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
1-A	Any 4	
1A-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.	1
	Heat capacity: It is the amount of heat required to increase the temperature of one gram of substance by one degree.	1
1A-b	**Law of conservation of mass:** It states that For any process input= output+accumulation	2
1A-c	**Value of R:**	1
	1.987 Kcal/kmol.K	
	8.315 J/mol.K	1
1A-d	$CO+2H_2$-----→CH_3OH Stoichiometric coefficient of $CO:H_2$ = 1:2	2
1 A-e	**Law for real gas is**	1
	Vander Waal's equation of state:	
	$(P+a/V^2)(V-b)= nRT$	1
	Where a & b are constants	
1A-f	**Law of conservation of energy:**	1
	Energy input= energy output + accumulation	1
1-B	**Any 2**	12
1B-a	**Basis: 100 kmoles of feed** A fed= 60 kmol B fed=30 kmol Inert fed = 10 kmol	
	Reaction is 2A+B ------→C	2

Conversion of A =80%

A converted= (80/100) *60 = 48 kmol

A unreacted= 60-48 = **12 kmol**

B reacted = 24 kmol

B unreacted = 30-24 = **6 kmol**

C formed**= 24 kmol** 2

Inert**= 10 kmol**

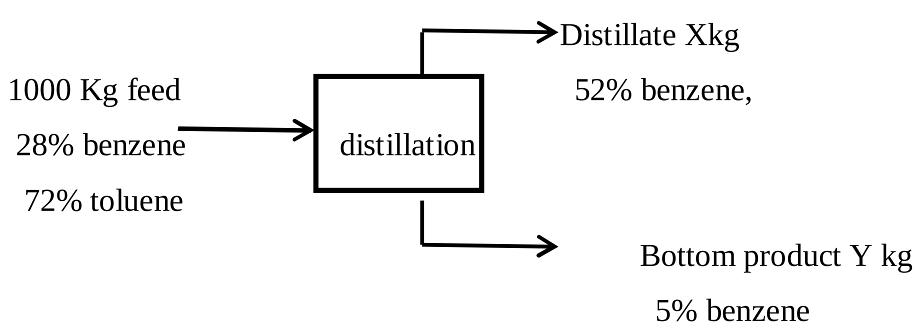
Composition of product stream:

component	kmol	Mol%
A	12	**23.07**
B	6	**11.54**
C	24	**46.15**
Inert	10	**19.23**
total	52	

2

1B-b 1

Basis: 1000 kg benzene-toluene



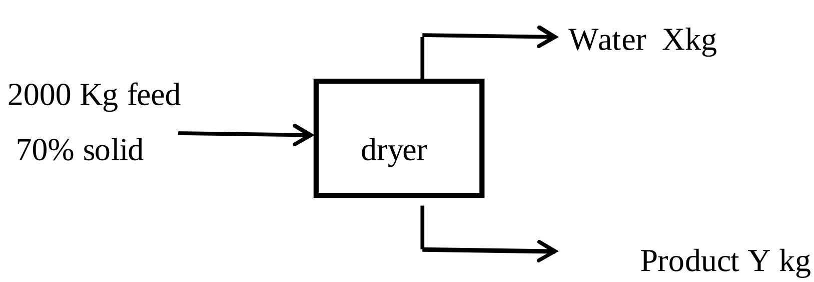
1

Overall balance is

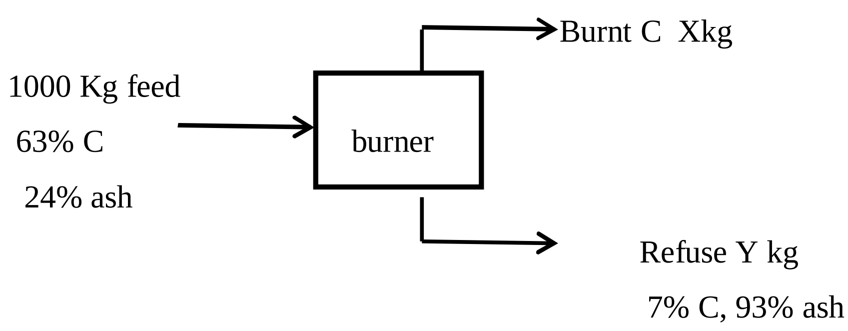
1000= X+ Y 1

Benzene balance is

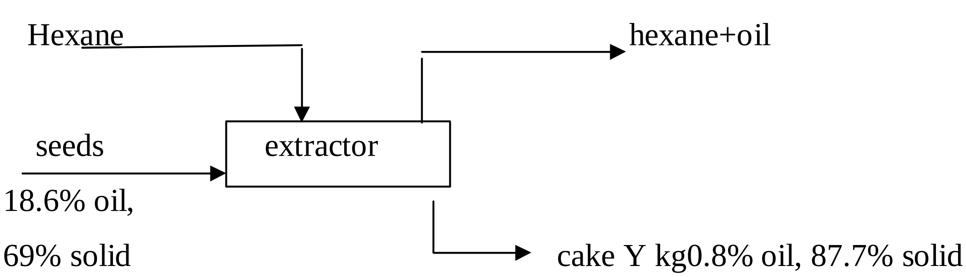
	(28/100)* 1000= 0.52X + 0.05Y Solving X= 489.36kg and Y = 510.64 Kg Distillate= **489.36kg** Bottom product = **510.64 Kg**	1 2
1B-c	Basis: 1 Kg HCl acid $4HCl + O_2$ --------→ $2Cl_2 + 2\ H_2O$ HCl fed = 1/36.5 = 0.027 kmoles From reaction Oxygen theoretically required = 0.027/4 = $6.85*10^{-3}$ % excess = 30 Oxygen fed = $8.9*10^{-3}$ kmoles Air fed = 0.042 kmoles = **1.22 kg**	1 1 1 1 1 1
2	Any 4	16
2-a	Basis: 1000 Kg/hr HCHO formed CH_3OH ------→HCHO + H_2 HCHO formed = 1000/ 30 = 33.33 kmole/h From reaction, CH_3OH reacted = 33.33 kmole/h Conversion = 65% Conversion= (kmoles of CH_3OH reacted/kmoles of CH_3OH fed)* 100 Therefore CH_3OH fed = 51.28 Feed rate of methanol= 51.28 * 32 kmol/h = **1640.96 Kg/h**	 1 1 1 1
2-b	**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 → B $\Delta T1$ B → C $\Delta T2$ C → D $\Delta T3$ A → D ΔT Then $\Delta T = \Delta T1 + \Delta T2 + \Delta T3$	2 2
2-c	Basis: 4.73 kg coal $C+O_{2}$ --→ CO_2 At NTP, P= 101.325 KPa T= 273 K PV=nRT Or n= PV/RT Moles of CO_2= 0.237 kmoles Weight of CO_2= 0.237*44 = 10.428 kg Carbon in the sample = (12/44)10.428 = 2.844 kg Carbon content in the sample = (2.844/4.73)100 = **60.13%**	 1 1 1 1
2-d	Basis: 2000 kg wet solid 	1

	1% moisture Overall balance is 2000 = X+ Y Balance for solid 0.70 * 2000 = 0.99 * Y Y = 1414.14 kg X = 585.86 Water removed = **585.86 kg** Product obtained = **1414.14 kg**	 1 1 1
2-e	Basis:15 kg propane Moles n= 15/44 = 0.341 kmoles At NTP, P= 101.325 KPa T= 273 K PV=nRT Or V= nRT/P = 0.341* 8.314 * 273/101.325 **= 7.64 m^3**	 1 1 1 1
2-f	Basis: 1 mol liquid C_5H_{12} $\Delta H^0_R = \Sigma \Delta H^0_{f(pr)} - \Sigma \Delta H^0_{f(react)}$ = [(-393.51*5)+(-285.83*6)]– (-173.49) = **-3509.04KJ**	 2 2
3	Any 4	16
3-a	Basis: Fixed mass of gas at at constant temperature Initial volume V1= $1m^3$ Initial pressure P1= P1atm Final volume V1= $V2m^3$	 1

	Final pressure P2= 1.85P1atm P1V1/T1 = P2V2/T2 P1*1/T = 1.85P1*V2/T V2= **0.5405 m^3**	1 1 1
3-b	Basis: 1 kmol methane gas $Q = n[\ 19.2494(T2-T1) + 52.1135*10^{-3}/2(T2^2 - T1^2) + 11.973 * 10^{-6}/3\ (T2^3 - T1^3) - 11.3173 * 10^{-9}/4\ (T2^4 - T1^4)$ $Q = 1[\ 19.2494(523-303) + 52.1135*10^{-3}/2(523^2 - 303^2) + 11.973 * 10^{-6}/3\ (523^3 - 303^3) - 11.3173 * 10^{-9}/4\ (523^4 - 303^4)$ = 4234.86 + 4735.03+459.9 – 187.84 = **9241.96 KJ**	2 1 1
3-c	Basis:100 kg coal  Component balance for ash 24= 0.93 Y Or Y = 25.80 Kg Balance for carbon 63= X+ 0.07*25.80 X= 61.194 Kg	1 1 1

	Unburnt carbon = 0.07*25.80 = 1.806 Kg % of original C unburnt = (1.806/ 63)*100 = **2.867%**	 1
3-d	$N_2 + 3H_2$ ---→ $2NH_3$ 1 kmol N_2 = 3 kmol H_2 25 " = ? Molal flow rate of H_2 **= 75 kmol/hr** % conversion of N_2 =(N2 reacted/ N2 fed)*100 25 = (N2 reacted/ 25)*100 N_2 reacted = 6.25 kmol/h From reaction NH_3 formed = 12.50 Kmol/h Kg NH_3 formed = 12.50 *17 = **212.5 Kg**	1 1 1 1
3-e	Basis: 1 kmol NH_3 Q = n[Cpm2(T_2-T_0) - Cpm1(T_1-T_0)] = 1[37. 7063(422-298) – 35.8641(311-298)] = **4209.35** KJ	 2 2
3-f	Basis: 100 kmol air Avg. mol.wt of air = $M_1X_1+M_2X_2$ = 28 * 0.79 + 32 * 0.21 = 28.84 Density = P* Mav / RT = 101.325 * 28.84/ 8.314 * 273 = **1.287 Kg/m^3**	 1 1 1 1
4	Any 2	16

4-a	Basis: Mixture of N_2, CO_2, O_2 Let X_1, X_2, X_3 be the mol fraction of N_2, CO_2, O_2 respectively. 1st person $28\ X_1 + 44\ X_2 + 32\ X_3 = 30.08$ 2[nd] person $14\ X_1 + 44\ X_2 + 32\ X_3 = 30.08$ $X_1 + X_2 + X_3 = 1$ Solving the equations, we get $X_1 = 0.81$ $X_2 = 0.11$ $X_3 = 0.08$ **Volume % of N_2 = 81%** **Volume % of CO_2 = 11%** **Volume % of O_2 = 8%**	 1 1 1 1 2 2
4-b	Basis: Mixture of N_2, CO_2 $X_{CO2} = 1 - X_{N2}$ Avg. mol.wt = $M_1X_1+M_2X_2$ $31 = 28\ X_{N2} + 44(1- X_{N2})$ Solving, $X_{N2} = 0.8125$ $X_{CO2} = 0.1875$ Partial pressure of N_2 = Total pressure * mol.fr = 101.325 * 0.8125 = **82.33 KPa**	1 1 1 2 1 2
4-c	**Basis:** 100 kg flaked seeds  	 1 1

	Component balance for solids 69 = 0.877 Y Or Y = 78.68 Kg Oil in cake = (0.8/100)78.68 = 0.63 Kg Oil balance is 18.6 = 0.63 + oil recovered Oil recovered = 17.97 kg % oil recovery = (17.97/18.6)* 100 = **96.61%**	 1 1 1 1 1 1
5	Any 2	16
5-a	**Basis :** 100 Kg of coke Amount of carbon in coke = 0.9 x 100 = 90 Kg Amount of C = 90/12 = 7.5 katom **Reaction :** $C + O_2$ ------> CO_2 From reaction , 1 katom C = 1 kmol O_2 12 Kg C = 32 Kg O_2 90 Kg C = (32/12) x 90 Kg O_2 O_2 theoretically required = (32/12) x 90 =240 Kg O_2 theoretically required = (240 x1000) / 32 =7500 mol **Moles of O_2 theoretically required for 100 kg coke for complete combustion = 750 mol -------- ans (a)** O_2 theoretically required = 240 / 32 =7.5 kmol Air theoretically required = 7.5 * (100/21) =35.71 kmol % excess	 1 1 1

	Air actually supplied = Air theoretically required $\left(1+\frac{\text{------------}}{100}\right)$ Air actually supplied = 35.71 x $\left(1+\frac{50}{100}\right)$ = 53.57 kmol Air actually supplied = 53.57 kmol O_2 in air supplied = 53.57 x 0.21 = 11.25 kmol N_2 in air supplied = 53.57 x 0.79 = 42.32 kmol O_2 reacted for complete combustion of coke =7.5 kmol **Material Balance of O_2** O_2 in air supplied = O_2 reacted + O_2 Unreacted O_2 Unreacted = 11.25 -7.5 =3.75 kmol CO_2 produced = (1/1) x 7.5 =7.5 kmol **Analysis of Gases at the end of Combustion:**	1 1 1 2
5-b	**Basis :** 15000 mol/h of N_2- H_2 mixture Molal flow rate of gas mixture = 5 kmol/h X_{N_2} = 25/100 = 0.25 X_{H_2} = 75/100 = 0.75 C_P^o mix = Σ C_P^o mix . X i = X_{N_2} . C_P^o N_2 + X_{H_2} .C_P^o H_2 $= 0.25 (29.5909 - 5.141 x 10^{-3} T + 13.1829 x 10^{-6} T^2 - 4.968 x 10^{-9} T^3)$ $+ 0.75 (28.6105 + 1.0194 x 10^{-3} T - 0.1476 x 10^{-6} T^2 + 0.769 x 10^{-9} T^3)$	1 2

Component	Quantity , Kmol	Mole%
CO_2	7.5	14
N_2	42.32	79
O_2	3.75	07
Total	53.57	100

	$= 28.8556 - 0.5207 \times 10^{-3} T + 3.185 \times 10^{-6} T^2 - 0.6652 \times 10^{-9} T^3$ Q = Heat added $Q = n \int_{T_1}^{T_2} C^o p\ mix\ dT$	1
	$Q = n \int_{T_1}^{T_2} [28.8556 - 0.5207 \times 10^{-3} T + 3.185 \times 10^{-6} T^2 - 0.6652 \times 10^{-9} T^3]\ dT$ $= n [28.8556 (T_2 - T_1) - \frac{0.5207 \times 10^{-3}}{2} (T_2^2 - T_1^2) + \frac{3.185 \times 10^{-6}}{3} (T_2^3 - T_1^3) - \frac{0.6652 \times 10^{-9}}{4} (T_2^4 - T_1^4)]$	2
	Where , n= 15 Kmol/h , T_2 = 473 K , T_1 = 298 K $= 15 [28.8556 (473 - 298) - \frac{0.5207 \times 10^{-3}}{2} (473^2 - 298^2) + \frac{3.185 \times 10^{-6}}{3} (473^3 - 298^3) - \frac{0.6652 \times 10^{-9}}{4} (473^4 - 298^4)]$ Q = 15(5049.73 -35.13 – 7.01) **Q = 76377.6 KJ/h = 21.216 kJ/s = 21.216 kW ------- ans**	2
5-c	**Basis :** 1 Kg of petrol Amount of H_2 in petrol = 0.15 Kg, Amount of C in petrol = 0.85 kg	

	$H_2 + ½ O_2$ ---→ H_2O	1
	$C + O_2$ ---→ CO_2	
	From reactions : 1 kmol of H_2 = 0.5 kmol O_2	
	2 kg of H_2 = 16 kg O_2	
	1 katom of C = 1 kmol O_2	
	12 kg of C = 32 kg O_2	1
	Therotical requriment of O_2 for H_2 = 0.15 x (16/2) =1.20 Kg	
	Therotical requriment of O_2 for C = 0.85 x (32/12) = 2.27 Kg	
	Total therotical requriment of O_2 = 1.20 + 2.27 = 3.47 Kg	
	Amount of air required for combustion = (3.47/0.23) =15.09 kg --- ans	1
	(Air contais 23% O_2 and 77 % N_2 on weight basis)	
	Amount of air supplied = 15.09 x 1.15 =17.35 kg	
	N_2 in supplied air = (0.77 x 17.35) /28 = 0.477 kmol	
	O_2 in supplied air = (0.23 x 17.35) /32 = 0.125 kmol	1
	O_2 in dry product = [0.23x(17.35-15.09)] /32 =0.016 kmol	
	We have , 1 katom of C = 1 kmol CO_2	
	(0.85/12) katom C = ?	1
	CO_2 produced = (1/1) x(0.85/12) = 0.071 kmol	
	The product flue gases contain CO_2, O_2 and N_2	1
	For ideal gases, Volume % = Mole %	
	Composition of Dry Product Gases :	

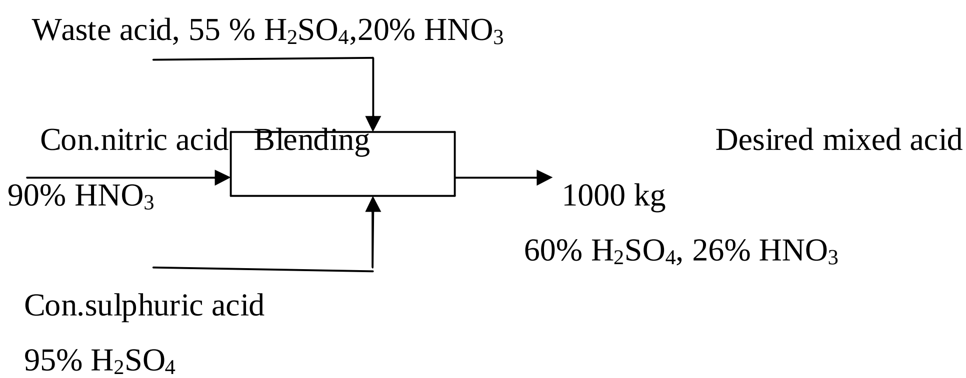
Component	Quantity , Kmol	Mole%
CO_2	0.071	12.6
N_2	0.016	2.8
O_2	0.477	84.6
Total	0.564	100

2

6 **Any 2** 16

6-a **Solve any TWO of the following**

Basis: 1000 kg of Desired mixed acid 1



1

Let x,y and Z be the kg of waste acid ,concentrated sulphuric acid and concentrated nitric acid to make 1000 kg desired acid. 1

Overall material Balance :

X+ Y+ Z = 1000 ---------------- (1) 1

Material Balance Of H_2SO_4

$0.55X + 0.95\,Y = 0.60 \times 1000$

$0.55X + 0.95\,Y = 600$

600 – 0.55 X

Y= -------------------

	0.95	1
	Y = 631.58 -0.58 X ----------------- (2)	
	Material Balance Of HNO_3	
	0.2X+ 0.90 Z = 0.26 x 1000	
	0.2X+ 0.95Y = 260	
	260 – 0.2 X	
	Z = -------------------	
	0.90	
	Z = 288.9 – 0.222 X ----------------- (3)	1
	Putting values of Y and Z in equation (1) from (2) and (3) and solve for X	
	X + (631.58-0.58 X) +(288.9 -0.222 X) =1000	
	0.198 X = 79.52	1
	X = 401.6 kg	
	We have Y = 631.58 -0.58 X	
	Y = 631.58 – 0.58 x 401.6 = 398.65 Kg	1
	We have Z = 288.9 – 0.222 X	
	Z = 288.9 – 0.222 x 401.6 = 199.75 Kg	
	Waste acid = 401.6 kg	
	Concentrated sulphuric acid = 398.65 kg	
	Concentrated nitric acid = 199.75 kg	
6-b	**Basis:** 1 Kmol /h benzene fed to reactor	
	Benzene, HNO_3, H_2SO_4 → **Reactor**	
	----→ Product stream NB, DNB, HNO_3 etc	

	H_2SO_4	
	Reaction 1: $C_6H_6 + HNO_3$ -------------→ $C_6H_5NO_2 + H_2O$	
	H_2SO_4	1
	Reaction 2: $C_6H_5NO_2 + HNO_3$ -------------→ $C_6H_4(NO_2)_2 + H_2O$	
	Benzene reacted = 0.9 x 1 = 0.9 kmol/h	
	Let X be the dinitrobenzene formed per hour	
	(kmol nitrobenzene /h) / (kmol dinitrobenzene /h) = 17/1	
	Nitrobenzene produced = 17 x kmol	
	From reaction 1 and 2	1
	1 kmol of C_6H_6 = 1 kmol of $C_6H_5NO_2$	
	= 1 kmol of $C_6H_4(NO_2)_2$	
	Benzene reacted to produce nitrobenzene = (1/1) x 17 x kmol/hr	1
	Benzene reacted to dinitrobenzene = x kmol	
	Benzene reacted = 0.9 = 17 x + x	
	x = 0.05 kmol/hr	
	Nitrobenzene produce = 17(0.05) = 0.85 kmol/h	1
	1 kmol of C_6H_6 = 1 kmol HNO_3	
	Stoichometric requriment of nitric acid for	
	1 kmol benzene /h = 1/1 x 1 = 1 kmol/h	
		1
	Nitric acid fed to reactor = 1 [1 + (65/100)] = 1.65 kmol/h	
	Nitric acid fed to reactor = 1.65 x 63 = 104.95 kg/h	
	Nitrobenzene produce = 17(0.05) = 0.85 x 123= 104.55 kg/h	1
	Benzene fed to reactor = 1 x 78 =78 kg/hr	
	Nitric acid fed to reactor fed to produce of 2000 kg/hr of nitrobenzene =	1
	(103.95/ 104.55) x 2000 = **1988.5 kg/hr**	

	Benzene fed to reactor fed to produce of 2000 kg/hr of nitrobenzene = (78/ 104.55) x 2000 = **1492.1kg/hr**	1
6-c	**Basis :** One day of operation Wet solids handled = 1000 kg Let X be the Kg of product obtained from first dryer and Y be the Kg of water removed in first dryer. **Material Balance of solids over First Dryer :** 0.50 * 1000 = 0.80 * X X = 625 Kg **Overall Material Balance over First Dryer :** X + Y = 1000 625 + Y = 1000 Y= 375 Kg Input to second dryer is 625 Kg of wet solid containing 20% moisture **Material Balance of solids over Second Dryer :** 0.8 * 625 = 0.98 * Z Z = 510.20 Kg **Weight of final product = 510.20 Kg ---------- ans. (b)** **Overall Material Balance over Second Dryer :** 625 = 510.20 + Water removed Water removed in second dryer = 625- 510.20 = 114.8 Kg	1 1 1 2

	Water in wet solids fed to first dryer =0.5 * 1000 = 500 Kg % of original water removed in first dryer = (375/500) *100 = 75 % % of original water removed in Second dryer = (114.8/500) *100 = 22.96 % **% of original water removed in first dryer = 75 %** **% of original water removed in Second dryer = 22.96 %** **------- ans. (a)**	1 2