Blast furnace stoichiometry –I

Preamble|

key words: Rist diagram, material balance, stoichiometry

In blast furnace iron oxide +coke + flux are charged from top and air is injected through the tuyeres located near the hearth region.

The gases CO, CO_2,and N_2 leave the furnace through the top. Some amount of carbon in dissolved in iron. Pig iron and slag leave the bottom.

Under simplified conditions, one can derive equation to represent stoichiometry in blast furnace on a diagram. Such diagram is called RIST diagram.

Stoichiometry in blast furnace:

Following assumptions are made:

i) iron of iron ore enters in hot metal (or pig iron)

ii) Oxygen enters through air blast and oxides of iron.

iii) Carbon enters through coke.

Consider 1 mole of iron

$$n_{Fe}^{i} = n_{Fe}^{o} = 1 \qquad (1)$$

$$n_{c}^{i} = n_{c}^{o} \qquad (2)$$

$n_{Fe}^{i}, n_{Fe}^{o} =$ Number of moles of iron entering and leaving the furnace

$n_{c}^{o} =$ Number of moles of carbon in gas phase + number of moles of carbon in Fe

$$n_{c}^{o} = (n_c)_g + \left(\frac{c}{Fe}\right)^{m.} \qquad (3)$$

By 2 and 3

$$n_c^i = (n_c)_g + \left(\frac{c}{Fe}\right)^m \quad (4)$$

Similarly oxygen balance

$$n_O^i = n_o^o \quad (5)$$

$n_O^i =$ Number of moles of oxygen entering

$$= (n_o)_B + \left(\frac{O}{Fe}\right)^X \quad (6)$$

Where $(n_o)_B$ moles of O_2 entering through air and $\left(\frac{O}{Fe}\right)^X$ moles of oxygen with Fe_2O_3 or Fe_3O_4 as the case may be

Since all oxygen leaves as CO or CO_2

$$n_o^i = n_o^o = (n_c)_g \times \left(\frac{O}{C}\right)g \quad (7)$$

By 6 and 7.

$$(n_o)_B + \left(\frac{O}{Fe}\right)^X = (n_c)_g X \left(\frac{O}{C}\right)g \quad (8)$$

$\left(\frac{O}{Fe}\right)^X$ and $\left(\frac{O}{C}\right)$ depends on incoming iron oxide and outgoing gases, for example

$\left(\frac{O}{Fe}\right)^X = 1.5$ in Fe_2O_3 .

Of the total carbon charged in the blast furnace a fraction reacts with oxygen and this carbon is called active carbon (n_A^C)and the rest fraction dissolves in iron and this carbon is termed as inactive carbon $; i.e. \left(\frac{C}{Fe}\right)^m$. In equation 8 (n_g^C) corresponds to the carbon which has reacted with oxygen and exited the furnace; and hence equal to (n_A^C). With this argument equation 8 modifies to

$$(n_o)_B + \left(\frac{O}{Fe}\right)^X = n_c^A \left(\frac{O}{C}\right)g \qquad (9)$$

Note that $n_c^A = n_i^c - \left(\frac{c}{Fe}\right)^m$

llustration of the above concepts

Calculate top gas composition for an ideal gas blast furnace operating with a mixture of Fe_2O_3 and coke. Coke is 90%C and is consumed at the rate $475kg \mid ton$ of iron.Oxygen is introduced at the rate of $350kg/1000kg$ iron. Hot metal has $4.5\%C.$

Blast in traduces oxygen at $350kg/1000kg$ iron. Hot metal has $4.5\%C.$

Basis of calculation $= 1000$ kg iron or 17.9 kg moles.

In $Fe_2O_3 \left(\frac{O}{Fe}\right)^X = 1.5$

Note that hot metal has $95.5\ \%$ Fe and 4.5%C

In hot metal $C = 47$ kg $\therefore \left(\frac{c}{Fe}\right)^m = 0.219$

In Coke: carbon $= 428$ kg, and hence $n_c^i = 35.6$ kg moles/ton Fe

Active carbon $n_c^A = 1.77$

Oxygen from blast $n_o^B = 1.22$ kg atams /moles of Fe

By using equation 9 we get

$$\left(\frac{O}{C}\right)g = 1.54$$

$$\times_{CO_2}^g = \left(\frac{O}{C}\right)^g - 1$$

$$\times_{CO}^g = 2 - \left(\frac{O}{C}\right)^g$$

$\times_{CO_2}^g$ and $\times_{CO}^g$ are mole fraction of CO_2 and CO.

Moles of

$$n^{g}_{CO_2} = n^{A}_{c} \times \left(\times^{g}_{CO_2}\right) = 0.96 \text{ moles / mole of Fe}$$

$$n^{g}_{CO} = n^{A}_{c} \times \left(\times^{g}_{CO}\right) = 0.81 \text{ mole / mole of Fe}$$

$$N_2 = \frac{0.79}{0.21} \times \frac{1}{2} \times 1.22 = 2.29 \text{ mole / mole of Fe}$$

Top gas composition: $20.0 \text{ vol \% CO}$

$23.6 \text{ vol \% } CO_2$

$56.4 \text{ vol \% } N_2$

Graphical representation of stoichiometric balance equation writing equation 9 as:

$$\left(\frac{O}{Fe}\right)^{x} - \left(-n^{O}_{B}\right) = n^{A}_{C}\left\{\left(\frac{O}{C}\right)g - o\right\} \qquad (10)$$

$\frac{O}{Fe}$ and n^{O}_{B} are atoms of oxygen /mole of iron.

Equation 10 is equivalent to

$$Y_2 - Y_1 = M\{(X_2 - X_1)\}$$

The equation 11 is straight line of slope M passing through $x_1 Y_1$ and $x_2 Y_2$

Thus we can plot $(O\,|Fe)^{x}$ vs $(O/C)_g$, which give a straight line with slope (n^{A}_{c}). This plot is shown in figure 31.1

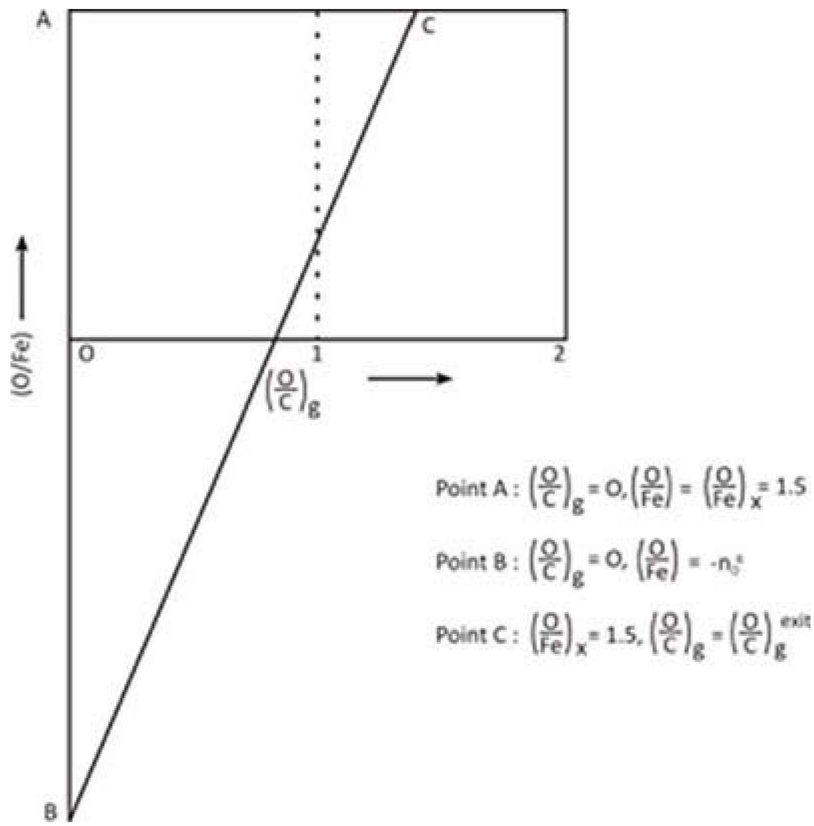

Figure 31.1 : Plot of $(O/Fe)^x Vs (O/C)_g$. The slope of the line is n_c^A.

In the figure $(O/Fe)^x$ is equal to 1.5 for Fe_2O_3. This point is fixed on the ordinate as shown by A. point B on the ordinate is $-n_B^O$ according to equation 10. X-axis is $(O/C)_g$.

Exit gas composition varies in between CO and CO_2, that is $\left(\frac{O}{C}\right)_g - 1$ and 2.

Point C is $(O/C)_g$ at $(O/Fe)^x = 1.5$

Illustration- 2

The exit gas composition from a Fe_2O_3 charged furnace is $24\ \text{vol}\ \%\ CO, 22\ \text{VOl}\ \%\ CO_2.54\%N_2$. The air blast is $1400\ m^3/1000\ kg$ of product Fe. The hot metal contains $5\%\ C$. Calculate

a) Quantity of active carbon in kg | ton Fe

b) Total carbon in kg

Solution

We know

$$n_O^B + \left(\frac{O}{Fe}\right)^x = n_C^A \left(\frac{O}{C}\right)_g \qquad (1)$$

Oxygen from blast $= 13.125\ kg$ moles .

$\therefore\ n_O^B = 1.466$ oxygen atom /mole Fe.

$$\frac{x_{CO}}{x_{CO_2}} = \frac{2-\left(\frac{O}{C}\right)_g}{\left(\frac{O}{C}\right)_g - 1} \qquad (2)$$

We get $\left(\frac{O}{C}\right)_g = 1.476$.

Substituting the value of $n_O^B, \left(\frac{O}{Fe}\right)^x$ and $\left(\frac{O}{C}\right)_g$ in equation 1 we get

$n_C^A = 431\ kg$

$nc_i = n_C^A + \left(\frac{C}{Fe}\right)_m$

C in $kg = 484$

Alternatively one can plot $(O/Fe$) against $\left(\frac{O}{C}\right)_g$.

$\left(\frac{O}{Fe}\right)^x = 1.5$ and $\left(\frac{O}{C}\right)_g = 0. \left(\frac{O}{Fe}\right)^x = -n_O^B$.

At $\left(\frac{O}{Fe}\right)^Y = 1.5, \left(\frac{O}{C}\right)_g = 1.476$

The straight line gaining the values of $-n_O^B$ and $(O/C)_g$ is the operating line of the furnace. Its slope is n_C^A

Plot yourself as an exercise.