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Selective agglomeration of fine coal using a water-in-oil emulsion

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ABSTRACT

Fine coal may be separated from an aqueous suspension of coal and mineral particles through the application of a pure oil. The pure oil preferentially wets and agglomerates only the coal, forming a high quality, granular product. However, the use of the pure oil also comes at a relatively high cost and this cost prohibits commercial implementation of this process. In this work a new, economic binder, was introduced. This binder consisted of a high internal phase water-in-oil emulsion which was 95 vol% water and 5 vol% organic. This type of binder was selected as it possessed the hydrophobic surface functionality of oil while the space filling functionality of the binder was primarily satisfied by the dispersed water droplets within the emulsion. The application of this emulsion in the agglomeration process led to a 10-fold reduction in the organic liquid dosage required to achieve agglomeration as compared a pure oil binder. It was also observed that the agglomeration time required when using the emulsion binder was one order of magnitude less than required when using a pure oil binder. This variation was considered to result from the five orders of magnitude difference in the viscosity of the two binders.

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1. Introduction

Coal must be processed to separate it from the clays and other minerals with which it is mined. These minerals must be removed as they lower the quality, or grade, of the coal products. Coarse particles, $>200\ \mu\text{m}$, can be processed using water-based gravity separation techniques which rely on the large density disparity of the materials to be separated (Galvin and Iveson, 2013; Honaker et al., 2013). Fine particles, on the other hand, cannot be effectively processed using these techniques (Honaker et al., 2013). That is, a separation cannot be achieved on a reasonable time scale due to the small size of the particles and the resulting limited effect of gravity. Therefore, other techniques which discriminate between the different particle types based on their surface chemistry are employed. The most prominent of these techniques is flotation. In flotation a separation is achieved by contacting the aqueous slurry of fine particles with fine air bubbles. The

hydrophobic coal particles attach to the bubbles and rise to the surface for collection whereas the hydrophilic mineral particles remain finely dispersed in suspension. Flotation has been applied with great success; however difficulties can be encountered when the coal to be processed contains a large amount of ultra-fine material or there is a substantial level of clays (Mehrotra et al., 1983; Miettinen et al., 2010). In a commercial setting, these difficult fine coal feeds are generally classified as waste as their processing is not economically viable. Therefore, a fine coal processing technique is required that is both effective on all fine coal feeds and economically viable.

Selective agglomeration is a technique which has received considerable attention in the past as having the potential to solve the aforementioned problems in fine coal processing (Brisse and McMorris, 1959; Mehrotra et al., 1983; Shrauti and Arnold, 1994; Swanson et al., 1977). As similar to flotation, the separation method applied in selective agglomeration is

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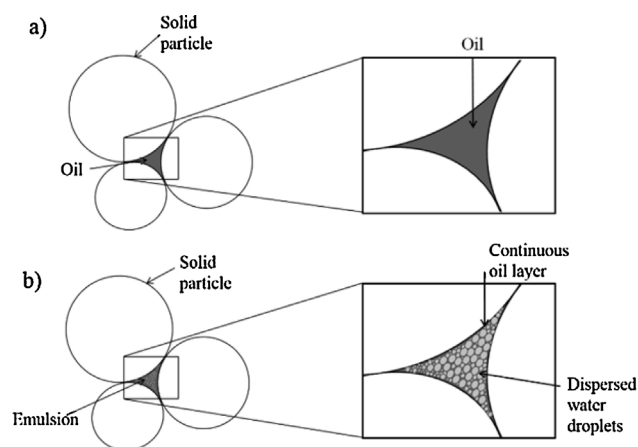


Fig. 1 – Three particles agglomerated using (a) pure oil and (b) a high internal phase water-in-oil emulsion.

based on the differing surface chemistry of the materials. However, instead of air bubbles, a hydrophobic liquid binder is used to achieve the separation. Under the application of agitation this binder, usually pure oil, preferentially wets and agglomerates only the hydrophobic coal particles (Steedman and Krishnan, 1987). These product agglomerates can then be separated from the still finely dispersed hydrophilic clay particles using a screen separation (Steedman and Krishnan, 1987). Almost complete recovery of the carbonaceous material can be achieved using this method and the product is usually of high quality, i.e. has a low mineral matter content (Aktas, 2002; Swanson et al., 1977). There is also no lower limit on the size of particle that can be processed and the separation is not hindered by the presence of clays (Capes and Germain, 1982; Mehrotra et al., 1983). It was for these reasons that a considerable effort was made to develop a commercial fine coal agglomeration process. However these attempts were unsuccessful due to unfavourable economics (Bensley et al., 1977; Capes and Darcovich, 1984; Shrauti and Arnold, 1994).

The main factor which influences the economic viability of a fine coal agglomeration process is the cost of the pure oil binder. For a successful agglomeration process a dosage of 10–20 wt% is required (Garcia et al., 1995; Mehrotra et al., 1983; Swanson et al., 1977). The exact dosage is, of course, dependent upon the characteristics of the coal feed but in any case there must be sufficient binder volume available to fill the void spaces within the agglomerates and, to a certain extent, provide surface coverage of the hydrophobic particles. This saturated state, known as the capillary state, must be achieved as it results in a maximum in agglomerate strength and sphericity (Capes and Germain, 1982). At dosages below 10–20 wt% the structural integrity of the agglomerates is low and as such they become difficult to recover using a screen or other gravity separation technique. However, many authors have noted that for fine coal agglomeration to be a commercial success, the level, and thus cost, of the oil must be significantly reduced (Darcovich et al., 1988; Mehrotra et al., 1983; Shrauti and Arnold, 1994). Therefore, a new binder was investigated in this work in an attempt to reduce the amount of oil required and develop an economically viable agglomeration process.

The binder used in this work was a high internal phase water-in-oil emulsion. A high internal phase (HIP) emulsion is an emulsion in which the volume fraction of the dispersed phase is greater than 0.74; the maximum theoretical packing fraction of close packed spheres (Cameron, 2005). Fig. 1 presents a comparison between the proposed emulsion binder

and a traditional pure oil binder and illustrates the potential of the emulsion to reduce the amount, and thus cost, of the oil required in the process.

Fig. 1 shows two groups of three particles agglomerated using a liquid binder. In Fig. 1a, the binder used is a pure oil, such as diesel, and in Fig. 1b the binder used is the emulsion. It can be seen in the figure that both binders have the capability to selectively agglomerate hydrophobic coal particles. That is, the oil is inherently hydrophobic and the emulsion is hydrophobic as oil forms the continuous phase. Also, both binders can fill the void space within the agglomerate, thus satisfying the requirement for the creation of strong and discrete agglomerates. Now, when an oil binder is used, as in Fig. 1a, the oil can be seen to completely fill the void space. However when the emulsion is used, as in Fig. 1b, the void space is filled only to a small extent by the oil as the dispersed water droplets occupy the majority of the space. Indeed, it is this space-filling functionality of the water droplets which creates the potential to greatly reduce the amount of oil required to form agglomerates.

Initially it was considered that the reduction in the oil requirement could be quantified if the composition of the emulsion was known. For example, it was thought that if an emulsion with a dispersed phase volume fraction of 0.90 was used, a 10-fold reduction would be achieved as only one-tenth of the void space would be occupied by oil. However, this calculation assumed that the emulsion agglomerated fine particles in the exact same manner as pure oil and previous work has indicated that this is not the case (van Netten et al., 2014, 2015). The emulsion appeared to act markedly different to a pure oil and its application added new dimensions to the process of agglomeration. For example, it was observed that the emulsion could agglomerate coal much faster than pure diesel (van Netten et al., 2015). Also, the stability of the highly concentrated emulsion was shown to be an issue in the turbulent, aqueous environment of the agglomeration process. That is, it appeared as though the emulsion was breaking down or degrading during the agglomeration process. Emulsion degradation is highly undesirable as it negates the benefits gained through the creation of the emulsion structure and, therefore, diminishes the potential of the emulsion to reduce the oil requirement.

In previous work, the effects of the aqueous phase composition, the emulsifier type and the aqueous phase volume fractions on the performance of the emulsion as a binder were investigated (van Netten et al., 2014). The performance of the emulsion refers to the reduction in the organic liquid dosage required to achieve agglomeration as compared to a pure oil binder for the same feed. Initially only a 3-fold reduction in the organic liquid dosage was achieved through the application of the emulsion (van Netten et al., 2014). However, it was found that the presence of salt within the dispersed aqueous phase improved the performance, i.e. led to a further reduction in the organic liquid dosage. It was considered that this result was achieved because the presence of the salt improved the stability of the emulsion such that it degraded to a lesser extent. It was also found that the emulsions with the higher dispersed volume fractions had the best performance, i.e. achieved the greatest reductions in the organic liquid dosage (van Netten et al., 2014). This result was important as it qualitatively confirmed that the reduction in the organic liquid dosage related to the extent that water replaced oil within the void space of the agglomerate. Finally, emulsions made with sorbitan mono-oleate (SMO) as the emulsifier performed better than

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