Preamble

In lecture 31 a simplified material balance is considered for ironmaking blast furnace and the results of material balance formulation are presented in the form RIST diagram.. In that it is considered that charge consists of pure iron oxide and coke and the product is hot metal containing carbon only. We have not considered heat balance for that simple case.

This lecture considers heat balance in terms of heat input and output. Heat input is required to meet the thermal demand of the process of ironmaking. Heat demand of the blast furnace is met principally by the combustion of coke. In the calculations of coke rate, it is therefore necessary to consider the heat requirements. In the following we will be considering a simplified case in which pure oxide is a source of iron supply and coke is the source of carbon to illustrate the concept. This means that slag formation in this simplified case does not occur.

Enthalpy balance in blast furnace

Consider a case where input is pure Fe_2O_3 (in reality iron ore is charged)and carbon (actually coke is used) at 298 K. Air is supplied at 298 K (in reality air is preheated). Hot metal is considered to be a molten mixture of iron and carbon and exits at $1800K$. At the moment we exclude slag formation. Top gas leaves at 298 K (this is an ideal case to explain the concept).

Enthalpy balance

Enthalpy into furnace per mole of product Fe=Enthalpy out of furnace per mole of product Fe.

$$n_{Fe_2O_3} \times H^o_{298, \atop Fe_2O_3} = H^o_{1800 \atop Fe(l)} + n^g_{CO}.H^o_{298} + n^g_{CO_2}H^o_{298} \qquad (1)$$

,Where

$n_{Fe_2O_3}, n^g_{CO}$ and $n^g_{CO_2}$ are moles of iron oxide, CO and CO_2 respectively |moles of product iron or

Or

$$n_{Fe_2O_3} \times \left(-H^o_{298 \atop Fe_2O_3} \right) + H^o_{1800 \atop Fe l.} = n^g_{CO}(-H^o_{298}) + n^g_{CO}(-H^o_{298}) \qquad (2)$$

Heat demand   **Heat supply**

Negative sign in equation 2 indicates that heat is produced. In the equation 2 heat is required to raise the temperature of hot metal from 298K to 1800K. Heat of formation of Fe_2O_3, CO and **CO₂** is given below:

$$H^o_{298}(Fe_2O_3) = H^f_{298} = -826000 \; kj|kg \, moleFe_2O_3$$

$$H^o_{298}(CO_2) = H^f_{298} = -394000 \; kj|mole \, CO_2$$

$$H^o_{298}(CO) = H^f_{298} = -111000 \; kj \, |kg \, mole \, CO$$

$$H^o_{1800}(Fe_l) = \left[\underset{\substack{Fe\,(l)}}{H^o_{1800}} - H^o_{298} \, Fe(s)\right] = 73000 \; kj \mid kg \, mole \, Fe$$

Substituting the values in equation 2 we get

$$n_{Fe_2}O_3 \times 826000 + 73000 = n^g_{CO} \, 111000 + n^g_{CO_2} \, 394000 \tag{3}$$

It is shown in lecture 31 that

$$n^g_{CO} = n^g_C \, X^g_{CO} = n^A_C \left(2 - (^O/_C)g\right) \tag{4}$$

$$n^g_{CO_2} = n^g_C \, X^g_{CO_2} = n^A_C \left(\left(\tfrac{O}{C}\right)_g - 1\right) \tag{5}$$

$$n_{Fe_2}O_3 = \tfrac{1}{2} \left(\text{one mole of Fe requires } ^1/_2 \text{ mole of } Fe_2O_3\right)$$

By equation 3 4 5 and noting $n_{Fe_2}O_3 = {}^1/_2$

$$\tfrac{1}{2}.826000 + 73000 = n^A_C \left\{283000 \left(\tfrac{O}{C}\right)^g - 172000\right\} \tag{6}$$

The eq. 6 is in terms of kj /kg mole of product iron.

Eq. 6 is a simplified approach. It considers heat demand for hot metal only. In reality one has to consider heat demand for slag formation, decomposition of limestone, heat of mixing etc.The heat demand terms can be added simply on the left hand side of the equation 6

Left hand side of eq. 6 is heat demand (D) which is a variable; variable because it may vary from furnace to furnace type of charge etc. Thus equation 6 is

$$D = n_c^A \left\{ 283000 \left(\frac{O}{C}\right)^g - 172000 \right\}$$

D= heat demand of the process /kg mole of iron produced.

Illustration of the concept

The CO / CO_2 in top gas leaving a hematite changed BF is ≈ 1. The carbon supply rate (incluing C in PI 5Wt.%) is 500 kg /ton of product iron. What is the enthalpy supply to the furnace (kj/kg mole of pnduct Fe) assuming blast and top gas leave at $298\ K$

Enthalpy supply $= n_c^A \left\{ 283000 \left(\frac{O}{C}\right)^g - 172000 \right\}$

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

$$\left(\frac{O}{C}\right)_g = 1.5$$

$n_c^i = 2.33$ and $\left(\frac{C}{Fe}\right)_m = 0.025$

$n_c^A = 2.33 - 0.25 = 2.08$

Enthalpy supply = **525200kj/g mole.**

Illustration 1

Equation 6 considers pure Fe as liquid product. On the demand side we can add more terms depending on the conditions.

a) Calculate heat demand kj /kg mole Fe when pure c and pure Fe_2O_3 enter at $298\ K$ and liquid Fe exits at $1800k$. $D = 486000\ kj$

b) Let iron contains $5\%C$. Neglecting heat of mixing $\left(\frac{C}{Fe}\right)_m = 0.25$kg mol/ mole of product iron.

Enthalpy of C at 1800k $= 7625\ kj$
Enthalpy of Fe 5% C $= 486000 + 7625 \approx 49400\ kj$

c) Let us consider that Fe 5%C contain 1% Mn and 1% Si

$$\left(\frac{Mn}{Fe}\right)^m = 0.011 \text{ kg mole Mn /kg mole Fe}$$

$$\left(\frac{Si}{Fe}\right)^m = 0.021 \text{ kg mole Si |kg mole Fe}$$
.

Heat demand in addition to Fe 5%C will consist of enthalpy of Mn, enthalpy of Si and heat required to reduce SiO_2 and MnO_2 to Si and Mn respectively.

Heat demand $= 521305 \text{ kj / kg}$ mole of iron.

Coupling of material and heat balance

In lecture 31, material balance equation was

$$n_O^B + \left(\frac{O}{Fe}\right)^x = n_C^A \left(\frac{O}{C}\right)_g \tag{7}$$

$$D = S = n_C^A \left[283000 \left(\frac{O}{C}\right)^g - 172000\right] \tag{8}$$

By equations 7 and 8

$$n_O^B + \left(\frac{O}{Fe}\right)^x - \frac{D}{283000} = n_C^A \frac{172000}{283000} \tag{9}$$

If $\left(\frac{O}{Fe}\right)^x$ and D are specified, then specification of either n_C^A or n_O^B fully defines blast furnace operation

Illustration 2

Consider pure Fe_2O_3 as a feed, hot metal exits at 1800k and hot metal contains 5% C. The value of $n_B^O = 1.41$ Substituting the values of $n_B^O, \left(\frac{O}{Fe}\right)^x = 1.5$ and D = 494000 (See case b).we get.

$$n_C^A = 1.91$$

$$n_i^C = \left(\frac{C}{Fe}\right)^m + n_C^A = 2.16$$
.

Carbon consumption $= 464 \text{ kg} | 1000 \text{ kg}_{\text{product}}$ Fe.

Graphical representation

Let us rewrite equation 9 as

$$\left\{\left(\frac{O}{Fe}\right)^x - \frac{D}{283000}\right\} - (-n_O^B) = n_C^A\left\{\frac{172000}{283000} - 0\right\}$$

$$Y_2 - Y_1 = M\,(X_2 - X_1)$$

One can plot $O|Fe$ as ordinate against $(O/C)g$. The slope of the line n_C^A will pass through points

$$\left(\frac{O}{C}\right) = 0, \left(\frac{O}{Fe}\right) = -n_B^O$$

$$\left(\frac{O}{C}\right) = 0.61\frac{O}{Fe} = \left(\frac{O}{Fe}\right)^x - \frac{D}{283000} = -0.57$$

Illustration 3

A blast furnace operates with 600kg C and pig iron Contains $5\% \text{ C}$. feedconsists of $Fe_2O_3 +$ gangue.

$$n_C^A = 2.55$$

We draw a line with slope 2.55, we determine

$$\left(\frac{O}{C}\right)_g = 1.42$$

Top gas composition $CO = 58\%, CO_2 = 42\%$.

References

1) Rosenquist: Principles of extractive metallurgy

2) Butts: Metallurgical problem

3) Coudrier; l, HupkinsD.W and I-Wilkomirnky : Fundamentals of metallurgical processes.

4) Y.K Rao: Strichiometrical calculation in mettalurgical; processes.