Vacuum filter and direct current electro-osmosis dewatering of fine coal slurry

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Abstract

With the increasing of mechanization of coal mining, the fine coal content in raw coal is more and more, which makes the work of dewatering difficult. The constant voltage and constant current electro-osmosis, combined with vacuum filtration were adopted to dewater the fine coal. The dewatering efficiency can be improved and the moisture of cake can be reduced when the electric field was imposed. When the initial electric field strength is less than 40 V/cm, the precipitation rate of constant voltage electro-osmosis dewatering (EOD) higher than the constant current EOD, can reach 30%. When the initial electric field higher than 40 V/cm, the precipitation rate of constant current EOD higher than the constant voltage EOD, can reach 55%.

Keywords: vacuum filtration; electro-osmosis; dewatering; fine coal

1. Introduction

In coal preparation plant, dewatering is one of the most economically significant unit operations. Conventional dewatering techniques based on a single non-thermal driving force, such as vacuum, pressure or centrifugal force, are inefficient for dewatering of very fine coal slurry. Thermal drying is disadvantageous for coal slurry because it consumes substantive amount of power [1-3]. Electro-osmotic dewatering (EOD) is a technique that removes water by placing a suspension or colloidal material between two electrodes. It is based on the electrostatic effects of the electrochemical double layers that are formed at the particle–water interface of the colloidal material. When an electric field is applied across the medium, the electric double layer causes the motion of the particles, i.e. electrophoresis, and of the water, i.e. electro-osmosis. In electro-osmotic dewatering, the solid particles move to the anode, while the electro-osmotic flow causes the water to move in the other direction. This technique is considered ideal for the dewatering of slurries with particle size in the ultrafine range, and possibly for heat-sensitive material which cannot be thermally dried [4]. The Schematic diagram of Electro-osmosis Dewatering (EOD) action was shown in the Fig. 1. There have been some reports on the mathematical modeling of grinding equipment by Chinese researchers. For example: The study of general grinding dynamic equations of ultra-critical speed mills [5]; multi-
factor experiments to determine the variation of grinding fineness and net energy consumption as a function of ball-mill rotation speed, grinding medium filling-ratio, feed quantity, slurry concentration and other processing variables; and research on classifier overflow control systems using a new prediction control algorithm and computer simulation [6–7].

There are few studies both at home and abroad concerning process simulation of recently developed new equipment such as vertical roller mills and stirring mills. In China almost no work has been done on the simulation of multi-factor industrial manufacturing systems.

This paper describes the simulation of the grinding process in vertical roller mills. It is based on actual experimental data obtained on a production line at the plant and from lab experiments.

2. Experimental

2.1. Material

The fine coal used in the test is obtained from Xiqu Coal Preparation Plant, Taiyuan, China. The raw coal of -0.5 mm was used, the size analysis results was shown in the Table 1.

<table>
<thead>
<tr>
<th>Grain size (µm)</th>
<th>Cumulative yield (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>592</td>
<td>100</td>
</tr>
<tr>
<td>418.6</td>
<td>94.52</td>
</tr>
<tr>
<td>352</td>
<td>74.19</td>
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<tr>
<td>322.8</td>
<td>74.69</td>
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<tr>
<td>296</td>
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<td>176</td>
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<td>0.42</td>
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<tr>
<td>3.27</td>
<td>0</td>
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</tbody>
</table>

2.2. Methods

To prepare 300 g/L around the coal slurry by adding 60 g coal and 200 mL water; firstly, poured the conditioned
coal slurry into the Buchner funnel, then open the vacuum pump and adjusted to 0.04 MPa to filter for 3 min until the coal slurry surface water vanished; put the anode copper-plate into the funnel, exerted a slight pressure on the anode so that the anode and the cake can keep contact continuously; set constant voltage or current value to a required value; recorded the change of filtrate volume, current or voltage in the dewatering course; the determination of the conductivity of filtrate, and PH value; the moisture content determination of filtration cake; take a certain amount of wet sample, dried at 108 °C for 2 hour until the weight of sample no longer changed. The moisture content M was calculated by the following Equation (1).

\[ M = \frac{m_1 - m_2}{m_1 - m_0} \]  

(1)

where m0 is the weight of evaporating dish, m1 is the weight of wet sample, m2 is the weight of dried sample.

### 2.3. Precipitation rate

After the precipitation rate of electro-osmosis treated water compared with the cake not the vacuum at the time of electro-osmotic leaching rate of cake moisture reduction, and its calculation formula is as follows

\[ P = \frac{p_1 - p_0}{p_0} \]  

(2)

where P is precipitation rate, p1 is the electro-osmotic water treatment cake, p0 is the same experimental conditions without the electro-osmotic pump vacuum to deal with only the rate of filter cake moisture.

### 2.4. Test equipment

Test equipment was shown in Fig. 2.

![Test device of dewatering](image)

Fig. 2. Test device of dewatering

1–anode copperplate; 2–cathode copper net; 3–filtrate collect bottle; 4–constant current power supply; 5–buffer bottle; 6–vacuum meter; 7–vacuum pumps; 8, 9–valves

### 3. Results and discussion

It can be seen from Fig. 3 that when the electrode is set to the upper electrode (anode) and the lower one (cathode), the rate of dewatering is higher than the upper electrode (cathode) and the lower one (anode). At the same time the rate of increased with the increasing of voltage when the electrode is set to the upper electrode (anode) and the lower one (cathode). If reversal the electrode, the rate of dewatering increase before it descend with the voltage
increasing. This can prove that it stop dewatering when the electric field direction set uniform with the direction of dewatering. Ulteriorly, it can prove than the coal grain show electronegative nature and the solution exist with the format of H3O+. So in the dewatering process coal grain move to anode and water move to cathode, adding electric field is advantageously for dewatering.

![Graph showing variation of dewatering rate with electric field direction](image1)

**Fig. 3.** Variation of the rate of dewatering when impose different direction electric field

### 3.1. Electro-osmotic time influence on the dewatering effectiveness and the energy consumption

It can be seen from Fig. 4 that with the electro-osmotic time extended, whether it is in constant voltage or constant current conditions, the filter cake moisture all the time lower with the Electroosmosis time extended, and the trend of the curve smaller and smaller, prove its rate become smaller. Electro-osmotic dewatering will be automatically terminated when to a certain extent, this may be due to saturation of the cake so to reduce the electro-osmotic dewatering process to achieve a balanced state.

![Graph showing relationship between cake moisture and electroosmosis time](image2)

**Fig. 4.** Relationship between Cake moisture and electroosmosis time

It can be seen from Fig. 5 and Fig. 6, in a long time electroosmosis the corresponding power consumption will increase, so, to choose the electro-osmotic time should consider two factors of cake moisture and energy consumption.

### 3.2. Electric field strength and current density on the electro-osmotic effects of dewatering

#### 3.2.1. Constant current EOD of coal slurry
Constant current electroosmotic dewatering of fine coal paste was investigated by fixing the electrical current while varying the voltage of the power supply. Six levels of applied current density on the system were 0.016, 0.031, 0.047, 0.063, 0.079 A/m². The fine coal suspension and the bed height were maintained at 300 g/L and 1 cm, respectively. The moisture content of coal cake was measured at last and the voltage was recorded from the power supply at different time points. The results are shown in Fig. 7.

![Fig. 5. Relationship of electro-osmotic time and energy consumption (constant current 0.01 A)](image)

![Fig. 6. Relationship of electro-osmotic time and energy consumption (constant voltage 30 V)](image)

![Fig. 7. Moisture content of coal cake and precipitation rate of dewatering under constant DC current)](image)
It can be seen from the Fig. 7 the moisture content of coal cake decrease linearly with voltage, and the rate of dewatering increase with voltage.

Without the application of electric current the system was essentially a simple filtration process. The filtration of coal paste suspension was not considerable without the application of electric current, as was noticed in the experiments. Filtration ceased due to the build-up of cake resistance on the filter paper, which blocked the flow of water, i.e. the filtration rate was very slow. The application of electric field reduced the cake thickness by repelling electric field reduced the cake thickness by repelling coal from the filter because of the charge on the anode that attracted coal colloids. In this case, application of electric field acts as a filtration aid as well as electro-osmosis.

3.2.2. Constant voltage EOD of coal slurry

The electroosmotic dewatering of coal suspension was achieved under constant voltage. A suspension of 300 g/L solid content was prepared and maintained in a bed of 1 cm height. Six levels of applied voltage on the system were studied, 10, 20, 30, 40, 50, 60 V/cm, while the current was varied. Results of rate of water removal and content of water in coal cake at different applied voltages are shown in Fig. 8.

![Fig. 8. Effect of voltage on the EOD process of fin coal suspension under constant DC voltage](image)

These results show that an increasing of the applied voltage resulted in an increasing of the dewatering rate and, consequently, electroosmotic flux. And it can be found that with increasing the voltage gradient, the general trend of the cake water content decreased drastically. The cake water content changed little in the range of 30 to 50 V/cm, then again dropped. Based on the above fact, it seemed that the voltage gradient was a marked factor in the electro-osmosis dewatering course. These results agree with the Helmholtz–Smoluchouski theory (Ellisand Sunderland, 1976; Hiemenz, 1986), where the increase in the water removal is attributed to the increase in the electrical field [4].

Chen et al (1996) investigated the effect of voltage on the electro-osmosis dewatering of mine tailing. The samples were tested at different applied voltages of 10, 20 and 30 V. There results showed that as applied voltage increased, the percentage of water removal increased: water removal was 25% at 10 V but increased to 45% at 30 V. Zhou et al (2001) have also examined the effect of applied voltage on the EOD of activated sludge. They obtained similar trends to that presented in Fig. 11, whereas the highest percentage of removed water of 60% was achieved at 80 V and the lowest percentage of 40% was achieved at 20 V. Shang and Lo (1997) studied the variation of applied voltage on the EOD of phosphate clay. Their results showed that the increase in the applied voltage resulted in an increase in the percentage of removed water.

3.2.3. Comparison of constant current and constant voltage

As shown in Section 2.2 by the constant pressure dewatering test methods, results in Fig. 9. The constant current of dehydration current density of the bed has been converted into electrical conductivity of the initial electric field strength.
As can be seen from the Fig. 9: 1) Test in the electric field strength, constant current at the end of dehydration, reduce the rate of cake moisture and electric field strength index for the relationship. 2) Electric field strength within the framework of constant voltage at the end of dehydration, reduce the rate of cake moisture and imposed electric field strength as a linear relationship between. 3) Fig. 9 from the line in the trend can be seen in about two lines 40 V/cm intersection Department, the start of this small electric field strength value, the same as the initial voltage and the initial water conditions, given coal slurry Constant voltage constant current dehydration depth than the high rate of dehydration; start when the electric field strength is larger than this value when the opposite is true, and along with the electric field strength to increase the difference between the two is growing. Have a reason for this phenomenon may be related to the surface of the water “release” and the current density, should be further examined.

3.3. The changes of voltage or current in electro-osmotic process

It can be seen from the Fig. 10, the voltage linear increase with time. And the greater the rate of current rise the greater the voltage increase rate.

The results for the variation of electrical current with time are presented in Fig. 11. The current decreased sharply during the first 50 min. This occurred as a result of the increase in the electrical resistance during that period. As the dewatering process went on, the electrical field resulted in significant formation of gases, thus the resistance increased rapidly and, according to Ohm’s law, the current decreased rapidly. This trend is similar to that presented in the Fig. 10.
To explain the trend of the above-mentioned results, it should be emphasized that the effective force on the dewatering process was the electrical potential only; neither external pressure nor bed height were varied during the EOD process of this work. This effective force is governed basically by Ohm’s law (\(V=I*R\); where \(V\) is the voltage, \(I\) is the current and \(R\) is the electrical resistance). In these experiments, DC power supply was used. The potential direction of the power was constant from the upper electrode (anode) to the lower one (cathode), thus the solid particles were attracted to the anode while the water content decreased at that portion. Close to the cathode, the water content increased and this in turn increased the driving force for water molecules. The dewatering rate ceased at the end of the process, where the electrical resistance attained its maximum value, and the effect of electrical field was minimum. When the current was fixed constant, the voltage increased. This is in agreement with Ohm’s law, since, as the resistance increased, the voltage increased in order to have a constant current. On the other hand, for a constant voltage value, the current decrease indicated an increase in the resistance. If the bed height decreased during the process, the resistance decreased and the current increased and vice versa. However this is not the case in this study.

4. Conclusions

1) With the increase of electro-osmotic time, the moisture content of filtration cake would not only reduce, but the dewatering velocity would also decrease; meanwhile, the corresponding electricity consumption increase as well.

2) The application of electric field upon the slurry for electro-osmotic dewatering, the dewatering velocity was fastest and its lowest cake moisture was 16.08% when electric field strength was 60 V/cm. While the dewatering velocity was fastest and its lowest cake moisture was 22.38% when current density was 0.079 A/m².

3) In the process of constant-voltage electro-osmotic dewatering, current would decline rapidly with the increase of electro-osmotic time. This indicated that the resistance of filtration cake increased continuously with the decrease of moisture content of filtration cake. With the continuation of time, the voltage would straight up. While with the current density increases, the rate of voltage change and dewatering would increase.

4) When the initial electric field is less than 40 V/cm, at the same initial voltage and moisture content, the dewatering depth of coal slurry using constant-voltage method was higher than that of coal slurry using constant-current method; when the initial electric field strength was greater than 40 V/cm, the opposite is true, and along with the increase of electric field strength, the difference of the two method is growing.

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References