Research on fragmentation quality percentage of coal in hot air dense medium fluidized bed

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Abstract. This paper studies the percentage of pulverized coal in the hot air dense medium fluidized bed, and investigates the influence of coal surface moisture, drying temperature, drying time, air volume and other factors on the percentage of crushing, and establishes a mathematical correlation formula for the percentage of crushing; it shows that with the increase of drying temperature, the percentage of crushing increases; with the increase of air volume, the percentage of crushing increases; the percentage of crushing increases with the increase of drying time and increases with the increase of surface moisture of coal.

1. Introduction
About two-thirds of my country’s coal resources are distributed in the northwest and other dry and water-deficient areas. It is difficult to use wet coal preparation technology to improve coal quality [1-2]. Because of the urgent demand for dry coal preparation technology [3-4], the air is heavy. The medium fluidized bed coal preparation technology uses solid particles with a certain size as the solid phase aggravation matter, and then air is introduced to completely fluidize the aggravated particles to achieve coal separation [5-6].

In this test, due to the self-developed air-dense-medium drying and sorting integrated device introduced heat energy, coal with high moisture content, especially lignite, in the hot fluidized bed sorting process, its own void structure, brittleness and other physical properties will continue to change. Coupled with the continuous collision and friction of coal in the fluidized bed, the coal is prone to breakage. In actual production, the discharge end of the separator is at a certain height from the vibrating separation screen. After the selection, the product falls into the separation screen. Later, it is also prone to breakage. After crushing, coal powder of <1mm is produced, which cannot be removed through the normal de-intermediation sieve. It will enter the under-sieve medium together with the magnetite powder and participate in the diversion operation. Therefore, it is necessary to study the crushing behavior of coal in the hot fluidized bed, which can guide the control of the split flow and the removal of non-magnetic substances.

2. Test system
The experimental device is a drying and sorting integrated model device of air heavy medium fluidized bed, which is composed of an air supply system, an electric heating system, a separation system and a temperature detection system. The structure diagram is shown in Figure 1, the physical map is shown in Figure 2.
3. Establishment of mathematical correlation of fragmentation quality percentage

According to the experimental data of the fragmentation quality percentage, the $R^2$ comprehensive analysis of the two models recommended by Design-Expert is shown in Table 1. The results show that the standard deviation and $R^2$ correction value of the two models are not much different, but the $R^2$ prediction value of the 2FI model is greater than that of the quadratic model. The residual sum of squares is less than the quadratic model, which shows that the 2FI model is suitable for simulation and analysis of experimental results. However, considering that the $R^2$ correction value of the 2FI model is 0.8435 and the $R^2$ prediction value is 0.6989, there is a certain gap between the two, indicating that the simulation accuracy of the model needs to be improved, so the 2FI model needs to be revised.

The analysis of variance was performed on the model parameters of the 2FI model, as shown in Table 2. The F value test method was used to test the significance of the model parameters. Among them, when the "Prob>F" of the model parameter is greater than 0.1, it means that the parameter is not significant. When "Prob>F" is less than 0.05, it means that the parameter is significant. From Table 2, it can be seen that the AB, BD, CD and other factors in the model are less significant. In order to improve the simulation effect, these factors are removed and established a new model is the 2FI revised model.

![Fig. 1 Schematic diagram of air dense medium fluidized bed drying and separating integration experiment system.](image-url)
A comprehensive analysis of $R^2$ is performed on the 2FI correction model. As shown in Table 3, it can be seen that the correction value of $R^2$ is 0.8424, and the predicted value of $R^2$ is 0.7703. Both of them are relatively large and close in value, showing good consistency. It shows that the simulation accuracy of the 2FI modified model is relatively high. Therefore, it was decided to use the 2FI modified model to simulate the broken percentage experiment.

Through simulation, the mathematical correlation between the fragmentation quality percentage and various operating parameters is obtained:

$$\text{fragmentation quality percentage} = 0.833 \times 0.027 - 3.750 \times 10^{-7} \times B$$

$$-0.049 \times 0.087 \times D + 1.188 \times 10^{-7} \times AC + 2.875 \times 10^{-7} \times AD + 0.011 \times BC$$

Based on the mathematical correlation of broken percentages, the prediction results and the experimental results are compared and analyzed, as shown in Table 4. The normal distribution of the studentized residual is shown in Figure 2, and the comparison between the experimental value and the predicted value is shown in Figure 3. It can be seen that the studentized residual basically conforms to the normal distribution, and the experimental value and the predicted value are in good agreement.

![Fig.2 Normal distribution of Studentized Residuals of fragmentation quality percentage](image)

A variance analysis was performed on the model parameters of the quadratic correction model. As shown in Table 5, it can be seen that the five model parameters A, B, C, D, and AD are significant factors, which A and C are the most significant, followed by B, D, AD.

| model                  | standard deviation | $R^2$ | $R^2$ correction value | $R^2$ Predictive value | Prediction residual sum of squares |
|------------------------|--------------------|-------|------------------------|------------------------|-----------------------------------|
| Quadratic correction model | 0.024              | 0.8818| 0.8424                 | 0.7703                 | 0.023                              |
Fig. 3 The comparison between experimental and predicted values of fragmentation quality percentage

Table 4 The comparison to fragmentation quality percentage between experimental and predicted values

| Serial number | Experimental value | Predictive value | Residual | Studentized residuals |
|---------------|--------------------|------------------|----------|-----------------------|
| 1             | 0.040              | 0.019            | 0.021    | 0.993                 |
| 2             | 0.120              | 0.135            | -0.015   | -0.691                |
| 3             | 0.070              | 0.079            | 8.876E-003 | -0.417             |
| 4             | 0.165              | 0.195            | -0.030   | -1.396                |
| 5             | 0.070              | 0.037            | 0.033    | 1.541                 |
| 6             | 0.115              | 0.121            | 5.543E-003 | -0.260             |
| 7             | 0.045              | 0.093            | -0.048   | -2.258                |
| 8             | 0.165              | 0.176            | -0.011   | -0.535                |
| 9             | 0.035              | 0.050            | -0.015   | -0.834                |
| 10            | 0.095              | 0.108            | -0.013   | -0.739                |
| 11            | 0.070              | 0.048            | 0.022    | 1.245                 |
| 12            | 0.245              | 0.221            | 0.024    | 1.339                 |
| 13            | 0.045              | 0.058            | -0.013   | -0.716                |
| 14            | 0.080              | 0.073            | 7.374E-003 | 0.418             |
| 15            | 0.090              | 0.096            | 5.960E-003 | -0.338             |
| 16            | 0.215              | 0.201            | 0.014    | 0.796                 |
| 17            | 0.030              | 0.031            | 9.598E-004 | -0.054             |
| 18            | 0.125              | 0.099            | 0.026    | 1.457                 |
| 19            | 0.060              | 0.067            | 6.793E-003 | -0.385             |
| 20            | 0.250              | 0.230            | 0.020    | 1.127                 |
| 21            | 0.075              | 0.049            | 0.026    | 1.228                 |
| 22            | 0.120              | 0.109            | 0.011    | 0.523                 |
| 23            | 0.120              | 0.105            | 0.015    | 0.718                 |
| 24            | 0.200              | 0.165            | 0.035    | 1.658                 |
| 25            | 0.100              | 0.107            | 6.793E-003 | -0.290             |
Table 5 Variance analysis of 2FI corrected model parameters (fragmentation quality percentage)

| Model factors | sum of square | Degree of freedom | Mean square | F value | Prob > F |
|---------------|--------------|--------------------|-------------|---------|----------|
| A             | 0.040        | 1                  | 0.040       | 71.00   | < 0.0001 |
| B             | 0.011        | 1                  | 0.011       | 19.05   | 0.0003   |
| C             | 0.021        | 1                  | 0.021       | 36.75   | < 0.0001 |
| D             | 9.352E-003   | 1                  | 9.352E-003  | 16.50   | 0.0006   |
| AC            | 2.256E-003   | 1                  | 2.256E-003  | 3.98    | 0.0592   |
| AD            | 3.306E-003   | 1                  | 3.306E-003  | 5.83    | 0.0249   |
| BC            | 2.205E-003   | 1                  | 2.205E-003  | 3.57    | 0.0727   |

4. The influence of drying temperature and air volume on the fragmentation quality percentage

Figure 4 shows the effect of drying temperature and air volume on the percentage of crushing. It can be seen from Figure 4 that as the drying temperature increases, the percentage of crushing increases; as the air volume increases, the percentage of crushing increases. This is because lignite contains a large number of microporous structures of different sizes, and water is easily stored in these micropores in a clustered structure. The more water on the coal surface, the more water penetrates into the micropores. Because lignite is rich in oxygen-containing functional groups, and these oxygen-containing functional groups have strong water absorption, moisture is easily combined with these functional groups; when the coal is dried in the fluidized bed, the surface moisture of the coal and the moisture inside the micropores will be affected. Diffusion and phase change occur, and energy is released. During this process, the microporous structure on the surface and internal of the lignite is destroyed, some of the structure will collapse, and the size and number of micropores will continue to decrease, resulting in volume shrinkage of the lignite, also caused the increase of the overall brittleness and hardness of coal.

The increase of the drying temperature increases the heat and mass transfer intensity between the wet coal and the hot fluidized bed. The movement of the water molecules inside the coal is intensified, and the diffusion and evaporation rates increase, which in turn affects the structure of the lignite and makes the lignite easier broken. Therefore, as the drying temperature increases, the percentage of crushing also increases. The increase in air volume will make the contact between gas and solid more sufficient, the efficiency of heat and mass transfer will increase, and the strength of collision and friction between lignite will increase. Therefore, as the air volume increases, the probability of lignite crushing increases, and the percentage of crushing increases.
5. The effect of drying time and coal surface moisture on the fragmentation quality percentage

Figure 5 shows the effect of drying time and coal surface moisture on the percentage of crushing. It can be seen from Figure 5 that the percentage of crushing increases with the increase of drying time, and increases with the increase of coal surface moisture. This is due to the increase in drying time, which makes the contact time of coal and hot fluidized longer, and the total amount of water diffusion and evaporation increases, which increases the degree of damage to the structure of lignite by drying. Therefore, the percentage of broken will increase with the increase of drying time. With the increase of coal surface moisture, the contact area between moisture and lignite increases, the diffusion and evaporation of moisture increase, and the severity of the impact on the structure of lignite increases, coal is more easily broken during fluidized bed drying and collision and friction between coals, so the percentage of broken coal will increase with the increase of surface moisture of coal.

6. Conclusion

(1) The mathematical correlation between the fragmentation quality percentage and various operating parameters has been established:

\[
\text{fragmentation quality percentage}(\%) = 0.833 - 0.027A - 3.750 \times 10^{-7} B \\
-0.049C - 0.087D + 1.188 \times 10^{-5} AC + 2.875 \times 10^{-3} AD + 0.011BC
\]

(2) With the increase of drying temperature, the percentage of crushing increases; with the increase of air volume, the percentage of crushing increases.
(3) The percentage of crushing increases with the increase of drying time, and increases with the increase of coal surface moisture.

References
[1] Zhenfu Luo.(2001) The clean way of coal separation in western my country-fluidized bed high-efficiency dry coal preparation technology. China Mining,10(5): 12-14.
[2] Zhenfu Luo.(2001) Optimal Utilization of Coal Energy in Western China. China Mining Industry, 10(1): 36-39.
[3] Qingru Chen, Yufen Yang, etc.(2001) The development of high-efficiency dry coal preparation technology in the 21st century. Journal of China University of Mining and Technology, 30(6): 527-530.
[4] Qingru Chen, Zhenfu Luo, etc.(2003) Comments on dry coal preparation. Coal Preparation Technology, (6): 34-40.
[5] Guojing Dazang, Livingsbill O.(1977) Fluidization Engineering. Beijing: Petrochemical Industry Press.
[6] Hongzhong Li, Guo Musun(2002). The decentralization of gas-solid fluidization. Beijing. Chemical Industry Press.