

## FIELD EVALUATION OF AN INLINE WET SCRUBBER FOR REDUCING FLOAT COAL DUST ON A CONTINUOUS MINER SECTION

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### ABSTRACT

Controlling float coal dust in underground coal mines before dispersal into the general airstream can reduce the risk of mine explosions while potentially achieving a more efficient and effective use of rock dust. A prototype, flooded-bed scrubber was evaluated for float coal dust control in the return of a continuous miner section. The scrubber was installed in line between the ventilation tubing and an exhausting auxiliary fan. Airborne and deposited dust mass measurements were collected over a period of three days at set distances from the fan exhaust to assess the changes in float coal dust levels in the return due to the operation of the scrubber. Mass-based measurements were collected on a per-cut basis and were normalized per foot of advance by the continuous miner. Results show that average float coal dust levels measured under baseline conditions were reduced by over 91% when operating the scrubber.

### INTRODUCTION

In 2012, underground mining in the United States produced over 342 million tons of coal [EIA 2013]. During the cutting, crushing, and transport of this coal, dust is generated and can be entrained in the air ventilating the mine. Title 30 Code of Federal Regulations Part 75.400-1 (30 CFR§ 75.400-1) defines float coal dust as particles of coal that can pass a No. 200 sieve. These coal particles can be carried by the ventilating air into return entries before settling onto mine surfaces [NIOSH 2006]. If this float coal dust becomes re-entrained into the airstream, it can propagate an explosion throughout mine workings [Harris et al. 2010].

Application of rock dust in underground coal mines is required by Federal regulation as a means of preventing the propagation of explosions by float coal dust. In order to meet Title 30 Code of Federal Regulations Part 75.403 (30 CFR § 75.403), 80% incombustible content must be maintained in the composition of dust deposited in mine entries [76 Fed. Reg. 35968 (2011)]. This fraction of incombustible content is increased if elevated levels of methane are present. In order to maintain the required incombustible content, frequent or constant application of rock dust is undertaken by mine operators. Title 30 Code of Federal Regulations Part 75.2 (30 CFR § 75.2) defines the properties of the rock dust that must be used by mine operators.

To assist mine operators, the Office of Mine Safety and Health Research (OMSHR) of the National Institute for Occupational Safety and Health (NIOSH) has initiated a research project to evaluate control technologies that can be used to minimize the amount of float coal dust generated during mining processes and/or capture float coal dust before it can be deposited in return or belt entries in underground coal mines. One control technology that has recently been evaluated by OMSHR is a prototype, inline flooded-bed scrubber (Figure 1). This scrubber was connected to an exhaust auxiliary face fan, which used ventilation tubing to capture dust-laden air at a continuous miner face. The scrubber contained a stainless steel filter panel that was wetted with water discharged from a series of 12 spray nozzles. In flooded-

bed scrubbers, dust particles are encapsulated by water droplets as both pass through the mesh in the filter panel, with the dust-laden water droplets then removed from the airstream by a mist eliminator. The air filtered by the prototype scrubber was discharged by the auxiliary fan into the mine return entry. The dust-laden water removed by the mist eliminator was pumped to a settling tank and recycled back to the scrubber unit. This prototype scrubber, Compact Filter Technic (CFT) Type HCN 600/1, was designed for a maximum airflow of 18,000 cfm.



Figure 1. Inline scrubber unit (left) prior to installation with scrubber filter panel and water spray nozzles (right).

Flooded-bed scrubbers mounted on continuous miners have similar components and operate in a similar manner to this prototype, but at lower air quantities. Past research has shown that flooded-bed scrubbers can remove over 90% of the respirable dust from the air drawn into the scrubber [Colinet and Jankowski 2000]. Consequently, there was potential that this prototype, inline scrubber would have the capability to remove a large quantity of float coal dust before it was discharged and deposited into the return entry.

### TEST CONDITIONS

Tests were conducted on a four-entry longwall development section, which was operated as a super section. One continuous miner operated in entries 1 and 2 on the left side of the section and was supported by two shuttle cars and a twin-boom roof bolter. The second continuous miner operated on the right side of the section in entries 3 and 4 and was also supported by two shuttle cars and a twin-boom roof bolter. NIOSH dust sampling was completed on the left side of the section over three consecutive day shifts. On shift 1, the scrubber had not yet been installed which allowed for the collection of baseline dust concentrations. On shifts 2 and 3, the scrubber was installed and operated. Dust levels from these two shifts were compared to baseline levels to determine the relative effectiveness of the scrubber.

Intake air was directed through entry 2 with entry 1 serving as the return. Face ventilation for entry 2 was provided by exhaust tubing connected to an auxiliary fan located in the return portion of entry 1. Face ventilation in entry 1 was delivered into the face by exhaust line brattice. Both the tubing and brattice were located on the left sides of the respective entries as shown in Figure 2. Because the scrubber was placed in line with the auxiliary fan, only dust generated in entry 2 could be cleaned by the scrubber. Therefore, the effectiveness of the

scrubber for controlling float coal dust was based upon cuts taken from entry 2. Also, the depth of the cut from one cut to the next was not consistent throughout the sampling period. Consequently, dust mass collected for each cut was divided by the depth of cut so that dust generation for each test condition was normalized per-foot of miner advance.

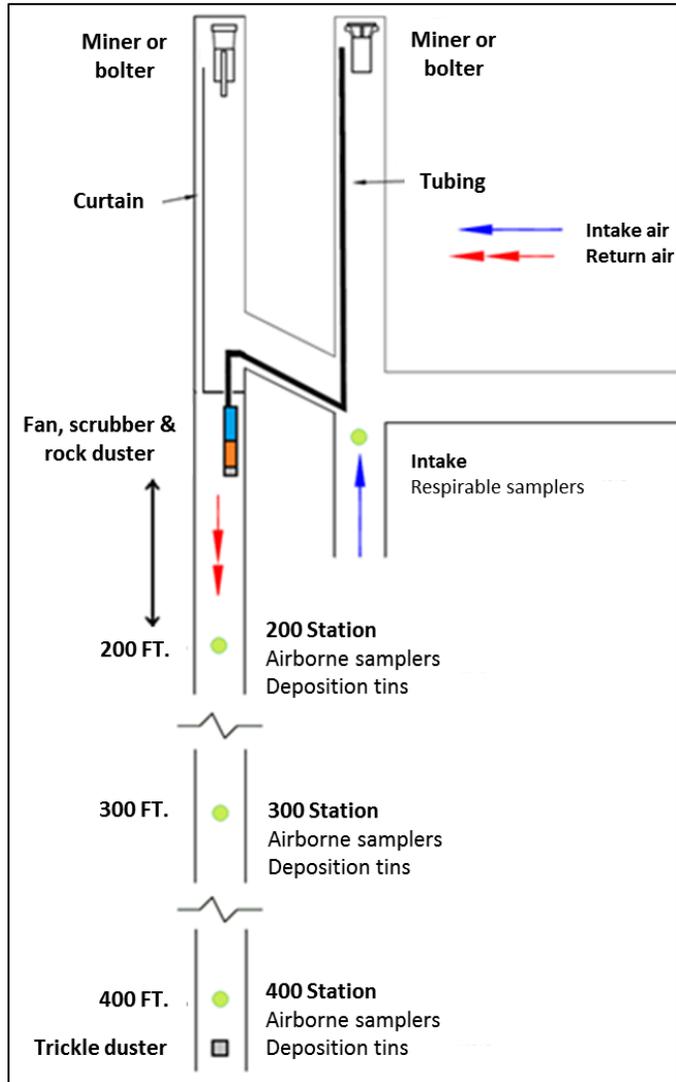


Figure 2. Schematic of mining entries and NIOSH sampling stations.

Dust sampling stations were located in the center of the return entry at distances of 200, 300, and 400 feet outby the discharge of the auxiliary fan as shown in Figure 2. Required rock dusting procedures on this section entailed the dispersal of rock dust at the auxiliary fan at all times while the continuous miner was cutting. However, the dispersal of rock dust under normal working conditions would overwhelm coal dust generated by the continuous miner and adversely impact NIOSH sampling efforts to assess float coal dust control. As a result, the mine obtained permission to place a trickle rock duster just outby the 400-foot sampling station. This rock duster was operated on a continuous basis. The 400 feet of return between the auxiliary fan and trickle duster was rock dusted on an intermittent basis. No rock dusting occurred in this zone while the miner was in entry 2 and NIOSH was collecting samples. After completion of each cut in entry 2, NIOSH would remove/cover the sampling equipment and rock dusting would be performed.

Although rock dusting at the auxiliary fan was suspended during the NIOSH sampling periods, it became apparent that the high-velocity air stream discharged by the fan (over 3,500 fpm) was causing rock

dust that had previously been deposited in the exhaust evase and in the entry to be entrained into the return airstream. NIOSH collected airborne dust samples in the return entry when no cutting or rock dusting was being conducted. These samples contained measurable amounts of rock dust thus indicating that rock dust contamination was occurring. Consequently, thermo-gravimetric analysis of collected samples was used to determine combustible content in order to quantify the fractions of coal and rock dust contained in the collected samples. This analysis is described in the next section.

### SAMPLING AND ANALYSIS METHODS

NIOSH collected three types of dust samples at each of the 200-, 300-, and 400-foot sampling locations in the return which included: airborne float dust samples, float dust deposition samples, and airborne respirable dust samples. These samples were only collected for the cuts taken in entry 2 which were ventilated with the auxiliary fan. Sampling for these deposition and airborne samples was initiated as close to the start of a cut and terminated as close to the end of the cut as possible. This maximized the amount of time that mining occurred during the NIOSH sampling periods.

#### Airborne Float Dust Samples

Because a sampler designed specifically for collecting airborne float dust is not available, an optional sampling method was sought. Total dust samplers were examined as a means to determine the mass concentration of airborne rock dust and float coal dust generated during the continuous miner cuts that remains airborne in the return entry. The Institute of Occupational Medicine (IOM) stainless steel samplers with internal stainless steel filter capsules containing binder-free, 25-mm quartz fiber filters were selected to collect the airborne dust samples. The IOM sampler is typically used as an open-faced sampler to collect inhalable airborne dust [Mark and Vincent 1986], which is considered 100 microns and smaller. Utilization of these samplers to obtain airborne float dust measurements would provide data to determine the relative dust reduction of the inline scrubber

NIOSH adapted the IOM samplers so that isokinetic sampling [Quilliam 1994] could be conducted in order to optimize sample collection. Isokinetic sampling nozzles, machined from stock stainless steel tubing, were connected to the IOM samplers. Straight tubing was used in order to minimize potential dust losses to the nozzle walls, and nozzle lengths were kept short for the same purpose. The nozzles were attached to the IOM assembly using a custom 3-D printed part with appropriate O-rings, as shown in Figure 3. When sampling at 2 liters per minute (using a Zefon Escort ELF sampling pump), a 0.152-inch-diameter nozzle inlet provided an inlet flow velocity of 560 fpm. Therefore, 100% isokinetic sampling would be achieved when return air speeds matched this velocity. For this study, the pumps were never adjusted from the 2.0 lpm setting and the same nozzles were used each test day.



Figure 3. Exploded (left) and assembled views of IOM sampler fitted with isokinetic nozzles.

Center line air velocities were measured near the sampling stations in the return entry during the test period. The average velocity for the center line velocities from the three sampling stations was 552 fpm, which is near ideal for the isokinetic probe selected. Some variation was observed from station to station and shift to shift with individual velocities ranging from 484 to 613 fpm, so that sampling was always maintained within 14% of ideal isokinetic conditions.

In preparation for sampling, quartz fiber filters were loaded into the IOM sampling capsules and the assemblies heated in a muffle

furnace at 515°C for 2.5 hours to remove any contaminants that may have existed on the filters as they arrived from the manufacturer. The samples were cooled to room temperature inside of the sealed muffle furnace. They were then moved into OMSHR's weighing laboratory, which is a temperature- and humidity-controlled clean room, and allowed to equilibrate for 24 hours. The samples were pre-weighed on an Ohaus Model AP310S analytical balance (0.1 mg resolution) and sealed inside of plastic bags for transport to the mine.

Each morning, prior to entering the mine, compressed air was used to blow out the isokinetic nozzles and the isokinetic adapters were installed on the sampling capsules. The nozzle ends were sealed with rubber caps in order to prevent fugitive dust contamination during transport to the mining section. At the end of each sampling day, the interiors of the nozzles were visually inspected to ensure that dust buildup inside was minimal compared to the amount of dust collected on the filter for that day's test. A polished finish was visible each day, so it is assumed that mass lost due to nozzle build-up was negligible in this study.

Before the start of each cut, nozzle caps were removed and sampling pumps were started. During the set-up process for sampling, researchers moved in an outby direction (from the 200-foot station to the 400-foot station) in order to avoid kicking up rock dust at upwind locations which could cause contamination in downwind samples. Pumps were allowed to run for the duration of one cut. Samplers were turned off, nozzles were capped, and assemblies were collected in the opposite manner (moving in an inby direction from the 400-foot station) to once again avoid contamination by rock dust.

Total dust samplers were handled and transported in an upright position (isokinetic nozzles facing upwards) in order to avoid dust collected on the filter from being dislodged onto the nozzle or end cap. Custom case inserts were used to ensure that samplers were always positioned upright inside of a top-loading container, which was also maintained in an upright position during transport out of the mine. The same precautions were taken when transporting the total dust samplers from the mine to OMSHR's weighing facilities in Pittsburgh.

The following thermo-gravimetric technique [Sapko et al 2006] was utilized to differentiate between the combustible coal and incombustible content contained in the samples. The capsule samples were allowed to set overnight inside of OMSHR's weighing room to equilibrate to environmental conditions. Prior to post-weighing, the outsides of the filter capsules were wiped clean with an alcohol swab so that only the dust contained within the capsule would contribute to mass gain. In order to determine float coal dust mass and exclude contributions from rock and moisture, the filter capsules were run through a series of heat treatments using a muffle furnace. First, the samples were heated at 105 °C for two hours to drive off moisture. The capsules were allowed to cool inside of the furnace and then equilibrate in the weighing room overnight in the same manner as described above. Next, the capsules were weighed to determine the dry dust mass. This mass represents the weight added from the combination of rock dust and float coal dust collected during sampling. The samples were returned to the muffle furnace and heated for 2.5 hours at 515°C. The time for the oven to reach the temperature set point was about 1.5 hours. The samples were then allowed to cool slowly inside of the muffle furnace before being transferred back to weighing room for equilibration and subsequent weighing. The weight loss of the sample during the high-temperature heating represents the mass of combustible material that was in the capsule (the sum of the combustible fraction of the rock dust collected and the combustible fraction of the coal dust collected). The difference between the final capsule weight and the pre-test capsule weight represents the amount of incombustible material in the capsule (the sum of the incombustible fraction of rock dust collected, the incombustible fraction of the coal dust collected, and the incombustible rock mined at the face).

Grab samples of coal dust and rock dust were collected during the test to obtain a reference combustible and incombustible percentage for both the coal being mined in entry 2 and the rock dust being applied in the return airway. The collection and analysis procedures for the grab samples are described below. Using the

measured combustible and incombustible fractions of grab samples, the amount of float coal dust and rock dust on the individual samples can be determined by solving two simultaneous equations with two unknowns for each filter sample (this was done manually using Excel's Solver add-on and was double checked in MATLAB).

#### **Float Dust Deposition Samples**

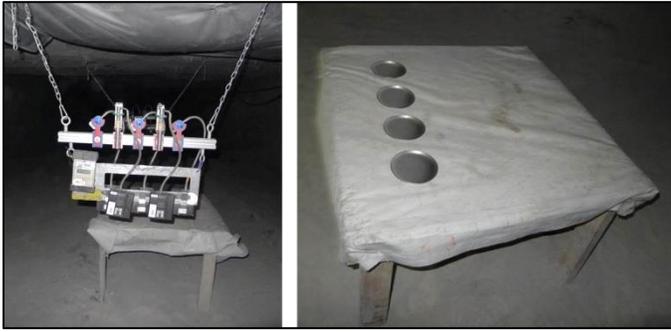
Deposition samples were collected in shallow tin pans (designed for holding compact discs) that were light enough to be weighed on the Ohaus balance. The tins were pre-weighed and kept in sealed plastic bags for transport to the mine. At the mine, four tins were opened just prior to the start of a cut, placed upon a brattice-covered table at each sampling station, and allowed to passively collect dust on the surface of the bottom half of each tin by sedimentation due to gravity (similar to how float dust passively collects on the surfaces of mine entries). Prior to sample collection, a section of brattice had been attached to the mine roof above the sampling table to prevent contamination of the tins from material that dropped from the roof. The samples were collected at the end of the cut by closing the tins (with deposited dust inside) and sealing for transport back to the weighing lab at OMSHR. Prior to post-weighing, the outside of each tin was cleaned with alcohol so that only the dust contained within the tin would contribute to the mass gain. The difference between the final weight and the pre-weight was used to determine the total mass of dust collected over the sampling time period. That total mass represents a combination of float coal dust plus deposited rock dust.

After post-weighing, the dust contained in each tin was transferred to an IOM capsule for thermo-gravimetric analysis. This was completed by vacuuming the surface of the tin using a fine-tip nozzle. A small-diameter nozzle was used, thus providing high-velocity suction air to dislodge dust from the surface of the tin. The nozzle was connected to a metal IOM capsule fitted with a quartz-fiber filter using a 3D-printed, threaded adapter with an O-ring seal. The nozzle tip was composed of plastic to prevent scratching of material from the tin surface, and the tubing leading to the IOM capsule was conductive to prevent particle losses due to electrostatic effects. Dust was removed with an airflow of 5 lpm using a 1-mm inner diameter nozzle tip. Vacuuming the entire surface required about 10 minutes for each tin. The IOM capsule was weighed using the Ohaus balance. The sample was then processed using the same heating sequence as previously described. The final results for deposition tin samples are reported in terms of the change in combustible mass collected per foot of advance due to the introduction of the scrubber. Since the rock dust had very low combustible content (less than 3%), interference that rock dust, applied or mined at the face, may have had on the results was minimized.

#### **Respirable Dust Samples**

Respirable coal dust samples were obtained with Zefon pumps operated at 2 lpm and equipped with a 37-mm diameter polyvinyl chloride (PVC) filters and Dorr-Oliver cyclones. These samplers are identical to those used by the coal mining industry and MSHA for respirable coal dust compliance sampling. In these tests, two respirable dust samples were collected at each sampling station to provide information on the change in airborne concentration of smaller float dust particles due to the introduction of the scrubber. Filter pre- and post-weights were obtained on a Mettler Toledo Model MT5 microbalance, after the filters were desiccated and allowed to reach equilibrium in the OMSHR weighing lab. Figure 4 shows the respirable and total airborne dust samplers and the deposition tins as they were deployed underground at each sampling station in the return entry.

Also, two respirable dust samplers and a Thermo Scientific personal DataRam (pDR) sampler were placed in the intake airstream in entry 2. The pDR uses light-scattering technology to provide a real-time measurement of dust concentrations, which are stored internally for later download onto a computer for analysis. This sampling package was started upon arrival at the section and operated throughout the NIOSH sampling period. The data gathered by this sampling package was examined to ensure that no significant dust changes occurred in the intake air during the sampling survey.



**Figure 4.** Airborne total and respirable samplers on left and deposition tins shown on right.

**Grab Samples of Mined Coal and Rock Dust**

A small sample of mined coal product was collected from the conveyor of the continuous miner during each cut and was sealed in a plastic jar. Likewise, one sample of rock dust used at the scrubber discharge location was collected and sealed in a plastic jar. These rock dust samples were obtained either from an open bag next to the rock duster or directly from the rock duster itself. These samples were used to measure the combustible and incombustible content of the coal being mined and the rock dust being used.

For the coal dust grab samples, the material was sized to minus 75 microns using a sieve shaker and appropriate sieve, which had been cleaned in an ultrasonic bath prior to use. A portion of that material (27 milligrams, on average) was then transferred manually into a pre-weighed IOM capsule for thermo-gravimetric analysis to determine combustible/incombustible content using the same method as previously described. Four sample splits were analyzed for each of the coal grab sample jars, and the average combustible and average incombustible fraction of all samples were used as input parameters in the aforementioned simultaneous equations. For the rock dust grab samples, one sample from each jar was analyzed in a similar manner. Average combustible content for the coal and rock dust was 90.9% (s.d. = 0.033) and 2.5% (s.d. = 0.004), respectively. The average incombustible content was 9.1% (s.d. = 0.033) for coal and 97.5% (s.d. = 0.004) for the rock dust.

**Mine Environment**

Airflow, temperature, and humidity measurements were recorded to provide information on the stability of environmental conditions throughout baseline and scrubber tests. Air quantity measured in the return entry was approximately 61,000 cfm, with an average entry velocity of 495 fpm. Airflow through the auxiliary fan/scrubber was over 16,000 cfm as determined from traverse measurements made with a pitot tube and differential pressure gage. Traverse and centerline airflow readings taken in the return entry were used to correct for the effect of changing dilution due to minor changes in the ventilation rate in the section from cut to cut for airborne dust samples. This correction factor was multiplied directly to the calculation of airborne mass collected per foot of advance for individual samples. In this survey, return entry airflow was relatively consistent. Therefore, application of these airflow correction factors caused less than 1% change in the final scrubber efficiency calculation with negligible impact on test results.

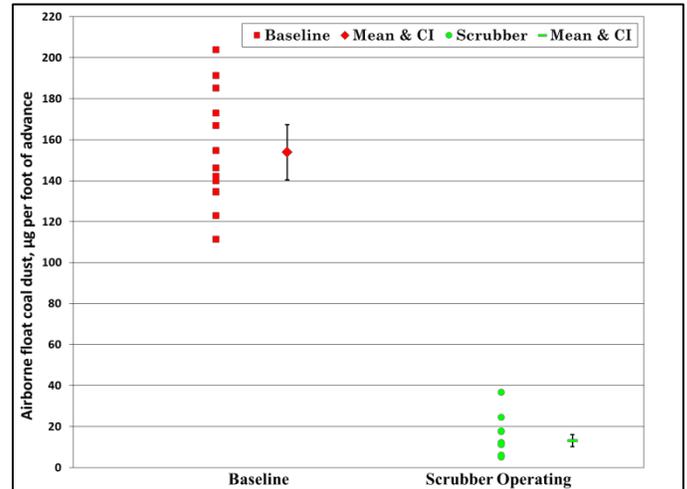
A mechanical thermometer and hygrometer (HTAB-169, +/- 3% Relative Humidity, +/- 1% Temperature scale) was used to monitor relative humidity and temperature in the return near the 400-foot station. The temperature and relative humidity were recorded intermittently throughout the test period by NIOSH personnel. Average temperature was 64°F (s.d. = 1.6), while average relative humidity was 78% (s.d. = 2.8). No corrections were made to the data to compensate for minor variations in temperature and humidity.

**SAMPLING RESULTS**

**Airborne Float Coal Dust**

The overall efficiency of the scrubber for removing airborne float coal dust was calculated by comparing mean values of all samples collected during the two baseline cuts (without the scrubber installed)

to the mean value for the three cuts with the scrubber installed. Data from the three sampling locations were combined to provide an average return mass for each test condition. All data were corrected for incombustible content (applied rock dust, coal ash, and rock mined at the face) using the thermo-gravimetric procedures described above. Figure 5 shows the individual float coal dust measurements (combustible fraction), mean dust level, and 95% confidence interval (CI) for the mean as determined for each test condition. The results showed a reduction in airborne float coal dust mass in the return of 91.5% when comparing the mean levels with the scrubber operating to baseline conditions without the scrubber. It is also obvious when comparing the confidence intervals for the mean dust levels that operation of the scrubber resulted in a statistically significant difference.



**Figure 5.** Airborne float coal dust collected with IOM samplers.

**Float Coal Dust Deposition**

The overall scrubber efficiency for reducing combustible coal dust deposited in the return was calculated by comparing the mean dust level for deposition samples from the baseline cuts to the mean dust level from the cuts with the scrubber installed. Once again, data from the three sampling locations were combined to provide an average return mass for each test condition, with the thermo-gravimetric procedures described above correcting for rock dust interference. Figure 6 shows the individual dust deposition measurements, mean dust level, and 95% confidence interval for the mean as determined for each test condition. The results showed a reduction in deposited coal dust mass in the return of 96.6% when comparing the mean levels with and without the scrubber operating. Again, it is apparent when comparing the data and confidence intervals for the means that a statistically significant difference was observed with the scrubber operating.

The effect of distance on deposited float coal dust mass is shown in Figure 7. As expected, these data show that higher levels of combustible dust mass deposit near the fan exhaust for baseline conditions and that the deposition rate decreases with increasing distance from the source. With the scrubber operating, the large differences in float coal dust deposition between sampling locations is mitigated due to the significant removal of dust mass by the scrubber.

**Respirable Dust**

Although upwind rock dusting was suspended during NIOSH sampling, it was apparent from the deposition samples that there was some amount of entrained rock dust in the return air during testing. However, the respirable dust samples could not be corrected for rock dust contamination by using the same thermo-gravimetric technique described above. For this reason, the data presented here represents the combination of respirable coal dust plus respirable rock dust in the return during a given cut. Importantly, since the concentration of entrained rock dust in the return should not be significantly affected by the presence of the scrubber, the efficiency value calculated below will



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