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The influence of dust particles on the stability of foam used as dust control in underground coal mines

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ABSTRACT

In China, the presence of significant levels of coal dust suspended in the air is a major health hazard and one of the main causes of disasters in coal production. A new technique was developed to control suspended dust by making use of foam. In this study, the foam structure and foam stability under the influence of dust were investigated. It was found that while foam stability is a key factor in the effectiveness of dust control, dust particles also affect foam stability. In this research, foam was classified to dry or wet foam based on its mass fraction. In this regard, it was observed that dry foam is more stable because of its polyhedral structure. Moreover, a series of experiments were applied to determine the relationship between dust particles in foams with different foaming multiples and foam drainage. The results show that dry foam with dust particles has a lower drainage rate, and it is more stable than foam without dust particles. Such improved foam stability could potentially extend the application of foam technology to dust control in underground coal mines in future.

1. Introduction

Dust is one of the primary air contaminants in underground coal mines. It is also the principal cause of coal mine accidents (Wang, 2007; Fred, 2003). Miners exposed to long-term inhalation of fine coal particles are threatened with serious health problems such as pneumoconiosis. According to the statistics released by the Ministry of Health in China, more than 300,000 coal miners suffered from pneumoconiosis by the end of 2007, accounting for 50% of the total number of pneumoconiosis patients in China. Every year, more than 10,000 people who work in major state-owned coal mines are added to the list of pneumoconiosis patients, and on an average, 2500 Chinese miners die from this disease. To control coal dust, different kinds of technologies have been applied, such as water infusion, ventilation, water spraying, wetting agent spraying, and dust collection using fans (Shi et al., 2005; Wang et al., 1999, 2011; Xie et al., 2007; Bian et al., 2010; Jin, 1993; Wang and Zhang, 1990). Although these technologies play an important role in reducing dust concentration, they have certain limitations too. For instance, inject water into a coal seam requires complicated equipment and large amounts of water that deteriorates underground working environments. Water spray nozzles gets easily clogged, thereby reducing the dust precipitation ratio. Dust collecting fans, which have complex structures, require substantial wind power, making it unsuitable for use in narrow underground working areas. To overcome these limitations of dust removal technologies, the authors developed a foam technology and equipment, which have demonstrated a remarkable effect on coal dust control (Ren, 2009; Ren et al., 2012; Qing et al., 2008).

The foam used for dust control is composed of air, water, and a foaming agent. Foam by itself is an unstable system that only exist for

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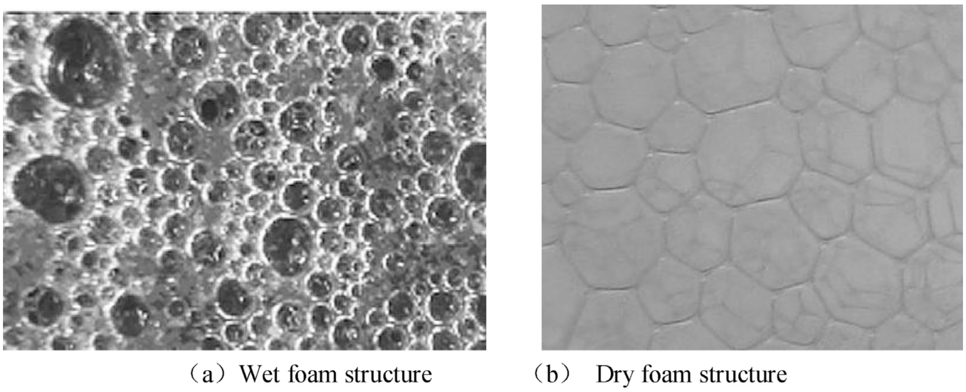

Fig. 1 – Two types of foam structures.

a specific length of time before it begins to break. During the process of dust control, dust particles that adhere to the foam positively influence the stability of the foam. Effectiveness of the technique is defined by the following critical factors: foaming multiple, foam stability, dust wettability, and particle size. Among these, particle size is one that is closely linked with the other factors and is crucial to the efficiency of dust suppression because it directly affects foam stability.

Many researchers all over the world have investigated foam stability. Qicheng Sun from the Institute of Process Engineering Chinese Academy of Sciences researched on the structure and stability of liquid foams (Sun and Huang, 2006). Ashok Bhakta and Eli Ruckenstein, who belong to the Department of Chemical Engineering of the State University of New York at Buffalo, had studied the decay of foam, and they proposed models for the drainage, coalescence, and collapse of foams with time (Bhakta and Ruckenstein, 1997). V. I. Kovalchuk and A. V. Makievski had investigated the film tension and dilational film rheology of a single foam bubble (Kovalchuk et al., 2005). P. Grassia and S. J. Neethling had studied the law on growth, drainage, and bursting of foams (Grassia et al., 2006). H. A. Stone and S. A. Koehler examined the perspectives on foam drainage and the influence of interfacial rheology (Stone et al., 2003). Professor Dippenaar found that particles could promote the merging of bubbles (Dippenaar, 1982). Ma B. Q pointed out that the height and half-life of a three-phase foam increased with concentration increasing of solid powder, and then decreased after the concentration reaching the maximum (Ma and Sun, 1992). B.P. Binks contrasted the differences of solid particles as foam stabilizers with traditional surfactants (Aveyard et al., 1994; Binks, 2002; Xu et al., 2005; Binks and Dong, 1998) and A. Britana examined the effects of fly ash with fine particles on the drainage and merger of foam (Britan et al., 2009).

Evidently, several studies have already been performed by various researchers. Nevertheless, the influence of solid dust particles on foam drainage, and foam stability has not been investigated in detail until recently through this study. This study on the influence of dust particles on foam stability provides a theoretical basis for the clearer understanding of foam stability and dust wettability.

2. Experimental

2.1. Foam structure

The foam used in this study for dust control is a system with gas dispersed in liquid as a continuous phase. When different volumes of gas are dispersed in equal volumes of liquid that leads to the different foaming multiples. While as the foam volume is the sum of the gas and liquid volumes, the volume of liquid per unit volume of foam also varies with the variation of gas volumes. Thus, for convenience, the concept of mass fraction was introduced in this investigation. The mass fraction of foam refers to the ratio of the volume of gas to the

Fig. 2 – Dry foam spatial structure.

total volume of foam at a specific temperature and pressure. It is expressed as follows:

$$\varphi = \frac{V_g}{V_g + V_l}. \tag{1}$$

Furthermore, by its definition, the foaming multiple n is

$$n = \frac{V_g + V_l}{V_l}. \tag{2}$$

Combining (1) and (2) yields the following relationship:

$$\varphi + \frac{1}{n} = 1$$

Transposing $(1/n)$ gives

$$\varphi = 1 - \frac{1}{n}, \tag{3}$$

where V_g is the volume of gas (m^3), V_l is the volume of liquid (m^3), and n is the foaming multiple of foam.

According to their mass fraction values, foams in this research were classified into two types: dry foam and wet foam. Through a series of laboratory experiments, the limiting value of the foaming multiple for the two types of foams was determined to be 2.17. Moreover, based on (3), the limiting value of mass fraction for the two types of foams is 54%. When $\varphi \leq 54\%$, the dispersed gas is in the form of spherical bubbles that are not in contact with each other, and thus, are unable to form an organic entity. The resulting foam is quite