9. (a) Water is to be pumped from a reservoir to an overhead tank at 30 l/min. The overhead tank is situated 15 m above the ground. A heater puts 250 kW into the water during its transfer from reservoir to overhead tank. If the tank water temperature is to be kept at 10°C above the reservoir temperature, what is the power required to drive the pump assuming the pump efficiency to be 60%? Given, heat capacity of water 4.184 kJ/kg K.

(b) Pure carbon monoxide is mixed with 50% excess air and completely burned at constant pressure. The reactants are fed to the furnace at 400K. Determine the rate of heat added to or removed from the furnace if carbon monoxide combustion rate is 42 kg/h. The standard heat of combustion of carbon monoxide at 298K is -283 kJ/mol. The mean specific heats in kJ/mol K applicable in the range of the problem are given for the following constituents: carbon monoxide 29.1, oxygen 29.7, nitrogen 29.1 and carbon dioxide 41.45.

6 + 6 = 12

INDUSTRIAL STOICHIOMETRY
(CHEN 2104)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) The unit of *a* in Van der Waal's equation of state is
(a) $[(\text{pressure})(\text{volume})]^2$ (b) [pressure]
(c) $[\text{pressure/volume}]^2$ (d) [volume].

(ii) A Bourdon gauge measures the pressure of a line being pulled by vacuum to be – *50 mm* of Hg. What is the absolute pressure?
(a) 810 mm (b) 710 mm
(c) 50 mm (d) none of the above.

(iii) The mass flow rate of heptane with density ρ = 0.6g/cc is 7 g/s. What is the volumetric flow rate?
(a) 12 cc/sec (b) 720 cc/min (c) 11 cc/sec (d) both (a) and (b).

(iv) A mixture of gases contain A and B in volume ratio 20:80. If ρ_A and ρ_B are 1.4 kg/m^3 and 0.7 kg/m^3, what is the w/w ratio of A:B?
(a) 1:2 (b) 22:78 (c) 2:1 (d) 80:20.

(v) Antoine's equation relates two variables for pure components. They are
(a) partial pressure and temperature (b) viscosity and temperature
(c) vapor pressure and temperature (d) density and temperature.

(vi) The relation between higher heating value (HHV) and the lower heating value (LHV) of a fuel is given by:
Where n = moles of water produced, ΔH_V = heat of vaporization of water at 25^{0}C
(a) HHV = LHV + ΔH_V (b) HHV = LHV - ΔH_V
(c) HHV = LHV + n ΔH_V (d) HHV = LHV - n ΔH_V.

(vii) In a chemical process, the recycle stream is purged for
(a) increasing the yield (b) enriching the product
(c) limiting the inert (d) increasing the selectivity.

(viii) Percentage saturation of a vapour bearing gas is always _____ the relative saturation for an unsaturated vapour gas mixture.
(a) greater than (b) less than
(c) equal to (d) either (a) or (b) depending on amount of vapour.

(ix) If partial pressure of water vapour in air is less than its vapour pressure at the temperature of air, the relative humidity is
(a) 0 (b) 100 %
(c) in between 0 to 100 % (d) greater than 100%.

(x) Refluxing of part of the distillate in a fractionating column is a recycling operation, aimed primarily at
(a) energy conservation (b) product enrichment
(c) yield enhancement (d) minimization of impurity.

Group - B

2. (a) Humid air at 75 °C and 1 atm pressure and 30% relative humidity is fed into a unit at 500 m^3/hr.
i. Determine the molar flow rate of dry air and water vapor entering the chamber. Assume ideal gas equation of state for wet air.
ii. In the above problem, what is the molal humidity, absolute humidity and percentage humidity?

(b) What do you understand by 'degrees of superheat'? if you are given the mole fraction of vapor and the total pressure, how do you determine the degree of superheat?

(3 + 4) + 5 = 12

3. (a) A rotameter gauge is calibrated against actual experimental data to measure unknown volumetric flow rate . Calibration data is given below:

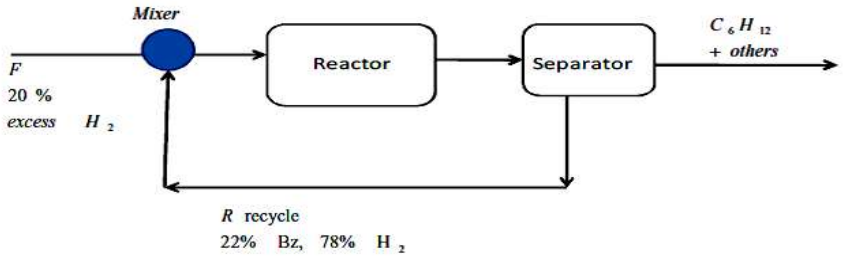
Rotameter Reading	Collection Time(min)	Volume Collected(m^3)
2	1	297
2	1	301
4	1	454
4	1	448
8	0.5	300
8	0.5	298
6	0.5	371
6	0.5	377
10	0.5	440
10	0.5	453

Use regression to evaluate an expression relating the rotameter reading to the volumetric flow rate.

i. Draw the flow chart of the process.
ii. Perform a degrees of freedom analysis with each stream
Evaluate the mass flowrate of toluene in the bottom.

(b) Cyclohexane (C_6H_{12}) can be made by the reaction of benzene (Bz, short for C_6H_6) with hydrogen according to the following:

$$C_6H_6 + 3H_2 \rightarrow C_6H_{12}$$



If the overall conversion of Bz is 90% and singlepass conversion through reactor is 15%, determine the ratio of recycle to feed. Also, determine yield based on feed. Percentages are based on mole.

(3 + 3) + 6 = 12

Group - E

8. (a) Find the heat of formation of chloroform ($CHCl_3$) from the following data:

H_2 (g) + ½ O_2 (g) = H_2O (l), ΔH_1 = - 68317.4 cal
C (β) + O_2 (g) = CO_2 (g), ΔH_2 = - 94051.8 cal
1/2H_2 (g) + ½ Cl_2 (g) = HCl (aq), ΔH_3 = - 40023 cal
$CHCl_3$(g) + ½ O_2 (g) + H_2O (aq) = CO_2 (g) + 3 HCl (aq), ΔH_4 = - 121800 cal

(b) Pyrites fines are roasted for making sulfuric acid. The gases leaving the roaster are at 775K and have molar composition SO_2: 7.09%, O_2: 10.55%, SO_3: 0.45%, and N_2: 81.91%. Calculate the heat content of 1 kmol gas mixture over 298K.

$C_P = A + BT + CT^2$ kJ / kmol; K and T are in °K.

Component	A	B × 10^3	C × 10^6
SO_2	24.7706	62.9481	- 44.2582
O_2	26.0257	11.7551	- 2.3426
SO_3	22.0376	121.6240	- 91.8673
N_2	29.5909	- 5.1410	13.1829

4 + 8 = 12

(b) Water is flowing through a pipe and the volumetric flow rate is measured with the same rotameter at different times as shown below.

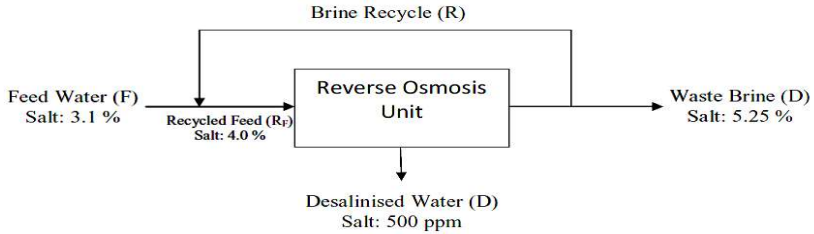
Time of reading(min)	Volumetric Flow rate (m^3/min)
2	300
4	295
6	301
8	301
10	296
12	300

Use a graph paper to plot the volumetric flow rate vs. time. If a bucket collects the water, what is the volume of water accumulated within the 6-8 minute timeframe? Show your calculations.

7 + 5 = 12

Group - C

4. (a) Sea water is to be desalinised by reverse osmosis using the scheme given in figure below. Based on fresh feed flow rate of 1000 kg/h, determine i) rate of desalinised water produced (D) and ii) the recycle ratio (R/B) of the process.



(b) Volume percent of a sample of flue gas is given as follows: SO_2 16%, SO_3 5.5%, O_2 10%, water vapour 0.5% and rest is nitrogen. Calculate the mass percent of all the constituent of the flue gas on a dry basis.

7 + 5 = 12

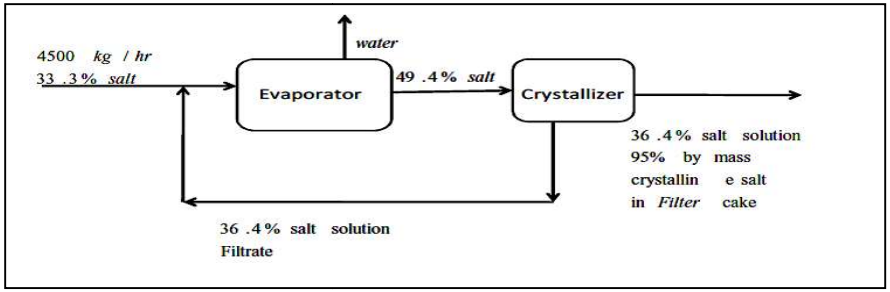
5. (a) In a continuous kraft pulp bleaching unit, caustic soda is required at a concentration of 10% NaOH (by wt) and a flow rate of 1.65 kg/s. The solution is prepared by introducing 50% caustic lye (by wt) and diluted with water continuously in a 1900 lt tank, equipped with an agitator and withdrawing water continuously at desired rate of 10% NaOH. Suddenly, the inflow of caustic lye fails. Assuming that the volume of liquid in the tank is constant, calculate the time required for the effluent concentration to fall to 8% NaOH. Given, NaOH sp.gr. in the range of 10 to 8% concentration to be approximately constant at 1.1.

(b) 2.5 m^3 of air initially at 50°C and 1 atm pressure with a molal humidity of 0.03 is compressed isothermally to 506.5 kPa and finally cooled to 21°C. Calculate the weight of water condensed and the final volume of air. Given: the vapour pressure of water at 50°C and 21°C are 12.34 and 2.49 kPa respectively.

6 + 6 = 12

Group - D

6. (a)

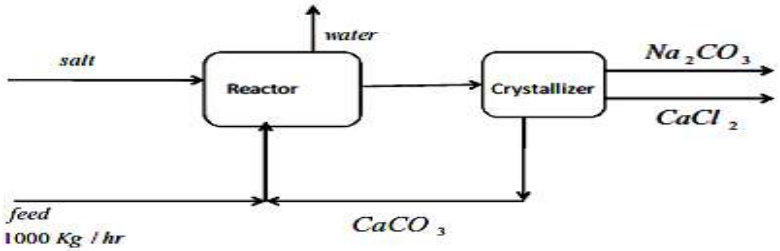


The above figure shows the salt crystalline process through evaporation.

i. Calculate the rate of evaporation in the evaporator.
ii. Calculate the rate of production of crystalline salt.

(b) In the given figure below, NaCl is fed to a reactor together with a solution of feed containing 90% $CaCO_3$ and 10% Na_2CO_3. 76% of $CaCO_3$ is converted. Unreacted $CaCO_3$ is recycled as shown in the figure. Calculate

i. the kg of Na_2CO_3 exiting the separator per 1000 kg of feed.
ii. the kg of $CaCO_3$ recycled per 1000 kg of feed.



6 + 6 = 12

7. (a) A liquid mixture containing 45% benzene(B) and the rest toluene(T) is fed to a distillation column. A product stream leaving the column at the top is rich in B contains 95% of the top stream. Single pass efficiency of separation of B is 92%. The mass flow rate of feed is 1600 kg/hr.

(b) Water is flowing through a pipe and the volumetric flow rate is measured with the same rotameter at different times as shown below.

Time of reading(min)	Volumetric Flow rate (m^3/min)
2	300
4	295
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Use a graph paper to plot the volumetric flow rate vs. time. If a bucket collects the water, what is the volume of water accumulated within the 6-8 minute timeframe? Show your calculations.

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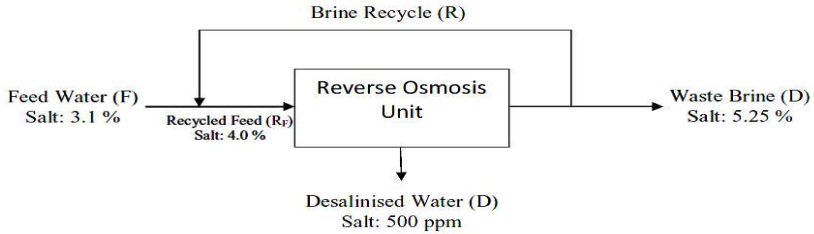

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Group - D

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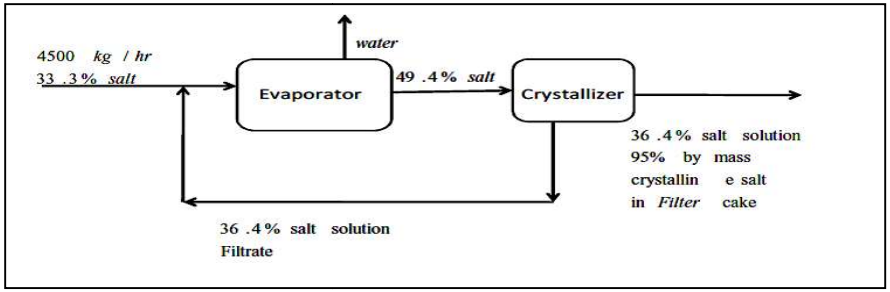

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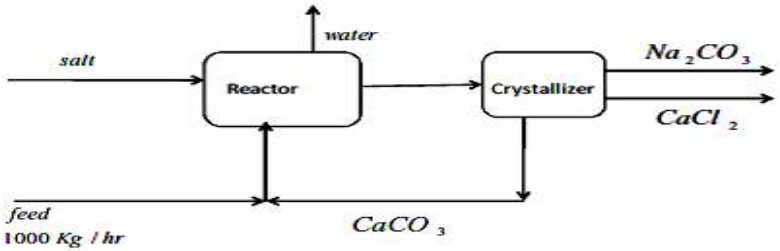

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