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A COMPARISON OF DIFFERENT WATER SPRAYS AT HIGH PRESSURES FOR RESPIRABLE COAL DUST KNOCKDOWN ABILITY IN A CONFINED CHAMBER

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ABSTRACT

Researchers at NIOSH's Pittsburgh Mining Research Division (PMRD) performed comparative testing of six different water sprays at pressures ranging from 689 kPa (100 psi) to 6,895 kPa (1,000 psi) in a 14.5-m^3 (512-ft^3) confined dust chamber. Testing was conducted to determine the effect of various pressures on each spray's respirable coal dust knockdown ability. It is known that higher water pressures are typically preferred for lowering airborne dust concentrations, but it was important to determine at what pressure range the dust knockdown ability of each spray plateaus or reaches its minimum dust concentration. Results from this testing showed that several sprays saw up to 100% decrease in dust concentrations during the five-minute water spray testing period, with some occurring well below the maximum 6,895 kPa (1,000 psi) spray pressure.

Keywords: Coal Mining; Health and Safety; Respirable Dust Control; Water Sprays; High Pressure; Black Lung

INTRODUCTION

There are many challenges when it comes to protecting the health and safety of underground coal miners. Underground coal mining personnel can face health risks due to exposure to respirable coal dust (< 10 µm in size) [1]. Overexposure to these dust particles can lead to coal workers' pneumoconiosis (CWP), more commonly known as black lung disease [1]. This preventable occupational lung disease develops over periods of time when coal miners are exposed to high levels of respirable dust [1][2]. This disease can be disabling and may ultimately lead to premature death [1][2]. Because of the continued presence of this disease, respirable dust control in underground coal mines must continue to be a focus for the mining industry for further prevention of black lung disease.

The Mine Safety and Health Administration (MSHA) provides laws on respirable dust standards for underground coal mines [3]. This dust standard (Rule 79 FR 24973) states that each operator shall continuously maintain the average concentration of respirable dust (1.5 mg/m^3) in the mine atmosphere during each shift to which each miner in the active workings of each mine is exposed [3]. Proper ventilation and positioning of mining personnel can help achieve low exposures to respirable coal dust. However, many times other methods are necessary to control respirable dust in underground coal mines, and one common technique is through use of water sprays. Water sprays have been a primary dust control method for many years in coal mines and have been studied extensively over this period [4][5]. Water sprays can help control mine workers' exposure to dust through suppression (wetting at the point of dust generation), redirection (directing dust away from mining personnel), and airborne dust capture (wetting airborne dust to knock it out of the airway) [1]. Water sprays are used in all underground coal mines and have proven to be a very effective tool for reducing coal miner exposure to respirable dust.

Although a water spray may seem like a simple tool for dust control, these sprays can vary greatly from one another. Two different sprays operating at the same pressure can produce significantly different spray patterns, water flow rates, airflow induction, and overall dust knockdown ability. An abundant amount of research has been done comparing different spray types and operation at different pressures, but the goal of this research is to determine the optimal spray pressure range for various spray types.

The dust knockdown ability of a single water spray can be defined as the spray's ability to capture airborne respirable dust particles and remove them from the air through quicker gravitational settling [1]. The dust is sprayed by similar-sized water droplets at the point of dust generation, causing the particles to collide, agglomerate, and fall out of the air due to their increased mass [1]. This is an important factor when selecting which water spray to use for dust control practices in an underground mine. Spray pressure, water flow rate, and spray droplet size are factors that can affect a spray's dust knockdown ability [4]. Typically, a spray operating at a higher pressure will produce a higher flow rate, which will then lead to a higher dust knockdown ability [5]. Two different sprays operating at the same pressure can produce significantly different flow rates and thus, different rates of dust knockdown. This is a topic that needed further exploration and the reason for this research study.

METHODOLOGY

For this study, researchers from the National Institute for Occupational Safety and Health (NIOSH) selected six water sprays from Spraying Systems Co. (Wheaton, IL) to be compared for their dust knockdown ability. These sprays are listed in Table 1. The BD3, BD5, BDM3, and BDM5 are hollow cone water sprays with a 0.95-cm (3/8-in) inlet connection. These sprays produce a circular, outer-ring spray pattern and are typically preferred for airborne respirable dust capture in mining operations [1][6]. The D4 is also a hollow cone spray but has a smaller 0.64-cm (1/4-in) inlet connection. This spray is slightly different because the orifice disc is located inside a separate nozzle body. This reduces maintenance time because only the inner disc needs to be cleaned or replaced when clogged or damaged [6]. Finally, the LNN is a hydraulic atomizing spray also with a 0.64-cm (1/4-in) inlet connection. This is different from the hollow cone sprays in that the water droplets are finely atomized, which means it produces smaller, and thus faster water droplets and a lower water flow rate at similar pressures [1][6]. Table 1 shows the specifications of these sprays from the Spraying Systems catalog [6]. These sprays were chosen based on their common use in underground coal mines, as well as their performance in other preliminary laboratory comparative testing. The BD3 and BD5 sprays were previously tested under a similar lab setup but were only tested up to 689 kPa (100-psi) [7]. In this study, each spray was tested at ten different water spray pressures ranging from 689 kPa (100 psi) to 6,895 kPa (1,000 psi). Three tests at the various pressures for each of the six sprays were conducted, and the results were averaged for data analysis. This resulted in a total of 180 tests.

Testing for each spray's respirable coal dust knockdown ability was completed in a 2.4-m x 2.4-m by 2.4-m (8-ft x 8-ft x 8-ft) unventilated dust chamber shown in Figure 1. Previous testing was performed in this dust chamber and produced valuable results for water spray comparisons [7][8]. The advantage of using an unventilated, well-mixed chamber for this testing is that only single-point dust sampling is required without the need for steady dust production [8]. For each test, the water spray was positioned in the center of the chamber and oriented downwards toward the floor. To begin each test, dust was injected into the upper portion of the chamber. The dust used for this testing was Keystone Mineral Black 325 BA (Keystone Filler and Manufacturing Co., Muncy, PA). During dust injection, a 1.1-m^3/s mixing fan located at the top corner of the chamber operated to disperse the dust across the interior of the chamber. Once the initial respirable dust concentration within the chamber reached 100 mg/m^3, the mixing fan was turned off and testing began. The first stage of testing was a three-minute pre-spray dust sampling period to determine the initial dust concentration within the chamber after mixing occurred. After three minutes, the water spray was turned on to the corresponding pressure and operated for a five-minute period to perform its dust knockdown. The water pressure remained constant for each test, and the water flow was recorded for comparison. The final period of testing was a 15-minute post-spray dust sampling period to determine the final dust concentration within the chamber after water spray application ended. This testing period was to ensure the dust filters collected enough mass to be a valid sample.

Table 1. Water spray specifications for the six tested sprays.

Spray	Full Name	Inlet Connection (cm)	Orifice Diameter (cm)	Flow Rate Capacity (m^3/hr.) @ 689 kPa (100 psi)
BD3	3/8BD3-SS	0.95 (3/8 in)	0.24 (0.09 in)	0.22 (0.95 gpm)
BD5	3/8BD5-SS	0.95 (3/8 in)	0.32 (0.13 in)	0.36 (1.60 gpm)
BDM3	3/8BDM-3	0.95 (3/8 in)	0.24 (0.09 in)	0.22 (0.95 gpm)
BDM5	3/8BDM-5	0.95 (3/8 in)	0.32 (0.13 in)	0.36 (1.60 gpm)
D4	1/4TT-SS+D4-46	0.64 (1/4 in)	0.16 (0.06 in)	0.20 (0.88 gpm)
LNN	1/4LNN-SS18	0.64 (1/4 in)	0.19 (0.08 in)	0.11 (0.47 gpm)

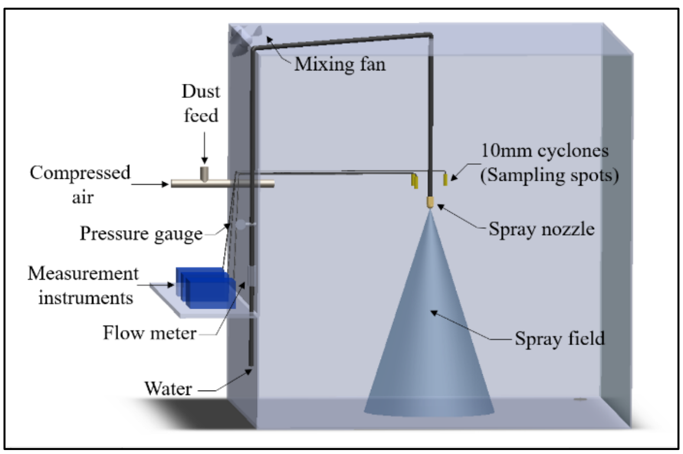

Figure 1. Dust chamber used for dust knockdown testing.

For this testing, a total of five DustTrak II 8530 aerosol monitors (TSI Inc., Shoreview, MN) were used to measure dust concentrations. These monitors were located on the outside of the dust chamber to maintain efficient operation during testing without needing to open the chamber door. One monitor ran continuously and was used to determine the initial 100-mg/m^3 concentration. Two monitors were used for the initial pre-spray dust concentration reading, and the final two were used for the post-spray dust concentration reading. These four monitors collected respirable size fraction coal dust via attached tubing to Dorr-Oliver 10-mm nylon cyclones positioned on each side of the water spray inside the dust chamber, with their inlets 20.3-cm (8-in) above the spray. The respirable dust was then collected on two-piece PVC filter cassettes located inside of the DustTrak monitors. These filters were pre-weighed and post-weighed for each test. The respirable dust fraction collected on the post-spray filters was compared to that collected on the pre-spray filters to determine the spray's knockdown ability for the corresponding testing parameters. It should be noted that previous testing within this dust chamber has shown that dust particles settled on their own over time without the assistance of water sprays [9]. However, it was also determined that larger sized particles were the most likely to settle, and that the respirable size fraction can remain suspended and potentially even resuspend in the air after settling [9]. This testing is solely focused on the respirable size fraction of coal dust particles.

RESULTS

The primary goal of this testing was to determine each of the water spray's dust knockdown ability. This was measured by comparing the post-test dust concentration to the pre-test concentration and calculating the percent decrease in the dust concentration within the chamber. Another important factor when analyzing these results was to compare the water flow rates of each spray to one another and compare the dust knockdown ability at that flow rate. A lower flow rate is preferred in underground coal mines to decrease water consumption both for the benefit of lower operating costs and not oversaturating the mine floor. However, a higher water flow rate will typically produce better dust knockdown ability, so the analysis will begin there.

Figure 2 shows the water flow rates (m^3/hr.) of the six water sprays at each pressure tested. These are the average flow rates of the three tests conducted at each pressure for each spray. This figure shows that the BD5 and BDM5 sprays produce the highest flow rates of the six sprays, ranging from 0.31 m^3/hr. to 0.95 m^3/hr. (1.36 gpm to 4.18 gpm). The BD3, BDM3, and D4 sprays all share similar flow rates, ranging from 0.17 m^3/hr. to 0.54 m^3/hr. (0.75 gpm to 2.40 gpm). The LNN spray stands out as producing the lowest flow rate of the six, ranging from 0.08 m^3/hr. to 0.27 m^3/hr. (0.35 gpm to 1.21 gpm). These groupings are important when comparing the results for dust knockdown ability.

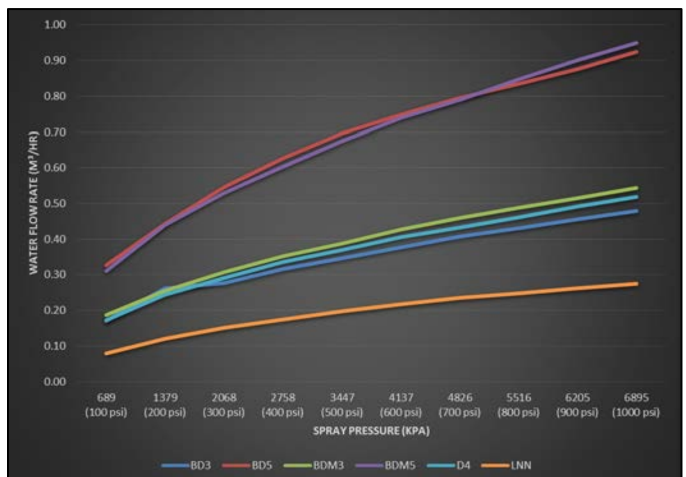

Figure 2. The average water flow rate (m^3/hr.) for each water spray at pressures from 689 kPa (100 psi) to 6895 kPa (1,000 psi).

As previously mentioned, the dust knockdown ability for this testing is defined as the percent decrease in dust level from the pre-test to the post-test measurements. This is a simplified way to determine which spray can suppress the dusty air in the chamber most effectively. Figure 3 shows the average percent decrease in dust concentrations for each spray at each of the ten tested pressures. From this figure, it is apparent that each spray works its way toward a 100% decrease in dust concentration (i.e., moves towards a 0-mg/m^3 dust concentration) as the pressure increases. Breaking it down by each spray type, the LNN spray requires higher pressures than the other sprays to achieve a 95% decrease in dust concentration. This is not surprising because the LNN spray had the lowest flow rate of the tested sprays. The highest flow rate sprays, the BD5 and BDM5, achieved 89.7% and 87.3% reductions, respectively, at 689 kPa (100 psi). This is higher than any of the other sprays, and again is not surprising based on their higher flow rates. The BD3, BDM3, and D4 sprays all perform better at 1,379 kPa (200 psi) and higher, with each going above 95% reduction at 2,068-kPa (300-psi). When looking at these three sprays' flow rates and respirable dust knockdown ability, they appear to provide the best balance of the six. The higher flow rate of the BD5 and BDM5 sprays are not as desirable, and the dust knockdown ability of the LNN spray requires higher pressure to perform as well as the other sprays.

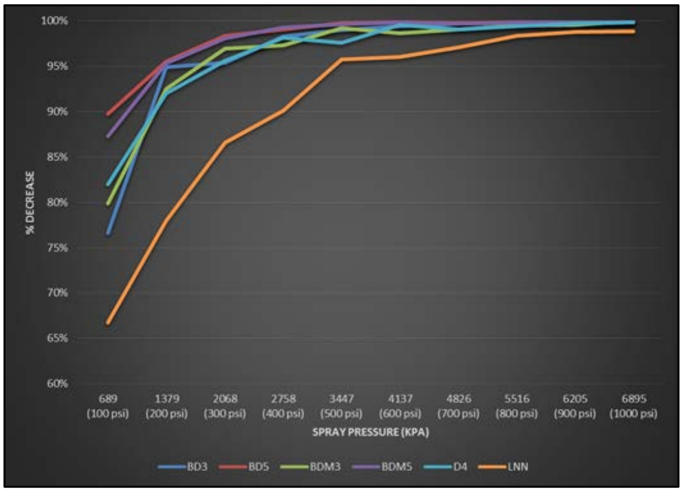

Figure 3. The average percent decrease in respirable dust concentration for each water spray at pressures from 689 kPa (100 psi) to 6,895 kPa (1,000 psi).

CONCLUSIONS

Laboratory testing was conducted to compare six different water sprays at ten spray operating pressures to determine each spray's dust knockdown ability. For this testing, the dust knockdown ability was defined as the percent decrease in dust concentration from the pre-test dust measurement to the post-test measurement after the spray had been operated. The flow rate of each spray was measured to compare water usage at each pressure.

Before this testing, it was known that a water spray's dust knockdown ability generally increases as the pressure and flow rate increase, but this testing showed that sprays do not require extreme pressures to reach a very high dust knockdown level. The one spray with a noticeably lower flow rate, the LNN spray, performed the worst in terms of its dust knockdown ability compared to the other sprays. It required at least 3,447 kPa (500 psi) to reach a 95% dust concentration decrease. The BD5 and BDM5, the highest flow rate sprays, hit this mark at just 1,379 kPa (200 psi), but the higher flow rate to achieve this is not as desirable. The BD3, BDM3, and D4 sprays all achieved a 95% decrease in dust concentration at 2,068-kPa (300-psi). Their dust knockdown ability, in conjunction with their lower flow rates, appear to make these the most favorable sprays, although this can be debated based on what factor is most important between dust knockdown ability and water consumption.

Overall, this testing determined that extreme pressures up to 6,895 kPa (1,000 psi) are not necessary for effective respirable dust knockdown and lower pressures can still greatly reduce respirable dust exposures for underground mining personnel. While the goal of this laboratory study was not to determine the perfect water spray type and pressure, it shows there are options for continuing to improve coal miner health with the use of water spray technology and further testing in actual underground coal mines would seem beneficial.

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DISCLAIMER

The findings and conclusions in this report are those of the author(s) and do not necessarily represent the official position of the National Institute for Occupational Safety and Health (NIOSH), Centers for Disease Control and Prevention (CDC). Mention of any company or product does not constitute endorsement by NIOSH.

CONFLICTS OF INTEREST

On behalf of all authors, the corresponding author states that there is no conflict of interest.

REFERENCES

1. NIOSH (2021). Best Practices for Dust Control in Coal Mining, Second Edition. By Colinet, J.F., Halldin, C.N., Schall, J. Pittsburgh, PA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 2021-119, IC 9532. https://doi.org/10.26616/NIOSHPUB2021119.

2. Mazurek, J.M., Wood, J., Blackley, D.J., Weissman, D.N. Coal Workers' Pneumoconiosis-Attributable Years of Potential Life Lost to Life Expectancy and Potential Life Lost Before Age 65 Years - United States, 1999-2016. MMWR Morb Mortal Wkly Rep. 2018 Aug 3;67(30):819-824. Doi: 10.15585/mmwr.mm6730a3. PMID: 30070982; PMCID: PMC6072058.

3. 79 FR 24973 (2014). Department of Labor, Mine Safety and Health Administration. Lowering Miners' Exposure to Respirable Coal Mine Dust, Including Continuous Personal Dust Monitors. CFR 70.100.

4. Pollock, D., and Organiscak, J. (2007). Airborne Dust Capture and Induced Airflow of Various Spray Nozzle Designs. Aerosol Science and Technology, 41:7, 711-720. https://doi.org/10.1080/02786820701408517.

5. Organiscak, J.A., Klima, S.S., Pollock, D.E. Empirical Engineering Models for Airborne Respirable Dust Capture from Water Sprays and Wet Scrubbers. Mining Engineering, 2018, Vol. 70, No. 10, pp. 50-57. https://doi.org/10.19150/me.8547.

6. Spraying Systems Co. Industrial Hydraulic Spray Products, C75. https://www.spray.com/-/media/dam/industrial/usa/sales-material/catalog/cat75hyd_us.pdf.

7. Klima, S., Seaman, C., Mischler, S., Organiscak, J. Comparison of Different Hollow Cone Water Sprays for Continuous Miner Dust Control Applications. SME Annual Meeting, Feb. 19-22, 2017, Denver, CO. Pre-print 17-026.

8. McCoy, J.F., Schroeder, W.E., Rajan, S.R., Ruggieri, S.K., and Kissell, F.N. (1985). New Laboratory Measurement Method for Water Spray Dust Control Effectiveness. American Industrial Hygiene Association Journal, 46:12, 735-740. https://doi.org/10.1080/15298668591395652.

9. Jiang, H., Zheng, Y., Klima, S., Seaman, C.E., Beck, T.W. A Laboratory Study of the Dust Deposition and Suppression Process for Respirable Coal Dust in a Confined Chamber. SME Annual Meeting, Feb. 27-Mar. 02, 2022, Salt Lake City, UT. Pre-print 22-007.