Fuzzy control of flue temperature in coke oven heating process

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Abstract

Coke oven production possesses the characteristics of nonlinear, large inertia, large disturbances, and highly-coup ling and so on. Coke oven heating temperature was reflected by flue temperature and adjusted by gas flow. The control method of intermittent heating control is adopted in traditional heating control system of coke oven, and cannot satisfy the command of coke oven heating control. The control principle of combining the intermittent heating control with the heating gas flow adjustment is adopted according to analysing the difficulty and strategy of heating control of the coke oven. On the basis of researching deficiency of the existing control strategy, fuzzy hybrid control is proposed to establish heating intelligent control model of coke oven, which combines feedback control, feed-forward control and fuzzy intelligent control. Carbonization index is utilized in the model to control coking management of coke oven. Then heating fuzzy intelligent control structure of coke oven is built. According to artificial experience and actual conditions, the fuzzy controller is designed. Fuzzy control can deal with fuzzy, inexact or uncertain information and is extraordinarily robust, which can realize intelligent control of heating process of coke oven. Better control result of temperature control is realized by fuzzy intelligent control model. Intelligent control methods were used to adjust stopping heating time and heating gas flow. The practical running results indicate that the system can achieve heating intelligent control of flue temperature, reduce temperature fluctuation, effectively improve quality of coke and decrease energy consumption, and has great practical value.

Keywords: coke oven heating, model, intelligent control, fuzzy control, hybrid control

1 Introduction

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The most important control in the production of coke oven is temperature control of coke oven [1-3], because temperature of coke oven is a key factor of affecting coke quality, economizing coal gas consumption, reducing smoke and dust pollution during charging coke. Practice in the coke oven has proved that it is of great difficulty in temperature control, which reflects concretely in several following aspects [4].

Coke oven has an uncommonly non-linear characteristic. According to characteristics of coke oven production, relationship between heating gas flow and longitudinal temperature at the top of the regenerator is affected by factors such as coke carbonization cycle, type of coal used in production, longitudinal temperature at the top of the regenerator and production plan of pushing coke and so on. Therefore, the uncommonly non-linear characteristic of coke oven is caused.

Heating process of coke oven possesses characteristics of great inertia characteristics and large time-delay. Because coke oven is bulky, hot capacity is very large, the course of heating-up and heating-down are all extraordinarily slow. There are some difficulties in measurement of relevant crafts parameters. For example, it is difficult to implement online measurement of longitudinal temperature at the top of the regenerator, calorific value of gas and water content of coal charging of coke oven. Production process of coke oven belongs to the intermittent type, which is operated by single stove according to the operation plan.

A lot of disturbances exist in production process of coke oven. Because there are two kinds of heating gas, namely coke oven gas and blast furnace gas. Calorific value difference between them is great, and flow heating is different. Affected by climate, water content of coal fluctuates greatly. Thus, heating temperature of coke oven is influenced. The Production plan of pushing coke has significant effect on heating temperature of coke oven too. Heating process has the characteristics of time changeable in one cycle, which is affected by such factors as market demand, government policy. Thus, coke carbonization cycle of coke oven often changes, and the kind of heating gas always varies too. These changes cause a lot of interference factors to production process of coke oven.

2 Control methods of heating control system in coke oven

Heating control of coke oven can generally adopt three kinds of control methods, namely feedback control system,

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feedforward control system and compound control system combined feedback with feed forward.

2.1 TEMPERATURE FEEDBACK REGULATION SYSTEM ADOPTING TEMPERATURE MEASUREMENT IN SUCCESSION

According to deviation between real flue temperature, real finished carbonization time or real coke temperature and target flue temperature, target finished carbonization time or target coke temperature, considering time-delay factor of coke oven temperature [1], settlement value of heating gas flow is adjusted in order to realize the optimal heating control of coke oven. Meanwhile, some control systems provide operation guidance of regulating flue-chamber depending on judgment of carbonization of coke-chamber, wall temperature measurement of coke-chamber or coke button temperature and its distribution. Advantages of feedback control are the influence of various kinds of parameters, which need not be considered. The deviation of controlled parameters is utilized to control. Shortcomings of feedback control are that the disturbance cannot be overcome in time, and the time-delay phenomenon is serious, because feedback control just works after disturbance takes place. Feedback control system is shown as Figure 1.

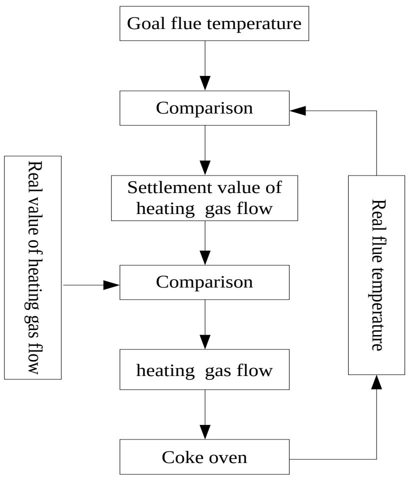

FIGURE 1 Feedback control system of coke oven

2.2 HEATION SUPPLY FEEDFORWARD REGULATION SYSTEM ADOPTION EXPERIENTIAL MODEL

Coking heating amount is calculated in the light of properties of coal and average humidity of coke button, and then coking heating consumption is computed through thermal balance according to amount of coal charging, production task, heat loss of waste gas and heat dissipation. Finally, heating supply is calculated depending on calorific value of gas, air excess coefficient and so on, and then gas flow is calculated. Coking heating consumption is adjusted by real temperature of coke button [2]. Advantages of feedforward control influence the slow course of temperature when regulation need not be considered. If monitoring point is less, instrument and measure error can be reduced. Shortcomings of feedforward control are to calculate accurate coking heating amount difficultly, and a lot of variables of calculating coking heating amount are difficult to be measured precisely and totally. The feed forward control system is illustrated in Figure 2.

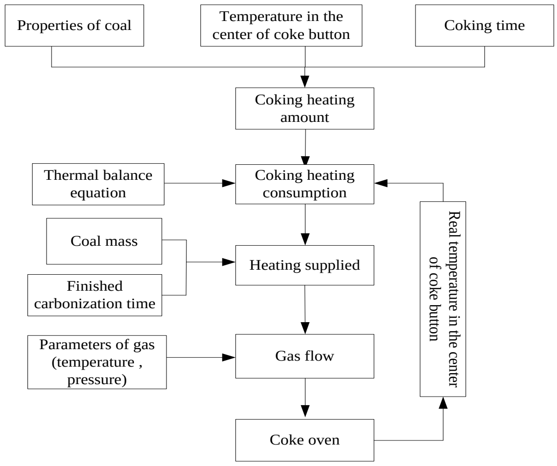

FIGURE 2 Feedback control system of coke oven

2.3 HYBRID CONTROL SYSTEM COMBINED FEEDBACK WITH FEEDFORWARD

When amount of coal charging, coal properties, production task of coke oven and operating time are regarded as input function, heating amount supplied is calculated by the heating supply model, and then settled heating amount supplied is feedback regulation according to deviation between real average temperature of the whole coke oven and settled average temperature of the whole coke oven [3]. The influence of unknown and difficult measure parameters produced is dispelled by feedback control. Influence caused by disturbance is compensated by feed-forward control at the same time in order to improve the time-delay of feedback control in the compound system. The compound control system is shown as Figure 3.

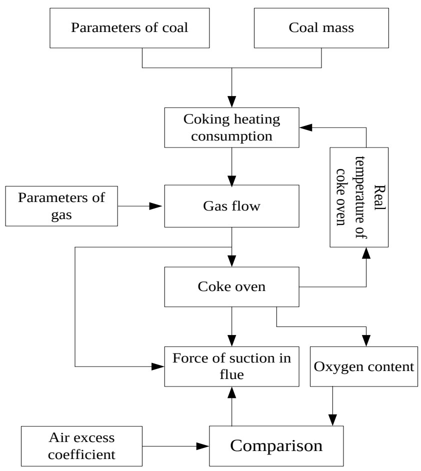

FIGURE 3 Control system of coke oven combined feedback with feedforward

3 Model of heating intelligent control system in coke oven

At present, the iron and steel enterprise usually utilizes "intermittent heating control" control method in the heating control system of coke oven, which can well optimize heating control of coke oven in a situation that the heating energy of coke oven is steady and rich [1-3]. But when pressure in main pipes of blast furnace fluctuates violently and heating coal gas flow is insufficient, the method can't instruct attendants how to operate heat control. The function of control system can only be analysed and judged artificially by the attendants, and during stopping heating time, blast furnace gas and coke oven gas are stopped using at the same time. Blast furnace gas is not fully utilized, either.

A new control principle [4, 5] combining the "intermittent heating control" with the heating gas flow adjustment is adopted in the control system. It analyses and processes data synthetically such as temperature, flow and calorific value of gas, pushing coke, charging coal, coal mass, water content and planned carbonization time, "stopping heating time" of PLC system and the heating blast furnace gas coke oven gas flow of DCS system are calculated and established through the model.

Therefore, heating of coke oven is even and stable and the whole heating level of coke oven is the intelligent control. Heating intelligent control of coke oven is realized. Its control system model is illustrated in Figure 4 [8, 9].

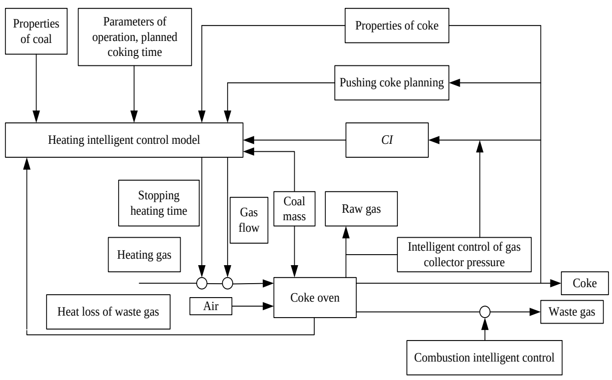

FIGURE 4 Intelligent control system model of coke oven

Carbonization index used in model of the control system is calculated according to the following equation [4]:

$$CI = \frac{t_{coking}}{t_{T\max}}, \quad (1)$$

where $t_{T\max}$ is the time from coal charging in coke-chamber to the temperature of the waste gas passing the peak, t_{coking} is the time of finished carbonization of each coke-chamber. CI is a carbonization parameter to control coking production management, it fluctuates among 1.2 – 1.24 suitably. Prediction model of t_{coking} is shown as follows:

$$t_{coking} = A \times t_{T\max} + C, \quad (2)$$

where $t_{T\max}$ is the time from coal charging in coke-chamber to the temperature of the waste gas passing the peak; A and C are characteristic coefficient of coke oven.

A hybrid control system is proposed to control heating of coke oven, which combines feedback control, feed-forward control and fuzzy intelligent control. Real-time data of production in coke oven are gathered by the system such as pressure, flow, calorific value, temperature of coal gas, water content, and composition of heating gas and dynamic plans and so on. Settlement value of controlled parameters is calculated through the energy prediction model, namely the feed-forward. And then the value is transferred to the basic automated system to be regulated. According to real-time information such as waste gas temperature, coke button temperature, flue temperature and oxygen content offered by the basic automated system at the same time, the energy balance is feedback regulated constantly in the course of heating in accordance with the fuzzy intelligent control model (Figure 5). Then the settlement value is calculated again in order to be kept within the range of control, which satisfy not only necessary temperature required in coking, but also optimal heating control. Its control flow chart is shown in Figure 6.

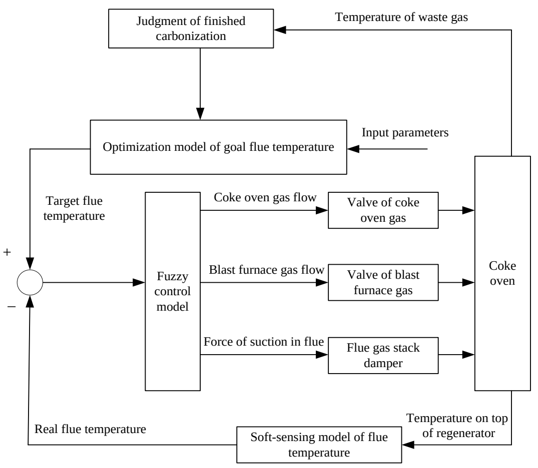

FIGURE 5 Heating fuzzy intelligent control structure of coke oven

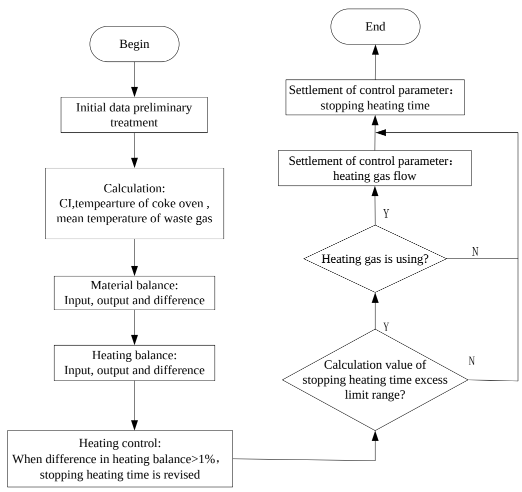

FIGURE 6 Flow chart of coke oven heating intelligent control model

In addition, gas flow and force of suction in flue (namely air-flue ratio) is intelligently controlled according to real-time processing production data in order to control total burning of heating gas as well as control waste gas content in the rational range. Meanwhile, intelligent control of gas collector pressure is achieved to control it in the suitable range in order to reduce the diffusing of coal gas.

4 Design of fuzzy control mode

4.1 ANALYSIS OF FUZZY CONTROL MODEL

Fuzzy control is the simulation behaviour of artificial intelligence, which utilizes the fuzzy theory to set up some rules of control and controls the production process to reach the satisfactory control result. The basic thinking of fuzzy control model in the system is according to deviation between present gas flow and feedforward gas flow, deviation between standard flue temperature and real flue temperature, and a temperature variation tendency of real flue temperature. Final gas flow is adjusted through certain fuzzy control algorithms [12-14].

ΔV – present gas flow – feed-forward gas flow, (3)

ΔT – standard flue temperature–real flue temperature, (4)

ΔC – flue temperature at present – flue temperature at last moment, (5)

where ΔV, ΔT and ΔC all include three kinds of value, namely greater than zero, equal to zero, less than zero approximately.

The control algorithm of final gas flow adopts the fuzzy control method. ΔV, ΔT and ΔC are defined as the input of the fuzzy controller. The change amount of gas flow is got through fuzzy control algorithm.

4.2 DESIGN OF FUZZY CONTROLLER

Deviation between measured value and settled value will be divided into three grades [6, 7], namely negative, normal and positive respectively. Then every input parameter has three kinds of situation, and therefore these parameters make up as twenty seven kinds of situations. According to the actual conditions, each kind of situation adopts corresponding operation, and opening degree of the gas valve will increase or reduce. Twenty seven rules are shown as Table 1 where NG represents "negative", NM represents "normal", PS represents "positive", IC represents "increasing", DC represents "decreasing", KEEP represents "keeping"

TABLE 1 Control rule of fuzzy intelligent controller

Rule number	ΔV	ΔT	ΔC	ΔU	Rule number	ΔV	ΔT	ΔC	ΔU
1	NG	NG	NG	IC 10%	15	NM	NM	PS	DC 2%
2	NG	NG	NM	IC 10%	16	NM	PS	NG	KEEP
3	NG	NG	PS	IC 5%	17	NM	PS	NM	DC 2%
4	NG	NM	NG	IC 5%	18	NM	PS	PS	DC 5%
5	NG	NM	NM	IC 5%	19	PS	NG	NG	IC 5%
6	NG	NM	PS	KEEP	20	PS	NG	NM	IC 2%
7	NG	PS	NG	KEEP	21	PS	NG	PS	KEEP
8	NG	PS	NM	DC 2%	22	PS	NM	NG	KEEP
9	NG	PS	PS	DC 2%	23	PS	NM	NM	DC 2%
10	NM	NG	NG	IC 5%	24	PS	NM	PS	DC 2%
11	NM	NG	NM	IC 2%	25	PS	PS	NG	DC 2%
12	NM	NG	PS	KEEP	26	PS	PS	NM	DC 5%
13	NM	NM	NG	IC 2%	27	PS	PS	PS	DC 10%
14	NM	NM	NM	KEEP					

Various kinds of influence and variation tendency of gas flow are summed up into twenty seven rules synthetically in the model according to artificial operation experience. The fuzzy control model of gas flow has been set up [10, 11], and thus heating intelligent control of coke oven is realized. Simulation program of fuzzy control is shown as Figure 7.

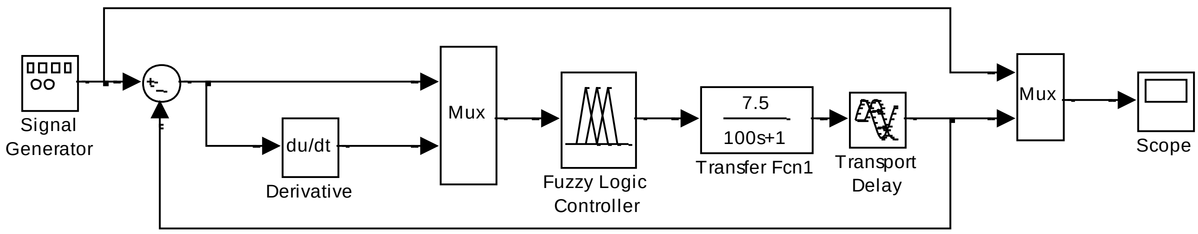

FIGURE 7 Simulink simulation program of fuzzy control

When operation condition of production changes, the change range of flue temperature will often exceed (–6, +6), if the simple control method is still adopted, because of the great inertia of coke oven, big exceeding adjusting amount and too long adjustment time are caused. Aiming at above-mentioned situations, a prediction part in the controlling course has been increased (Figure 8). Furthermore the deviation of temperature is judged firstly, when the range of deviation does not exceed (–6, +6), fuzzy control is adopted. If it exceeds above-mentioned ranges, Bang-Bang intelligent control is used. So coal gas flow and stopping heating time are adjusted, control precision and fast responses of controlled target are guaranteed [15-17].

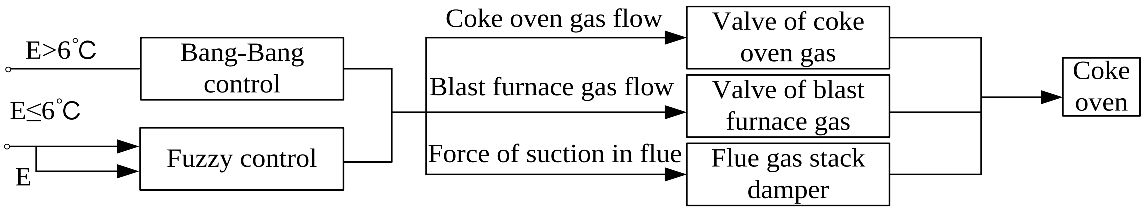

FIGURE 8 Intelligent control

5 Application

This system has already been succeeded in applying intelligent control system of coke oven heating in some iron and steel company. Settled temperatures of machine and coke sides are 1260°C and 1310°C respectively in coke oven production, temperature control of machine side and coke side are shown in Figures 9 and 10, respectively. The statistics show that temperature errors of machine side and coke side are up to 89.5% and 86.7% among ±5°C, meet the real industrial production demand.

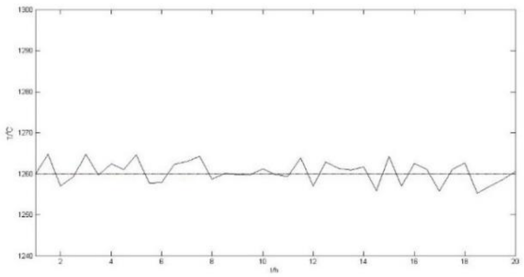

FIGURE 9 Temperature control of machine side

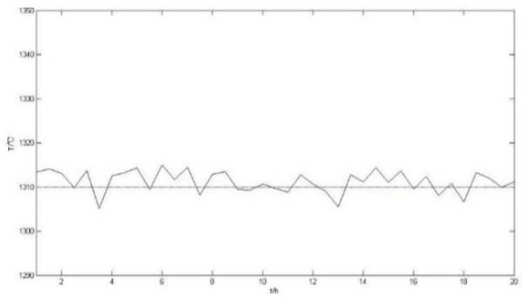

FIGURE 10 Temperature control of coke side

6 Conclusions

According to characteristics of coke oven and actual craft states in coking plants, a fuzzy intelligent hybrid control method is proposed, which combines feedback control, feed-forward control and fuzzy intelligent control. Feed-forward and feedback are utilized to dispel influence of examined disturbance and no examined disturbance respectively. Advantages of the method consider not only change of flue temperature at present, but also demand of heating supplied in the future. Finally fuzzy intelligent control module has been designed to solve temperature fluctuation of coke oven effectively, which reaches the better control result. The system is of great practical value. The system is put into operation in the company for more than three years, the system runs normally, the result is good. It is easy to operate and master for operators, lightens labour intensity, and has improved operation condition. The system not only can regulate the heating supplied amount of coke oven in time, but also have stronger anti-interference ability. The system has reduced fluctuation of whole temperature of coke oven to a great extent, and heating supplied amount needed is also reduced relatively, so consumption of gas has been reduced. At the same time stable coefficient is improved too, therefore, the life of coke oven is lengthened and coke quality is improved. It has reached the anticipated result and very great practical value.

Acknowledgments

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