Frontier of Converter Steelmaking Endpoint Control Technology

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Abstract

Converter steelmaking end point control technology has gone through three stages of development so far: static control, dynamic control and converter fully automatic control. Traditional experience-controlled steelmaking has been replaced by modern automatic control and intelligent control technology. Among them, furnace gas analysis and flue gas analysis technologies have unique advantages compared with other current technologies in terms of cost savings, shortened smelting cycle, and carbon prediction. This article will summarize and analyze the end-point control technology of converter steelmaking, and put forward prospects for further technological improvements in the future to improve the end-point hit rate, reduce process energy consumption, and realize green steel smelting.

Keywords

BOF; Endpoint Control; Flue Gas Analysis.

1. Introduction

Converter steelmaking end point control technology is also of great significance to resource utilization and environmental protection. Usually end-point control mainly refers to the control of carbon content and temperature of molten steel at the end-point. Too high a carbon content is unfavorable for dephosphorization and desulfurization, while too low a carbon content will result in a significant increase in oxygen and nitrogen content; a reasonable temperature is the guarantee for the execution of subsequent processes.[1][2] Inaccurate endpoint control will extend the smelting time, reduce the life of the furnace lining, and increase metal consumption, Affect the quality of steel. Modern end-point control technology can also realize the on-line monitoring and control of environmental pollutants, reduce the occurrence of environmental pollution, and realize sustainable development and green manufacturing.

2. Analysis of Various Types of End-point Control Technologies for BOF

2.1 Artificial Empirical Model

This kind of model is mainly divided into three categories, namely, carbon pulling method, carbon increasing method and high drawing blowing method. In this method, the operator relies on his own experience through auxiliary means such as quick analysis and temperature measurement and carbon determination in front of the furnace. However, due to the harsh environment, short smelting cycle, and complex process of converter steelmaking, it is difficult to rely on manual control to ensure that molten steel with appropriate composition and temperature is obtained. Moreover, in the blowing process, the temperature measurement and sampling results are taken as the basis for the next

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operation, and supplementary blowing is often needed, which not only reduces the production efficiency but also is difficult to guarantee the production quality.

Table 1. Three Scheme comparing

Methods	Advantages	Disadvantage
One-time carbon pulling method	The recovery rate of metal is high, the consumption of ferromanganese is low, the FeO in slag is low, which is beneficial to increase the furnace life, and the content of gas and impurities in steel is low.	In practical application, the success rate is about 60%, the one-time hit rate is relatively low, and the risk is high.
Carbon increment method	It can effectively achieve high iron oxide content in the final slag, and has high stability, and can well achieve the goal of desulph-urization and dephosphorization. The hit rate of the finish line is more than 85%	However, it must use low-sulfur, low-ash and dry carburizing agents, and the cost is relatively high.
High pull blowing method	The iron oxide content of the final slag is low, the metal recovery rate is high, the oxygen consumption is low and the gas content of molten steel is low.	The low iron oxide content in the final slag makes it difficult to dephosphorize.

2.2 Static Model

2.2.1 Theoretical Model

The theoretical model is also known as the mechanism model, which reflects the reaction in the furnace by thermodynamic parameters and is deduced according to the material balance equation and heat balance equation under a series of assumptions. Most of the mathematical relations used to describe the phenomena in the furnace are partial differential equations (groups) or ordinary differential equations, which are solved numerically together with the corresponding initial conditions or / and boundaries, so as to obtain the cooling dose needed in the converter smelting process. functions such as oxygen consumption and slag consumption.Then these functions are programmed and applied to production. The adaptability of the theoretical model is very strong, but because the converter is a high temperature and multiphase complex reaction system, and the understanding of the converter steelmaking process is limited, some of the factors affecting smelting have not been recognized. So far, it has not been able to accurately describe the equation that reflects the converter smelting process, so the end point hit rate of the model established on this basis is low.

2.2.2 Statistical Model

With the help of the black box principle, the statistical model can be established. In the process of iron and steel smelting, there is no need for detailed analysis of physical and chemical laws, only with the help of the system. Systematic analysis can be carried out through the actual relationship between input and output. By collecting and sorting out a large amount of experimental data and performing mathematical statistics, the model is constructed by realizing changes in variables and numerical values. In the converter smelting production process, there are many influencing factors. Therefore, in the actual smelting application process, a large amount of data is needed to support it. The application rate of this model is not high.

2.2.3 Empirical Model

The empirical model is the incremental model, which uses the reproducibility principle of the steelmaking process, that is, the same smelting effect should be obtained by using the same blowing process under the same raw material conditions. In order to improve the applicability of the model and reduce the influence of system error, many steel mills adopt the incremental method based on reference heats, which is expressed by unit oxygen consumption and unit cooling dose. That is, an incremental model is established for the difference between the parameters of the current furnace and the reference furnace. The oxygen consumption and coolant addition amount of this furnace are equal

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to the oxygen consumption and coolant addition amount of the reference furnace plus their respective increments. This type of model is simple to model and has self-learning capabilities. The basic formula looks like this:

$$y_b = y_r + \alpha_1 \Delta x_1 + \alpha_2 \Delta x_2 + \Lambda + \alpha_n \Delta x_n + \beta \tag{1}$$

In the formula: yb--target value output of this heat; yr--target value output of reference heat; α1, α2,⋯,αn,β--coefficient; Δx1, Δx2,⋯, Δxn--this The difference between the initial variables and operating parameters of the furnace and the reference furnace.

When β, Δ x1, Δ x2, Δ xn are all zero, yb=y, the model is based on the reproducibility principle, that is, under the same process conditions and raw materials, the smelting results should be reproduced if the same smelting mode is adopted. However, with the change of process conditions such as the loss of refractories in the furnace, it will inevitably lead to the use of the same mode of operation under the premise of the same raw materials and different results. Therefore, the database needs to be continuously updated during the smelting process to make the process conditions in the database as close as possible to the process conditions of the furnace. If any of the parameters is not zero, the target value of this furnace can be calculated based on the difference in process, raw materials and other conditions between this furnace and the reference furnace. It can be seen from the model calculation equation that the calculation results of the model are closely related to the reference heat, and the selection of the reference heat is the key to the applicability of this type of model. The biggest disadvantage of the incremental model is that it has nothing to do with time, but in the actual blowing process, the operating conditions such as the increase of furnace life, the composition of raw materials and furnace conditions are all related to time.

2.2.4 Artificial Neural Network Model

The artificial neural network model has developed rapidly, and many scholars at home and abroad have applied artificial neural network technology to the static control of the converter end point. In recent years, some predictive control methods based on artificial intelligence technology, especially neural networks or algorithms combined with them, have been widely used in the control and optimization of converter production processes.[3][4] Compared with the traditional static model, because the artificial neural network has the ability of self-learning, self-organization, strong robustness and the ability to approach any nonlinear function, the emergence of neural network provides a new way to overcome the problems that are difficult to be described by traditional mathematical models. The static model based on this can guide the production more accurately, and its application is more and more extensive. Artificial intelligence technology, especially artificial neural network, is a hot spot in the research and application of converter end-point control field at present. It has become the mainstream of converter end point control technology.

2.3 Dynamic Model

Static control only considers the variable relationship between the initial state and the final state without considering the changes of variables over time, so the hit rate of static control is limited. In order to improve the hit rate, the blowing parameters should be corrected based on the dynamic control information of the metal composition, temperature, slag conditions and other related quantities detected during the blowing process that change with time to achieve the predetermined blowing target. This method is called the dynamic control method. . The detection of molten pool reaction information during the smelting process is the basis for dynamic control. The current testing information includes molten pool temperature, carbon content, secondary lance measurement, exhaust gas medium component furnace gas analysis method, slag surface height sonar, oxygen lance vibration accelerometer measurement, etc.

2.3.1 Secondary Gun Dynamic Control Technology

The sub-lance dynamic end-point control technology controls the smelting process by detecting the information of the temperature composition change of molten steel in the converter smelting process. The general method of using the auxiliary gun control is to insert the auxiliary gun when the oxygen blowing amount reaches 80%-90% in the late blowing period or 1.5-2.0 minutes before stopping the blowing, determine the carbon temperature and take samples, and start the auxiliary gun control model based on the measurement results. , calculate the oxygen blowing amount and blowing time required to achieve the target carbon content and the coolant addition amount required to reach the end target temperature.

2.3.2 Furnace Gas Analysis Dynamic Control Technology

Furnace gas analysis technology is a method to predict the carbon content in molten metal during the smelting process by analyzing the composition of the furnace gas. Compared with the secondary gun monitoring system, the cost is lower and the economy is good. Converter gas analysis technology can continuously detect the amount of flue gas and flue gas components (H2, CO, O2, CO2, N2, Ar) generated during the smelting process. However, the furnace gas analysis is an indirect method to measure the carbon content, so it is not possible to measure the carbon content in the furnace directly. It is necessary to obtain the reaction information through the analysis of the furnace gas composition, and then dynamically predict the carbon content in the blowing process according to the model. The furnace gas analysis process curve can be used to effectively predict splashing and slag backdrying, and perform process control of dynamic steelmaking. In addition, Han Yang and Zhang Caijun developed a multi-scale convolution neural network algorithm to deeply mine the converter mouth flame spectrum big data, and established a steelmaking end point control model driven by the furnace mouth flame spectrum. the hit rate of carbon content and temperature at the end point of steelmaking is further improved.

2.4 Sublance + Furnace Gas Analysis

At present, automated steelmaking mainly adopts a method that combines static control and dynamic control based on auxiliary gun monitoring information. The key to dynamic control is to accurately predict the temperature and carbon content of the converter blowing end point, and timely adjust the added raw materials, auxiliary materials and oxygen, thereby improving the hit rate of the blowing end point. The converter production record data is true, accurate and real-time. According to the analysis and processing of the data, the operation parameters which have great influence on the objective function can be determined according to the interrelation of many operation parameters, and the mathematical model can be established to realize the prediction of the objective function and the feedback of information, which is of great significance to improve the process control of converter smelting.

Japan began to develop converter fully automatic blowing technology in the late 1980s, which adopts the following technologies on the basis of converter dynamic control: (1) Use online slag status detection technology to achieve closed-loop control of the slag-making process; (2) Use furnace gas analysis technology to dynamically predict the carbon content and temperature of the molten pool throughout the blowing process; (3) the fuzzy judgment and neural network system are used to detect the composition change of Mn in the molten pool on-line to predict the change of S and P in the whole process, and (4) the sub-lance technology is used to dynamically correct the blowing end point to improve the end point prediction accuracy. The use of fully automatic blowing technology can significantly reduce the splash rate, reduce the number of additional blows, shorten the smelting time, and significantly improve the end point control accuracy.

2.5 Artificial Intelligence Fully Automatic Control Mode

Intelligent control often achieves better control results for controlled objects whose models are unknown or poorly understood and whose model structures and parameters vary greatly. With the development of intelligent control technology, converter steelmaking has gradually begun to apply

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this new technology and has become a hot research topic in the world's major steel-producing countries. Japan's Nippon Steel Corporation uses an artificial intelligence expert system. The main features of its control technology are: (1) Based on the initial blowing conditions and end-point target, use the incremental model to determine the sub-lance sampling time, the amount of various auxiliary materials added, and the adding procedure; (2) Calculate the excess oxygen and other furnace information based on the measurement results of the furnace gas analysis system during the blowing process, and use fuzzy reasoning method to predict the end-point phosphorus content; (3) When the blowing is approaching the end-point, use the sub-gun to measure the temperature and determine the carbon content and carry out Dynamic correction to determine the oxygen supply and coolant addition required to achieve the end goal; (4) the luminous intensity of the frequency lines of iron and manganese in the molten pool is continuously measured by the photoelectric sensor installed in the oxygen lance, the manganese content in the molten steel is directly calculated and the temperature of the molten steel is estimated.

2.6 Human-computer Interaction Converter End Point Control

In the entire converter steelmaking process, there are primary and secondary systems for intelligent automation control. The first-level system refers to various equipment in the entire smelting process. It mainly collects data and equipment status information during the smelting process and executes system instructions during the process. The secondary system mainly includes smelting model, static calculation, dynamic calculation simulation model and self-learning model. The incremental model of the intelligent automation control system is mainly based on the rich raw smelting data accumulated in the secondary database. Once there are situations such as some raw data not being collected or raw material conditions changing greatly, it is necessary to manually input the change information, and the computer will It will search for similar production heats from the database, and then conduct simulation calculations based on the data to achieve reasonable blowing process control.[5] When the intelligent automatic control system fails or the prediction deviation is large and the wrong command is issued, the staff can change the oxygen lance control mode at any time according to the situation on the spot. In the process of control mode conversion, the system calculation and prediction do not stop, continue to track and record all events occurred on the steelmaking equipment, and record them in the treatment report, which are provided to managers for production and technical analysis. When the raw material structure condition is stable and the blowing process is stable, the artificial end point can be judged with reference to the prediction of intelligent steelmaking system, which can effectively improve the converter end point control level, as shown in the following figure.[6].

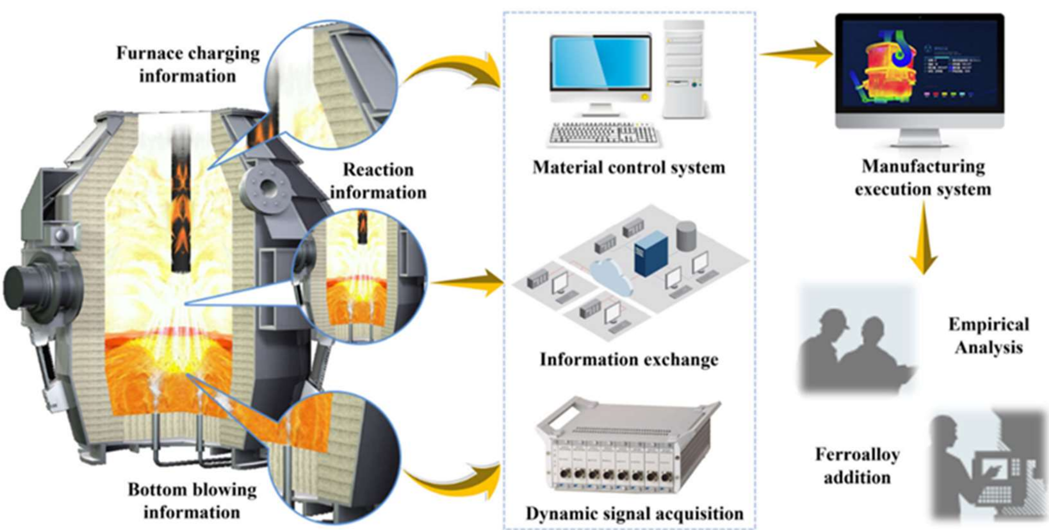

Figure 1. Diagram of production information transfer in converter steelmaking.[6]

3. Converter end point control technology optimization

(1) Improvement of measurement accuracy of relevant parameters

During the smelting process, the timely and accurate measurement of the composition and temperature of molten steel in the molten pool and furnace gas, as well as smelting slag and other information is the basis for automatic control of converter steelmaking. How to improve the speed and accuracy of various types of information and data measurement in the smelting process to achieve online real-time detection is an important issue that urgently needs to be solved for converter automatic control in a certain period of time in the future.

(2) Improvement of accuracy of existing converter control models

According to the actual situation of each plant, the modeling algorithms of static control model and dynamic control model in converter smelting process are further studied. Especially in the actual situation that the raw materials, equipment and operation conditions of steel mills often change, it is more important to further improve the accuracy of static control model and dynamic control model.

(3) Improving the accuracy of data analysis systems

The existing data analysis system analyzes the oxygen and carbon content at the end of steelmaking mainly through the fitting of oxygen potential, oxygen activity and carbon and oxygen balance models. With the continuous development of steelmaking technology, carbon and oxygen balance and oxygen activity The model is no longer suitable for the current process. In order to improve data accuracy, in-depth research on carbon-oxygen balance and oxygen activity models is particularly important in the future.

4. Conclusion

At present, the end-point control technology of converter steelmaking has some problems, such as low precision, poor stability, poor informatization and so on. Although the introduction of some new technologies and equipment can improve the accuracy and stability of end-point control, the cost of these technologies and equipment is high and the investment to the enterprise is large. The development direction of converter steelmaking end point control technology should be to achieve intelligence and automation. By introducing artificial intelligence technology and automation equipment, the accuracy and stability of end point control can be greatly improved, while manual intervention can also be reduced and production efficiency and safety improved. In the future, we should also strengthen informatization construction, establish a complete data collection and processing system, realize data sharing and interconnection, and improve the level of informatization and management.

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