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Prediction of Isothermal Drying Process of Anthracite

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Abstract. To improve the quality of high-moisture anthracite treated by hydraulic reservoir reconstruction technologies, the isothermal drying process of anthracite were studied experimentally. Based on the experiment results, after the fitting of thin layer drying model and the regression analysis, the prediction model was established. The results show that the isothermal drying process can be divided into the acceleration and deceleration stage. The effective water diffusivity increases with the increase of temperature and particle size. And the Page model fits the best. The prediction model is in good agreement with experimental data.

1. Instruction

Hydraulic fracturing and coal seam water injection are the main technical means of coal reservoir reconstruction at home and abroad, which are widely used in anthracite coal mine [1]. Moisture is one of the most important indexes to evaluate the scientific and economic value of coal. However, the high moisture does no good to the processing and utilization of coal as it will lead to the acceleration of weathering and rupture of coal, the increase of transportation costs [2] and so on. As the coal with the highest degree of coalification, anthracite is widely used in chemical fertilizers, power fuel and other industries [3]. But the application of hydraulic reservoir reconstruction technologies in anthracite coal mine will cause the high moisture content of anthracite, thus limit the efficient utilization of it [4]. Therefore, it is necessary to dehydrate the high-moisture anthracite. For the high natural water content of lignite, the study of anthracite dehydration is relative less. In order to solve the problem of high moisture of anthracite, figure out the drying process and predict it, the thermal analyzer was used to study the isothermal drying process. And according to the thin layer drying model and the mathematical treatment of the experimental data, the prediction model including drying equation, drying rate equation, activation energy and preexponential factor were obtained, which can be the theoretical basis for the isothermal dehydration of anthracite.

2. Experiment

2.1. Samples and instruments

The coal samples used in this experiment are anthracite from Chongqing Songzao Coal Mine of China. After being broken, the coal samples were sieved into 0.2-0.25mm, 0.25-0.50mm, 0.50-1.0mm three



particle sizes and then sealed respectively. The synchronous TG-DSC thermal analyzer STA 499 F3 Jupiter was adopted for the thermal drying dehydration experiments of anthracite.

2.2. Experimental methods

10.00g of three kinds of particle size coal samples were obtained to be uniform humidified to reach the target moisture of 25%. After sealed at room temperature for 48 hours, in the nitrogen protection environment of 30ml/min, the samples had been isothermally dehydrated at 55°C, 65°C, 75°C, 85°C, 95°C and 105°C for 2 hours. The quality of samples was recorded per minute and finally outputted.

3. Analysis of isothermal drying process of anthracite

The percentage of moisture (M_R) shows the speed of drying, which can be calculated as follows:

$$M_R = M_t/M_0 \quad (1)$$

Where M_t is the moisture of samples at t time and M_0 is the initial moisture of anthracite. Then the drying rate of anthracite can be calculated as follows:

$$R_D = (M_{t+\Delta t} - M_t)/(\Delta t) \quad (2)$$

3.1. The influences of the drying temperature and particle size on the drying process

As shown in Figure.1a and 1b, the isothermal drying process can be divided into the acceleration stage and the deceleration stage. The higher the drying temperature is, the shorter the drying time is and the greater the rate of drying is. Furthermore, the effects of drying temperature are much more obvious in the deceleration drying stage. Figure.1c also shows that there are two stages of the process and there is no obvious constant speed stage. Furthermore, the decrease of the particle size leads to the drying time and drying rate enhancement.

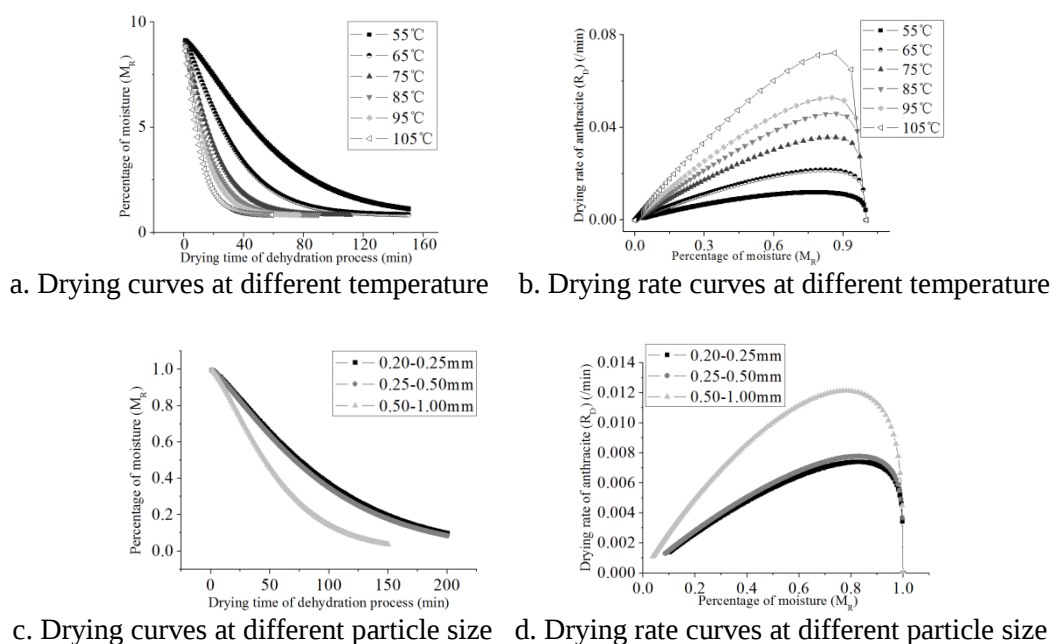


Figure 1. Drying curves and drying rate curves of anthracite.

3.2. Analysis of the effective water diffusivity of anthracite

The effective diffusivity is one of the most important parameters for optimum design of drying process. And the Fick diffusion equation can be used to describe the drying characteristics in deceleration stage [5]. Assuming all the samples have the same initial moisture distribution, then the effective water diffusivity satisfies the following equation:

$$M_R = \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-\frac{4n^2\pi^2 D_{eff} t}{d^2}\right) \quad (3)$$

Where D_{eff} is the effective water diffusivity (m^2/s), t is the drying time (s), and d is the average diameter (m). After the simplification ($n=1$), the equation can be showed as follows:

$$\ln M_R = -\ln\left(\frac{6}{\pi^2}\right) - \frac{4n^2\pi^2 D_{eff} t}{d^2} \quad (4)$$

The effective water diffusivity under different conditions was obtained and showed in Figure.3. Therefore, the D_{eff} increases approximately linearly with the increase of temperature and average diameter. Influenced by the temperature increase, the enhancement of driving force of moisture diffusion and particle size leads to the increase of D_{eff} and drying rate, and shortens the drying time.

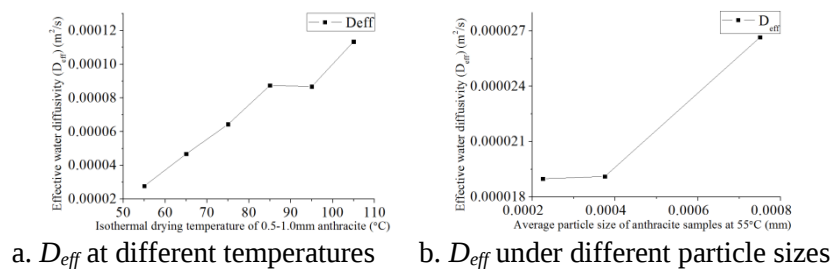


Figure 2. The effects of drying temperature and particle size on the effective water diffusivity.

4. Drying equation and drying rate equation of anthracite

There are 9 common used drying models [6]. In order to find the optimal model to describe the isothermal drying process of anthracite, the experimental data were fitted to the 9 models. As shown in Table.1, the best fitting model is Page model, whose correlation coefficient R^2 is the largest (above 0.999) and its variance range is the smallest ($4.11E-7 \sim 5.35E-6$). According to the Page model, drying equation and drying rate equation of anthracite are as follows:

$$M_R = \exp(kt^n); \frac{dM_R}{dt} = knt^{n-1} \exp(kt^n) \quad (5)$$

Table 1. The simulation results of Page model.

D/mm	T/°C	k	n	R^2	X^2
0.5-1.0mm	55	0.00449	1.4281E-1	0.999466109	4.71E-6
0.2-0.25mm	55	0.00348	1.1774E-1	0.99966487	2.02E-6
0.25-0.5mm	55	0.00369	1.1818E-1	0.99955867	2.13E-6

5. Parameters determination of drying equation and drying rate equation of anthracite

According to the experimental data and drying equation, the n and $\ln k$ values can be determined. After the taking the logarithm of the drying equation, it can be simplified as $\ln(\ln M_R) = \ln k + n \ln t$ [7]. The temperature and particle size have little influence on the n value, and in this paper, the value of n

is 1.191402 to ensure that the correlation coefficient is greater than 0.99. The parameter fitting results are shown in Table.2 and Table.3 and can be approximated by the following formulas:

$$k = A \exp\left(-\frac{E_a}{RT}\right); E_a = E_v + E_d \quad (6)$$

$$k = A \exp\left(-\frac{E_a}{RT}\right) = A \exp\left(-\frac{E_v + E_d}{RT}\right) = A \exp\left[\frac{-E_v(1+C_d d)}{RT}\right] \quad (7)$$

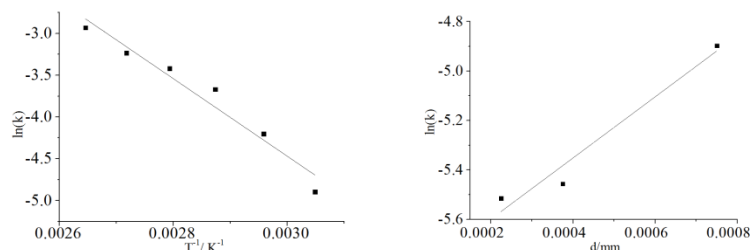
Table 2. Parameter fitting values for different isothermal drying temperatures

Temperature/°C	55	65	75	85	95	105
lnk	-4.89733	-4.20097	-3.66810	-3.41906	-3.23397	-2.93109
n	1.191402	1.191402	1.191402	1.191402	1.191402	1.191402
R ²	0.99084	0.99933	0.99965	0.99843	0.99918	0.99743

Table 3. Parameter fitting values for different particle sizes

Average particle size/m	0.000225	0.000375	0.00075
lnk	-5.51508	-5.45654	-4.89733
n	1.191402	1.191402	1.191402
R ²	0.99913	0.99913	0.99084

Thus $\ln k = \ln A - \frac{E_v(1+C_d d)}{RT}$. Where C_d is the empirical constant, A is the pre-exponential factor and E_v is the interface evaporation activation energy. As shown in Figure.4a, when particle size is constant, the $\ln k$ is linear with $1/T$, and A equals $12735.97 \text{ min}^{-1}$. In Figure.4b, when drying temperature is constant at 55°C , the $\ln k$ is linear with d . After calculation, the E_v is 41.74 kJ/mol and C_d is 80.87 m^{-1} .



a. The relationship diagram of “lnk” and “1/T” b. The relationship diagram of “lnk” and “d”

Figure 3. The relationship diagrams between “lnk”, “1/T”, and “d”.

Then the predicted values are compared with those in experiment. As shown in Figure.5, the predicted value is in good agreement with the experimental values.

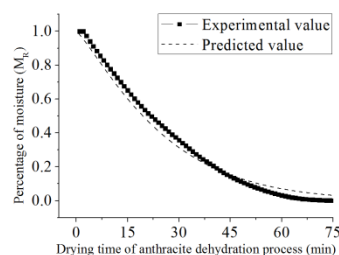


Figure 4. Comparison of predicted and experimental values

6. Conclusion

The drying process of anthracite can be divided into the acceleration stage and deceleration stage, and there is no obvious constant speed drying stage. The increase of drying temperature and particle size leads to the increase of the drying rate and effective water diffusivity and the decrease of drying time. Besides, the drying equation and drying rate equation of anthracite simulated by thin layer drying model (Page model) are in good agreement with experimental values.

Acknowledgments

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