Research on the drop strength of coal powder in hot air dense medium fluidized bed

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Abstract. In this paper, the drop strength of pulverized coal in a hot air dense medium fluidized bed was studied, and the influence of factors such as coal surface moisture, drying temperature, drying time, air volume and other factors on the drop strength were investigated, and the mathematical correlation of the drop strength was established; it shows that with the increase of drying time, the fall intensity of coal decreases; as the drying temperature rises, the fall intensity decreases; as the surface moisture of coal increases, the coal fall intensity decreases; as the air volume increases, the coal fall intensity decreases.

1. Introduction
The dominant position of coal in my country’s energy production and consumption structure is difficult to change significantly in a short period of time [1-5], air dense medium fluidized bed technology has always been a key research direction in the field of dry coal preparation [6]; drop intensity is an index for judging the brittleness of coal under specific conditions and can reflect the impact resistance of coal. Therefore, it is necessary to study the law of falling strength after fluidized bed drying. The drop strength is an index for judging the brittleness of coal under certain conditions, and it can reflect the impact resistance of coal. After the separation of the air heavy medium fluidized bed, the coal will fall into the de-intermediation sieve for de-intermediation. In this process, the coal will collide with the sieve plate to break and produce coal powder of <1mm. The lower the falling strength of coal, the higher the amount of pulverized coal produced by crushing <1mm. This part of pulverized coal will be mixed into the medium and enter the under-sieve, thereby reducing the purity of the circulating medium and increasing the workload of the diversion operation; At the same time, the selected coal will go through many links such as belt transportation, loading and unloading, storage, etc. During this process, the coal is unavoidable to be crushed by external forces; only after the selected coal has a higher falling strength, can the crushing quality be reduced to meet the needs of users. Therefore, it is necessary to study the law of drop intensity after fluidized bed drying.

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.
2.1. Air supply system
It is mainly composed of Roots blower, air bag, rotameter and pipelines. The range of rotameter is 100m³/h. Roots blower provides compressed air. The compressed air is filtered to remove impurities and moisture in the gas. The purified air is stabilized by the air bag and enters the air chamber of the sorter; meanwhile, the control valve is used to adjust the air volume entering the air chamber. And wind pressure, air volume can be measured by a rotameter.

2.2. Heating system
The main body of the heating system is an electric heating device with a temperature control range of 0~500°C. There is a temperature sensor inside the electric heating device, which can output the corresponding digital signal by converting the signal generated by the gas temperature change after heating, and display it on the digital display. The pipeline is wrapped with insulating cotton to reduce heat loss.

2.3. Sorting system
It is mainly composed of an air-dense-medium fluidized bed sorting model machine and a gas distributor. The model machine is made of carbon steel with a size of 200mm×200mm×250mm. The installation process of the device has undergone strict sealing treatment.
3. Establishment of mathematical correlation of fall intensity

According to the experimental data of the drop strength, the $R^2$ comprehensive analysis was carried out on the two models recommended by Design-Expert, as shown in Table 1. The results show that the standard deviation of the quadratic model and the sum of squares of the predicted residuals of the two models are smaller than the 2FI model, and the $R^2$ corrected value and $R^2$ predicted value are both greater than the 2FI model, which shows that the quadratic model is suitable for simulation and analysis of experimental results, but considering that the $R^2$ corrected value of the quadratic model is 0.8394, the predicted value of $R^2$ is 0.5394. The difference between the two values is very large, indicating that the simulation accuracy of the model needs to be improved, so the quadratic model needs to be revised.

The model parameters of the quadratic model were analyzed by variance analysis, and the F value test method was used to test the significance of the model parameters. 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 $B^2$, $C^2$, $D^2$, $AB$, $AC$, $AD$, $BC$, $CD$ and other factors in the model are less significant. In order to improve the simulation As a result, these factors were removed, and a new model, namely the quadratic correction model, was established.

| Table 1. $R^2$ comprehensive analysis (drop strength). |
|-----------------------------------------------------|
| model               | standard deviation | $R^2$  | $R^2$ correction value | $R^2$ Predictive value | Prediction residual sum of squares |
|---------------------|-------------------|--------|------------------------|------------------------|-----------------------------------|
| 2FI model           | 3.85              | 0.8312 | 0.7375                 | 0.5297                 | 743.53                            |
| Quadratic model     | 3.01              | 0.9197 | 0.8394                 | 0.5394                 | 728.07                            |

| Table 2 Variance analysis of Quadratic model parameters (drop strength) |
|-----------------------------------------------------------------------|
| Model factors | sum of square | Degree of freedom | Mean square | F value | Prob > F |
|---------------|---------------|-------------------|-------------|---------|----------|
| A             | 710.556       | 1                 | 710.556     | 78.35   | < 0.0001 |
| B             | 188.021       | 1                 | 188.021     | 20.73   | 0.0005   |
| C             | 229.425       | 1                 | 229.425     | 25.30   | 0.0002   |
| D             | 146.231       | 1                 | 146.231     | 16.12   | 0.0013   |
| A2            | 135.297       | 1                 | 135.297     | 14.92   | 0.0017   |
| B2            | 13.961        | 1                 | 13.961      | 1.54    | 0.2351   |
| C2            | 6.497         | 1                 | 6.497       | 0.72    | 0.4116   |
| D2            | 14.708        | 1                 | 14.708      | 1.62    | 0.2236   |
| AB            | 11.731        | 1                 | 11.731      | 1.29    | 0.2745   |
| AC            | 0.608         | 1                 | 0.608       | 0.07    | 0.7994   |
| AD            | 10.017        | 1                 | 10.017      | 1.10    | 0.3111   |
| BC            | 0.570         | 1                 | 0.570       | 0.06    | 0.8057   |
| BD            | 16.728        | 1                 | 16.728      | 1.84    | 0.1959   |
| CD            | 0.160         | 1                 | 0.160       | 0.02    | 0.8962   |
A comprehensive analysis of $R^2$ is performed on the quadratic correction model. As shown in Table 3, it can be seen that the correction value of $R^2$ is 0.8582 and the predicted value of $R^2$ is 0.8013, both of which are relatively large and close in value, showing good consistency. This shows that the simulation accuracy of the quadratic correction model is high, therefore, it is decided to use the quadratic correction model to simulate the drop strength experiment.

Through simulation, the mathematical correlation between the drop strength and various operating parameters is obtained:

$$\text{drop strength} (%) = 140.297 + 2.448A - 24.408B - 2.186C - 7.581D - 0.040A^2 + 2.045BD$$

Based on the mathematical correlation of the drop strength, the predicted results and the experimental results were compared and analysed, as shown in Table 4. The normal distribution of the studentized residual is shown in Figure 3, and the comparison between the experimental value and the predicted value is shown in Figure 4. 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.
Table 4 The comparison to drop strength between experimental and predicted values

| Serial number | Experimental value | Predictive value | Residual | Studentized residuals |
|---------------|--------------------|-----------------|----------|-----------------------|
| 1             | 94.980             | 91.212          | 3.768    | 1.538                 |
| 2             | 74.530             | 75.822          | -1.292   | 0.527                 |
| 3             | 83.400             | 83.295          | 0.105    | 0.043                 |
| 4             | 69.800             | 67.905          | 1.895    | 0.773                 |
| 5             | 88.510             | 91.443          | -2.933   | -1.178                |
| 6             | 79.510             | 82.698          | -3.188   | -1.281                |
| 7             | 88.500             | 84.462          | 4.038    | 1.622                 |
| 8             | 80.300             | 75.717          | 4.583    | 1.841                 |
| 9             | 89.980             | 90.744          | -0.764   | -0.312                |
| 10            | 77.370             | 75.354          | 2.016    | 0.823                 |
| 11            | 81.500             | 83.763          | -2.263   | -0.923                |
| 12            | 62.560             | 68.373          | -5.813   | -2.372                |
| 13            | 89.770             | 91.911          | -2.141   | -0.860                |
| 14            | 82.500             | 83.994          | -1.494   | -0.600                |
| 15            | 79.660             | 83.166          | -3.506   | -1.408                |
| 16            | 73.900             | 75.249          | -1.349   | -0.542                |
| 17            | 91.360             | 91.626          | -0.266   | -0.108                |
| 18            | 77.210             | 76.236          | 0.974    | 0.398                 |
| 19            | 82.300             | 82.881          | -0.581   | -0.237                |
| 20            | 69.710             | 67.491          | 2.219    | 0.906                 |
| 21            | 94.170             | 93.074          | 1.096    | 0.535                 |
| 22            | 81.000             | 81.068          | -0.068   | -0.033                |
| 23            | 80.390             | 82.003          | -1.613   | -0.787                |
| 24            | 75.400             | 78.176          | -2.776   | -1.355                |
| 25            | 84.670             | 83.580          | 1.090    | 0.397                 |
| 26            | 85.610             | 83.580          | 2.030    | 0.740                 |
| 27            | 85.570             | 83.580          | 1.990    | 0.725                 |
| 28            | 85.710             | 83.580          | 2.130    | 0.776                 |
| 29            | 85.690             | 83.580          | 2.110    | 0.769                 |

Table 5 Variance analysis of Quadratic corrected model parameters (drop strength)

| Model factors | sum of square | Degree of freedom | Mean square | F value | Prob > F |
|---------------|--------------|-------------------|-------------|---------|----------|
| A             | 710.556      | 1                 | 710.556     | 88.78   | < 0.0001 |
| B             | 188.021      | 1                 | 188.021     | 23.49   | < 0.0001 |
| C             | 229.425      | 1                 | 229.425     | 28.66   | < 0.0001 |
| D             | 146.231      | 1                 | 146.231     | 18.27   | 0.0003   |
| A²            | 113.774      | 1                 | 113.774     | 14.21   | 0.0011   |
| BD            | 16.728       | 1                 | 16.728      | 2.09    | 0.1624   |

4. The effect of drying temperature and drying time on drop strength
Figure 5 shows the effect of drying temperature and drying time on drop strength. As shown in Figure 5, as the drying time increases, the drop strength of coal decreases; as the drying temperature increases, the drop strength decreases.
With the increase of the drying temperature and the extension of the drying time, the diffusion and evaporation rate of the moisture inside the lignite will increase, the structure of the lignite will be easily damaged, and the volume of the lignite will shrink, and the coal will become hard and brittle. It is easier to break when hit by collision and impact. Therefore, the increase in drying time and drying temperature will lead to a decrease in drop strength.

5. Influence of coal surface moisture and air volume on falling intensity

Figure 6 shows the influence of coal surface moisture and air volume on the fall strength. As shown in Figure 6, as the coal surface moisture increases, the coal fall strength decreases; as the air volume increases, the coal fall strength decreases. As mentioned above, the changes in the structure of lignite are mainly caused by the phase change of the surface and internal moisture of the coal. When the moisture content of the coal is high, the water that penetrates into the micropores of the coal will naturally increase. Under the same conditions, the scale of water movement will increase. The damage to the internal structure of coal increases; the increase in air volume can increase the efficiency of heat and mass transfer between coal and the hot fluidized bed, which in turn affects the internal structure of coal.

6. Conclusion

(1) The mathematical correlation between the drop strength and various operating parameters has been established:

$$\text{drop strength}(\%) = 140.297 + 2.448A - 24.408B - 2.186C - 7.581D - 0.040A^2 + 2.045BD$$
(2) As the drying time increases, the drop strength of coal decreases; as the drying temperature increases, the drop strength decreases.

(3) As the moisture on the coal surface increases, the coal's fall intensity decreases; as the air volume increases, the coal's fall intensity decreases.

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