

## L 11 Converter steelmaking

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Key words: BOF steelmaking, material balance, pretreatment of hot metal, lance, gas jet

### Preamble

Converter steelmaking processes are also known as BOF (Basic oxygen Furnace) steelmaking. These processes include top blown steelmaking and combined blown steelmaking processes. These processes are based on hot metal. Hot metal from Blast furnace is refined to steel. Blast furnace hot metal contains 3-4 % C, 0.8 to 1% Si, 0.6 to 0.8 % Mn and 0.15 - 0.2 % P. In all BOF processes, oxygen is blown from top. In most of the steelmaking practices hot metal is pretreated to remove Si, P and S from hot metal to the extent it is possible. This lecture discusses pretreatment of hot metal and material balance.

### Pretreatment of hot metal

In recent years pretreatment of hot metal prior to charging in converter has become common practice. The objective is to reduce S, P and Si of hot metal to produce steel with good surface finish, free from internal cracks. P and Si removal reactions are dealt in lectures 6, 7 and 8. Here S removal is discussed

### Removal of Sulphur

Removal of sulphur is called desulphurization. Sulphur exhibits negative deviation from Henry's Law in molten iron. Bonds between Fe and S are strong. Activity coefficient of S increases with increase in C, Si and P.

Desulphurization reaction is a slag /metal reaction.



$$\frac{a_{S^{2-}}}{[Wt \% S]} = \frac{(Wt \% S)}{[Wt \% S]} = \frac{K f_s a_{O^{2-}}}{[Wt \% O]} \quad 2)$$

K is equilibrium constant of reaction 1 and  $f_s$  is activity coefficient of sulphur in metal.

$(\text{Wt } \% S)/[\text{Wt } \% S]$  is called partition coefficient of sulphur or index of desulphurization. From equation 2 the best conditions for desulphurization can be derived.

- High  $f_s$  i.e. high activity coefficient of sulphur in metal. Carbon, silicon and phosphorus increases  $f_s$  which means hot metal is better for desulphurization than molten steel.
- High  $a_{O^{2-}}$  in slag which means highly basic slag.
- Low  $[\text{Wt } \% O]$  in metal. Reaction 1 suggests that removal of S from hot metal is accompanied by oxygen transfer to metal. This oxygen must be removed for efficient desulphurization.
- High temperature which leads to high K.

Silicon can be removed easily by oxygen and is discussed in detail in lecture 6.

Dephosphorization requires low temperature, basic slag and oxidizing conditions. Presence of silicon in hot metal impedes dephosphorization. The best conditions for dephosphorization are discussed in lecture 8.

### Reagents for hot metal pretreatment

- Soda ash

It is effective reagent for both desulphurization and desiliconization. But disposal of soda bearing slag is a problem. Also soda ash generates dense fumes on addition to hot metal.

- Calcium carbide and Magnesium granules

Both are highly efficient desulphurizing agents and can decrease sulphur content to very low value. Calcium carbide along with lime is injected into the bath. Magnesium granules help to reduce injection time and slag volume.

- In some situations mill scale and sinter fines are used to desiliconize hot metal.

### Location of hot metal pretreatment

Hot metal pretreatment can be carried out either at blast furnace runner, or in transfer ladle or in torpedo.

Pretreatment in the blast furnace runner (Figure 11.1a) has certain advantages: such as adequate mixing of the reagents due to flowing of hot metal. This practice saves time and increases ladle availability compared with when treatment is carried out in ladles.

Figure 11.1 (a) Blast furnace runner

(b) Torpedo car

### Material balance

Hot metal of composition 0.8% Si, 0.2% P, 0.25% Mn, 4% C and rest iron is refined in a converter to produce steel of composition 0.1% C and rest iron. Pure oxygen is blown. During refining scrap is charged whose amount is 15% of hot metal. The composition of slag is CaO 54%, FeO 18%, and MnO 2.5%, with  $\text{CaO/SiO}_2 = 3.5$ . Exit gases analyses 15% CO and 85% CO<sub>2</sub>. Calculate amount of steel, slag, oxygen and waste gases per ton hot metal.

**Basis:** 1000 kg hot metal.

Fe balance: Let X kg is mass of steel and Y kg mass of slag

$$\text{Fe in hot metal} + \text{Fe in scrap} = \text{Fe in steel} + \text{Fe in slag} \quad (3)$$

**Mn balance:**

$$\text{Mn in hot metal} = \text{Mn in slag} \quad (4)$$

Putting the values in 3 and 4 we get.

$$X = 1080.68 \text{ kg steel}$$

$$Y = 126.7 \text{ kg slag.}$$

**Carbon balance:**

$$\text{C in hot metal} + \text{C in scrap} = \text{C in steel} + \text{C in waste gases} \quad (5)$$

$$\text{C in waste gases} = 39.07 \text{ kg}$$

$$\text{C in CO}_2 = 5.86 \text{ kg}$$

$$\text{C in CO} = 33.21 \text{ kg}$$

Exit gas volume = 73.93 m<sup>3</sup> (1 atmospheric pressure and 273K).

O<sub>2</sub> required can be calculated from Si, C, Mn and Fe balance.

Calculations give O<sub>2</sub> = 52.70 m<sup>3</sup> (1atmospheric pressure and 273K)

Material balance gives an idea of the charge materials required.

For example 100 ton capacity would require approximately 93 tons hot metal and 1 ton scrap. The amount of slag would be 12 tons and total oxygen required would be 1900m<sup>3</sup>. The volume of exit gas is 6800m<sup>3</sup>. These are the approximate values and are given to develop a feel of the converter design.

### Design of converter

From the metallurgical point of view an ideal converter keeps the liquid steel in space and allows all necessary metallurgical reactions to take place within the temperature range of 1400 – 1600°C.

The mechanical part, which keeps the liquid steel in space, is steel shell lined with refractory material.

The inner volume enclosed by the refractory should be maximized so as to achieve an optimum metallurgical process without sloping of slag. A ratio of 3 m<sup>3</sup> (internal volume/ ton) is typical in converter design.

A modern LD-converter consists of a top cone with the lip ring a barrel section and a lower cone with a dished bottom. The nose diameter and angle are chosen with reference to problems of heat loss, erosion, skulling, and stability of nose lining.

The vessel is supported by a suspension system which transmits the load to the trunion ring.

Converter design requires knowing height of molten steel bath, ( $h_b$ ) diameter of bath ( $d_b$ ) working height of the converter, ( $h_w$ ) as shown in the figure 11.2

Figure 11.2 Nomenclature of the bath dimensions of a converter

Some correlations are given below:

$$\frac{h_b}{d_b} = 0.328 (T)^{-0.0148}$$

T is capacity in tons, and

$$d_b \text{ (m)} = 0.704 (T)^{-0.386}.$$

$$\frac{\dot{V}}{\text{min.tons}} = 3.07$$

Where  $\dot{V}$  is m<sup>3</sup> of oxygen.

For 150 ton converter capacity

$$h_b = 1.48\text{m}, d_b = 4.87\text{m}, \dot{V} = 460 \frac{\text{m}^3}{\text{min}} \text{ (1atm, 273K)}.$$

$$h_w \approx 3.5 \times \text{bath height} = 5.2 \text{ m}.$$

Total height of converter is 6.7 m excluding bottom refractory thickness.

Assuming bottom refractory thickness to be around 1 to 1.5 m, total converter height from conical to bottom becomes approximately 8m .

**Lance**

Oxygen gas is supplied through a water cooled lance, the tip of which fitted with multi-hole Laval nozzles made of copper

Figure 11.3: Lance to blow oxygen

Lance is nearly 8-10m long and its diameter varies between 20cm to 25cm depending on the furnace capacity. Water requirements are around  $50 - 70 \text{ m}^3/\text{hr}$  at a pressure of  $5 - 7 \text{ kg/cm}^3$ . Lance movement is controlled by electrically operated gear system.

Lance life is determined by the life of the nozzles. Failures of the lance may be due to faulty cooling, manufacturing defects and differential expansion between copper tip and steel tube.

The most important part of the lance is the Laval nozzle. Functions of the nozzle are

- Supply and distribution of oxygen
- To produce a gaseous jet
- To induce bath agitation,
- To produce droplets

Lance is designed to produce non-coalescing free oxygen get. The lance is designed to operate at an upstream pressure of 10- 12 bar.

### **Shop Layout**

Layout requires rational arrangement of equipments to ensure smooth handling of solid raw materials like scrap, fluxes, movement of oxygen lance and hot metal. Also layout should ensure smooth flow of ladles containing hot metal and steel. The refining of hot metal to steel is very fast and hence an efficient system of material transport and weighing is required.

Some essential considerations of layout

- A tall shop is required to raise and lower the lance in the vessel
- An elaborate gas cleaning facilities are required.
- The number of vessels in a shop may be generally two or three and one out of two or two out of three operating at a time.
- The refractory lining maintenance facilities must be adequate.
- An efficient process control strategy using computers and automatic spectro-chemical analytical methods is required.
- The shop is provided with separate cranes for handling hot metal, refined steel, scrap and slag
- The hot metal mixer should be located on the ground floor.

## **Feed Materials:**

- Hot metal
- Cold pig iron
- Steel scrap
- Fluxes
- Gaseous oxygen

### *Hot Metal*

Sulphur in the hot metal should be close to final specification level

Silicon content of hot metal determines amount of lime and slag.

Mn in hot metal produces MnO. MnO tends to retard the dephosphorization of the bath. Mn could be 0.5 to 0.8%

Temperature of hot metal at charging is around 1250°C to 1300°C. Proportion of hot metal in the charge is 75-90%

### *Fluxes*

Commonly used lime/limestone/ dolomite to bring down the softening point of the oxides, to reduce the viscosity of slag and to decrease the activity of some components to make them stable in the slag phase.

### *Scrap and ore*

Used as coolants to best utilize the excess heat energy. Iron ore is sometimes used by some plant as a coolant and to promote slag formation.

### *Oxygen*

Consumption of oxygen per tonne of steel varies with proportion of scrap and ore, and also with single and multi-hole designs and is approximately  $2.5 - 3 \text{ m}^3/\text{min}$ .

Source of heat: No external heat. Refining reactions are exothermic

### *Deoxidisers and alloying elements*

Elements like Al, ferrosilicon and ferromanganese are added as deoxidisers. The elements like Cr, Ni, V, Nb etc are added as alloying elements. Carbon is added to recarburize steel if required

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