Lecture 21: Evolution of ladle Treatment and Requirements

Contents:

Key words: Ladle metallurgy, Secondary steelmaking, injection metallurgy, synthetic slag practice

Preamble

In steelmaking, ladles are employed to transfer molten steel from BOF/EAF to ingot casting or continuous casting. It has been realized that ladles can be used very effectively as a reactor which can perform any of the following functions:

- To desulphurize molten steel tapped from BOF/EAF
- To homogenize molten steel to minimize gradients in concentration and temperature and to attain desired teeming temperature.
- To deoxidize molten steel
- To improve cleanliness of steel by removing inclusions
- To engineer the inclusions so as to alleviate their harmful effects on mechanical properties of steel
- To add alloying elements
- To remove dissolved gases

The effectiveness of each of the function requires modifying the ladle in terms of molten steel flow, and extra heating facility etc.

What modifications are required?

Ladle is a cylindrical refractory lined vessel and aspect ratio of the bath varies between 0.8 and 0.9. This means that the bath is deep.

Bath agitation would be required to carry-out the functions effectively. At high temperature, bath can be agitated either by an inert gas or by induction. One has to determine the amount of stirring gas and location of the injection of gas in the ladle. The gas can either be injected through the nozzle or porous plugs. Location of the injection elements is an important issue. Injection elements could be located either axis-symmetric or asymmetric to the center of the ladle.

Enough free board height in the ladle must be available to accommodate the quantity of slag required for refining and to absorb inclusions.

Additional heating may be required to keep the molten steel to the teeming temperature. This can be achieved either by tapping steel at slightly higher temperature or to provide addition heating arrangement in the ladle itself.

In many situations it is required to inject the slag forming materials either for refining or for inclusion engineering. In this case suitable injection device must also be available.

Above all, the most important would be the selection of refractory (see lecture 9 and 10) to meet the refining requirements. Refractory materials for injection elements and their fixing must also be considered.

Basics of gas stirring

Argon is usually bubbled into the molten steel covered with slag either through the top lance or through a porous plug fitted at the bottom. A plume of gas rises upwards when gas is injected through the bottom. The stirring homogenizes bath composition and temperature. With centrally placed nozzle at the bottom, stirring action is small near the bottom of the ladle. An asymmetrically placed bubble plume gives velocities near the bottom which are greater than for symmetrically placed nozzle.

The liquid flow in the ladle occurs via bulk motion of the metal. Very roughly, characteristic velocity v_c for gas bubbling is

$$v_c = \left(\frac{Q g H^2}{V}\right)^{1/3}$$ (1)

Where Q is gas flow rate$\left(\frac{m^3}{s}\right)$, g is$\left(\frac{m}{s^2}\right)$, H is bath height (m) and V is bath volume (m^3). For gas injection at 50 l/min in a ladle of bath diameter 3.5m and bath height 3.5m, equation 1 calculates 0.14 m/s as the gas bubbling velocity.

At velocities greater than 0.3 m/s at the slag/metal interface slag droplets may be entrained by the metal flowing along the interface and into the melt.

For gas stirring recirculation rate of molten steel is of interest. The mass flux in (tons/s) of entrained steel passing through the top section of the bubble plume can be calculated by the following semi-empirical equation:

$$\dot{M} = 13.3 \, (H + 0.8) \left[\ln\left(1 + \frac{H}{1.48}\right)\right]^{0.5} \times Q^{0.381}$$ (2)

Consider a ladle with bath height 3m and Q=650 l/min (1 atm and 273K). We can calculate$\dot{M} = 9.5$ tons /s. Increasing the flow rate to 800 l/min increases $\dot{M}$ to 10.3 tons/s.

The calculations show that the recirculation time of a 200 ton melt is 21 s for 600 Nl/min and 20 s for 800 Nl/min gas flow. At higher gas flow rates slag droplets may be entrained in molten steel which may increase the rates of refining reaction because of transitory phase contact (Readers may see the references at the end of this lecture).

For evaluating the efficiency of gas stirring, an alternative approach is to calculate energy input W in watt. The energy input can be calculated by

$$W = 6.18 \times 10^{-3} QT \left[\left(1 - \frac{273}{T} \right) + \ln \frac{P_1}{P_2} \right] \tag{3}$$

Here W is stirring energy in watt, Q is flow rate in Nl/min, t is bath temperature in K, P_1 is pressure at the bottom surface of the bath ($P_1 = P_2 + \rho_l gH$; where ρ_l is density of molten steel, H is bath height and P_2 is atmospheric pressure). For gas injection rate 200 Nl/min into a bath of 2m height the stirring energy would be 390W/m^3 when the bath diameter is 2.5 m.

Electromagnetic induction induces stirring energy about 100 W/m^3. RH degassing gives about 800 W/m^3 stirring energy at a circulating rate of 40 tons/minute.

Mixing time i.e. time to homogenize the bath indicates the conditions for stirring. Good mixing promotes the rate of slag/metal reaction as indicated by smaller mixing time. The following results are to be noted:

i. Scrap enhances the mixing time. Homogenization is possible within a definite time only up to a certain maximum scrap ratio.
ii. The mixing time decreases with increase in bottom gas rate
iii. Mixing time decreases with increasing the aspect ratio of bath.
iv. Mixing time(τ) in seconds can be correlated with the energy input in W/m^3, volume of scrap (V_S):

$$\tau = [\exp(4.338 + 0.006\%V_S)] \times \left(W \frac{h_b}{d_b} \right)^{-0.00847\%V_S - 0.5564} \tag{4}$$

where V_S in %. $\frac{h_b}{d_b}$ expresses aspect ratio.

Gas injection rates

The following are some typical values of specific gas injection rates:
Stirring < 5Nl/ (min. t)
Lime steel desulphurization $\approx$ 14Nl/ (min. t)
Vacuum Arc Decarburization < 2Nl/ (min. t)

High gas flow rats though supply large amounts of stirring energy, large freeboards are needed. Large freeboards decrease the molten steel holding capacity of ladle. Lack of large freeboards and splashing often limits rate of gas injection.

Choice of stirring energy

Correct stirring is of utmost importance. It should be known when to stir what, and how vigorously. Vigorous stirring would be required for slag/metal reaction such as desulphurization. Inclusions removal would require weak stirring. Bath homogenization would also require weak stirring. Vigorous mixing of metal and slag is achieved with gas stirring. Less disturbance at the slag/metal interface can be obtained by induction stirring. Slag carry-over from BOF/EAF must be avoided. Vigorous stirring in the neighborhood of slag/metal phase boundary activates interfacial mass transfer, leading to reduction of slag by deoxidizing elements, reversion of phosphorus, and oxygen and nitrogen pick up from the atmosphere.

REFERENCES:

S C Koria and S Singh
Measurements on local properties of a heterogenerous air/water plume formed during uptward Injection of gas
Steel Research, Vol.60 (1989) No.7, p.301-307

S C Koria and C D Khai
Model study on dissolution time of metallic materials in steelmelt
Trans. Ind. Inst. Of Metals, Vol.42 (1989) No.1, p.47-54

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
Model investigations on liquid velocity induced by submerged gas injection in steel bath
Steel Research 59 (1988) No.11, p.484-491

S C Koria
Thermodynamic considerations in designing gas injecting lances submerged in melt
Ironmaking and Steelmaking 16 (1989) No.1, p.21-27

S C Koria
Modelling of submerged gas inecting lance design parameters
Steel Research, Vo.60, (1989) No.2, p.60-66.

S C Koria and S Singh
Experimental investigations on the design of gas injecting lances
ISI Japan International, Vo.29 (1989) No.8, p.650-657

S C Koria and S Singh
Measurements on local properties of a heterogenerous air/water plume formed during uptward Injection of gas
Steel Research, Vol.60 (1989) No.7, p.301-307

S C Koria and C D Khai
   Model study on dissolution time of metallic materials in steelmelt
   Trans. Ind. Inst. Of Metals, Vol.42 (1989) No.1, p.47-54

A.Chakrabarti: Steelmaking
A.Ghosh: Secondary steelmaking