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## DUST CONTROL AT A BELT CONVEYOR TRANSFER POINT USING WATER SPRAYS AND A WETTING AGENT

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### ABSTRACT

Coal conveying and transfer can release significant amounts of dust into the mining environment, causing a health and safety risk to mine workers. Efforts to control emissions during coal transport could reduce exposures to both airborne respirable dust and accumulations of combustible float dust. The National Institute for Occupational Safety and Health (NIOSH) evaluated the ability of a water spray system at an underground belt-to-belt transfer point to reduce concentrations of airborne coal mine dust. Experiments conducted by NIOSH researchers compared the base condition of no water application to treatments with plain water and a plain water solution with a 0.2% wetting agent concentration. Airborne measurements showed that applying plain water reduced float dust levels by 32%. Plain water reduced the observed respirable dust concentrations by 28%. The addition of an anionic wetting agent reduced float dust levels around the transfer point by 49% and respirable dust by 46%. These results suggest that while plain water applications may alleviate some float dust liberation, the use of wetting agents can provide much more effective dust control during material transfer.

### INTRODUCTION

Float coal dust is characterized as coal dust particulate smaller than 75 µm in diameter. This material is a known explosion hazard when deposited in mine entries (Harris et al. 2009). Prior studies of underground material handling operations have identified belt-to-belt transfer points as a primary contributor to airborne float coal dust deposition (Kost et al. 1981; Shahan et al. 2017). Although much of the belt line can be isolated in still air to prevent mine-wide transport of any dust emissions, accumulations near the transfer point source can be significant and may require frequent or continual treatment by inerting materials, like limestone rock dust (Harris et al. 2010).

Respirable dust, with a particle diameter less than 10 µm, can also pose a significant respiratory hazard to mine workers during material handling. Cheng (1973) observed that about 10 percent of the respirable dust adhering to broken coal can be dislodged and become airborne during simulated conveyor belt transfer operations. A study by Cronjé et al. (1997) found that each belt transfer point contributed between 1.2 and 6.8 percent of the total respirable dust in the coal mine atmosphere. This respirable coal mine dust can penetrate the respiratory tract beyond the terminal bronchioles and become deeply embedded in the lungs (Potts et al. 1990). Breathing excessive amounts of respirable coal mine dust can lead to the disabling and potentially fatal lung disease, Coal Workers' Pneumoconiosis, also commonly known as black lung disease (Cowie et al. 2010). Maintaining respirable dust concentrations below the Mine Safety and Health Administration's (MSHA's) permissible exposure level is essential for preventing the development of occupational lung disease in coal mine workers.

Conveyor transfer point dust controls often take the form of physical enclosures with large internal volumes and appropriately sized exhaust ventilation systems (Morrison 1970; Swinderman et al. 2009). In these cases, the facility must have sufficient surrounding space to accommodate a large structure. While these systems have been shown to be effective, this approach can be costly and introduce maintenance issues with obstructions and lack of 360-degree access preventing the cleanup of spills and accumulated material. In underground settings, these material handling spaces must be mined out and are made typically only large enough for the belt structure and drive motors. Additionally, these large openings in coal mines would typically require mining additional roof rock for clearance. This practice may expose workers to high respirable dust concentrations, potentially with high levels of crystalline silica (Pollock et al. 2009).

The addition of water has been shown to be an effective dust control in many diverse coal mining applications, including material handling (Jankowski and Organiscak 1983, Ruggieri and Jankowski 1983, Zimmer et al. 1987, Colinet et al. 1997). Treating coal products with water prior to or during the belt-to-belt transfer can reduce dust emissions and improve the effectiveness of float dust inertization efforts (Kost et al. 1981). Hamilton and Knight (1957) demonstrated that coverage of coal with a water film, tested at 2.5, 5, and 10 percent addition (by weight), can suppress the dispersion of dust during handling by 2, 10, and 20 percent, respectively. This laboratory research also showed that effective wetting is best achieved by thoroughly mixing the water into the coal product prior to handling. Continuing research into water applications for material handling, Walton and Woolcock (1960) showed that wetting of the material was a much more effective control than using water sprays to capture airborne dust released by handling.

Several in-mine studies have demonstrated the effectiveness of water sprays in controlling conveyor belt dust. Underground tests with plain water conducted by the U.S. Bureau of Mines measured the dust levels around a coal mine belt feeder with a water spray dust control system (Seibel 1976). With eight sprays applying a total of 72.7 liters per minute (19.2 gpm), respirable dust levels were reduced by 56 percent during coal handling. Total dust levels were similarly reduced by 58 percent. An underground study of four coal mine belt transfer points by Kost et al. (1981) observed airborne total dust concentrations as high as 31.35 mg/m$^3$ when no water spray system was in use. At the transfer points with water spray systems in operation, ranging from 1 to 4 sprays and total water consumption of 6.1 to 12.9 liters per minute (1.6 to 3.4 gpm), total dust levels were reduced to as low as 1.38 mg/m$^3$. In Cronjé et al.'s 1997 study, transfer points with water sprays exhibited rates of respirable dust suppression ranging from 4.3 to 27.2 percent.

Wet suppression of coal handling dust with plain water has its limitations. A study by the UK National Coal Board on the effects of water, wetting agents, and steam on suppressing medium and high volatile bituminous coal dust was performed at a simulated loading or transfer point. Adding 10 percent water (by weight) and allowing one minute for penetration, dust dispersion could only be reduced by 7 to 18 percent (Hamilton and Knight 1963). The addition of this same amount of liquid with a 0.2 percent concentration of a commercial anionic wetting agent reduced the amount of medium volatile coal dust released by 26 percent when compared to plain water. Increasing the concentration to 0.5 percent improved dust suppression by 67 percent over water. Finally, a 2 percent concentration of wetting agent produced results 97 percent better than plain water. Similar effects were seen with high volatile coals, though to a lesser extent, with 82 percent reduction at 2 percent concentration. Various subsequent studies have shown the benefits of wetting agents in terms of respirable dust control compared to plain water. While some mine

studies showed minimal improvements, ranging from zero to 30 percent (Kost et al. 1980, MRDE 1981, Chander et al. 1991), several researchers have observed reductions exceeding 40 percent when using wetting agents (Meets and Neethling 1987, Kilau et al. 1996, Chugh et al. 2005).

To control the explosion hazard posed by float dust during material handling, the National Institute for Occupational Safety and Health (NIOSH) installed a spray-based conveyor belt dust control system in an underground coal mine. The objective of this study was to measure and compare the airborne coal mine dust concentrations during the operation of the dust control system with plain water and a wetting agent to a base condition of no spray control. This paper describes the dust control system, the effect of wetting agent additions on water properties, and the dust control results obtained during underground evaluations.

## METHODS

### Belt Transfer Point

NIOSH contracted with Martin Engineering (Neponset, IL) to install a wet dust suppression system at a single underground transfer point at a West Virginia coal mine. The subject transfer point consisted of a 90-degree belt-to-belt transfer with a vertical drop of 1.5 m (5 feet) to a receiving belt. Both the feed and receiving belts were 1.2 m (48 inches) wide. The average coal throughput observed during this study was 790 metric tons per hour (870 short tons per hour) with a range from 508 to 1029 metric tons per hour (560 to 1135 short tons per hour). Vertical rubber skirting on the receiving belt centralized the coal from the edges of the belt to minimize spillage (Grierson 1954). A vertical exit curtain of rubber belting across the lower opening was present to minimize induced airflow through the transfer chute (Cecala et al. 2019).

The direction of airflow in the belt entry was opposite to that of the material flow. The ventilation air speed was monitored and recorded periodically at the belt transfer point using an intrinsically safe Davis vane anemometer (Tektronix, Beaverton, OR). Continuous rock dusting did not occur during the study period to minimize the contamination of the measured samples. When required, the conveyor belt areas were spot dusted with limestone rock dust after the sampling shift to maintain a sufficient incombustible content ratio in the accumulated material (Maintenance of incombustible content of rock dust, 2017).

### Water Spray System Design

The NIOSH-installed dust suppression system consisted of four major components:

- Water spray heads and associated piping
- Material flow monitor
- Control unit and solenoid valve
- Chemical proportioning unit

Four water sprays (Spraying Systems H1/2U-4020, Wheaton, IL) were located above and below the head pulley to wet the falling material. The two top sprays are shown in operation in Figure 1. These four sprays operated at 241 to 276 kPa (35 to 40 psi) for a total water flowrate of 30.3 liters per minute (8.0 gpm). The sprays featured a 40-degree flat fan spray pattern and were oriented such that the width of the spray pattern covered the width of the belt. The presence and movement of coal on the receiving belt was monitored by the material flow monitor, which operated using Doppler flow detection (BinMaster Model FDS1000, Lincoln, NE). This sensor communicated with a controller (BinMaster Model FDC1000) to open a solenoid valve on the water supply when moving coal was present. Both the sensor and controller components are shown in Figure 2. The system had the additional capability to inject additives through a Dosatron USA chemical injection pump (Model D45RE3, Clearwater, FL), allowing tests to be completed using plain mine water or plain water with the addition of a wetting agent. The minimum chemical injection concentration possible by this device was 0.2 percent. Additional system components included a Y-strainer, pressure regulator, Webtec flow meter (Milwaukee, WI), and 100-psi pressure gauge as labeled in Figure 3.

**Figure 1.** Two top sprays angled downward to treat the top surface of the falling coal material (shown with no material present).


**Figure 2.** BinMaster Doppler Flow Sensor installed above the receiving belt (left) and BinMaster Doppler Flow Control module (right).

### Wetting Agent

The wetting agent was chosen based on availability from prior NIOSH research. No efforts were made to match the wetting agent to the coal type encountered during this study. The selected wetting agent was an anionic surfactant composed primarily of sodium alpha-olefin sulfonate (CAS 68439-57-6). This main component is often found in personal care products, such as bath, shower, and hair care cleansers. The National Fire Protection Association (NFPA) 704 rating for health is 3, due to the potential for skin and eye irritation upon overexposure (NFPA 2017). The undiluted wetting agent is a pale-yellow liquid with a relative density of 1.06 and viscosity of less than 200 centipoise at 25°C. The target concentration for these wetting agent tests is 0.2 percent wetting agent concentration, due to the capabilities of the chemical injection pump. At an average water consumption of 30.3 liters per minute (8.0 gpm), these tests used about 3.8 liters (1.0 gallon) of wetting agent per hour.

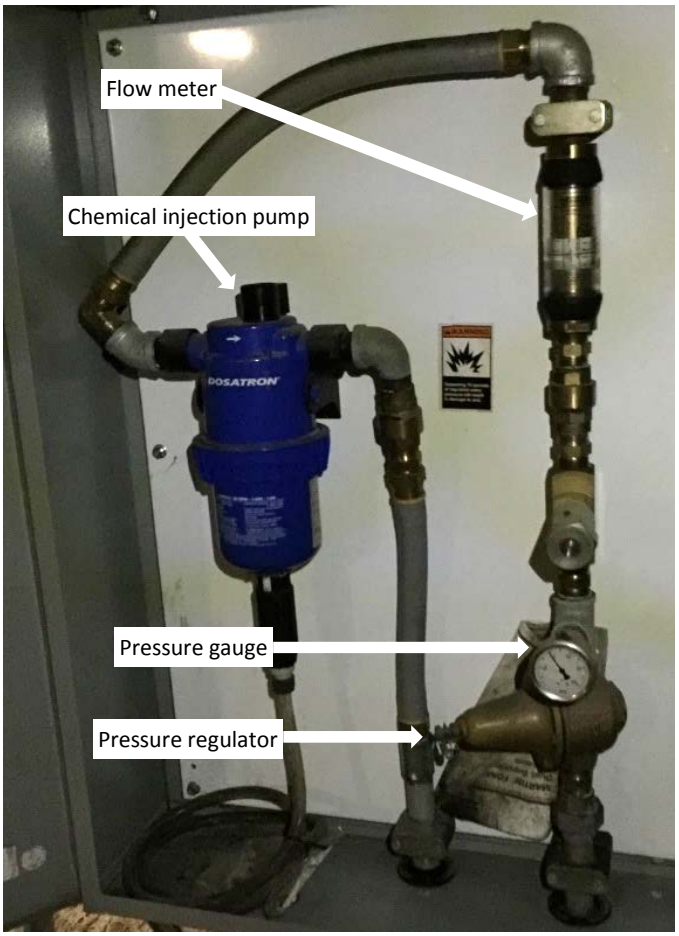


**Figure 3.** Additional system components, as labeled.

Water samples were collected during both plain water and wetting agent tests to separately evaluate and record the following water properties: pH, temperature, conductivity, total dissolved solids, and salinity. These water samples were analyzed by an Oakton Multiparameter pCSTestr35 (Oakton Instruments, Vernon Hills, IL) and compared to both distilled water and municipal water in Pittsburgh, PA. Additional water samples were created for 0.2, 0.5, 1.0, 1.5, and 2.0 percent wetting agent solutions with all water types to enable additional property tests. The collected and lab-produced water samples were further tested for surface tension using a capillary rise test device (Cole Parmer, Vernon Hills, IL). The surface tension was calculated from the following equation:

$$y = 1/2(h)(r)(d)(g)$$

where:

- $y$ = surface tension (dynes/cm)
- $h$ = height of capillary rise (cm)
- $r$ = radius of capillary (cm)
- $d$ = density of sample (g/cc)
- $g$ = acceleration due to gravity (cm/s$^2$)

**Sampling and Test Design**

A series of tests was performed to measure the respirable and airborne float coal mine dust concentrations generated during the transfer of coal from one belt to another. The sampling strategy for this study consisted of area sampling. Dust concentrations were continuously measured at four stations around the transfer point. One station was located along the feed belt on the inside of the 90-degree transfer point. Other stations were located above the backstop on either side of the feed belt, and one set of samplers was situated on the crossover walkway above the receiving belt. These locations are shown in Figure 4.

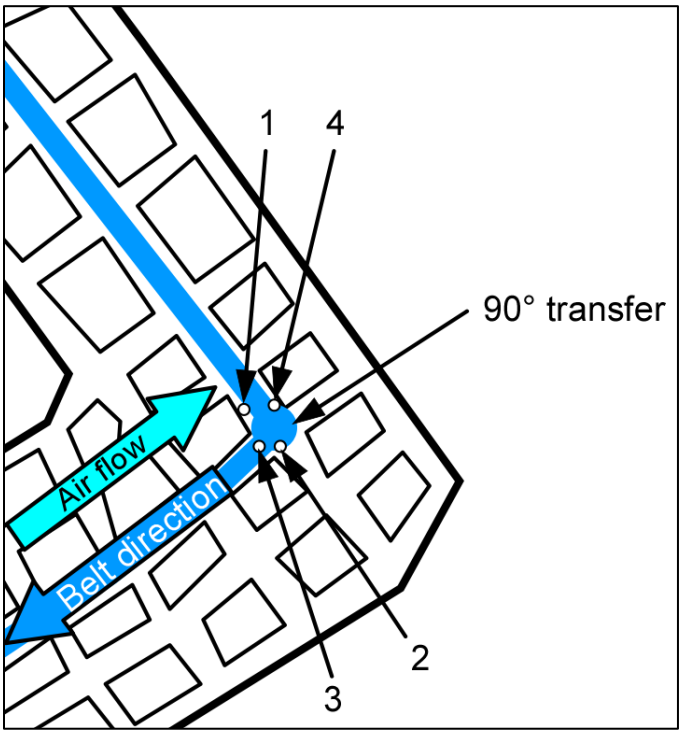


**Figure 4.** Sampling locations around the 90-degree transfer point.

Respirable dust concentrations were monitored at each station by near real-time continuous personal dust monitors (CPDMs) with respirable dust sampling inlets (PDM3700, Thermo Fisher Scientific, Waltham, MA). At the same sampling stations, float dust data were collected using CPDM samplers (PDM3600) modified for airborne float dust sampling. The CPDM was modified to sample and measure these larger particles by removing the sensing unit from the main instrument body, which contains the pump, cyclone, battery, and display. In order to bypass the cyclone separator, the sensing unit is reconnected by means of an electrical cable and a length of flexible tubing. These modifications allow sampled dust to pass through an appropriately sized isokinetic inlet and be deposited directly onto the instrument's filter for subsequent mass measurement. The NIOSH-developed assembly has received experimental permission by MSHA for use in underground coal mine environments. Float dust concentrations reported here are dust concentrations as collected by the modified CPDMs, used as a surrogate for airborne float dust. Both CPDMs and modified CPDMs provided time-based mass concentration data to allow test periods to be separated to calculate average dust concentrations for individual periods through the shifts. Average dust concentrations at each station were calculated for each test session and used in comparisons between conditions.

**Test Sequence**

Test periods were established for 120 minutes during the operating shift. This duration was selected to account for small production delays or inconsistencies in coal throughput. During each test period, one of three conditions was selected: baseline with no control operating, plain water application via four sprays, and water with 0.2 percent wetting agent solution application via four sprays. For analysis, each dust control testing period was paired with an immediately preceding baseline period. The alternating sequence was repeated in this fashion to generate ten pairs of tests, five comparing the use of plain water to the baseline and five comparing water with wetting agent to the baseline.

## RESULTS AND DISCUSSION

**Water Properties**

The water properties of samples collected underground were compared with those of distilled water and municipal water samples collected at NIOSH's Pittsburgh Laboratory. The pH measurements of

the plain mine water samples are consistent with municipal water at 7.91 versus 8.05 (Figure 5). By adding 0.2 percent wetting agent, the pH of municipal water was reduced, though this same addition to plain mine water increased the pH measurement above 8.0. At wetting agent concentrations above 0.5 percent, the pH measurements remained stable at values higher than 8.0 for all water types.

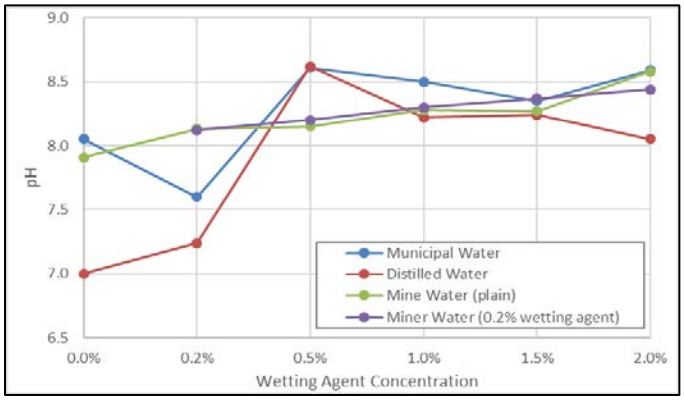


**Figure 5.** pH measurements for plain water (0.0 percent) and 0.2, 0.5, 1.0, 1.5, and 2.0 percent wetting agent solutions.

The initial surface tension of plain mine water was higher than municipal water at an average of 58.4 versus 41.8 dynes/cm (Figure 6). Both municipal water and plain mine water had lower initial surface tension values than distilled water, which was found to be 72 dynes/cm. Containing 0.2 percent wetting agent, the observed surface tension for the sample collected during wetting agent tests was 30 dynes/cm. Continued additions of wetting agent did not have much effect on either mine water sample's surface tension measurements. A similar effect is seen for municipal water solutions, where after an initial decrease with 0.2 percent wetting agent, the surface tension does not continue to decrease. Surface tension for distilled water continued to decrease until the wetting agent concentration increased to 1.0 percent and then stabilized. The measurements for conductivity, total dissolved solids, and salinity each increased with increased wetting agent concentrations for all different water types (Figures 7, 8, and 9).

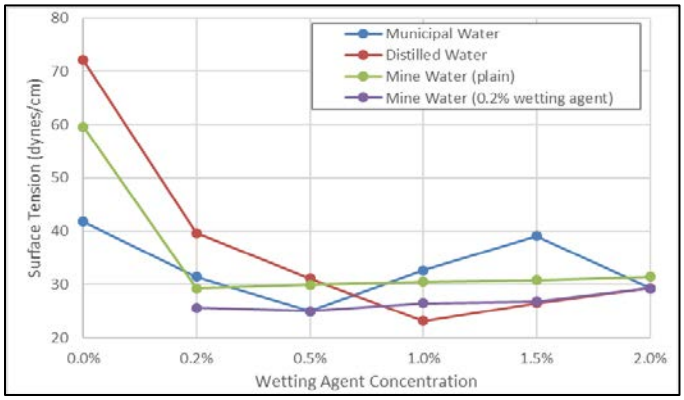


**Figure 6.** Surface tension measurements for plain water (0.0 percent) and 0.2, 0.5, 1.0, 1.5, and 2.0 percent wetting agent solutions.

**Dust Control**

During the baseline periods of the plain water study (with no sprays in operation), the average float dust concentrations were 24.4 mg/m$^3$, varying from 6.7 to 47.1 mg/m$^3$, while respirable dust concentrations averaged 2.8 mg/m$^3$, with a range of 0.6 to 5.4 mg/m$^3$. Applying plain water produced a similar range of float dust concentrations, from 6.7 to 32.0 mg/m$^3$, with an average of 14.7 mg/m$^3$. The respirable dust concentrations during plain water periods were lower, with an average of 1.6 mg/m$^3$, and a smaller range of values from 0.5 to 2.7 mg/m$^3$. Airborne float dust concentrations for dry test periods of the wetting agent study averaged 10.0 mg/m$^3$, with a range of 6.2 to 13.4 mg/m$^3$.

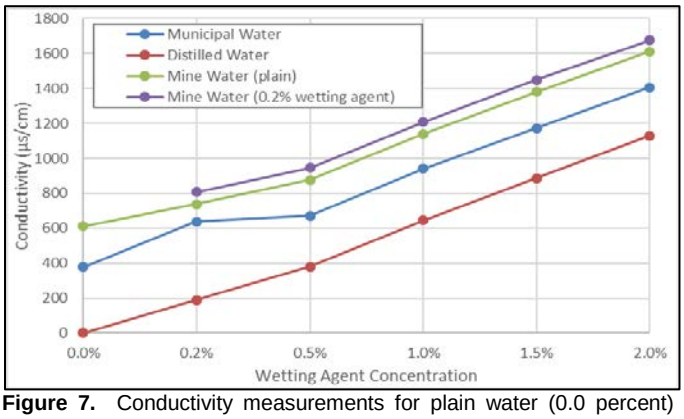


**Figure 7.** Conductivity measurements for plain water (0.0 percent) and 0.2, 0.5, 1.0, 1.5, and 2.0 percent wetting agent solutions.

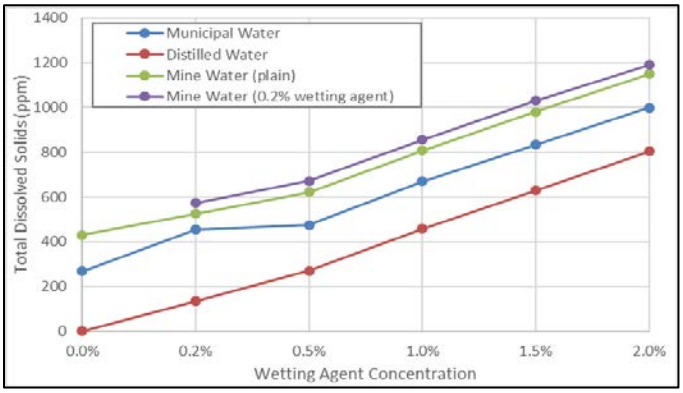


**Figure 8.** Total dissolved solids measurements for plain water (0.0 percent) and 0.2, 0.5, 1.0, 1.5, and 2.0 percent wetting agent solutions.

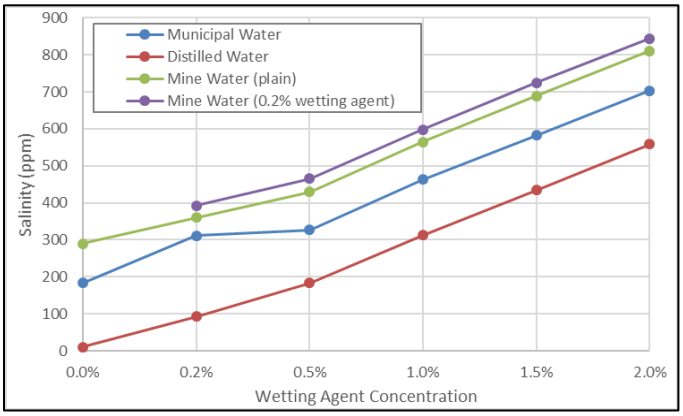


**Figure 9.** Salinity measurements for plain water (0.0) and 0.2, 0.5, 1.0, 1.5, and 2.0 percent wetting agent solutions.

During the wetting agent tests, airborne float dust concentrations averaged 4.9 mg/m$^3$ and varied from 4.3 to 5.1 mg/m$^3$. Respirable dust was also lower during wetting agent test periods at 0.4 mg/m$^3$ versus 0.8 mg/m$^3$ for the wetting agent baseline periods. Both tests periods had a small range of concentrations, varying from 0.5 to 1.1 mg/m$^3$ during dry baseline periods and 0.3 to 0.6 mg/m$^3$ when wetting agent was applied.

The reductions in dust concentrations that were calculated for each condition and sampling station are shown in Table 1 (see APPENDIX) . Over the course of the five pairs of alternating tests, the observed float dust concentrations were lower for each station when comparing plain water tests to baseline conditions. The average reduction in float dust concentration was 32.3 percent. A similar reduction was seen in respirable dust during the application of plain water, at 28.3 percent. Station 1 measured the lowest dust control

efficiency, finding a 23.6 percent reduction with float dust and an increase of 12.9 percent in respirable dust. Comparing the paired wetting agent and baseline tests, float dust levels were reduced by an average of 49.5 percent. Respirable dust levels saw a similar reduction of 46.4 percent for these same tests. In these comparisons, Station 1 again measured the lowest dust control efficiency, finding 36.7 and 26.0 percent reductions in float dust and respirable dust, respectively.

As shown in Table 1 (see APPENDIX) , some trials of both plain water sprays and wetting agents increased dust concentrations at sampling stations around the transfer point. These were believed to possibly be the result of variations in production and air movements that were not detected during the studies. Additional investigations would be required to positively identify the source of this variability.

There also appeared to be a general trend when comparing sampling stations; Station 1, near the belt take-up, observed lower control effectiveness than any of the other sampling stations. For example, using plain water, Station 1 found a 23.6 percent reduction in float dust, though the other stations measured reductions between 34.2 and 36.3 percent. Similarly, for respirable dust concentrations measured during the same tests, Station 1 saw a 12.9 increase in dust levels, though the reductions realized at other stations ranged from 10.4 to 37.6. This effect was apparent during wetting agent tests as well, with Station 1 observing 36.7 and 26.0 percent reductions in float and respirable dust, respectively. The other stations saw float dust reductions ranging from 41.9 to 61.3 percent and respirable dust reductions ranging from 40.7 to 54.7. The nature of this effect is unclear, though this station was located the farthest from the transfer point, was nearby the belt take-up, and sampled at a height of 1.2 m (4 ft) above the mine floor.

The dust control system added water to the coal product at a ratio of 0.24 to 0.29 percent by weight. While this is much less than the typical water addition rate of 5 percent for plain water suggested by Swinderman et al. (2009), this study demonstrates that some dust reductions may still be achieved at the transfer point with very little water usage. The same authors suggest using a chemical-to-water ratio of 1:5000 to produce a 0.02 percent wetting agent solution. The current study applied wetting agent at a ten times higher rate, or 0.2 percent. This is important as it increased the chemical usage rate ten-fold and therefore the application costs. Because these tests were conducted at only one target concentration, it is unclear if similar results would be obtained through reduced chemical usage rates. As demonstrated in water property tests, there was no continued decrease in surface tension measurements with higher solution mixtures. Because surface tension is an indicator of water penetration into coal mixtures (Kilau et al. 1996, Organiscak 2013), and therefore capacity to suppress dust, it is unlikely that tests performed at higher concentrations would improve this study's results.

While the respirable dust concentrations at some locations and test periods exceeded the MSHA full shift standard of 1.5 mg/m$^3$, it should be noted that these are not personal samples and do not represent a full shift. Belt-to-belt coal transfer remains a significant dust-producing activity. With the plain water dust control system in use, the average respirable dust concentration at the transfer point remained at 1.6 mg/m$^3$. Additional dust control measures may be desired to further reduce the risk of overexposure to respirable coal mine dust. The use of personal protective equipment may be advised for those working in the area during active coal transport when no control system is in use.

Additionally, the ventilating air velocity at the transfer point was observed to be under 0.5 m/s (100 fpm) for the duration of the study. This ventilating air velocity exceeds the MSHA minimum belt air course speed of 0.254 m/s (50 fpm) (Belt air course ventilation, 2017), but is also low enough to prevent the transport of airborne dust along the entire belt line. The low velocity promotes float dust deposition adjacent to the transfer point, limiting the region that must be intensively managed through cleanup and treatment with inerting materials.

It is also important to mention that system designs may need to consider multiple issues and site-specific characteristics. Small changes may be necessary during initial setup to fully realize the system's benefits. In this site's case, adjustments were required to improve the orientation of the bottom sprays. The bottom sprays were not positioned to fully blanket the underside of the falling coal and runoff water was collecting beneath the transfer point structure. Because of these issues, the mine had chosen to temporarily discontinue use of these bottom sprays. Prior to this series of tests, the sprays were adjusted to better treat the falling coal, ensuring that overspray impinges on the chute for collection on the lower belt.

Finally, this study only measured dust concentrations at and around a single belt transfer point. As shown by Seibel (1976), single point water applications can have positive downstream impacts, as applied water remains on the coal product to affect continued dust control throughout the mine. Though the mine in this study reported reduced float coal dust accumulations at subsequent transfer points, no evaluations were made as a part of the study.

## CONCLUSIONS

Float coal dust and respirable coal mine dust originating from belt transfer points remain a health and safety hazard in underground coal mines. One of the goals of the NIOSH Mining Program's float dust research project is to develop, implement, and evaluate float dust controls for conveyor belts and belt transfer points. Prior studies have found that movement of coal on belts through the mine did not produce a significant amount of float dust except at belt transfer points (Kost et al. 1981; Shahan et al. 2017). This study contributes to the aim of producing an effective and generalizable approach to controlling float dust at transfer points in the underground coal mining industry. The study findings indicate that a strategically arranged water spray and wetting agent system may be an effective float dust control method. Underground samples show that airborne float dust levels at transfer points can be reduced by 32.3 percent by applying plain water at a rate of 30.3 liters per minute (8.0 gpm). This study also indicates that low concentrations of a wetting agent can improve dust suppression during material handling. Though this study cannot attribute the observed decline in dust levels during wetting agent tests to corresponding reductions in surface tension, additions of a wetting agent reduced the surface tension of plain mine water from 59.5 to 29.3 dynes/cm at 0.2 percent concentration. By applying this 0.2 percent concentration of anionic wetting agent in the same water spray configuration, airborne float dust levels were reduced from a dry baseline by 49.5 percent. The extra cost of the system and its operation may be economical and relatively low if it improves the effectiveness or reduces material and labor costs associated with rock dusting.

An additional NIOSH Mining Program area seeks to develop engineering controls to reduce occupational exposures to respirable coal mine dust. This underground investigation confirms prior research findings by showing that respirable dust concentrations can be effectively lowered around transfer points with both plain water and wetting agent solutions. Using just plain water, respirable dust levels were lowered by 28.3 percent. By adding an anionic wetting agent at a concentration of 0.2 percent, respirable dust was reduced by 46.4 percent.

Future work could include testing of foam treatments or enclosures at conveyor belt transfer points to potentially achieve better dust control with decreased water addition. Additionally, future evaluations could evaluate wetting agents and foam treatments in providing continued dust reduction throughout the mine as coal is transported to the surface.

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## DISCLAIMER

The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the

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**APPENDIX**

**Table 1.** Reductions in dust concentrations, in percent, when compared to baseline conditions of no dust control.

| Comparison Number | Station 1 | | Station 2 | | Station 3 | | Station 4 | | All Stations Average | |
|---|---|---|---|---|---|---|---|---|---|---|
| | *Float* | *Resp.* | *Float* | *Resp.* | *Float* | *Resp.* | *Float* | *Resp.* | *Float* | *Resp.* |
| Plain Water 1 | -13.6 | -51.3 | -1.9 | -10.6 | 23.0 | -36.1 | NA | -108.2 | 2.5 | -32.4 |
| Plain Water 2 | 13.1 | NA | 36.5 | 50.6 | 51.6 | 36.1 | 49.5 | 42.4 | 37.7 | 44.5 |
| Plain Water 3 | 76.5 | NA | 54.7 | 48.9 | 64.1 | 53.9 | 50.1 | 48.5 | 61.4 | 49.9 |
| Plain Water 4 | 12.1 | 17.0 | 55.2 | 62.7 | 15.8 | 32.6 | 24.1 | 26.5 | 26.8 | 43.6 |
| Plain Water 5 | 29.8 | -4.5 | 31.5 | 36.5 | 16.2 | 40.3 | 21.5 | 42.6 | 24.8 | 36.0 |
| **Plain Water Average** | **23.6** | **-12.9** | **35.2** | **37.6** | **34.2** | **25.3** | **36.3** | **10.4** | **32.3** | **28.3** |
| Wetting Agent 1 | 48.6 | 35.3 | 61.9 | NA | 54.4 | 37.1 | 50.0 | 53.8 | 54.3 | 45.7 |
| Wetting Agent 2 | 60.8 | 54.4 | 61.3 | NA | 68.3 | 52.6 | 62.6 | 60.1 | 63.4 | 56.9 |
| Wetting Agent 3 | 12.9 | -17.5 | 56.4 | 52.5 | 30.4 | 19.0 | 14.9 | 34.2 | 33.5 | 38.2 |
| Wetting Agent 4 | 20.3 | -3.6 | 70.7 | 62.2 | 43.0 | 42.3 | 34.6 | 55.5 | 49.9 | 49.6 |
| Wetting Agent 5 | 40.7 | 61.5 | 56.0 | 49.2 | 57.5 | 52.7 | 47.6 | 47.1 | 46.3 | 41.5 |
| **Wetting Agent Average** | **36.7** | **26.0** | **61.3** | **54.7** | **50.7** | **40.7** | **41.9** | **50.2** | **49.5** | **46.4** |

Resp. – Respirable
NA – Comparison not possible due to concentration measurement not available.