

Lecture 28: Materials Balance in Iron making

Introduction

Illustration

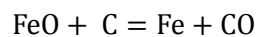
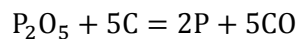
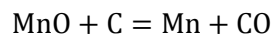
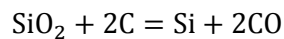
Key words: Ironmaking, reduction of iron oxide, material balance

Introduction

The blast furnace is essentially a continuous counter-current reactor in which the descending charge is 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 CO₂.

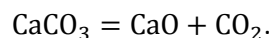
The combustion of coke at the tuyere level with air raises the temperature in between 1800°C to 2100°C, and melts slag and metal.

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:



The gases consisting mainly of CO and N₂ and some H₂, derived from moisture of blast, ascend through the charge. Heat transfer occurs as the gas rises upward and simultaneously reduction of wustite to Fe occurs. The CO₂ so produced quickly reacts with C and produces CO $\text{CO}_2 + \text{C} = 2\text{CO}$

Further reaction between CO and higher oxides of iron will produce CO₂ which accumulates in the ascending gases. The content of CO₂ increases with the decomposition of CaCO₃



at about 950°C. The exit gas may contain CO/CO₂ 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 %): $\text{Fe}_2\text{O}_3=78$, $\text{SiO}_2=8.4$, $\text{MnO}=0.6$, $\text{Al}_2\text{O}_3=5.0$,
 $\text{P}_2\text{O}_5=1.7$ $\text{MgO}=1.2$ and $\text{H}_2\text{O}=5.1$
Coke (weight %): $\text{C}=88$, $\text{SiO}_2=9$, $\text{Al}_2\text{O}_3=1$ and $\text{H}_2\text{O}=2$
Flue : $\text{CaCO}_3=96\%$, $\text{MgCO}_3=2\%$ and $\text{SiO}_2=2\%$

Pig iron analyses (weight percent %) = Fe = 92.7, C = 4, Si = 2, P = 0.9 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/CO₂ ratio in the top gas is 2/1

Calculate

- Weight of iron ore
- Weight and composition of slag
- Volume of air required
- Volume and% composition of exit gas.

Solution:

Fe balance: $(0.995) \cdot (\text{Fe in iron ore}) = \text{Fe in pig iron}$

Let x kg iron ore

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

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

Weight of slag:

Slag consists of FeO, SiO₂, Al₂O₃, MgO, P₂O₅, CaO

$$\begin{aligned} \text{Si in slag} &= \text{Si in ore} + \text{Si in coke} + \text{Si in limestone} = \text{Si in pig iron} \\ &= 88.65 \text{ kg} = 3.166 \text{ kg moles} \end{aligned}$$

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

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

$$= 94.3 \text{ kg}$$

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

$$= 5.04 \text{ kg}$$

$$\text{P}_2\text{O}_5 \text{ in slag} = \frac{142}{62} [\text{P from ore} - \text{P in pig iron}]$$

$$= 8.4 \text{ kg}$$

$$\text{MgO in slag} = 24.53 \text{ kg}$$

$$\text{CaO in slag} = 229 \text{ kg}$$

$$\text{FeO in slag} = 6 \text{ kg}$$

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

	Kg	%
SiO₂	189.97	34.09
FeO	6.00	1.08
Al₂O₃	94.30	16.92
MnO	5.04	0.90
P₂O₅	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 O₂ available from charge = 17.742 kg moles

$$\text{Total C in gases} = \frac{0.88 \times 900}{12} + \left[\frac{0.96}{100} + \frac{0.02}{84} \right] \frac{1706}{4} - \frac{40}{12}$$

$$= 66.863 \text{ kg moles}$$

$$\begin{aligned} \text{C in to CO} &= 44.575 \text{ kg moles} & \text{O}_2 \text{ required} &= 22.2875 \\ \text{C to CO}_2 &= 22.288 \text{ kg moles} & \text{O}_2 \text{ required} &= 22.288 \\ & & \text{Total} &= 44.5755 \text{ kg moles} \end{aligned}$$

$$\text{O}_2 \text{ from air} = 44.5755 - 17.742 = 26.8335$$

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

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 ₂ O = 4.834	2.80
Total 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.

N₂ of blast is inert and O₂ react with carbon only.

All oxygen of blast reacts with C and forms CO

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

$$\text{O}_2 = 26.8 \text{ kg mole. } \text{C} + \frac{1}{2}\text{O}_2 = \text{CO}$$

$$\text{C} = 53.7 \text{ kg mole} = 644 \text{ kg}$$

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