unit saturated at 18°C, it is then mixed with air, which is bypassed the unit. The final air contains 0.012 kg water vapour per kg of dry air. The vapour pressure of water at 35°C is 8400 N/m^2 and at 18°C is 1400 N/m^2. **[10]**

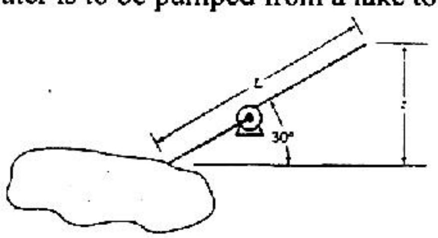
Calculate:

(i) The ratio of amount of dry air bypassed to the amount of dry air sent through the dehumidifer.

(ii) The volume of final air on the basis of 20,000 m^3 of original wet air/h.

(b) A cylinder containing CH_4, C_2H_6 and N_2 has to be prepared in which the ratio of the moles of CH_4 to C_2H_6 is 1.3 to 1. Available are (1) a cylinder containing a mixture of 70% N_2 and 30% CH_4. (2) a cylinder containing a mixture of 90% N_2 and 10% C_2H_6, and cylinder of pure N_2. Determine the proportions in which respective gasses from each cylinder should be used. **[07]**

(c) Water is to be pumped from a lake to a ranger station on the side of a mountain (see figure). The flow rate is to be 95 gal/min, and the flow channel is a standard 1-in. Schedule 40 steel pipe (ID =1.049 in.). A pump capable of delivering 8 hp (= - $\dot{W}_s$) is available. The friction loss is negligible. Calculate the maximum elevation, z, of the ranger station above the lake if the pipe rises at an angle of 30°. **[08]**



2. (a) The process shown below is the dehydrogenation of propane (C_3H_8) to propylene (C_3H_6) according to the reaction

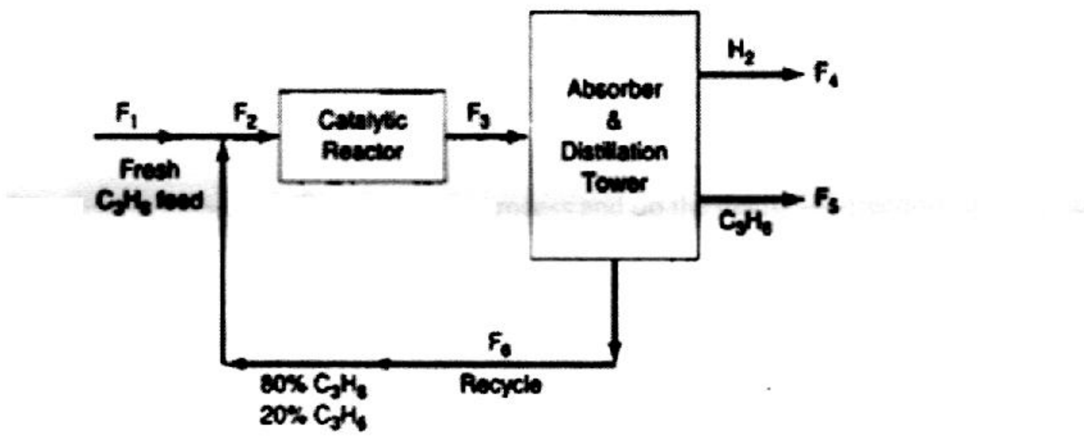
$$C_3H_8 \rightarrow C_3H_6+H_2$$

[Turn over

The conversion of propane to propylene based on the total propane feed into the reactor at F2 is 40%. The product flow rate F5 is 50 kg mol/hr.

(i) Calculate all the six flow rates F1 to F6 in kg mol/hr.

(ii) What is the percent conversion of propane in the reactor based on the fresh propane fed to the process (F1). **[15]**



(b) Liquid water is fed to a boiler at 23°C under a pressure of 10 bar, and is converted at constant pressure to saturated steam. Calculate Δh for this process and the heat input required for producing 15,000 m^3/h of steam at the exit conditions. Assume that the inlet velocity of liquid entering the boiler is negligible and that the steam is discharged through a 0.15 m ID (inner diameter) pipe. Inlet and exit pipes are at the same level. **[10]**

h1 at 23°C 10 bar = 96.2 kJ/kg h2 at 10 bar, sat'd steam = 2776.2 kJ/kg

The specific volume (v) at 10 bar, saturated steam is 0.1943 m^3/kg

3. (a) Cold air at 20°F, 760 mm Hg pressure, and 70% relative humidity is conditioned by being passed through a bank of heating coils, then through a water spray, and finally through a second set of heating coils. In passing through the first coil bank, the air is heated to 75°F. The temperature of the water supplied to the spray chamber is adjusted to the wet-bulb temperature of the air admitted to the chamber, so that the humidifying unit may be assumed to operate adiabatically. It is required that the air emerging from the conditioning unit be at 70°F and 35% relative humidity. Use psychometric chart to solve the following problems.

Calculate:

(i) the temperature of the water supplied to the spray chamber and the relative humidity and dry-bulb temperature of the air leaving the spray chamber.

(ii) the mass of water evaporated (lbm) per cubic foot of air fed to the conditioning unit.

(iii) the required heat transfer rates *(Btu/ft³* entering air) in each of the heating coil banks.
(iv) Sketch a psychrometric chart and show the path followed by the air in each of the three step of this process. **[15]**

(b) A liquid mixture containing 30.0 mole% benzene (B), 25.0% toluene (T), and the balance xylene (X) is fed to a distillation column. The bottoms product contains 98.0 mole% X and no B, and 96.0% of the X in the feed is recovered in this stream. The overhead product is fed to a second column. The overhead product from the second column contains 97.0% of the B in the feed to this column. The composition of this stream is 94.0 mole% B and the balance T.

(i) Draw and label a flowchart of this process and do the degree-of-freedom analysis to prove that for an assumed basis of calculation, molar flow rates and compositions of all process streams can be calculated from the given information. Write in order the equations you would solve to calculate unknown process variables. In each equation (or pair of simultaneous equations), circle the variable(s) for which you would solve. Do not do the calculations. **[10]**

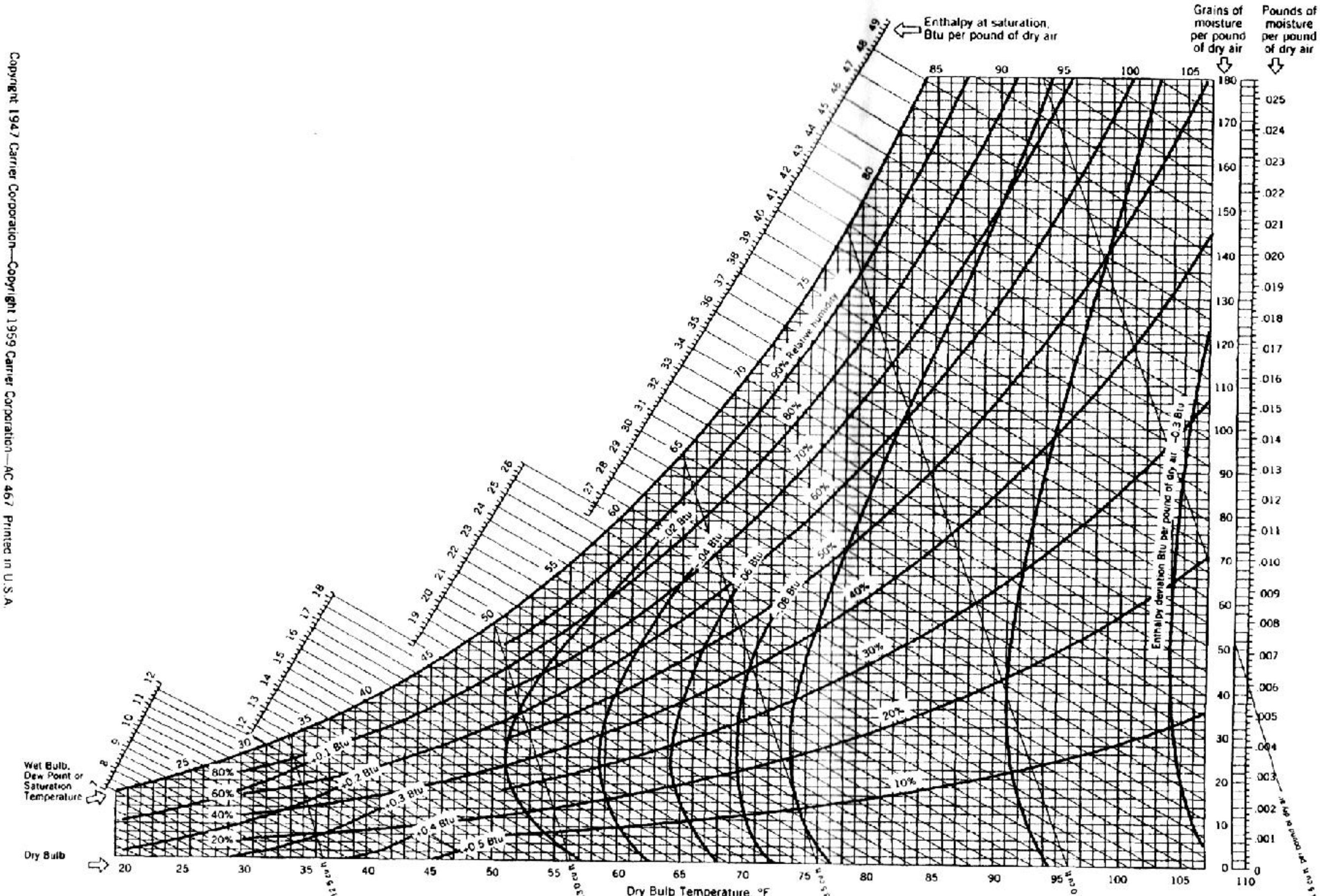


Figure 8.4-2 Psychrometric chart—American Engineering units. Reference states: H_2O (L, 32°F, 1 atm), dry air (0°F, 1 atm). (Reprinted with permission of Carrier Corporation.)

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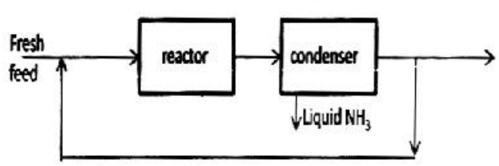
B.E. Chemical Engineering 2nd year 2nd Semester Examination, 2017
Chemical Process Calculations

PART - II (50 Marks)

Assume any missing data
Answer any *two* questions

1(a) The fresh feed for production of synthetic ammonia contains nitrogen and hydrogen gas mixture along with argon (0.2 moles of Argon to 100 moles of nitrogen-hydrogen mixture). The ratio of N_2:H_2 in feed and in every stream containing these two gases is 1:3. The feed is combined with recycle stream and fed to the reactor. The single-pass conversion in the reactor is 25%. The tolerance limit of argon entering the reactor is 5 moles of argon to 100 moles of nitrogen-hydrogen mixture. The ammonia formed is separated in the condenser. A part of the unconverted nitrogen-hydrogen mixture gas mixture (along with argon) is purged and the remaining is recycled. Determine the



(a) ratio of the moles of the argon and nitrogen-hydrogen mixture recycled to the fresh feed

(b) ratio of the moles of the argon and nitrogen-hydrogen mixture purged to the fresh feed. Perform degrees of freedom analysis (10)

(b) A 50 L tank contains an air-carbon tetrachloride gas mixture at an absolute pressure of 1 atm and a temperature of 34 °C and a relative saturation of 30%. Activated carbon is added to the tank to remove CCl_4 from the gas by adsorption and the tank is sealed. The volume of activated carbon can be assumed negligible compared to the volume of the tank.

(i) Calculate the moles of CCl_4 at the moment the tank is sealed?
(ii) How much activated carbon has to be added to the tank to reduce the mole fraction of CCl_4 in the tank to 0.001? (15)

The amount of CCl_4 adsorbed (q^*) is related to the partial pressure of CCl_4 (p_{CCl_4}) in the tank by the following equation [p_{CCl_4} is in mm Hg]

$$q^*\left(\frac{\text{g CCl}_4\text{ adsorbed}}{\text{g carbon}}\right)=\frac{0.0762\,p_{CCl_4}}{1+0.096\,p_{CCl_4}}$$

Molecular weight of carbon tetrachloride is 153.8.

The vapor pressure of CCl_4 can be estimated from the following equation

$$\log_{10} P^{sat}(\text{mm Hg})=6.84-\frac{1177.91}{t(^{\circ}C)+220.576}$$

2(a) An aqueous solution of magnesium sulfate containing 30 wt% $MgSO_4$ is feed to a crystallizer in which the temperature is reduced to 10 $^{\circ}$C. The stream leaving the crystallizer is a slurry of solid magnesium sulfate heptahydrate [$MgSO_4.7H_2O$] suspended in liquid solution. Determine the percentage of $MgSO_4$ present in the feed that forms crystals. A saturated solution contains 23.2 wt% $MgSO_4$. [Molecular weight of $MgSO_4$ is 120.4.] (8)

(b) A SO_2-air stream (100mol/h) containing 45 mole% SO_2 is contacted with fresh water in a continuous absorber at 30 $^{\circ}$C. The liquid leaving the absorber contains 2g SO_2/100 g H_2O. Assuming that the gas and liquid stream leaving the absorber are in equilibrium at 30 $^{\circ}$C and 1 atm, calculate the fraction of SO_2 absorbed and the flow rate of water entering the absorber. [Molecular weight of SO_2 is 64 g/mol.] (12)

The partial pressure of H_2O and SO_2 in the exiting gaseous stream is 31.6 mm Hg and 176 mm Hg respectively.

(c) When air (21 mole% O_2, 79 mole% N_2) is placed in contact with 1000 cm^3 of liquid water at body temperature (36.9 $^{\circ}$C) and 1 atm absolute, approximately 14.1 cm^3 [STP] of gas is absorbed in the water at equilibrium. Subsequent analysis of the liquid reveals that 33.4 mole% of the dissolved gas is oxygen and the balance nitrogen.

An adult absorbs approximately 0.4 g O_2/min in the blood flowing through lung. Assuming that blood behaves as water and enters the lungs free of oxygen, estimate the flowrate of blood into lungs in L/min. [standard condition is 0 $^{\circ}$C and 1 atm] (5)

3. A gaseous fuel composed of 70 mole% n-butane (C_4H_{10}) and 30 mole% propane (C_3H_8) is burned with 100% excess air to ensure complete combustion of the fuel. The fuel and the air enters the burner at 50 °C and 75 °C respectively. Calculate the flame temperature in an adiabatic burner. (25)

The standard heat of formation of $C_3H_8(g)$, $C_4H_{10}(g)$, $CO_2(g)$ and $H_2O(g)$ at 25 °C is -103.85, -126.15, -393.52 and -241.82 kJ/mol respectively. The molar heat capacity in ideal gas state is given by

$$C_p^o\left(\frac{J}{\text{mol K}}\right) = a + bT; \text{ T is in K}$$

Gas	a	bx10^3		Gas	a	bx10^3
O_2	30.2	4.2		H_2O	28.85	12.05
N_2	27.27	4.93		C_3H_8	-4.79	307.26
CO_2	45.37	8.69		C_4H_{10}	0.47	383.3