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Examination of water spray airborne coal dust capture with three wetting agents

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Abstract

Water spray applications are one of the principal means of controlling airborne respirable dust in coal mines. Since many coals are hydrophobic and not easily wetted by water, wetting agents can be added to the spray water in an effort to improve coal wetting and assist with dust capture. In order to study wetting agent effects on coal dust capture, laboratory experiments were conducted with three wetting agents used by the coal industry on -325 mesh sized Pocahontas No. 3 coal dust. Significant differences in coal dust sink times were observed among the three wetting agents at water mixture concentrations of 0.05%, 0.1% and 0.2%. The best wetting agent as identified by the coal dust sink test was only tested at the lowest 0.05% water mixture concentration and was found to have a negligible effect on spray airborne dust capture. Water spray airborne dust capture results for all three wetting agents tested at a 0.2% water mixture concentration showed that all three wetting agents exhibit similar but small improvements in dust capture efficiency as compared with water. These results indicate that the coal dust sink test may not be a good predictor for the capture of airborne dust. Additional research is needed to examine if the coal dust sink test is a better predictor of wetting agent dust suppression effects during cutting, loading, conveying and dumping of coal products by comparison to airborne dust capture from sprays.

Keywords

Coal; Coal mining; Dust control; Respirable dust; Health and safety; Air quality

Introduction

Advancement of engineering controls such as ventilation practices, water spray systems, airborne dust scrubbers/collectors and equipment remote control have all contributed to reducing worker airborne respirable dust exposure at underground coal mining operations. The most effective of these engineering controls have been recommended for mitigating respirable coal mine dust concentrations below the federally mandated 2.0 mg/m^3 eight-hr shift standard (Kissell, 2003; Colinet et al., 2010). Water sprays provide several dust control roles, including airborne dust capture and coal product wetting. Dust suppression from uniform coal wetting near the cutting machine drum is considered to be a more effective use

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of water sprays compared to airborne dust capture (Kissell, 2003). However, the art of adding wetting agents into the coal mine water spray systems to enhance dust control has not been fully understood, nor fully developed (Kissell, 2003).

Previous wetting agent studies have investigated the wettability of various coal dusts in the laboratory using different wetting agents and bench testing procedures (Kost et al., 1980; Zeller, 1983). This research had shown that there were notable variations in coal seam wettability by water alone and between the various wetting agents tested (Kost et al., 1980). The research also found minor correlations between the different test procedures at predicting the effectiveness of various wetting agents on a particular coal (Zeller, 1983). In particular, water droplet contact angle and zeta potential test procedures were not considered to be very useful as wettability measures, since they were difficult to perform and interpret, respectively (Zeller, 1983). The capillary rise test and the coal dust sink test for finely ground coal dust tended to be the primary methods of wetting agent selection for underground dust control testing (Kost et al., 1980; Zeller, 1983). The capillary rise test measures the percentage of water by weight that penetrates a column of finely ground dust (-42 mesh) over a specified time period and was found to be reproducible. The sink test measures the time it takes for 3 g of finely ground coal dust (-325 mesh) to sink below the surface of 100 mL of wetting agent solutions. Both the capillary rise test and coal dust sink test laboratory results indicated that wetting agent concentrations can have a significant impact on the wettability of many of the coals tested, which wetted moderately or significantly when the wetting agent concentrations were increased from 0.1% to 1%. An underground field study of multiple wetting agents selected by these laboratory tests for an auger mining section in the Lower Kittanning coal seam showed that an average respirable dust reduction of 27% was achieved with wetting agent concentrations of 0.2% to 0.7% (Kost et al., 1980).

Others have conducted laboratory studies to investigate the mechanisms of wetting agents and water spray droplet coal dust capture (Chander et al., 1991; Hu et al., 1992; Polat et al., 1993). In one study, a high speed motion analyzer was used to study the collision of spray droplets and fnely ground dust particles made from the Upper Freeport coal seam. Chander et al. illustrated in this study that hydrophobic coal dust particles attached themselves to the surface of plain water droplets, whereas they penetrated the surface of the spray droplets when several wetting agents were used (1991). Their small-scale airborne dust capture efficiency tests using a full cone air atomizing nozzle with several wetting agents at a 1% mixture concentration showed negligible to slight improvement over plain water. The most significant improvement to spray dust capture efficiency was achieved by generating smaller spray droplet sizes through an air pressure increase to the atomizing nozzle. The authors concluded that the dust concentrations in their experiments were not high enough to take advantage of the dust loading capabilities of filing up the water droplets when wetting agents were added.

Hu et al. examined wetting agent solution concentrations below 1% with respect to surface tension, contact angle, spray droplet charging, dust aging and airborne dust capture, using similar finely ground dust from the Upper Freeport coal seam (1992). They used the same small-scale dust chamber with the full cone air atomizing nozzle as in the above study, but increased dust concentrations and separately measured the spray droplet charge with different wetting agent solution concentrations below 1%. The cationic wetting agent produced more net positively charged water droplets at lower solution concentrations than the nonionic and anionic wetting agents. This net of positively charged water droplets for the cationic wetting agent corresponded to higher airborne dust capture efficiencies of 53% to 59% for a wider range of solution mixtures, compared to the 42% to 52% achieved with the nonionic and anionic wetting agents.

In the Hu et al. study, surface tension and droplet contact angle were not good predictors of dust capture, but their role in the determination of work of adhesion of water droplets (i.e., work done by surface tension to pull a particle into the droplet) did account for the anionic and nonionic wetting agent concentration relationships with dust capture efficiency (Hu et al., 1992). The authors also found an increase in dust capture after the dust was aged for six months and when a 50:50 mix of coal and silica dust was used.

Polat et al. (1993) further examined the effects of spray droplet charging capture efficiency on anthracite, bituminous and subbituminous coal dusts using the same laboratory testing equipment and procedures as Hu et al. (1992; Polat et al., 1993). The authors found that the dust particle charge magnitude increased for higher ranked coals, but noted that there were almost equal numbers of positively and negatively charged particles for the various coal ranks of airborne dust generated. They also concluded that there was no correlation between coal rank and the effects of wetting agent charge on dust capture efficiency.

Wetting agent dust capture efficiency was also studied by using a venturi scrubber in a 10:1 laboratory scale model of a continuous miner face (Kim and Tien, 1993). Kim and Tien concluded that there was no correlation between the coal dust sink tests and contact angle measurements for various wetting agents used on an eastern Kentucky coal seam. They concluded that the coal dust sink test had some correlation with dust capture, so it could be used as an initial screening test for wetting agent selection for dust capture. Their dust capture experiments showed that the venturi scrubber collection efficiency on average increased from 22% with plain water to 27% and 32%, respectively, with wetting agent concentrations of 0.05% and 0.2%. Results for the individual wetting agents tested ranged from negligible dust capture improvement to nearly double the efficiency of plain water. Thus, wetting agent selection for a particular coal seam is important to its effectiveness on dust capture.

Additionally, underground coal mine studies were performed using a combination of wetting agent and polymer mixtures to increase dust capture and dust agglomerate stability at two longwall operations (Kilau, 1993; Kilau et al., 1996). Initial selection of the wetting agent and polymer mixtures for these longwalls was conducted using the drop penetration test. This test consisted of placing a 2.5-μL droplet of wetting agent solution on a planar bed of -200 mesh coal particles and observing through a microscope the time it takes for the droplet to fill up with agglomerated coal particles (Kilau, 1993). Several anionic wetting agents and nonionic polymer solution combinations at solution mixture concentrations between 0.02% to 0.08% notably improved the droplet penetration and agglomeration of dusts from the medium and high volatile coal seams studied. Dust control evaluation of these wetting agent and polymer mixtures tested at one longwall operation typically showed a better than 40% respirable dust reduction, while inconclusive results were obtained from the second longwall operation (Kilau et al., 1996).

Researchers at the National Institute for Occupational Safety and Health (NIOSH) recently tested three wetting agents used by coal mines for increasing water spray dust capture. These wetting agents were screened by the sink test for their ability to wet -325 mesh Pocahontas #3 coal dust in water solution concentrations of 0.05%, 0.1% and 0.2%. Water spray dust capture tests were also conducted with the same Pocahontas #3 coal seam dust in a full-scale spray dust chamber to examine if there is a correlation between the coal dust sink test results and airborne dust capture test results. This report describes the laboratory testing procedures and results obtained with these wetting agents.

Laboratory test procedures

Three wetting agents used by coal mines for dust control were examined in the laboratory to assess their airborne dust capture effectiveness compared to untreated water. Wetting agent A is a homogenous blend of colloids, sequesterants and nonionic surfactants. Wetting agent B is a blend of anionic surfactants and polymers. Wetting agent C is an anionic surfactant. Pulverized Keystone Mineral Black 325BA (Keystone Filler & Manufacturing Co., Muncy, PA), which is -325 mesh (-44 μm) Pocahontas No. 3 coal dust, was used throughout laboratory testing. Figure 1 shows the cumulative size distributions for several samples of this coal dust and indicates that 45% of this dust was less than 10 μm in size. This coal seam was previously found to be one of the most difficult to wet (Kost et al., 1980). Coal dust sink tests were performed with the wetting agents at solution concentrations of 0.05% (1:2000), 0.1% (1:1000) and 0.2% (1:500) by volume in water. It must be noted that this range of solution concentrations are initially recommended for coal mine dust control with further adjustments made to match a particular mine's dust control needs. Airborne dust capture efficiency testing was also conducted in a full-scale closed system dust chamber using a Spraying Systems BD3 hollow cone nozzle, operating at water pressures of 552 kPa (80 psig) and 1,103 kPa (160 psig).

Coal dust sink tests

Sink tests were performed with pulverized Keystone Mineral Black 325BA using municipal public water and the three wetting agents. The tests were performed in similar fashion as described by others (Kost et al., 1980; Zeller, 1983). Five hundred mL of tap water was divided into a 100-mL water sample and four 100-mL wetting agent solution samples after premixing the desired volume of wetting agent into the remaining 400 mL of water. A graduated syringe was used to add the wetting agent into the water to acquire solution mixtures of 0.05%, 0.1% and 0.2% after stirring. All the 100-mL samples were placed in 150-mL beakers for the coal dust sink tests. The water sample and one of the wetting agent solution samples were checked for pH, temperature, conductivity, total dissolved solids, salinity and surface tension as described below. Three grams of Keystone Mineral Black was placed on the surface of the water sample and on the other three wetting agent solution samples with the times recorded for all the dust to sink below the liquid surface. If most of the dust was floating on the liquid surface at 900 seconds, the test for that sample was stopped and the time recorded as greater than 900 seconds. If most of the dust sank by 900 seconds, the test was continued until all of the dust settled below the liquid surface and the time was recorded.

Airborne dust capture tests

Full-scale water spray dust chamber experiments were conducted with water and the three wetting agents. The water spray efficiency testing was conducted in a 2.44-m (8-ft) high by 2.44-m (8-ft) wide by 2.44-m (8-ft) deep closed system dust chamber (unventilated). A water spray was located at the center of the dust chamber and was oriented down towards the floor of the chamber. Dust was injected by an air inductor into the dust chamber until it reached a desired dust concentration. A 1.1-m^3/s (2,300-cu ft per min) mixing fan in the chamber was used to disperse the injected dust throughout the chamber before the test. Airborne dust capture efficiency of the water spray can be determined by the removal rate of a known amount of dust in a known volume of the chamber over the spray application time period. This can be determined by the differential equation shown below (Ruggieri et al., 1983; McCoy et al., 1985):

$$V\frac{dC}{dt}=-C(Q+F) \quad (1)$$

which, when solved, reduces to:

$$F=\eta Q'=\frac{-V}{\Delta t}\ln\left(\frac{C}{C_0}\right)-Q \quad (2)$$

where:

F = dust removal mechanism(s), m^3/s

Q = ventilation dilution or removal, m^3/s

η = dust capture efficiency, %

Q' = spray-induced air quantity, m^3/s

$\eta Q'$ = dust removal rate or cleaned airflow rate, m^3/s

V = fixed volume of closed system, m^3

Δt = spray operating time, s

C = final dust concentration, mg/m^3

C_0 = initial dust concentration, mg/m^3

The dust removal rate ($\eta Q'$) or dust capture efficiency (η) measured during the experiment is the cumulative dust capture of all the mechanisms taking place in the dust chamber. This includes spray capture, as well as other background removal mechanisms of the chamber (settling, impact adhesion, etc.). Generally, all of these background removal mechanisms become a notably smaller portion of the dust capture measurement when water spray testing is conducted at higher dust concentrations in the enclosed dust chamber (Ruggieri et al., 1983; McCoy et al., 1985). Previous experiments in NIOSH's dust chamber showed background dust removal to be about 1% (Organiscak and Pollock, 2007). Therefore, most of the dust removal rate or dust capture efficiency can be attributed to the spray nozzle. The closed system dust chamber testing procedure was used successfully in the past to conduct comparative dust capture rates of various types of uncoined sprays (air-atomizer, hollow cone, full cone, fat fan) and a water-powered scrubber operating in the center of the chamber (Ruggieri et al., 1983; McCoy et al., 1985; Organiscak and Pollock, 2007; Pollock and Organiscak, 2007). It was also used for comparative dust capture testing of a hollow cone spray nozzle on a variety of bituminous coal seam dusts (Organiscak and Leon, 1994).

Dust capture performance was measured by using personal gravimetric dust samplers for a given time period before and after operating a Spraying Systems BD3 hollow cone water spray nozzle, with instantaneous real-time dust sampling conducted during the complete test. Keystone Mineral Black 325BA was injected into the dust chamber to achieve just over 100 mg/m^3 of respirable dust concentration, as measured with an instantaneous real-time dust monitor (RAM-1, MIE, Inc., Bedford, MA). The RAM-1 was operated at 2 L/min with a Dorr-Oliver 10-mm nylon cyclone to measure the respirable size fraction of dust. When the instantaneous respirable dust concentration naturally decayed to 100 mg/m^3, two personal MSA coal mine dust samplers were run for a three-minute time interval to determine the initial average respirable gravimetric dust concentration for calibrating the RAM-1 dust concentration at the beginning of spray application (C_0). The MSA coal mine dust samplers were made up of an Elf personal sampling pump drawing 2 L/min of air through a Dorr-Oliver 10-mm nylon cyclone, which collected the respirable fraction of airborne dust in an MSA coal mine filter cassette. Following the completion of the initial three-minute sampling period, the Spraying Systems BD3 water spray was operated for five minutes at 552 kPa (80 psig) or three minutes at 1,103 kPa (160 psig) to reduce RAM-1 dust concentrations to approximately 30 mg/ m^3. After the water spray application was stopped, another two personal MSA coal mine dust samplers were run for a 15-minute period to determine the final average respirable gravimetric dust concentration for calibrating the RAM-1 dust concentration (C) at the end of the spray application. The dust removal rate ($\eta Q'$) was determined from the equation above by using the chamber volume (V), the spray operating time (Δt), the dust concentration (C_o) at the beginning of the spray operation, the dust concentration (C) at the end of the spray operation and zero for Q in an unventilated chamber.

In order to determine the spray dust capture efficiency (η) for each test, the spray nozzle-induced airflow was previously measured by operating a BD3 spray nozzle along the centerline of a 91.4-cm (3-ft) wide by 91.4-cm (3-ft) high by 122.9-cm (4-ft) long open-ended duct. The spray nozzle was located one foot inside the duct inlet and directed towards the other opening or outlet. A VelociCalc model 8346 hot-wire anemometer (TSI Inc., Shoreview, MN) was used to take air velocity measurements over an equal nine-point area traverse of the duct's cross-sectional area, located 15 cm (6 in.) upstream of the spray nozzle just inside the duct inlet, as previously described by Pollock and Organiscak (2007). The average air velocity/quantity induced through the duct was determined for the BD3 water spray nozzle while operating at 552 kPa (80 psig) and 1,103 kPa (160 psig). These spray airflow quantities (Q') were divided into the dust removal rates ($\eta Q'$) to determine the spray capture efficiencies.

Water and wetting agent mixtures were pumped out of a graduated 115-L (30-gal.) tank through a series of a pumps, pressure regulators and bypass valves. A bypass circuit around the spray dust chamber was used so that the pumps and regulators could be adjusted to the proper operating pressures and the water spray could be quickly activated (within a few seconds) using a two-way redirection valve. Dust capture experiments were conducted using batches of water and wetting agent mixtures sprayed through the BD3 hollow cone spray at 552 kPa (80 psig) and 1,103 kPa (160 psig), randomly selected within the batches tested. At least three replicates were conducted for each wetting agent test condition. A graduated cylinder was used to add the proper amount of wetting agent into the holding tank between tests. The tank was emptied and thoroughly rinsed between the batches of wetting agent solutions tested.

Baseline water testing was initially conducted and was followed up by testing wetting agent A at a 0.05% solution mixture, given its ability to wet the Keystone Mineral Black coal dust during the sink test at that solution mixture. Wetting agents A, B and C were then tested at the 0.2% solution concentrations, respectively, follow by additional baseline testing with water. After the end of each test run, a water/solution sample was collected at the spray nozzle for water parameter measurements as described below.

Water solution parameters measurements

Water and wetting agent solution test samples were measured for pH, temperature, conductivity, total dissolved solids and salinity using an Oakton Multi-Parameter PCS Tester 35 (Oakton Instruments, Vernon Hills, IL). Surface tensions of the solution test samples were also measured with a capillary tube surface tension apparatus (Cole Parmer, Vernon Hills, IL).

Test results

The coal dust sink test results for water and the various wetting agent solution concentrations are shown in Table 1. As can be seen in this table, wetting agent A appeared to noticeably wet the Keystone Mineral Black coal dust better than wetting agents B and C. The Keystone Mineral Back coal dust (Pocahontas # 3 coal seam) was difficult to wet without any wetting agent added because there was no observable amount of dust penetration below the water surface after 900 seconds. All the coal dust sank below the water surface by 897 seconds, 385 seconds and 215 seconds when using wetting agent A at solution concentrations of 0.05%, 0.1% and 0.2%, respectively. On the other hand, only some of the dust penetrated the water surface at 900 seconds for both wetting agents B and C at solution concentrations of 0.05% and 0.1%. Because most of the coal dust penetrated the water surface within the initial 900 seconds for these two wetting agents at the 0.2% solution concentration, these tests were continued until all the dust penetrated the solution surface—up to 1,297 seconds for wetting agent B and up to 1,320 seconds for wetting agent C.

The spray dust capture results and surface tension of the water and wetting agent A at a 0.05% solution mixture are shown in Fig. 2. The BD3 hollow cone spray, operating at 552 kPa (80 psig) and 1,103 kPa (160 psig), induced airflow of 0.62 m^3/s (1,314 cu ft/min) and 0.922 m^3/s (1,953 cu ft/ min), respectively. Average spray dust capture efficiencies with their 95% confidence levels for the replicated tests are shown in Fig. 2. As can be seen from this figure, the airborne dust capture was slightly less when using wetting agent A at a 0.05% solution mixture as compared to water. The surface tension of the municipal water was reduced from 33 dynes/ cm to 27 dynes/cm with the wetting agent A at a 0.05% solution mixture. Therefore, wetting agent A dust capture results obtained at the 0.05% concentration were considered to be negligible compared to plain municipal water.

Spray dust capture results for all the wetting agents tested at the 0.2% concentration compared to water are shown in Fig. 3. Average dust capture efficiencies are shown with their 95% confdence levels for the replicate tests for the BD3 hollow cone spray operated at 552 kPa (80 psig) and 1,103 kPa (160 psig). Discernible spray dust capture efficiency improvements were observed for all wetting agents tested at the 0.2% solution concentration as compared to water. Dust capture efficiency improvements were similar for the three wetting agents tested. Spray dust capture efficiencies at 552 kPa (80 psig) increased from 9.4% with water to 10.5%, 11% and 10.5%, respectively, for wetting agents A, B and C. At 1,103 kPa (160 psig), the spray dust capture efficiencies increased from 11.4% with water to 13.5%, 13.2% and 13.1%, respectively, for wetting agents A, B and C. Although the wetting agent dust capture improvements were small, they all were statistically significant compared to water at the 95% confidence level, as illustrated by their confidence intervals in Fig. 3. Increasing spray operating pressure showed slightly better dust capture efficiency improvement compared to adding a wetting agent. Spray dust capture efficiency increased from 9.4% to 11.4% with water alone by increasing spray pressures from 552 to 1,103 kPa (80 to 160 psig). Wetting agent dust capture efficiencies increased from 10.5% to 13.5% (A), 11% to 13.2% (B) and 10.5% to 13.1% (C) by increasing spray pressures from 552 kPa (80 psig) to 1,103 kPa (160 psig). Surface tension of the water was reduced from around 32 dynes/cm to 25 dynes or less for the three wetting agents at the 0.2% concentration.

Figures 4 and 5 show the other water and wetting agent solution parameters measured during the spray dust capture testing. The pH and conductivity of the water and wetting agent tested indicate that the municipal water had a pH slightly above 8 and was reduced to the lowest pH slightly above 7 by adding 0.20% of wetting agent A. Wetting agent B reduced the pH slightly below 8, while wetting agent C increased the pH to slightly higher than that of water at the wetting agent concentration of 0.20%. Figures 4 and 5 show that the pH, conductivity, total dissolved solids (TDS) and salinity were directly associated with each other.

Discussion

The surface tension of the municipal water used in these experiments ranged from 32 to 33 dynes/cm, instead of about 72 dynes/cm expected for plain water. The wetting agents used in these experiments reduced the surface tension of the water down to 25 to 27 dynes/cm. The initial lower surface tension of the untreated water in this study may call into question whether the dust capture effectiveness of the wetting agents was actually reduced during this study, so some interpretation is in order. The fact that the coal dust floated and did not penetrate the surface of the untreated municipal water during the sink tests indicate that the wetting agents were necessary to get the coal dust to wet and penetrate the water surface. Hu et al. found in their study that surface tension and droplet contact angle with the particular coal tested were, in themselves, not good predictors of airborne dust capture, but their role in the determination of work of adhesion of water droplets (i.e., work done by the surface tension to pull a particle into the droplet) did account for wetting agent concentration relationships with dust capture efficiency (Hu et al., 1992). It was previously shown by Chander et al. that airborne dust capture was more significantly influenced by water droplet size (spray pressure-related) as compared to wetting agents (Chander et al., 1991). Independent spray droplet size measurements made by others showed that the most significant spray droplet size reductions and subsequent droplet velocity increases were primarily attributable to higher operating spray pressures and not surface tension reductions from wetting agents used in sprays operating at or above 414 kPa (60 psig) (Kim and Kim, 1997). Pollock and Organiscak also confirm the increased operating pressure relationship with smaller droplet size, increased droplet velocity, and improved airborne dust capture (Pollock and Organiscak, 2007). Given the findings from these other studies, the lower surface tension of the municipal water would not be expected to considerably change the results or conclusions of these experiments.

Secondly, the airborne dust capture results of this laboratory study only address one particular aspect of adding wetting agents into water spray systems. Another aspect not addressed by this study is the wetting and suppression of the dust in the mined product from becoming airborne during cutting, loading, conveying and dumping of the mined coal product. Inconsistencies observed between the coal dust sink tests and airborne dust capture tests indicate that coal wettability as defined by the test may not be a good predictor of airborne dust capture. The sink tests indicated that wetting agent A was significantly faster in wetting the coal dust as compared to the other two wetting agents while producing comparable airborne dust capture results.

The comparable airborne dust capture between the wetting agents in this study may be more of a consequence of the fact that spray droplet airborne capture occurs over a short time period. The BD3 spray nozzle, located 1.2 m (4 ft) above and directed at the dust chamber floor, has less than two seconds to capture the airborne dust before the induced airflow and water droplets reach the floor. Spray nozzle-induced airfow quantities of 0.62 m^3/s (1,314 cu ft per min) and 0.922 m^3/s (1,953 cu ft per min) at the two water pressures tested translate into air velocities of 0.73 m/s (2.4 ft/s) and 1.1 m/s (3.6 ft/s), respectively. The most effective spray airborne dust capture is when the velocity difference between the spray droplets and the dust particles is at its greatest (Gemci et al., 2003). Previously measured water droplet velocities for a BD3 spray nozzle operating at 552 kPa (80 pisg) and 1,103 kPa (160 psig) indicate that an approximately 20% decrease in water droplet velocities was measured after traveling between 0.3 - 0.6 m (1-2 ft) away from the spray nozzle (Gemci et al., 2003). Therefore, it can be inferred that the most efficient airborne spray droplet capture occurs within a short time period near the nozzle before the spray droplets appreciably slow down, approach the surrounding air velocity and settle out. In these particular experiments, this process occurred within the 1.2-m (4-ft) distance to the dust chamber floor.

Wetting agent suppression effects on PM10 dust were more recently examined in the laboratory by others using a dust tower method on taconite and one subituminous coal mixture (Copeland et al., 2008). The dust tower test apparatus had multiple defection plates inside the tower to provide reproducible material agitation. The coal dust sink test, contact angle and droplet penetration wettability characterization on the taconite and coal materials did not correspond to an improvement of PM10 dust suppression from wetting agents as compared to water, after the taconite and coal mixture were allowed to wet and cure before being dropped down the dust tower test apparatus. Further examination of a spray application or kinetic wetting of the taconite feed into a laboratory cone crusher apparatus, near the point of generation, showed that the PM10 dust generated was approximately cut in half when a wetting agent was added to the water. The authors believed that kinetic wetting increases the wetting rate near the point of generation, improving dust suppression at that source of generation (Copeland et al., 2008).

Previous underground wetting agent field studies included both dust control aspects of airborne spray dust capture and product dust suppression. In all of these field studies, water and wetting agents were applied at the cutting machine through both external sprays and drum sprays, near the point of generation. Underground wetting agent field studies showed respirable dust reductions of 27% at an auger miner section operating in the Lower Kittanning coal seam (Pennsylvania), greater than 40% at multiple locations on a longwall operation in the Blue Creek coal seam (Alabama) and inconclusive results for a longwall operation in the O'Connor seam (Utah) (Kost et al., 1980; Kilau et al., 1993). It was difficult to ascertain from these field studies whether the dust reductions were more a result of improved airborne dust capture or suppression. Before these field studies were conducted, the wetting agent and its target concentration were selected using a repeatable bench test such as capillary rise, sink or droplet penetration to optimize the wettability of pulverized coal dusts made from the specific coal seams. It was challenging to achieve the targeted wetting agent solution mixtures at the underground mining machines due to dynamic water pressure and flow conditions. At the auger mining section, the wetting agent concentrations were tested from 0.2% to 0.7% and measureable dust reductions of 27% were clearly realized. During the longwall studies, the wetting agent and polymer mixtures achieved were typically less than the targeted 0.02% to 0.08% solution mixtures. At the Alabama longwall, dust reductions were typically greater than 40% and were clearly realized at multiple locations along the face. For the inconclusive Utah longwall study, dust levels were reduced on average by about 20% immediately downstream of the shearing machine, while they were inconsistently higher and lower at other face locations. Mining production, wetting agent mixtures and polymer mixtures at the Utah longwall were substantially more variable between test conditions compared to the Alabama longwall study, thus presenting more uncertainty in quantifying dust control improvements. However, it is important to recognize from these underground field studies that water sprays were both externally applied to airborne dust and were applied on the cutting drums near the primary source of dust generation during cutting, where additional effects of kinetic wetting could be realized.

Conclusions

Wettability and water spray dust tests were conducted with three wetting agents used by the coal industry on -325 mesh Pocahontas No. 3 coal dust. Wetting agent A more quickly wet the coal dust in the sink tests as compared to wetting agents BE and C at the various solution concentrations, but all wetting agents provided relatively similar airborne respirable dust capture improvements over water at a 0.2% solution concentration. At 0.2% concentrations, all the wetting agents showed a small incremental increase of 1.1% to 2.1% or a 12% to 18% improvement in spray airborne capture efficiency as compared to water. These small spray dust capture improvements were attributed to the brief time period (several seconds) that the spray droplets have to capture the dust, not exploiting the interior dust holding capacity of the spray droplets. A slightly larger incremental spray dust capture efficiency increase of 2% to 3% or a 20% to 29% improvement was realized by increasing the spray operating pressure from 552 kPa (80 pisg) to 1,103 kPa (160 psig), irrespective of wetting agent use.

The inconsistencies observed between the coal dust sink test results and airborne dust capture test results indicate that coal wettability as defined by the sink test may not be a good predictor of airborne dust capture. Additional research is needed to examine the aspect of wetting agent dust suppression effects on airborne dust generated during cutting, loading, conveying and dumping of the mined coal product. Repeatable dust suppression/agitation testing procedures should be developed and compared with previous wettablility screening test procedures for assisting mine operators with the successful selection of wetting agents and concentration mixtures for their particular coal mine.

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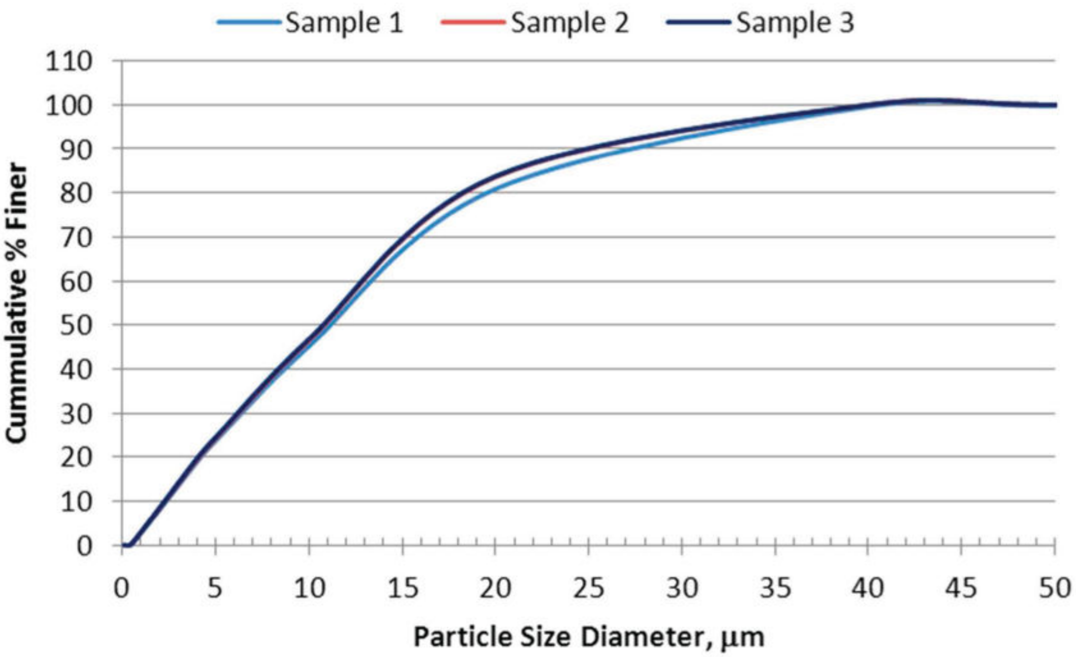

Figure 1.

Cumulative size distribution of Keystone Mineral Black 325BA used for experiments.

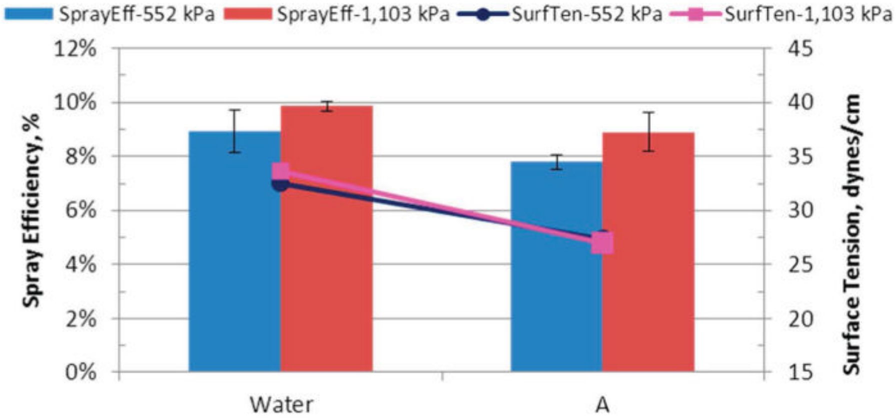

Figure 2.
Initial water spray dust capture results for water and wetting agent A at 0.05% solution concentration.

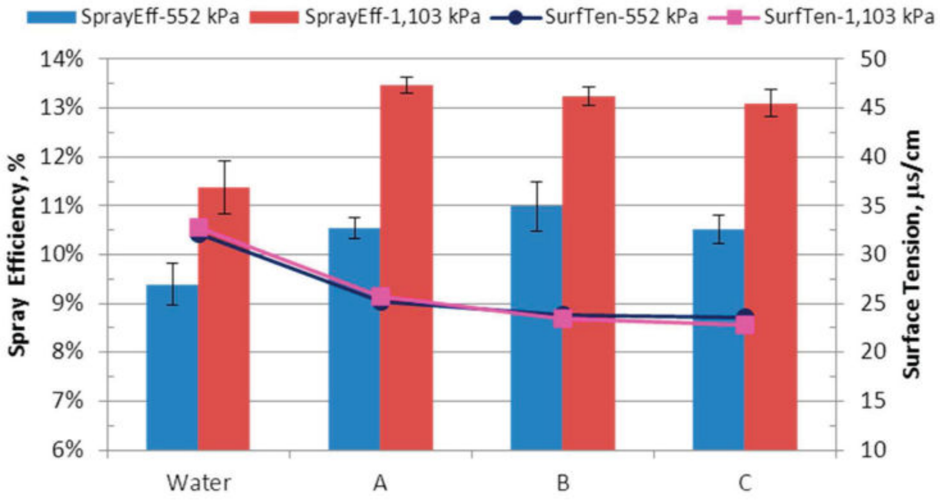

Figure 3.

Water spray dust capture results for the three wetting agents at 0.2% solution concentration.

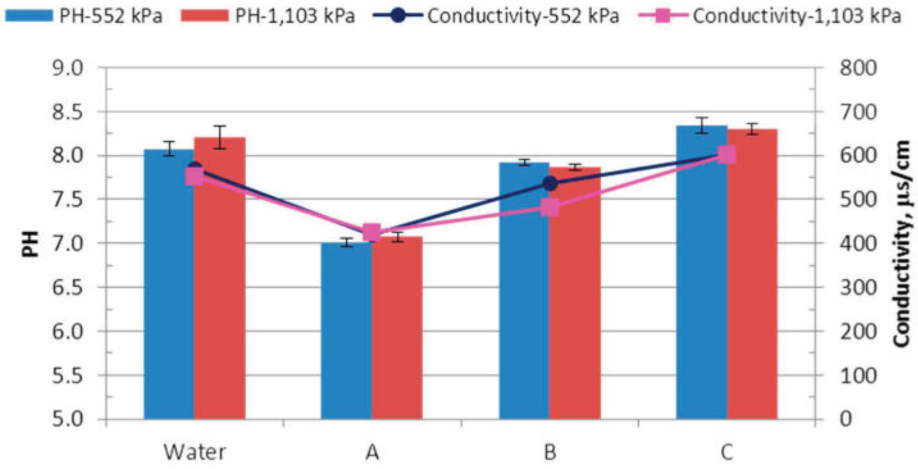

Figure 4.

pH and conductivity measurements for water and 0.2% wetting agent solutions.

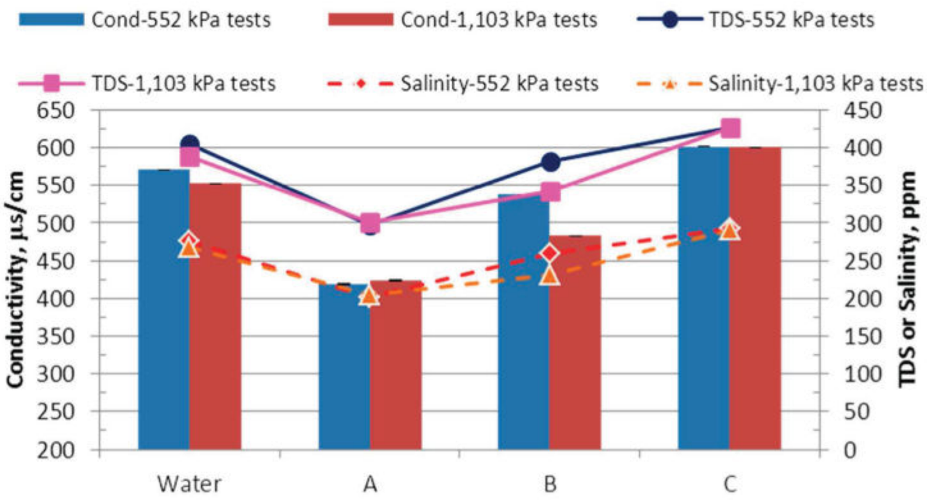

Figure 5.

Conductivity, TDS and salinity measurements for water and 0.2% wetting agent solutions.

Table 1

Keystone Mineral Black sink times with the various wetting agent solutions.

Wetting agent	Water sample[1]	0.05% Solution	0.1% Solution	0.2% Solution
A-Sample # 1	>900 sec.	847 sec.	385 sec.	191 sec.
A-Sample # 2	>900 sec.	897 sec.	356 sec.	215 sec.
A-Sample # 3	>900 sec.	845 sec.	378 sec.	173 sec.
B-Sample # 1	>900 sec.	>900 sec.	>900 sec.	1,204 sec.
B-Sample # 2	>900 sec.	>900 sec.	>900 sec.	1,297 sec.
B-Sample # 3	>900 sec.	>900 sec.	>900 sec.	1,214 sec.
C-Sample # 1	>900 sec.	>900 sec.	>900 sec.	1,279 sec.
C-Sample # 2	>900 sec.	>900 sec.	>900 sec.	1,304 sec.
C-Sample # 3	>900 sec.	>900 sec.	>900 sec.	1,320 sec.

[1] Note: All the Keystone Mineral Black was observed to be floating on the water surface after 900 sec. without any wetting agent, whereas some of it sunk below the water surface at 900 sec. for the wetting agent B and wetting agent C solutions of 0.05% and 0.10%.