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Properties of sodium lignosulfonate as dispersant of coal water slurry

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Abstract

In order to use lignosulfonates (a by-product of pulp and paper processes) as an effective dispersant of coal water slurry five purified sodium lignosulfonate (SL) samples with different molecular weights were prepared by fractionation using ultrafiltration and dialysis. The effect of SL on the apparent viscosity of coal water slurry (CWS) was investigated. The adsorption behavior of the SL on the coal water interface has much greater effect on the viscosity of coal water slurry. The higher adsorption amount and compact adsorption film of SL on the coal surface help reduce the viscosity of CWS, and the zeta potential is also an important factor, which is influenced by the sulfonic and carboxyl group contents of the lignosulfonate molecule. Furthermore, the SL with its molecular weight ranging from 10,000 to 30,000 has both a higher adsorbed amount and zeta potential on the coal surface and the best effect on reducing the viscosity of the coal water slurry.

Keywords: Sodium lignosulfonate; Molecular weight; Coal water slurry; Dispersant; Apparent viscosity

1. Introduction

Lignin is derived from an abundant and renewable resource. Lignosulfonates are a by-product of the pulping industry and are rather cheap and widespread chemicals. Lignosulfonates can be used as concrete admixtures. Apart from that, lignosulfonates have also been used in other fields including applications as oil well dispersants, dyestuff, coal water slurry (CWS) dispersants, agricultural chemicals and other industrial binders [1–3]. Of the 50 million tones of technical lignin produced annually, only 3 million tones of lignosulfonates are used for other purposes. There have been attempts for several decades to increase the utilization of lignin as a raw material, but there is still a wide gap between theory and practice, in other words, between what is technically possible and what is economically achievable. Until now, apart from a few exceptions, lignin based products could not compete with products derived from petrochemicals [4].

Recently, continuously increasing demands for energy have led scientists to seek ways of finding new energy sources. Thus, researchers have directed their attention towards various methods of burning coal water slurries for energy generation. A typical coal water slurry (CWS) consists of 60–75% coal, 25–40% water and about 1% chemical dispersants. It is desirable that the coal water slurry has high coal solids content and a low viscosity. In order to control the desired viscosity of the CWS, a dispersant needs to be added [5]. Because of the relatively complex chemical composition and the wide range of molecular weight distribution, lignosulfonates are not an effective dispersant for CWS [6].

In our earlier research [7], it was found that the surface activity and foaming property of lignosulfonate with high molecular weight were more excellent than that of low molecular weight. Furthermore, the effect of molecular weight of the lignosulfonate on the adsorption property in a cement–water dispersed system was investigated, and

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the results showed that the saturation adsorption amount of lignosulfonate with lower molecular weight (less than 30,000) on the surface of cement particles increased with the increase of molecular weight, while the same properties of high molecular weight fractions were independent of their molecular weight. In addition, other studies showed that the lignosulfonate with molecular weight ranging from 5000 to 10,000 had the best effect on the dispersion of titanium dioxide particles in water. In coal water suspension, the molecular weight of the dispersant is also an important factor that affects the viscosity and stability of the CWS. For example, for the common CWS dispersant, humate, it was found that the higher molecular weight had the better effect on reducing the viscosity of CWS [8]. Another common dispersant, NDF (methylene naphthalene sulfonate – styrene sulfonate – maleate copolymer), has the best effect on reducing the viscosity of CWS when the molecular weight is 20,000 [9]. The aim of this investigation is to determine the influence of SL with different molecular weights on the viscosity of CWS and the adsorption behavior of SL on the coal surface.

2. Experimental

2.1. Experimental materials

The beneficiated clean Panjiang coal was selected for study. The coal was dried under vacuum at 105 °C for 24 h. The crushed coal was comminuted in the ball mill to obtain products of different particle size distributions by controlling the grinding time. The elemental and proximate analyses of the coal are given in Table 1.

The commercial sodium lignosulfonate (SL) was part of a by-product of sulfite pulping from the Guangzhou Paper Making Co. Ltd., China; it was composed of 70 wt% sodium lignosulfonate, about 10 wt% reductive substances and 20 wt% low molecular weight organics such as sugar acid and inorganic salts as well as ash. This commercially available SL was a water soluble, light yellow powder, turning to brown when dissolved in water.

2.2. Ultrafiltration of SL

The SL sample in the study was refined through the anion exchange resin and cation exchange resin to remove the low molecular weight organic acid, inorganic salt and other impurities. The SL sample was separated into five fractions with molecular weight ranges [10]: less than 5000, 5000–10,000, 10,000–30,000, 30,000–50,000 and more than 50,000, using a hollow fiber membrane ultrafiltration apparatus (Hangzhou Water Treatment Factory, China). The effective filtration area of each membrane was 0.008 m^2. The cut off molecular weights of the membranes used in the experiments is, respectively, 5000, 10,000, 30,000 and 50,000. The operation was under a pressure of 2–4 MPa and a temperature of less than 45 °C. The nominal cut off ratio was more than 90%.

The molecular weight distribution of the SL sample was determined by using aqueous gel permeation chromatography (GPC) with Ultrahydragel 120 and Ultrahydragel 250 columns. The GPC analyses were performed using a Waters 1515 Isocratic HPLC pump with a Waters 2487 UV Absorbance Detector (Waters Corp., USA). The influences of the mobile phases on the elution behaviors of the samples are determined. It is confirmed through a series of experiments that the eluent of a neutral aqueous solution containing a low concentration of electrolyte could separate the components of SL. The best results were obtained by using 0.10 mol/L $NaNO_3$ solution with pH 8 as the eluent with the velocity of 0.50 mL/min. The polystyrene sulfonate was used as the standard substance [11–13].

2.3. Measurements of functional group content of fractions

The sulfonic group in the SL sample was determined with the conductometric titration method [14]. The carboxyl and phenolic hydroxyl groups in the SL were also determined by means of the non-aqueous conductometric titration method for weak acid. The Pyridine–acetone mixture of Pyridine or acetone was used individually as solvent. A KOH–benzalcohol standard solution of 0.05–0.10 mol/L was used as the titrant. The titration temperature was 20–30 °C [15,16]. The above titration experiments were conducted using an automatic potentiometric titrator (809Titrando, Metrohm Corp., Switzerland).

2.4. Preparation of CWS and viscosity measurement

The coal powder was mixed slowly in a pot containing a quantity of dispersant and deionized water. The contents were continuously stirred by means of a mixer during the addition of coal, and then the stirring of the slurry was continued for another 10 min at 1200 rpm to ensure homogenization of the CWS. The slurry so prepared was left for study of its characteristics. The viscosity measurement was performed employing the Brookfield viscometer. Before measurement, the slurries were allowed to stand for 5 min. The measurements were taken within the first 15 s at a speed of 100 rpm. The temperature was kept at 25 °C.

Table 1
Elemental and proximate analyses of the Panjiang coal

Sample	Inherent moisture (wt%)	Ash (wt%)	Volatile matter (wt%)	Carbon (wt%)	Hydrogen (wt%)	Oxygen (wt%)	Sulfur (wt%)	Nitrogen (wt%)
Panjiang	1.08	9.21	30.98	88.03	5.04	2.1	0.17	1.72