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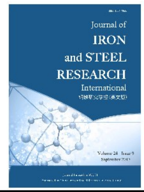

Dephosphorization stability of hot metal by double slag operation in basic oxygen furnace

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ABSTRACT

Double slag process was adopted to produce low-phosphorus steel from middle-phosphorus hot metal. To achieve a stable dephosphorization operation, conventional process was modified as follows: the blowing time was extended by approximately 1 min by reducing the oxygen supply flow rate; calcium ferrite pellets were added to adjust the slag composition and viscosity; the dumping temperature was lowered by 30－50 ℃ by the addition of calcium ferrite pellets during the double slag process to prevent phosphorus in the slag from returning to the molten steel; and the bottom-blown gas flow was increased during the blowing process. For 40 heats of comparative experiments, the rate of dephosphorization reached 91% and ranged between 87% and 95%; the phosphorus, sulfur, manganese, and oxygen contents calculated according to the compositions of molten steel and slag as well as the temperature of molten steel at the end-point of the basic oxygen furnace process were similar to the equilibrium values for the reaction between the slag and the steel. Less free calcium oxide and metallic iron were present in the final slag, and the surface of the slag mineral phase was smooth, clear, and well developed, which showed that the slag exhibited better melting effects than that produced using the conventional slag process. A steady phosphorus capacity in the slag and stable dephosphorization effects were achieved.

1. Introduction

Inexpensive high-phosphorus ore has been added to blast furnaces to reduce the production costs of steelmaking in many plants[1-3]; the use of such ore has resulted in hot metal phosphorus contents between 0.12% and 0.20% and has caused many difficulties in converter production. The current Chinese converter devices are appropriate for smelting hot metal with phosphorus contents less than 0.10%. Achieving the required phosphorus content in molten steel via single slag process is difficult when the phosphorus content in hot metal is greater than 0.10%.

Previous researches[4-7] have indicated that double slag operation can be adopted to accommodate medium-phosphorus hot metal. However, following problems persist:

(1) The dephosphorization effect in the primary blowing period of a converter is unstable. The temperature and slag composition must be controlled before the slag is dumped because of the poor slag-forming capability of the converter.

(2) Slag dumping is difficult. The first slag is usually dumped within 3－5 min, and certain preconditions must be met to ensure appropriate melting behavior and viscosity of the slag.

(3) Slag undergoes severe drying during double slagging. The slag is easily dried during the smelting process with high basicity, and less slag is removed after the two slagging operations. Extensive drying causes the rephosphorization of molten steel, resulting in an unstable dephosphorization rate.

Many scholars[8-17] have attempted to solve the aforementioned problems. Tian et al.[8] reported that approximately 80% of the phosphorus was removed in the first slag when the Fe^{3+} content and basicity were high, whereas the Fe^{3+} content had less effect on dephosphorization during the second slag treatment. Yang et al.[9] studied the dephosphorization mechanism of the double slag process and speculated that dephosphorization was determined by the mass transfer of phosphorus from the

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slag and the metal interface to the bulk slag phase rather than by the equilibrium thermodynamic conditions before intermediate deslagging. Naito et al.[10] varied the inclination angle of the converter and adjusted the properties of the slag to increase the deslagging rate. Tripathy et al.[11] optimized the slag chilling process near the blowing end to reduce the phosphorus content in molten steel. Jeoungkiu et al.[12] proposed that the phosphorus distribution ratio depends more on the CaO content than on the Fe_tO content of the slag. Babenko[13] attributed the low oxidation rates of phosphorus in the final stages of refining to inadequate heat transfer in metals with a low carbon content.

The aforementioned research results offer no good options for achieving stable dephosphorization effects of hot metal. Therefore, an improvement scheme for increasing the dephosphorization rate of hot metal was proposed in this paper. To realize the stable operation of dephosphorization, two processing methods, referred to as process I and process II, were used to increase the dephosphorization effects of the primary blowing process of a converter and to prevent phosphorus in the converter slag from returning to the molten steel. The improvement methods include inducing rapid slag formation and ensuring appropriate slag melting characteristics and viscosity to the extent possible in the primary converter blowing process. In the final blowing stage, the second slag formation process in the converter was enhanced and the converter end-point control process was adjusted to prevent phosphorus in the converter slag from returning to the molten steel.

2. Experimental

2.1. Design and preparation of calcium ferrite pellets

To increase the slagging effect, calcium ferrite pellets were prepared. Four types of calcium ferrite pellets were designed for heating and melting tests by referring to the specifications for commercial products. The pellets were coded as A, B, C, and D, with iron oxides (total Fe 55%)-to-CaO ratios of 1.3 : 1.0, 2 : 1, 3 : 1, and 4 : 1, respectively[18]. These designed pellets were prepared using solid byproducts, including lime powder and mill scale from continuous casting and rolling operations in steel plants. A resistance furnace was used to carry out the tests. In general, the furnace was first powered on for 10-15 min to heat crucibles or refractory blocks to the desired test temperature, which ranged from 1250 to 1350 ℃. The results indicated that sample C exhibited the best melting and liquefaction characteristics; this sample was designed with a 3 : 1 ratio of iron oxides to CaO, and this ratio was selected for the calcium ferrite pellets used in the present study. The strength and wear resistance of the calcium ferrite pellet during the manufacturing process satisfy the quality requirements for converter burden.

2.2. Hot-metal double slag dephosphorization in a basic oxygen furnace

The experiments were performed using a 120 t converter; the refining time and average tapping mass of the molten steel were 37 min and 116 t, respectively. The supply intensities in normal pressure for the top oxygen lance and for the bottom stirring system were 3.3 $m^3/(t \cdot min)$ and 0.03-0.08 $m^3/(t \cdot min)$, respectively. The hot metal charged was 116 t with a temperature of 1250-1458 ℃ and C, Si, Mn, P, and S contents of 4.0%-5.8%, 0.4%-0.8%, 0.15%-0.37%, 0.102%-0.203%, and 0.006%-0.012%, respectively. The scrap charged for steelmaking was 7 t. The slag-forming materials were lime, light-burned dolomite, sinter and calcium ferrite pellets.

To increase the dephosphorization stability of the hot metal, the process was improved to ensure rapid slag formation and appropriate melting properties and viscosity of the slag. The process parameters are reported in Table 1.

Table 1 details processes I and II, which represent the conventional and improved processes, respectively. The following changes were incorporated into the improved process:

(1) The oxygen supply flow rate was reduced to extend the blowing time by approximately 1 min.

(2) Calcium ferrite pellets were added to adjust the slag composition and viscosity and to decrease the dumping temperature by 30-50 ℃.

(3) Calcium ferrite pellets were added during the double slagging process to prevent phosphorus in the slag from returning to the molten steel.

(4) The bottom-blown gas flow was increased during the blowing process.

For the experimental heats, lime and light-burned dolomite needed for the first slag were added at the beginning of oxygen blowing. Afterwards, the sinter and calcium ferrite pellets were charged according to the progress of slag formation within a 3 min period. A constant pressure and variable lance height were used for the oxygen supply. After 6 min of oxygen blowing, the converter was tilted to tap the first phosphorus-enriched slag as much as possible. At the time of slag tapping, the slag basicity was controlled in the range from 1.8 to 2.0.

2.3. Sampling and analysis methods

The chemical composition, melting point, and petrographic characteristics of the slag were analyzed. The fluorimetric method was used to measure the