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Full Length Article

Reducing quartz entrainment in fine coal flotation by polyaluminum chloride

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ABSTRACT

Flotation tests using artificial mixtures of clean coal and quartz were conducted with and without the presence of sodium hexametaphosphate (SHMP) to study the effect of polyaluminum chloride (PAC) on quartz entrainment in fine coal flotation. Comparisons of flotation results show that the degree of quartz entrainment was greatly reduced using a suitable amount (e.g., 20 mg/L) of PAC in the absence of SHMP, however, significant changes of PAC on quartz entrainment did not appear in the presence of SHMP. The possible mechanisms responsible for the reduced quartz entrainment using PAC in fine coal flotation were investigated by particle size distribution measurements, zeta potential measurements, and interaction force calculations. Analysis of particle size distribution results reveals that when SHMP was not added, quartz particles were selectively aggregated with the addition of 20 mg/L PAC and the aggregation of quartz or coal particles was negligible at a high PAC dosage (e.g., 50 mg/L). Meanwhile, the aggregation of quartz particles induced by PAC was eliminated with the presence of SHMP. The electrostatic double layer repulsive force between quartz particles was calculated using the Deyaguin-Landau-Verwey-Overbeek (DLVO) theory with incorporating the results of zeta potential measurements. At 20 mg/L of PAC, the negative surface charge of quartz particle was neutralized and the electrostatic double layer repulsive force between quartz particles reached the minimum. These findings might be reasons of the aggregation of quart particles and therefore reduce the quartz entrainment in fine coal flotation.

1. Introduction

Gangue entrainment is the main reason that results in the deterioration of flotation concentrate grade. The gangue entrainment problem in coal flotation has become more severe since the proportion of fine and ultrafine particles in coal flotation feed increases greatly with the popularization of mechanical mining and heavy medium cyclone separation technologies. Since China has adopted much stricter environmental regulations, the production of high quality clean coal has become a major challenge faced by the coal flotation industry today. Reducing the entrainment of fine and ultrafine gangue minerals seems to be a promising approach to improving the grade of clean coal, although, studies reported that it is very difficult to deal with [1–3].

In recent years, a number of studies have been conducted to improve the quality of flotation clean coal. Jiang et al. [4] and Peng et al. [5] applied inclined plates in the flotation column to increase the segregation rate between the rising bubbles and descending liquid by which both the capacity and the separation efficiency of the flotation column increased. Ni et al. [6] designed an unconventional flotation column by adopting the mechanism of gravity sedimentation into flotation. They found that the ash of clean coal obtained with the new column was reduced by 1.17% compared with the conventional flotation column. The successes in improving clean coal quality also have been achieved by the development of new compound collector to promote fine particle recovery [7], the uses of ultrasonic [8], and high intensity conditioning to realize surface cleaning [9]. Recently, two liquid flotation, for example the Hydrophobic-Hydrophilic Separation (HHS) technology, has been developed to remove the gangue minerals by dispersing coal in hydrocarbon phase [10,11]. The entrainment of gangue minerals such as quartz, kaolinite, and montmorillonite in fine coal flotation has been recognized since the beginning of employing flotation. However, research effort has been mainly focused on developing new processes to improve the clean coal quality as above-mentioned. On the other hand, various studies have also been carried out to understand the gangue entrainment. A comprehensive review paper by Wang et al. [12] summarized the effect of major contributing

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factors on entrainment, the methods for quantifying entrainment, and the models of gangue entrainment. Wiese et al. [13] proposed that the shape of particles had influence on entrainment, it was found that the particles of a flaky shape would be more easily entrained than those of a spherical shape. Recently, Sheni et al. [14] investigated thoroughly the effects of pulp chemistry on entrainment, which included pulp potential, pH, dissolved oxygen, and ionic strength, and found that only the pulp potential had significant influence on entrainment. Although a number of methods as to how to mitigate gangue entrainment have been put forward, the report on their practical application is scare.

It is well recognized that there is a positive correlation between the gangue entrainment and water recovery. As to fine coal flotation, researches on reducing gangue entrainment were mainly focused on enhancing the water drainage in froth by increasing the froth height [15] and the use of bias water [4,16] to reduce water recovery. The effectiveness of these methods largely depends on whether the gangue particles are extremely fine, and whether the motion path of fine particles is exactly the same as the water flow. That is to say, the commonly used methods on gangue entrainment reduction might not be effective when the gangue mineral particles are selectively aggregated. Successful use of selective aggregation to mitigate the entrainment of gangue has been frequently reported in the flotation of metalliferous ores [17–19]. However, attempt on reducing gangue entrainment by selective aggregation has rarely been given in fine coal flotation. It might be attributed that the hydrophobic coal will be preferably aggregated when an organic polymer is used [20–22]. Thus, it will be of interest to explore an effective method on how to reduce gangue entrainment in coal flotation by selective aggregation without deteriorating of the recovery of coal.

In the present work, a model system (mixtures of fine clean coal and quartz particles) was used to study the gangue entrainment in fine coal flotation. Polyaluminum chloride (PAC), a low-cost and commonly used inorganic polyelectrolyte, was chosen to aggregate quartz particles. The effect of PAC on quartz entrainment was investigated through determining clean coal ash and water recovery, and also analyzed through measurements of aggregation degree of particles and zeta potential, and calculations of interaction energy.

2. Experimental

2.1. Materials

The quartz particles with a top size of 125 μm were purchased from Wanquan Co. Ltd, China. X-ray diffraction (XRD) analysis in Fig. 1 shows that only a trace amount of muscovite was found in the sample.

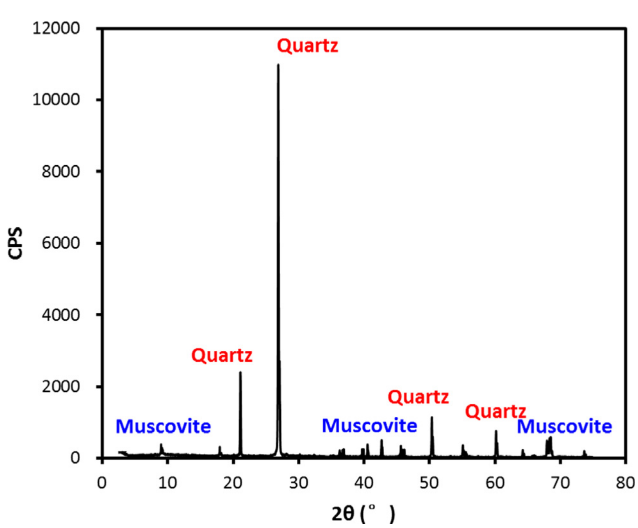

Fig. 1. X-ray diffraction results of quartz sample.

Table 1
Proximate and ultimate analysis of the clean bituminous coal sample.

Proximate analysis (dry basis)			Ultimate analysis (dry-ash-free basis)				
Ash content (%)	Volatile matter (%)	Fixed carbon (%)	C (%)	H (%)	N (%)	O (%)	S (%)
6.25	48.93	44.82	81.56	5.11	1.66	11.12	0.55

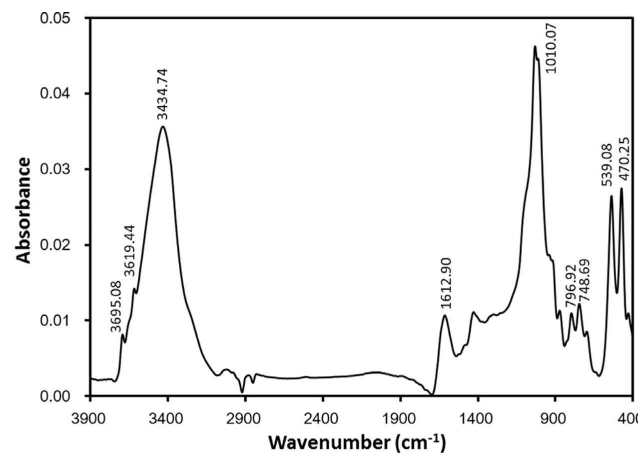

Fig. 2. FTIR spectrum of the clean coal sample.

Therefore, the quartz sample was used without further purification. A clean bituminous coal sample was collected from a coal mine in Shandong province, China. The coal sample was firstly crushed and ground to −250 μm. Then, the $-1.4\ g/cm^3$ density fraction was collected and used in flotation tests, particle size distribution and zeta potential measurements. Table 1 presents the results of proximate and ultimate analysis of the clean coal sample used in this study. As shown, the ash content of the clean coal is 6.25% (dry basis). The FTIR spectrum of the clean coal sample is shown in Fig. 2. There were no obvious peaks at $1100\ cm^{-1}$ or $1750\ cm^{-1}$ which respectively originated from the symmetric stretching of Si–O–Si linkages and the asymmetric stretching of the Si–O–Si systems [23]. The FTIR measurements validated that quartz was not present in the clean coal sample.

The PAC of 0.5–0.7 basicity from Sinopharm Chemical Reagent Co. Ltd, China was used as received. A 1% by weight PAC solution was aged for 24 h before use. Sodium hexametaphosphate (SHMP) of analytical grade (Sinopharm Chemical Reagent Co. Ltd, China) was used as a dispersant. Kerosene and 2-octanol were used as the collector and frother, respectively. These two reagents are the conventional flotation reagents used in the coal preparation plant where the coal sample was obtained. Sodium hydroxide (NaCl) of analytical grade was used as a background electrolyte. All the experiments were conducted in the presence of 1 mM NaCl. Deionized water with a resistivity of 18.2 MΩ·cm (Watson, Ltd.) was used for preparation of reagent solutions and flotation tests.

2.2. Flotation experiments

The flotation experiments were conducted using a XFD laboratory mechanical flotation machine with a 1.5 L cell. In each test, a mixture of 25 g clean coal and 25 g quartz was placed in the cell containing 1.5 L of 1 mM NaCl solution and agitated for 4 min at 1800 rpm. After, the slurry was first conditioned with PAC (predetermined dosages) for 4 min, then kerosene (40 mg/L) for 2 min with each reagent addition. Frother (2-octanol, 10 mg/L) was added last followed by 1 min of conditioning. For the tests using dispersant, 2 g/L SHMP was added prior to the addition of PAC followed by 2 min conditioning. During all