Development of Smelting Reduction Ironmaking Process

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Abstract: The production practice of COREX 3000 shows that COREX is a new type of ironmaking production method that has become mature in recent years. While achieving good environmental and social benefits, it also faces many problems. Production found that COREX 3000 has a high fuel cost and high production costs. Coal injection through the tuyere can effectively use the pulverized coal generated during transportation, reduce production costs, and obtain better economic benefits. During the COREX coal injection process, pulverized coal passes through the tuyere of the melter and gasifier and enters the swirling zone for combustion. Generate hot gas to meet the needs of metallurgical reactions. Unburned pulverized coal moves up, participates in metallurgical reactions, or stays somewhere. This has a certain effect on the melting gasifier.

1 Background

Melting reduction refers to the smelting process of producing qualified molten iron with equipment other than blast furnace [1]. The earliest melting reduction includes two aspects from the viewpoint of researchers. First, there is no need for iron ore powder to be briquetted. Second, expensive metallurgical coke is not used. At the same time, in terms of production, it is required to obtain iron of qualified quality without causing pollution. The current researchers generally believe that iron ore, sinter and pellet are used as the main raw materials, while a small amount of coke can be used in smelting. However, non-blast furnace ironmaking methods that do not use coke as the main fuel belong to its category [2].

Since the 1920s, the research and development of fusion reduction method has begun. Professor Eketorp put forward the thermodynamic principle of melting reduction in 1960s [3-4].

\[
\begin{align*}
\text{Fe}_2\text{O}_3 + 3\text{C} &= 2\text{Fe} + 3\text{CO} & \Delta H_{1700} &= 455.6 \text{ kJ/mol} \quad (1) \\
3\text{CO} + 3/2\text{O}_2 &= 3\text{CO}_2 & \Delta H_{1700} &= -840.2 \text{ kJ/mol} \quad (2) \\
\text{Fe}_2\text{O}_3 + 3\text{C} + 3/2\text{O}_2 &= 2\text{Fe} + 3\text{CO}_2 & \Delta H_{1700} &= -384.6 \text{ kJ/mol} \quad (3)
\end{align*}
\]

Researchers expect that the heat released by reaction (2) can effectively compensate for the heat required by reaction (1). Summing up its characteristics is to combine the reactions, resulting in the complete conversion of carbon into the final product CO2. Theoretically, the lowest carbon consumption in the production process is 321 kg per ton of iron.
Since 1970s, various countries have begun to study non-blast furnace ironmaking technology, especially two-step melting reduction. In this process, iron ore or iron ore powder is properly prereduced by using the tail gas of final reduction. So far, the main processes of the two-step method in the world include COREX, DIOS, AISI, FINEX, HIsmselt, etc. [5-8]. Among these melting reduction processes, few have successfully realized industrial production. COREX is the first smelting reduction ironmaking process to realize industrial production, and it has already produced steel at Baosteel in China.

2 COREX process

2.1 Process development

COREX process was originally called KR method [9]. It is a two-step melting reduction process developed by Korf and VAI in the late 1970s. The registered trademark is COREX. At the end of 1989, the first industrial COREX ironmaking plant was named C 1000. Its ISCOR company in Pretoria, South Africa, was completed and put into production at the same time. In November 1995, one COREX unit was built in POSCO, South Korea and named C 2000. Later it was modified and FINEX was named. In December 1998, one COREX unit was built in Saldana, South Africa and named C 2000. In August 1999 and April 2001, two COREX units were built in Indian G Company and named C 2000. On November 8, 2007, the first COREX ironmaking plant was built in Luojing, Pugang, Baoshan Iron and Steel Group and named C 3000 [10].

2.2 Process flow

COREX’s process flow includes three main parts, as shown in Figure 1. COREX’s core equipment includes iron ore reduction furnace, melting furnace and gas distribution system. COREX chemical reactions are numerous. They are shown in Table 1.

The system is added with artificial pellet rich ore, natural high-quality lump ore, a small amount of limestone and a small amount of dolomite. In order to reduce the cohesiveness of iron-containing materials and maintain the air permeability of the shaft furnace bed, a small amount of coke is added to the materials. The temperature of reducing gas is about 800~850°C. This gas enter that shaft furnace through an annular blast pipe located at the bottom of the shaft furnace. Shaft furnace gas is discharged from the top. Its temperature is 250~300°C. Pellets and other materials are reduced in a shaft furnace. The metallization rate of DRI is 70%~90%. Directly reduced iron, flux, coke and other materials become shaft furnace products. These products are discharged from the shaft furnace through a screw feeder.

The shaft furnace product at high temperature enters the melter-gasifier through the downcomer. It is arranged in a suitable position by a cloth baffle. In addition, non-coking coal (lump coal), coke and silica are continuously distributed to the material bed through a sealed tank and a universal distributor. Industrial pure oxygen blown from the tuyere of the gasifier reacts with coke to generate a large amount of gas and release heat. This area is called the combustion zone. The produced gas contains a lot of heat. This part of heat is the main heat source for the whole COREX ironmaking system. Gas transfers heat to the falling material in the furnace. This meets the needs of melting directly reduced iron and flux. At the same time molten iron and slag are generated. Slag iron is accumulated in the hearth. This area is called slag iron belt. The energy utilization efficiency of the equipment depends on the distribution of gas flow in the bed to a large extent. Of course, it also includes the conduction and utilization of sensible heat from gas. There is a free space in the upper part of the gasifier. Its working temperature range is 980~1050°C. This temperature can ensure that all volatiles released from coal can be cracked. At the same time, it can provide a part of heat for pre-reduction of pellets.
Figure 1 Three Core Devices

Table 1 The Reactions

| Shaft furnace | Melting Gasifier |
|---------------|------------------|
| $3\text{Fe}_2\text{O}_3 + \text{CO} = 2\text{Fe}_2\text{O}_4 + \text{CO}_2$ | $\text{FeO} + \text{CO} = \text{Fe} + \text{CO}_2$ |
| $\text{Fe}_2\text{O}_4 + \text{CO} = 3\text{Fe}_2\text{O}_3 + \text{CO}_2$ | $\text{FeO} + \text{C} = \text{Fe} + \text{CO}$ |
| $\text{FeO} + 3\text{CO} = \text{Fe} + 2\text{CO} + \text{CO}_2$ | $\text{MnO} + \text{C} = \text{Mn} + \text{CO}$ |
| $3\text{Fe}_2\text{O}_3 + \text{H}_2 = 2\text{Fe}_2\text{O}_4 + \text{H}_2\text{O}$ | $\text{SiO}_2 + 2\text{C} = \text{Si} + 2\text{CO}$ |
| $\text{Fe}_2\text{O}_4 + \text{H}_2 = 3\text{Fe}_2\text{O}_3 + \text{H}_2\text{O}$ | $\text{FeS} + \text{CaO} = \text{FeO} + \text{CaS}$ |
| $\text{FeO} + 3\text{H}_2 = \text{Fe} + 2\text{H}_2 + \text{H}_2\text{O}$ | $2\text{FeO} + \text{Si} = 2\text{Fe} + \text{SiO}_2$ |
| $\text{Fe} + \text{H}_2\text{S} = \text{FeS} + \text{H}_2\text{O}$ | $\text{FeO} + \text{Mn} = \text{Fe} + \text{MnO}$ |
| $\text{CaO} + \text{H}_2\text{S} = \text{CaS} + \text{H}_2\text{O}$ | $3\text{Fe} + \text{C} = \text{Fe}_2\text{C}$ |
| $\text{MgO} + \text{H}_2\text{S} = \text{MgS} + \text{H}_2\text{O}$ | $\text{C} + \text{H}_2\text{O} = \text{CO} + \text{H}_2$ |
| $\text{CaCO}_3 = \text{CaO} + \text{CO}_2$ | $\text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2$ |
| $\text{CaMg(CO}_3\text{)}_2 = \text{CaO} \cdot \text{MgO} + 2\text{CO}_2$ | $\text{C} + \text{CO}_2 = 2\text{CO}$ |
| $2\text{CO} = \text{CO}_2 + \text{C}$ | $\text{C} + \text{O}_2 = \text{CO}_2$ |

The reaction with * in the table indicates that the reaction may occur again in the melter-gasifier.

A large amount of gas is produced in the melter-gasifier. These gases contain furnace dust. In the gas treatment system, cooling gas is added. The gas temperature was reduced to about 850°C. The furnace dust is separated by a thermal cyclone. The dust content is reduced from 100–200 g/m3 to about 20 g/m3, which is beneficial to production. The collected dust is sprayed into the melter-gasifier. This method is beneficial to improve the yield of molten iron. The larger part of purified gas is supplied to up. The rest of gas is cooled by circulation. It is called cooling gas. Excess gas can control the pressure in COREX production.

2.3 COREX 3000

COREX's annual design output is 1.5 million tons [11]. Its shaft furnace has a total height of 29 m. The material layer height is 12 m. The inner diameter of shaft furnace is 8 m. There are 8 screw dischargers at the lower part of the shaft furnace. The screw discharger includes some equipment, which consists of screw conveyor, blanking pipe and distributor.

The height of Pugang's lower furnace is 33 m. The inner radius of its hearth is 4.5 m. It has 28 tuyeres. These tuyeres inject industrial pure oxygen. The tuyere consists of small sleeve, large sleeve, oxygen lance and other parts. Six lances are installed on the free zone melter. These burners are used to regulate the heat of production. The gasifier has two tapholes. The angle between the two tapholes is 180°.

Four hot cyclone dust collectors are arranged in the gas output pipeline system of the melting gasifier. The high temperature gas pipeline from the Melting Gasifier and the inner wall of the dust
remover are lined with refractory materials. The dust collected by the hot cyclone is blown into the melting gasifier by four dust burners on the upper part of the melting gasifier through four sets of dust injection systems.

3 Melting Gasifier

Melting Gasifier, also known as melting gasifier, is a complex container for gas-solid-liquid multiphase high temperature reaction. Its main internal structure and external structure are shown in Figure 2, and the corresponding areas of its internal physical and chemical behavior are shown in Figure 3.

An important function of melting gasifier is to melt DRI and produce high quality molten iron. Most of the oxygen in the melting gasifier is blown in from the tuyere. Semicoke burns in front of the tuyere, producing a lot of high temperature gas. The sensible heat of hot gas is transferred to the material in the rising process, which provides the heat needed for the final reduction, melting, slag iron separation and other metallurgical reactions of iron oxide. The molten iron and slag are deposited in the hearth and finally discharged from the iron port. The production efficiency of melter-gasifier is greatly affected by the bed.

The added material forms a material column in the furnace. The existence of the material column increases the contact time between slag iron and semi coke, which creates conditions for the full reaction of hot metal carburizing and desulfurization. The bed under the tuyere is composed of coke and semi coke, in which the reaction directly affects the composition of molten iron. The reaction of desulphurization and carburization of molten iron reaches or approaches equilibrium in this region. The reaction between slag iron and semi coke promoted the final reduction of Si and Mn, and ensured that COREX process could produce products with similar quality to molten iron of blast furnace.

![Figure 2 Schematic diagram of COREX melter gasifier](image-url)
Another important function of melting gasifier is to produce high quality gas. It needs to ensure that the dome temperature of gasifier is about 1000 °C. If the dome temperature is lower than 950 °C, the hydrocarbon in the volatile can not be completely cracked, which leads to the decline of gas quality. At the same time, tar will appear in the pipeline of the gas treatment system and block the gas pipeline. If the temperature of the vault is higher than 1100 °C, it may cause the dust soft melting to stick at the inlet of the hot cyclone. This will cause the gas pipeline to be blocked. At the same time, due to the high temperature of the gas, the CO content in the gas is too high. After adding cooling gas, the temperature decreases. This causes carbon evolution and affects the strength of the gas pipeline. Generally, measures such as adjusting coal supply, oxygen supply distribution ratio, DRI feeding speed and dust injection are taken to control the output gas temperature of the melting gasifier.

4 Conclusion

The production practice of COREX 3000 shows that COREX, as a new ironmaking method, has become mature in recent years. At the same time, it also faces many problems. Pugang found that the COREX 3000 fuel was relatively high and the production cost remained high [12-13]. Coal injection through tuyere can effectively utilize the pulverized coal produced in the transportation process, reduce the production cost and obtain better economic benefits.

In the process of production, it is often found that the air vent is damaged. In order to strengthen the control of tuyere area, coal injection technology in blast furnace ironmaking process is introduced into COREX ironmaking process. It can be used as a means to adjust the temperature of the tuyere area. Strengthen the control of tuyere area in the production site to reduce the damage rate of tuyere. This is conducive to stable production and has important practical value.

In the process of COREX coal injection, pulverized coal enters the raceway through the tuyere of the Melting Gasifier for combustion. Hot gas is generated to meet the needs of metallurgical reaction. Unburned pulverized coal moves upward, participates in metallurgical reaction or stays somewhere. This has a certain impact on the melting gasifier. Melting gasifier is the key equipment of COREX process, which plays the role of gas making, reduction, melting, carburizing, etc. In many published patents and documents [14-17], the description of the internal structure of the melting gasifier is not consistent. The possible areas from top to bottom include fluidization zone, block zone, soft melting zone, dropping zone, combustion zone and slag iron zone. Determine the area of gasifier, and study the influence of different operation conditions on its internal. It can be used as a basis for the research of COREX Melting Gasifier, and has important theoretical significance.

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