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Coke Oven Intelligent Integrated Control System

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Abstract: In order to improve the level of management and control of coke oven, the research on intelligent integrated control system is carried out. In modern advanced control system of coke oven, the control scheme of feedback combined with feed-forward, and control merged with management are widely utilized. The integrated management and control system of coke oven is introduced systematically, including the system model, production plan and management, heating control system, the model and method of evaluating temperature, intelligent combustion control and the pressure control gas collector of coke oven. It is pointed out that the integration of management and control develops towards the orientation of coke oven control system. Considering the complexity and importance of flue temperature control in coke oven heating process, the control method of combining the stopping heating time control with the heating gas flow adjustment is proposed, hybrid intelligent control models of flue temperature are built.

Keywords: Coke oven, control strategy, production management, intelligent control, integrated system, control model

1. Introduction

Coke oven is key thermal equipment and consumes energy massively in the metallurgy industry. Therefore, how to save energy, promote production and quality of coke are key problems of coke oven control and management. Coking is a complex intermittent thermal process. Coke oven possesses a complex structure, operation condition is extraordinarily tough, and test facility is few, so it's hard to realize automatic control. The goals of coking process control are realizing steady heating of coke oven, enhancing production of coke oven and quality of coke, reducing energy consumption and prolonging coke oven service life, and decreasing environment pollution in the course of coking production. There is a large distance about the coke oven control level between home and abroad. For example, the output of large and medium-size coke oven take above 50 percent of the total output in China in 2004. These coke ovens mostly bear the hard assignment of promoting the output, reducing energy consumption, decreasing fluctuation, prolonging service life, declining production cost and environment pollution. Consequently, it's essential to enhance the control level of coke oven in China.

At present, the feed-forward control is always utilized in automation control system of coke oven heating in China, and a part of systems use the feedback control method [1, 2]. Coke oven heating control is a complex control system, so it's hard to realize effective and accurate control by using single control approach. The modern advanced coke oven heating control systems all use the control method of combining feedback with feed-forward and control merged with management, use artificial intelligence, such as fuzzy control, expert system and neural networks and so on, and adopt multilevel control system to reach a new level of coke oven computer control. It will be a main direction of coke oven automation control in the future. In recent years, in order to introduce, digest and absorb the advanced technology of coking process management system, and realize the innovation of technology and management, it develops towards the direction of putting forward the concept and thoughts of integration control and management system of coke oven to realize the global optimization.

2. Integrated System of Coke Oven

Integrated management and control system of coke oven is the integration of management system and control system of coke oven, and this system should have high level of automatic test, control and management.

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A total frame (as shown in Fig.1) of integrated management and control system of coke oven and logic relationship (as shown in Fig. 2) of every model are established. Intelligent control model of coke oven heating and actual application research are combined by using mathematic analysis, fuzzy control, linear programming, neural networks and genetic algorithm. Some models suitable for integrated control and management system of coke oven are set up. The factor relationship fitting for automatic control and management of coke oven is determined through correlative parameters of temperature and flux of coke oven extracted by experiment research to validate experiment research, application and theory model. Estimation method of model is founded and integrated intelligent control and management of coke oven is realized.

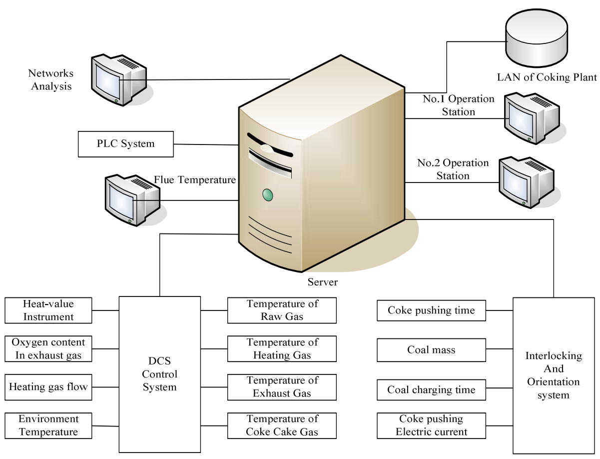

Figure 1 Integrated Control and Management System of Coke Oven.

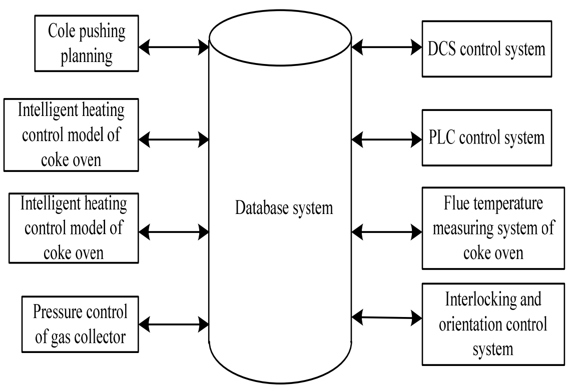

Figure 2 Logic Relationship of Every Model.

3. Production Plan and Management

3.1. Production Plan of Coke Oven

Production Plan management [3] is daily management work, such as coke pushing plan, production monitoring and report forms outputting and so on, arranging coke pushing and coal charging plan, confusing letter and driving oven plan because of changed coking time and disposal of coke-chamber, and displaying or printing new planning of drawing a charge and major cycle plan. When there is a great change in the production condition, the automatic arranging system exits, and the computer offers the production guidance. Production monitoring is mainly monitoring and guiding coke pushing and coal charging production, and usually transferring the information to the computer center, which is convenient to total control. In the monitoring course above, operation time, pushing electric current, K1, K2, K3 and other parameters automatically are recorded and computed in computers, and pushing day report form also can printed.

Main functions of job management [4] are to arrange production plan from coal charging to coke pushing, displaying, setting and printing the practical production. There are four data charging work in these functions as follows: basic plans, job plans, job data and practical job data. The processing flow and schematic function is shown in Fig. 3.

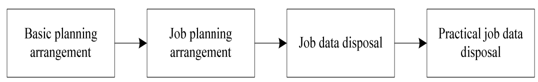

Figure 3 Function Module of Job Management.

Main function of the basic plan arrangement is to calculate the start time, ending time and the number of drawing a charge, and arranging the plan of drawing a charge. According to the difference of operation rate, repair needs usually 4 hours and the number of drawing a charge of the last letter yesterday. There are many different modes about the plan of drawing a charge. When there is no repair, the operation rate is above 85%, or is more than 80% .

Main function of the job planning arrangement is to choose a mode from the basic plan according to production plan today, which is the number of drawing a charge operation rate, repair and the number of drawing a charge of the last letter yesterday, and producing the job plan about the start time, ending time and the number drawing a charge.

Main function of the job data disposal is to compute the coke pushing and coal charging time according to the arranged operation plan, and arranging plan table which can guide the location and time of coke oven machine through the oven number sequence. This plan is designed per week and month.

Main function of the practical job data disposal is sampling and saving the practical job data about coke pushing signal, coal charging signal, ceasing-fire time and coal properties of each coke-chamber.

3.2. Real Time Coke Pushing Plan Model

Coking is a process of carbonizing coal to coke in high temperature in the coke-chamber. When coke is matured, coke cake will have some constriction and the center temperature will reach up to $950 \sim 1050^0C$. If the center temperature can not reach the temperature, the coke cake will half-cooked and does not constrict well and this will affect coke oven service life consequently. If the center temperature higher than the temperature, the coke cake is easy to broke. This will affect the quality of coke. There are 3 stages in the whole operation as follows: running, pushing and setting off, which means that coke pusher runs to the appointed chamber to push according to the presupposed programming, and set off the coal when larry car finished the work about the last chamber. Therefore, pushing coke should be operated according to definite sequence, and the designing model of this sequence is to push plan model.

In large coking plants of the iron and steel companies in china, most operators estimate that the coke pushers are in the right place and alignment timely or not just by vision and experience. Sometimes the coke pushers lag or the chamber are lead appointed. Hence the master controller must operate continuously, the reducer must be restarted and stopped continuously, and the hydraulic brake must be restarted continuously to reduce the security and shorten power equipment service life. The coke pushing plan is still arranged by hand, and the work is trivial and stiff. Therefore, it is very essential to arrange the pushing plan automatically and give the coke pushing plan timely.

Automatic arrangement and control of coke pushing plan are realized by using automatic control and computer technologies combined with linear programming and genetic algorithm in the system.

Thinking about time relationship and real command, the algorithm of average subsection and proportional correction focusing on the coke pushing job is adopted to arrange the coke pushing plan, which means making average subsection according to commanded number of overhaul in every little circle, and then getting coke pushing time of each chamber in turn and inserting overhaul time based on operation time and start pushing time of each chamber. If the pushing chamber number is less or more than the total chamber number of every little circle in the arrangement, the plan will be corrected according to the scale of each section. Thinking about the flexibility and adaptability, the circle time, total chamber number, overhaul number of each little circle, starting coke pushing time, starting coke pushing chamber number and operation time of each chamber should be filled before automatic arrangement.

Coke pushing sequence can be arranged in accordance with the algorithm of average subsection and proportional correction, and then the mature of coke in each chamber should be analyzed in term of the practical production of coke battery. The following pushing coke-chamber number and pushing time should be calculated and transferred to the operator in coke pusher. Therefore, linear programming should be introduced and dynamic programming is applied to establishing the plan model. In the plan model, the target function is target temperature, such as flue temperature or coke cake temperature and so on. The constrained conditions are the restriction of operation time and circle time. The coking time of consecutive chambers has a half discrepancy. Coal charged lastly must be uniformly distributed in the chamber and the distance of outputting chamber number and holding outputting chamber number must be given. Genetic algorithm can be adopted to find the solution. At first, the appropriate sample should be chosen, the target function should be mapped to adaptable function, the constrained condition should be charged properly and genetic tool box of MATLAB can be utilized into programming to find the solution.

Combining computer with chamber number orientation system, the real coke pushing time is recorded. Compared with the coke pushing plan, they are computed to estimate coke pushing operation and realize effective operation and monitoring. In this system, the arrangement of the coke pushing plan mainly selects VB language, and the database adopts Oracle or Access and so on. There is some additional management, such as real time pushing electricity current, history current, coke pushing plan arrangement and job report forms and so on.

4. Coke Oven Heating Control System

The most important control in coke oven production is temperature control [5], because the coke oven temperature is the key factor of influencing coke oven quality, saving heating gas, decreasing pollution. In the same coking circle, if the coke oven temperature is too low, the coke will not mature enough, and the coke cake can not constrict to well-balanced station. The rigidity of coke is low, and the density is high, and the pushing electricity is high. Whereas, the coke will mature too enough if the temperature is too high. The coke cake constricts more than well-balanced station, the rigidity of coke is high, the density is low, and the pushing electricity is low, which brings too much soot into the pushing course.

In this system, the control combined with the system of feed forward-feedback-fuzzy intelligent control was utilized in coke oven heating control. The system can collect real time production data of coke oven, such as coal gas pressure, flux, heat value, temperature, the moisture of blended coal, the constituent of heating gas and dynamic plan. According to energy forecasting model, the system can compute the given value of controlling parameters, which is feed-forward, and this value is sent to the basic automatic system to be adjusted. The heating intelligent control of coke oven adopts the control theory combined with intermittent heating control and heating gas flow adjustment, analyzes and charges raw gas temperature, heating gas flow, heat value, pushing coke, setting of coal oven computes and sets stopping heating time of PLC and heating blast furnace/coke oven gas flow of DCS to make coke oven heating even and steady, The total chambers heating level is controlled intelligently and intelligent control of coke oven heating is realized. The large complex process automatic system focusing on the practice of coke oven production with high flexibility, high efficiency and high quality of the function of diction, control, optimizing, attempter, management and decision-making is developed to realize global optimization. The system can not only make the coke oven production possess independent intellectual property rights of the control and management system with the function of local examine, advanced control, optimal schedule, production management, but also can make the coke oven production be promoted to a higher level in quality, realize the intelligent control of coke oven, make the coke oven control and management level from basic automatic control to coking process management, realize saving energy, stabilize and promote the quality of coke and prolonging coke oven life and achieve distinct economic profits. Its intelligent control model is illustrated in Fig. 4.

If the total coking heating amount, heating dissipation of coke oven body and sensible heating of exhaust gas are known, then the total output heating amount is got. Therefore feed forward gas flow V_0 is calculated according to the thermal balance equation. Among them the calculation of every parameter is as follows.

1) Burning heat Q_1

$$Q_1 = V_0 \times (1 - m\tau) \times Q_{net} \tag{1}$$

Where m is an exchange times of coke oven per hour; τ is exchange time; Q_{net} is calorific value of coal gas.

2) Sensible heating of coal gas Q_2

$$Q_2 = V_0 \times (1 - m\tau) \times T_m \times C_m \tag{2}$$

Where T_m is temperature of coal gas entering coke oven; C_m is specific heat of coal gas.

3) Sensible heating Q_3 of air

$$Q_3 = V_0 \times (1 - m\tau) \times \alpha \times T_k \times (C_k + \psi_s \times W_s \times C_s) \tag{3}$$

Where α is ideal air fuel ratio;T_k is air temperature; C_k is specific heat of air; ψ_s is the relative humidity; W_s is the content of the saturation moisture in the air; C_s is specific heat of water-gas in the air.

4) Sensible heating Q_4 of coal entering coke oven

$$Q_4 = G_M \times T_m \times C_m \tag{4}$$

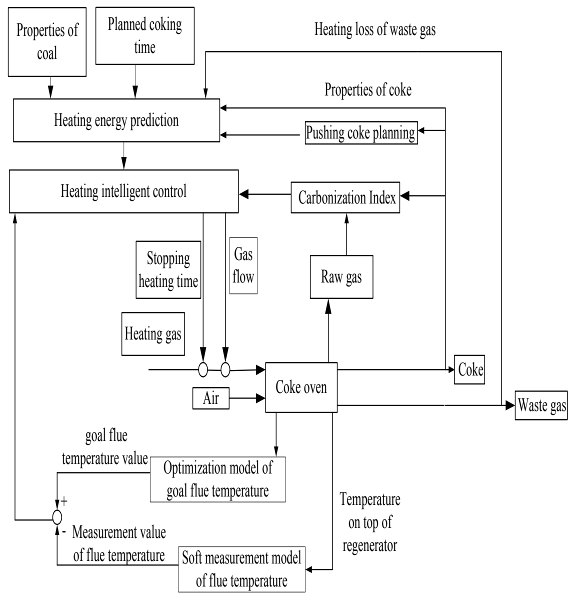

Figure 4 Intelligent Control Model.

Where G_M is mass of coal entering coke oven; C_m is specific heat of coal entering coke oven; T_m is temperature of coal entering coke oven.

Total input heating amount is got according to above calculation.

$$Q_{input} = Q_{output} = Q_1 + Q_2 + Q_3 + Q_4 \tag{5}$$

CI (carbonization index) is used to revise coking heating consumption.

CI used in model of the control system is calculated according to the following equation.

$$CI = t_{coking} / t_{T_{max}} \tag{6}$$

Where $t_{T_{max}}$ is the time from coal charging in coke-chamber to when the temperature of the waste gas passes the peak; t_{coking} is the time of finished carbonization of each coke-chamber.

Prediction model of t_{coking} is shown as following.

$$t_{coking} = A \times t_{T_{max}} + C \tag{7}$$

Where $t_{T_{max}}$ is the time from coal charging in coke-chamber to when the temperature of the waste gas passes the peak; A and C are characteristic coefficient of coke oven.

CI is a carbonization parameter to control coking production management, and it fluctuates among $1.2 \sim 1.25$ suitably. Goal flue temperature is revised according to *CI*. Their relationships are shown as Table 1.

Through conducting heating model, the relationship between carbonization time and width of coke-chamber, thickness of stove wall, thermal conductance rate of coal material and stove wall, thermal diffusion rate of coal

Table 1 Revised Relationship Between CI and Goal Flue Temperature

CI	Revised value of temperature
CI > 1.35	-3°C
1.30 < CI ≤ 1.35	-2°C
1.25 < CI ≤ 1.30	-1°C
1.20 < CI ≤ 1.25	0°C
1.15 < CI ≤ 1.20	1°C
1.10 < CI ≤ 1.15	2°C
CI < 1.10	3°C

material, flue temperature, temperature in the center of coke cake. Finally the optimal model of goal flue temperature is built.

Electric thermocouples are installed on top of twenty typical regenerators at machine side and coke side respectively, and the exchange signal of the exchanger is inputted into DCS system. After exchanging ten minutes and twenty minutes, when the temperature is stable in regenerator, temperature of regenerator discharging waste gas is measured, average temperature of two times is got, predicted value $\hat{y_1}$ is got according to LR model. According to the neural network model, predicted value $\hat{y_2}$ of flue temperature is got. After receiving present value $\hat{y_1}$ and $\hat{y_2}$, output $\hat{T_k}$ of flue temperature soft measurement model is got after weighing combination of two values.

$$\hat{T_k} = \alpha\hat{y_1} + \beta\hat{y_2} \tag{8}$$

Where $\alpha + \beta = 1$, and $0 \le \alpha \le 1$, $0 \le \beta \le 1$. Initial value of α and β is equal, and they are changed by rules as following, $y(k-1)$ is real value of flue temperature at early moment.

Rule1: If $|\hat{y_2}(k-1) - y(k-1)|1^0C$, Then $\beta(k) = 1$, $\alpha(k) = 0$;

Rule2: If $|\hat{y_2}(k-1) - y(k-1)|$ is minimum,Then $\beta(k) = 1.5\beta(k-1)$;

Rule3: If $|\hat{y_2}(k-1) - y(k-1)|$ is maximum, Then $\beta(k) = 0.5\beta(k-1)$;

Goal flue temperature value is got by optimization model of goal flue temperature, and measurement value of flue temperature is got by flue temperature soft measurement model according to temperature on top of regenerator.

Therefore the flue temperature intelligent control is achieved as following.

1) Considering properties of coal and coke, planned coking time and pushing coke planning, the Q_{input} is got according to heating energy prediction model. Then the feed forward gas flow V_0 is calculated according to (1)-(5).

2) CI is calculated according to (6)-(7), therefore the revised goal flue temperature is got.

3) $\hat{T_k}$ is got by using (8).

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 (shown as Fig. 5). 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 response of controlled target is guaranteed.

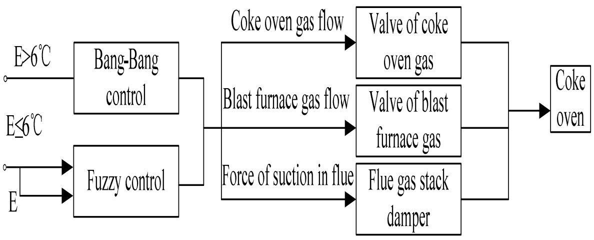

Figure 5 Intelligent Control.

5. Assessment Model and Method of Temperature

Coke oven temperature mainly consists of raw gas temperature, flue temperature, cross wall temperature and so on. In order to realize automatic control of heating course in coke oven, the measurement value of various control parameters of coke oven should be got firstly, and the most key one is measurement, assessment and prediction of different temperature of coke oven among them [6].

The key of furnace temperature feedback control is to establish goal flue temperature rationally and accurately. There are a lot of factors influencing goal flue temperature. Hence, in order to investigate the influence of various factors and find out quantitative relationship between them, it is necessary to carry out research on calculation model of goal flue temperature. But when establishing calculation model of goal flue temperature in fact, several main factors are only considered generally, such as the influence of coal mass, moisture of coal material, carbonization time and operating condition and so on. Analysis model of goal flue temperature is in equation (9).

$$F(j) = f(x, y, z, u, v, w, g, k) \tag{9}$$

where F is goal flue temperature; x is goal carbonization time; y is goal time; z is passing carbonization time after charging coal; u is real coal mass; v is moisture of coal; w is gas flow; g is prediction temperature of coke button in coke-chamber; j is a serial number of coke-chamber; k is revised coefficient.

Assessment and prediction of temperature in coke oven consider not only goal temperature calculation model, but also the interrelation models of various kinds of temperature of coke-chamber. For example when analyzing the interrelation model between flue temperature and temperature at the top of the regenerator, temperatures at the top of regenerator at machine side and coke side are measured through the electric thermocouple. The average temperature at the top of the regenerator is changed into longitudinal temperature at machine side and coke side through the interrelation model between flue temperature and temperature on the top of the regenerator.

This kind of interrelation model is set up generally by adopting linear regression method, but actual physics system is non-linear system because there is a greater error sometimes in this method. Thus, neural network is applied to establish the model. When modeling, neural network of three layers is utilized. The neural network structure is 1x6x1. Input layer is one node among them, and average temperature at the top of the regenerator is inputting value; Hidden layer is 6 nodes. Nodal function is linear function is linear function, and flue temperature is output value. Right value and valve matrix got after neural network learning are used to construct interrelation model between flue temperature and temperature at the top of regenerator.

6. Combustion Intelligent Control and the Pressure Control Gas Collector of Coke Oven

There is much raw gas produced which is collected from gas collector and is sent to the following work section by air delivery pipe through fan in coking process. Because the amount of raw gas varies with the coking time, the pressure of gas collector changes continuously, and the pressure of gas collector will have a vast fluctuation especially in pushing coke and coal charging. When the pressure of the chamber in operation is negative, the air will come into the chamber from the door and cover of chamber, which makes the coke burn, ash content inverse and coke quality decrease. The ingoing air also can generate chemical reactions with the constructional materials of the chamber, which leads to the denudation of the oven and shortening coke oven service life. The air also can pick up the burning of the raw gas, improve temperature of the coal gas system, which pricks up the burden of cooling system and brings needless energy consuming. When the pressure in the chamber is higher, the raw gas will burst out from the door and the cover of the chamber, which leads to the discharge of soot and fire, environment pollution in one hand, and the recovery of raw gas and waste of the energy decreases in the other hand. In conclusion, the stabilization of the pressure in the gas collector not only affects the quality of coke, but also effects coke oven service life. Therefore, it's essential to control the pressure of gas collector, and control it to a setting pressure arrange. Thinking about that it's hard to establish a mathematic model focusing on the pressure of gas collector in coke oven and the pressure of gas collector has a good coupling. The combination of classical control with intelligent control is used to control the pressure of gas collector. Intelligent pressure control of gas collector will control the press in an appropriate arrange and decrease the emanation.

The integrated management and control system of coke is a complex control and management system. In order to realize effective and correct automatic management and control, the single control mode cannot reach the expected effect. The modern coke oven control and management system adopts the method with the combination of feedback and feed forward, the integration of control and management, and artificial intelligence, which consists of fuzzy control, expert system and neural networks, and integrates with multilevel control system in control method to reach a new level in computer control of coke oven. This system is achieved based on all thoughts above.

7. Conclusions

The integrated management and control system of coke is a complex control and management system. In order to realize effective and correct automatic management and control, the single control mode cannot reach the expected effect. The modern coke oven control and management system adopts the method with the combination of feedback and feed forward, the integration of control and management, and artificial intelligence, which consists of fuzzy control, expert system and neural networks, and integrates with multilevel control system in control method to reach a new level in computer control of coke oven. This system is achieved based on all thoughts above.

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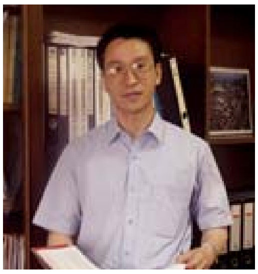

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