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Suspension mechanism and application of sand-suspended slurry for coalmine fire prevention

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ABSTRACT

North and west China has abundant coal resources, however, such resources make these regions prone to serious mine fire disasters. Although the copious sand and fly ash resources found in these areas can be used as fire-fighting materials, conventional grouting is expensive because of water shortage and loess particles. A new compound material (i.e., a sand-suspended colloid), which comprises a mineral inorganic gel and an organic polymer, is developed in the current study to improve the quality of sand injection and reduce water wastage when grouting. The new material can steadily suspend the sand, through the addition of a small amount of colloid yielding steady sand-suspended slurry. The process of producing the slurry is convenient and quick, overcoming the shortage of sand-suspending thickeners which need heat and are difficult to produce. The space work model based on the theory of the double-electric layer is established to study the suspended mechanism of the solid particles in the sand-suspended colloid. The dispersion effect of the sand-suspended colloid is demonstrated by the incorporation of the electrostatic effect by the double-electric layer and the steric hindrance effect on the sand particles, ensuring the stability of the colloid system and the steady suspension of sand particles in the sand-suspended colloid. Mechanical analysis indicates that the sand is suspended steadily under the condition that the rock sand particles stress on the lower part of the fluid is less than the yield stress of the colloid. Finally, the fire-prevention technology of sand suspension was applied and tested in the Daliuta Coal Mine, achieving successful results.

1. Introduction

At present, coal is still the most important energy in China. And there are plenty of coal in north and west China. However, the exploitation of coal in north and west China has led to the frequent occurrence of serious mine fire disasters. In order to prevent the coalmine fire, many measures are widely used, such as ventilation by even air pressure, grouting the mud or three-phase foam, spraying inhibitor, injecting N_2 or CO_2, etc. [1–5]. Therefore, the fire-fighting measures in the coalmines have some shortages as follows: (1) grouting the mud could consume plenty loess which competes with the arable land; (2) grouting the fly ash couldn't plug leakage effectively; (3) spraying inhibitor and injecting the nitrogen could diffuse with the leakage and couldn't cool the high temperature areas effectively; and (4) the grouted foam has the shorter steady time and couldn't become solid. Currently, the conventional grouting is one of the most widely used measures for fire preventing based on its simple operation and low cost. However, the cost of conventional grouting for fire prevention is high due to shortage of water and loess particles in north and west China. Nevertheless, abundant fly ash and sand resources found in the area can be used as materials for coalmine fire fighting.

Until now, some studies have reported the grouting for fire prevention in coalmines, and the conventional sand injection are mainly applied [6–8]. The ratio of water to sand must reach 7:1 to 15:1 if the fly ash or sand with water is simply injected to ensure that the sand would not subside [9–11]. The technology, however, tends to waste large amounts of water, leading to the severe abrasion of the pipeline [12]. Otherwise, according to the reports, the emulsion fracturing fluid in oilfield, the drilling fluid and the completion fluid could settle the sand for less than 1 h, in which the ratio of water to sand could reach 3:5 [13–15]. But these couldn't match the demand for coalmine fire prevention. Moreover, there are no reports about the materials for settling the sand abroad.

Therefore, a new kind of appending material, called sand-suspended colloid, is developed in the current study to improve the utilization ratio of water and the fly ash or sand.

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2. Developing the sand-suspended colloid and testing suspended character

2.1. Developing the sand-suspended colloid

The compound appending material of sand-suspended colloid is composed of an inorganic mineral gel, an organic polymer and the dispersant; here, the inorganic gel is used as the base. Fig. 1 shows images of the three different concentrations of the sand-suspended colloid.

2.2. Testing suspended character

The materials of the sand-suspended colloid were taken to prepare colloids with different concentrations. The suspension effects of the colloids were also investigated. Different concentrations of colloid materials and sand were selected and used for the suspension experiments. The grain size was set at under 0.5 mm. Colloid concentrations of 0.2%, 0.3%, 0.4%, and 0.5% were chosen to prepare the sand-suspended slurries with different mass ratios of 4:1, 2:1 and 1:1, respectively. Figs. 2–5 present the suspension states of sand in the sand-suspending slurries at different periods.

The results of the suspension experiment show that the colloid with a concentration of 0.3% and higher can steadily suspend the sand. The colloid with a concentration of 0.2% could not suspend the sand, which completely deposited after 5 h (Fig. 2). The samples that suspend the sand well, especially those with concentrations of 0.4% and 0.5%, are unable to deposit any sand after 5 days, which is in accordance with the demand for stabilization. The stabilization of the sand-suspended colloid is derived from the elastic cohesive action, wherein the power source is the interaction force among the colloid grains and the hydrones within a three-dimensional net construction of the colloid. The sand-suspended experiments and the stabilization tests show that the compound colloid demonstrates sand-suspending stability.

2.3. Flowing test of the sand-suspending slurry in the pipeline

The system for preparing the sand-suspending slurry and simulating the flow in pipeline was developed in the laboratory to meet the needs of the coalmines. The system consists of the preparation equipment for the slurry, the blender, the pump for transporting, and the straightness pipeline. The volume of the preparation equipment is 2 m^3, and is capable of preparing 30 m^3/h of slurry. The power plant is a type G85-1 pump with a single screw, which has a maximum flow of 43.5 m^3/h. The pump, with the import and export diameters of 150 mm, has a power of 15 kW and has the ability to transport the slurry with particles as large as 10 mm and viscosity as high as 200 Pa·s. The length of the straight pipeline is 80 m with a straight layout. The straight pipeline with the input diameter of 100 mm and the output diameter of 125 mm was used to test the resistance of the pipeline. Fig. 6 displays the entire system.

(a) 0.2% concentration (b) 0.4% concentration (c) 0.5% concentration

Fig. 1. Photographs of sand-suspended colloids in different concentrations.

(a) Suspension state at the initial time (b) Suspension state after 5 h

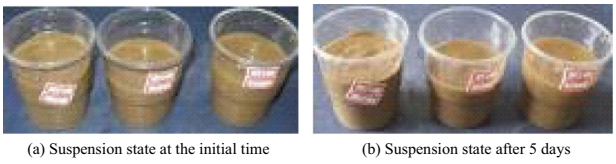
Fig. 2. Suspension results at 0.2% concentration.

(a) Suspension state at the initial time (b) Suspension state after 5 days

Fig. 3. Suspension results at 0.3% concentration.

(a) Suspension state at the initial time (b) Suspension state after 5 days

Fig. 4. Suspension results at 0.4% concentration.



(a) Suspension state at the initial time (b) Suspension state after 5 days

Fig. 5. Suspension results at 0.5% concentration.

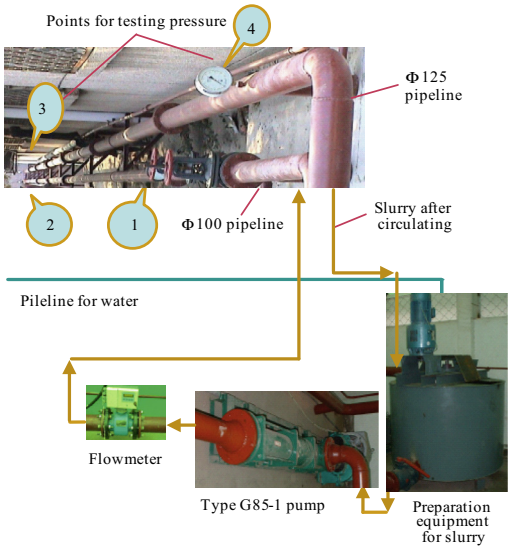


Fig. 6. Mortar preparation and pipeline flow simulation system.

The 0.5% solution was mixed with the colloid. Then, the sand-suspension experiment was performed with a water-to-sand ratio of 2:1. The sand-suspending slurry was prepared using the preparation equipment in the upper proportion at normal temperature