18th International Conference on
TRANSPORT AND SEDIMENTATION OF SOLID PARTICLES
11-15 September 2017, Prague, Czech Republic
ISSN 0867-7964 ISBN 978-83-7717-269-8

INFLUENCE OF CONCENTRATION AND ADDITIVES ON RHEOLOGICAL PROPERTIES OF COAL WATER SLURRY

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The rheological properties of coal water slurry (CWS) have an important influence on the transportation and mixing process. In this study, rotary viscometer was used to measure the rheological properties of coal water slurry at different concentrations. Additionally, the effect of the dose of additive on CWS was evaluated. The results show that coal water slurry exhibits thixotropy and shear thinning behavior and the relative viscosity of slurry increases with increasing concentration. The optimal concentration of CWS was about 50%. The additives improved the flow-ability of CWS. It is suggested that the amount of additive should be between 1 and 2% of the mass of the mixture.

KEY WORDS: viscosity; concentration; additive dose

1. INTRODUCTION

The continued rise in oil prices, difficulties with supply of crude oil, and increased fuel consumption make looking for alternative fuel essential. The coal water slurry (CWS) is a combustion-able mixture of fine coal particles suspended in water. It is a promising alternative to conventional fuels, mostly because it is relatively cheap, widely distributed, and has good stability and liquidity. At present, for transporting CWS the pipeline is widely used. This is efficient, economical and environmentally friendly method. It has become the fifth largest transportation way after the highway, railway, water transport and air transport. But, pipeline conveying CWS for a long distance and large volume might be challenging. Therefore, ensuring stability and safety of slurry transport is gaining importance. One of the most challenging parameter is the slurry's resistance. The requirement of an economic transport is that CWS concentration should be made as high as possible, and at the same time the viscosity should to be kept at a minimum level (Singh 2016). The diversity of coals in their physical and chemical properties, e.g. particle size composition, ash content and concentration, variously impact the rheological properties of CWS. Additionally, chemical additives are required in the preparation of CWS, but the type and amounts of additives also affect its rheological properties.

Mohapatra et al. (2013) investigated the rheological behavior of CWS with different concentration using Rheolab-QC viscometer. They found that, when the concentration is lower than 30%, the viscosity of the slurry increases slowly with increasing concentration, and it increases sharply when the concentration is above 30%. While Panda et al. (2014) did similar tests of rheological properties using the HAAKE RV30 rotation viscometer. They found that the optimal concentration is about 50%. Cao et al. (2014) studied the rheological behavior of CWS with different concentrations using capillary rheometer, and their research confirmed that the critical slurry concentration was also approx. 50%. Therefore, choosing proper rheometer may have a significant influence on data interpretation.

On the basis of rheological experiments, Yang (2011) obtained the relationship between the rheological parameters and the concentration of tailings in the Jinling city. Then Wang et al. (2002) established a quantitative relationship between rheological parameters and mass concentration of tailings paste in Jinchuan. So far, most of the studies have been carried out to analyze the rheological characteristics and influencing factors of the CWS only.

Lately, chemical additives have been used in CWS transportation in order to improve fluidity and stability of slurry. Song et al. (2016) prepared a certain concentration of slurry with different amounts of additives to analyze the influence of additive dose on the properties of CWS. From the perspective of slurry stability, increasing the dosage of additive isn't a good solution. Song et al. (2016) proposed that additive dosage should be about 0.15% for coal (mass ratio). Slaczka et al. (2008), when investigated the effect of three kind of additives on the stability and rheology of CWS fuels, discovered that the Rokwinol 60 additive had the best impact on CWS flowability. They tested different dosages of that additive up to CWS concentration of 55%, and they found that under the same shear rate, the apparent viscosity of slurry was the lowest when the added dose is 0.075%. The rheological properties of the suspensions concerned are strongly affected by addition of small amount of any chemical species that influences the degree of particle-particle of fluid-particle interaction.

The dosage of additive is related to the coal particle surface modification. Various investigators have studied the effect of additive on CWS flowability. Some of them evaluated the dosage and kind of additives, others were focusing on evaluation of the relationship between the yield stress and ash content. Panda（2014）found that yield stress has a linear relation with ash content, yield stress increases with the increased ash content.

The present work describes the effect of CWS concentration and additives dosage on the rheological properties of slurry employing the HAAKE rotary viscometer.

2. EXPERIMENTAL SETUP

2.1. MATERIAL & METHODS

The coal used in the experiment was derived from a factory in Poland. The particle size was measured by Laser Particle Size Analyzer. The grain size distribution was between 3.89 and 418.60μm, the average size was 104.90μm and is presented in Figure 1.

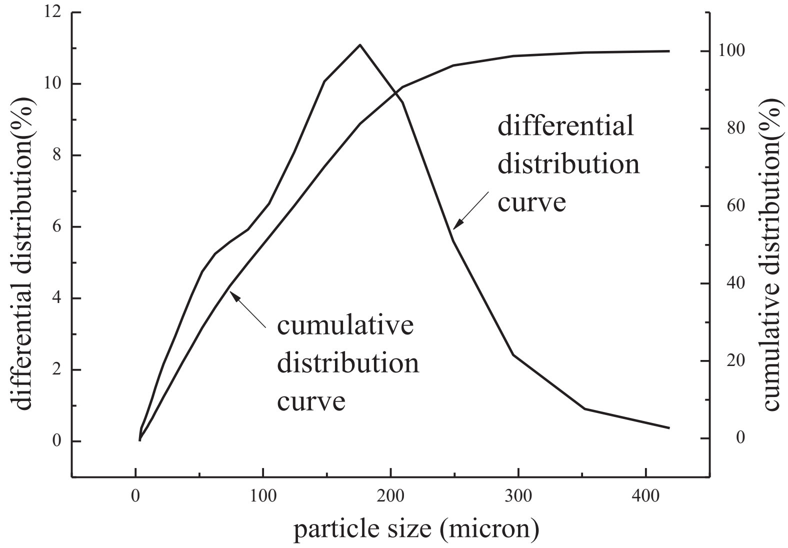

Fig.1 Grain size distribution of used coal

The rheological properties of prepared CWS were usually measured by rotational rheometer, capillary rheometer, or extensional rheometer. The most commonly used is rotational rheometer. The HAAKE rotational viscometer (Germany, model VT550) was used in this work with inner rotating coaxial cylinder, under a constant temperature of 20oC ± 2oC.

2.2. CWS PREPARATION & EXPERIMENTAL PROCEDURE

The experiments were performed according to the following procedure: first rapid mixing of pulverized coal and water at a proper ratio, then set it aside, to allow the full wetting of coal. After 15 minutes, stir quickly again to form a homogeneous slurry. Transfer the slurry to a measuring cylinder and measure the shear stress caused by a shear rate.

In the tests where the influence of additives on the rheological properties of CWS were evaluated, the following procedure was applied. First, preparation of different concentration of pulverized coal and water, then stirring them quickly, and then setting aside for some time. After 15 min a proper additive was added, followed by stirring for the next 15 min before measuring the mixture viscosity.

The measurements were carried out in steady flow so that the laminar shear flow condition could be established, meaning that the value of shear rate of $300 s^{-1}$ was not exceeded. The measuring conditions can be summarised as follows: decreasing shear rate from 300 to 0

s^{-1} and then increasing to 300 s^{-1}, two repetitions for each shear rate, each repetition is measured for 5 seconds.

The concentration of tested sample was calculated using Equation 1:

$$C = \frac{M_2 - M_0}{M_1 - M_0} \times 100\% \tag{1}$$

where: M_0-weight of beaker with slurry, g, M_1- total mass, g,M_2- dry sample, g.

3. EXPRIMENTAL RESULTS

3.1. THE GENERAL CHARACTERISTICS OF CWS

The tested CWS concentrations ranged from 41 to 61.8%. From Figure 2 we can see that the CWS showed Non-Newtonian fluid behaviour under a certain range shear rate, but when the shear rate reached a specific value, the apparent viscosity didn't change with shear rate changes, and then the CWS has the Newtonian fluid behaviour. The reason may be connected with destruction of flocculent structures.

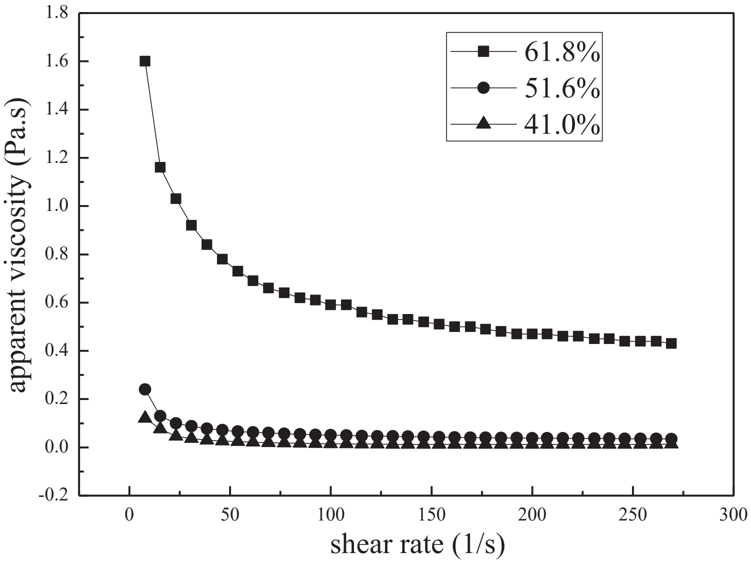

Fig.2 Shear thinning phenomenon of CWS

3.2. RHEOLOGICAL PROPERTIES AT DIFFERENT CONCENTRATIONS OF CWS

In order to evaluate the influence of concentration on rheological properties of the CWS, a series of different concentrations of CWS was prepared and measured. The rheological property measurements were performed using a rotating-type rheometer (Fig.3). And the relative viscosity coefficient was used in order to describe the rheological properties of CWS and its changes with concentration (Fig. 4).

Based on the analysis of the relationship between the relative viscosity coefficient and concentration of CWS. The evaluation confirmed that the relative viscosity increases with increasing concentration. But the increase of the slurry viscosity was relatively slow until the concentration of the CWS reached about 50%, then a rapid increase of the viscosity was observed (Fig.4). Presented results are in good agreement with results reported by Cao (2014) and Chen (2008).

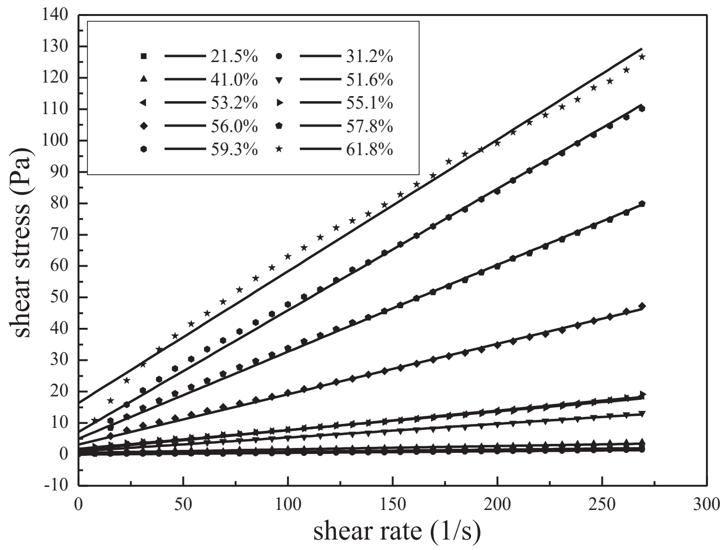

Fig.3 Rheological properties of CWS

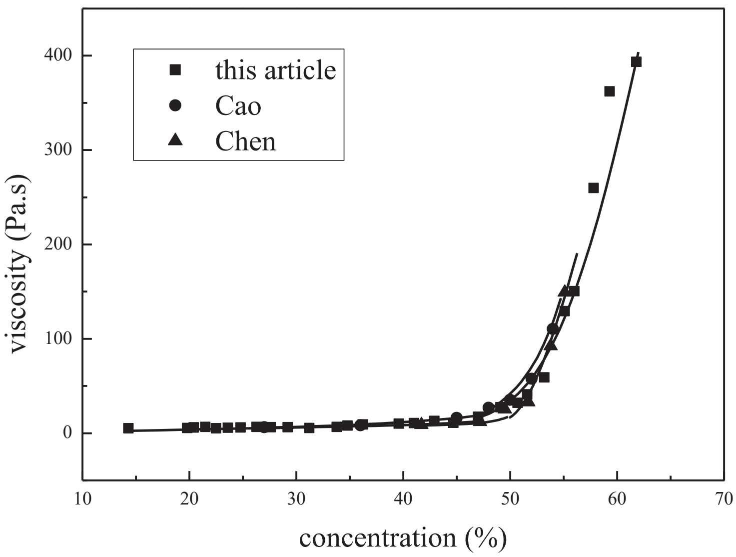

Fig.4 The relationship between concentration and relative viscosity

Accurate calculation of the limit concentration (Ct) might be challenging, since others reported that this concentration could be related to the average size of the coal particle (Sun 1996, Zheng 2011, Chen 2008). The linear fitting was applied to obtain the relationship between the Ct and the average particle size, as is shown in Figure 5.

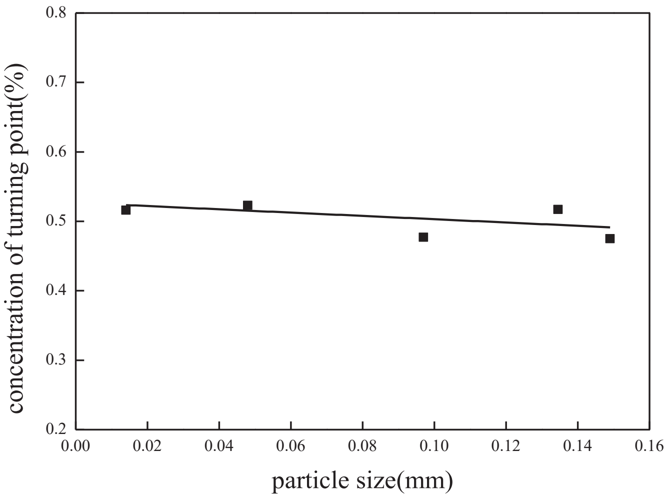

Fig.5 The relationship between the limit concentration (Ct) and particle size

Based on the analysis of the dependence between concentration and average particle size (d), the following equation was established:

$$C_t = 0.53 - 0.24 \times d \tag{2}$$

Equation (2), in principle, enables us to determine the concentration Ct when diameter of the particles is known.

3.3. ADDITIVES AND THE RHEOLOGICAL PROPERTIES OF CWS

In order to improve the liquidity and stability of CWS, quite often different additives are applied in the process of its preparation. The most commonly used additives are dispersants or stabilizers. A dispersant is usually used to change the surface properties of the coal particles, and enhance the electrostatic repulsion, as well as promote the coal particles to be dispersed in water. They can also prevent the coalescence between coal particles, so as to reduce the viscosity of CWS, and improve fluidity of CWS.

In this study PANTARHIT ®TB-100(FM) was used as an additive. It is quite often used to improve the flow-ability of the mixtures. A CWS concentration of 60.7% was tested with different amounts of additives (1.22, 2.44, 3.66, 4.88, 6.10, 7.32, 8.54, 9.76, 10.98 and 12.20%). Test results are shown in Figure 6.

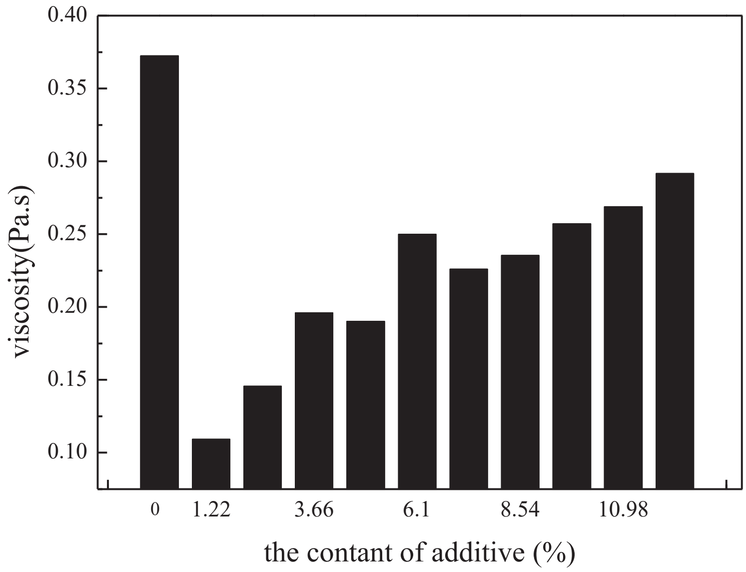

Fig.6 The relationship between content of additive and viscosity

After adding the PANTARHIT ® TB - 100 (FM) additive to tested concentration of CWS, the viscosity decreased, it did so to a certain value and then raised (Fig. 6). Zou (2004) had reported similar results. The dosage of an additive is most efficient when it reaches saturated adsorption on the surface of the coal particles. However, the amount of saturated adsorption depends on the specific surface area and properties of coal particles, as well as the structure and properties of additives. When the additive dosage is too big, it easily produces multilayer adsorption on the surface of coal particles, thus making the coal particle steric hindrance too big. Although this will increase stability of the slurry, it easily leads to reduced accumulation efficiency, reduced slurry concentration and increased viscosity. Therefore, it is suggested that an appropriate additive should be added when a high concentration of slurry is transported, which can improve liquidity of the slurry. The recommended amount of additive is 1-2% of the mass of the mixture.

4. CONCLUSION

In this study, the effects of concentration and additives on CWS rheological characteristics have been investigated and the following conclusion can be drawn:

(1) Experimental investigation revealed that CWS viscosity rises slowly with increasing concentration up to a certain critical point (Ct), and then the viscosity increases exponentially. The equation for calculating the relative viscosity of the slurry as dependent diameter of the particles has been proposed.

(2) The optimal concentration Ct is about 50% in this experiment.

(3) It has been found that additives can improve the fluidity of CWS, but an excessive additive dosage does not improve its flow-ability. It was suggested that, at high concentration of transported slurry, only 1 to 2% of the mixture mass should belong to the additive.

ACKNOWLEDGEMENTS

Financial supports are acknowledged from: The Natural Science Foundation of China (Grant 51339008 and Grant 51209238).
The authors want to thank Professor Jerzy Sobota from Wroclaw University of Environmental and Live Sciences, Poland for giving the experimental conditions and guidance.

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