

Soln m- QP Code - 21504

Sem III - Chemical Engg - Process Calculations

Q1(b)

Solution: Basis: 500 ml of solution.

Amount of caustic soda dissolved = 20 g

Molecular weight of NaOH = 40

Equivalent weight of NaOH =  $\frac{40}{1} = 40$

Volume of the solution = 500 ml = 0.5 l

Gram-equivalents of NaOH =  $\frac{20}{40} = 0.5 \text{ g.eq}$

$$\therefore \text{Normality (N)} = \frac{\text{g-eq of NaOH}}{\text{Volume of solution in l}} = \frac{0.5}{0.5} = 1$$

$$\text{Moles of NaOH} = \frac{20}{40} = 0.5 \text{ mol}$$

$$\therefore \text{Molarity (M)} = \frac{\text{moles of NaOH}}{\text{Volume of solution in l}} = \frac{0.5}{0.5} = 1$$

Q1(c)

Q1(c): Crude oil is analysed to contain 87% carbon and 13% hydrogen by weight. Calculate the net calorific value of the crude oil.

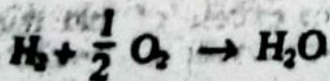
Gross calorific value of crude oil at 298 K (25°C) = 45071 kJ/kg

Latent heat of water vapour at 298 K (25°C) = 2447.8 kJ/kg

Basis: 1 kg of crude oil.

0.87 kg carbon and 0.125 kg hydrogen.

Hydrogen burnt = Hydrogen in crude oil = 0.125 kg



1 kmol H<sub>2</sub> = 1 kmol H<sub>2</sub>O

2 kg of H<sub>2</sub> = 18 kg of H<sub>2</sub>O

$$\text{Water produced} = \frac{18}{2} \times 0.125 = 1.125 \text{ kg}$$

Latent heat of water vapour at 298 K (25°C) = 2447.8 kJ/kg

Net calorific value = Gross calorific value - Latent heat of water vapour

$$= 45071 - 2747.8 = 42323.2 \text{ kJ/kg}$$



NCV of ...

Q 1

$$\begin{aligned} \text{NCV} &= \text{GCV} - \frac{\% \text{ hydrogen by wt} \times 9 \times \lambda}{100} \\ &= 45071 - \frac{12.5 \times 9 \times 2442.5}{100} \end{aligned}$$

Q 2 (a)

$$\begin{aligned} \therefore \text{gram-equivalents of } \text{H}_2\text{SO}_4 &= \text{Normality} \times \text{Volume of solution} \\ &= 1 \times 0.5 = 0.5 \text{ g eq} \end{aligned}$$

$$\text{Molecular weight of } \text{H}_2\text{SO}_4 = 98$$

$$\therefore \text{Equivalent weight of } \text{H}_2\text{SO}_4 = \frac{98}{2} = 49$$

Amount of  $\text{H}_2\text{SO}_4$  required for 1 normal solution

$$= 0.5 \times 49 = 24.5 \text{ g}$$

$$\text{Molarity of the solution} = \frac{\text{gram moles of } \text{H}_2\text{SO}_4}{\text{Volume of solution in litre}}$$

$$\begin{aligned} \therefore \text{Moles of } \text{H}_2\text{SO}_4 &= \text{Molarity} \times \text{Volume of solution} \\ &= 1 \times 0.5 = 0.5 \text{ mol} \end{aligned}$$

Amount of  $\text{H}_2\text{SO}_4$  required to make 1 molar solution

$$= 0.5 \times 98 = 49 \text{ g}$$

Let x be the quantity in grams of  $\text{H}_2\text{SO}_4$  required for making 1 molal solution.

$$\text{Density of the solution} = 1.075 \text{ g/cm}^3$$

$$\text{Quantity of the solution} = 500 \times 1.075 = 537.5 \text{ g}$$

$$\text{grams of the solvent} = \text{grams of solution} - \text{grams of solute} = 537.5 - x$$

$$\text{Weight of solvent} = (537.5 - x) \times 10^{-3} \text{ kg}$$

$$\text{Molecular weight of } \text{H}_2\text{SO}_4 = 98$$

$$\text{Moles of } \text{H}_2\text{SO}_4 = \frac{x}{98} \text{ mol}$$

$$\text{Molality of the solution} = \frac{\text{gram moles of solute}}{\text{Weight of solvent in kg}}$$

$$\therefore 1 = \frac{x/98}{(537.5 - x) \times 10^{-3}}$$

$$\text{Solving, we get } x = 58.3 \text{ g}$$

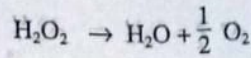
$$\text{Amount of } \text{H}_2\text{SO}_4 \text{ required for preparing 1 molal solution} = 58.3 \text{ g}$$



**Solution:** As per the data provided, it liberates 60 l of  $O_2$  at 101.325 kPa and 289 K.

$$\begin{aligned} \text{Moles of } O_2 \text{ liberated} = n &= \frac{PV}{RT} \\ &= \frac{101.325 \times 60}{8.31451 \times 289} \\ &= 2.53 \text{ mol} \end{aligned}$$

Oxygen liberation reaction is



From the reaction :

$$1 \text{ mole } H_2O_2 \equiv 0.5 \text{ mole } O_2$$

i.e., to liberate 0.5 moles of  $O_2$ , 1 mole of  $H_2O_2$  is required.

$$\begin{aligned} \left[ \text{Moles of } H_2O_2 \text{ required for} \right. \\ \left. \text{liberation of 2.53 mol } O_2 \right] &= \frac{1}{0.5} \times 2.53 \\ &= 5.06 \text{ mol} \end{aligned}$$

$$\text{Molecular weight of } H_2O_2 = 34$$

$$\text{Amount of } H_2O_2 \text{ in the solution} = 5.06 \times 34 = 172.22 \text{ g}$$

$$\text{Density of the solution} = 1.075 \text{ kg/l} = 1075 \text{ g/l}$$

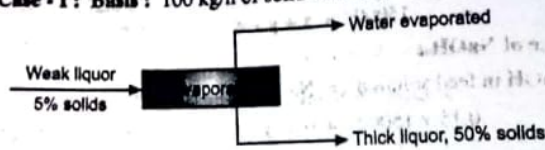
$$\text{Amount of the solution} = 1075 \times 1 = 1075 \text{ g}$$

$$\begin{aligned} \text{Weight \% } H_2O_2 \text{ in the solution} &= \frac{172.22}{1075} \times 100 \\ &= 16.02 \end{aligned}$$

... A

**Q 2 (a)**  
Take an overall material balance and a material balance on water. get  $x$  and  $y$  known. With the help of  $x_1$  or  $y_1$ , obtain the solid handling capacity in the case-II.

**Solution : Case - I :** Basis : 100 kg/h of solid handling capacity of the evaporator.



**Fig. Ex 3.4 :** Block diagram for evaporation system

Let  $x$  be the kg/h of weak liquor then we have,

$$0.05 x = 100$$

$$x = 2000 \text{ kg/h}$$

Let  $y$  be the kg/h of thick liquor then we have,

$$0.5 y = 100$$

$$y = 200 \text{ kg/h}$$

**Overall Material Balance :**

$$\text{kg/h weak liquor} = \text{kg/h thick liquor} + \text{kg/h water evaporated}$$

$$2000 = 200 + \text{kg/h water evaporated}$$

$$\text{Water evaporated} = 1800 \text{ kg/h}$$

Water evaporation capacity in case-II i.e. in the process of concentration of solids from 5% solids to 35% solids is the same as in case-I, i.e., 1800 kg/h.

**Case - II :** Basis : 1800 kg/h water evaporated.

**Q 3 (a)**  
Put the value of  $x_1$  from equation (2) in equation (1) and solve for  $y_1$ .

$$8.75 y_1 = y_1 + 1800$$

$$y_1 = 232.26 \text{ kg/h}$$

We have,

$$x_1 = y_1 + 1800 = 232.26 + 1800 = 2032.26 \text{ kg/h}$$

$$\text{Solids in weak liquor} = 0.04 \times 2032.26 = 81.3 \text{ kg/h}$$

$$\therefore \text{Solid handling capacity in case-II} = 81.3 \text{ kg/h}$$



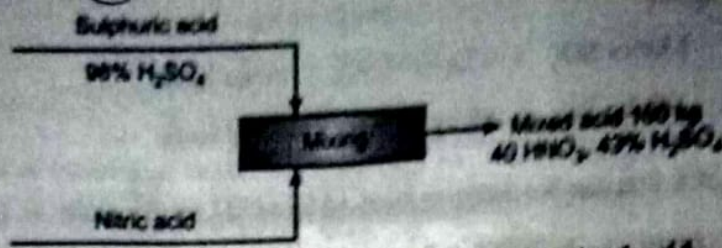


Fig. Ex 3.11 : Block diagram for making mixed acid

Let  $x$  and  $y$  be the kg of sulphuric acid and nitric acid required to make 100 kg mixed acid.

Material Balance of  $H_2SO_4$  :

$$0.43 \times 100 = 0.98 x$$

$$x = 43.88 \text{ kg}$$

Overall Material Balance :

$$x + y = 100$$

$$43.88 + y = 100$$

$$y = 56.12 \text{ kg}$$

$HNO_3$  in the mixed acid should come from the nitric acid used for preparing

$$HNO_3 \text{ in nitric acid} = HNO_3 \text{ in mixed acid} = 40 \text{ kg}$$

$$\text{Strength of nitric acid in wt. \%} = \frac{\text{kg } HNO_3 \text{ in nitric acid}}{\text{kg nitric acid}} \times 100$$

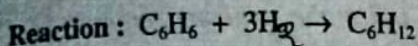
$$= \frac{40}{56.12} \times 100 = 71.27$$

Weight ratio of sulphuric acid to nitric acid

$$= \frac{x}{y} = \frac{43.88}{56.12} = 0.782 \text{ kg/kg}$$

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Solution : Basis : 100 kmol of cyclohexane.



Cyclohexane produced = 100 kmol

From the reaction : 1 kmol  $C_6H_6 \equiv$  1 kmol  $C_6H_{12}$

i.e., 1 kmol  $C_6H_{12}$  needs 1 kmol  $C_6H_6$  to be reacted/hydrogenated.

$$C_6H_6 \text{ reacted to } C_6H_{12} = \frac{1}{1} \times 100 = 100 \text{ kmol}$$

$$\% \text{ yield of cyclohexane} = \left( \frac{\text{kmol } C_6H_6 \text{ reacted to produce } C_6H_{12}}{\text{kmol } C_6H_6 \text{ totally reacted}} \right) \times 100$$

$$90 = \left( \frac{100}{\text{kmol } C_6H_6 \text{ totally reacted}} \right) \times 100$$

$$\text{Moles of } C_6H_6 \text{ totally reacted} = \frac{100 \times 100}{90} = 111.11 \text{ kmol}$$

$$\% \text{ conversion of } C_6H_6 = 50$$



$$\% \text{ conversion of } C_6H_6 = \left( \frac{\text{kmol } C_6H_6 \text{ totally reacted}}{\text{kmol } C_6H_6 \text{ charged}} \right) \times 100$$

$$50 = \left( \frac{111.11}{\text{kmol } C_6H_6 \text{ charged}} \right) \times 100$$

$$\therefore \text{Moles of } C_6H_6 \text{ charged} = \frac{100 \times 111.11}{50} = 222.22 \text{ kmol}$$

... Ans. (a)

From the reaction, 1 kmol of  $C_6H_6 \equiv 3$  kmol  $H_2$

Theoretical requirement of hydrogen gas

$$= \frac{3}{1} \times 222.22 = 666.66 \text{ kmol}$$

$$H_2 \text{ supplied} = \text{Theoretically required } H_2 \left[ 1 + \frac{\% \text{ excess}}{100} \right]$$

$$= 666.66 \left[ 1 + \frac{30}{100} \right] = 866.66 \text{ kmol}$$

$$\text{Requirement of benzene} = 222.22 \text{ kmol}$$

$$\text{Requirement of hydrogen gas} = 866.66 \text{ kmol}$$

... Ans. (b)

The quantity of  $H_2$  is calculated based on the % excess of  $H_2$  required as per hexane formation reaction.)

For the  $C_{pm}^\circ$  data of the components, the standard heat of reaction at any temperature given by

$$\Delta H_{RT}^\circ = \Delta H_o^\circ + \Delta C_{pm}^\circ T$$

$$\Delta C_{pm}^\circ = \sum (n_i C_{pmi}^\circ)_{\text{products}} - \sum (n_i C_{pmi}^\circ)_{\text{reactants}}$$

where  $n_i$  is the stoichiometric coefficient of  $i^{\text{th}}$  component.

$n$  for  $C_5H_{12} = 1$ ,  $n$  for  $O_2 = 8$ ,  $n$  for  $CO_2 = 5$  and  $n$  for  $H_2O = 6$

$$\begin{aligned} \Delta C_{pm}^\circ &= [5 \times 52.32 + 6 \times 38.49] - [1 \times 247 + 8 \times 33.62] \\ &= -23.42 \end{aligned}$$

$$\Delta H_{RT}^\circ = \Delta H_o^\circ - 23.42 T \quad \dots \text{ in J/mol}$$

To evaluate the value of  $\Delta H_o^\circ$ , substitute  $T = 298$  K and  $\Delta H_{RT}^\circ = \Delta H_{298}^\circ$  in the equation.  $C_{pm}^\circ$  data are in J/(mol·K), so use  $\Delta H_{298}^\circ$  in J/mol.

$$\Delta H_R^\circ = \Delta H_{298}^\circ = -3271.71 \times 10^3 \text{ J/mol}$$

$$-3271.71 \times 10^3 = \Delta H_o^\circ - 23.42 (298)$$

$$\Delta H_o^\circ = -3264.73 \times 10^3 \text{ J/mol}$$

The desired relationship between  $\Delta H_{RT}^\circ$  and  $T$  is

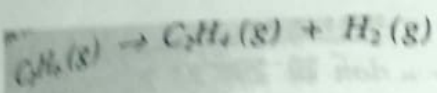
$$\Delta H_{RT}^\circ = -3264.73 \times 10^3 - 23.42 T \quad \dots \text{ in J/mol}$$

To find  $\Delta H_{RT}^\circ$  at  $T = 800$  K, substitute  $T = 800$  K in the above equation

$$\Delta H_R^\circ = \Delta H_{800}^\circ = -3264.73 \times 10^3 - 23.42 (800)$$

$$= -3283.466 \text{ J/mol} = -3283.466 \text{ kJ/mol}$$

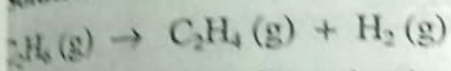
Q 5 (b)



Data :

Component	$\Delta H_c^\circ$ kJ/mol
$C_2H_6(g)$	-1560.69
$C_2H_4(g)$	-1411.2
$H_2(g)$	-285.83

Solution : Basis : 1 mol of ethylene gas produced.



The standard heat of reaction is given by the relation

$$\begin{aligned}\Delta H_R^\circ &= [\sum \Delta H_c^\circ]_{\text{reactants}} - [\sum \Delta H_c^\circ]_{\text{products}} \\ &= [1 \times \Delta H_c^\circ_{C_2H_6(g)}] - [1 \times \Delta H_c^\circ_{C_2H_4(g)} + 1 \times \Delta H_c^\circ_{H_2(g)}] \\ &= [1 \times (-1560.69)] - [1 \times (-1411.2) + 1 \times (-285.83)] \\ &= -1560.69 + 1697.03 \\ &= 136.34 \text{ kJ}\end{aligned}$$

... Ans