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Suppression of airborne particulates in iron ore processing facilities

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ABSTRACT

Taconite (iron ore) pellets abrade during handling, forming large quantities of fine particulate matter that are easily carried by the air as dust. This dust must be controlled in order to meet air quality standards for particles finer than 10 µm (PM_{10}). It has been assumed that the most effective method for suppressing dust is to spray the pellets with surfactant solutions that maximize the wetting ability of the fine particulates. However, surfactants that provide the most rapid wetting of iron ore have not proven to be highly effective taconite dust suppressants. In order to determine what factors were actually important in controlling taconite dust, a novel dust tower apparatus was used. In these studies, improving the suppressants ability to engulf fine particles did not result in PM_{10} reductions. Furthermore, surface area coverage did not appear to be a significant factor in iron ore dust suppression. Using a hygroscopic reagent which retained moisture (and actually made the iron ore wet more slowly) reduced PM_{10} by as much as 85%.

1. Introduction

The inadvertent generation of airborne particulate matter (PM) at iron ore processing plants can be a significant problem. During handling and transportation, the taconite pellets produced at the plants are subjected to abrasion which results in the generation of large quantities of fine material (Petavratzi et al., 2005). These fine particles can easily become airborne, particularly particles finer than 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$), (Copeland and Kawatra, 2005). PM_{10} and $PM_{2.5}$ are fine enough to be inhaled and cause health effects (NIH, 2005), and their levels are therefore regulated (EPA, 2006). To meet regulations for airborne particulate matter at iron ore facilities, dust emissions must be prevented. It is frequently impractical to lower dust sufficiently by redesigning processes to be less dusty or by using mechanical dust collectors, and so effective dust suppressant chemicals are needed (Smandych et al., 1998).

Previous dust suppression studies have focused on materials like coal (Mohal and Chander, 1986; Chander et al., 1987; Kilau, 1993; Kim and Tien, 1993, 1994). Coal is difficult to wet when plain water is used as the dust suppressant, and these studies recommended that surfactants be used as coal dust suppressants since they improve the wetting behavior of the material. It was therefore believed that iron ore particulate matter control could also be improved by using wetting reagents. Previous studies, however, have indicated this is not necessarily true for iron ore, with surfactant suppressants being not more effective for particulate control than plain water (Copeland and Kawatra, 2005). Previous studies also showed that hygroscopic reagents were effective in suppressing iron ore dust. However, it was not clear if and how wetting ability factored in to effective dust suppression.

Various methods for evaluating the wetting ability of a material have been used to characterize suppressant effectiveness. These methods include contact angle measurements, fine particle engulfment rates, and suppressant penetration into particle beds (or soakability). It has been assumed that the important factors in dust suppression with water sprays are: (1) low contact angle, (2) rapid particle engulfment, and (3) effective suppressant penetration (Wu et al., 2007). But, it has not been previously established if these wetting factors were key in suppressing dust. Furthermore, it has not been established whether it is more important to have a low contact angle, rapid particle engulfment, or easy suppressant penetration into a bed of particles. Still other factors such as suppressant longevity (Copeland and Kawatra, 2005) and effective surface area coverage have been suggested as being important. Therefore, there was a tremendous need to conduct controlled studies on iron ore to establish how the contact angle, particle engulfment, suppressant penetration (or soakability), and surface area coverage influenced iron ore dust suppression. Some work has been done previously using a wind-tunnel apparatus to measure dust lift-off from surfaces, but this did not simulate the effects of actually handling the material (Smitham and Nicol, 1991).

For a suppressant to be effective in reducing airborne particulate matter, it must weigh the particles down to prevent them from becoming airborne. This can be achieved in two ways. First, the suppressant itself coats the individual particles that it wets, increasing their weight. This increased weight means they will be less likely to

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become airborne. Secondly, individual particles agglomerate together through capillary adhesion forces. The agglomerates retain the fine particulates, which prevent them from becoming airborne.

This particular aspect has been explored in literature for coal dust studies (Kilau, 1993). It was argued that wetting reagents, which improved particle engulfment, were successful in producing agglomerates. However, since the wetting reagents reduced surface tension, these agglomerates were weak meaning they could break down easily. This could potentially release the airborne particulates. Eq. (1) below shows how the interparticle adhesion force depends on the surface tension of the suppressant. As the surface tension decreases, the adhesion force decreases proportionally (Zimon, 1969).

$$F_k = 2\pi R\gamma_{lv}\cos\theta \quad (1)$$

where

F_k	capillary adhesion force
R	particle radius
γ_{lv}	suppressant surface tension
θ	contact angle

The purpose of this work was to conduct systematic studies to characterize both the wetting characteristics, particle adhesion forces, and dust suppressant behavior as they related to dust suppression. To achieve this, a novel dust tower apparatus was used which allowed the investigators to characterize a dust suppressants' ability to reduce airborne dust. Utilizing this novel method, the authors were able to identify which wetting characteristics and dust suppressant properties were critical in achieving effective dust control.

2. Materials and methods

2.1. Materials

Iron ore taconite pellets were obtained from a processing facility located in the Midwest United States, identified as "Plant D". The sample, received in a 208 liter (55 gal) drum, was split into twelve 19 liter (5 gal) buckets each weighing approximately 23 kg (50 lb), using coning and splitting techniques. The 23 kg split samples were oven dried (100 °C, 24 h) and divided for experiments using a 12-segment rotary sample splitter. The rotary split portion was hand screened at 3 mesh (Tyler series, 6.70 mm openings) to remove pre-existing loose fines and chips. This was done to allow the fines:pellet ratio to be controlled by adding back measured quantities of fines for dust experiments. Chemical analysis of Plant D pellets revealed they were 67% hematite (Fe_2O_3), 10% magnetite (Fe_3O_4), with the balance being comprised of silica and other gangue minerals.

Iron ore tumble test fines were received from two processing facilities in the Midwest United States (Plant A and Plant D). Each sample (11 liter container) was screened at 28 mesh (Tyler series, 0.6 mm openings) to remove the broken chips. The −28 mesh portion was split using a 12-segment rotary sample splitter. Each sample was analyzed using a MicroTrac instrument to determine the size distribution of the material. The size distribution of Plant A tumble test fines was $P_{90} = 39$ µm, $P_{80} = 29$ µm, $P_{10} = 3$ µm. The size distribution of Plant D tumble test fines was $P_{90} = 40$ µm, $P_{80} = 27$ µm, $P_{10} = 3$ µm. Chemical analysis of Plant A tumble test fines revealed it was 81% hematite (Fe_2O_3) and 11% magnetite (Fe_3O_4), with the balance being silica and other gangue minerals. Plant D tumble test fines were 84% hematite (Fe_2O_3), 1% magnetite (Fe_3O_4), with the balance being silica and other gangue minerals. Three surfactants (acetylenic glycol, alkyl ester, and polypropylene glycol methyl ether) and three hygroscopic reagents (calcium chloride, magnesium chloride, and sodium metasilicate) were used in this study.

2.2. Contact angle analysis

Contact angle analysis is a popular and simple method for evaluating the wetting behavior of a material. This method is outlined in Fig. 1. A low contact angle means the suppressant effectively wets the material making it able to significantly reduce airborne dust. Previous studies have shown that iron ore in water exhibits contact angles less than 25° (Copeland and Kawatra, 2005). These studies reported here were conducted to establish whether various dust suppressants could reduce the contact angle further. Each data point is an average of 4 individual samples, with contact angle (θ) measured 12 times per sample with error bars $= \pm 1\sigma$ (standard deviation of the mean).

2.3. Walker Sink test

It has been argued that effectiveness of dust control is maximized when the suppressant engulfs the particles very rapidly. This means that in the Walker Sink test, the material should sink very rapidly. Previous studies have examined materials like coal (Chander et al., 1987; Kilau, 1993; Kim and Tien, 1994), copper sulfides (Cristovici, 1991) and iron ore (Copeland and Kawatra, 2005). Studies here were conducted using acetylenic glycol, alkyl esters, and polypropylene glycol methyl ether (PPGME) surfactants; and calcium chloride, magnesium chloride hygroscopic agents to study their effects on iron ore particle engulfment. For these experiments, a Thermo Electron Cahn C35 Ultra-Microbalance which was accurate within 0.1 µg was used. Walker Sink measurements were accompanied by surface tension measurements utilizing the DuNouy Ring Method to examine how the wetting time and surface tension curves correlated.

The Walker Sink test apparatus is outlined in Fig. 1. In this experiment, 40 mg of fine particles was dropped onto the surface of the suppressant contained in a Petri dish. The amount of time required for the particles to wet on the surface, and subsequently settle onto the balance pan was the wetting time. A low wetting time meant that the particles settled onto the pan rapidly (low wetting time means a rapid wetting rate). Each data point is an average of 4 measurements with error bars $= \pm 1\sigma$ (standard deviation of the mean). Surface tensions determined using DuNouy Ring Method. Each surface tension data point composite of 4 measurements with error bars $= \pm 1\sigma$ (standard deviation of the mean).

2.4. Particle bed soak test

The last set of wetting experiments involved a soakability test which measured how quickly a liquid droplet soaked into a bed of dry particles. This type of method has been previously used to determine how well a suppressant engulfed fine coal particles for enhanced coal dust control (Kilau, 1993). The particle bed soak test is outlined in Fig. 1. In this test, the liquid drop will soak into easily-wettable materials in a few seconds, while it can take in excess of 30 min to soak into beds of water-repellent materials such as coal. For this experiment, a flat bed of particles was placed into a 25 milliliter Petri Dish. A hemispherical depression with a diameter of 12 mm was created and 200 µl of suppressant was added to the depression. Following the addition of the suppressant, the behavior was observed and the total time required for the droplet to soak into the bed of particles was recorded.

2.5. Dust tower studies

To examine how effective various reagents were in reducing respirable dust from iron ore, a novel dust tower was used. A diagram of this unique apparatus is given in Fig. 2. This tower is unique in that it simulates material handling while allowing for direct PM_{10} measurements. Previous studies using this apparatus indicated that