

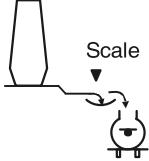
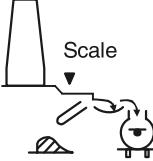
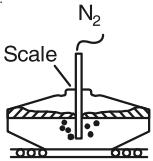
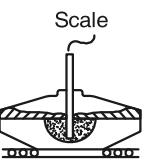
fluxes of sulphur through the boundary layers, around each particle. Therefore, the step of calcium diffusion through the product layers does not contribute any significant resistance to the overall rate of desulphurisation. The layers of graphite and calcium sulphide progressively thicken so that the calcium vapour has to diffuse through them. These two layers are formed topo-chemically on the surface of the particles, and the mass transfer resistance offered by the chemical reaction rate is negligible. As a result, the rate of desulphurisation is relatively fast.

## 16.8 HOT METAL PRE-TREATMENT STATION(S)

### 16.8.1 Desiliconisation

The blast furnace runner, transfer ladle or torpedo car can be used as the place for desiliconisation as shown in Figure 16.10. The desiliconisation agent is added using one of the following methods:

- Top charging with nitrogen bubbling
- Blasting
- Injection.

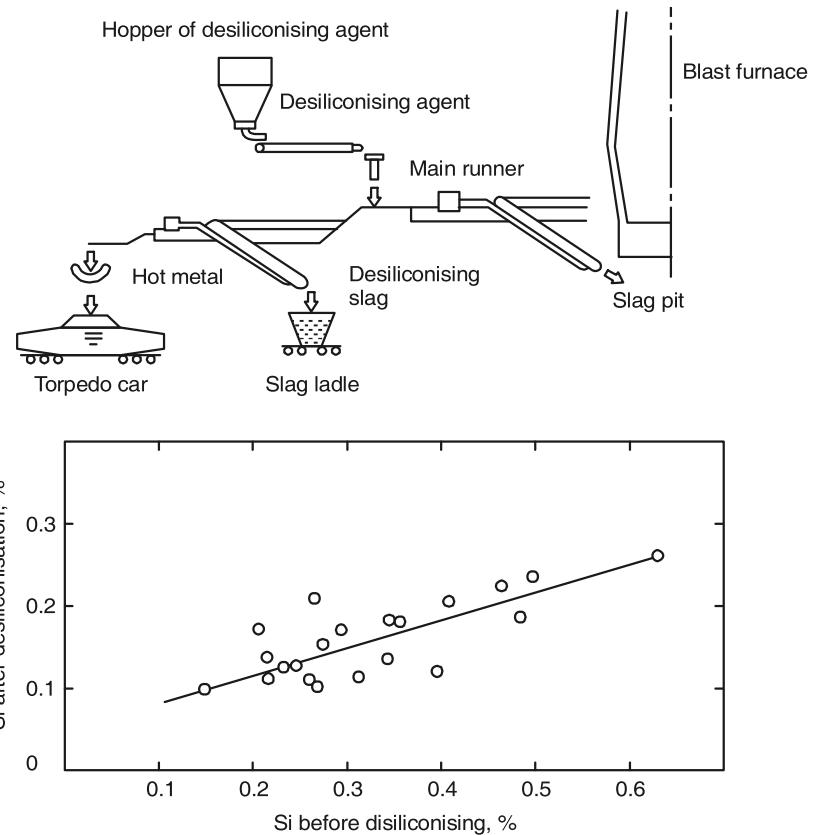
Method	In blast furnace runner		In torpedo car and ladle	
	Top addition (1)	Top addition (2)	Top addition	Injection
Schematic diagram				
	<ul style="list-style-type: none"> <li>• Additional process not required</li> </ul>		<ul style="list-style-type: none"> <li>• Selective treatment possible</li> </ul>	
Merits		<ul style="list-style-type: none"> <li>• Easy separation of desiliconisation slag</li> </ul>		<ul style="list-style-type: none"> <li>• High desiliconisation efficiency ([Si] 0.10% attainable)</li> </ul>
Demerits	<ul style="list-style-type: none"> <li>• Slag foaming in torpedo car</li> </ul>	<ul style="list-style-type: none"> <li>• Low desiliconisation efficiency</li> <li>• Restriction due to cast house layout</li> </ul>	<ul style="list-style-type: none"> <li>• Low desiliconisation efficiency</li> </ul>	<ul style="list-style-type: none"> <li>• Complicated equipment</li> </ul>
Remarks	<ul style="list-style-type: none"> <li>• Blasting method is tested</li> </ul>		<ul style="list-style-type: none"> <li>• O<sub>2</sub> blowing practice can be used jointly</li> </ul>	

\* Both blasting (very high rate of addition) or normal feeding can be applied

**Figure 16.10** Desiliconisation processes used industrially.

In Japan, desiliconisation of hot metal is carried out in the blast furnace runner because of advantages, such as adequate mixing of the reagents owing to the energy of the flowing molten iron stream, saving in time, and increased ladle availability compared with separate

desiliconisation in a ladle. Figure 16.11 shows a typical set-up that is often used for runner desiliconisation, along with the results obtained (Gupta and Chatterjee, 1995). It needs to be stressed that hot metal from blast furnace has to be separated from slag using a slag skimmer in the main runner before desiliconising agents such as mill scale and calcined lime are added



**Figure 16.11** Schematic diagram of desiliconisation treatment in a blast furnace runner.

continuously. Only in this way can the reagent efficiency be increased. Normally, about 20 kg mill scale per tonne of metal is needed to reduce the silicon level from 0.5% to less than 0.2%. On the other hand, for reducing silicon from 1.5% to 0.6%, 35–40 kg/thm is required. The heat balance for runner desiliconisation, given in Table 16.3, indicates that there is no temperature drop during this treatment even though it is carried out in an open runner (Gupta and Chatterjee, 1995). This is because of the heat generated by the oxidation of silicon to silica.

### 16.8.2 Desulphurisation

Previously, desulphurisation used to be carried out by injecting the desulphurising agent in powder form into blast furnace ladles, en route from blast furnaces to steelmelting shops.

**Table 16.3** Typical heat balance for runner desiliconisation treatment

Heat source	Desiliconising with mill scale (mixed with 20% lime)	
	kcal/t	Quantity
Input heat		
(1) $\text{Si} + \text{O}_2 \rightarrow \text{SiO}_2 + 7460 \text{ kcal/kg-Si}$	14920	Si = 0.20%
(2) $\text{Mn} + (\text{1/2})\text{O}_2 > \text{MnO} + 1680 \text{ kcal/kg-Mn}$	840	Mn = 0.05%
(3) $\text{Ti} + \text{O}_2 \rightarrow \text{TiO}_2 + 2830 \text{ kcal/kg-Ti}$	570	Ti = 0.02%
(4) $\text{C} + (\text{1/2})\text{O}_2 \rightarrow \text{CO} + 2200 \text{ kcal/kg-C}$	220	C = 0.01%
(5) Average slagmaking heat 140 kcal/kg-slag	1260	Amount of slag: 9 kg/t
Total Input	17810	
Output heat		
(1) $\text{FeO} \rightarrow \text{Fe} + (\text{1/2})\text{O}_2 - 900 \text{ kcal/kg-FeO}$	9040	FeO in mill scale: 77%
(2) $\text{Fe}_2\text{O}_3 \rightarrow 2\text{Fe} + (\text{3/2})\text{O}_2 - 1230 \text{ kcal/kg-Fe}_2\text{O}_3$	2570	Fe <sub>2</sub> O <sub>3</sub> in mill scale: 16%
(3) Sensible heat of slag formed 0.217 kcal/kg-slag. °C	2940	Amount of slag: 9 kg/t
(4) Sensible heat of iron reduced 0.170 kcal/kg Fe °C	2300	Amount of iron reduced: 9 kg/t
Total output	16850	
Sum total	960	
Net increase in hot metal temperature	+5.6°C	

Nowadays desulphurisation stations normally form a part of the BOF shop. In a typical case of reducing the initial sulphur content of hot metal from 0.070% to a level of 0.020%, i.e. a desulphurisation efficiency of 70–75%, the operating parameters would be:

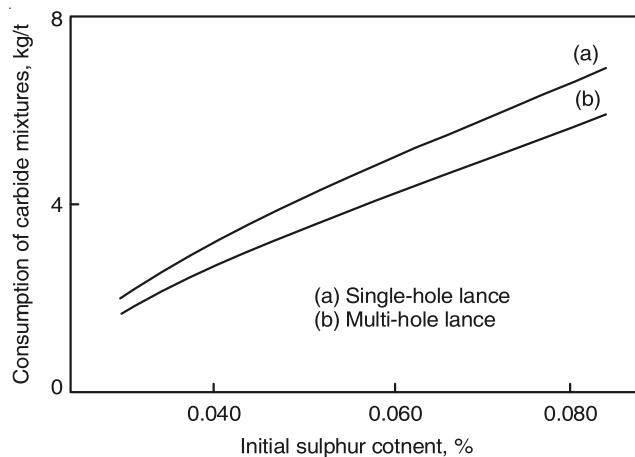
- Reagent consumption: 5 kg/thm
- Reagent rate: 45 kg/minute
- Hot metal temperature: 1300°C and more.

It is possible to complete the treatment in around 15–20 minutes in most cases by adjusting the reagent addition rate. For this purpose, sometimes even two lances are used as shown in Figure 16.12 (Frithjof et al. 1980).

## 16.9 SIMULTANEOUS REMOVAL OF SULPHUR AND PHOSPHORUS

Based on Japanese research, the optimum conditions for simultaneous removal of sulphur and phosphorus have been identified as follows:

- Slag basicity, CaO/SiO<sub>2</sub> > 2
- Hot metal temperature < 1400°C
- Hot metal silicon < 0.25%



**Figure 16.12** Consumption of calcium carbide as a function of the initial sulphur content in hot metal using single-hole and multi-hole injection lances (final sulphur 0.015 %).

The pre-treatment procedure is carried out in two-stages—first, desiliconisation, and second, simultaneous removal of sulphur and phosphorus using either lime-based or soda-based reagents. Since the silicon content of Indian hot metal is far higher than that in Japan, the first-step becomes even more important.

In any case, it is not advisable to attempt the reduction of silicon, sulphur and phosphorus simultaneously because of the following reasons:

- High reagent consumption coupled with abnormal drop in temperature, which would pose problems in steelmaking
- Severe slag handling problems
- Unfavourable techno-economics.

## 16.10 GENERAL COMMENTS ON PRE-TREATMENT

In recent years, injection metallurgy has been developed to such an extent that it is now widely used to pre-treat hot metal before charging into BOF vessels, thereby virtually restricting steelmaking to decarburisation alone. Desulphurisation has now become an integral part of most integrated steel plants. Reagents like soda ash were directly added into open ladles earlier, but owing to ecological considerations (aggressive fumes, ground water contamination by the post-treatment slag, etc.), injection of calcium carbide based reagents is now widely employed. Efficient removal of the slag after pre-treatment, utilisation of the optimum lance(s) design and geometry as well as the development of suitable refractories for the ladle in which pre-treatment is carried out, are areas in which work is still continuing.

Nonetheless, it can be concluded that with ever-increasing demand for lower levels of impurities in steel (particularly sulphur and phosphorus), pre-treatment of hot metal will be adopted even more widely in the years to come.

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- Frithjof, T., Eichinger, and Reinhold. K. Grosz, Scanjet II, 2nd International Conference on Injection Metallurgy, Lulea, Sweden, Preprints, Jernkontoret, June, 1980.
- Gupta, S.S. and Amit Chatterjee, *Blast Furnace Ironmaking*, SBA Publication, 1995.
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# 17

## Metallurgical Features of Oxygen Steelmaking

### 17.1 INTRODUCTION

Chapter 3 contained an outline of modern steelmaking processes as an introduction. Chapter 15 presented some important physicochemical aspects of primary steelmaking processes including basic oxygen steelmaking (BOS). The description of BOF plant practices has been given in Chapter 16. This chapter will deal with the metallurgical features of oxygen steelmaking processes only. For the sake of logical presentation of this chapter, some important points from the earlier chapters are reproduced below.

1. In the 1950s, the size of the LD converters was a maximum of 50 tonnes of liquid steel and oxygen was top blown through a single-hole lance. With the passage of time, the vessel size kept on increasing. Converters above 150 tonnes are very common now, and many above 250 tonnes in capacity are in operation. This has necessitated increasing the number of holes in the lance for better distribution of the total oxygen required for refining. 5–6 hole lances are common nowadays and even 8 hole lances are in use.
2. Through extensive investigations in the 1960s, it was found that the molten metal bath was not homogeneous with respect to temperature and composition during oxygen blowing in BOFs, despite stirring by the top jet as well as vigorous evolution of CO gas owing to the reaction of carbon in the bath with oxygen. It was also found that this inhomogeneity was resulting in serious process control problems. Interestingly, it was also found that simultaneous bottom gas injection, even at a very low flow rate, was capable of homogenising the bath.
3. In continental Europe (France, Germany, Luxembourg, etc.), a significant fraction of hot metal contains high phosphorus (1.5–2 wt. %). The classical BOF process was not found suitable. Instead, variants of the original LD process (like, LD–AC) were innovated to refine high phosphorus hot metal by simultaneous blowing of lime powder and oxygen. This resulted in engineering/environmental problems connected with lime fines and was

not an acceptable long-term solution. The problem was resolved in late 1970s by the introduction of specially designed bottom tuyeres through which oxygen could be introduced directly into the bath. To take care of the heat generated in the tuyere area, the inner oxygen tube had to be protected by shielding it with hydrocarbons. This innovation gave rise to the OBM process in Germany, LWS in France and Q-BOP in the USA.

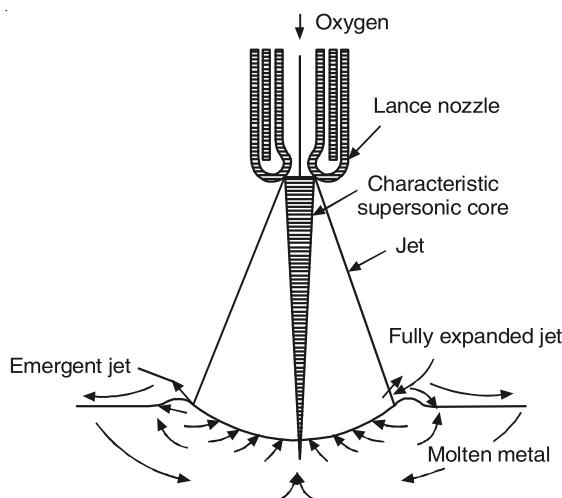
In the decade of 1970s, several commercial processes were patented where oxygen was blown through a top lance, but mixing in the bath was simultaneously enhanced by blowing inert gas at a low flow rate through several bottom tuyeres. These processes, under the generic name of combined blown processes/bath agitated processes, are the most widely used oxygen steelmaking processes in the world today.

In this chapter, the metallurgical features of all oxygen steelmaking processes—exclusive top blowing, combined blowing and bottom blowing will be taken up.

## 17.2 INTERACTION OF THE OXYGEN JET WITH THE SURROUNDINGS AND THE BATH

### 17.2.1 Mechanical Interactions

Figure 17.1 schematically shows the nature of jet-bath interaction. The *Mach Number* can be as high as 2.5, when the *Supersonic Jet* emerges from the nozzle. In the potential core (length three to seven times nozzle diameter), the velocity is constant. Then the jet starts entraining the surrounding fluid (in this case, the gaseous converter atmosphere). This *Jet Entrainment* causes lateral expansion of the jet and decreases the jet velocity to make it finally *subsonic*. Beyond a distance about 25–30 nozzle diameters, the supersonic jet becomes fully subsonic.



**Figure 17.1** Mechanical interaction of oxygen jet with the molten metal bath causing circulation in the bath outwards on the surface and upwards along the axis (schematic).

The jet ultimately impinges on the liquid metal bath surface to form a cavity. The impingement of the jet and the dissipation of the jet momentum causes circulation of the liquid bath in the upward direction at the vessel central axis. The intensity of jet-bath interaction is expressed in terms of the *Jet Force Number* (JFN) defined as:

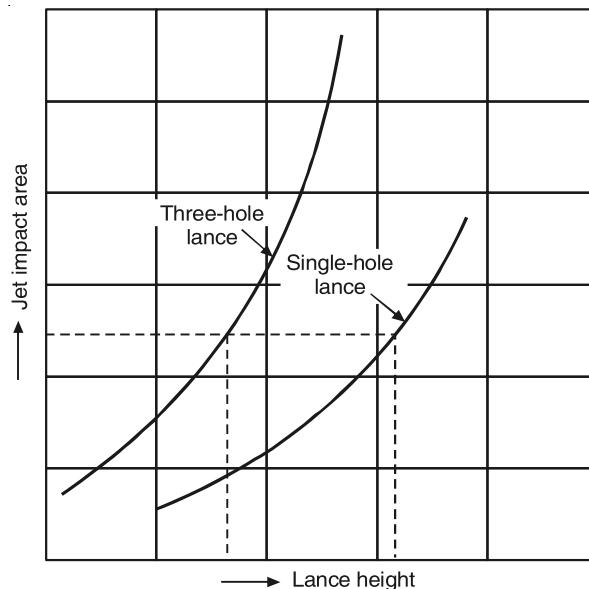
$$\text{JFN} = \frac{\text{Gas pressure } (P_d) \times \text{Nozzle diameter } (d_n)}{\text{Lance height } (L)} \quad (17.1)$$

where  $L$ , the height of the lance tip above the bath surface, is a key operating variable in the BOF process. With changing JFN (say, by changing  $L$ ), the following behaviour of the liquid bath at the impact zone has been observed.

- At low JFN, dimpling with a slight surface depression (as in Figure 17.1)
- At medium to high JFN, splashing with a shallow depression
- At high JFN, penetrating mode of cavity with reduction in splashing.

Only the last two types of behaviour are usually encountered in BOF steelmaking. Metal droplets are formed on the lip of the cavity and get ejected (i.e. splashed) above the bath in both modes. Several empirical relations have been proposed co-relating the depth of jet penetration into the bath with the variables  $P_d$ ,  $d_n$ ,  $L$ , etc. They give somewhat different predictions and more importantly, since they are generally for single-hole lance, and nowadays multi-hole lances are employed, these relations cannot be directly applied to current oxygen steelmaking.

As stated earlier, for the larger size BOFs in use today, in order to distribute the oxygen over a larger surface of the bath, multi-hole lances are employed. The axes of each of the nozzles in a multi-hole lance are typically inclined at around  $10^\circ$  with respect to the lance axis. Figure 17.2 shows schematically the increase in jet impact area on the bath by switching over from a single-hole to a three-hole lance.



**Figure 17.2** Comparison of jet impact areas for single-hole and three-hole lance.