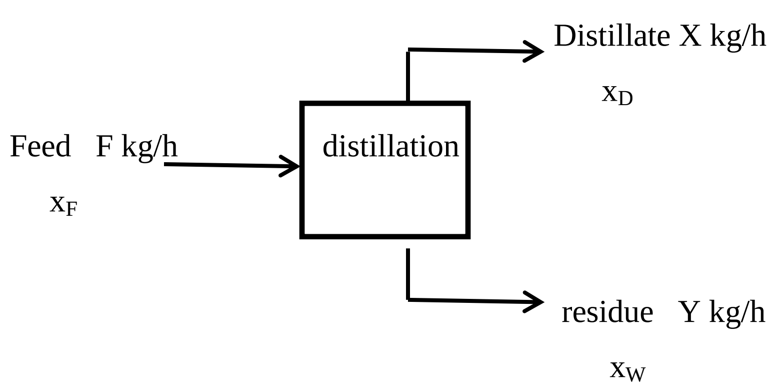
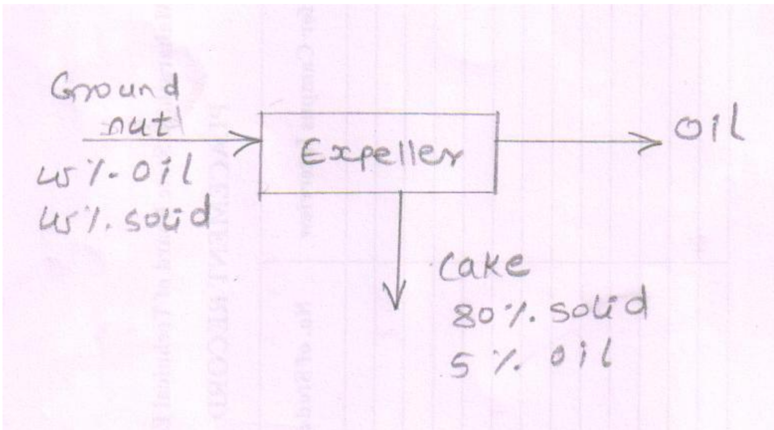
Important Instructions to examiners:

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	Sub q.no.	Answer	marks
1		**Any 5**	**10**
1	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. **Latent Heat:** It is the heat required to change the phase of a substance at constant temperature and pressure.	1 1
1	b	**Dalton's law:** It states that the total pressure exerted by a gas mixture is equal to the sum of partial pressures **Mathematical Statement**: $P = P_1 + P_2 + P_3$ where P is the total pressure of gas mixture , P_1, P_2, P_3 are partial pressures **Amagat's law:** Amagat's law states that total volume occupied by a gas mixture is equal to the sum of pure component volumes. $V = V_A + V_B + V_C$ Where V is the total volume of gas mixture V_A, V_B, V_C are pure component volumes	1 1
1	c	**Heat capacity:** It is the amount of heat required to increase the temperature of one kg of substance by 1 K. It is expressed on a unit mass or unit mole basis. **Unit:** kJ/(kmol.K) or kJ/(kg.K)	1 1
1	d	475 torr Absolute pressure = Atmospheric pressure – Vacuum = 760 – 475 = 285 torr = (285/760) * 101.325 **= 37.99 kPa**	1 1

1	e	**Stoichiometric coefficient** HCl = 4 O_2 = 1 Cl_2 = 2 H_2O = 2	½ mark each
1	f	**Net Calorific value(NCV):** It is the calorific value of the fuel when the water in the combustion products is present in vapour form **Gross Calorific value(GCV)**: It is the calorific value of the fuel when the water in the combustion products is present in liquid form	1 1
1	g	**Block diagram for distillation:**  Overall balance is F = X+ Y Component balance for MVC is $Fx_F = Dx_D + Wx_W$	1 1
2		**Any 3**	**12**
2	a	1 m^3 = 1000 lit 1h = 3600 sec 1000 l/h = (1000 * 1000 / 3600) l/s = **277.78 l/s**	1 1 1 1

2	b	Basis: 100 kg of groundnut seeds.  kg of solid=45kg kg of oil=45kg unchanging component is solid let weight of cake=x kg solid balance 0.8x=45 Therefore x=45/0.8=56.25kg Oil in cake=56.25*0.05 =2.81kg Therefore oil recovered=45-2.81 =42.19 % recovery of oil =(42.19/45)*100 =**93.75 %**	1 1 1 1
2	c	Basis : 100 kmol product stream Reaction is 2A + B ----→ C	

Kmol of inerts in product stream = 19.23 kmol

Kmol of A in product stream = 23.08 kmol (unreacted)

Kmol of B in product stream = 11.54 kmol (unreacted) 1

Kmol of C in product stream = 46.15 kmol (product)

Kmol of A reacted (from reaction) 2 * 46.15 = 92.3

Kmol of A fed = Kmol of A reacted + Kmol of A unreacted

= 92.3 + 23.08 = 115.38 kmol 1

Kmol of B reacted (from reaction) = 46.15

Kmol of B fed = Kmol of B reacted + Kmol of B unreacted

= 46.15 + 11.54 = 57.69 kmol 1

Inerts = 19.23 kmol

Component	Kmol	Mole %
A	115.38	60
B	57.69	30
Inerts	19.23	10

1

2 d

Hess's law of constant heat summation : It states that the enthalpy change i.e. heat evolved or absorbed in a particular reaction is the same whether the reaction takes place in one or several steps. 2

For Example : Carbon can be converted into CO_2 by two ways

Path 1 : C (s) + O_2 (g) ------> CO_2 (g) ----- Δ H 2

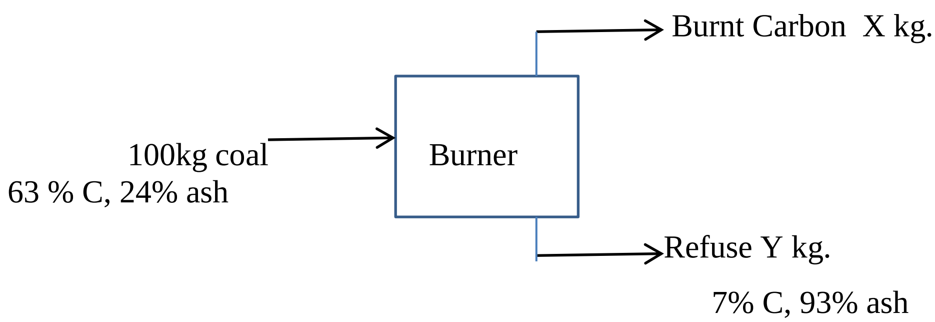
Path 2 : (i) C (s) + ½ O_2 (g) ------> CO (g) ----- Δ H1
(ii)2CO (g) +½ O_2 (g) ------> CO_2 (g) ----- Δ H2

(i) + (ii) C (s) + O_2 (g) ------> CO_2 (g)

Thus Δ H = Δ H1 + Δ H2

3 **Any 3** **12**

3 a Basis : 100 kg. of coal.



Individual balance for ash.

24 = 0.93 Y

Y = 25.80 kg. 1

Balance for carbon

63 = X + 0.07 * 25.80

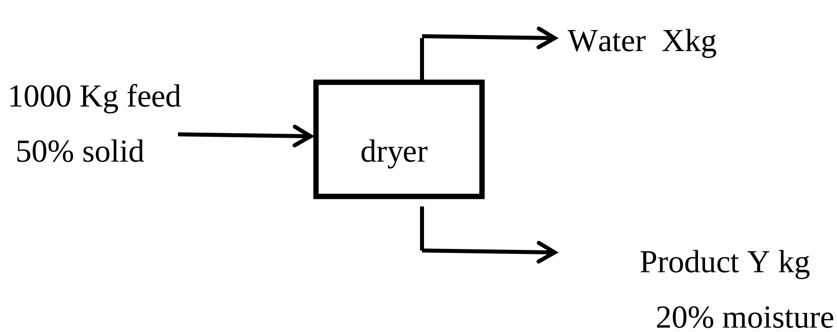
X = 61.194 kg. 1

Unburnt carbon = 0.07 * 25.8 = 1.806 kg. 1

% of original carbon unburnt =(1.806/63) * 100

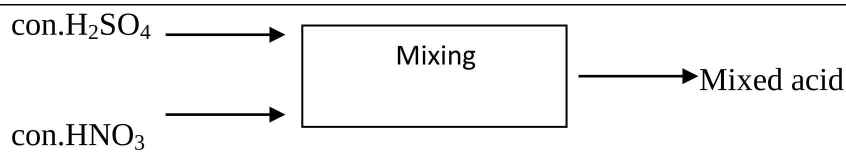
= **2.867%** 1

3 b Basis: 1000 kg wet solid



1

		Overall balance is 1000 = X+ Y Balance for solid 0.50 * 1000 = 0.8 * Y Y = 625 kg X = 375 Water removed = **375 kg** % of original moisture removed = (375/ 500)* 100 = **75%**	1 1 1
3	c	Basis 100 mol of ethylene Reaction I $C_2H_4 + \frac{1}{2}O_2 \longrightarrow C_2H_4O$ Reaction II $C_2H_4 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$ From reaction I 1Kmol of C_2H_4O formed≡ 1Kmol C_2H_4 reacted ∴ C_2H_4O reacted to from 80 kmol C_2H_4O $= \frac{1}{1} \times 80$ = 80Kmol From reaction II 2kmol of CO_2 formed≡ 1Kmol C_2H_4 reacted ∴C_2H_4 reacted to form 10 kmol CO_2 $= \frac{1}{2} \times 10$ = 5Kmol ∴C_2H_4 totally reacted = 80 + 5= 85 ∴% conversion of $C_2H_4 = \frac{85}{100} \times 100$ = **85%** % yield of $C_2H_4O = \frac{80}{85} \times 100$	1 1 1 1

		= **94.12%**	
3	d	Basis : 1 kmol ammonia $Q = n[Cp_{m2} (422 – 298) - Cp_{m1} (311 – 298)]$ $= 1 [37.7 (422 – 298) - 35.86 (311 – 298)]$ = **4208.62 KJ**	 1 1 2
4		**Any 3**	**12**
4	a	**Basis:** Average molecular weight of gas mixture=22.4 Let X_A& X_B be the mole fractions of CH_4& C_2H_6 respectively $M_{av}=M_AX_A+M_BX_B$ $22.4= 16X_A+30X_B$ ……….(1) $1= X_A+X_B$ ……………(2) Solving (1) &(2) we get $X_A= 0.543$ and $X_B=0.457$ **Mole fraction of CH_4 =0.543& Mole fraction of C_2H_4=0.457**	 1 1 2
4	b	 Basis : 100 kg. mixed acid. Weight of HNO_3 in mixed acid = 40 kg. Weight of H_2SO_4 in mixed acid = 43 kg. Let weight of con.H_2SO_4 be X kg and weight of con.HNO_3 be Y kg Balance for H_2SO_4 0.98X = 43 or X = 43.88 kg. Overall balance is X+Y =100 Or Y =100 – 43.88 = 56.13 kg Let N be the strength of nitric acid Balance for HNO_3	 1 1

		(N/ 100) 56.13 = 40 or **N = 71.26** Weight ratio of H_2SO_4 to HNO_3 fed=43.88/56.12=**0.7819**	1 1
4	c	**Basis:** 50 kmoles /hr butane C_4H_{10} + 6.5 O_2 -----→ 4CO_2 + 5 H_2O 100 kmol air fed = 21 kmol O_2 fed 2100 kmol air fed = ? O_2 fed = 2100*21/100= 441kmoles 1 kmol C_4H_{10} fed = 6.5 kmol O_2 theoretically required 50 kmol C_4H_{10} fed = ? O_2 theoretically required = 325 kmol % excess= (O_2 fed-O_2 theoretical)*100/ O_2 theoretical = (441-325)*100/325 = **35.69%**	 1 1 1 1
4	d	**Basis:** 100 kmol of flue gas. It contains 13.4 kmol CO_2,80.5 kmol N_2 and 6.1 kmol O_2 N_2 in supplied air = N_2 in flue gas = 80.5 kmol Air contains 79% N_2 by volume. Amount of air supplied = 80.5/ 0.79 = 101.9 kmol Amount of O_2 in supplied air = 0.21X101.9=21.4 kmol Amount of O_2 in flue gas = 6.1 kmol Amount of O_2 consumed in combustion of fuel = 21.4 - 6.1 = 15.3 kmol % excess air = % excess O_2 % excess air supplied = (21.4 – 15.3)/ 15.3 X 100 **= 39.9 % ------ Ans.**	 1 1 1 1

4	e	Force = 19.65 kgf Diameter of piston (d)= 5 cm Area = $\pi d^2/4$ $= \pi\ 5^2/4 = 19.625 cm^2$ Pressure = F/area $= 19.65/ 19.625 = 1.0013\ kgf/cm^2$ $= 1.0013* 9.808*10^4/1000 =$ **98.08 kPa**	 1 1 1 1
5		**Any 2**	**12**
5	a	**Basis :** 100 kmol of mixture (Volume % = Mole %) It Contain N_2 = 70.5 kmol, O_2 =18.8 kmol , H_2O =1.2 kmol , NH_3 = 9.5 kmol Mole fraction of N_2 = 70.5/100 = 0.705 Mole fraction of O_2 = 18.8/100 = 0.188 Mole fraction of H_2O = 1.2 /100 = 0.012 Mole fraction of NH_3 = 9.5 /100 = 0.095 M_{N2}= 28 , M_{O2} = 32 , M_{H2O} = 18 , M_{NH3}= 17 M avg = Σ Mi.Xi where i =1 to n M avg = [28 x 0.705 + 32 x 0.188 + 18 x 0.012 + 17 x 0.095] M avg = **27.587** Density of gas mixture ρ = (P x Mavg)/ (R x T) Where P = 810.325 Kpa and T = 923 K R = 8.3145 m^3 kpa / Kmol K ρ = (810.325 x 27.587) / (8.3145 x 923)	 1 1 1 1 1

		$\rho = 2.914\ Kg / m^3$	1
5	b	Basis : 100 kmol of gas mixture Let X_1 , X_2, X_3 be mol fraction of N_2 , CO_2 , O_2 respectively. Mavg. using correct molecular wt. of N_2 = 28 By engineer 1 is $30.08 = 28 X_1 + 44X_2 + 32X_3$ …………(1) Mavg. Using in correct molecular wt. of N_2 = 14 By engineer 2 is $18.74 = 14 X_1 + 44X_2 + 32X_3$ ………..(2) Sum of mol fraction = 1 $1 = X_1 + X_2 + X_3$ ………..(3) Solving (1) , (2) and (3) $X_1 = 0.81$ $X_2 = 0.11$ $X_3 = 0.08$ **Volume % of N_2 = 81%** **Volume % of CO_2 = 11%** **Volume % of O_2 = 8%**	 1 1 1 2 1
5	c	**Basis :** 100 kmol feed gas mixture containing A and inters entering per unit times Solvent to gas entering ratio = 2 : 1 Solvent fed to the tower = (2/1) x 100 = 200 kmol / time A in feed gas = 0.15 (100) = 15 kmol / time Inters in feed gas = 0.85 (100) = 85 kmol / time **Material balance of Inerts**	 1

		Inerts in outlet gas = Inerts in feed gas = 85 kmol/ time Let X be the gas leaving the tower per unit time Mole % inerts in gas leaving = 100 – (2.5 + 1.5) = 96 (85/ X) x 100 = 96 Solving , we get X = 88.54 kmol/time Solute 'A' in gas leaving the tower = 0.025 x 88.54 =2.21 kmol/time Solute 'A' absorbed = 15 -2.21 = 12.79 kmol/time **% recovery of 'A' = (12.79/ 15) x 100 = 85.27 % ------ ans (a)** Solvent (B) in gas leaving the tower = 0.015(88.54) = 1.33 kmol/time **[Fraction of solvent fed to and lost in the gas leaving the tower] =** **1.33 / 200 = 0.00665 --------------- ans (b)**	1 1 1 1 1
6		**Any 2**	**12**
6	a	**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 But O_2 is calculated based on reactant feed. $\therefore$ O_2 Therotical requirement = 1/ 4 x 100 = 25 kmol	 1 1 1

As 30 % excess air is provided.

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

= 2.5 – 20 =12.5 kmol

O_2 unreacted = O_2 in air - O_2 reacted 1

= 32.5 – 20 = 12.5 kmol

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**
	234.76	100

1

6 b **Basis :** 100 Kmol of feed

Feed contains 60 kmol A , 30 kmol B and 10 kmol inerts

Let X be the kmol of A reacted by reaction : 1

		2A + B ----- C	
		From reaction 2 kmol A = 1 kmol B = 1 kmol C	
		B reacted = (1/2)* X = 0.5 X kmol	
		C formed = (1/2)* X = 0.5 X kmol	
		Material Balance of A give	1
		A unreacted = (60 – X) kmol	
		Material Balance of Inerts :	
		Inerts in feed = Inert in product = 10 kmol	
		C formed = (1/2)* X = 0.5 X kmol	
		B unreacted = (30 - 0.5 X) kmol	1
		Total moles of product stream = (60-X) + (30-0.5X) + 10=0.5X	
		= 100 –X Kmol	
		Mole % of A in product stream = 2%	
		Mole % of A = $\frac{\text{Kmol A in product stream}}{\text{Total kmol of product stream}} * 100$	1
		$2 = \frac{60 - X}{100 - X} * 100$	
		X = 59.184 kmol = amount of A reacted	
		Conversion of A = $\frac{\text{Kmol A reacted}}{\text{Total kmol of A feed}} * 100$	1

		Conversion of A = $\frac{59.184}{60}$ * 100 = **98.64 % ------ Ans**	1
6	c	**Basis :** 1 mol of Phenol crystals 1. $C(s) + O_2(g) \text{------>} CO_2(g)$ $\Delta H_1 = -393.51$ KJ/mol 2. $H_2(g) + 1/2\ O_2(g) \text{------>} H_2O(l)$ $\Delta H_1 = -285.83$ KJ/mol 3. $C_6H_5OH(c) + 7.5\ O_2(g) \text{------>} 6CO_2(g) + 3\ H_2O(l)$ $\Delta H^0c = -3053.25$ KJ/mol 4. $6C(s) + 3\ H_2(g) + 0.5\ O_2(g) \text{------>} C_6H_5OH(c)$ $\Delta H^0f = ?$	2
		ΔH^0f = Standard heat of formation of phenol crystal Reaction(4) = 6 x Reaction (1) + 3x Reaction (2) – Reaction (3) $\Delta H^0f = 6 \times \Delta H_1 + 3 \times \Delta H_2 - \Delta H^0c$ $= 6 \times (-393.51) + 3 \times (-285.83) - (-3053.25)$ $= (-2361.06) + (-857.49) - (-3053.25)$ $= -165.3$ KJ/mol	2
		ΔH^0f = -165.3 KJ/mol ------- ans.	2