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Rheological behaviors of coal slime produced by filter-pressing

Dai Zhaohui, Shi Lele, Wang Lijun, Guo Chuwen *

School of Electrical and Power Engineering, China University of Mining and Technology, Xuzhou 221116, China

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ABSTRACT

It is an effective way to use coal slime as fuel for circulating fluidized bed boilers, which will not only solve its pollution to the environment, but also turn waste to treasure. In order to provide basic technical information for transportation of coal slime from the coal preparation plant to the boiler, this paper experimentally studied the rheological behaviors of coal slime produced by filter-pressing. By using a rotational viscometer, the influences of water content, temperature, and shear time on the rheological behaviors of coal slime were investigated. Experimental results show that the coal slime will behave like Bingham plastics with low water content and like Bingham pseudo-plastics with 37.5% water content, while like pseudo-plastics with 40% water content. This indicates that the water content of coal slime must be controlled in consideration of both transportation resistance and combustion efficiency. Study results also show that, the apparent viscosity of coal slime at 5 °C is about 1.5–1.7 times of that at 40 °C for water contents 32%–37.5%, while the influence of temperature can be neglected when the water content is 40%. With increasing of water content, the influences of shear time on the apparent viscosity of coal slime becomes less. When the water content is more than 30%, the effect of shear time is negligible. It indicates that water content has the most important influence on the rheological behaviors of coal slime. There must be an optimal water content in considering conveying resistance and combustion efficiency. The environmental temperature must also be considered in coal slime transportation.

1. Introduction

Coal slime produced from coal preparation plants is mainly composed of coal, coal gangue, and clay mixed with water. Its calorific value varies with the type of coal, usually 2000–4000 kcal/kg [1]. It is a kind of viscous and dense material with high concentration and high viscosity, which belongs to the typical non-Newtonian fluid. Serious environmental pollution may be caused by directly discarding coal slime, because harmful poisonous soluble components inside coal slime will be washed out by rains, causing pollution to surface water and underground water; and fine particles from dry coal slime may fly into the atmosphere. Utilization of coal slime will not only solve its pollution to the environment, but also turn waste to treasure. At present, with the continuous improvement in combustion technology of low calorific value fuel, the application of circulating fluidized bed boilers has become more and more popular [2]. It is an effective way to use coal slime for power generation with circulating fluidized bed boiler [3]. However, the transportation of coal slime from the coal preparation plant to the power plant is still a problem.

Lots of studies on transportation of coal slime and other dense pastes have been done. Chakravarty et al. [4] studied the rheological behavior and transportation performance of highly concentrated coal-water slurries prepared from Indian coals by using an Anton Paarrheometer. The rheological data were utilized to predict the pressure drop characteristics of coal water slurry flowing through a 53 mm diameter slurry pipeline. Wu et al. [5] carried out an experimental study on the transportability and pressure drop of the CGFB slurry through the loop pipe. Gao et al. [6] studied the influences of concentration, flowrate and pipe diameter on the transportation resistance loss of dense paste. Chen et al. [7] carried out experiments on a pilot scale slurry transportation apparatus to investigate wall-slip phenomenon and rheological properties of concentrated coal water slurries in pipe flows.

From the above studies, it can be found that the rheological property of high density viscous material is an indispensable basic parameter for the design and operation of feeding process. After obtaining the rheological parameters and rheological curve, the type of flowing, velocity distribution and pressure drop in the pipe can be determined. Therefore, it is very important to study the rheological characteristics of dense pastes. Lots of researches have been done on the rheological properties of various dense pastes.

* Corresponding author.
E-mail address: cwguo@cumt.edu.cn (C. Guo).

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Sahoo et al. [8] studied the influence of microwave energy on iron ore-water slurry rheology. It was seen that microwave-treated ore has better rheological properties compared to untreated ore. This type of slurry is shear thinning and easy to transport as it exhibited pseudo-plastic behavior. Meikap et al. [9] studied the effect of microwave pretreatment of coal for improvement of rheological characteristics of coal–water slurries. Microwave pretreatment reduces the viscosity and the pumping cost and opens a new outlook for pipeline transport. Marchand et al. [10] examined and modified the rheological properties of petroleum coke-water slurries by using polyvinyl alcohol (PVA), naphthalene sulfonate (NS), and xanthan gum (XG). Singh et al. [11] studied the rheological behavior of coal-water slurry of Indian coal by using rheometer, investigating the effect of particle size, solid concentration, and temperature on the rheology of the coal-water slurry. Assefa and Kaushal [12] carried out extensive experimental investigations to evaluate the rheological behavior of fly ash slurry without and with the addition of bottom ash. Ciesinska [13] studied the changes of rheological properties of coal-tar pitch due to modification with chosen polyesters, including poly (ethylene terephthalate), unsaturated polyester resin and polycarbonate. The modification effects became more intensive with increasing amount of the modifier added to CTP. Sahoo et al. [14] studied the treatment of microwave energy for rheological characteristics of coal-water slurries performed in an online Bohlin viscometer. The paper studied the influence of particle diameter, solid concentration, microwave (MW) exposure time and shear rate on apparent viscosity for rheology characteristics of coal-water slurry. Stryczek et al. [15] studied the influence of specific surface and granular composition of lignite fluidal ashes on rheological properties of sealing slurries. Braga et al. [16] studied the influence of heat and pressure treatment on the rheological behavior of petroleum pitches with a rotational rheometer using a parallel-plate sensor. Sahoo et al. [17] enhanced the rheological behavior of Indian high ash coal-water suspension by using microwave pretreatment. Umar et al. [18] studied the effect of dispersing and stabilizing additives on rheological characteristics of the upgraded brown coal water mixture. The study results indicate that the addition of naphthalene sulfonic formaldehyde condensate 0.3% (by weight) together with rhansam gum 0.01% (by weight) is effective in preparing upgraded brown coal water mixture with good slurry ability and stability. Baudez et al. [19] found that the rheological behavior of pasty sewage sludges, regardless of origin, treatment or composition, follows a Herschel-Bulkley model.

From the above researches, it is found that the rheological behaviors of high density viscous materials depend on their physical properties, and could be improved by pre-treatment. Because of its special physical properties, coal slime is generally difficult for transportation from the coal preparation plant to the boiler. The distance for transportation of coal slime is generally hundreds of meters. In different seasons, the pipeline or conveyor belt are affected by the environmental temperature. Therefore, this paper will experimentally study the rheological behavior of coal slime produced by filter-pressing under different concentration, temperature and shear time. The results will provide basic technical information for transportation of coal slime.

2. Experimental

2.1. Basic physical properties of coal slime

The samples of coal slime used in our experiments are produced by thickening the coal slurry with a filter press. Table 1 shows the important properties of the coal slime used at a power plant. It shows that the average calorific value of the coal slime is 3496 kcal/kg, which is high enough for combustion in circulating fluidized bed boilers.

Table 1
Important properties of the coal slime.

Item	Value
Received base carbon, C_{ar} (wt%)	44.8
Received base hydrogen, H_{ar} (wt%)	2.87
Received base sulfur, S_{ar} (wt%)	0.33
Total moisture, M_{ar} (wt%)	29
Received base ash content, A_{ar} (wt%)	15.66
Received base volatile parts, V_{ar} (wt%)	21.24
Density, ρ (kg/m^3)	1400–1500
Average calorific value, Q (kcal/kg)	3496

Fig. 1 gives the particle size distribution of the coal slime. It shows that the coal slime mainly consists of fine coal particles.

2.2. Preparation of coal slime

In order to prepare samples of coal slime with different water contents, the coal slime was dried in an air drying oven with constant temperature for 12 h. The temperature was set to be 120 °C, because the properties of coal will not be changed under this temperature. An electronic balance with the smallest measuring unit of 0.0001 g was used to weight the dried coal sample and water. Samples of coal slime were prepared by mixing certain dried coal with water. The mixtures were stirred by an electric mixer for 10 min. The water contents in the experiments are 25%, 27.5%, 29%, 30%, 31%, 32.5, 35%, 37.5%, and 40%. Fig. 2 shows the samples of coal slime prepared.

2.3. Test methods

A constant temperature water bath was used to keep the temperature of coal slime samples. In our experiments, the temperature is set to be 5–40 °C. Because in northern China, the environmental temperature for coal slime transportation may be as low as 5 °C in winter, and 40 °C in summer. A NDJ-79A rotational viscometer was used to measure the viscosity of coal slimes. With the aid of a software, the measuring results can be directly output to a computer. The experimental system is shown in Fig. 3.

The apparent viscosity at different shear rates can be measured by regulating the rotating speed of the spindle. The spindle speed can be regulated continuously between 7.5 and 750 r/min. At each rotational speed, the measurement time is 5 min. During this 5 min, a value will be taken after every 15 s. Totally 20 points are obtained. The average value of these 20 points is used as the final result for this point. The time is controlled with a stop-watch.

Three groups of experiments were carried out: (1) Setting a temperature value, the variation of apparent viscosity with shear rate was measured under different water contents. (2) Keeping a constant rotational speed, the variation of apparent viscosity with temperature was measured under different water contents. (3) Set-

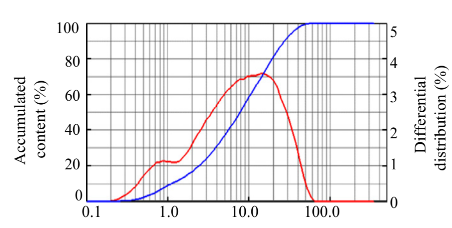

Fig. 1. Particle distribution of coal slime.