Study on the Influence of Pulping Process on Rheological Properties of Coal Water Slurry

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Abstract. The fluidity of the coal water slurry during transportation, the stability during storage, and the combustion characteristics during atomization combustion have a great relationship with the rheological properties of the coal water slurry. In this chapter, the zwitterionic humic acid graft copolymer coal water slurry dispersing agent HSC and anionic humic acid graft copolymer dispersing agent HS were used to prepare Binchang coal water slurry. Dispersing agent, pulping concentration and temperature were discussed. The effect on the rheological properties of coal water slurry. The result shows that the coal water slurry made by HSC and HS with graft structure has obvious yielding pseudoplastic fluid characteristics, while the NSF and HA coal water slurry show slight yielding pseudoplastic fluid characteristics. With the increase of pulping concentration, water coal the apparent viscosity, yield stress and flow coefficient of the pulp show an increasing trend. The greater the pulping concentration, the flow characteristics of the coal water slurry will develop to the yielding plastic fluid; for the pulp made by HSC, when the pulping concentration At 67 wt%, the slurry exhibited a slight yielding plastic fluid characteristic. For the HS slurry, when the pulping concentration was 68 wt%, the slurry exhibited a slight expansion plasticity characteristic. At 25 °C, the fluid model of the coal water slurry yields a pseudoplastic fluid, after which the elevated temperature can weaken the yield pseudoplastic properties of the slurry and cause the slurry to transform into a plastic fluid.

1. Introduction

Coal water slurry is a liquid-solid two-phase suspension system consisting of 60% to 70% by mass of coal powder, 30% to 40% water and a small amount of additives. It is a new type of coal-based fluid fuel, which is burned in coal. It is widely used in clean coal technology such as gasification. Coal-water slurry has similar fluidity and stability to petroleum. It can easily realize storage, pipeline transportation,
atomization and combustion. It has many benefits such as energy saving, environmental protection and comprehensive utilization of coal slime. It is highly valued by the industrial circles of various countries.

The coal water slurry with excellent performance not only has a higher coal slurry concentration, but also has good rheological properties. The fluidity of the coal water slurry during transportation, the stability during storage, and the combustion characteristics during atomization combustion have a great relationship with the rheological properties of the coal water slurry. The rheology of coal water slurry is generally affected by factors such as coal used for pulping, particle size distribution, concentration, pH, temperature and additives used [1-4].

In this chapter, Binchang coal-water slurry was prepared by zwitterionic humic acid graft copolymer coal water slurry dispersant HSC and anionic humic acid graft copolymer dispersant HS. The effects of dispersant, pulp concentration and temperature on the rheological properties of coal water slurry were discussed [5].

2. Preparation of coal water slurry

Coal-water slurry is produced by dry-process pulverizing method. Pulverized coal is pulverized by a FW-200 type pulverizer, sieved by a sample sieve of 20, 40, 120, 200 and 300 meshes, Particle size distribution of the ratio of mixing, into the grinding tank. At the same time add a certain amount of dispersant and water, and then add the appropriate amount of grinding ball, placed on a planetary ball mill XM-4 grinding, rotation 600 r / min, time 10 min.

HSC and HS coal water slurry dispersants were prepared according to literature procedures, and NSF dispersants were commercially available dispersants.

3. Results and discussion

3.1. Effect of dispersant type on rheology of coal water slurry

The dispersant HSC and HS were used in the preparation of Binchang coal-water slurry, the concentration of coal-water slurry was 65 wt%, and the amount of dispersant was 0.75 wt% (compared with the commercially available naphthalene dispersant NSF, sodium humate dispersant HA). The addition amount is 0.75%), and the rheology test is carried out by R/S-SST Plus rheometer. The effects of different kinds of dispersants on the rheology of coal water slurry are investigated. The rheological curve is shown in Figure 1. The obtained data were fitted using the Herschel-Bulkley model. The fitting parameters are shown in Table 1:

It can be seen from Fig.1(A) that the slurry prepared by using four kinds of dispersing agents, HSC, HS, HA and NSF, exhibits obvious shear thinning characteristics, and the viscosity of the slurry is present. The order of the four types of dispersants on the apparent viscosity of coal water slurry is: HA>NSF>HSC>HS.

It can be seen from Fig. 1(B) and Table 2 that the correlation coefficient R2 of the Herschel-Bulkley model of coal water slurry prepared by HSC, HS, HA and NSF dispersing agents is 0.9998, 0.9995 and 0.9961, respectively. 0.9978, with a high degree of agreement. The flow index of HSC and HS with graft structure has a value of n<1, showing obvious yielding pseudoplastic fluid properties, and due to the existence of graft chains, the interior of the slurry can form a certain strength at rest. The three-dimensional space grid structure is characterized by a large yield stress, which is beneficial to coal water slurry pulping. The unmodified HA and the slurry made by NSF have a flow coefficient n>1, showing a slight characteristic of yielding plastic fluid, and the yield stress of the slurry made by HA and NSF is small. Among them, the apparent viscosity of the slurry prepared by HA is the smallest, HA is not able to improve the hydrophilicity of the surface of the coal particle because of its poor hydrophilicity, so HA cannot form the interior of the slurry. The three-dimensional space structure with a certain strength has the smallest yield stress, which is easy to cause the static stability of the slurry. When the shear rate increases, the HA molecules desorb from the coal particles, causing the large particles in the slurry to precipitate continuously and exhibit yielding. Expanded plastic fluid characteristics. Therefore, although
the viscosity of the slurry made by HA is small, its stability is poor and it is not suitable for separate pulping[6-8].

![Figure 1](image1.png)

**Figure 1.** Influence of dispersant on the rheological properties of coal water slurry

| Dispersant | τ_0 (Pa·s) | K | n | R^2 |
|------------|------------|---|---|-----|
| HSC        | 35.9180    | 1.2488 | 0.7299 | 0.9996 |
| HS         | 37.7632    | 2.0720 | 0.5863 | 0.9725 |
| HA         | 14.5919    | 0.0451 | 1.5019 | 0.9961 |
| NSF        | 23.3342    | 0.2013 | 1.2050 | 0.9978 |

**Table 1.** Rheological data for Binchang CWS with different dispersant

3.2. Effect of pulping concentration on rheology of coal water slurry

The dispersing agents HSC and HS were used for the preparation of Binchang coal-water slurry, and the coal water slurry with a concentration of 66 wt%, 67 wt% and 68 wt% was prepared, and the dispersant addition amount was 0.75 wt%. Investigate the influence of pulping concentration on the rheology of coal water slurry. The rheological curves are shown in Figures 2 and 3. The data obtained are fitted by Herschel-Bulkley model. The fitting parameters are shown in Table 2:

It can be seen from Table 2 that the rheological models of coal water slurry prepared by HSC and HS are highly consistent with the Herschel-Bulkley model at different temperatures, and the correlation coefficients are all greater than 0.97. In the experimental test range, with the increase of pulping concentration, the apparent viscosity, yield stress and flow coefficient of coal water slurry show an increasing trend. The greater the pulping concentration, the flow characteristics of coal water slurry will be to yield and plasticity. Fluid development. For the slurry prepared by HSC, when the pulping concentration is 67 wt%, the slurry exhibits a slight yielding plastic fluid characteristic. When the concentration is 68 wt%, its expansion and plasticity characteristics are more obvious; for HS slurry, when the pulping concentration is 68 wt%, the slurry exhibits a slight swelling plasticity characteristic [8-9].

3.3. Effect of temperature on rheology of coal water slurry

The dispersants HSC and HS were used for the preparation of Binchang coal-water slurry, the concentration of coal-water slurry was 66 wt%, the amount of dispersant was 0.75 wt%, and the rheology was carried out by R/S-SST Plus rheometer. test. The influence of temperature on the rheology of coal water slurry was investigated. The rheological curves are shown in Figures 4 and 5. The data were fitted using the Herschel-Bulkley model. The fitting parameters are shown in Table 3:
Figure 2. Effect of pulp concentration on the rheological curve of CWSs prepared from HSC

Table 2. The rheological data of CWS under different pulp concentration

| Dispersant | concentration /% | $\tau_0$ | $K$     | $N$     | $R^2$   |
|------------|------------------|----------|---------|---------|---------|
| HSC        | 66               | 35.9180  | 1.2488  | 0.7299  | 0.9996  |
|            | 67               | 60.5397  | 0.1091  | 1.2403  | 0.9942  |
|            | 68               | 99.0324  | 0.0091  | 1.8065  | 0.9942  |
| HS         | 66               | 37.7632  | 2.0720  | 0.5863  | 0.9725  |
|            | 67               | 69.8528  | 0.6874  | 0.9271  | 0.9992  |
|            | 68               | 141.4026 | 0.4038  | 1.0442  | 0.9943  |
Figure 4. Effect of preparation temperature on the rheological curve of CWS prepared from HSC

Figure 5. Effect of preparation temperature on the rheological curve of CWS prepared from HS

Table 3. The rheological data of HS CWS under different temperature

| Dispersant | temperature / °C | τ₀ (Pa) | K (Pa.s⁰.⁹⁹) | N | R² |
|------------|------------------|---------|--------------|---|----|
| HSC        | 5                | 54.7093 | 0.2958       | 1.0413 | 0.9996 |
|            | 25               | 35.9180 | 1.2488       | 0.7299 | 0.9996 |
|            | 35               | 28.5152 | 0.6230       | 0.8810 | 0.9972 |
|            | 45               | 19.1591 | 0.4017       | 0.9775 | 0.9957 |
| HS         | 5                | 50.9316 | 0.3451       | 1.1329 | 0.9953 |
|            | 25               | 37.7632 | 2.0720       | 0.5863 | 0.9725 |
|            | 35               | 27.9422 | 0.8959       | 0.8030 | 0.9907 |
|            | 45               | 19.8274 | 0.1091       | 1.2403 | 0.9943 |

It can be seen from Fig. 4, 5 and Table 3 that the rheological models of coal water slurry prepared by HSC and HS are highly consistent with the Herschel-Bulkley model at different temperatures, and the correlation coefficients are all greater than 0.99. Temperature has a complex effect on the rheology of coal water slurry. At low temperature, the HSS and HS coal water slurry maintained high apparent viscosity and yield stress, and the flow coefficient n>1, the slurry has a slight characteristic of yielding plastic fluid; after the temperature rises to 25 °C, The slurry recovered to the characteristics of yielding pseudoplastic fluid. In the range of 25–45 °C, the apparent viscosity, yield stress and consistency
coefficient of the slurry decreased with the increase of temperature, and the flow coefficient increased with the increase of temperature. For the coal water slurry produced by HSC, the temperature increase weakens the characteristics of the slurry yielding pseudoplastic fluid; while for the HS coal slurry produced by HS, the flow coefficient of the coal water slurry is greater than 1 at 45 °C, showing a slight yield. Expanded plastic fluid characteristics.

According to the analysis, as the temperature increases, the volume of coal water slurry increases, and the Brownian motion of the coal particles in the slurry and the activity of the dispersant molecules are enhanced, thereby achieving the effect of reducing the viscosity. For HSC and HS dispersants, the apparent viscosity, yield stress and flow coefficient of coal water slurry show a decreasing trend with increasing temperature. It indicates that the elevated temperature is beneficial to the coal water slurry pulping [10-11].

4. Conclusion
The effects of different kinds of dispersants on the rheology of coal water slurry were studied. The results show that the coal water slurry made by HSC and HS with graft structure has obvious yielding pseudoplastic fluid properties, while the NSF and HA coal water slurry exhibit slight yielding pseudoplastic fluid properties.

The effect of pulping concentration on the rheology of coal water slurry was studied. The results show that with the increase of pulping concentration, the apparent viscosity, yield stress and flow coefficient of coal water slurry show an increasing trend. The greater the pulping concentration, the flow characteristics of coal water slurry will develop to the yielding plastic fluid; For the slurry prepared by HSC, when the pulping concentration is 67 wt%, the slurry exhibits a slight yielding plastic fluid characteristic. For the slurry prepared by HS, when the pulping concentration is 68 wt%, the slurry exhibits Slightly bulging plastic fluid characteristics.

The effect of pulping temperature on the rheology of coal water slurry was studied. The results show that at 5 °C, the HSS and HS coal water slurry maintains high apparent viscosity and yield stress, and the slurry exhibits slight yield and plasticity. At 25 °C, the fluid model of coal water slurry changes to After yielding the pseudoplastic fluid, the apparent viscosity, yield stress and consistency coefficient of the coal water slurry produced by HSC and HS decreased with the increase of pulping temperature, while the fluidity index increased continuously and increased. The temperature can weaken the yield pseudoplastic properties of the slurry and transform the slurry into the expanding plastic fluid.

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