Lecture 12 Converter Steelmaking Practice & combined blowing

Contents:

Refining of hot metal

Composition and temperature during the blow

Physico-chemical interactions

Developments in Top blown steelmaking practice

Concept of bottom stirring in top blowing

Top blowing attributes

Characteristic feature of converter steelmaking

Environmental issues in oxygen steelmaking

Causes of high turnover rates of BOF

Key words: Top blown steelmaking, combined blowing, bottom stirring, hot metal refining

Refining of hot metal

After the previous heat is tapped and slag is drained, lining is inspected. Scrap and hot metal are charged. Converter is tilted into the vertical position and the lance is lowered in the vessel to start the blowing. Selection of the starting lance distance is such that the concentration of the force at the bath level should not cause ejection of tiny iron particles (sparking) and at the same time maximum bath surface area is covered by the oxygen jet. The starting lance distance$(\mathrm{X_i})$ for specific oxygen blowing rate $3\,\frac{\mathrm{Nm}^3}{\mathrm{ton}\times\mathrm{min}}$ can be calculated by

$$\mathrm{X_i} = 0.541(\mathrm{d_b})^{1.04}$$

$\mathrm{d_b}$ is bath diameter in meter. For 150 Tons converter, $\mathrm{d_b} = 4.87\ \mathrm{m}$ and $\mathrm{X_i} = 2.8\ \mathrm{m}$, when oxygen flow rate in approximately $450\ \mathrm{Nm^3/min}$.

Initially oxygen is blown soft by keeping lance distance higher to promote slag formation and to avoid ejection of small particles, because hot metal is not covered by slag. Lime may be added either at the beginning of the blow or in portion during the blow. Oxygen is blown for nearly 15-20 minutes by progressively decreasing the lance distance such that slag foaming remains under control and oxidation reactions occur uninterruptedly. Slag and metal samples are analyzed.

Composition and temperature during the blow

Typical variation of composition of metal with the blowing time is shown in figure 12.1

Figure 12.1: Variation of composition of metal during the blow

The following observations can be made:

- Impurities like C, Si, Mn begin to oxidize simultaneously. Si and Mn oxidize faster relative to C. Also Fe oxidizes to FeO. Rate of carbon removal is low in the beginning.
- Formation of slag begins with the oxidation of $\mathrm{Si} - \mathrm{SiO_2}$, $\mathrm{Mn} \rightarrow \mathrm{MnO}$ and $\mathrm{Fe} \rightarrow \mathrm{FeO}$
- Dissolution of lime increases during the blow. In the initial periods FeO helps lime dissolution.
- Formation of basic and limy slag promotes removal of P. It may be noted that once slag is formed both C and P removal occur simultaneously.
- In the initial stages, carbon removal rate is kept lower than P removal since P removal is favoured at lower temperatures. If carbon is removed at a faster rate in the beginning bath temperature would increase which impedes dephosphorization. Once phosphorus removal is complete, carbon removal rate can be increased.
- Note that Mn content of metal decreases initially but at later periods of blow Mn content of bath increases. This is due to the onset of the following reaction:

$$(\mathrm{MnO}) + [\mathrm{Fe}] = [\mathrm{Mn}] + (\mathrm{FeO})$$

In the later stages of the blow bath temperature increases due to decrease in carbon content and at the sametime FeO content of slag decreases. Both conditions are responsible for increase in Mn content of the bath. To overcome, sometimes iron ore additions are made to increase the FeO content of slag to adjust the Mn content of steel.

- Temperature of the bath increases continuously.

Physico-chemical interactions

Physico- chemical interactions of molten bath with oxygen jet depends on the lance profile i.e. change of lance height during the blow. The lance profile is specific to each converter and depends on converter profile, hot metal composition, oxygen flow rate, hot metal chemistry and steel of desired composition. Nevertheless, in all converters initial lance distance is such as to promote iron oxidation so that dissolution of CaO commences. The idea is to create a basic and limy slag at the early part of the blow to onset dephosphorization. Shallow jet penetration covers the larger bath surface and is favorable more for iron and silicon oxidation. Small amount of carbon may be removed. Once slag is formed, lance is lowered. Oxygen jet penetrates into the bath and carbon reaction favours because oxygen is available now deep into the bath. At the same time, force of the oxygen jet creates metal droplets and as a consequence three phase dispersion of gas/slag /metal droplets are formed which enhance the rate of decarburization.

Figure 12.2 shows the lance profile and the accompanying physico-chemical interactions

A= hot metal, B=slag, C= oxygen jet, B^1 There phase dispersion of slag/ gas bubbles / metal droplets

We note that at higher lance distance, oxygen jet penetration into bath is shallow and slag formation occurs. (See 12.2 a) As the lance distance is decreased, jet penetrates deep into the bath, carbon reaction commences, CO forms, droplets are produced which together leads to the formation of a three phase dispersion consisting of gas bubbles/slag/metal droplets (See 12.2 b and c). In this state of blow, both carbon and phosphorus removal occur at a faster rate. Formation of three phase dispersion is a characteristic feature of the top blown steelmaking. Three phase dispersion creates conditions for faster removal rates of C and P. Foaming of slag has to be controlled to avoid expulsion of slag, which can be controlled by controlling C reaction with FeO in slag. Reaction between C and FeO of slag in slag will not allow CO bubbles to grow. Smaller size gas bubbles can be trapped easily in slag as compared to larger sizes. Slag may foam and may be expelled from the converter.

Developments in Top blown steelmaking practice

The most important development in top blown steelmaking practice is the simultaneous gas stirring of the bath form the bottom of the converter. This has resulted in combination blowing processes. These processes differ in terms of bottom gas rate, number and arrangement of bottom tuyeres and type of bottom injection elements i.e. porous plugs or tuyeres and whether inert gas or oxidizing gas is used.

All processes which use top blowing of oxygen and bottom stirring by inert gas is known as bath stirred top blown processes. In another type, oxygen is blown form top and bottom and is called top and bottom blowing processes.

Concept of bottom stirring in top blowing

In pure top blown steelmaking, bath agitation is very weak particularly during the initial and final stages of the blow. In the initial stages Si and Mn removal delays carbon removal whereas in the final stages carbon removal rate decreases. Figure 12.3 shows decarburization rate Vs time, typically observed in top blown steelmaking practice.

Figure 12.3: Rate of carbon removal as a function of time of blow

In the hatched regions, CO evolution in the bath is very low in pure top blown steelmaking; O_2 jet could not produce adequate bath stirring. Evolution of CO is the principle cause of bath agitation. Both in initial periods (silicon oxidation period) and in final periods (where rate of carbon removal is mass transfer controlled), evolution of CO is low. Slag analysis reveals higher rate of oxidation of Fe to FeO in both the periods which is due to weak stirring in the bath. In main part of the blow higher carbon removal rate produces higher amount of CO and produces enough bath stirring. It is considered appropriate to introduce bottom stirring gas in a top blowing converter to stir the bath.

Top blowing attributes

- Energetic supply of oxygen
- Control of slag formation
- Control of oxygen distribution.
- Simultaneous removal of C and P.
- Inadequate stirring of slag /metal phases.

In bottom blown steelmaking, all oxygen is injected through the bottom tuyeres .Though this technology provides efficient bath stirring and enhanced carbon removal, but it is difficult to distribute oxygen within the bath and also to control slag formation.

The advantages of pure top and pure bottom are coupled and a new technology is developed under the name combined top blowing of oxygen and bottom stirring. The advantages of such a technology when compared with pure top blowing like reduced FeO content of slag and O content of steel etc. are obvious.

Several process technologies for combined blowing were developed under different names. These technologies differ in

- Amount of inert gas
- Type, number and arrangement of bottom tuyeres and porous plugs.

The reader may see the references given at the end of lecture to get technological details.

Characteristic feature of converter steelmaking

Supply of oxygen in the form of free gas jet is an important feature of converter steelmaking both in pure and different versions of combined blown ones. In this form of oxygen supply, the total time of blowing of oxygen is almost independent of converter capacity, oxygen blowing rate and bottom stirring. This was reflected by evaluating dimensionless momentum flow rate vs. ratio of time of blowing (t) /total blowing time$(\mathrm{t_{tot}})$ for different converter capacities ranging from 40-400 tons. (See reference at the end). Dimensionless momentum flow rate was correlated as

$$\frac{\dot{m}}{\rho_l g \times L^3} = 7.25 \times 10^{-3} (\phi)^{0.78}$$

Where $\phi = {}^{t}/_{\text{total}}$

It is illustrated in lecture 13 that dimensionless momentum flow rate describes the action of free oxygen jet produced by constant volume flow rate of oxygen at various lance distances. The dimensionless momentum flow rate number increases with the decrease in lance distance. Decrease in lance distance makes the blow hard and increase in lance distance makes the blow soft. Lance profile can be considered to generate soft blow initially and progressively harder blow with the progress of the blow.

The fundamental requirements of the lance profile in all converter steelmaking are formation of FeO rich slag in the initial stage and then removal of carbon and phosphorus by progressively increasing the availability of oxygen in the bath to avoid over oxidation of slag. The first requirement is achieved by "soft blow" (shallow penetration of jet) and the other requirement is achieved by hardening the blow (deep penetration of jet into bath) progressively. Thus soft and hard blow are essential requirement of refining of hot metal by impinging oxygen jet irrespective of the converter capacity and type of converter steelmaking practices (pure top blowing combined blowing) as a result the total oxygen blow time remains more or less same.

Environmental issues in oxygen steelmaking

- Control of emissions during transfer of hot metal to desulphurization station.
- Disposition of slag
- Capture and removal of contaminants in hot and dirty exit gas from the converter.
- Particulate matter exiting with the exit gas.
- Emission of CO. for this purpose sufficient excess air must be used at the hood to burn CO.

Causes of high turnover rates of BOF

i) Energetic supply of oxygen: This method ensures.
   - Availability of oxygen where it is needed during refining
   - Faster mechanism of mass transfer by producing droplets and slag/metal emulsion.

ii) Bottom stirring

iii) A basic and limy slag of required basicity is formed at the early stages of the blow.

References:

A.Ghosh and A. chatterjee: ironmaking and steelmaking

A chakrabarti: steelmaking

R.H. tupkary and V.R. tupkary: modern steel making

S C Koria: Dynamic variations of lance distance in impinging jet steelmaking processes, Steel Research, Vol. 59 (1988), No.6, p.257-262.

S C Koria and K W Lange: Experimental investigation on selection of bottom injection parameters in combined blown steelmaking

S C Koria and and A George: Experimental investigation on selection of bottom injection parameters in combined blown steelmaking, Ironmaking & Steelmaking, Vol.15 (1988) p.127-133

S C Koria and K W Lange: Penetrability of impinging gas jets in molten steel bath, Steel Research 58 (1987) No.9 p.421-426

S C Koria and K W Lange: Experimental investigation on selection of bottom injection parameters in combined blown steelmaking, Ironmaking & Steelmaking, Vol.15 (1988) p.127-133

S C Koria: Nozzle design in impinging jet steelmaking processes , Steel Research 59 (1988) No.3, p.104-109.

S C Koria and K W Lange: Estimation of drop sizes in impinging jet steelmaking, Ironmaking and steelmaking V.13 (1986) No.5 p.236-240.

S C Koria and K W Lange, Development of blowing practice for combined top blowing and bottom stirred processes, Process, Techn. Proceedings 5th Intern. Iron and Steel Congress Vo.6, (1986) p.219-224

S C Koria and K W Lange: Correlation between drop size distribution or total drop mass and oxygen top blowing parameter, Process Techn./ Proceeding (5th Intern. Iron and Steel Congress) Vol.6 (1986) p.353-356

S C Koria and K W Lange: Penetrability of impinging gas jets in molten steel bath, Steel Research 58 (1987) No.9 p.421-426

S C Koria, K W Lange and R. Siemssen: Application of empirical correlations to develop blowing pattern for small scale, combined blown Steelmaking converter, Institute for Ferrous Metallurgy, Technical Report (1987)p.1-117.

S C Koria and A George
Experimental investigation on selection of bottom injection parameters in combined blown steelmaking
Ironmaking & Steelmaking, Vol.15 (1988) p.127-133

S C Koria and K W Lange
Mixing – time correlation in top gas stirred melts
Arch. Eisenhuttenwes, 55 (1984) p. 97-100.

. S C Koria and K W Lange
Effect of Melting scrap on the mixing – time of bottom gas stirred melts
Proceeding 6th Japan-Germany seminar, Tokyo, Japan (1984) p.91-101

S C Koria and K W Lange
A new approach to investigate the drop size distribution of BOF steelmaking Met. Trans. 15B (1984) p.109-116.