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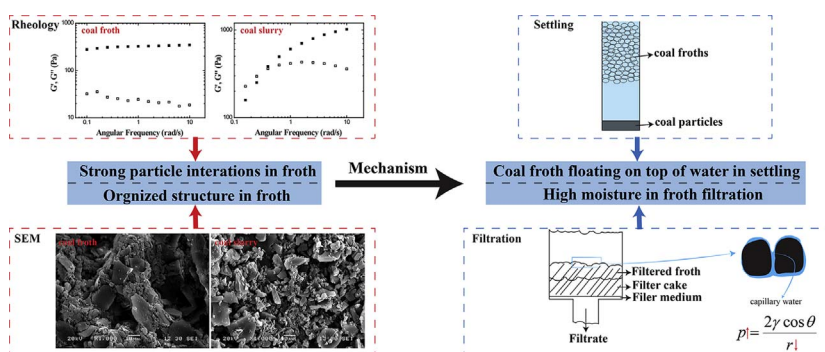
The effect of froth on the dewatering of coals – An oscillatory rheology study

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GRAPHICAL ABSTRACT



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ABSTRACT

Dewatering of fine coal flotation products is discouraged by the presence of stable coal froth, which is becoming a common problem in coal preparation plants, however, the underpinning mechanism is still unclear. In this study, the dewatering behaviours of fine coal flotation products in both thickening and filtration were investigated and compared with those of coal slurry under the same condition. The mechanism that how coal froth influenced dewatering was investigated by analysing the froth properties using oscillatory rheology in conjunction with the characterization of particle arrangements on the air-water interface using Scanning Electron Microscopy (SEM). It was found that, in the presence of air, particle interactions in coal froth were stronger than those in coal slurry, which was caused by the capillary attractive force between particles on the air-water interface. In addition, particles in coal froth were arranged regularly, while particles in coal slurry were distributed randomly. Strong particle interactions and well organised structures in coal froth made the capillary radii smaller, and as a result, a large amount of froth stabilized on top of water during settling and the final moisture of filter cake was high in filtration.

1. Introduction

Effective dewatering of fine coal flotation products is crucial to reduce the transportation cost and to increase the calorific value of fuels [1,2]. Thickening and filtration are the two most commonly used processes in fine coal dewatering. For thickening, gravity works to separate particles in water by sedimentation, while filtration utilises pressure to

separate solid and water [3,4]. Although dewatering of slurry is a straightforward process, poor dewatering performances are usually observed in coal preparation plants when dewatering flotation products with a high content of overly stable froth. During thickening, stable coal froth floats on top of thickeners, therefore decreasing the recovery of coal particles and discouraging the reuse of process water. During filtration, coal froth with a high moisture content stays on top of or is

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entrapped into filter cakes, which has a negative effect on filtration [5,6].

The negative effects of coal froth on dewatering are supposed to be related to the structures of coal froth and the interactions of particles inside froth. In thickening, only coal particles that detach from bubble surfaces have the possibility to settle. When particles attach on the bubbles, they will float on the top. In this case, the interactions of coal particles on bubble surfaces are important. In the filtration of coal flotation products, previous studies have shown that the presence of bubbles blocked pores and passages through which water was drained, reducing the permeability of the water phase in the filter cake and therefore decreasing the filtration efficiency [5–7]. However, there are limited studies so far to characterize the coal particle interaction in coal froth and link it with the dewatering behaviour of coal particles.

There are three kinds of water associated with hydrated coal particles: surface water, capillary water and chemical water. Surface water includes that presents on the external surfaces of particles as well as that occupies the pore space (inter-particle) between them, capillary water (intra-particle) resides within the internal pores of the particle, and chemical water is chemically bounded within the solids [8]. Capillary water is the crux for filtration of fine particles. The large surface area of particles and small capillaries in filter cakes lead to a difficulty in capillary water removal [9]. The presence of froth during filtration and the interaction of coal particles in froth are expected to modify the capillaries in the filter cake and then affect the filtration, however, this type of studies has not been reported so far.

Surface forces in fine particles are key factors influencing the removal of capillary water, and hence the dewatering efficiency [10,11]. Surface forces not only control the surface wettability of particles, but also determine the interactions between particles [12]. The influence of hydrophobicity of particles on the dewatering efficiency has been well studied [13–16], and methods to increase the dewatering efficiency by increasing hydrophobicity of particles have been widely applied [1,2,4,8]. However, how the surface forces affect the interactions between particles in coal froth and the relationship with the dewatering performance have not been studied. Therefore, it will be important to characterize the froth structures on the level of surface forces and analyse the interaction of particles in froth to understand the negative impacts of froth on the dewatering.

Froth is a three-phase material whose structure can be easily broken when external forces are applied. Therefore, the characterization of froth without destroying its original structure is a significant challenge. Oscillatory rheology is a potential method to study the properties of particle interactions in froth, and has been used to characterize the interfacial properties of foam, a two-phase soft material [17–20]. Compared with other rheological methods including rotational rheology, oscillatory rheology is a non-destructible method when it is performed in the linear viscoelastic (LVE) region [21]. In this way, the particle interactions in froth can be investigated without altering their structures. Besides, viscoelastic measurements by oscillatory rheology can be used to classify the particle associations [22]. The time-dependent stability properties of samples can also be identified [23]. Models that have been developed to understand the rheological properties of foam subjected to external stress [19] may therefore be helpful to understand the rheological properties of froth, but the investigation on froth is more challenging because of the presence of particles interacting with both liquid and gas phases.

In this study, to understand the effect of froth on the dewatering of coals, the dewatering of coal froth and coal slurry under the same condition was investigated. Oscillatory rheology was then employed to investigate the interaction between particles in coal froth and in coal slurry. The measured storage G' and loss G'' moduli were employed to explain the froth properties and the difference of dewatering efficiencies between coal froth and coal slurry. In addition, Scanning Electron Microscopy (SEM) was applied to directly characterize the particle interaction in the froth structure.

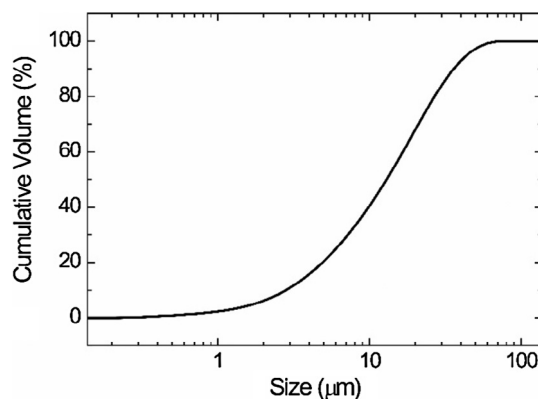


Fig. 1. The size distribution of coal particles used in this study.

2. Materials and methods

2.1. Raw materials

A coal sample was obtained from Bulli Mine, New South Wales, Australia. It was crushed by a cone crusher. The combustible matter content in the raw coal was 89.5%. The water used in the test was tap water with the conductivity of 493 $\mu\text{S}/\text{m}$. MIBC (Methyl Isobutyl Carbinol) and diesel of industry grade were used as frother and collector in coal flotation, respectively.

The crushed sample was ground in a laboratory stainless steel rod mill, and then sieved to obtain the $-38\ \mu\text{m}$ size fraction. To minimise the effect of ash, this sample was purified by flotation in the absence of collector and frother. 300 g coal of $-38\ \mu\text{m}$ was dispersed in tap water in a 3.0 L flotation cell at an agitation speed of 1000 rpm, and flotation concentrate was collected at an air flow rate of 3.0 L/min every 10 s until no froth was generated. Then the concentrate was filtered and dried at room temperature. The combustible matter content in the purified coal was 96.0%. The size distribution of the purified sample was measured by laser diffraction (Mastersizer 2000, Malvern Instrument Ltd., UK) as shown in Fig. 1. 90% coal particles were smaller than $38\ \mu\text{m}$, and the median particle size was around $20\ \mu\text{m}$. This purified coal sample was used throughout the study.

2.2. Dewatering of coal froth and coal slurry

2.2.1. Settling

Froth used in dewatering was obtained from batch flotation. Flotation was performed in a 1.5 L Batch Flotation Cell with 30.0 g purified coal, 2.0 mL MIBC (1.0% v/v), 0.01 mL diesel and 1.5 L tap water at an agitation speed of 1000 rpm. Coal froth was generated at an air flow rate of 3.0 L/min and collected every 10 s for 1 min. The yield of the flotation was greater than 95%. Settling tests were conducted to evaluate the thickening of coal froth and coal slurry. Coal froth from the flotation was transferred to a 500 mL measuring cylinder to be settled.

The coal slurry was prepared by mixing 28.5 g coal particles with the same amount of tap water that occurred in coal froth, 2 mL MIBC (1.0% v/v) and 0.01 mL diesel to simulate the condition of the coal froth. The coal slurry was also transferred to a 500 mL measuring cylinder with the same solid concentration as the coal froth.

The measuring cylinder was then placed on a flat bench at room temperature. After 4 h, the height of settled particles and froth floating on the top was recorded.

2.2.2. Filtration

Filtration of coal froth and coal slurry was conducted by a vacuum filter at a vacuum of 40 kPa. The vacuum filter was instrumented to record the filtrate weight against time. After filtration, filter cakes were weighted and then dried in an oven at $70\ ^\circ\text{C}$ to enable the moisture

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