Research on the Separation Model of Dense Medium Coal Preparation and Analysis of Separation Effect

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Abstract. This paper studies the heavy medium coal separation model, analyzes the heavy medium separation experiment, fits the distribution curve, and examines the coal separation effect. Through research, it can be seen that the coal preparation accuracy Ep value gradually decreases with the increase of particle size; The mathematical expression for the Ep value of Xiaojihan Coal Preparation Plant was obtained through data fitting, with a goodness of fit of 0.999 and a good fitting effect.

Keywords: separation model; dense medium; separation effect.

1 Introduction

The intelligent construction of domestic coal preparation plants is still in the exploratory and initial stage, and the level of automation needs to be improved. In terms of production management, comprehensive control, equipment management and maintenance, as well as cost consumption control, it still mainly relies on the experience of management personnel for analysis, decision-making, and operational management. The vast majority of valves and single machine automation equipment on site are operated manually through centralized control scheduling, resulting in complex procedures and low efficiency; The degree of automation in the process of adding agents is low, requiring manual operation and high labor intensity; The coal slurry pressure filtration process requires manual job placement operation; In the actual production process, relying more on manual fast ash inspection for product quality takes a long time, resulting in a time delay in adjusting the density of heavy medium shallow groove sorting according to product quality, large fluctuations in product quality, high labor intensity of workers, and inability to achieve maximum economic benefits[1-2]. The National Energy Administration has proposed the "Construction Guidelines" and "Acceptance Methods" for intelligent coal preparation plants, focusing on building a complete intelligent system for coal preparation plants in four aspects: basic platform construction, basic automation, intelligent control, intelligent management, and decision-making [3-4].

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The automation and intelligence level of the heavy medium sorting system is a key factor affecting the sorting effect in the process of heavy medium coal preparation. At present, operators mainly rely on practical experience to control the density of heavy medium sorting, and evaluate the rationality of the current sorting through fast ash or fast float data. On site reselection systems often maintain the same sorting density for a long time, which may result in substandard ash content or loss of clean coal in the product. By systematically understanding and optimizing the process of heavy medium coal preparation, the efficiency of the coal preparation system can be improved, energy consumption can be reduced, precise control of the amount of medium added and sorting density can be achieved, the stability of heavy medium suspension can be improved, and medium consumption can be reduced; To avoid issues such as product failure or loss of clean coal caused by additives, and to ensure that the quality of the final product meets the requirements, providing strong support for the sustainable development of the coal preparation industry [5].

The production system of the coal preparation plant has complex processes, flexible and varied production methods, and a wide range of production areas. Traditional PLC systems are difficult to meet the complex and flexible logic control and production management needs. At present, many aspects such as starting and stopping, density adjustment, adding media, production statistics, and equipment inspection still rely on manual methods for operation. Job drivers inquire about real-time production parameters through walkie talkies, resulting in heavy on-site workload, slow response, low efficiency, and poor real-time performance. In terms of product quality control, manual laboratory testing is still used to obtain production quality data. Frontline personnel are lagging behind in obtaining data and cannot timely and accurately regulate the quality of each production link, which cannot meet the increasing production and operation needs of large coal preparation plants. To solve the problems of low automation level, high dependence on manual experience in the production process, and certain lag in adjusting the density of heavy medium separation in Xiaojihan Coal Preparation Plant, various intelligent decision-making algorithms and programs were developed by processing, analyzing, and mining the production data of heavy medium system, filter press system, and raw coal screening float and sink data. The intelligent application functions were encapsulated through software deployment, and finally human-machine interaction and collaboration were achieved through server and cloud configuration, forming a new production operation mode, realizing active control of equipment operation, quality, and process parameters in the production process, and truly realizing intelligent production. Therefore, if we want to achieve precise control of the coal preparation heavy medium system, it is very important to study the heavy medium coal separation model and analyze the separation effect.

2 Research Status of Intelligent Decision System in Coal Preparation Plant

The impact of intelligent and digital construction on the operation and management mode of coal enterprises is becoming increasingly significant. The key to the digital transformation of coal preparation plants is to "simplify" the business by sorting and integrating existing operational processes, and establishing efficient and streamlined intelligent decision-making models. The basic approach for integrating intelligent decision-making models in coal preparation plants is to sort out core businesses such as production and operation, mechanical and electrical management, and safety management. After subdividing functional modules, the model follows a vertical to bottom principle and runs through the production line, coal preparation plant management, and company decision-making to provide homogeneous data reports for intelligent decision-making. Then, the business data is horizontally integrated. Targeting key requirements at the production and operation level, based on data from production operations, mechanical and electrical management, and operating costs, various data algorithms and statistical methods are used to calculate and deduce key target parameters, assisting business management personnel and leadership decision-makers in making decisions on key production and operation issues.

At present, decision-making systems are mostly focused on coal blending, scheduling, and structural optimization. The Shendong Washing and Selection Center has researched and established an intelligent control and integration linkage mechanism for the entire process of the coal preparation plant, and built an intelligent scheduling center functional system. Ningmei Company collects production, safety, and operation data from various business centers, conducts coal industry data modeling, and provides decision support for coal safety, production, operation management, and risk control. The Huangling No.1 Coal Preparation Plant has set up various washing processes for raw coal, washing, and loading. Based on annual and monthly product coal production decomposition plans, market demand for commodity coal, and large-scale maintenance plans at the plant level, production instructions are automatically pushed to different intelligent control production systems.

The accurate prediction of reselection effect is the core element of intelligent control in heavy medium sorting process. Currently, the mechanism model usually adopts Gaussian probability distribution. Although the model parameters have clear physical meanings, the prediction accuracy is relatively low. The empirical model of distribution curve can also be established using the single machine inspection data of the coal preparation plant, but the mechanism of distribution curve transformation under different sorting densities is not clear, and the applicability of the model is poor. Therefore, it is necessary to deepen the research on the mechanism of the re-election process and combine intelligent algorithms to construct a more reasonable and accurate mathematical model of the allocation curve. Studying the physical mechanism of distribution curve transformation under different sorting densities and constructing a high-precision distribution curve mathematical model suitable for intelligent control of the reselection process is of great significance for the product structure of coal preparation plants, improving the sorting accuracy and economic benefits of coal preparation plants.

3 Research on the Separation Model of Heavy Medium Coal Preparation

The actual distribution curve of the reselection equipment is based on the single machine inspection data of the equipment, using the Grignard method to calculate the actual yield of the product, and then calculating the corresponding distribution rate according to the mass percentage of heavy products of a certain density in the material.

3.1 Analysis of Heavy Medium Separation Test

This project conducted screening tests, float sink tests, and ash content measurements on coal samples from Xiaojihan Coal Preparation Plant at various particle size and density levels. The experimental data are as follows:

Table 1. Single machine inspection data of 200-13mm shallow groove in Xiaojihan Coal Preparation Plant

Density g/cm^3	Clean coal yield %	Clean coal ash content %	Gangue yield %	Gangue separation %
<1.30	82.86	4.12	0.76	5.19
1.30~1.40	9.52	12.12	0.59	10.93
1.40~1.50	6.26	17.36	9.43	22.07
1.50~1.60	1.28	24.86	9.85	27.99
1.60~1.70	0.05	33.99	7.34	32.29
1.70~1.80	0.01	37.87	12.69	40.87
+1.80	0.03	44.14	59.36	69.17
total	100.00	6.00	100.00	52.84

From Table 1, it can be seen that the ash content of the feed is 9.59%. After shallow groove sorting, the fine coal ash content has decreased to 6.00%, and the content of fine coal with a density level greater than 1.8 is only 0.03%, indicating that the gangue in the feed has been basically completely removed through sorting.

3.2 Allocation Curve Fitting Model

Let γ_f , γ_c and γ_t be the yields of raw coal, clean coal, and gangue, fi, ci and ti be the corresponding contents of different density levels in raw coal, clean coal, and gangue, and n is the number of density levels. According to the product equilibrium, there are:

$$\begin{cases} \gamma_c + \gamma_t = 1 \\ \gamma_c c_i + \gamma_t t_i = f_i \end{cases} \quad (i = 1, 2, \cdots\cdots n) \tag{1}$$

To ensure that each product has an optimal solution, the sum of squared deviations between the experimental and calculated values of each density level should be minimized. The objective function can be expressed as:

$$\sum_{i=1}^{n}\Delta_i^2=\sum_{i=1}^{n}[f_i-(\gamma_c c_i+\gamma_t t_i)]^2 \tag{2}$$

The actual yield of clean coal is 89.59%, and the yield of gangue is 10.41%.

Before calculating the allocation rate, it is necessary to first calculate the feed rates of raw coal, clean coal, and gangue at different density levels. The corresponding calculation formula is as follows:

Yield of various density levels of clean coal:

$$C_i=\gamma_c\times c_i \tag{3}$$

Yield of various density levels of gangue:

$$T_i=\gamma_t\times t_i \tag{4}$$

Yield of each density level of feed:

$$F_i=C_i+T_i \tag{5}$$

Distribution rate calculation formula:

$$\varepsilon=\frac{T_i}{F_i} \tag{6}$$

In the formula, T_i and F_i are the feed yield of each density level of gangue, and the calculated yield of each density level of raw coal.

To calculate the actual sorting density and possible deviations, it is necessary to establish a fitting model for the distribution curve. The shape of the distribution curve is S-shaped, and an S-shaped function should be selected to fit the curve. The calculated values of the model should be compared with the actual values, and the model parameters should be determined based on the principle of least squares to establish an empirical model for the optimal distribution curve. In coal selection, commonly used empirical models for distribution curves include:

Hyperbolic tangent model

$$y=100\cdot(b1+b2\cdot\tanh(b3\cdot(x-b4))) \tag{7}$$

Composite hyperbolic tangent model

$$y=100\cdot(b1+b2\cdot x+b3\cdot\tanh(b4\cdot(x-b5))) \tag{8}$$

antitangent model

$$y = 100 \cdot (b1 \cdot \arctan(b2 \cdot (x - b3)) + b4) \quad (9)$$

In the above function expression, x is the average density of sorting, y is the allocation rate, and b1~b5 are the corresponding model parameters.

To preliminarily evaluate the fitting effect of the model, MSE (mean square error) is used here. The fitting accuracy is compared by the magnitude of MSE of the three models, and the smaller the MSE value, the higher the fitting accuracy.

$$MSE = \frac{1}{n}\sum_{i=1}^{n}(y_i - y_i')^2 \quad (10)$$

In the formula, n is the number of samples, y_i is the actual value, and y_i' is the fitted value.

It can be seen that the fitting accuracy of the hyperbolic tangent and composite hyperbolic tangent models is higher than that of the arctangent model. To comprehensively evaluate the quality of the model, corresponding function graphs need to be drawn to observe the trend of the distribution curves of different models.

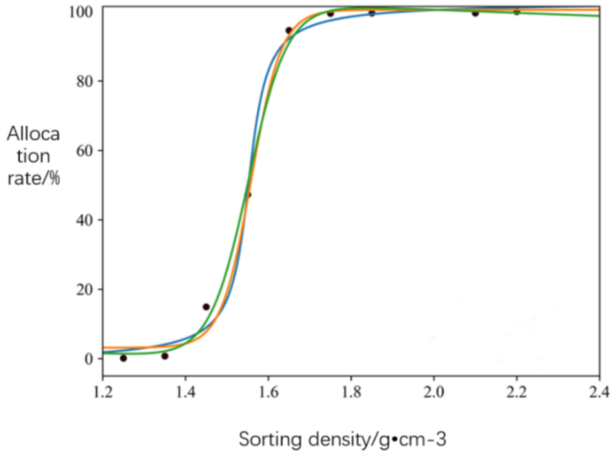

Fig. 1. Comparison of Empirical Models for Distribution Curve of Medium Shallow Groove

The results in Figure 1 indicate that the hyperbolic tangent and composite hyperbolic tangent models have high fitting accuracy. Considering the comprehensive fitting effect and model complexity, the hyperbolic tangent function is selected as the distribution rate curve model for the heavy medium shallow groove in Xiaojihan Coal Preparation Plant.

The characteristic parameters of the shallow groove equipment in the coal preparation plant were calculated based on the selected hyperbolic tangent model, and the results are shown in Table 2.

Table 2. Equipment characteristic parameters

type	δ_{25}	δ_{50}	δ_{75}	E_p
Heavy medium shallow groove	1.515 g/cm^{-3}	1.557 g/cm^{-3}	1.597 g/cm^{-3}	0.04 g/cm^{-3}

3.3 Research on the Influence of Coal Preparation and Sorting Efficiency

In the above chapters, the calculation methods related to allocation rates and the most suitable empirical model for allocation curves have been elaborated in detail. In order to systematically study the variation of Ep values with granularity, allocation rates composed of different granularities were calculated.

The hyperbolic tangent model was used to fit the data, and the Ep values and sorting densities of each particle size were obtained. The calculation results are shown in Table 3.

Table 3. Different particle size Ep and sorting density

Average granularity level mm	E_p g/cm^{-3}	Sorting density g/cm^{-3}
125	0.010	1.619
38	0.049	1.524
24	0.068	1.526
10	0.089	1.534

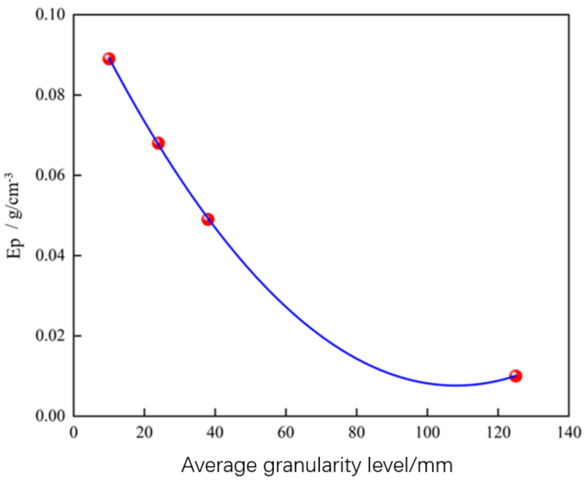

Fig. 2. Variation of Ep with Average Particle Size Scale

To observe the mathematical relationship between the average granularity level and Ep more intuitively, Figure 2 was plotted, which shows that Ep gradually decreases with increasing granularity. Through data fitting, the mathematical expression of Ep with particle size in Xiaojihan Coal Preparation Plant was obtained, with a goodness of fit of 0.999 and good fitting effect. The specific expression is as follows

$$y = p_1 * x^2 + p_2 * x + p_3 \tag{11}$$

4 Conclusion

The accuracy of fitting the distribution curve directly affects the evaluation effect and reliability of the separation process, and is the basis for predicting the effect of gravity coal selection and optimizing the process. The study of the characteristics of the distribution curve and its corresponding mathematical models is very important. Through research, it can be seen that the coal preparation accuracy Ep value gradually decreases with the increase of particle size; The mathematical expression for the Ep value of Xiaojihan Coal Preparation Plant was obtained through data fitting, with a goodness of fit of 0.999 and good fitting effect. The specific expression is $y = p_1 * x^2 + p_2 * x + p_3$.

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