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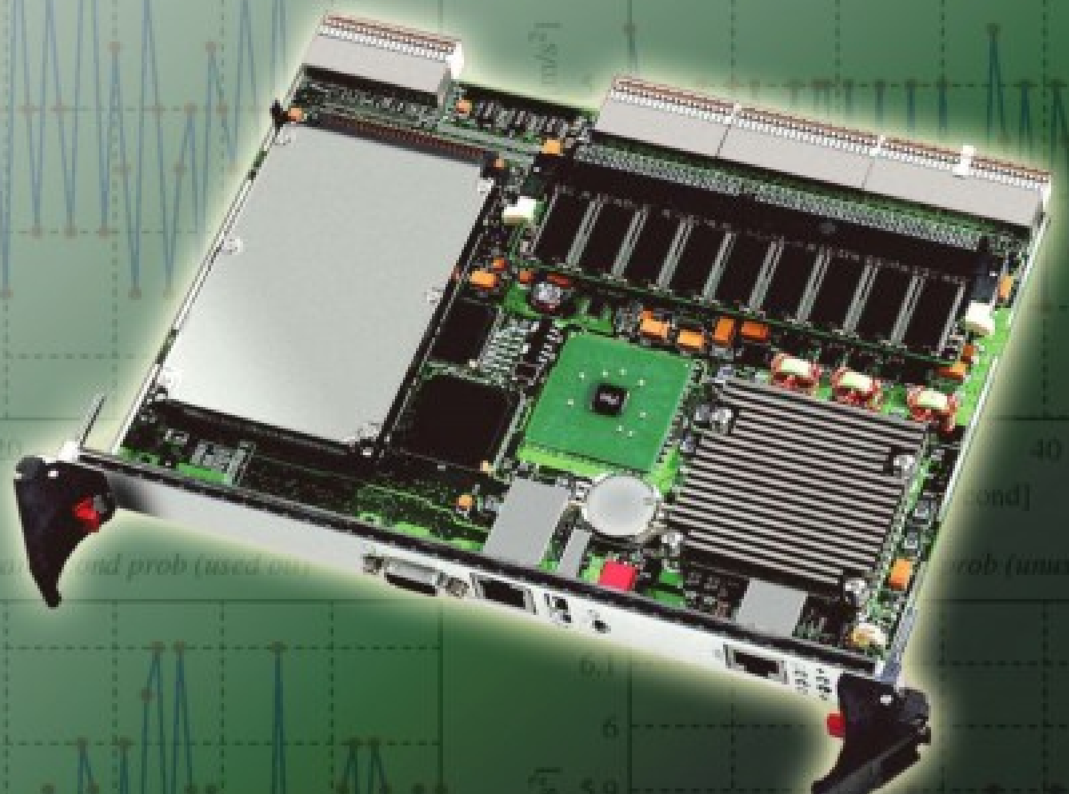

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Coke Oven Heating Model of Fuzzy Intelligent Control System

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Abstract: Coke oven production has the characteristics of nonlinear, large inertia, large disturbances, and highly-coup ling and so on. The control method of “intermittent heating control” is adopted in traditional heating control system of coke oven, and cannot satisfy the command of heating control on coke oven. The control principle of combining the “intermittent heating control” with the heating gas flow adjustment is adopted according to analysis the difficulty and strategy of heating control on coke oven. On the basis of studying deficiency of the existing control strategy, fuzzy compound control is proposed to establish heating intelligent control model of coke oven, which combines feedback control, feedforward control and fuzzy intelligent control. Carbonization index *CI* is used 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 condition, fuzzy controller is designed. Fuzzy control can deal with fuzzy, inexact or uncertainty information and has great 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. The system has great practical value. *Copyright © 2012 IFSA.*

Keywords: Coke oven heating model, Fuzzy intelligent control, Intelligent control system.

1. Introduction

Coke oven is an important thermal equipment of metallurgical industry, produces coal gas and coke mainly, it is the important raw materials production equipment in such trades as metallurgy and chemical industry and so on, and the quality and output of the products concern the stability of follow-up industrial production directly. Coke oven consumes energy heavenly in the iron and steel enterprise, how to economize energy consumption, and improve output and quality of cokes are key questions of controlling and management of coke oven. It is significant to strengthen the competitiveness and increase economic efficiency of iron and steel enterprise to improve output of coke steadily and guarantee coke quality. Goal of the optimal control coking course of coke oven are heating steadily and evenly, improving productivity and quality of coke oven, reducing energy consumption and prolonging the age of coke oven, reducing the environmental pollution in coking production.

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 coke oven has proved that it's very great degree of difficulty in temperature control which reflects concretely in several following aspects [4].

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

Heating process of coke oven has 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 very slow. There are some difficulties in measurement of relevant crafts parameters. For example it is difficult to online measure longitudinal temperature on top of regenerator, calorific value of gas and water content of coal charging of coke oven. Production process of coke oven belongs to intermittent type, is operated by single stove according to operation planning.

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, flow while heating is different. Affected by climate, water content of coal has greater fluctuations, thus heating temperature of coke oven is influenced. Production planning of pushing coke has heavy influence on heating temperature of coke oven too. Heating process has the characteristics of time changeable in one cycle, 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 often changes 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, feedforward control system and compound control system combined feedback with feedforward.

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 according to 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 is not need to consider, the deviation of controlled parameters is utilized to control. Shortcomings of feedback control are the disturbance can't 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 Fig. 1.

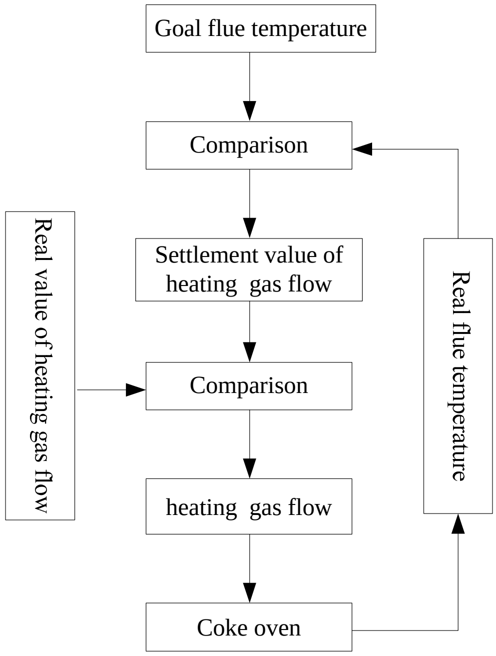

Fig. 1. Feedback control system of coke oven.

2.2. Heating Supply Feedforward Regulation System Adopting Experiential Model

Coking heating amount is calculated according to properties of coal and average humidity of coke button, and then coking heating consumption is calculated through thermal balance according to amount of coal charging, production task, heat loss of waste gas and heat dissipation. Finally heating supplied is calculated according to calorific value of gas, air excess coefficient and so on, then gas flow is calculated, and coking heating consumption is adjusted [2] by real temperature of coke button. Advantages of feedforward control are influence of the slow course of temperature when regulation isn’t need to consider, monitoring point is less, instrument and measure error can be reduced. Shortcomings of feedforward control are difficulty in calculating coking heating amount accurately, and a lot of variables of calculating coking heating amount are difficult to measure accurately and totally. The feedforward control system is illustrated in Fig. 2.

2.3. Compound Control System Combined Feedback with Feedforward

Regarding amount of coal charging, coal properties, production task of coke oven and operating time as input function, heating amount supplied is calculated by the heating supplied model, then settled heating amount supplied is feedback regulated 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 are dispelled by feedback control, influence caused by disturbance is compensated by feedforward 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 Fig. 3.

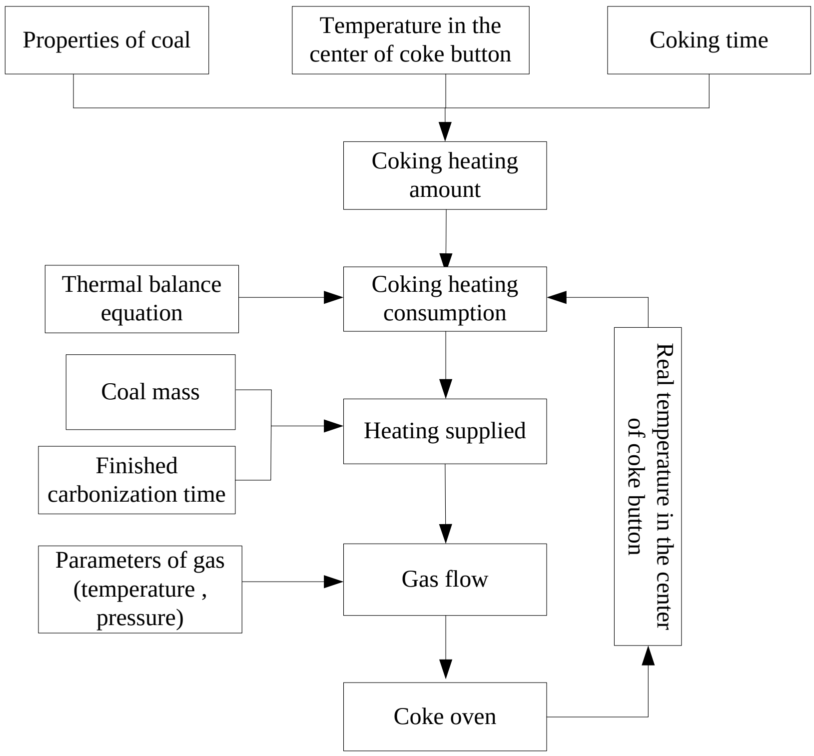

Fig. 2. Feedforward control system of coke oven.

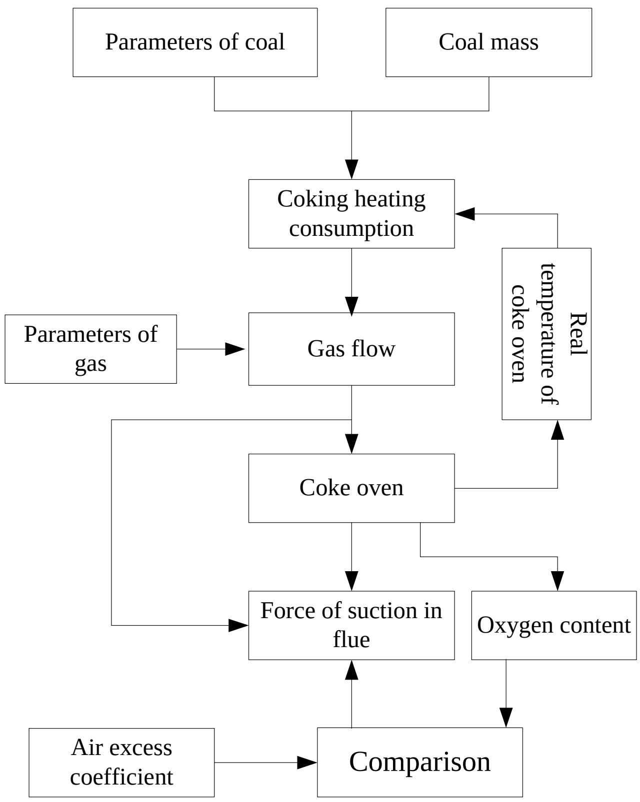

Fig. 3. Control system of coke oven combined feedback with feedforward.

3. Model of Heating Intelligent Control System in Coke Oven

At present, iron and steel enterprise usually use “intermittent heating control” control method in 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 pipe of blast furnace fluctuates violently and heating coal gas flow is insufficient, the method can't instruct attendants how to operate heat controlling, the function of control system can only be analyzed and judged artificially by the attendants, and during stopping heating time, blast furnace gas and coke oven gas are stop 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 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 stability, the whole heating level of coke oven is intelligent control, heating intelligent control of coke oven is realized. Its control system model is illustrated in Fig. 4.

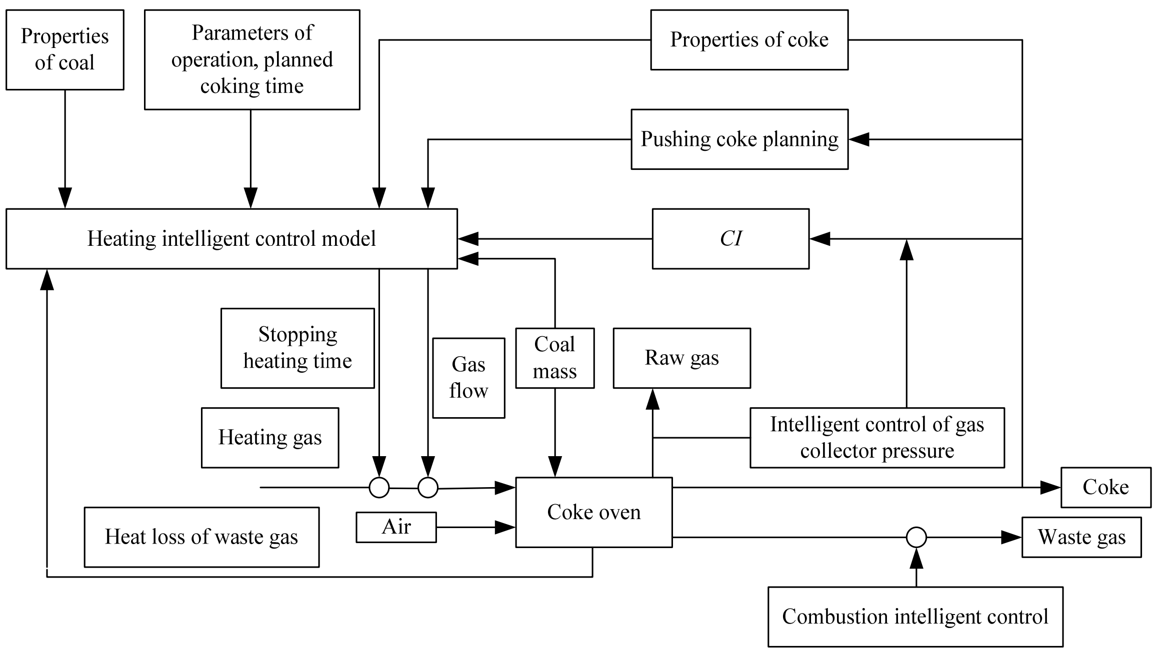

Fig. 4. Intelligent control system model of coke oven.

Carbonization index *CI* used in model of the control system is calculated according to the operation (1) [4].

$$CI = \frac{t_{coking}}{t_{T\max}}, \tag{1}$$

where $t_{\mathrm{T\,max}}$ is the time from coal charging in coke-chamber to when the temperature of the waste gas passes the peak, h; t_{coking} is the time of finished carbonization of each coke-chamber, h.

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 following.

$$t_{coking} = A \times t_{T\,\max} + C, \tag{2}$$

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

A compound control system is proposed to control heating of coke oven, which combines feedback control, feedforward control and fuzzy intelligent control. Real-time data of production in coke oven are gathered by the system such as pressure, flow, calorific value and temperature of coal gas, water content, composition of heating gas and dynamic plan and so on, settlement value of controlled parameters is calculated through energy prediction model, namely the feedforward, then the value is transferred to the basic automated system to regulate. 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 according to the fuzzy intelligent control model (See Fig. 5) constantly in the course of heating. Then the settlement value is calculated again in order to enable to keep within the range of control, which not only satisfy necessary temperature needed in coking, but also optimal heating control. Its control flow chart is shown as Fig. 6.

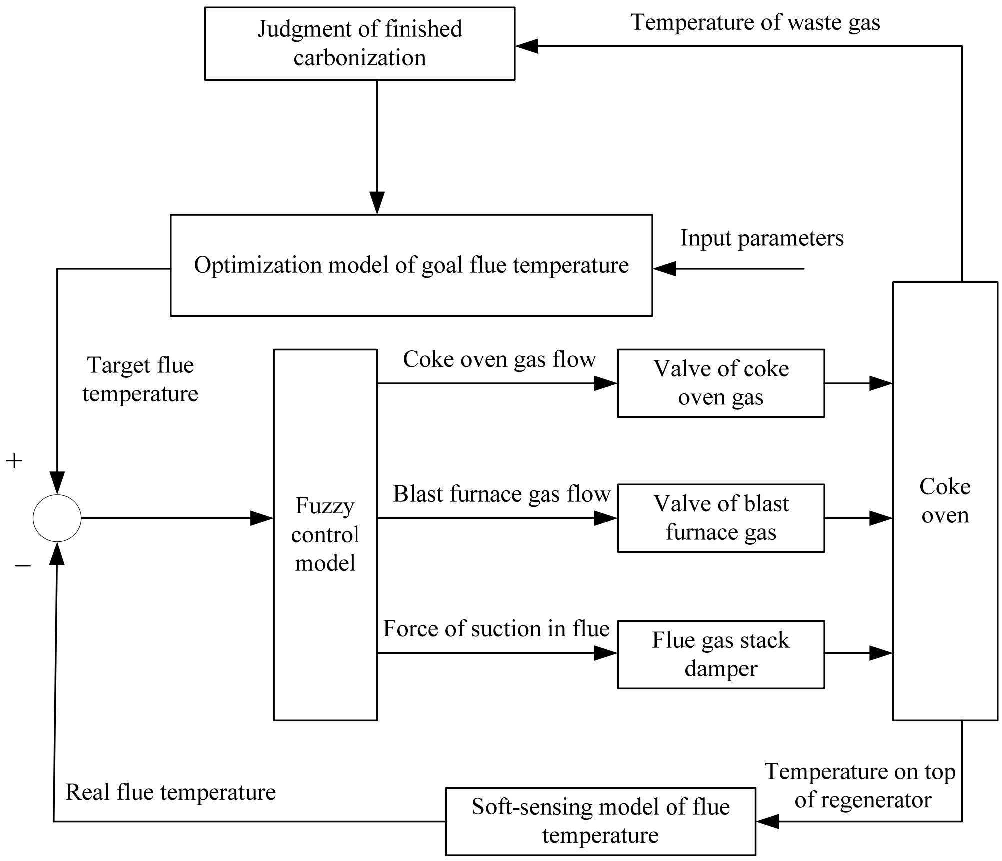

Fig. 5. Heating fuzzy intelligent control structure of coke oven.

In addition, gas flow and force of suction in flue (namely air-flue ratio) is intelligent controlled according to real-time processing production data in order to control totally burn 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.

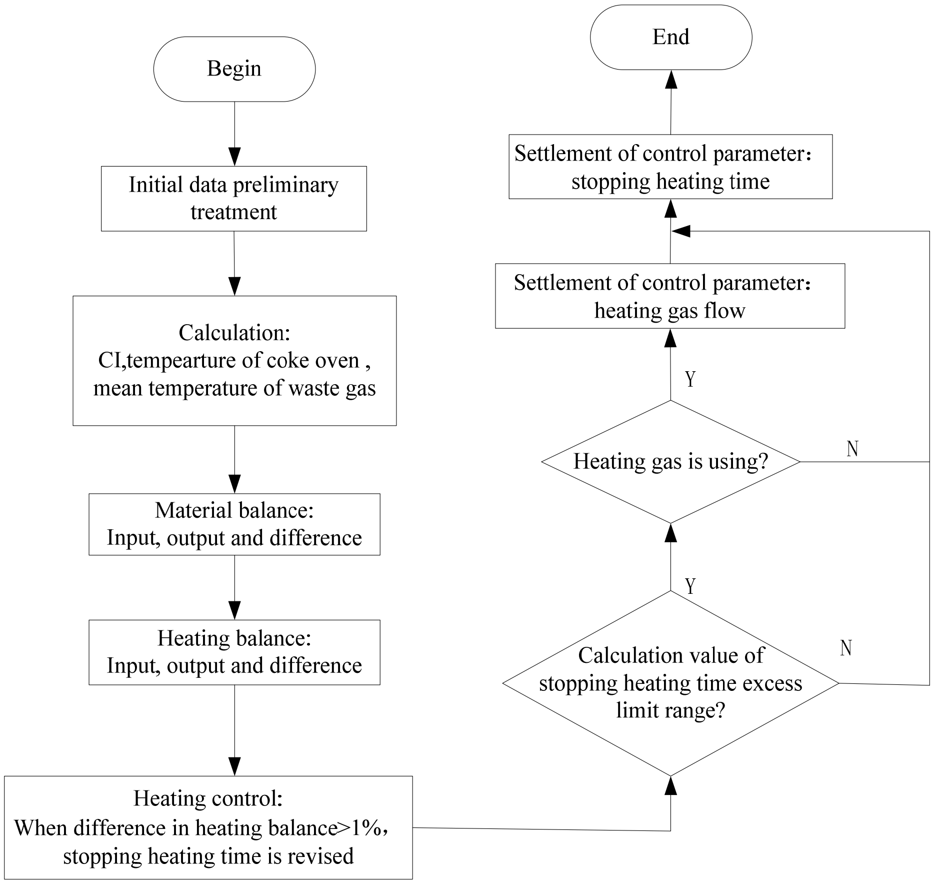

Fig. 6. Flow chart of coke oven heating intelligent control model.

4. Design of Fuzzy Control Model

4.1 Analysis of Fuzzy Control Model

Fuzzy control is the simulation behaviour of artificial intelligence, utilizes the fuzzy theory to set up some rules of control, 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.

$$\Delta V = \text{present gas flow- feedforward gas flow}, \tag{3}$$

$$\Delta T = \text{standard flue temperature- real flue temperature}, \tag{4}$$

$$\Delta C = \text{flue temperature at present- flue temperature at last moment}, \tag{5}$$

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

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

4.2. Design of Fuzzy Controller

Deviation between measuring value and settlement value will be divided into 3 grades [6, 7], namely negative, normal and positive respectively, then every input parameter has 3 kinds of situation, and therefore these parameters make up as 27 kinds of situation. According to the actual conditions, each kind of situation is adopted corresponding operation, and opening degree of the gas valve will increase or reduce. 27 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 27 rules synthetically in the model according to artificial operation experience, fuzzy control model of gas flow has set up, and thus heating intelligent control of coke oven is realized. Simulation program of fuzzy control is shown as Fig. 7.

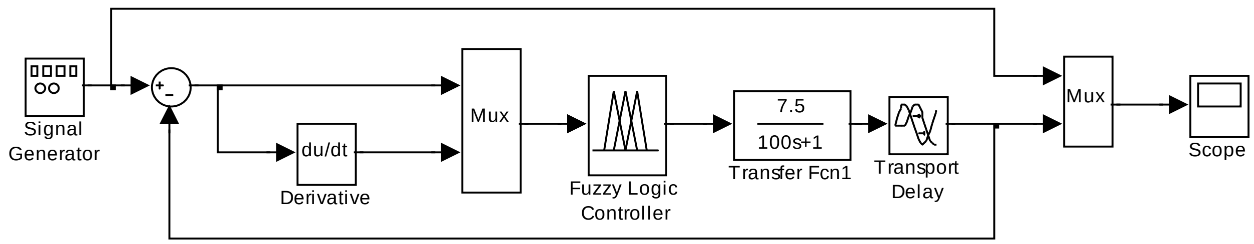

Fig. 7. Simulink simulation program of fuzzy control.

5. Conclusions

According to characteristics of coke oven and actual craft states in coking plant, a fuzzy intelligent compound control method is proposed, which combines feedback control, feedforward control and fuzzy intelligent control. Feedforward and feedback are utilized to dispel influence of examined disturbance and not examined disturbance respectively. Advantages of the method are not only considering change of flue temperature at present, but also considering demand of heating supplied in the future. Finally fuzzy intelligent control module has been designed to solve temperature fluctuation of coke oven effectively, reaches the better control result. The system has very great practical value.

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References

[1]. Jukka Swanijung and Petri Palmu, Development of Coke-oven Battery Process Management System at Rautaruukki Steelworks, *Iron and Steel Engineer*, Vol. 73, 1996, pp. 46-49.

[2]. Jukka Swanijung and Petri Palmu, Experience and results of new heating control system of coke oven batteries at Rautaruukki OY Raahe Steel, in *Proceedings of the Ironmaking Conference*, 1997, pp. 79-83.

[3]. E. T. Battel and K. L. Chen, Automatic coke oven heating control system at Burn Harbor Works for normal and repair operation, in *Proceedings of the Ironmaking Conference*, 1997, pp. 499-504.

[4]. Jiang Guozhang, Kong Jianyi and Li Gongfa, Intelligent Control System for Coke Oven Heating, *Chinese Journal of Iron and Steel*, Vol. 41, 2006, pp. 73-76.

[5]. Li Gongfa, Kong Jianyi and Jiang Guozhang, Research and Application on Compound Intelligent Control System for Coke Oven Heating, *Chinese Journal of Iron and Steel*, Vol. 43, 2008, pp. 89-92.

[6]. Euntai Kim, A new approach to numerical stability analysis of fuzzy control systems, *IEEE Trans on Systems*, Vol. 31, 2001, pp. 107-133.

[7]. Tanaka. H, Yasuno. M and OSHIMA. h, Application of Fuzzy Inference to Combustion Control for Coke Oven, in *Proceedings of the Ironmaking Conference*, 1992, pp. 509-513.

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