Contents lists available at ScienceDirect

Process Safety and Environmental Protection

journal homepage: www.elsevier.com/locate/psep

Characteristics of thermoplastic powder in an aqueous foam carrier for inhibiting spontaneous coal combustion

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ARTICLE INFO

Article history:
Received 12 April 2016
Received in revised form 12 September 2016
Accepted 13 September 2016
Available online 21 September 2016

Keywords:
Aqueous foam
Coal powder
Self-heating of coal
Flame retardant
Thermoplastic powder

ABSTRACT

For retarding self-heating of coal, a technique is described by applying a blend of thermoplastic and coal powder (TCP) in a foam carrier. The experimental study includes the behavior, microstructure and evolution of the foam, and the properties of the thermoplastic powder (TP) for inhibiting the spontaneous combustion of coal. It was found that increased TCP concentrations led to decreased foamability, with the detrimental effect on foamability levelling of at concentrations above 30 wt.%. The low fusing temperature and high heat of fusion of the TP absorbed the heat generated by the self-heating coal at low temperatures. The liquid fused TP sealed gaps and cracks in the coal dust from oxygen entry. Infrared spectra showed that the TP suppressed alkyl and hydroxyl functional groups in the coal powder (CP) at higher temperatures. It was concluded that TP retarded self-heating in coal, and that the combined thermoplastic and coal powder in a foam carrier has the potential to prevent and control the spontaneous combustion of coal.

1. Introduction

In China, annual uncontrolled spontaneous coal combustion has resulted in a loss of up to 10–20 million tonnes of coal in recent years, equivalent to a loss of $US125–250 million per year. It is well known that the main cause of self-heating and/or spontaneous combustion of coal is the interaction between coal and oxygen at low temperatures. It not only causes economic losses, but heating also adversely affects the calorific value of coal and releases toxic gases (Garcia et al., 1999; Jones and Townend, 1949). Therefore, it is highly desirable that self-heating and spontaneous combustion of coal is inhibited.

The fire prevention or fire-fighting materials that have industrial applications in underground coal mines (e.g., three-phase foam (Wang et al., 2006; Zhou et al., 2006; Qin et al., 2014), inert gases (Adamus, 2001; Zhou et al., 2015; Mohalik et al., 2005; Mohalik et al., 2009; Ray and Singh, 2007), slurries (Kim and Kociban, 1994; Wei et al., 2004), gels (Xu et al., 2000; Wang, 2006; Deng et al., 2014) etc.) are effective for goaf heating and fires, but are rarely used in coal storage and transportation, mainly because they contain non-flammable media which, once injected into the coal, may affect its quality and render the treated coal unacceptable to the end user. Inert gas injection cuts off the O_2 supply to the coal but this treatment is difficult to implement because stored or transported coal piles are relatively open.

Many studies have been conducted on the prevention of self-heating and spontaneous combustion of coal. In 1988, Smith et al. (1988) studied 10 kinds of additive (directly added to coal in powder form and as aqueous solutions) in detail and found that $NaNO_3$, NaCl and $CaCO_3$ were the most effective. Sujanti and Zhang (1999) studied in detail 11 kinds of additive, finding that NaAc had the most obvious effect in inhibiting self-heating and spontaneous combustion of coal. In 2011, a study by Taraba et al. (2011) of 14 additives found that urea had the most obvious effect in inhibiting self-heating and spontaneous combustion of coal. Zhan et al. (2011) found that Na_3PO_4 improved the thermal stability of coal and also effectively reduced the generation of free radicals; unfortunately, Na_3PO_4 was effective only above about 265 °C. Wang et al.'s (2012) study of the effect of six kinds of ionic solution concluded that [Bmim] [AC] and [Bmim] [OTf] solutions had the best effect in reducing the oxidation rate of bituminous coal. Wang et al. (2014) and Dou et al. (2014) found that catechin and polyethylene glycol were the most effective inhibitors. Inorganic inhibitors retard coal oxi-

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http://dx.doi.org/10.1016/j.psep.2016.09.012

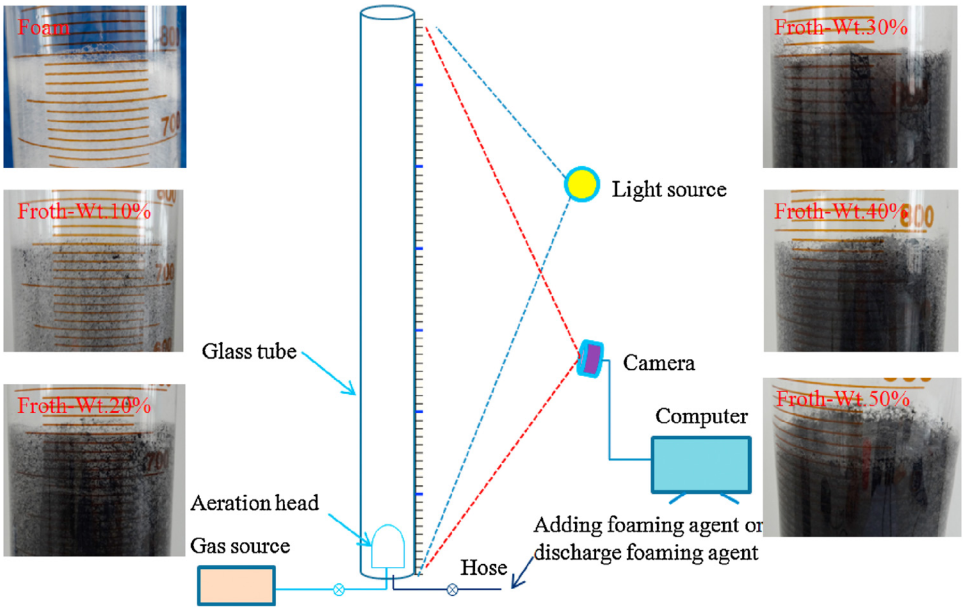

Fig. 1 – Foam analysis system.
Note: **① Foaming agent is added into the glass tube through the hose; ② Foams are generated by blowing gas which is supplied to the aeration head through gas source (Aeration head of 30 μm aperture); ③ Camera records the entire course of the experiment and the data are fed into the computer; ④ The images of wt.0%, wt.10%, wt.20%, wt.30%, wt.40% and wt.50% TCP during the experiment are shown.**

dation simply by creating a barrier to oxygen and by the adsorption of water (Wang et al., 2014). Organic inhibitors retard coal oxidation either by reducing the rate of formation of reactive species or by inhibiting the free radical reactions associated with combustion (Shi et al., 2005; Wang et al., 2003). However, inorganic compounds have poor efficiency and short active lifetimes, and organic compounds are slightly toxic and non-biodegradable, and create other pollution issues (Wang et al., 2014; Dou et al., 2014).

Taking these previous results into account, this paper describes an efficient approach to inhibit self-heating of coal using thermoplastic and coal powder (TCP) carried by an aqueous foam.

2. Properties of thermoplastic powder (TP) and coal powder (CP) in aqueous foam

The selected TP had the following properties: low fusing temperature, good flowability when fused, no side effects with coal combustion, non-toxic and biodegradable. The foam carrier for the TCP comprised mixtures of TP and CP added into the foam solution and evenly stirred such that the TCP became attached to the bubbles forming the froth. Note the terminology used here: *foam* was the gas–liquid phase, and *froth* was the gas–liquid–solid phase (Pugh, 2005). The low surface tension, large volume, ready flow and upward accumulation of the foam allowed it to deliver the TCP evenly to gaps and cracks in the pile of stored coal.

3. Materials and methods

Three aspects of the foam carrying the TCP are emphasized below: (i) the effect of the TCP on the foamability of the surfactant and the stability of the foam; (ii) analysis of TP morphological changes with temperature; and (iii) the effect of the TP on the functional groups of the coal.

3.1. *Materials*

The TP mainly comprised industrial-grade polycaprolactone with a particle size less than 100 mesh (0.15 mm); the coal

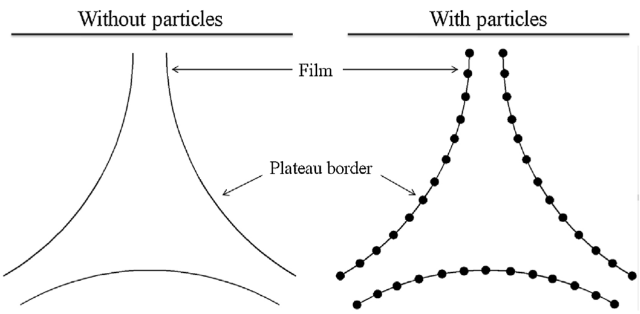

Fig. 2 – Plateau border.

sample, also with a particle size less than 100 mesh (0.15 mm), was collected from Nanjing Wharf, Tianjin Port, China. The CP:TP (TCP) ratio was 1. The foaming agent consisted mainly of sodium dodecyl sulfate, polyethenoxy ether dodecyl sodium sulfate and water glass (SPG, surfactant). The aqueous foaming solution (AFS) comprised 5 wt.% SPG and 95 wt.% water (Xi et al., 2015). Slurry foaming solutions (SFS) with TCP/AFS ratios 1:9, 1:4, 3:7, 2:3 and 1:1 were prepared from approximately 10, 20, 30, 40 and 50 wt.% TCP concentrations, respectively.

3.2. *Methods*

The surface tensions of the AFS and SFS were measured using a BCZ-800 surface and interface tension meter. The foam/froth parameters—foamability, half-life (the time taken for half of the original amount of liquid to drain from the foam) and liquid drainage—were analyzed using the purpose-built foam analysis system shown in Fig. 1. The interface morphology of the foam/froth surface Plateau border (i.e., the junction of the interconnecting channels, similar to triangular-shaped liquid, inside the foam body formed at the junction of the bubble gap, as shown in Fig. 2) was observed using an XP-550C polarizing optical microscope. Differential scanning calorimetry (DSC) analysis of the TP was performed using a Netzsch