Fuel 235 (2019) 639–646

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Influence of alkaline additive on viscosity of coal water slurry

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ARTICLE INFO

Keywords:
CWS
Viscosity
Alkaline additive
Zeta potential

ABSTRACT

This paper was mainly about the influence of alkaline additive on the viscosity of coal water slurry (CWS). The study showed that the viscosity of CWS was sensitive to the alkaline additive. Less than 1% of alkaline additive could reduce the viscosity to more than half of the viscosity of the CWS without alkaline additive. As the content of the alkaline additive increased, the viscosity of CWS increased. The change in zeta potential, the freedom and content of the water in the CWS, the microstructure of the particles in the CWS as well as the FT-TR spectrum of the coal particles was investigated. The results show that with low concentrations of the alkaline solutions, the zeta potential of the particles in the CWS decreased which mean the absolute value of the zeta potential increased and the content of the free water in the CWS were increased. Meanwhile, the nonpolar of the particle with alkaline salts strengthened. These were all benefited to reduce the viscosity.

1. Introduction

Coal water slurry (CWS) which is composed of coal powder, water and small amounts of additives [1] is regarded as a possible replacement for petroleum and gas [2]. CWS as a cleaning fuel is very important for China since it is rich in coal but deficient in oil [3]. Research on CWS has attracted attention because, if stable slurry of high coal concentration can be prepared, coal can be transported by pipeline more cheaply than by rail or road [4–7]. In order to get higher economic benefits, the CWS should be prepared with high concentration, low viscosity, and good rheological properties. Research on the slurryability of coal has been carried out for a long time. Many researchers have studied the effect on the slurry of the properties of coal particles [7], the type of dispersant [8–11], particle-size distribution [12] and other additives [1,13–15].

The intrinsic properties of coal are the most important factors influencing the slurryability of coal. Relevant properties include the rank of coal, the composition of the minerals, pore structure as well as the surface properties of coal. The rank of the coal is the main factor that affected the properties of CWS. The slurryability of the coal increases with increasing coal rank. The characteristics of the coal are the key factors that determine the properties of CWS [16]. It is easier to prepare CWS with high solid content from high-rank than from low-rank coal. Particle-size distribution could affect the slurryability of the coal. The particle size of CWS not only requires certain fineness to ensure its full combustion, but also requires a good particle size distribution to have higher stacking efficiency. In other words, when the solid particle size in CWS accumulates, it is hoped that different sizes of coal particles can fill each other. The consumption of water between particles can be reduced as much as possible, and the high concentration slurry is easy to be made. The coal samples prepared by granularity gradation of coarse and fine particle have the characteristics of bimodal particle size distribution and are suitable for slurry. An optimal particle size distribution can give more stable slurry, with slower settlement of the particles, than a sub-optimal distribution [17].

The coal particles are easy to aggregate and settle when the CWS is prepared. Chemical additives are required to modify the surface properties of the coal particles and produce the stable slurry. The properties of such additives are important, and a suitable additive can lead to a stable CWS even for coals with intrinsically poor slurring properties. Most researchers focus on the dispersant for CWS preparation [11,18–21]. Among the anionic additives, the sulfonate and carboxylic water-soluble polymers are the main type, such as naphthalene sulfonate formaldehyde condensate [22], sodium polystyrene sulfonate [23], lignosulphonate [21], and humic acid [24]. Among the nonionic additives, the polyoxyethylene water-soluble polymers are the main type, such as polyoxyethylene alkyl phenol ether [25] and oxirane-epoxy propane copolymer.

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https://doi.org/10.1016/j.fuel.2018.08.060
Received 4 January 2018; Received in revised form 12 August 2018; Accepted 13 August 2018
Available online 18 August 2018
0016-2361/

Table 1
Proximate and ultimate analyses of Shenfu coal.

Proximate analysis (wt%)										
Sample	M_{ad}	error	A_d	error	V_d	error	FC_d			
Coarse	2.32	0.297	5.42	0.015	34.17	0.135	58.09			
Fine	2.46	0.065	8.21	0.017	32.16	0.096	57.17			
Ultimate analyses (wt%)										
Sample	C_d	error	H_d	error	N_d	error	O_d	error	S_d	error
Coarse	74.59	0.170	4.49	0.018	0.95	0.0058	11.89	0.2215	0.46	0.0485
Fine	73.14	0.120	4.05	0.018	0.85	0.015	13.80	0.149	0.55	0.004

The dispersant could change the surface properties of the coal. The ionic dispersants could also change the surface charge of the coal particles. When negatively charged copolymer dispersants are adsorbed on the surface of coal particles, repulsion of overlapping diffuse double layers affords electrostatic stabilization [26]. Steric hindrance can be obtained when the hydrophilic pendants of adsorbed copolymer stretch out from the surface of coal particle into water and form a brush-like dense layer [27]. The dispersants are mainly high polymers.

There are many factors which influence the preparation of CWS, including the properties of coal particles, particle size distribution and additives. In addition to the dispersant, the other additives can also affect the preparations of the CWS. The existence of dispersant is necessary because of the nature of particles. In addition to water, coal particles and dispersants, the addition of other additives to CWS will also affect the preparation of CWS. In fact, the influence of waste water on the preparation of coal-water slurry is mainly due to the influence of the waste water on the preparation of coal-water slurry in addition to water. Using waste water to prepare CWS is a way of countering shortages of potable water. Many researchers have studied the preparation of CWS using waste water directly [28–30]. Waste water usually contains an amount of inorganic and organic pollutants. The study of the influence of small molecules which are common pollutants on the slurryability of the CWS may be useful in the preparation of CWS from coal and waste water. The small organic molecules that have been studied are adsorbed on the coal surface in preference to added dispersants, so that they make it more difficult to slurry the coal [31]. Inorganic salts have also been studied [15,32,33]. Most of the research was focus on the relationship between the inorganic salts and viscosity rather than the mechanism of the effect.

This paper is mainly about the influence of alkaline additive on viscosity of CWS. A mechanism for the effect of alkalis on the properties is proposed and verified by experiment.

2. Experimental

2.1. Materials

Shenfu bituminous coal was used in the experiment after drying in an oven at 105 °C for 24 h. The proximate and ultimate analyses of the coal were showed in Table 1. Methyl naphthalene sulfonate formaldehyde condensation (MF, CAS NO. 9084-06-4) was used in the CWS as dispersant. The alkaline substances used in the experimental included NaOH, $NH_3{\cdot}H_2O$, $NaCO_3$, Na_3PO_4, K_3PO_4 (Shanghai Titan Scientific Co., Ltd.).

2.2. Particle size measurements

To obtain two sizes of samples, the coal was milled into powder and the particles were sieved by 40 and 200 mesh screens. The particle size distribution was measured by Automatic laser granularity analyzer (Malvern Mastersizer 2000, UK). Particles were suspended in water and dispersed by ultrasonic. The particle size distributions of the coarse particles (sample A) and fine particles (sample B) are shown in Fig. 1.

2.3. Preparation of CWS

To get good distribution, CWS usually made by mix two sizes of the particles [34]. The particle size of CWS not only requires certain fineness to ensure its full combustion, but also requires a good particle size distribution to have higher stacking efficiency. In other words, when the solid particle size in CWS accumulates, it is hoped that different sizes of coal particles can fill each other. The consumption of water between particles can be reduced as much as possible, and the high concentration slurry is easy to be made. The coal samples prepared by granularity gradation of coarse and fine particle have the characteristics of bimodal particle size distribution and are suitable for slurry.

Coarse and fine particles with a total weight of 40 g were mixed together. The dispersants used in the experiments were a dosage of 0.8 wt% based on dry coal. Varied concentrations of the alkaline additives solutions were used to prepare the CWS with a solids loading of 61 wt%. The mixtures were stirred with electric agitator at 1000 rpm for about 15 min to ensure good mixing.

2.4. Viscosity measurements

The viscosity of the CWS was measured by Malvern Bohlin CVO rotational rheometer. The slurries were placed in the annular space between the inner rotor and outer cylinder for measurement. The viscosity was measured by logarithmically increasing the shear rate from $0.01\,s^{-1}$ to $100\,s^{-1}$ over a period of 100 s. The apparent viscosity of the suspension was the numerical value at shear rate of $100\,s^{-1}$. Every sample was measured three times to ensure the results were reproducible.

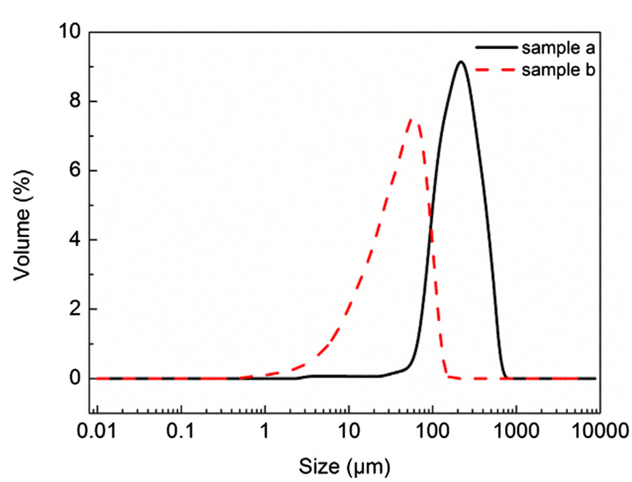

Fig. 1. Particle size distribution: the average diameter of sample a was 148 μm; the average diameter of sample b was 19.5 μm.