

## Lecture 23: Injection ladle metallurgy

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**Keywords:** alloying, permanent contact, ladle refining, transitory contact, ladle furnace, wire feeding

### Injection of solid powders

Injection techniques have the advantages of dispersing the reactants in the steel bath and at the same time provide a large reaction surface area. The type of powders used is governed by the purpose of injection. Table below shows the slag forming materials used for injection.

Purpose	Type of powder
Dephosphorization	$\text{CaO} + \text{CaF}_2 + \text{Fe}_2\text{O}_3$ + mill scale soda
Desulphurization	$\text{CaO} + \text{Al}$ $\text{CaO} + \text{CaF}_2 + \text{Al}$ $\text{Ca C}_2$ $\text{Mg} + (\text{MgO}, \text{Al}_2\text{O}_3, \text{chloride slag})$ $\text{CaC}_2 + \text{CaCO}_3, \text{CaO}$
Alloying	$\text{Fe Si}, \text{CaCN}_2, \text{NiO}, \text{Mo O}_2$ $\text{Fe B}, \text{Fe Ti}$ etc
Deoxidation and inclusion shape control	$\text{Al}, \text{Ca Si}, \text{Ca}, \text{Si}, \text{Mn}, \text{Al},$ $\text{Ca Si}$ and $\text{Ba}$

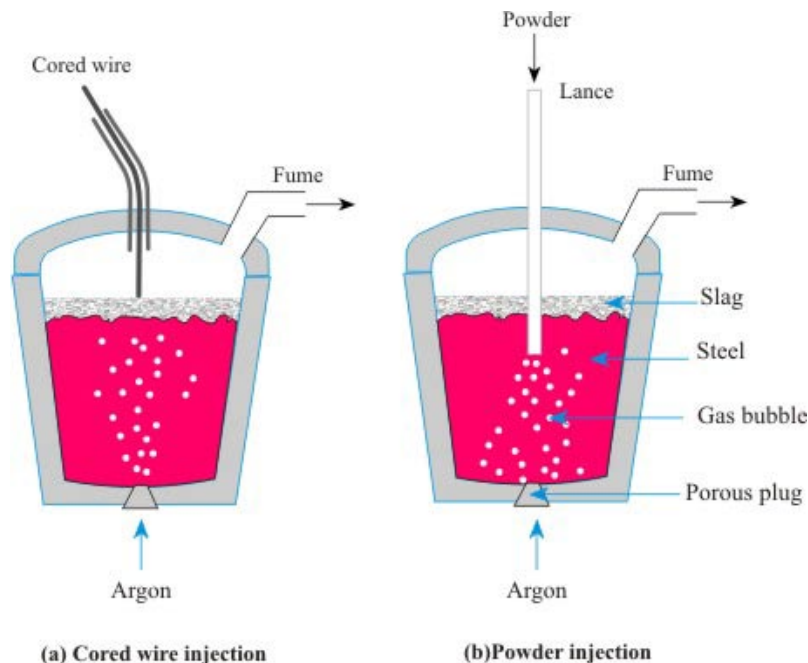
### Desulphurization mechanism

Desulphurization can be carried out by injecting lime based powder, for example 90%  $\text{CaO}$  + 10%  $\text{CaF}_2$  or 70%  $\text{CaO}$  + 20%  $\text{Al}_2\text{O}_3$  + 10%  $\text{CaF}_2$ . The injection rate varies between 2 -4 kg/ton of melt. When

slag forming materials are injected into melt, they melt and the molten slag particles begin to rise and accumulate at the top surface of the melt. The desulphurization reaction occurs in two ways:

- During contact between rising molten slag particles and the melt. In this mechanism of desulphurization it is important that the powder becomes molten on injection. Residence time of the rising particles in the melt is also important, which means that the gas powder injection velocity must be suitably selected. Powder melts and the rising gas imparts mixing in the melt. This mechanism is known as **transitory contact**.
- Contact between top slag and the melt. As the molten slag particles rise they accumulate at the top surface of the melt and after a while top slag also takes part in the desulphurization. In this mechanism slag/metal interface area is important. Gas injection rate may be suitably selected to produce and entrain slag droplets into the melt for the faster rates of reaction. Once all the powder is injected, reaction between top slag and sulphur of melt governs the final sulphur content of steel. This mechanism is known as **permanent contact**

It must be noted that methods for injection of powder must also be developed. The slag forming materials are lighter than steel and deep injection would be required for the efficiency of the reaction. Powder can be injected either through cored wire or pneumatic transport. Figure 23.1 shows arrangement of ladle desulphurization carried out either by injecting cored wire or by pneumatic injection through a top lance. In both argon is bubbled through a porous plug fitted at the bottom of the ladle. The desulphurization efficiency can be estimated by the mass balance.



**Figure 23.1 Ladle desulphurization carried out by powder injection technology (a) cored wire injection and (b) Pneumatic injection through a top lance**

In the transitory contact mode, the desulphurization can be determined by performing sulphur balance:

$$-1000 \frac{d[m_s]}{dt} = \dot{W}_s L_s [m_s] \quad (1)$$

$\dot{W}_s$  is rate of injection of slag powder,  $m_s$  is sulphur in steel at time  $t$ . integration of equation 1 and putting the limit

$t = 0, [m_s] = [m_s]_0$  and  $t = t, [m_s] = [m_s]$  we get,

$$\frac{[m_s]}{[m_s]_0} = \exp \left[ -\frac{\dot{W}_s L_s}{1000} \right] = \exp(-Z) \quad (2)$$

$L_s$  is the partition coefficient of sulphur.

Similarly in the permanent contact zone sulphur balance

$$1000[m_s]_0 + W(m_s)_0 = 1000 [m_s] + W_s(m_s) \quad (3)$$

Where  $W$  is amount of top slag, and  $(m_s)_0$  is initial S in slag and  $(m_s)$  is final sulphur in slag. Re-arrangement of equation 3 gives

$$R = 1 - \frac{[m_s]}{[m_s]_0} = \left\{ \frac{L_s W_s}{1000 + L_s W_s} \right\} = \frac{1}{1+Z} \quad (4)$$

### Illustration

A slag with high value of  $L_s$  is desirable for efficient desulphurization. Consider two different slags whose partition coefficient is 80 and 500. Amount of slag injected is 4 kg/ton, 8 kg/ton, and 12 kg/ton. To illustrate the role of transitory and permanent contact on desulphurization, let us calculate  $[m_s]/[m_s]_0$  for each case: The following table gives the calculated values

$L_s = 80$			and $L_s = 500$	
$W_s$ kg/ton	$[m_s]/[m_s]_0$ trans.	$[m_s]/[m_s]_0$ Perm.	$[m_s]/[m_s]_0$ trans.	$[m_s]/[m_s]_0$ Perm.
4	0.73	0.76	0.14	0.33
8	0.53	0.61	0.018	0.20
12	0.38	0.51	0.0025	0.14

We note the following:

- Both amount of slag and partition coefficient are important for desulphurization
- At lower amount of slag and lower partition coefficient there is not much difference in the ratio of  $[m_s]/[m_s]_0$  for both permanent and transitory contact modes.. For example for  $L_s = 80$  , when the powder injection rate is 4 kg/ton, the said ratio is 0.73 for transitory and 0.76 for permanent contact. However, when the powder injection rate is increased to 8 and 12 kg/ton, transitory contact mode becomes more efficient than permanent contact.
- At higher value of  $L_s = 500$ , transitory contact gives much lower value of sulphur in metal than permanent contact

Transitory contact mode requires designing powder injection systems which can inject powder at constant and uniform rate.

### **Alloying with gas injection**

Alloying can be done during tapping by simply dropping the material on the surface, or with a carrier gas. The dissolution and homogenization of the alloying additions are enhanced by stirring and small particle size. Stirring intermixes top slag with the bath which should be minimized to avoid oxidation. The vigorous intermixing of top slag with the bath can be minimized by the lowering of a refractory lined cylinder into the liquid steel. This will minimize reaction of steel exposed to air.

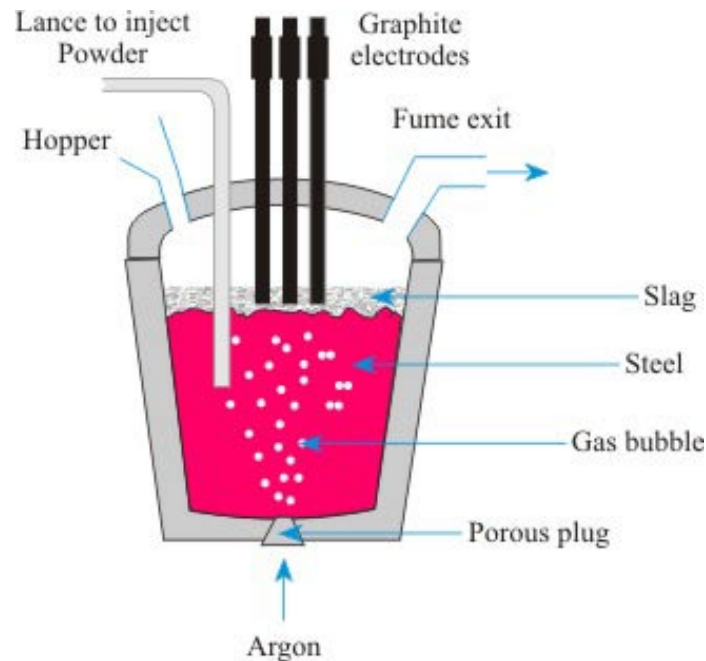
### **Heating of steel**

Synthetic slag practice with argon stirring or injection of solid powder requires higher tap temperatures to compensate for the heat losses during refining. This increased tap temperature causes problems in BOF such as poor phosphorus removal and increased lining wear. In EAF increased power and electrode consumption and an increase in furnace time are the main issues to tap steel at higher temperature.

Arc heated ladle processes have been developed. Ladle arc furnace in addition to allowing for lower temperatures, also allows steelmakers to perform many metallurgical processes like

- i. Bath homogenization by argon stirring
- ii. Inclusion removal and inclusion engineering
- iii. Desulphurization by synthetic slag or by injection metallurgy
- iv. Holding of ladles for long periods if and when need arises for example in sequence casting.
- v. The ability to make addition of alloying elements.

There are three different types of ladle arc heated furnaces: Induction stirred, gas stirred by porous plugs and gas stirred using a tuyere.



**Figure 23.2: Ladle furnace showing arrangement of electrodes and porous plug**

Figure 23.2 shows ladle arc furnace where a cover equipped with three graphite electrodes are shown. The ladle bottom has a porous refractory plug for argon stirring. The ladle furnace is equipped with a hopper for additions of reactants. Fumes are taken out through the roof of the ladle.

The processes are under the following names:

ASEA- SKF: The process uses induction stirring. Induction stirring requires a stainless steel ladle or a stainless steel section of the ladle. Electrodes are used for heating.

Diado ladle furnace: The process is gas stirred. The furnace uses three graphite electrodes with submerged are heating.

FineKI- Mohr uses vacuum arc degassing (VAD) the system is under partial vacuum during heating. Argon bubbling is maintained through a porous plug.

For the detailed description, readers may see the references.

References:

K W Lange : International materials Review, 1988 vol. 33 No.2

R.J. Fruehan : Ladle metallurgy principles and practices

A. Ghosh: Secondary steelmaking: principles and applications.

SC Koria and K S Rao: Mathematical model for powder injection refining of steel melt. Iron making and steelmaking 25 (6), 1998 453-459

S C Koria: Influence of injection metallurgy on mass transfer in steelmaking, Trans. Ind, Inst. Metals 47 (10), 199, 287 -299

S C Koria and R Dutta: Study on the effect of some process parameters on the powder injection refining by a mathematical model, Scand. Jl. Of Metallurgy 29, No.6 (2000) 259-270