Expert System for Control Guidance of Grate-Kiln Pellet Production

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The characteristics of large-scale equipments, continuous process, close system and severe environment make grate-kiln process hard for parameter detection and difficult to control. The accuracy and normalization of grate-kiln process control need to be improved. Therefore, an expert system providing real time control guidance for grate-kiln pellet production is presented. The “roasting temperature of pellet in kiln & gas temperature in gas hood of preheating section” dominated control strategy is put forward and control rules for grate-kiln process are established based on expertise. A multistage reasoning strategy of “parameter status estimation – reason analysis – adjustment measure selection” is developed and forward reasoning is adopted. The application of software, which is programmed with Visual C++, is outlined. The results show that, with the assistance of expert system, stability rate of grate-kiln pellet production is increased from 91.0% to 94.2%, FeO content of finished pellet is 0.05% lower, compressive strength is 86 N/pellet1 higher, first grade rate of pellet is increased by 2.54%.

KEY WORDS: grate-kiln; iron ore oxide pellet; expert system; online control guidance.

1. Introduction

Iron ore pellet with high grade, good reducibility, homogenous particle size, stable composition and favorable metallurgical performance is a desirable feedstock for ironmaking furnaces. There are three main processes for pellet production: shaft furnace, straight grate and grate-kiln. The characteristics of large production capacity, high product quality, especially low requirements of equipment materials and satisfying flexibility of raw materials make grate-kiln the dominant process in China. However, as a relatively closed system, online detections of thermal process and reactions are hard to implement, moreover, production process has multiple procedures and strong coupling, thus grate-kiln is still low in control after decades of applications. Sharp fluctuations and ring forming occur frequently and regular production is influenced.

Intelligent control, which is the outcome of the combination of artificial intelligence technology and modern control theory, can make analysis and judgment of expert level by simulating thinking process of human beings. It is the future direction of pellet production control.1) At present, most researches on intelligent control of grate-kiln pellet production focus on historical data based method2–5) instead of empirical knowledge of domain experts, and reports of production application are rarely seen.

Based on analysis of grate-kiln process and summarizing of empirical knowledge of domain experts, expert system for control guidance of grate-kiln pellet production is developed and discussed in this paper, with a focus on knowledge base and inference engine.

2. System Architecture

Expert system for control guidance of grate-kiln pellet production consists of 5 parts: data preprocessing, simulation model, knowledge base, inference engine and global database. Its structure is shown in Fig. 1.

Grate-kiln pellet production has multiple procedures. Detection is under severe conditions. And the signals are susceptible to external interference. Therefore, data collected from production have to be preprocessed to ensure their validity and authenticity, avoid over-frequent adjustment and misoperation. Abnormal data elimination and signal smoothing are involved in this part.

Mathematical model can make up the deficiencies of the existing detection techniques and provide real time information for production control. The models used in this paper

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are described in earlier papers, including model of temperature field, model of moisture distribution and model of magnetite oxidation. These models are developed based on steady-state hypothesis. Therefore, steady-state judgment is implemented as trigger condition of model calculation.

Knowledge base has multi-base structure, which fits the feature of multiple knowledge type, improves reasoning efficiency and facilitates knowledge maintenance. It has 4 main parts which are data base, model base, fact base and rule base. Data base stores current and historical data of grate-kiln pellet production by both direct detection and model calculation. Model base stores structures and parameters of mathematical models. Static facts of process features, production requirement and inference are stored in fact base. Rules for parameter status estimation, reason analysis and adjustment measure selection are stored in rule base. Knowledge in fact base and rule base can be added, modified and deleted by knowledge base management system.

Inference engine is a computer program, which is used to select necessary knowledge from the knowledge base, infer with production information which is already known, and finally obtain guidance for production control. The inference process of "parameter status estimation – reason analysis – adjustment measure selection" is used based on the requirements of grate-kiln pellet production control.

Global database stores information of the current system status, including production data, facts, rules, internal information and final results. Its contents are constantly changing in the running process of the system. And the results of inference are provided as control guidance from the global database.

3. Knowledge Base

3.1. Control Strategy

A typical grate-kiln-cooler pellet induration system is shown in Fig. 2. Grate consists of 4 sections which are updraught drying section (UDD), downdraught drying section (DDD), tempered preheating section (TPH) and preheating section (PH). Cooler has 4 sections as well, which are cooling section 1 (C1), cooling section 2 (C2), cooling section 3 (C3) and cooling section 4 (C4).

Green pellets enter the induration system by charging on grate, go through grate, kiln and cooler successively for drying, preheating, roasting and cooling, and finally discharged as finished pellets. As an important carrier of heat, gas circulates in grate-kiln-cooler system and is considered to be the main reason for grate-kiln control complexity. Influence factors of each section of grate-kiln system (Fig. 3) were indicated by analysis of pellet flow and gas flow.

Figure 3 shows that:

1. Heat released by coal combustion in kiln is the primary heat source for grate-kiln induration system. Temperature in kiln gives the earliest signal of heat variation in the whole system. Roasting temperature of pellet is not only the determinant of product quality, but also a measure of heat level in kiln.

2. Gas going into downdraught drying section comes from wind boxes of preheating section, hence, is affected by gas temperature of the latter. Besides the part comes from cooling section 2, gas going into tempered preheating section partially comes from gas hood of preheating section through the hole in the windbreak wall between these two sections as heat supplement. So temperature of tempered preheating section is also affected by preheating section. As a continuous process, results of the previous section, such as temperature, flow rate, moisture and FeO content of pellet, have effects on the following one. Accordingly, kiln is affected by preheating section as well. It indicates that preheating section has direct influence on almost all the other sections in grate-kiln system. Production status of grate process can be considered essentially normal when temperatures of preheating section are controlled in suitable ranges and temperatures of preheating section will respond to the anomaly of the others in a short time, due to the existence of air circulation.

Therefore, the “roasting temperature of pellet in kiln & gas temperature in gas hood of preheating section” dominated control strategy was put forward for grate-kiln pellet production control. If roasting temperature of pellet in kiln and gas temperature in gas hood of preheating section are both in acceptable ranges, no adjustment is needed for the time being, even when there are anomalies in the other parameters. If either of them is abnormal, the adjustment measures will be provided according to the specific situation.

3.2. Control Rules

Control rules for grate-kiln pellet production were established based on expertise, as shown in Fig. 4. Where nodes A–F represent roasting temperature of pellet in kiln, gas temperature in gas hood of preheating section, height of pellet bed, running speed of grate, inlet gas temperature of main exhaust fan and gas temperature in wind box of preheating section, respectively. And the leaf nodes K1–K55 are adjustment measures.

The cause of anomalies in grate-kiln pellet production can be divided into 4 types: fluctuation of pellet amount (PA), unsuitable level of heat in the whole grate-kiln system (WS), unsuitable distribution of heat between grate and kiln (GK) and unsuitable distribution of heat among sections of grate (GS). These causes can overlap each other. Therefore,
adjustment measure should be selected out of comprehensive consideration of the production state. Table 1 shows some examples of the control rules.

The personal experience based adjustment measures selected by different operators are probably distinct even for the same cause of anomaly. And even the right measures differ in adjust efficiency. Control rules of this expert system were established based on the combination of experience from multiple experts, model calculation, and heat and mass transfer analysis. The adjustment process is composed of a series of “judge-adjust” process. Optimal measures are selected to make the current status change towards normal, after the formation of a new status, corresponding new measures are suggested, and this process is repeated until normal status is finally achieved. Instead of blind pursuing of less adjustment steps, the primary objective of these control rules is ensuring that every step is in the correct direction, the status is changing towards normal, and sharp fluctuations are avoided.

4. Inference Engine

Though lack of specific objectives and low in inference efficiency, forward reasoning is simple, direct and easy-realizing, therefore, fit for solving problems such as design, prediction, monitoring and diagnosis. Forward reasoning was adopted by comprehensive consideration of the characteristics of knowledge base and operation mode of this expert system.

Inference of this expert system is a multistage process of acquiring signs from data information, analyzing cause with these signs, and guiding adjustments. Therefore, multistage reasoning strategy was established as shown in Fig. 5.

5. Software Development and Application

Software of expert system for control guidance of grate-kiln pellet production was developed by Visual C++ programming. And the main interface is shown in Fig. 6.
This software has been put into field practice in a pellet plant with an annual output of 2 million tons in China since January 2011. Table 2 shows a set of production data recorded in database. Roasting temperature of pellet is calculated by mathematical model of temperature field in rotary kiln, \(^7\) while the rest parameters are field detected.

For the production status in Table 2, “decrease kiln speed and increase coal injection rate” was displayed on the software interface as suggestion of adjustment measures, and the explanation for this measure selection was “The current status of grate-kiln system is ‘roasting temperature of pellet in kiln is too low, gas temperature in gas hood of preheating section is low, height of pellet bed is normal, and inlet gas temperature of main exhaust fan is low’. Cause of the anomaly is ‘heat level of the whole grate-kiln system is low’ ”. According to the records, the production status was back to normal and stabilized about 10 minutes after this adjustment.

The comparisons of gas temperature fluctuations in gas hood of preheating section and pellet quality indexes before and after system application are shown in Fig. 7 and Table 3.

While 1060–1090°C was defined as the suitable range for gas temperature in gas hood of preheating section, and production status was considered stable under this condition, the grate-kiln pellet production was stabilized by application of this system that stability rate of pellet production was increased from 91.0% to 94.2%. Quality indexes of product were improved that FeO content of finished pellet was 0.05% lower, compressive strength was 86 N·pellet\(^{-1}\) higher, first grade rate of pellet was increased by 2.54%, tumbler strength, abrasion resistance index and screening index were improved in varying degrees.

### 6. Conclusions

Expert system consisting of data preprocessing, simulation model, knowledge base, inference engine and global database was developed to solve the problem of low control level in current grate-kiln pellet production. It makes the experience based control process automated, normalized and more accurate.

The “roasting temperature of pellet in kiln & gas temperature in gas hood of preheating section” dominated control strategy was put forward based on analysis of production process and influence factors of each section. Control rules for grate-kiln process were established based on expertise. And grate-kiln pellet production can be stabilized by a series of “judge-adjust” process.

Forward reasoning was adopted by comprehensive consideration of the characteristics of knowledge base and operation mode of this expert system. Multistage reasoning strategy was established according to the inference process of “parameter status estimation – reason analysis – adjustment measure selection”.

Software was developed by Visual C++ programming and put into field practice. The results show that, with the assistance of the expert system, stability of grate-kiln pellet production, pellet quality and economic benefit are all improved.

### References