Lecture 28: Materials Balance in Iron making

Introduction

Illustration

Key words: Ironmaking, reduction of iron oxide, material balance

Introduction

The blast furnace is essentially a continuous counter-current reactor in which the descending chargeis heated and reacted with ascending gases, derived from combustion of carbon at the tuyere. The charge consists of iron sinter/pellets +coke and limestone. During descent, iron oxide is reduced to FeO and limestone decomposed to CaO and CO_2.

The combustion of coke at the tuyere level with air raises the temperature in between $1800°C$ to $2100°C$, and melts slag and metal.

The reduction of FeO to Fe and the melting of iron and formation of hot metal and slag begin once the charge descends to the bosh region. The following reduction reactions occur:

$\mathrm{SiO_2 + 2C = Si + 2CO}$

$\mathrm{MnO + C = Mn + CO}$

$\mathrm{P_2O_5 + 5C = 2P + 5CO}$

$\mathrm{FeO + C = Fe + CO}$

The gases consisting mainly of CO and $\mathrm{N_2}$ and some $\mathrm{H_2}$, derived from moisture of blast, ascends through the charge. Heat transfer occurs as the gas rising upward and simultaneously reduction of wustile to Fe occurs.The $\mathrm{CO_2}$ so produced quickly reacts with C and produces CO $\mathrm{CO_2 + C = 2CO}$

Further reaction between CO and higher oxides of iron will produce $\mathrm{CO_2}$ which accumulates in the ascending gases. The content of $\mathrm{CO_2}$ increases with the decomposition of $\mathrm{CaCO_3}$

$$\mathrm{CaCO_3 = CaO + CO_2}.$$

at about $950°C$. The exit gas may contain $\mathrm{CO/CO_2}$ ratio close to one and leaves the furnace at about 500-600K.

It may also be noted that the reduction of FeO to Fe occurs both by carbon (called direct reduction) and CO (called indirect reduction)

Illustration

Let me illustrate material balance through a problem

Consider a blast furnace which is charged with iron ore coke and flux of the following composition:

Iron ore (weight %): $Fe_2\,O_3$ =78, SiO_2 -8.4, MnO = 0.6, Al_2O_3=5.0, P_2O5 = 1.7MgO = 1.2 and H_2O=5.1

Coke (weight %): C=88, SiO_2 =9, Al_2O_3 =1 and H_2O = 2

Flue : Ca CO_3=96 %, Mg CO_3 =2% and SiO_2 =2%

Pig iron analyses $(\text{weigh percent }\%) = \text{Fe} = 92.7, \text{C} = 4\ \text{Si} = 2, \text{P} = 0.9 \text{ and Mn} = 0.4$

The coke rate is 900kg/ton of pig iron. (Modern blast furnace operates with much lower coke rate)

During smelting 99.5% of Fe is reduced and 0.5% is slagged. The CO/CO_2 ratio in the top gas is 2/1

Calculate

a) Weight of iron ore
b) Weight and composition of slag
c) Volume of air required
d) Volume and% composition of exit gas.

Solution:

Fe balance: (0.995).(Fein iron ore) =Fe in pig iron

Let x kg iron ore

$$0.995 \times \frac{112}{160} \times 0.78 \times = 927$$

$\mathbf{x = 1706\ kg\ Ans}$ (a)

Weight of slag:

Slag consists of $\text{FeO}, \text{SiO}_2, \text{Al}_2\ \text{O}_3, \text{MgO}, \text{P}_2\ \text{O}_5, \text{CaO}$

$$\text{Si in slag} = \text{Si in ore} + \text{Si in coke} + \text{Si in limestone} = \text{Si in pig iron}$$

$$= 88.65\text{kg} = 3.166 \text{ kg moes}$$

$$\text{SiO}_2 \text{in slag} = 189.97 \text{ kg}$$

$$\text{Al}_2\text{O}_3 \text{ in slag} = 0.05 \times 1706 + 900 \times 0.01$$

$= 94.3 \text{ kg}$

MnO in slag $= \frac{71}{55}[\text{Mn from ore} - \text{Mn in pig iron}]$

$= 5.04\text{kg}$

P_2O_5 in slag $= \frac{142}{62}$ $[\text{P from ore} - \text{P in pig iron}]$

$= 8.4 \text{ kg}$

MgO in slag $= 24.53$ kg

CaO in slag $= 229$ kg

FeO in slag $= 6$ kg

Weight of slag and its composition in percent in given below:

	Kg	**%**
$\mathbf{SiO_2}$	**189.97**	**34.09**
FeO	**6.00**	**1.08**
$\mathbf{Al_2O_3}$	**94.30**	**16.92**
MnO	**5.04**	**0.90**
$\mathbf{P_2O_5}$	**8.40**	**1.50**
MgO	**24.53**	**4.41**
CaO	**229.00**	**41.10**
Total	**557.24**	**100%**

Volume of air required calculation to consider the top gas. All the carbon charged except that dissolves in iron will be available in the top gas. Air is required in the blast furnace to combust carbon of coke at the tuyere level. From the amount of coke and the oxygen available through the reduction of oxides, volume of air can be determined.

Oxygen available from the charge = Decomposition of $CaCO_3$ *and* $MgCO_3$ + oxygen released through the reduction of the oxides

Total O_2 available from charge $=$ 17.742 kg moles

$$\text{Total C in gases} = \frac{0.88\times900}{12} + \left[\frac{0.96}{100} + \frac{0.02}{84}\right]\frac{1706}{4.} - \frac{40}{12}$$

$= 66.863$ kg moles

C in to $CO = 44.575$ kg moles O_2 required $= 22.2875$

C to $CO_2 = 22.288$ kg moles O_2 required $= 22.288$

Total $= 44.5755$ kg moles

O_2 from air $= 44.5755 - 17.742 = 26.8335$

Air $= \mathbf{2862.24m^3}$

Volume and % composition of flue gas

	Kgmoles	%
CO	$= 44.575$	25.82
CO_2	$= 22.288$	12.91
N_2	$= 100.945$	58.47
H_2O	$= 4.834$	2.80
Total	$\mathbf{172.642}$ ***kg moles***	**100**%

Also important is the amount of carbon burnt at the tuyere level.

In order to find amount of carbon, burnt at the tuyere, volume of blast can be used.

N_2 of blast is inert and O_2 react with carbon only.

All oxygen of blast reacts with C and forms CO

Volume of blast $= 2862.24\text{m}^3 = 127.8$ kg moles

$O_2 = 26.8$ kg mole. $C + \frac{1}{2}O_2 = CO$

$C = 53.7$ kg mole $= 644$ kg

% C. burnt at tuyere level $= \frac{644}{9000 \times 0.88} = 81.3\%$.