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Physical properties and filter cake structure of fine clean coal from flotation

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ABSTRACT

In order to improve the dewatering rate and the effect of fine clean coal (FCC), the advanced method of fine coal (−0.5 mm) dewatering and the correlated basic theory were investigated in this study. It was found that the dewatering by sleeve type press filter was an efficient way of FCC dewatering. On the other hand, the results also proved that particle size distribution, volatile matter, ash content, pore size distribution and specific surface area of coal particles of FCC samples, as well as viscosity and density of FCC slurry, were important parameters in determining the process of efficient dewatering. Especially, wet mass to dry mass, specific resistance of average mass, compressibility factor and microstructure of filter cake explained the reasons and mechanisms of fine clean coal efficient dewatering.

1. Introduction

The depletion of high rank coal leads to a rise in the value of low rank coal with more minerals. More and more mining and mineral processing operations are realizing to obtain the fine coal. At present, large amount of fine coal is purified by flotation and becomes refined FCC products [1–3]. Flotation process is widely and efficiently used to get clean fine coal particles by separating them from clay, silt, shale and other ash-producing matter using air bubbles and agentia [1,4]. Since coal washing (flotation) is a wet process, this fine fraction (−500 μm) is a slurry form, or at least, a very moist solid stream. After flotation the slurries of FCC product must be dewatered for practical and economic interest. Formerly, the main reason of fine coal was not fully exploited is the high levels of moisture. With the study of theory and practice, it shows that a little decrease in the final moisture of millions of tons of clean coal can lead to a saving of large amount of cost in the same using, and these amounts of moisture left in the fines are becoming a big financial liability for each coal enterprises and produce some technical barriers in the coal processing and utilization process [5–16]. Therefore, FCC dewatering is an important segment for coal high efficiency utilization.

Efficient removal of this moisture will yield definite benefits in finances and handling of the fine coal will also have a positive impact on the environment. However, FCC coming from the flotation process usually has high moisture content accompanying a great quantity of tiny particles, which brings many new changes on the slurry properties, e.g., viscosity and density of FCC slurry and filtrate, and new subjects on coal dewatering, e.g., a decrease of filtration rate. The literatures indicated that it was important for coal efficient dewatering to study the physical properties and filter cake structure of the FCC from flotation [6–8,17–22]. However, there were very few deep studies on the early theoretical basis and research technology for dewatering behavior of the FCC. In this study, the physical properties of FCC filter cake from flotation was studied by the sleeve type press filter, and we expected the studies could offer a little help to coal dewatering, especially for fine coal.

2. Experimental details and theory basic study

2.1. FCC and FCC slurry physical properties

The FCC samples used in the study were obtained from Yongcheng coal preparation plant in Henan province of China. According to the national standards (GB 4472-84, GB/T 18856.4-2008 and GB/T212-2008) of China, the true relative density (TRD) of the FCC, the viscosity and density of FCC slurry and filtrate and the proximate analysis of the FCC samples were determined, respectively. Average specific surface area of FCC samples was given by full-automatic physical chemical adsorption analyzer (Quanta chrome Instruments Autosorb-1, USA). Determination conditions were as follows: temperature 105 °C, high vacuum system, degassing time 6 h, high purity nitrogen as the adsorbate.

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Particle size distribution of FCC samples was presented by Beckman Coulter laser particle analyzer (LS 100P, USA).

2.2. Filter cake structure properties of the FCC

The ratio of wet mass to dry mass of the filter cake is an evaluation index of filter process and an important reference to solid liquid separation capacity. The ratio of wet mass to dry mass of the filter cake is defined as the mass ratio of wet filter cake to dry filter cake (represented commonly by the letter m) and represented by the following Eq. (1),

$$m = m_1/m_2 \quad (1)$$

where m_1 is the wet filter cake mass and m_2 the dry filter cake mass.

The specific resistance of average mass (represented by α_{av}) of FCC filter cake is the core data on dynamics of solid liquid heterogeneous separation, and it has important uses in theory study and engineering application. According to the Ruth Filter Theories, the filtration rate (represented by u) can be characterized by using the following Eq. (2),

$$u = dV/(Adt) = \Delta P(1 - ms)A/[\mu\alpha_{av}(V + V_m)\rho s] \quad (2)$$

where V is the volume of filtrate (m^3); V_m the filtrate equivalent volume of filter medium; t the filtration time (s); A the filtration area (m^2); ΔP the pressure drop across the filter cake (Pa); μ the filtrate viscosity (mPa s); m the ratio of wet mass to dry mass of filter cake; s the concentration of solids in the slurry (mass per unit volume of the filtrate) (kg/L); and ρ the filtrate density (kg/m^3). The specific resistance of average mass α_{av} can be characterized by using the following Eq. (3),

$$\alpha_{av} = \alpha_0(\Delta P)^n \quad (3)$$

where α_0 is the unit specific resistance of filtration, it is a constant determined by experiments; n the compressibility index (factor) of filter cake.

The filtrate volume of unit filtration area (represented commonly by the letter v) can be expressed by V/A, and V_m/A expresses the filtrate equivalent volume of the filter medium unit area. A new Eq. (4) can be got by Eq. (2) as following,

$$dt/dv = 2(v + v_m)/K = \mu\alpha_{av}(V + V_m)\rho s/[P(1 - ms)] \quad (4)$$

where K is the constant pressure filtration coefficient of Ruth Filter Theory, and it can be characterized using the following Eq. (5),

$$K = 2P(1 - ms)/(\mu\alpha_{av}\rho s) \quad (5)$$

The specific resistance of average mass α_{av} is also expressed with the following Eq. (6) according to Eq. (5).

$$\alpha_{av} = 2P(1 - ms)/(\mu K\rho s) \quad (6)$$

As is known to all, if $\alpha_{av} < 10^{11}$, the filter cake has good filtration ability; $10^{11} \leqslant \alpha_{av} \leqslant 10^{13}$, the filtration ability of filter cake is middle; $\alpha_{av} \geqslant 10^{13}$, the filtration process is difficult.

Eq. (4) can be translated as the following Eq. (7) by integral calculus and filtration boundary conditions.

$$t/v = (v + 2v_m)/K = 1/kV + 2/kV_m \quad (7)$$

Eq. (7) shows that t/v is the dependent variable and v is the independent variable. Thus, a linear graph of t/v versus v permits the calculation of the gradient $1/K$ and intercept $2/Kv_m$ by the experiments of filtration, which can be used to calculate α_{av}.

Eq. (3) can be translated as the following Eq. (8) by logarithm operation and translation.

$$\lg\alpha_{av} = n\lg\Delta P + \lg\alpha_0 \quad (8)$$

Eq. (8) shows that $\lg\alpha_{av}$ is a dependent variable while $\lg\Delta P$ is an independent variable, which presents a linear relation on the filtration pressure and filter cake properties, where n is the gradient of Eq. (8), i.e., the compressibility factor of filter cake, and n ranges from 0 to 1 for different kinds of materials. If $n = 0$, the material is named incompressible material; $n < 0.3$, named low compressible material; $0.5 \leqslant n \leqslant 0.3$, named middle compressible material; $0.5 \leqslant n \leqslant 1.0$, named high compressible material. So, what kinds of the compressibility for filter cake is certain with the value of n determined by filtration experiments.

The filter cake structure is of importance for the pressing dewatering of fine clean coal. In this experiment, the particle size distribution can be shown by the image of scanning electron microscope and determined according to different layers of filter cake.

3. Results and discussion

3.1. Physical properties of FCC and FCC slurry

The FCC samples are the flotation product less than 0.5 mm particle size (Fig. 1).

As shown in Fig. 1, the content of micro fine particles in the coal sample is quite high. About 55% of FCC sample particles can pass through a 200 mesh sieve and 90% can pass through an 80 mesh one (Taylor sieve).

The TRD average value of FCC samples is 1.77 kg/m^3 obtained by three times experimental determinations. Table 1 shows the results of proximate analysis of FCC samples.

Judged from the above data, FCC samples are anthracite. Therefore, the side-chains and functional groups of water absorption are very few in the structure of the FCC molecules, and it is convenient for the dewatering of the FCC.

According to the experiments examined by Density Functional Theory (DFT) model and Brumauer–Emmett–Teller Theory (BET) model, the average pore volume and the average specific surface area of FCC sample is 8.07×10^{-3} cm^3/g and 2.15 m^2/g, respectively (Fig. 2). The specific surface area is one of the basic properties of coal particle, which affects the dewatering rate of filter pressing and the moisture content of filter cake.

Fig. 3 shows the results of viscosity and density of different FCC slurry concentrations at 14 °C. Both of them increased with increasing FCC slurry concentrations from 200 to 400 g/L. However, an increase in concentrations from 310 to 390 g/L caused a sharp increase in the viscosity, at the same time, the density of FCC slurry increased relatively slowly.

Fig. 4 shows the filtrate viscosity μ increased quickly from 1.60 to 1.89 mPa s with the pressure of filter pressing increased from 0.30 to 0.60 MPa. Then, an increase in filter pressing pressure from 0.65 to 0.75 MPa only caused a low change in filtrate viscosity from 1.94 to 1.97 mPa s, i.e., the increasing level of filtrate viscosity dropped slowly. Therefore, the filtrate viscosity did not keep a strict linear relation with the pressure of filter pressing. The filtrate

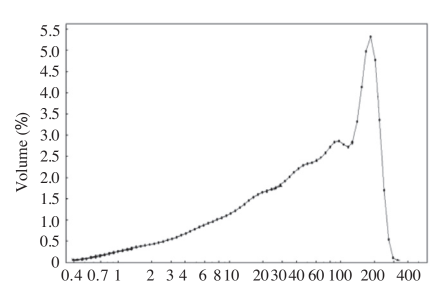

Fig. 1. Particle size distribution of FCC sample.