

# **NATIONAL INSTITUTE OF TECHNOLOGY**

## **JAMSHEDPUR**

**Metallurgical and Materials Engineering**  
**SUBJECT: Principle of Extractive Metallurgy**

**COURSE CODE: MM1403**

### **ASSIGNMENT**

**TOPIC: NUMERICALS FROM CHAPTERS DAY 8 TO DAY 15**

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## **Numericals from Chapters Day 8 to Day 15**

**Question 1:-** In flash smelting process copper concentrate used has following composition: 66% CuFeS<sub>2</sub>, 24% FeS<sub>2</sub> and 10% SiO<sub>2</sub>. It will form matte as well as slag. According to chemical analysis, slag contains 40% Fe; matte contains 70% Cu, 8% Fe and 22% S. Calculate: Amount of matte produced, Amount of SO<sub>2</sub> formed, Amount of slag formed, Amount of flux and air used.

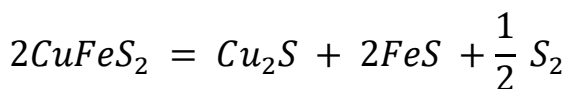
**Solution:-**

Assume 1000 kg of Cu concentrate to be charged.

$$66\% \text{ CuFeS}_2 = 660 \text{ kg of CuFeS}_2$$

$$24\% \text{ FeS}_2 = 240 \text{ kg of FeS}_2$$

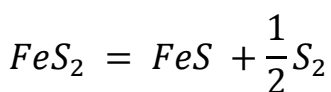
$$10\% \text{ SiO}_2 = 100 \text{ kg of SiO}_2$$



$$2 \times 183.5 \qquad \qquad \qquad 32$$

367 kg of CuFeS<sub>2</sub> forms 32 kg of S

660 kg of CuFeS<sub>2</sub> forms [(32\*660)/367] = 57.55 kg of S

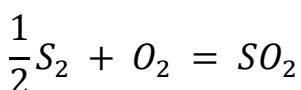


$$(56 + 64) \qquad 32$$

120 kg of FeS<sub>2</sub> forms 32 kg of S

240 kg of FeS<sub>2</sub> forms [(32\*600)/120] = 64 kg of S

Total free S for burning = 57.55 + 64 = 121.55 kg



32 kg of S reacts with 32 kg of Oxygen

121.55 kg of S reacts with [(32\*121.55)/32] = 121.55 kg of Oxygen

367 kg of  $\text{CuFeS}_2$  forms  $(2 \cdot 88)$  kg of FeS

660 kg of  $\text{CuFeS}_2$  forms  $[(2 \cdot 88 \cdot 660)/367] = 316.51$  kg of FeS

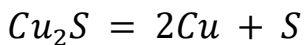
120 kg of  $\text{FeS}_2$  forms 88 kg of FeS

240 kg of  $\text{FeS}_2$  forms  $[(88 \cdot 240)/120] = 176$  kg of FeS

Total FeS =  $316.51 + 176 = 492.51$  kg of FeS

367 kg of  $\text{CuFeS}_2$  forms 159 kg of  $\text{Cu}_2\text{S}$

660 kg of  $\text{CuFeS}_2$  forms  $[(159 \cdot 660)/367] = 285.94$  kg of  $\text{Cu}_2\text{S}$



159  $2 \cdot 63.5$

159 kg of  $\text{Cu}_2\text{S}$  contains 127 kg of Cu

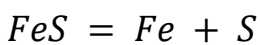
285.94 kg of  $\text{Cu}_2\text{S}$  contains  $[(127 \cdot 285.94)/159] = 228.39$  kg of Cu

Since matte contains 70% Cu

i.e., 70 kg of Cu = 100 kg of matte

228.39 kg of Cu =  $[(100 \cdot 228.39)/70]$  kg of matte = 326.27 kg

Fe presents in matte =  $326.27 \cdot 0.08 = 26.10$  kg



56 + 32 56

88 kg of FeS contains 56 kg of Fe

492.51 kg of FeS contains  $[(56 \cdot 492.51)/88] = 313.42$  kg of Fe

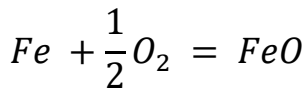
So Fe goes to slag =  $313.42 - 26.1 = 287.32$  kg

Slag contains 40% Fe

i.e., 40 kg of Fe content in 100 kg of slag

287.32 kg of Fe content in  $[(100 \cdot 287.32)/40] = 718.29$  kg of slag

Wt of slag = 718.29 kg



56                      72

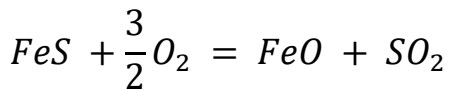
56 kg of Fe forms 72 kg of FeO

287.32 kg of Fe forms  $[(72 \times 287.32)/56] = 369.41$  kg of FeO goes to slag

10% SiO<sub>2</sub> in Cu concentrate = 100 kg of SiO<sub>2</sub>

Total wt of flux = Wt of slag – (wt of FeO + wt of SiO<sub>2</sub>)

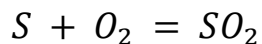
$$= 718.29 \text{ kg} - (369.41 + 100) = 248.88 \text{ kg}$$



56 + 32    22.4

88 kg of FeS forms 22.4 m<sup>3</sup> of SO<sub>2</sub>

492.51 kg of FeS forms  $[(22.4 \times 492.51)/88] = 125.37$  m<sup>3</sup> of SO<sub>2</sub>



32 kg of S by burning forms 22.4 m<sup>3</sup> of SO<sub>2</sub>

121.55 kg of S by burning forms  $[(22.4 \times 121.55)/32] = 85.09$  m<sup>3</sup> of SO<sub>2</sub>

Total SO<sub>2</sub> formed = 125.37 + 85.09 = 210.46 m<sup>3</sup> of SO<sub>2</sub>

**Question 2:- A copper matte contains 30 wt% copper. Calculate the wt% iron and sulphur in it. Assume the matte to be a pure mixture of Cu<sub>2</sub>S and FeS.**

**Solution :**

Cu<sub>2</sub>S contains 2 parts of Cu, i.e.,  $2 \times 63.5 = 127$

Molecular wt. of Cu<sub>2</sub>S =  $2 \times 63.5 + 32 = 159$

127 parts of Cu is present in 159 part of Cu<sub>2</sub>S

30 parts of Cu is present in  $[(159/127) \times 30] = 37.6$  part of  $\text{Cu}_2\text{S}$

Wt% of  $\text{Cu}_2\text{S}$  in matte = 37.6

So FeS in matte =  $100 - 37.6 = 62.4$

Mol. Wt. of FeS =  $56 + 32 = 88$

88 parts of FeS contains 56 parts of Fe

62.4 parts of FeS contains  $[(56/88) \times 62.4] = 39.71$  parts of Fe

Wt% of S =  $100 - (\text{Wt\% Cu} + \text{Wt\% Fe}) = 100 - (30 + 39.71) = 30.29\%$

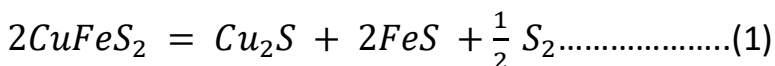
**Question 3:- Find the weight and grade of a matte produced by smelting one tonne of copper-ore containing 25% iron pyrite and 25% chalcopryrite. Assume that only the free atom of sulphur is lost by volatilization.**

**Solution:-**

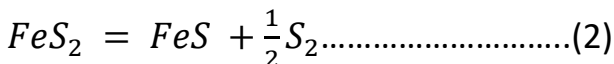
Wt of Cu-ore = 1000kg containing

- 25% of pyrite( $\text{FeS}_2$ ) – 250kg
- 25% of chalcopryrite( $\text{CuFeS}_2$ ) – 250kg

Assuming that only free atom of S is lost by volatilization:



2\*184      160      2\*88



120      88

According to eqn(1):

(1) To find  $\text{Cu}_2\text{S}$ :

2\*184 kg  $\text{CuFeS}_2$  to form 160 kg of  $\text{Cu}_2\text{S}$

250 kg  $\text{CuFeS}_2$  to form  $[(160*250)/(2*184)] = 108.7$  kg of  $\text{Cu}_2\text{S}$

(2) To find FeS:

$2 \times 184$  kg  $\text{CuFeS}_2$  to form 176 kg of FeS

250 kg  $\text{CuFeS}_2$  to form  $[(176 \times 250) / (2 \times 184)] = 119.56$  kg of FeS

According to eqn(2):

(1) To find FeS:

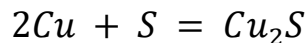
120 kg  $\text{FeS}_2$  to form 88 kg of FeS

250 kg  $\text{FeS}_2$  to form  $[(88 \times 250) / 120] = 183.33$  kg of FeS

Hence total FeS form =  $119.56 + 183.33 = 302.89$  kg

Hence wt of matte = wt of  $\text{Cu}_2\text{S}$  + wt of FeS =  $108.7 + 302.89 = 411.59$  kg

To find the grade of matte:



$$2 \times 64 \quad 2 \times 64 + 32$$

$$128 \quad 160$$

160 kg  $\text{Cu}_2\text{S}$  contains 128 kg of Cu

108.7 kg  $\text{Cu}_2\text{S}$  contains  $[(128 \times 108.7) / 160] = 86.96$  kg of Cu

86.96 kg of Cu presents in  $\text{Cu}_2\text{S}$ , i.e., 411.59 kg of matte

Or 411.59 kg of matte contains 86.96 kg of Cu

100 kg of matte contains  $[(86.96 \times 100) / 411.59] = 21.13$  kg of Cu = 21.13% of Cu.

**Question 4 :- Copper ore contains 20%  $\text{Cu}_2\text{S}$ , 40%  $\text{Fe}_2\text{S}$ , 30%  $\text{SiO}_2$  and 10%  $\text{H}_2\text{O}$ . Ore is roasted using fuel oil which is 5% of charged ore. The roasted ore consists of  $\text{CuO}$ ,  $\text{Fe}_2\text{O}_3$  and  $\text{SiO}_2$ . Oil consists of 85% C and 15%  $\text{H}_2$ .**

**Find out:**

**(1) air used in  $\text{m}^3$  at STP per tonne of ore**

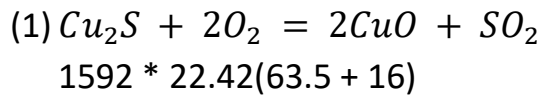
**(2) weight of roasted ore**

**(3) grams of  $\text{H}_2\text{O}$  per  $\text{m}^3$  of fuel gases.**

### Solution:-

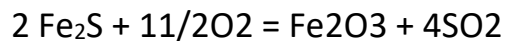
Assume one tonne (1000 kg) of ore.

Oil used 5% of charged ore, i.e.,  $(5/100) * 1000 = 50\text{kg}$



159kg of  $\text{Cu}_2\text{S}$  react with  $(2 * 22.4) \text{ m}^3$  of oxygen

$\{(20/100) * 1000\}$  kg of  $\text{Cu}_2\text{S}$  react with  $[(2 * 22.4)/159] * 200 = 56.35 \text{ m}^3$  of oxygen.



$2(56 + 2*32) \quad 11/2(22.4) \quad 160$

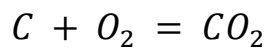
240 kg of  $\text{Fe}_2\text{S}$  react with  $(11/2*22.4) \text{ m}^3 = 123.2 \text{ m}^3$  of oxygen

$\{(40/100)*1000\}$  kg of  $\text{Fe}_2\text{S}$  react with  $\{(123.2*400)/240\} = 205.33 \text{ m}^3$  of oxygen.

Oxygen consumed for roasting =  $56.35 + 205.33 = 261.68 \text{ m}^3$

21 parts of Oxygen in 100 parts of air

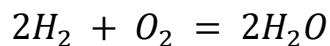
$261.68 \text{ m}^3$  oxygen content in  $[(100*261.68)/21] \text{ m}^3$  of air =  $1246.11 \text{ m}^3$  air required for roasting.



12 22.4

12 kg of carbon burn by  $22.4 \text{ m}^3$  of oxygen

$[(85/100)*50]$  kg of carbon burn by  $[(100*261.68)/21] = 79.33 \text{ m}^3$  of oxygen.



4 22.4 2\*18

4 kg of hydrogen burn by  $22.4 \text{ m}^3$  of oxygen

$[(15/100)*50]$  kg of hydrogen burn by  $[(22.4*7.5)/4] = 42 \text{ m}^3$  of oxygen

Oxygen consumed for burning oil =  $79.33 + 42 = 121.33 \text{ m}^3$  oxygen

21 parts of Oxygen in 100 parts of air

$121.33 \text{ m}^3$  oxygen content  $[(100*121.33)/21] \text{ m}^3$  of air =  $577.76 \text{ m}^3$  of air required for burning oil.

Total air required =  $1246.11 + 577.76 = 1823.87 \text{ m}^3$

$\text{N}_2$  present in air =  $0.79 * 1823.87 = 1440.86 \text{ m}^3$

(2) 159 kg of  $\text{Cu}_2\text{S}$  forms  $(2 \times 79.5)$  kg of  $\text{CuO}$

200 kg of  $\text{Cu}_2\text{S}$  forms  $[(2 \times 79.5) \times 200 / 159] = 200$  kg of  $\text{CuO}$

240 kg of  $\text{Fe}_2\text{S}$  forms 160 kg  $\text{Fe}_2\text{O}_3$

400 kg of  $\text{Fe}_2\text{S}$  forms  $[(160 \times 400) / 240] = 266.67$  kg of  $\text{Fe}_2\text{O}_3$

30%  $\text{SiO}_2$  in ore =  $(30/100) \times 1000 = 300$  kg of  $\text{SiO}_2$

Total weight of roasted ore = wt of  $\text{CuO}$  + wt of  $\text{Fe}_2\text{O}_3$  + wt of  $\text{SiO}_2$   
 $= 200 + 266.67 + 300 = 766.67$  kg

(3) 4 kg of  $\text{H}_2$  burns to form 36 kg of  $\text{H}_2\text{O}$

$[(15/100) \times 50]$  kg of  $\text{H}_2$  burns to form  $[(36 \times 7.5) / 4] = 67.5$  kg of  $\text{H}_2\text{O}$

10%  $\text{H}_2\text{O}$  in ore =  $(10/100) \times 1000 = 100$  kg

Total  $\text{H}_2\text{O}$  present in ore and oil =  $100 + 67.5 = 167.5$  kg

159 kg of  $\text{Cu}_2\text{S}$  forms 22.4  $\text{m}^3$   $\text{SO}_2$

200 kg of  $\text{Cu}_2\text{S}$  forms  $[(22.4 \times 200) / 159] = 28.18$   $\text{m}^3$   $\text{SO}_2$

240 kg of  $\text{Fe}_2\text{S}$  forms  $(4 \times 22.4)$   $\text{m}^3$   $\text{SO}_2$

400 kg of  $\text{Fe}_2\text{S}$  forms  $[(4 \times 22.4 \times 400) / 240] = 149.33$   $\text{m}^3$   $\text{SO}_2$

Vol of  $\text{SO}_2 = 28.18 + 149.33 = 177.51$   $\text{m}^3$

12 kg of C forms 22.4  $\text{m}^3$  of  $\text{CO}_2$

$[(85/100) \times 50]$  kg of C forms  $[(22.4 \times 42.5) / 12] = 79.33$   $\text{m}^3$  of  $\text{CO}_2$

4 kg of  $\text{H}_2$  burns to form  $2 \times 22.4$   $\text{m}^3$  of  $\text{H}_2\text{O}$

$[(15/100) \times 50]$  kg of  $\text{H}_2$  burns to form  $[(2 \times 22.4 \times 7.5) / 4] = 84$   $\text{m}^3$  of  $\text{H}_2\text{O}$

Total fuel gas = vol of  $\text{N}_2$  + vol of  $\text{SO}_2$  + vol of  $\text{CO}_2$  + vol of  $\text{H}_2\text{O}$

$1440.86 + 177.51 + 79.33 + 84 = 1781.7$   $\text{m}^3$

$\text{H}_2\text{O}$  contains per  $\text{m}^3$  of fuel gases =  $(167.5 \times 1000) / 1781.7 = 94.01 \text{ gm} / \text{m}^3$ .

**Question 5:- A lead roasting operation at  $1100^\circ\text{K}$  is proposed with 12%  $\text{SO}_2$  and 4%  $\text{O}_2$  in the roaster gases at 1 atm total pressure. Is lead sulphate the stable solid phase? with 1%  $\text{O}_2$  in the gas, what partial pressure of  $\text{SO}_2$  is necessary to form the lead oxysulphate  $\text{PbSO}_4 \cdot \text{PbO}$  ?**



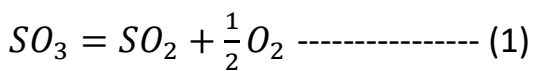
Given: (i)  $SO_3 = SO_2 + \frac{1}{2} O_2$ ,  $k_1 = 0.19$

(ii)  $2PbSO_4 = PbSO_4 \cdot PbO + SO_3$ ,  $\Delta G^\circ_2 = 309,616 + 70.33 T \log T -$

407.52 T J/mol

**Solution:**

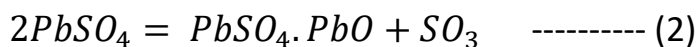
At 1100°K, the equilibrium constant for the reaction:



$$k_1 = \left[ \frac{\left( p_{SO_2} \cdot p_{O_2}^{\frac{1}{2}} \right)}{p_{SO_3}} \right] = 0.19$$

$$p_{SO_3} = \left[ \frac{\left\{ 0.12 \times (0.04)^{\frac{1}{2}} \right\}}{0.19} \right] = 1.01 \times 10^{-3} \times 100 = 0.101 \text{ atm}$$

This pressure can be utilized for comparison with the  $SO_3$  pressure determined for the equilibrium :



$$k_2 = \left[ \frac{(a_{PbSO_4 \cdot PbO} \cdot p_{SO_3})}{(a_{PbSO_4})^2} \right] = p_{SO_3}$$

$$\Delta G^\circ_2 = 309,616 + 70.33 T \log T - 407.52 T \text{ J/mol}$$

$$= 96,635.26 \text{ J/mol (at 1100 K) = -RT ln } k_2$$

$$\ln k_2 = (-96,635.26)/(8.314 \times 1100) = -10.57$$

$$k_2 = 2.57 \times 10^{-5} \text{ atm} = p_{SO_3}$$

This partial pressure of  $\text{SO}_3$  is well below that existing in the roaster gases, and hence,  $\text{PbSO}_4$  is the thermodynamically stable phase.

If the gases contained 1% oxygen, using eqn. (2) the partial of  $\text{SO}_2$  in equilibrium with  $\text{PbSO}_4$  and  $\text{PbO}$  would be:

$$P_{\text{SO}_2} = \left[ \frac{(k_1 \cdot p_{\text{SO}_3})}{(p_{\text{O}_2})^{\frac{1}{2}}} \right] = \left[ \frac{\{0.19 \times (2.57 \times 10^{-5})\}}{(0.01)^{\frac{1}{2}}} \right] = 4.88 \times 10^{-5} \text{ atm}$$

Lead has an extremely strong tendency to react with Sulphur.

**Question 6:-** A Copper ore contains 18%  $\text{Cu}_2\text{S}$  , 55%  $\text{FeS}_2$  , and 27%  $\text{SiO}_2$ . This ore is smelting in a reverbatory furnace using  $\text{CaCO}_3$  as flux. The slag is formed, which contains 35%  $\text{FeO}$ , 20%  $\text{CaO}$  and rest  $\text{SiO}_2$ .

**Calculate:**

- (i) wt. of slag formed
- (ii) wt. of limestone needed
- (iii) wt. of matte

**Solution:**

Assume total charge is 1000 Kg

18%  $\text{Cu}_2\text{S}$  = 180 Kg

55%  $\text{FeS}_2$  = 550 Kg

27%  $\text{SiO}_2$  = 270 Kg

Assume wt. of slag formed = 100 Kg  $\rightarrow$  35%  $\text{FeO}$ , 20%  $\text{CaO}$  and 45%  $\text{SiO}_2$

(i) 45 Kg of SiO<sub>2</sub> present in 100 Kg of slag

270 Kg of SiO<sub>2</sub> present in [(100 x 270)/45] = 600 Kg of slag

(ii) 100 Kg of slag contains 20 Kg CaO

600 Kg of slag contains [(600 x 20)/100] = 120 Kg CaO



According to the above equation:

56 Kg of CaO is formed by 100 Kg of CaCO<sub>3</sub>

120 Kg of CaO is formed by [120 x 100/56] = 214.29 Kg of CaCO<sub>3</sub>

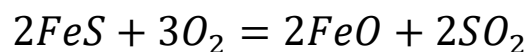
(iii)  $2FeS_2 = 2FeS + S_2$

According to the above equation:

240 Kg of FeS<sub>2</sub> forms 176 Kg of FeS

550 Kg of FeS<sub>2</sub> forms [(176 x 550)/240] = 403.33 Kg of FeS

35% FeO in slag → (600 x 35/100) = 210 Kg of FeO in slag



According to the above equation:

144 Kg of FeO is formed by 176 Kg of FeS

210 Kg of FeO is formed by [(176 x 210)/144] = 256.67 Kg of FeS

FeS remain = 403.33 – 256.67 = 146.66 Kg

Total matte = wt. of  $\text{Cu}_2\text{S}$  + wt. of  $\text{FeS}$  = 180 + 146.66 = 326.66 Kg

**Question 7:-** Find out the % of CO in CO-CO<sub>2</sub> mixture in equilibrium with Fe<sub>2</sub>O<sub>3</sub>

for the reduction of Fe<sub>2</sub>O<sub>3</sub> to Fe<sub>3</sub>O<sub>4</sub> at 1100 K.

**Given: (i)**  $3\text{Fe}_2\text{O}_3 + \text{CO} = 2\text{Fe}_3\text{O}_4 + \text{CO}_2$ ,  $\Delta G^\circ = -37,934.32 - 61.956 T \text{ J}$

**Solution:**

At T = 1100 K

$$\Delta G^\circ = -37,934.32 - 61.956 \times (1100) \text{ J} = -106,085.92 = -RT \ln k$$

$$\ln k = 11.6 \Rightarrow k = 109,089.21 = \left[ \frac{p_{\text{CO}_2}}{p_{\text{CO}}} \right] = (1 - x) / (x)$$

Since  $p_{\text{CO}_2} + p_{\text{CO}} = 1$ , if  $p_{\text{CO}} = x$ , then  $p_{\text{CO}_2} = 1 - x$ ;

$$x = 9.166 \times 10^{-6}$$

$$\text{CO}\% = 9.166 \times 10^{-4} \%$$

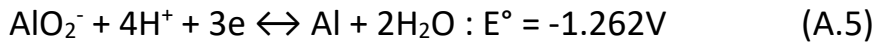
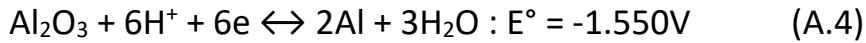
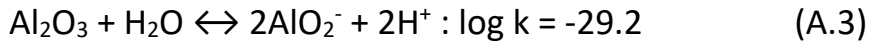
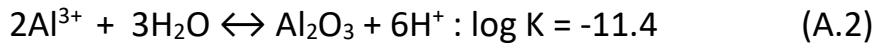
- **Thermodynamic aspects of leaching:-**

Thermodynamic data may be used to predict the general conditions likely to be favourable to the dissolution of a mineral. Appropriate thermodynamic data are succinctly presented in the form of potential/pH diagrams.

- **Construction of a potential/pH or Pourbaix diagram:-**

The aluminium - water system is used as an example to illustrate the construction. The thermodynamic data relating to the appropriate equilibria are as follows:-

Data at 25°C(298K)



For leaching purposes an activity of  $10^{-3} \text{ mol.kg}^{-1}$  for all metal ionic species may be considered to represent a significant concentration of the species in aqueous solution.

Equilibrium (A.1) involves electrons, and the nernst equation is applied

$$E = E^\circ + (RT/Zf)\ln a_{\text{Al}^{3+}}$$

Assuming  $a_{\text{Al}^{3+}} = 10^{-3} \text{ mol.kg}^{-1}$  and substituting numerical values ( $z = 3, T = 298 \text{ etc.}$ )

$$E = -1.663 + \frac{8.314 * 298}{3 * 96470} \ln 10^{-3} = -1.772 \text{ V}$$

Equilibrium (A.2) involves  $\text{H}^+$  ions but not electrons. An expression for the equilibrium constant

is  $K = a_{\text{H}^+}^6 / a_{\text{Al}^{3+}}^2$  from which  $\log K = 6 \log a_{\text{H}^+} - 2 \log a_{\text{Al}^{3+}}$ .

But  $\text{pH} = -\log a_{\text{H}^+}$  hence  $\log K = -6\text{pH} - 2 \log a_{\text{Al}^{3+}}$ . Rearranging and substituting numerical data for  $\log K$  and  $a_{\text{Al}^{3+}}$

$$\text{pH} = 2.9$$

Equilibrium (A.1) is independent of pH and equilibrium (A.2) is independent of potential as shown when the calculated potential and pH values respectively are inserted in the E/pH diagram. Each line is terminated by the other at their intersection.

Equilibrium (A.3) involves  $H^+$  ions but not electrons. An expression for the equilibrium constant is  $K = a_{AlO_2^-}^2 * a_{H^+}^2$  from which

$$\log K = 2 \log a_{AlO_2^-} + 2 \log a_{H^+}$$

But  $pH = -\log a_{H^+}$ , hence  $\log K = 2 \log a_{AlO_2^-} - 2pH$ .

Rearranging and substituting numerical data for  $\log K$  and  $a_{AlO_2^-}$  ( $10^{-3} \text{ mol.kg}^{-1}$ ).

$$pH = 11.6$$

This equilibrium is independent of potential and the pH value can be only tentatively inserted in the diagram because its lower termination point has still to be determined.

Equilibrium (A.4) involves  $H^+$  ions and electrons and is consequently pH and potential dependent. Application of the Nernst equation yields

$$E = E^\circ + \frac{RT}{zF} \ln a_{H^+}^6$$

Which at 298 K becomes

$$E = E^\circ + \frac{0.0591}{z} \log a_{H^+}^6$$

But  $pH = -\log a_{H^+}$ , and substituting  $z = 6$  and  $E^\circ = -1.550 \text{ V}$

$$E = -1.550 - 0.0591 pH$$

Hence at  $pH = 11.6$ , equilibrium (A.4) has a potential of  $-2.236 \text{ V}$ . This value provides the termination point for equilibrium (A.3) and allows the line to be drawn for equilibrium (A.4).

Equilibrium (A.5) involves  $H^+$  ions and electrons, and is consequently pH dependent and potential dependent. Application of the Nernst equation yields

$$E = E^\circ + \frac{RT}{zF} \ln(a_{AlO_2^-} * a_{H^+}^4)$$

Which at 298 K becomes

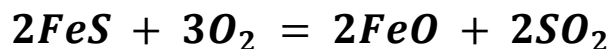
$$E = E^\circ + \frac{0.0591}{z} \log a_{AlO_2} + \frac{0.0591}{z} \log a_H^{4-}$$

But  $pH = -\log a_H^+$ , and substituting  $z = 3$ ,  $E^\circ = -1.262$  V and  $a_{AlO_2^-} = 10^{-3} \text{ mol.kg}^{-1}$

$$E = -1.262 - 0.0591 - 0.079 \text{ pH} = -1.321 - 0.079 \text{ pH}$$

To complete the line for equilibrium (A.5) an appropriate pH value can be substituted in the latter equation. Selecting  $pH = 15$ , its potential co-ordinate is  $E = -1.321 - 0.079 * 15 = -2.506$  V. Insertion of this point on the E/pH diagram allows the line to be constructed and completes the delineation of the domains. The thermodynamically stable species appropriate to each domain. It is customary to superimpose the domain of thermodynamic stability of water.

**Question 8:- Copper converter receives average of 60 tonnes of matte containing 54% FeS. FeS is oxidized by blowing air into converter according to the reaction:**

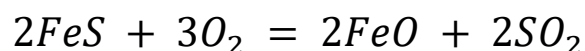


**Find the following:**

- (1) Total volume of air in m<sup>3</sup>**
- (2) Volume of SO<sub>2</sub> formed,**
- (3) Wt of slag formed in tonne, if FeO contribute 65% of slag.**

**Solution:-**

54% FeS in matte =  $(54/100) * 60000 = 32400$  kg of FeS



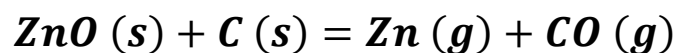
$(2 * 88)$  kg FeS react with  $3 * 22.4$  m<sup>3</sup> Oxygen

(1) 32400 kg FeS reacts with  $[(3 \times 22.4 \times 32400) / (2 \times 88)] = 12370.9 \text{ m}^3$  Oxygen  
 21 parts of oxygen in 100 parts of air  
 12370.9 m<sup>3</sup> oxygen content in  $[(100 \times 12370.9) / 21] = 58909.04 \text{ m}^3$  of air

(2)  $(2 \times 88)$  kg FeS reacts with  $2 \times 22.4 \text{ m}^3 \text{ SO}_2$   
 32400 kg FeS reacts with  $[(2 \times 22.4 \times 32400) / (2 \times 88)] = 8247.27 \text{ m}^3$  of  $\text{SO}_2$   
 $(2 \times 88)$  kg FeS reacts to form  $(2 \times 72)$  kg of FeO  
 32400 kg FeS reacts to form  $[(2 \times 72 \times 32400) / (2 \times 88)] = 26509.09 \text{ kg}$  of FeO

(3) FeO contributes 65% of slag  
 i.e., 65 kg of FeO wt of slag is 100 kg  
 26509.09 weight of slag is  $[(100 \times 26509.09) / 65] = 40783.22 \text{ kg}$  of slag =  
 40.783 tonne of slag

**Question 9:-** The reaction in the zinc retort can be represented by:



The reaction products enter the condenser at 950°C and leave at 450°C.

Assuming equilibrium condensation, estimate the efficiency of zinc recovery in the condenser. The equilibrium partial pressure of zinc over liquid pure zinc is given by:

$$\log p_{\text{mm Hg}} = - \left( \frac{6670}{T} \right) + 12.0 - 1.126 \log T$$

**Solution:**

At 450°C, i.e.,  $(450 + 273) = 723 \text{ K}$

$\log p_{\text{mm Hg}} @ (723 \text{ K}) = -0.44$



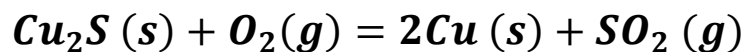
Therefore  $P_{zn} = 0.36$  mm of Hg

Since gases escape at one atm (i.e., 760 mm of Hg), so  $P_{CO} = 760 - 0.36 = 759.64$

So the moles of zinc per mole of CO would be :  $\left[ \frac{0.36}{759.64} \right] = 4.74 \times 10^{-4}$

One mole of zinc is released per mole of CO, so the zinc loss is 0.0474%, i.e., the efficiency of recovery under these conditions would be 99.95%.

**Question 10:-** A copper converter contains 8000 Kg of  $Cu_2S$ , air is passed to oxidize  $Cu_2S$  by the reaction:



**Find the total volume of air used.**

**Solution:**

Mol. Wt. of  $Cu_2S = 2 \times 63.5 + 32 = 159$

159 Kg of  $Cu_2S$  reacts with 22.4 m<sup>3</sup> oxygen

8000 Kg of  $Cu_2S$  reacts with  $[(22.4 \times 8000)/159] = 1127.04$  m<sup>3</sup> oxygen

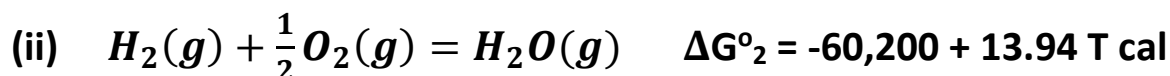
21 parts of oxygen in 100 parts of air

1127 parts of oxygen in  $[(22.4 \times 1127)/21] = 5366.88$  parts (m<sup>3</sup>) of air

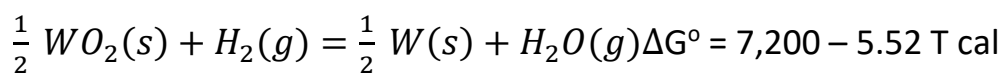
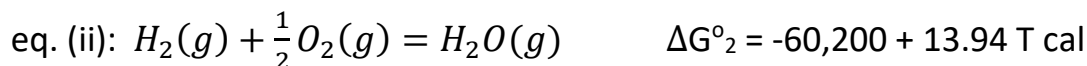
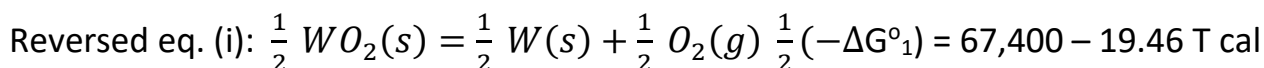
Total air volume = 5366.88 m<sup>3</sup>

**Question 11:- Tungsten dioxide is reduced to metallic tungsten by hydrogen.**

**What is the maximum concentration of water vapour which could be allowed in the reducing atmosphere ?**



**Solution:**



At  $T = 1400 + 273 = 1673 \text{ K}$

$\Delta G^\circ = 7,200 - 5.52 \times (1673) \text{ cal} = -2034.96 \text{ cal} = -RT \ln k$

$\ln k = 2034.96 / (1.98 \times 1673) = 0.614$

$k = 1.85$

$$k = \frac{\left[ \frac{1}{(a_W^{\frac{1}{2}} \cdot p_{H_2O})} \right]}{\left[ \frac{1}{(a_{WO_2}^{\frac{1}{2}} \cdot p_{H_2})} \right]} = \left[ \frac{p_{H_2O}}{p_{H_2}} \right]$$

Since  $p_{H_2O} + p_{H_2} = 1$ , if  $p_{H_2} = x$ , then  $p_{H_2O} = 1 - x$ ;

Therefore,  $k = \left[ \frac{p_{H_2O}}{p_{H_2}} \right] = (1 - x) / (x) = 1.85$

$$1 - x = 1.85x, x = 1/(2.85) = 0.35$$

$$\text{So } p_{\text{H}_2\text{O}} = 0.65$$

Hence 65% water vapour max could be allowed in the reducing atm.