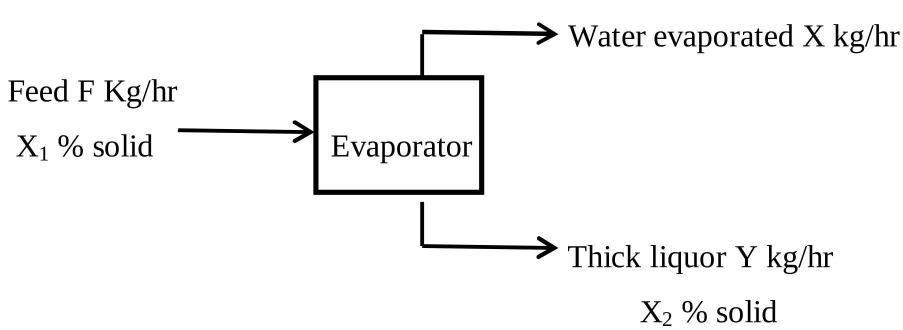
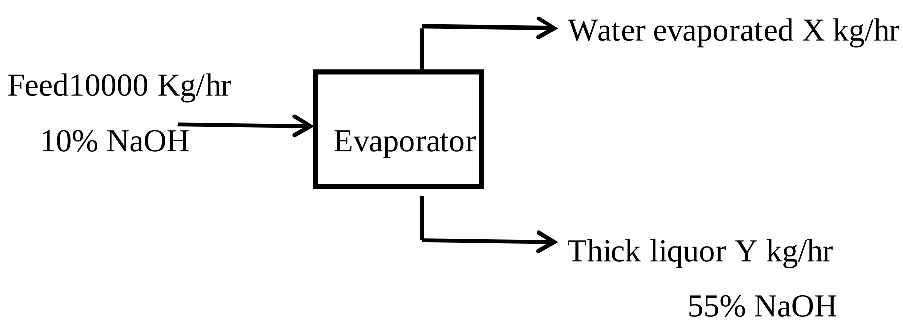
SUMMER-15 EXAMINATION
Model Answer

Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q No.	Answer	marks	Total marks
1A-a	**Raoult's law:** Raoult's law states that equilibrium partial pressure of a constituent at a given temperature is equal to the product of its vapour pressure in pure state and its mol fraction in the liquid phase. $P_A = P^0_A X_A$	1 1	2
1A-b	**Relationship between partial pressure and total pressure**: For a gaseous mixture, total pressure is equal to the sum of partial pressures of its components. This is called Dalton's law. $P=P_1+P_2+P_3$ Where P is the total pressure of gas mixture and P_1,P_2,P_3 are partial pressures	1 1	2
1A-c	**Ideal Gas law:** PV=nRT where P - pressure, V - volume, n- moles, K-absolute temperature and R – universal gas constant Value and unit of R is **8.314 KPa m^3/ kmol K**	1 1	2
1A-d	 Material balance for solids is $X_1/100 * F = X_2/100 * Y$	1 1	2

1 A-e	**Limiting component**: It is the component or reactant which gets over first in a chemical reaction or it is the reactant which decides the extent of a reaction or it is the reactant which is added in limited quantity. **% Conversion**: (moles of limiting component reacted/ moles of limiting reactant fed) * 100	1 1	2
1A-f	**Hess's law:** It states that the heat involved in a chemical reaction is same whether the reaction takes place in a single or in several steps. $A \rightarrow B$ $\Delta T1$ $B \rightarrow C$ $\Delta T2$ $C \rightarrow D$ $\Delta T3$ $A \rightarrow D$ ΔT Then $\Delta T = \Delta T1 + \Delta T2 + \Delta T3$	2	2
1B-a	**Basis: 100 kmoles of air** Average mol.wt of air= 0.79*28+0.21*32= 28.84 Density of air = P*Mav/ RT At NTP, P= 101.325 KPa, R= 8.314, T=273 K Density = **1.29 kg/m^3**	1 1 1 2 1	6
1B-b	Basis: 10000 Kg/hr of weak liquor  Overall balance is 10000= X+Y	1 1 1	6

	Individual balance for caustic is 10/100 *10000 = 55/100 * Y Y= 1818.18 & X= 8181.81 Kg/hr of water evaporated = **8181.81 Kg/hr** Kg/hr of thick liquor obtained = **1818.18 Kg/hr**	 1 2	
1B-c	Basis: 10 kg C $C+O_2 \rightarrow CO_2$ Kmoles of C = 10/12= 0.833 kmoles Theoretical requirement of O_2 = 0.833 Air is used 20% excess Fed O_2 = 1.2* 0.833 = 0.9996 Fed N_2= (79/21)* 0.9996 = 3.76 CO_2 formed = 0.833 kmoles O_2 unreacted = 0.9996-0.833 = 0.167 kmoles **Composition of gases leaving combustion chamber:**	 1 1 1 1	6

compound	kmoles	Mol%
O_2	0.167	3.51
CO_2	0.833	17.5
N_2	3.76	78.99

(Marks for composition table: 2)

2-a	**General Material Balance Procedure** 1) Assume Suitable Basis of calculation. 2) Adopt weight basis for without chemical reactions. 3) Draw Block diagram of the process of each operation with input and output stream. 4) In the block diagram drawn, indicate the information provided regarding input and output.	4	4

5) Search out unknown and ascertain them and Calculate it by generating and solving material balance equations.

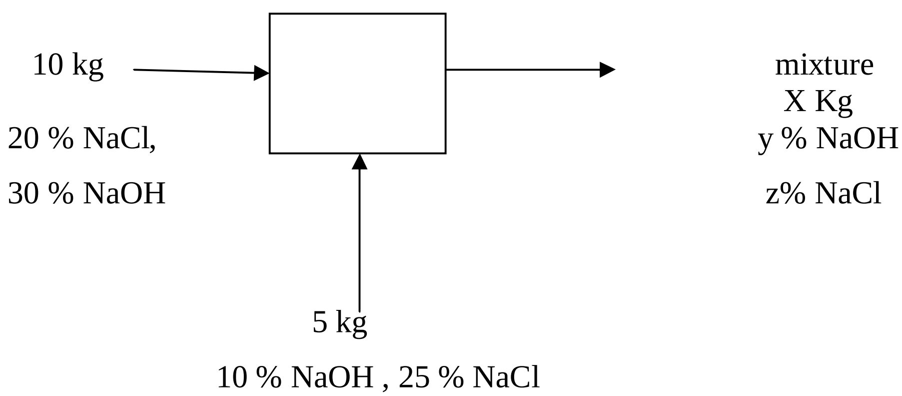
2-b (Total marks: 4)

Basis: 100 kg gas mixture (1)

component	weight	Mol.wt	kmoles	Mol %
CO_2	10	44	0.227	5.90
N_2	40	28	1.43	37.21
O_2	30	32	0.938	24.41
CH_4	20	16	1.25	32.53

(3)

2-c (Total marks: 4)



(1)

Basis: 10 Kg solution 1 and 5 Kg solution 2 (1)

Overall balance is 10+5 = X=15 Kg

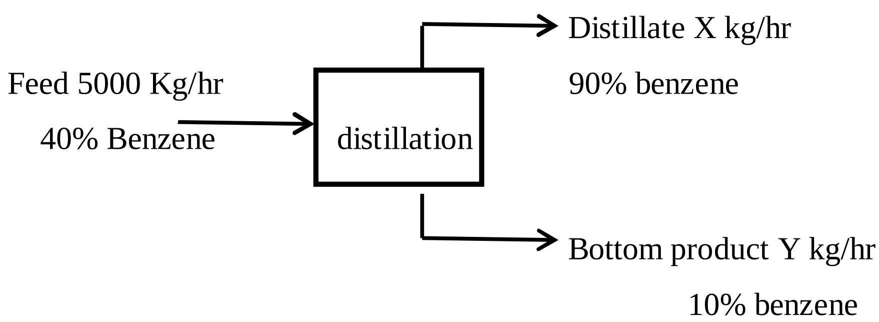
Balance for NaOH is 30/100* 10 + 10/100*5 = y/100* 15

y= 23.33 %

Balance for NaCl is 20/100* 10 + 25/100*5 = z/100* 15 (1)

z= 21.67 %

Composition of resulting mixture is 23.33% NaOH, 21.67 % NaCl and 55% water. (1)

2-d		1	4
	Basis: 5000 kg/hr feed Overall balance is 5000 = X+Y	1	
	Balance for benzene is 0.4* 5000 = 0.9 X +0.1Y Solving the equations X= 1875 and Y = 3125	1	
	Flow rate of top product = **1875 Kg/hr** Flow rate of bottom product = **3125 Kg/hr**	1	
2-e	Basis: 100kg methane fed Moles of methane fed = 100/16= 6.25 kmoles		4
	$CH_4 + 2 O_2 \rightarrow CO_2 + 2H_2O$ Theoretical oxygen = 12.5 kmoles Excess= 50 % Fed O_2= 18.75 kmoles	1	
	Fed N_2 = **70.54 kmoles** % conversion is 40 Methane reacted = 2.5 kmoles O_2 Reacted= 5 O_2 unreacted= 18.75-5 = **13.75 kmoles**	1	
	CO_2 formed= **2.5 kmoles** H_2O formed = **5 kmoles**	1	

CH_4 unreacted= 6.25-2.5 =**3.75 kmoles**

compound	kmoles	Mol%
O_2	13.75	14.39
CO_2	2.5	2.62
H_2O	5	5.23
CH_4	3.75	3.93
N_2	70.54	73.83

Total moles= 95.54 kmoles — 1

2-f (4)

$SO_2 + 0.5\ O_2 \rightarrow SO_3$

Basis: 10 moles SO_2 fed — 1

SO_2 fed = 10 kmoles

Air fed = 100 kmoles

O_2 Fed = 21 kmoles — 1

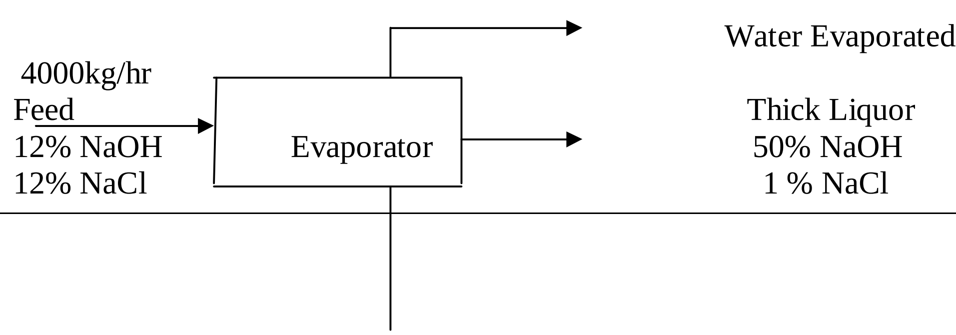
Theoretical O_2 = 5 kmoles — 1

Excess O_2 = [(Fed O_2- theoretical O_2)/ theoretical O_2]* 100

=(21-5/5)*100 — 1

= **320 %**

3-a — 1 (8)



	76% H_2O 49% H_2O → NaCl Precipitated **Basis :** 40000 kg/hr of weak solution fed to the evaporator. Let X,Y,Z be the kg/hr of water evaporated thick liquor & Nacl precipitated respectively. Overall Material Balance : ΣInput stream =Σ Output stream 40000 = X + Y + Z Material balance of NaOH NaOH in feed = NaOH in thick liquor 0.12 x 40000 = 0.5 x Y $\therefore Y = 9600\ kg/hr$ Material balance of NaCl NaCl in feed = NaCl in thick liquor + NaCl precipitated 0.12 x 40000 = 0.01 x Y + Z $\therefore 4800 = 0.96 + Z$ $\therefore Z = 4704 \frac{kg}{hr}$ We know X + Y + Z = 40000 $\therefore X = 25696\ kg/hr$ $\therefore Water\ evaporated = \mathbf{25696 \frac{kg}{hr}}$ Thick liquor obtained = **9600 kg/hr** NaCl crystal precipitated = **4704 kg/hr**	1 2 2 2	
3-b	$2\,S + 2\,O_2 \longrightarrow 2\,SO_2$	1	8

	$2\ SO_2 + O_2 \longrightarrow 2\ SO_3$ $2\ SO_3 + 2\ H_2O \longrightarrow 2\ H_2SO_4$ $2S + 3\ O2 + 2\ H2O \longrightarrow 2\ H_2SO_4$ 20ton/hr 20000 kg/hr of 93.2 % = 20000 x 0.932 = 18640 kg/hr	1	
	2 x 98 196 kg H_2SO_4 = 64 kg Sulphur $H_2SO_4 = \frac{18640\ x\ 64}{196}$ S = 6086.5 kg/hr = **6.0865 T/hr**	2	
	$O_2 = \frac{18640\ x\ 96}{196}$ = 9129.79 kg/hr = **9.1297 T/hr**	2	

	$H_2O = \frac{18640 \times 36}{196}$ = 3423.6 kg/hr = **3.4236 T/hr**	2	
3-c	**Basis :** 1 mole of liquid CH_3COOH $C_{(s)} + O_2 \longrightarrow CO_2$ $\Delta H^of = -393.3$ KJ/mol $H_{2}(g) + ½ O_2 \longrightarrow H_2O$ $\Delta H^of\ H_2O = -285.8$ KJ/mol $CH_3COOH_{(l)} + 2O_2 (g) \longrightarrow 2CO_2 (g) + 2 H_2O$ $\Delta H^oc = -875$ KJ/mol $2Cs + 2H_2(S) + O_2 (g) \longrightarrow CH_3COOH_{(l)}$ $\Delta H^of = ?$ $\therefore \Delta H^of = 2 \Delta H^of + 2 \Delta H^of\ H_2 - \Delta H^oc$ $= 2 (-393.3) + 2 (-285.8) – (-875)$ = **- 483.2 KJ/mol**	1 2 3 2	8
4-a	**Basis :** Gas mixture containing 0.274 kmol HCl,0.337 kmol N_2,0.089 kmol O_2. Total moles of the gas mixture = 0.274 +0.337 +0.089 = 0.7 kmol Mole fraction of HCl (X_{HCl}) = 0.274/0.7 = 0.399 Mole fraction of N_2 (X_{N2}) = 0.337/0.7 = 0.481 Mole fraction of O_2 (X_{O2}) = 0.089/0.7 = 0.127 (i)Volume occupied by this mixture V =3 atm = 303.975 kPa	1	8

	$PV = nRT$ $\therefore V = \frac{nRT}{P}$ $= \frac{0.7 \times 8.3145 \times 303}{303.975}$ **$= 5.80\ m^3$**	1	
	(ii) Density of the Gaseous mixture $Mavg = \Sigma\ MiXi$ $= M_{HCl}.X_{HCl} + M_{N2}.X_{N2} + M_{O2}.X_{O2}$ $= 36.5 \times 0.391 + 28 \times 0.481 + 32 \times 0.127$ $\therefore Mavg = 31.80$	1	
	$\therefore$ Density of the Gaseous mixture = Mavg / R x T $= \frac{303.975 \times 31.80}{8.3145 \times 303}$ **$= 3.83\ kg/m^3$**	1	
	(iii) Partial pressure exerted by each component Total Pressure =303.975 Kpa Partial pressure of HCl = $P_{HCl} = X_{HCl}.P$ $= 0.391 \times 303.975 =$ **118.85kPa** Partial pressure of HCl = $P_{N2} = X_{N2l}.P$		

= 0.481 x303.975 = **146.21kPa**

Partial pressure of HCl = P_{O2}= X_{O2}.P 2

= 0.127x303.975 = **38.60kPa**

(iv) Composition in Wt%

HCl = 0.274 x 36.5 = 10.001 kg

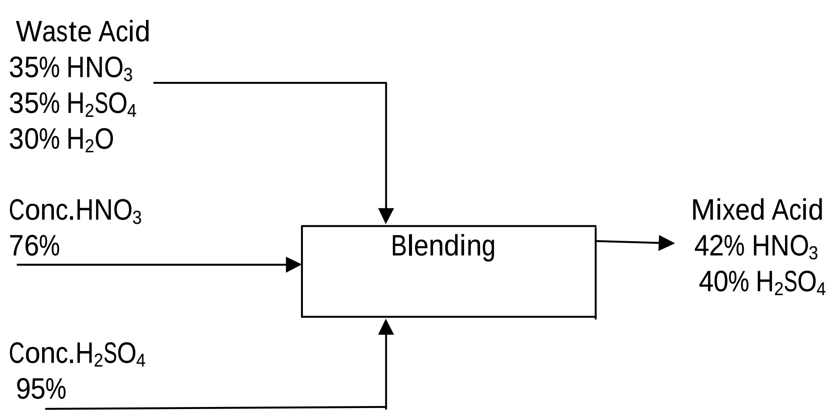
N_2 = 0.337 x 28 = 9.436 kg

O_2 = 0.089 x 32 = 2.848 kg

2

Composition	Quantity in kg	Wt %
HCl	10.001	**44.87**
N_2	9.436	**42.34**
O_2	2.848	**12.77**
	22.285	**100**

4-b **Basis :** 1000 kg of desired mixed acid. 2 8



Let , X = kg of waste acid

	Y = kg of conc. H_2SO_4 Z = kg of conc. HNO_3 ∴ Overall Material Balance 1000 = X + Y + Z ……………(i) Material Balance of H_2SO_4 0.35 x + 0.95 z = 0.4 x 1000 $\therefore Z = \frac{400-0.35x}{0.95}$ Z = 421.05 – 0.368 x Material Balance of HNO_3 0.35 x + 0.76 z = 0.42 x 1000 $\therefore Z = \frac{420-0.35x}{0.76}$ Z = 552.63 – 0.460 x Put value of Y & Z in eqn (i) ∴ 1000 = x + 421.05 – 0.368 x + 552.63 – 0.460 x 26.32 = 0.172 x ∴ x = 153.02 kg ∴ Y = 421.05 – 0.368 (153.02)	 1 1 1	

	Y = 364.73 kg Z = 552.63 – 0.460 (153.02) = 482.24 kg $\therefore$ Waste acid required **= 153.02 kg** conc. H_2SO_4 reqd. = **364.73 kg** conc. HNO_3 reqd. = **482.24 kg**	3	
4-c	**Basis :** 100 kmol of HCl $4\ HCl + O_2 \longrightarrow 2\ Cl_2 + H_2O$ 30 % excess air required 80 % Conversion $\therefore$ HCl reacted = 0.80 x 100 = 80 kmol HCl unreacted = 20 kmol 4 kmol of HCl ≡ 2 kmol of Cl_2 produced $\therefore$ Cl_2 produced from HCl = 2/4 x 80 = 40 kmol 4 kmol of HCl ≡ 1 kmol of O_2 $\therefore$ O_2 reacted = 1/ 4 x 80 = 20 kmol	1 1 1	8

But O_2 is calculated based on reactant feed.

∴ O_2 Therotical requirement = 1/ 4 x 100 = 25 kmol

As 30 % excess air is provided. 1

O_2 in supplied air = 25 x $\left(1 + \frac{30}{100}\right)$ = 32.5 kmol

= 2.5 – 20 =12.5 kmol

1

O_2 unreacted = O_2 in air - O_2 reacted

= 32.5 – 20 = 12.5 kmol

1

N_2 in supplied air = 79 /21 x 32.5 = 122.26 kmol

4 HCl reacted ≡ 2 kmol of H2O

1

H2O produced = 2/ 4 x 80 = 40 kmol

∴ Composition of flue gas

Vcl Component	Kmol	Mol %
HCl	20	**8.51**
Cl_2	40	**17.04**
O_2	12.5	**5.33**
N_2	122.26	**52.08**
H_2	40	**17.04**

1

	234.76	100		
5-a	**Basis :** 100 Kg of Soyabean seeds It contains 18.6 kg oil ,69 kg solids and 12.4 kg moisture Let X be the Kg of cake obtained **Material balance of Solids :** Solids in seeds = Solids in cake 0.69 * 100 = 0.877* X X = 78.68 Kg **Material balance of Oil :** Oil in seeds = Oil in cake + Oil recovered 0.186* 100 = 0.008* 78.68 + Oil recovered 18.6 = 0.6294 + Oil recovered Oil recovered = 18.6 – 0.6294 =17.97 Kg % recovery of Oil = $\frac{\text{Oil recovered}}{\text{Oil in Seeds}}$ * 100 % recovery of Oil = $\frac{17.97}{18.6}$ * 100 **% recovery of Oil = 96.61 % ----------- ans.**	1 2 2 1 1 1	8
5-b	**Basis :** 100 Kmols of Water gas produced Volume % = Mole % It contain H_2= 55.4 Kmol CO= 44 Kmol CO_2 = 0.6 Kmol	1 1	8

	Chemical Reactions $C + H_2O$ ------→ $CO + H_2$ $CO + H_2O$ --------→ $CO_2 + H_2$ From Reactions 1 Katom C ≡ 1 kmol CO ≡ 1 Kmol CO_2 Amount of C reacted = 1/1 *44 +1/1 *0.6 = 44.6 Katom = 44.6 * 12 = 535.2 kg Yield is 90% and coke contain 90% 'C' Consumption of Coke = 535.2 / (0.9 * 0.9) = **660 kg** From the Reactions, 1 Kmol of H_2O ≡ 1 kmol H_2 Steam required = 1/1 * 55.4 = 55.4 kmol Consumption of Steam = 55.4 *18 = **997.2 kg**	2 2 2	
5-c	**Basis :** 100 Kg/hr of Water at 25 ^oC Q= Amount of heat required. $Q = m \lambda v + m Cp (T_B - T)$ Where , m = 100 kg/hr Cp = 4.187 KJ/ Kg.K λv = 2240 KJ/ Kg T = 25 ^oC =298 ^oK T_B = 100 ^oC =373 ^OK Q = (100 * 2240) + (100 * 4.187 *(373-298))	1 2 2 2	8

	Q = 255402 KJ/hr **Q = 70.95 KJ /S ------ ans.**	1	
6-a	**Basis :** 1 m3/hr gas entering to absorption tower Amount of Gas Entering at 298 ^{o}K and 101.325 Kpa n = PV/RT = (101.325* 1) / (8.3145* 298) =0.040 kmol /hr It contain Solute gas = (5/100)* 0.040 = 0.002 kmol Inert gas =(95/100)* 0.040 = 0.038 kmol 90% solute is absorb Amount of solute absorb =(90/100)* 0.002 =0.0018 kmol Material balance of Solute Solute in Feed gas = Solute absorb + Solute in outlet gas 0.002 = 0.0018 + Solute in outlet gas Solute in outlet gas = 0.0002 kmol Inert Balance Inert in Inlet gas = Inert in Outlet gas **Composition Outlet Gas :**	1 1 1 1	8

Component	Kmol	Mol %
Solute gas	0.0002	0.52
Inert gas	0.038	99.47
Total	0.0382	100%

(marks: 2)

Flow rate of Outlet gas (marks: 2)

V= nRT/ P = (0.0382*8.3145*298)/ 101.325

	V = 0.934 m^3 /hr		
6-b	**Basis :** 5000 Kg/day MCA produced in small scale unit Amount Of MCA = 5000 Kg , Mol.Wt.Of MCA = 94.5 Amount Of Cl_2 = 4536 Kg , Mol.Wt.Of Cl_2 = 71 Amount Of DCA = 263 Kg , Mol.Wt.Of DCA = 129 Moles Of MCA = 5000/94.5 = 52.91 Kmol Moles Of Cl_2 = 4536/71 = 63.89 Kmol Moles Of DCA = 263/129 = 2.03 Kmol Reactions CH3COOH + Cl_2--→ CH2ClCOOH +HCL (MCA) CH2Cl COOH + Cl_2 --→ CH Cl_2COOH +HCL (DCA) Moles of MCA produced = Moles of MCA Charged = 52.91 From reaction 2, 1 Kmol of DCA ≡ 1 kmol of MCA 2.03 Kmol of DCA ≡ 1/1 * 2.03 kmol MCA Moles of MCA reacted = 2.03 kmol % Conversion of MCA = Moles of MCA reacted/ Moles of MCA reacted = (2.03 /52.91) * 100 **% Conversion of MCA = 3.83 % ----------- ans.** From reaction 1 1 Kmol of MCA ≡ 1 kmol of Cl_2 52.91 Kmol of MCA ≡ 52.91 kmol of Cl_2 reacted From reaction 2, 1 Kmol of DCA ≡ 1 kmol of Cl_2 2.03 Kmol of DCA ≡ 2.03 kmol of Cl_2 reacted	1 1 1 2	8

	Total Cl_2 reacted = 52.91 + 2.06 = 54.94 Kmol % yield of MCA = (Cl_2 reacted for MCA / Cl_2 totally reacted)*100 = (52.91 / 54.94) * 100 **% yield of MCA = 96.20% -------------- ans**	2 1	
6-c	**a) Sensible Heat: -** Sensible heat is the heat that must be transferred to raise or lower the temperature of a substance or mixture of substance. **b) Latent Heat:-** When matter undergoes a phase change, the enthalpy change associated with unit amount of matter at constant temperature and pressure is known as Latent Heat of phase change. **c) Heat of Reaction:-**It is the enthalpy change resulting due to reaction wherein, reactants are fed in stoichiometric amounts and the reaction proceeds to completion. **d) % Conversion:** It is the ratio of amount of limiting reactant reacted to the amount of limiting reactant totally charged. Express in percentage. **e) Adiabatic Process:** A process in which no heat can leave or enter the system is known as Adiabatic process. **f) Absorption of Gases:** This the unit operation in which solute gas components from gas mixture is recovered or removal of gases with help of suitable liquid solvent in which solute gas is absorbed.	2 2 1 1 1 1	8