# Coke oven production process hybrid intelligent control

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**Abstract**

Coke oven production possesses the characteristics of nonlinear, large inertia, large disturbances, and highly-coup ling and so on. According to the characteristics of coke oven production process and control demand of coke oven production, intelligent control structure and models of coke oven production process was conducted. Firstly the intelligent control structure of coke oven production process was established. Then coal blending intelligent control, gas collector pressure intelligent control and combustion intelligent control of coke oven were discussed simply, while heating intelligent control, the production plan and schedule were discussed in detail. The control principle of combining the intermittent heating control with the heating gas flow adjustment was adopted, and fuzzy hybrid control was proposed to establish heating intelligent control strategy and model of coke oven, which combined feedback control, feed forward control and fuzzy intelligent control. The production plan and schedule of coke oven were optimized by utilizing the dynamic program and genetic algorithm. The practical running indicates that the system can effectively improve quality of coke and decrease energy consumption.

*Keywords:* Coke oven production process, Hybrid intelligent control, Heating intelligent control, Production plan and schedule

## 1 Introduction

Coke oven consumes energy substantially in the iron and steel enterprise, how to economize energy consumption, and improve quality and output 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 enterprises to guarantee coke quality and improve output of coke steadily. The coke oven is disposed by a lot of coke-chambers and flue-chambers alternatively. The coke oven is disposed by a lot of coke-chambers and flue-chambers alternatively. The coal gas and air enter the coke-chamber to spread and burn after preheating from coke-chamber, and then heat produced is spread to coke-chamber by the stove wall. The coal material carries on the high-temperature dry distillation in the coke-chamber, and then coke is formed; waste gas produced by burning is discharged after holding retrieving the remaining heat energy via regenerator. Flow direction of coal gas, air and waste gas is exchanged per twenty minutes. According to production technology of coke oven, production process of coke oven has the following characteristics: 1) Production process of coke oven belongs to intermittent type, which is operated by single stove according to the operation plan; 2) Coke oven has characteristics of great inertia and large time-delay; 3)Mechanism of coking course is complicated, which has complexity of non-linear and coupling parameters; 4)The variable changes violently, which results in strong interfering in the production process; 5) The coke oven is a big hot-close system, where temperature measurement has particularity and complexity [1]. In order to effectively control and manage coke oven production process, intelligent control structure of coke oven production process has been set up at first, and then its intelligent control models are established. The production plan and schedule have described especially. The application of the system in some plants indicates that the system can stabilize production of coke oven, reach the anticipated result and is of great practical value.

## 2 Intelligent control structure of coke oven production process

According to the equipment state and market information, production task is made, production schedule is arranged rationally, four carts are managed in order and intelligent control of coke oven heating process is carried out in accordance with the production schedule. Therefore, coke quality is guaranteed, cost is lowered and energy consumption is economized. So production process from coal preparation to cooling cokes are controlled and managed effectively. Information and knowledge offered through the information processing of the production process and support system, production statistics, production schedules, supply-balance, production cost, equipment, quality and security are managed in real time. Meanwhile, according to the information gathered from the field, the heating and burning control of coke oven are

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optimized and controlled in real time. The production schedule of pushing coke and coal injection are adjusted in real time, the repair schedule is arranged rationally, coke oven production and stability of the whole stove temperature are guaranteed effectively. In accordance with the technological process and characteristic of production of the coke oven, the intelligent control structure of coke oven production process is set up, which is shown as Fig. 1. The intelligent control model of coke oven production process, basic automation system and actual application research are combined by using fuzzy control, mathematic analysis, linear programming, neural networks and genetic algorithm. Some models suitable for intelligent control system of coke oven production process are established. The factor relationship fit for intelligent control of coke oven production process is constructed through correlative parameters of temperature, flux, pressure, and hear-value of coke oven extracted by experiment research to validate experiment research, application and theory model. The estimation method of model is found and intelligent control of coke oven production process is realized. The DCS control system, interlocking and orientation system and PLC system in Fig. 1 are basic composition in the intelligent control of coke oven production process. Content above are not described here, because these are only the infrastructure of systematic research.

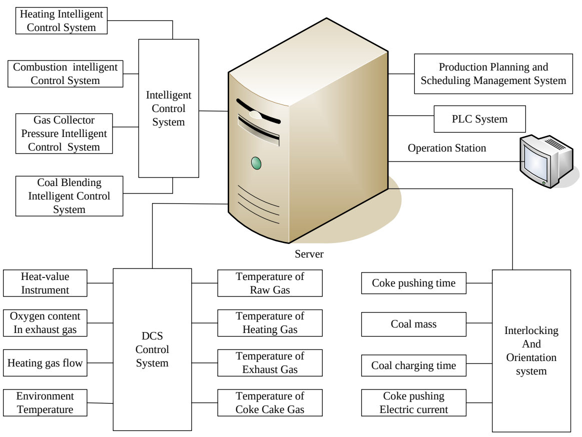


FIGURE.1 Intelligent control structure of coke oven production process

## 3 Intelligent control models of coke oven production process

From coke oven production technological process, intelligent control of coke oven production process involves coal blending intelligent control, gas collector pressure intelligent control, combustion intelligent control, heating intelligent control, the production plan and schedule of coke oven. Because coal blending intelligent control, gas collector pressure intelligent control, combustion intelligent control and heating intelligent control have already been conducted on the systematic research [2-5], a simple introduction is only given in this paper. The production plan and schedule of coke oven are discussed in detail.

### 3.1 COAL BLENDING INTELLIGENT CONTROL

In iron and steel industrial production, the blast furnace requires coke with the characteristics of low ash content, little sulphur, great intensity and high anisotropism degree. With the development of blast furnace maximization and injection technology with high pressure, requisition for coke quality is stricter and stricter. In coal blending and coking process, coal blending ratio is main factor influencing coke quality. Adopting suitable coal blending ratio to coking, coke quality can be guaranteed and coal resources can utilized rationally. But coal blending and coking process is a complicated industrial production process with a series of physics and chemical change and numerous of qualitative factors influencing coke quality. It is very difficult to describe the relationship between a kind of coal quality, coal blending ratio and coal blending quality, coke quality. The coal blending and coking process, in which much uncertainty exists, is too complicated to describe with mathematical models, and it cannot be controlled properly by traditional methods. According to the coking theory and using statistical data acquired from industry processes, a mathematical model is designed and a rule model is proposed with qualitative knowledge derived from experts' experience by utilizing statistical data acquired from industry processes. The rule model is combined with the mathematical model and qualitative and quantitative methods are integrated to establish a model for prediction of coke quality and to compute the blending ratio of coal. Furthermore, the flow of each kind of coal is controlled. The system has been running in a plant with accuracy of coal blending and prediction precision of coke quality reaches up to 97% and 95% respectively [2].

### 3.2 GAS COLLECTOR PRESSURE INTELLIGENT CONTROL

There is much produced raw gas which is collected from gas collectors and sent to the following work section by air delivery pipe through fan in coking process. Because the amount of raw gas changes along with the coking time, the pressure of gas collectors varies 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 enter 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 shortens coke oven service life. The air also can prick up the burning of the raw gas and improve temperature of the coal gas system, which could prick up the burden of cooling system and bring 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 not only leads to the discharge of soot and fire, and environment pollution, but also decreases raw gas recovery and energy waste. So the stabilization of the pressure in gas collector affects the quality of coke and coke oven service life. Therefore, it's essential to control it to a setting pressure arrange. The combination of classical control and intelligent control are utilized to control the pressure of gas collector. Intelligent pressure control of gas collector will control the press within an appropriate arrange and decrease the emanation [3].

### 3.3 INTELLIGENT CONTROL OF COMBUSTION

It processed production data in real-time, intelligent control the amount of air-flue ration, and controls coal gas totally burning as well as enables abolishing gas within the rational range. During actual combustion process, combustible components in flue and oxygen of air cannot carry out ideal mixing, and the air amount of supply must be more than theory needed in order to guarantee totally burning of fuel. The ration of real air amount to the theory air amount is called the air consumption coefficient, air surplus coefficient too.

$$\alpha = \frac{L_1}{L_2}, \quad (1)$$

where L1 represents real air amount, L2 represents theory air amount.

Value of $\alpha$ must be more than 1, and the choice of $\alpha$ is very important for coke oven production. If value of $\alpha$ is too small, the coal gas is burnt incompletely, and the flammable composition is given off with the waste gas; If value of is too great, amount of abolished gas produced is large, and the heat of taking away increases. So that value of $\alpha$ is too great or small can increase amount of gas consumption. Therefore, the suitable control value of $\alpha$ must seek through practice. Under the general normal situation, while burning the coke oven coal gas, $\alpha$ =1.2-1.3; while burning the blast furnace gas, $\alpha$ =1.15-1.2. Aiming at the main problems existing in some coking production, with the analysis of coking process, a new control strategy is proposed, which integrates the technique of zoom chaos optimization with the method of expert control system for coke oven combustion. The application results demonstrate its feasibility and effectiveness [4].

### 3.4 HEATING INTELLIGENT CONTROL

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.

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, in order to investigate the influence of various factors and find out quantitative relationship between them, it is necessary to carry on research on calculation model of goal flue temperature. But when establishing calculation model of goal flue temperature in fact, generally only several main factors are considered, 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 (2).

$$\mathrm{F}(j) = f(x, y, z, u, v, w, g, k), \quad (2)$$

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

This kind of interrelation model is set up generally by adopting linear regression method, but because there is a greater error sometimes in this method, and actual physics system is non-linear system, so neural network is used to build model. When modelling, neural network of three layers is used, neural network structure is $1 \times 6 \times 1$. Input layer is one node among them, average temperature on top of regenerator is inputting value; hidden layer is 6 nodes, nodal function is linear function is linear function, 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 on top of regenerator.

The most important control in coke oven production is temperature control, 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 cannot constrict to well-balanced station, the rigidity of coke is low, and the density is high, and the pushing electricity is high. Whereas, if the temperature is too high, the coke will mature too enough, and the coke cake constrict more than well-balanced station, the rigidity of coke is high, and the density is low, and the pushing electricity is low, which bringing too much soot in pushing course.

At present, iron and steel enterprises usually utilize the intermittent heating 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 [5]. 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 analysed and judged artificially by the attendants, and during stopping heating time, blast furnace gas and coke oven gas are stopped to be utilized at the same time and blast furnace gas is not fully utilized either. A new control principle combining the "intermittent heating control" with the heating gas flow adjustment is adopted in the control system [6]. 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 intelligent control model is illustrated in Fig. 2.

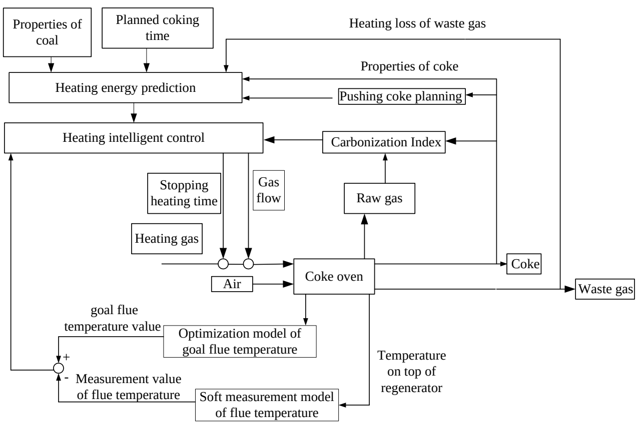


FIGURE 2 Intelligent control model of coke oven heating

Goal flue temperature of coke oven is the goal value of average temperature at machine side and coke side, is a main craft index to guarantee coke button ripe within carbonization time. There are a lot of main factors influencing goal flue temperature such as carbonization time, temperature in the centre of coke button, piling density of coal, water content, width of coke-chamber, thickness of stove wall. Because there are many variables and restrains, suitable optimization method is necessary to adopt. Through analysing some main factors influencing goal flue temperature and course of conducting heating of coke oven, conducting heating model is set up, thus 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 material, flue temperature, temperature in the centre of coke button. Finally the optimal model of goal flue temperature is built.

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. Deviation between goal value and measurement value, heating supplied amount of coke oven is revised real-time, thus coal gas flow and stopping heating time are adjusted.

When operation condition of production changes, the change range of 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 two long adjustment time are caused. Aiming at above-mentioned situations, a prediction part in the controlling course has been increased (shown as Fig.3). Furthermore, the deviation of temperature is judged firstly when the range of deviation does not exceed (-6, +6), and fuzzy control is adopted. If it exceeds above-mentioned ranges, Bang-Bang intelligent control is used. So control precision and fast response of controlled target are guaranteed.

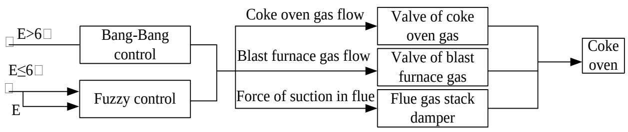


FIGURE 3 Intelligent control

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, and composition of heating gas and dynamic plans 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 constantly in the course of heating. Then the settlement value is calculated again in order to enable CI to be kept within the range of control, which satisfies not only necessary temperature needed in coking, but also optimal heating control.

## 3.5 PRODUCTION PLAN AND SCHEFULE

Production schedule of coke oven is affected by such information as production task, technological process characteristic of coke oven, equipment state and resource situation. It's an optimal control question with multi-object and many-restrains. When the unusual situation is coming, coke oven production is influenced and the production schedule of the coke oven can be adjusted dynamically. So making a plan by men or traditional methods is more difficult to solve problems above. Automatic arrangement and control of coke pushing a plan are realized by using automatic control and computer technologies combining with linear programming and genetic algorithm in the system. Its structure is shown as Fig. 4.

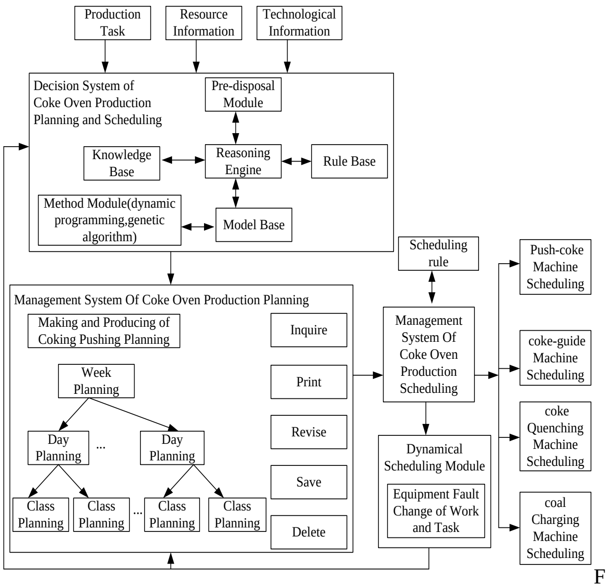


FIGURE 4 Structure of production planning and scheduling in coke oven

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 centre temperature will reach to 950~1050℃. If the centre temperature cannot reach the temperature, the coke cake will half-cooked and does not constrict well, this will affect coke oven life consequently. If the centre 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 following, running, pushing and setting off, which means coke pusher running to the appointed chamber to push according to the presupposed programming, and setting 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 pushing planning 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, the hydraulic brake must be restarted continuously to reduce the security and shorten power equipment life. Coke pushing planning is still arranged by hand, and the work is trivial and stiff. Therefore, it is very essential to arrange pushing planning automatically and give coke pushing planning timely.

Automatic arrangement and control of coke pushing planning are realized by using automatic control and computer technologies combines 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 coke pushing job is adopted to arrange coke pushing planning, which means making average subsection according to commanded number of overhaul in every little circle, 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 total chamber number of every little circle in the arrangement, the planning 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 according to the algorithm of average subsection and proportional correction, then the mature of coke in each chamber should be analysed in term of the practical production of coke battery, the following pushing coke-chamber number and pushing time should be computed and transferred to the operator in coke pusher. Therefore, linear programming should be introduced and dynamic programming is used to build planning model. In the planning model, the target function is target temperature, like 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 uniform 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 used to programming to find the solution.

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

According to such real-time information as production task, resource information, craft information and so on, the production plan is made by decision system of the production plan and schedule. Production plan management system is composed of the pushing coke plan, coal injection plan, plan requirement, plan type, plan revision, plan conversation and plan delete. All plans are divided into several grades of class, day and week. The schedule management system carries out the management of four carts of coke oven in order according to schedule rules. This system coordinates production capacity online, and has inspection ability to each production process of the production line. When equipment is unusual, either operating mode or production task will vary. The system starts and adjusts the module dynamically to manage in real time, and give feedback information to the decision system to resume producing steadily and fast, and then an automatic dynamic schedule decision scheme is given to administrative staff on the spot. This system has guaranteed implement of pushing coke and coal injection on the schedule, steady production operation, and carbonization time, which improves coke quality and lengthen the furnace service life.

## 4 Application

The system puts into operation for more than four years in some coke oven of iron and steel company. The system runs normally and the effect is good. The system can not only regulate the size of heat-supply in time but also have stronger anti-interference ability. The system has reduced the fluctuation of the whole temperature of the coke oven, and fluctuation with furnace temperature to a great extent. It diminishes the heat of supporting that the coke oven need is also relative, so consumption of the blast furnace gas has decreased, and energy is saved by 2%-3% under the normal situation. The fluctuation of longitudinal temperature is kept straightly on 3-5 degrees centigrade. At the same time, the control system improves stable coefficient, lengthens the service life of the coke oven, and boosts coke quality.

## 5 Conclusions

The intelligent control of coke oven production process is carried out, the fluctuation of furnace temperature has been solved effectively, and the better control result has been achieved. The production plan and schedule of coke oven are optimized, which has realized the intelligent control of coke oven production operation effectively through utilizing the dynamic plan and genetic algorithm correctly at the same time. After the system is put into operation, it runs steadily and can stabilize stove temperature and coke oven production. The energy-conserving result is obvious, improves coke quality effectively, and has reached the anticipated effect. The system is of great practical value.

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