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Air filtration technology for respirable dust control in room-and-pillar mining

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ABSTRACT: A novel dry and wet air dust filter concept was conceived and demonstrated successfully at two mines. A steel-wool and a fiberglass filter, suitable for underground use were identified through laboratory testing and demonstrated in the mine. The steel wool filter was operated with and without water sprays while the fiberglass filter was only operated in the dry mode. The dry steel wool filter provided a dust capture of 37% at a negligible pressure drop. When fine misting water sprays were used on the steel wool filter, the dust capture increased to 51% again with a negligible pressure drop. The filter screen also remained clean and no change in air flow characteristics was observed as a function of time. The dry fiberglass filter however did not perform as well achieving only 11% dust capture while introducing a significant resistance to air flow. This technology is seen to have several applications in underground coal mines.

1 Introduction

In the last decade, underground coal mine productivity in the United States has increased from 2.54 tons to 3.99 tons. This has put a strain on mine operators who must comply with the Federal dust standard of 2 mg/m^3. A few mines already operating close to the regulated limit, usually result in noncompliant dust samples when attempts are made to further increase productivity. Therefore, optimizing existing dust control systems and finding new ones has become a top priority.

In that regard, the authors have identified air filtration technology as a possible means to improve dust control in underground coal mines. A low-cost dust control device for total and quartz dust control using filter panels of suitable material for underground use was envisioned, developed and demonstrated to achieve the objective of improved dust control. These filter panels can be stretched across the cross-section of an entry at a suitable location away from the paths of mine equipment and would allow for passage of personnel through an opening or a doorway within the filter panel. The installation of the filter was proposed so that some of the respirable dust from upstream mining activities could be filtered before the air reached the down-stream miner and roof-bolter. Other applications of this filter material would be downstream of the development work cutting overcasts and underpasses to keep the generated dust out of the intakes of mining sections. The panels could also be employed in the face area to control dust exposures of downstream miner and bolter occupations in the face area from the dust generated by the upstream miner. Possible locations for installing the filter panels in the face area are indicated in Figure 1.

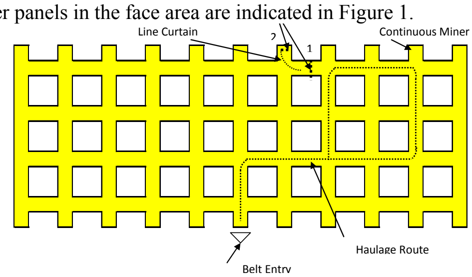


Figure 1. Possible installation locations of the filter panels in the face area.

2 Methodologies

2.1 Filter Material Selection Criteria and Material Selection

The following criteria for filter material characteristics were identified for selection of the appropriate media. These were:

- Low-pressure drop
- High respirable dust (less than 10 micron) capture efficiency
- Approved for underground use (should not be flammable and produce toxic gases upon combustion)
- Light-weight to allow easy installation and removal.

- High dust capacity so that replacement is necessary no more than once every shift.

Based upon these selection criteria, three materials for filter panel use were identified. The material chosen initially was polyester which was tested in the laboratory and the field. Unfortunately, this material did not meet the criteria for flammability for underground use. Hence, subsequently a fiberglass and steel-wool filter materials were investigated and demonstrated which met all necessary usability criteria.

2.2 Laboratory Testing

The development of this concept was initiated in the laboratory. The polyester and fiberglass filters were tested in a test chamber constructed with a 15-inch x 14 5/8-inch cross-section and 6-feet in length. An exhaust fan was installed at one end of the chamber and the gaps between the chamber and the fan were sealed. Arrangements were made to introduce the filter being tested about 3-ft (half-way) along the length of the chamber. The other end of the chamber was left open. Pre-weighed dry dust was introduced in to the test chamber at one end over a fixed length of time (20 minutes) by elutriation with a small compressed air nozzle. Air velocity measurements were taken at nine locations in a grid pattern across the cross-section of the test chamber before and after installation of the filter and at the end of the test. These measurements provided an estimate of the pressure drop across the filter and also allowed for computation of the dust accumulation capacity of the filter. The steel-wool filter was tested in a set-up sketched in Figure 2. Pressure and velocity measurements were taken at the indicated sampling locations marked 1-6. Sampling points 1-2-3-4 were located upstream of the filter and spaced horizontally across the duct. Sampling points 5-6 were located downstream of the filter in the center of the duct and spaced approximately 16-inches apart.

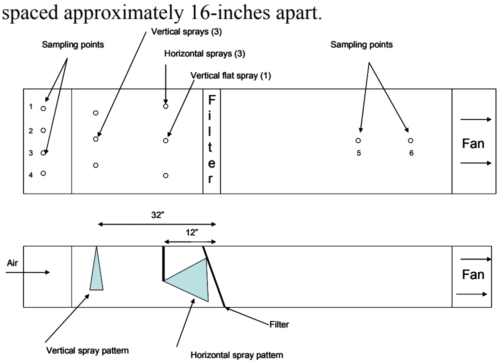


Figure 2. Schematic of the laboratory test set-up utilized for evaluation of the steel-wool filter.

2.3 Field Demonstration

Field demonstration of the polyester filters was conducted at two mines; one in southern Illinois and one in central Illinois. At the southern Illinois mine, a 20-ft x 6-ft filter panel was mounted on a wooden frame and installed across the entry cross-section in the panel return (Figure 3). Gravimetric dust sampling pumps were located upstream and downstream of the filter panel as shown in Figures 4 and 5. Air velocity measurements were conducted before filter installation and at the beginning and end of the tests. The test duration was 60 minutes. Air velocity measurements were also taken across two parallel entries before and after installation of the filter to estimate the impact of the filter on air flows.

Figure 3. Filter panel installation and dust and air velocity measurements during field testing of the air filtration concept at a southern Illinois mine.

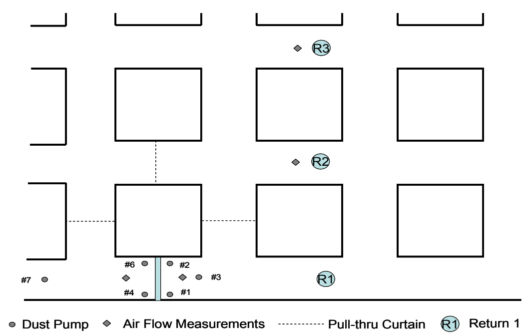


Figure 4. Field testing setup of the polyester filter panels at a Southern Illinois mine.

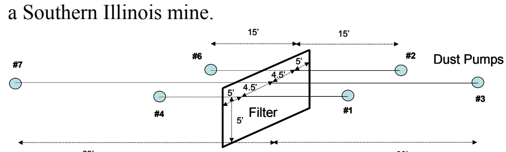


Figure 5. Dust sampling layout of air filtration concept field testing at a southern Illinois mine.

The fiberglass and steel-wool filter materials were demonstrated in the field over long durations (3-5 hour tests) to determine their dust capture efficiency and resistances to air flow. The steel wool filter was operated with and without water sprays to accomplish higher dust capture efficiency and filter cleaning with the use of water. A set of 6 misting sprays delivering 0.4 gpm of water at 80 psi were placed 4–ft away from the filter panel spraying vertically down such that a uniform spray coverage was achieved on the filter panel. Tests were conducted in the production shaft area of a central Illinois mine since the mine was facing major dust issues in this area. Figure 6 shows the field demonstration test setup at the mine. It can be seen that prior to this demonstration, the mine was already using sprays for dust control which were not very effective. During the demonstration tests, these sprays were turned off. The steel-wool filter was operated with and without water sprays installed by SIU. The fiberglass filter was only tested dry. Dust concentrations upstream and downstream of the filters were monitored. Air flow measurements through the filter were also recorded over periodic intervals.

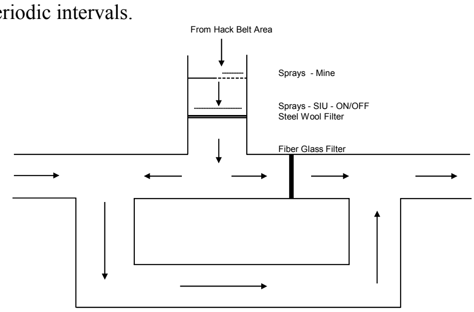


Figure 6. Fiberglass and Steel-wool filter demonstration at a central Illinois mine.

3 Results and Discussion

3.1 Testing of Polyester Filter Panels

The studies on development of panel filters were initiated with polyester filter materials. Nine of these filter materials were tested in the laboratory in a set up described above. Exact specifications of the filter materials are available with the authors. The results presented in Table 1 indicate that the dust capture efficiencies ranged from 9% to 89%. However, high capture efficiencies were associated with higher pressure drops across the filter material (Figure 7). Hence, to achieve a balance between capture efficiency and resistance to air flow, two materials (2-layer purple and 1-layer yellow) were selected for additional field testing. These materials provided a dust capture efficiency of 40-60% at a moderate pressure drop of 0.0055 to 0.0078 inches of water column under laboratory conditions. During field testing, however, respirable dust reductions of 13% and 12%, which corresponded to dust reductions from 2.53 mg/m^3 to 2.19 mg/m^3 and 2.23 mg/m^3 to 1.96 mg/m^3, were achieved with these materials. The reason for lower dust capture efficiency in the field was that the tests were run only for duration of 60 minutes each. As seen in Figure 7, the dust capture efficiency increases as a function of pressure drop. If the tests were carried out for a longer duration, higher capture efficiencies should have resulted, albeit at an increased pressure drop as the captured dust closed any openings or leakages across the filter.

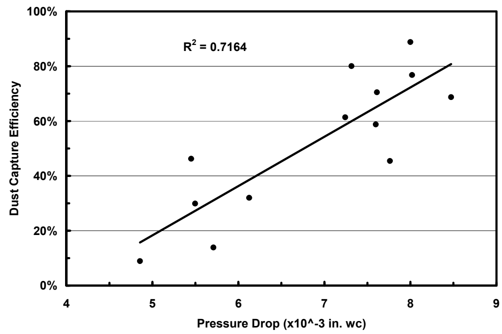


Figure 7. Relationship of pressure drop across filter panel with the dust capture efficiency measured during laboratory experimentation using different varieties of polyester based filter materials.

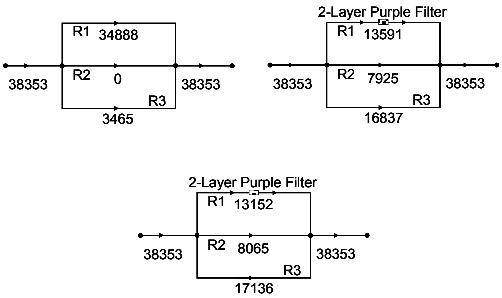
Table 1. Laboratory polyester filter panel testing results.

Filter Material	Air Flow* (fpm)			Head Loss	Resistance	Dust Concentration (mg/m^3)		Dust Reduction
	Unobstructed	Pre-Test	Post-Test	(in. wc)	(P.U.)**	Input	Output	(%)
White - 2 Layer	366	109	0	0.00761	276	30	9	70%
White - 2 Layer (Repeat)	385	111	0	0.00847	296	24	8	69%
Purple - 2 Layer	366	129	88	0.00760	197	25	10	59%
Purple - 2 Layer (Repeat)	375	127	94	0.00776	207	18	10	45%
Yellow - 2 Layer	366	110	0	0.00731	260	17	3	80%
Yellow - 2 Layer (Repeat)	375	111	60	0.00800	280	14	2	89%
Purple - Back Layer	374	204	152	0.00613	63	14	10	32%
Purple - Front Layer	374	249	209	0.00486	34	10	9	9%
Yellow - Back Layer	374	154	31	0.00724	132	37	14	61%
Yellow - Front Layer	374	229	157	0.00545	45	17	9	46%
Yellow - Front Layer (Repeat)	375	229	184	0.00550	45	14	10	30%
White - Back Layer	385	140	95	0.00802	176	13	3	77%
White - Front Layer	385	238	212	0.00571	43	13	11	14%

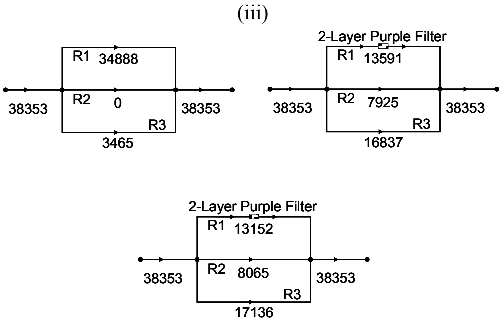
* C/S Area: 1.52 ft^2
** P.U. - Practical Units

During the duration of the tests, a moderate drop in air velocities was observed in the entry after introduction of the filters (Figure 8). The authors believe that these issues can be resolved effectively through proper installation of pull-thru curtains, changes in regulator openings and appropriate simulations of mine ventilation within a panel.

To estimate filter change requirements during the shift, a dust reduction target from 2 mg/m^3 to 1.5 mg/m^3 was established. The filter change timing was set at the time when airflow reductions across the filter were greater than about 30%. At this level of air reduction, the filter capacity was estimated at about 850 mg/ft^2 of respirable dust. Hence, it appears that at 20,000 cfm of air in the last open cross cut (LOXC) at 2.0 mg/m^3 being filtered to a level of 1.5 mg/m^3 without causing more than a 30% reduction in airflow before the filter is changed, total filter area of 160 ft^2 would be required. The entry cross-section is typically about 20-ft x 6.75-ft or 135 ft^2. Hence, it appears that the life of the filter would be slightly less than duration of the entire shift. A more appropriate filter material selection is possible that will ensure that the filter installation is effective for the duration of at least one full-shift making its use more practical.



(a) (i) (ii) (iii)



(b) (i) (ii) (iii)

Figure 8. Airflows (in cfm) across three return entries during field testing of the innovative "Total Air Filtration" concept for (a) 1-Layer Yellow Filter and (b) 2-Layer Purple Filter at (i) before filter installation, (ii) after filter installation, and, (iii) at the end of test period. Most airflow measurements indicated are direct measurements. The measurements that were not taken have been simulated using a VentSim PC model.

Additional tests on the low-cost filter panel for dust control were conducted at a central Illinois mine. These tests were conducted in the production shaft hack belt area. The results indicated that the filter panel, when used in conjunction with water sprays, was the most effective measure for controlling the dust. Downstream dust concentrations as measured by the personal data rams were reduced from 14.5 mg/m^3 to 5.3 mg/m^3. The reductions using the existing system employed by the mine using just water sprays only reduced the dust concentrations marginally. When the filter panel was installed initially, air reduction and pressure drops were only marginal. However, the air flow reduced significantly after 15 minutes. Given these results, it appears that the application of the filter panel in the face area may be effective. The filter panel blinding may not be as big an issue when used in the last open crosscut where the dust concentrations are an order of magnitude lower than in the area where these tests were conducted.

To determine the permissibility of the filter material for underground use, the Manufacturer's Safety Data Sheet (MSDS) information on the filter materials was forwarded to MSHA. After initial evaluations, this material was unfortunately found to be inappropriate for underground use due to flammability concerns. However, the applicability of the concept was demonstrated through this exercise if a suitable filter material could be identified. Such materials were subsequently identified and successfully demonstrated as described in the following sections.

3.2 Testing of Fiberglass and Steel-Wool Filter Panels

The selection of suitable filter materials for field demonstration first involved a series of laboratory tests. The fiberglass filter materials were tested only in a dry mode while the stainless steel-wool filter was tested both in a dry and wet mode. Tests on three fiberglass materials involved measurement of reduction in airflow and the dust capture efficiency of the filters. Table 2 lists the results obtained from the three tested materials. The three materials provided similar performance and hence, Material 2, which provided the highest dust capture, was selected for field demonstration. The laboratory test results of steel-wool filter material are summarized in Table 3. In addition to dry testing, several spray arrangements were evaluated as part of the wet testing. The highest dust capture of 88% was achieved with vertically oriented, hollow-cone, and flat sprays. Vertically oriented atomizing sprays with the filter also provided a very good dust suppression of 74.6%. Hence, this was the spray system selected for field demonstration since it utilized significantly less water.

Table 2. Laboratory airflow and dust capture tests for selection of a suitable fiberglass material for field demonstration. Dust concentrations were measured by PDR.

Filter Material	Air Flow* (fpm)			Head Loss	Resistance	Dust Concentration (mg/m^3)		Dust Reduction
	Unobstructed	Pre-Test	Post-Test	(in. wc)	(P.U.)**	Input	Output	(%)
Fiberglass 1	421	244	228	0.00734	53	7.5	6.2	17%
Fiberglass 2	421	238	215	0.00758	58	6.4	4.6	28%
Fiberglass 3	421	236	200	0.00752	58	10.0	7.5	25%

* C/S Area: 1.52 ft^2, ** P.U. - Practical Units

The selected fiberglass material and a 1/8-inch thick steel-wool filter were demonstrated in the field. Tests were conducted in the production shaft area of a central Illinois mine. Dust levels as measured by a PDR in this area were 13.5 mg/m^3. Even though there were no occupations operating in this area or downstream of this area, the high dust levels was a cause for concern due to dust depositions in the downstream areas. The mine had a spray system installed which was only marginally effective in reducing the dust concentration down to 11.1 mg/m^3 as measured by the PDR.

The authors conducted the filter demonstration in this area using a fiberglass filter operating dry and a steel wool filter operating dry as well as in the presence of sprays.

Table 3. Laboratory testing of 1/8-inch thick steel-wool filter.

Test	Air Flow (cfm)	Pressure Drop (in. wc)	Downstream Dust Conc. (mg/m^3)	Dust Reduction (%)	Water Usage (gpm)	Test Description
A	7422	1.07	7.53	-	-	Free Flow
B	6826	4.25	-	-	-	Free Flow with Filter
C	6510	6.15	0.84	88.8	3.3	Dust Measurements with Filter and Vertical Sprays - HC and Flat 3 vertical hollow cone sprays @ 30psi (0.78 gpm/spray) at 32" & 1 vertical flat spray @ 40psi at 12" (1 gpm)
D	6901	3.97	-	-	-	Free Flow with Filter
E	6333	4.34	4.14	45.0	3.6	Dust Measurements with Filter and Horizontal FC Sprays 3 horizontal full cone sprays @ 40psi (1.2gpm/spray) at 7"
F	6717	4.96	1.92	74.6	0.9	Dust Measurements with Filter and Vertical Atomizing Sprays 3 1/4 LNN18 atomizing sprays (0.9 gpm/spray) @ 40psi in same location as test E
G	7271	0.90	3.16	58.0	0.9	Dust Measurements with only Horizontal Atomizing Sprays as in Test F

The dry fiberglass filter reduced the respirable dust as measured by gravimetric sampling down to 3.2 mg/m^3 (corresponding PDR value of 5.6 mg/m^3). This filter did not present a large resistance to air flow as measured by the insignificant change in air flow after introduction of the filter. When a steel wool filter was tested in the dry mode, the dust levels downstream were reduced to 2.1 mg/m^3 (PDR – 3.9 mg/m^3). This represented a 37% dust capture as measured by the difference in the upstream and downstream dust concentrations obtained from gravimetric sampling. This filter however reduced air flow by 19% after introduction and 3 hours of operation. When water sprays were used in front of the steel wool filter a 51% reduction in dust was achieved with the measured downstream dust concentrations at 0.95 mg/m^3 (PDR – 3.0 mg/m^3). This superior dust capture is related to the use of sprays which when combined with the filter provide the residence time required to wet the dust. Due to the presence of water which kept the filter clean, absolutely no reduction in air flow resulted from the installation of this filter. The results of all these tests are summarized in Table 4.

Table 4. Summary of demonstration of filter panels for dust control at a central Illinois mine.

Test/Filter Material	Test Duration (min)	Upstream Dust Conc. mg/m^3	Downstream Dust Conc. mg/m^3	Reduction in Dust (%)	Reduction in Airflow (%)
Mine Sprays	15	(13.5)	(11.1)	18%	0%
Fiberglass	290	3.5 (8.2)	3.2 (5.6)	11%	0%
Steel Wool – Dry	173	3.3 (6.9)	2.1 (3.9)	37%	19%
Steel Wool - Wet	75	1.95 (6.3)	0.95 (3.0)	51%	0%

4 Summary and Conclusion

In 2005 the authors conceived novel dry and wet air dust filter concepts and demonstrated them successfully at two mines. The dry air filter during field testing provided respirable dust concentration reductions from 2.53 mg/m^3 to 2.19 mg/m^3 and 2.23 mg/m^3 to 1.96 mg/m^3 for two different filter materials. The capture efficiencies could have been much higher, albeit at an increased pressure drop, if the tests would have been run for duration longer than 60 minutes. A moderate drop in air velocities was observed in the entry after introduction of these filters. It was believed that this issue could be easily resolved through proper installation of pull-thru curtains and changes in regulator openings.

Another issue related to the use of this filter was related to the flammability of the filter material. Hence, newer filter materials made of fiber glass and steel wool were identified and tested in the laboratory. A suitable fiberglass filter material with low resistance (0.007 in. wc @ 300 cfm) and 20-30% dust reduction was identified for field demonstration. Other non-combustible filter materials for wet use were also evaluated in the laboratory. With these materials, a range of dust capture efficiencies from 58% to 88% were achieved at different levels of pressure drops (ranging from 0.9 to 6.15 in-wc @ ~6,600 cfm) and water usage (0.9-3.3 gpm). Two of the filter materials were demonstrated at a central Illinois mine which was facing a major issue related to dust in the production shaft area. Despite the efforts of the mine staff, excessive dust was a problem in the production shaft area prior to the demonstration. The existing dust concentration in the production shaft area was 13.5 mg/m^3 as measured by a real-time dust monitor (PDR). The water sprays employed by mine staff were only able to reduce the dust by 18% down to 11.1 mg/m^3 also measured by the PDR. The authors conducted three sets of tests with two suitable filter types identified during laboratory testing. The two filter types were a steel wool filter and a fiberglass filter. The steel wool filter was operated with and without water sprays while the fiberglass filter was only operated in the dry mode. The dry steel wool filter provided a dust capture of 37% at a negligible pressure drop. When fine misting water sprays were used on the steel wool filter, the dust capture increased to 51% again with a negligible pressure drop. The filter screen also remained clean and no change in air flow characteristics was observed as a function of time. The dry fiberglass filter however achieved only 11% dust capture while introducing a significant resistance to air flow. The steel wool filter material is probably the material of choice for underground coal mine use due to its non-combustible nature and higher durability.

Acknowledgement

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