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The necessity of hot metal desiliconization process

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Abstract

The technology of hot metal pretreatment had tremendous improvements in past decades and was widely used by the overwhelming majority of steelworks in Japan. While, since the first hot metal pretreatment station was established in Taiyuan Iron and Steel Co., Ltd in the later period of 1980s, this process began to be applied in domestic steel plants. And now 30 years have passed, the desiliconization and dephosphorization process are still rarely seldom used in China except desulphurization process in most carbon steel plants. So in this paper, the metallurgical principles and effects of hot metal desiliconization were analyzed in great details. Meanwhile, the optimum silicon content of hot metal between iron-making and steelmaking process was summarized and calculated. The necessity of hot metal desiliconization was discussed for the iron and steel companies in China.

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Keywords: Desiliconization; Dephosphorization; Less slag steelmaking; Duplex steelmaking process; Low-phosphorous steel

1. Introduction

Hot metal pretreatment process, including desiliconization, dephosphorization and desulphurization began to be popular during last decades in Japan. An important benefit of it prior to the oxygen converter process is optimizing the operation of converter via pre-treatment under thermo-dynamically favorable conditions. And among which, silicon removal is beneficial to converter by reducing chemical attack on

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the basic refractory lining and allowing the use of only minimal amounts of slag-making flux, thereby minimizing slag volume, maximizing metal yield and stabilizing converter operation.

The technology of hot metal pretreatment had tremendous improvements in past decades and was widely used by the overwhelming majority of steelworks in Japan. Even in some steel plants, 100% hot metal was pre-treated, such as the SRP process (Simple Refining Process) developed by Wakayama steelworks of SMI. Different from Japan, North American and European steelworks presently focused on desulfurization due to the common use of relatively low phosphorous containing iron ores [1]. Chinese situation is similar to North America and Europe. At present, the percentage of hot metal pretreatment is about 60% and most of Chinese steelworks often choose only desulfurization process, the process of desiliconization and dephosphorization were merely in use in some stainless steel companies to obtain low phosphorous hot metal, such as TISCO stainless steel and Baosteel stainless steel.

In fact, since the first hot metal pretreatment station was established in Taiyuan Iron and Steel Co., Ltd in the later period of 1980s, hot metal pretreatment process began to be accepted by domestic steel plants. And now, 30 years have passed, the desiliconization and dephosphorization process are still rarely seldom used in China except desulphurization process for most carbon steel plants. In addition, nowadays in China, the silicon content of hot metal fluctuates severely because of the actual operation practice in blast furnace. Furthermore, there are almost no desiliconization facilities, so this has great effects on next converter blowing. For example, silicon content of hot metal before being charged to converter ranges from 0.2 to 1.2% in a steelworks, which results in unstable convert blowing control, larger lime consumption and slag volume, serious spitting and so on, especially for those steel works where hot metal is transferred in one ladle from blast furnace to converter. And then it is imperative to improve this situation. Another reason, it can be predicted that rich iron ore resource is becoming exhausted in future and its price fluctuates constantly. To response this, the lower-grade iron ore can be developed. And there are abundant lower-grade iron ore, such as high-phosphorous iron ore in China. In order to make better use of these iron ores, hot metal pretreatment is necessary to adopt to remove the impurities, especially phosphorous.

2. Desiliconization of hot metal

2.1. Silicon content in hot metal

It is well-known that the silicon content mainly comes from ash content of coke in blast furnace process and its content is also dependent on the volume of blast furnace. There is a quantitative relationship between them, which is shown in Table 1. It can be clearly seen that the larger blast furnace is, the lower the silicon content of hot metal. When the volume of blast furnace is larger than 1500m³, the silicon content of hot metal can be stably reduced to no more than 0.4%.

Table 1. Silicon content from blast furnace with different capacities

Blast furnace capacity	1500~3000m ³	≧ 5000 m ³ or so
Silicon content of hot metal, %	≧ 0.4	≧ 0.25

Silicon content of hot metal is much lower and stable in Japan, which is shown in Table2 [2]. We can see that the silicon content is all decreased to less than 0.2% and when the volume of blast furnace is higher, the silicon content of hot metal is lower.

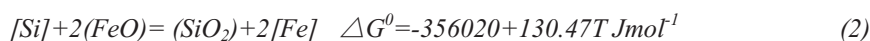
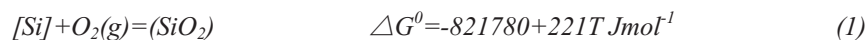
Table 2. Silicon content from blast furnace with different capacities

Steelworks	Volume of blast furnace, m ³	Silicon content, %	Year
Mizushima works of JFE	(No.2 blast furnace)	Average 0.18	1984
Fukuyama works of NKK	2828(No.2 blast furnace)	Average 0.15	1984
Nagoya works of NSC	3424(No.3 blast furnace)	Average 0.12	1985

However, silicon content of hot metal in Chinese steelworks is far higher than this and fluctuates sharply. Data from some steelworks shows that silicon content from blast furnace with capacity of 2500m³ is ranging from 0.2 to 0.8%. Of course, there are many measures can be taken to reduce silicon content. One of is to realize the low silicon operation practice of blast furnace, which is not introduced here. The other is pre-desiliconizaion during hot metal pretreatment process, which will be referred to in the following.

2.2. Metallurgical principles and methods of desiliconization

Silicon is an important heat source in converter and usually removed by oxidization method owing to its superior affinity to oxygen. The slag-metal reaction can be expressed by Equation (1) and (2). The oxidation product SiO₂ will combine with alkaline in slag-making material, e.g. CaO, and forms 2CaO·SiO₂, then silicon is removed.



Often the oxygen source can be supplied via oxygen gas (O₂) or solid oxidant (scale, sintered ore and iron ore powder). Initially, desiliconization process was performed by adding iron ores or sinter to hot metal during its flow in blast furnace runner [3]. Further improvements were attained by addition via subsurface injection of the agents in dedicated vessels, such as torpedo cars or ladles [4]. This brought on the use of a variety of chemical agents, including soda ash. While, since the evaporation of soda will erode the refractory of ladle, which lead to the lower operation efficiency and lining life. Meanwhile the price of soda ash is higher, so this flux was not used again. When using iron oxides for desiliconization, it is essential to remove the process slag before the process of desulfurization or dephosphorization for efficient performance.

There are many factors influencing the reaction mechanism of hot metal desiliconization, one of is the type of desiliconization agents. The rate of desiliconization changes with different desiliconization agents, which is shown in Fig. 1. It can be seen that oxygen top blowing is the most efficient for desiliconization and the oxygen gas is more efficient than solid oxidant. Meanwhile, desiliconization reaction rate is controlled by the rate of oxygen supply when oxygen gas is used, while the rate of silicon oxidation was controlled by the FeO in the slag when the solid oxygen is used [5].

Generally, being desiliconization agents, oxygen gas and solid oxygen had different desiliconization rate. In practical operation, to improve desiliconization rate and ensure temperature after desiliconization process, both of oxygen gas and solid oxygen can be used by adjusting the percentage of them.

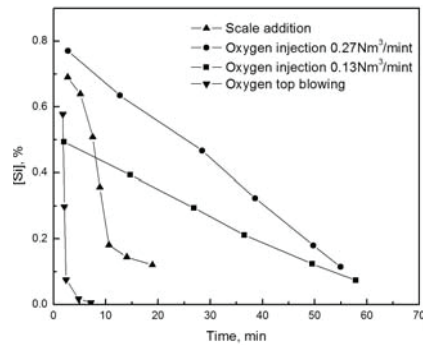


Fig. 1. Comparison of desiliconization behavior

3. Metallurgical effects after Desiliconization process

3.1. To produce low-phosphorous steel

Just like sulfur element in steel, appreciable residual contents of phosphorous have an adverse effect on not only the mechanical properties but also corrosion resistance of steels. While, for high grade and high purity steel, such as pipeline steels and interstitial free steels, much lower phosphorous content is strictly required.

It was well accepted that the development of desiliconization was based on the need of dephosphorization, because the silicon content of hot metal had great effect on the dephosphorization. As is known to all, silicon has higher affinity and is preferred oxidation than phosphorous. If silicon content of hot metal is higher, the agents will react with silicon during the process of dephosphorization, and then the amount of dephosphorization agents can be increased, meanwhile, the efficiency of dephosphorization will be reduced. In order to improve the dephosphorization efficiency, the silicon content of hot metal is usually in the range of 0.1~0.15%, when CaO-based agents are adopted for dephosphorization, which can not only promote the dissolution of lime but also increase the fluidity of slag [6].

3.2. To realize less slag steelmaking

Less slag steelmaking process means refining of low silicon hot metal in converters. And of course, it was noticed that reducing silicon content of hot metal was effective to control the slag volume of converters. Based on this view, the slag minimum refining process (SMP), less slag process (LSP) zero slag process (ZSP) and slag recycling process (SRP) had been developed in 1985 or so [7-9]. After desiliconization and dephosphorization process, the low-silicon hot metal was charged to converters, the main tasks of converter operation were reduced to be decarburization and heating. A comparison between conventional converter and less slag process under the condition of initial hot metal with 0.11% phosphorous content was shown in Table 3. Obviously, great economic performance could be achieved.

Table 3. A comparison between conventional converter process and SMP

Process route	Conventional	SMP
Silicon content of hot metal, %	≈ 0.4	≈ 0.25
Si of hot metal, %	0.6	0.15
Slag volume, kg/t	110	42
Lime consumption, kg/t	42	18
Metal yield, %	Standard	Improve 0.5~0.7%
Erosion of refractory	Standard	Decreased
Others	Stopping happened	Stable blowing and no slopping

4. The optimum silicon content in different steelmaking process

As stated above, to produce low-phosphorous steel and achieve stable operation of converter, silicon must be removed to certain content. Then, how much lower silicon content should be reduced, and why?

Firstly, it is important to recognize that dephosphorization occurs only silicon content of hot metal is less than 0.15%, which have been talked of. And this conclusion has been used to guide the operation of dephosphorization in torpedo car, transfer car or ladle during hot metal pretreatment process.

Secondly, with the percentage of low-phosphorous steel increasing, other dephosphorization methods had been developed in converters, such as SRP process, we can also call it duplex steelmaking process. And how much is the optimum silicon content in this process?

It is convinced that this process differs from the traditional converter steelmaking. We all know that the new planning for steel industry in the following 5 years of China requires high speed, high quality and resource environment-friendly steelmaking process. Duplex steelmaking process (DSP), being the total hot metal pre-treatment process, can realize the above purposes and it often applied two top and bottom blown converters for preliminary phosphorous removal, thereby dividing phosphorous and carbon removal processes between two different furnaces, which is shown in Fig. 2.

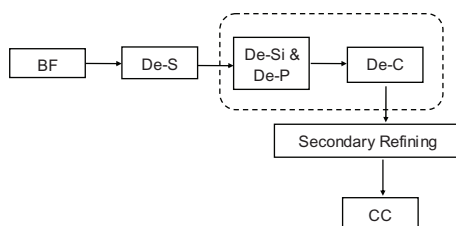


Fig. 2. The flow of Duplex steelmaking process

In this process, less slag blowing can be achieved in De-C furnace because of pre-desiliconization and dephosphorization treatment in De-P furnace. One of task of this DSP is rapid dephosphorization in De-P furnace. To realize this, optimum silicon content is required. According to the operating parameter of De-P furnace, a mass equilibrium calculation had been made, and the optimum silicon content based on basicity of slag and distribution ratio of phosphorous (L_P) in terminal slag was calculated, which was demonstrated in Table 4 and Table 5.

Table 4. Silicon content of hot metal in De-P furnace with phosphorous content of semi-steel less than 0.02%

Initial conditions	[P] _{hm} 0.1%	[P] _{sm} 0.02%	L _p 80~150	Slag volume 20~35kg/t
Basicity of slag	1.8	2	2.5	3
Silicon content of hot metal, %	0.23~0.4	0.21~0.36	0.17~0.29	0.14~0.24

Table 5. Silicon content of hot metal in De-P furnace with phosphorous content of semi-steel less than 0.01%

Initial conditions	[P] _{hm} 0.1%	[P] _{sm} 0.01%	L _p 150~200	Slag volume 45~60kg/t
Basicity of slag	1.8	2	2.5	3
Silicon content of hot metal, %	0.52~0.7	0.47~0.63	0.38~0.50	0.31~0.42

That is to say, the good effects of dephosphorization can be obtained by controlling the silicon content of hot metal charged to De-P converter. When phosphorous content in semi-steel is required to be less than 0.025%, the silicon content of charged hot metal should be controlled to be less than 0.4%. When phosphorous content in semi-steel is required to be less than 0.01%, the optimum silicon content is influenced by the basicity of slag. Correspondingly to improve dephosphorization efficiency, the basicity of slag should be higher than 2.5 in the practical operation and the silicon content is no more than 0.5%.

5. Summary and conclusions

After the above analysis, the following conclusions could be drawn.

- 1) It is imperative to pre-desiliconization to achieve stable converter blowing and less slag blowing.
- 2) There is optimum silicon content for dephosphorization in torpedo car, transfer car or ladle during hot metal pretreatment process, the silicon content should be reduced to no more than 0.15%.
- 3) For duplex steelmaking process, the optimum silicon content is dependent on the operation parameters of De-P furnace. When phosphorous content in semi-steel is required to be less than 0.02%, the suitable silicon content is less than 0.4%. When phosphorous content in semi-steel is lower than 0.01%, the silicon content is correspondingly no more than 0.5%.

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