WINTER-14 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
1-a	**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	1 1	2
1-b	**Standard heat of combustion:** It is the amount of heat liberated when one mol of a compound is combusted or burned in oxygen at standard conditions.(25^0C and 1atm pressure)	2	2
1-c	**Vapour pressure** : It is the pressure exerted by vapour which is in equilibrium with liquid.	2	2
1-d	**Value of universal gas constant** **R** = 8.315 KPa m^3/ kmol K	2	2
1-e	**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. $A \longrightarrow A \quad B \quad \Delta T1$ $B \longrightarrow C \quad \Delta T2$ $C \longrightarrow D \quad \Delta T3$ $A \longrightarrow D \quad \Delta T$ Then $\Delta T = \Delta T1 + \Delta T2 + \Delta T3$	2	2

1-f	**Stoichiometric equation:** It is defined as the balanced chemical reaction Eg: $N_2+3H_2\text{------}\rightarrow 2NH_3$	2	2
1-g	**Vander Waal's equation of state:** $(P+a/V^2)(V-b)= RT$ Where a & b are constants.	2	2
1-h	**Charles Law** : It states that for a given mass of an ideal gas the ratio of volume to absolute temperature is constant at a given pressure. V/T = constant	1 1	2
1-i	**%Yield of desired product =** (moles of limiting component reacted to form desired product/ total moles of limiting component reacted)* 100	2	2
1-j	1 mol of air at STP n= 1 mol p= 101.325 Kpa R= 8.314 T=300K PV=nRT or V=nTR/P V= 1 * 8.314 * 300/ 101.325 = 24.62 m^3	1 1	2
1-k	Oxygen is supplied in excess to ensure complete combustion of compound. The source of oxygen for combustion is air which is readily available. Therefore in order to get maximum conversion air is always added in excess quantity.	2	2

<table>
<tr><td>1-l</td><td>101.325 Kpa g
Absolute pr = gauge pr + atmospheric pr
= 101.325 KPa + 101.325 Kpa
= 202.65 KPa</td><td>2</td><td>2</td></tr>
<tr><td>1-m</td><td>Raoult’slaw:It states that at a given temperature, the equilibrium partial pressure of a component of a solution in the vapour is equal to the product of the mole fraction of the component in the liquid phase and the vapour pressure of the pure component.</td><td>2</td><td>2</td></tr>
<tr><td>1-n</td><td>Amagat’s law: It states that the total volume occupied by a gas mixture is equal to the sum of pure component volumes.
Mathematical Statement: $V = V_1+V_2+V_3$
where V is the total volume of gas mixture , V_1,V_2,V_3 are pure component volume</td><td>2</td><td>2</td></tr>
<tr><td>2-a</td><td>Basis: 100 kmoles of gas mixture
<table>
<tr><td>compound</td><td>kmol</td><td>Mol fr(xi)</td><td>Mol.wt (Mi)</td><td>Mi*xi</td></tr>
<tr><td>CH_4</td><td>70</td><td>0.7</td><td>16</td><td>11.2</td></tr>
<tr><td>C_2H_6</td><td>22</td><td>0.22</td><td>30</td><td>6.6</td></tr>
<tr><td>N_2</td><td>8</td><td>0.08</td><td>28</td><td>2.24</td></tr>
</table>
Average molecular weight = 11.2+6.6+2.24 = 20.04</td><td>1
2
1</td><td>4</td></tr>
<tr><td>2-b</td><td>Basis: 50 kmoles /hr butane
$C_4H_{10} + 6.5\ O_2 \text{-----}\rightarrow 4CO_2 + 5\ H_2O$
100 kmol air fed = 21 kmol O_2 fed
2100 kmol air fed = ?</td><td>1</td><td>4</td></tr>
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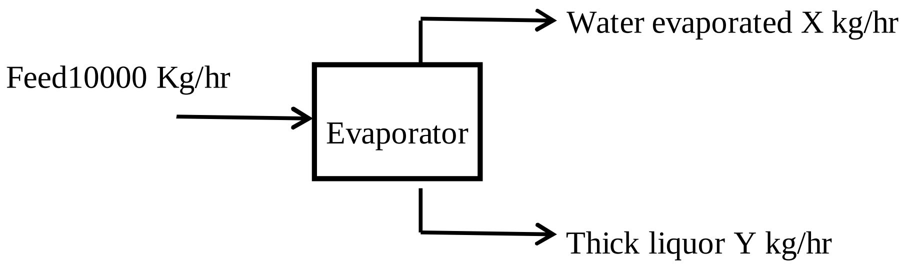
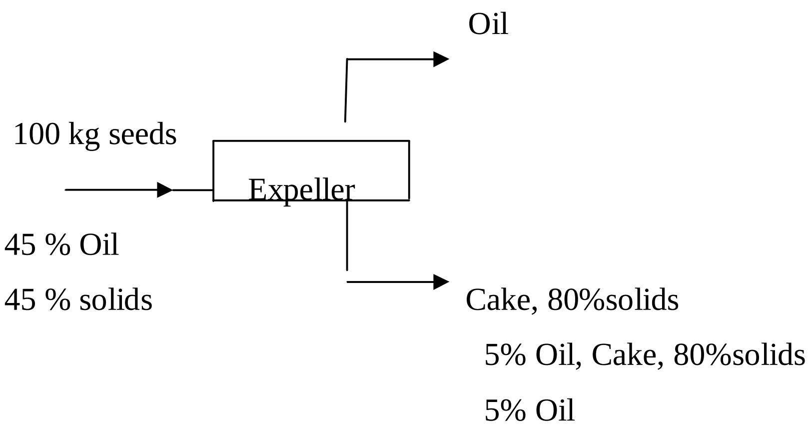
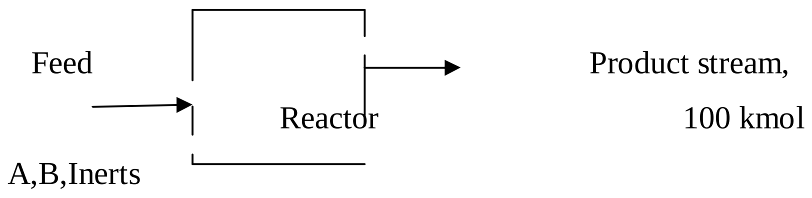
	O_2 fed = 2100*21/100= 441kmoles 1 kmol C_4H_{10} fed = 6.5 kmol O_2 theoretically required 50 kmol C_4H_{10} fed = ? O_2 theoretically required = 325 kmol % excess= (O_2 fed-O_2 theoretical)*100/ O_2 theoretical = (441-325)*100/325 = **35.69%**	1 1 1	
2-c	Basis: $1m^3$ fixed mass of gas at constant temperature $P_1 = 1 \quad V_1 = 1\ m^3 \quad T_1 = T = T_2$ $P_2 = 1.85 \quad V_2 = ?\ m^3$ $P_1V_1/T_1 = P_2V_2/T_2$ $1*1/T = 1.85*V_2/T$ Or V_2**= 0.54 m^3**	 2 1 1	4
2-d	Basis: 10000 Kg/hr of weak liquor  Overall balance is 10000= X+Y Individual balance for caustic is 15/100 *10000 = 40/100 * Y Y= 3750 & X= 6250 Kg/hr of water evaporated = **6250 Kg/hr** Kg/hr of thick liquor obtained = **3750 Kg/hr**	1 1 2	4

2-e	Basis: 5 m^3 Cl_2 gas		4
	P=100 KPa		
	T=400 K		
	N= PV/RT	1	
	= 100 *5/ 8.314*400		
	= 0.15 kmoles	1	
	Weight of Cl_2 gas = kmoles * mol.wt	1	
	Weight = 0.15*71		
	= **10.65 Kg**	1	
2-f	$N_2 + 3H_2 \text{-------}\rightarrow 2NH_3$	1	4
	N_2 fed = 10 kmoles		
	Theoretical requirement of H_2 = 30 kmoles		
	H_2 fed = 60 kmoles	1	
	% excess H_2 = (H_2 fed - H_2 theoretical) *100 / H_2 theoretical	1	
	= (60-30)100/30		
	= **100 %**	1	
3-a	**SOLUTION :**		8
	BASIS : 100 kg of ground nut seeds.		
		2	

	Let x be the kg of the cake obtained.		
	Material Balance of Solids :		
	Solids in seeds = Solids in cake	2	
	$\therefore 0.45 \times 100 = 0.8\,x$		
	$\therefore \quad X = 56.25$ kg		
	Material balance of Oil :		
	Oil in seeds = Oil in cake + Oil recovered	2	
	$\therefore$ 0.45 x 100 = 0.05 x 56.25 + Oil recovered		
	$\therefore$ Oil recovered = 45 – 2.81 = 42.19 kg		
	% recovery of oil = (kg of oil recovered / kg oil in seeds) x 100	2	
	= (42.19 / 45) x 100 **= 93.75%** **….Ans**		
3-b	**SOLUTION :**		8
	BASIS : 100 kmol of product stream.		
	It contains 23.08 kmol of A, 11.54 kmol of B, 46.12 kmol of C and 19.23 kmol of inerts.	1	
		1	
	$2A + B \rightarrow C$		
	From reaction, 2 kmol = 1 kmol C	1	
	A reacted = (2 /1) x 46.15 = 92.3 kmol		

Material Balance of A :

A in feed = A reacted + A unreacted 1

= 92.3 + 23.08 = 115.38 kmol

From reaction ,2 kmol A = 1 kmol B

B reacted = (1 /2) x 92.3 = 46.15 kmol 1

Material Balance of B :

B in feed = B reacted + B unreacted 1

= 46.45 + 11.54 = 57.69 kmol

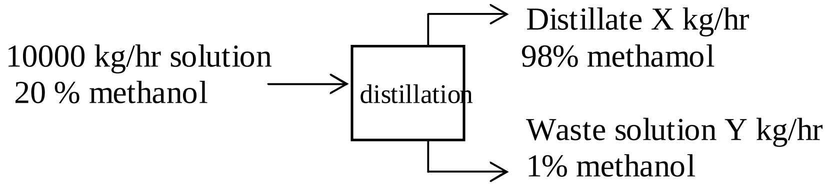
Material Balance of Inerts :

Inerts in feed = Inerts in product stream = 19.23 kmol

Analysis of Feed :

Component	Quantity , kmol	Mole %
A	115.38	60
B	57.69	30
Inerts	19.23	10
Total	192.30	100

3-c Basis: 10000 kg/hr of feed 8



2

	Overall balance is	1	
	10000 =X+ Y……………(1)		
	Individual balance for CH_3OH is	1	
	0.2*10000 = 0.98X+0.01*Y…………..(2)		
	Solving the equations	2	
	X= 1959 Kg/hr		
	Y= 8041 kg/hr	1	
	CH_3OH in bottom product = 0.01*8041 = 80.41Kg/hr		
	% loss of CH_3OH=(CH_3OH in bottom product/ CH_3OH in feed)*100	1	
	= (80.41/2000)*100		
	= 4%		
4-a	**SOLUTION :**		8
	BASIS : 100 mol of gas.		
	It contains 25 mol CO, 5 mol CO_2, 2 mol O_2 and 68 mol N_2.		
	$CO + \frac{1}{2} O_2 \longrightarrow CO_2$		
	1 mol CO = 0.5 mol O_2		
	Theoretical O_2 = 0.5 /1 x 25 = 12.5 mol	1	
	Net O_2 demand (by difference) = 12.5 – 2 = 10.5 mol		
	O_2 in supplied air = 1.20 x 10.5 = 12.6 mol	1	
	N_2 in air supplied = (79/21) x 12.6 = 47.4 mol	1	
	CO reacted = 0.8 x 25 = 20 mol		
	CO unreacted = 25 – 20 = 5 mol	1	

CO_2 Produced= 20 mol — 1

Total CO_2 in gas leaving = 20 + 5 = 25 mol — 1

O_2 reacted =(1 / 2) x 20 = 10 mol

O_2 unreacted = 12.6 – 10 = 2.6 mol — 1

N_2 in gas leaving = 47.4 +68 = 115.4 mol

Component	**Moles**	**Mole %**
CO2	25	16.89
O2	2.6	1.77
N2	115.4	77.97
CO	5	3.37
Total	148	100.00

1

4-b **SOLUTION :** — 8

BASIS : 15000 mol /h of $N_2 – H_2$ mixture.

Molal flowrate of gas mixture = 15 kmol /h

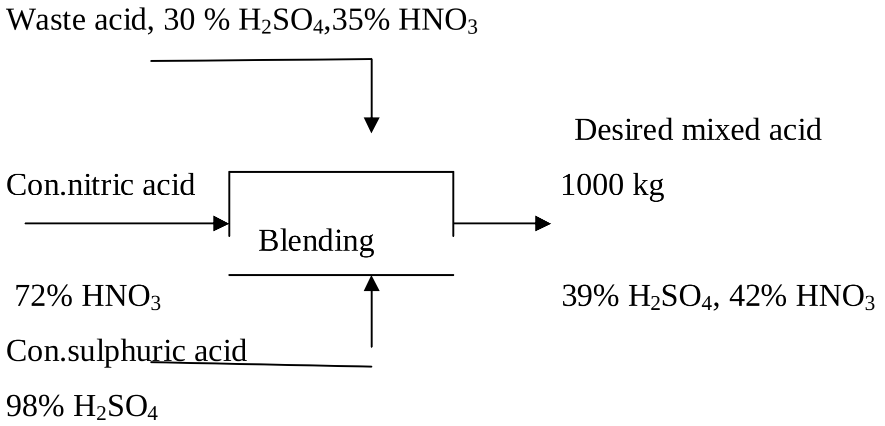
$X_{N2} = 25 /100 = 0.25$

$X_{H2} = 75 /100 = 0.75$ — 1

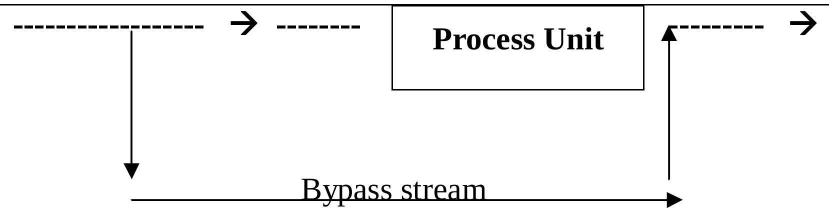
C^o_p mix = $\sum C^o_{p\ mix} . x_i$

$= X_{N2}\, C^o_{p\,N2} + X_{H2}\, C^o_{p\ H2}$ — 2

	$= 0.25 (29.5909 – 5.41 \times 10^{-3} T + 13.1829 \times 10^{-6} T^2 – 4.968 \times 10^{-9} T^3) + 0.75 (28.6105 + 1.0194 \times 10^{-3} T – - 0.1476 \times 10^{-6} T^2 + 0.769 \times 10^{-9} T^3)$	1	
	$= 28.8556 – 0.588 \times 10^{-3} T + 3.185 \times 10^{-6} T^2 – 0.6652 \times 10^{-9} T^3$ Q = Heat transferred $= n \int_{T1}^{T2} C^o_{p\ mix}.\ dT$	1	
	$= n \int_{T1}^{T2} (28.8556 – 0.588 \times 10^{-3} T + 3.185 \times 10^{-6} T^2 – 0.6652 \times 10^{-9} T^3)\ dT$ $= n [28.8556 (T_2 - T_1) – 0.588/2 \times 10^{-3} (T^2_2 – T^2_1)$ $+3.185 \times 10^{-6}/3 (T^3_2 – T^3_1) –0.6652 \times 10^{-9}/4 (T^4_2 – T^4_1)]$ Where ,n = 15 kmol / h , T_1 = 298 K , T_2 = 473 K.	2	
	$Q = 15 [28.8556 (473 – 298) – 0.5207/2 \times 10^{-3} (473^2 – 298^2)$ $+ \frac{3.185 \times 10^{-6}}{3} (473^3 -298^3) – \frac{0.6652 \times 10^{-9}}{4} (473^4 -298^4)]$	1	

	$= 15 (5049.73 – 35.13 + 84.25 - 7.01)$ $= 76377.6$ kJ/h = **21.21 kJ/s = 21.21 kW ….Ans**		
4-c	**SOLUTION :** **BASIS :** 1000 kg of desired mixed acid.		8
		2 1	
	Block diagram for fortifying waste acid with concentrated acids	1	
	Let x, y and z be the kg of waste acid , concentrated sulphuric acid and concentrated nitric acid required to make 1000 kg desired acid. **Overall material Balance:** $x + y + z = 1000$…..(i)	1	
	Material Balance of H_2SO_4 : $0.3 x + 0.98 y = 0.39 x 1000$….(ii)	1	

	$0.3x + 0.98y = 390$	1	
	$Y = (390 - 0.3x) / 0.98$	1	
	$\therefore \quad Y = 397.96 - 0.306x$….(iii)		
	Material Balance of HNO_3 :		
	$0.35x + 0.72z = 0.42 \times 1000$		
	$0.35x + 0.72z = 420$…..(iv)		
	$z = (420 - 0.35x)/ 0.72$		
	$\therefore \quad z = 583.3 - 0.486x$…..(v)		
	Put values of y and z from equations (iii) and (v) in eqn (i) and solve for x.		
	$\therefore \quad x + (397.96 - 0.306x) + (583.3 - 0.486x) = 1000$		
	$\therefore x = 90.1$ kg		
	We have , $y = 397.96 - 0.306x$		
	$= 397.96 - 0.30 \times 90.1$		
	$\therefore y = 370.4$ kg		
	We have , $z = 583.3 - 0.486x$		
	$= 583.3 - 0.486 \times 90.1$		
	$\therefore \ z = 539.5$ kg		
	Amount of waste acid required = 90.1 kg		
	Amount of concentrated sulphuric acid required = 370.4 kg		
	Amount of concentrated nitric acid require = 539.5 kg **….Ans**		
5-a	**Bypass Operation :**		8
	In these operations, a fraction of the feed stream to a process unit is diverted around and combined with the output stream.	2	
	Feed		

		2	
	- Bypassing is practiced industrially whenever accurate control of the composition or concentration of the process exit stream is expected. - The composition and properties of the product may be varied by varying the fraction of the feed that is bypassed.	2	
	Example: A juice concentration process in which the dehydration process runs most efficiently by removing more water than is desired. A portion of the feed may be directed around the dehydrator in a bypass loop, to be mixed with unprocessed feed. **Or** any other example	2	
5-b	**Basis :** 1 mol of C_4H_6 (liq)	1	8
	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	2	
	3. C_4H_6 (liq.) $+ 5.5\ O_2(g) \text{------>} 4CO_2(g) + 3\ H_2O(l)$ $\Delta H^0c = - 2520.11$ KJ/mol		
	4. $4C(s) + 3\ H_2(g) \text{------>} C_4H_6$ (liq.) $\Delta H^0f = ?$		

	ΔH^0f = Standard heat of formation of gaseous ethyl alcohol		
	At 2198.15 K		
		2	
	Reaction(4) = 4* Reaction (1) + 3* Reaction (2) – Reaction (3)		
	$\Delta H^0f = 4*\Delta H_1 + 3*\Delta H_2 - \Delta H^0c$		
	$= 4(-393.51) + 3*(-285.83) -(-2520.11)$	2	
	$= (-1547.04) + (-857.49) + 1410.09$		
	= 88.58 KJ/mol		
	ΔH^0f = **88.58 KJ/mol** ------- ans.	1	
5-c	Basis 100 mol of ethylene		8
	Reaction I $C_2H_4 + \frac{1}{2}O_2 \longrightarrow C_2H_4O$		
	Reaction II $C_2H_4 + 3O_2 \longrightarrow 2CO_2 + 2H_2O$	2	
	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		
	$= \frac{1}{1} \times 80 = 80$Kmol	1	
	From reaction II		
	2kmol of CO_2 formed≡ 1Kmol C_2H_4 reacted		
	∴ C_2H_4 reacted to form 10 kmol CO_2		
	$= \frac{1}{2} \times 10 = 5$Kmol	1	
	∴ C_2H_4 totally reacted = 80 + 5= 85		
	∴ % conversion of $C_2H_4 = \frac{85}{100} \times 100$		
		2	

	= **85%** % yield of $C_2H_4O = \frac{80}{85} \times 100$ = **94.12%**	2	
6-a	**General Material Balance Procedure** 1) Assume Suitable Basis of calculation. 2) Adopt weight basis for without chemical reactions and molar basis for with 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. 5) Search out unknown and ascertain them and Calculate it by generating and solving material balance equations. 6) In case of material balance with chemical, write balance chemical reaction and search out limiting component. 7) In with chemical reaction, the quantity of a reacting component appearing in the product stream is the quantity of that material remains unreacted. 8) Supplied quantity of an excess reactant calculated from the theoretical requirement is based on the quantity of a limiting reactant fed.	½ marks each	4
6-b	**Basis :** 1 Kmol of ammonia gas Heat need = Q $= n [C^o pm_2(T_2-T_0) – C^o pm_1(T_1-T_0)]$	1	4

	Where , n=1 kmol, T_0=298K, T_2=422 K, T_1=311 K $C^o pm_1$= 35.8641 KJ/(kmol.K) $C^o pm_2$=37.7063 KJ/(kmol.K) Q = 1 [37.7063(422-298) – 35.8641(311-298)] Q = **4209.35 KJ ……….** Ans.	1 1 1	
6-c	**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 : 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 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 Total moles of product stream = (60-X) + (30-0.5X) + 10=0.5X = 100 –X Kmol	1 1	4

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<td>
Mole % of A in product stream = 2%

$$\text{Mole \% of A} = \frac{\text{Kmol A in product stream}}{\text{Total kmol of product stream}} * 100$$

$$2 = \frac{60 - X}{100 - X} * 100$$

X = 59.184 kmol = amount of A reacted

$$\text{Conversion of A} = \frac{\text{Kmol A reacted}}{\text{Total kmol of A feed}} * 100$$

$$\text{Conversion of A} = \frac{59.184}{60} * 100 = \mathbf{98.64\ \%}$$ **------Ans (i)**
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1</td>
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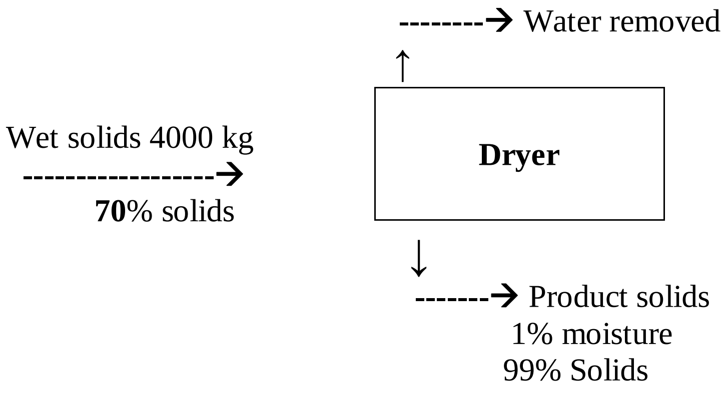
<td>6-d</td>
<td>
Basis : 4000 Kg of wet solids fed to dryer.



Let X be the kg of product obtained and Y be the kg of water removed.

Moisture in product = 1%

Solids in product = 100 – 1 = 99 %
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	Material Balance of Solids: Solids in wet solids = Solid in Product $0.7 * 4000 = 0.99 X$ $X = 2828.28$ Kg of Product Obtained	1	
	Overall Material Balance : $4000 = X + Y$ $Y = 4000 – 2828.28 = 1171.71$ Kg of Water Removed	1	
	Product Obtained = 2828.28 Kg **Water Removed = 1171.71 Kg**	1	
6-e	**Basis:** 1 Kmol of Methane gas Q= Heat added		4
	$= n\int_{T_1}^{T_2} Cp\, dT$	1	
	$= n\int_{T_1}^{T_2} [19.2492 + 52.1135 \times 10^{-3} T + 11.973 \times 10^{-6} T^2]\, dT$ $= n [19.2492 (T_2 – T_1) + 52.1135 \times 10^{-3}(T^2_2 – T^2_1) + 11.973 \times 10^{-6} (T^3_2 – T^3_1)]$	1	
	Where $n = 1$ kmol, $T_2 = 523$ K, $T_1 = 298$ K $= 1 [19.2492 (523 – 298) + 52.1135 \times 10^{-3} /2 (523^2 – 298^2) + 11.973 \times 10^{-6}/3 (523^3 – 298^3)]$ $= 1 [4331.1 + 4813.33 + 465.31]$	1	
	Q = 9609.74 KJ --------------- Ans.	1	

6-f	**Basis :** 75 kmol of SO_2 and 200 Kmol air entering the reactor		4
	Reaction:		
	$SO_2 + \frac{1}{2} O_2 \dashrightarrow SO_3$	1	
	Air used = 200 kmol		
	O_2 in supplied air = 200 * 0.21=42 kmol		
	From reaction,		
	1 kmol $SO_2 \equiv$ 0.5 kmol O_2		
	Theoretical requirement of O_2 for 75 kmol SO_2	1	
	$= \frac{0.5}{1} * 75 = 37.5 \text{ kmol}$		
	$\% \text{ excess } O_2 \text{ used} = \frac{O_2 \text{ in supplied air} - O_2 \text{ Theoretical required}}{O_2 \text{ Theoretical required}} \times 100$	1	
	$= \frac{42 - 37.5}{37.5} \times 100 = 12\%$	1	
	% excess O_2 used = 12 % ----------- Ans.		