ISBN 978-0-615-20009-5

Improving the performance of fan-powered dust collectors in stone cutting applications

G.J. Chekan
National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA, USA

A.B. Cecala, D.E. Pollock, & J.A. Zimmer
National Institute for Occupational Safety and Health, Pittsburgh Research Laboratory, Pittsburgh, PA, USA

ABSTRACT: In the dimension stone industry, workers in processing shops may be exposed to harmful levels of respirable silica dust when conducting the different tasks in stone preparation, which include cutting, grinding, polishing, and thermaling. To protect workers from this health hazard, operators sometimes ventilate processing shops using fan-powered dust collectors to capture and filter dust. To investigate this issue, NIOSH, Pittsburgh Research Laboratory, in cooperation with a dimension stone operation, upgraded an off-the-shelf dust collector the operator was utilizing in a polishing/cutting shop. Initial dust surveys showed that the unit was under-designed for the amount of dust being generated in the shop. The objective of the research was to cost-effectively increase the air cleaning volume and improve dust capture efficiency of the unit with a larger motor and blower. The unit's original stock 0.56 kw motor and blower was replaced with a 2.24 kw motor and matching blower to increase airflow. The unit was evaluated both in the laboratory and the shop before and after the retrofit to determine the improvement of the upgrade. The study showed that the 2.24 kw upgrade improved the performance over the original 0.56 kw motor resulting in more dust being cleaned from the ambient air in the shop. The 2.24 kw unit cleaned 19% more air and captured 32% more respirable dust than the 0.56 kw unit.

1 Introduction

Many types of respirable dust are potentially harmful to workers, but overexposure to respirable silica is extremely hazardous. Exposure to crystalline silica dust may lead to silicosis, which creates irreversible and progressive deterioration once the dust has been deposited within the lung tissue. This disease may be chronic, accelerated, or acute depending on the length and magnitude of exposure. Workers who develop silicosis have an increased incidence of lung cancer and pulmonary disorders (NIOSH, 2002).

Recent data from the Mine Safety and Health Administration's (MSHA) compliance sampling database indicate that several occupations in the metal/nonmetal industry are at high risk to respirable silica. Inspector samples collected from 2000 through 2004 reveal that occupations exhibiting frequent overexposures include mobile workers (such as cleanup man, laborer, utility man, and mechanics), which had an average of 15% of the samples over the permissible exposure limit (PEL). Crusher operators and bagging operators also have a high percentage of samples over the PEL, averaging 14% and 23%, respectively. In the dimension stone industry, 31% of the samples for the stone polishers/cutters exceeded the PEL (MSHA, 2000–2004).

Reducing silica levels in large metal/nonmetal processing facilities has been a long-term objective in NIOSH research. Reduction in dust levels has been demonstrated at several mineral processing facilities by implementing total mill ventilation systems. These systems are designed to create a flow pattern to dilute, capture, and remove respirable dust from a structure (Cecala et al, 1993; Cecala et al, 2006). Another method is to clean the air with stand-alone fan-powered dust collectors. Some small operators in the dimension stone processing shops tend to rely on natural ventilation by opening doors and windows and using exhaust fans to remove dust, during the summer months. However, during the winter months, when the shop doors and windows are closed, dust levels tend to increase. To lower dust levels, some shops have adopted the use of fan-powered dust collectors as the primary dust control method. These units are ambient air cleaners that can be purchased off-shelf. Specifications vary depending on the manufacturer, so operators do not necessarily size units for a particular application based on the shop size and the quantity of dust being generated. To evaluate the issue outlined above, the objective in this study was to compare the performance and dust capture capabilities of an off-shelf fan-powered dust collector to that of an upgraded unit in both the laboratory and the field.

2 Background

The unit evaluated in the study was an Aercology AmbientAer 2000 air cleaner.[1] This unit is a self-contained, fan-powered dust collector, shown in Figure 1.

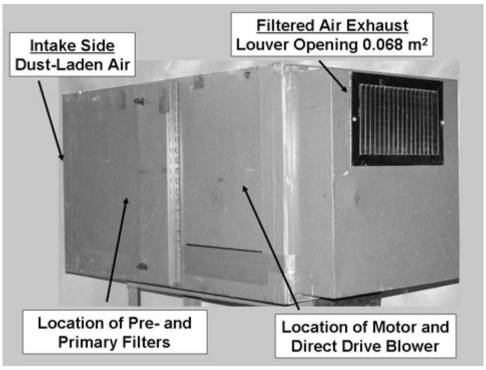

Figure 1. Fan-powered air cleaner used in study.

The outside dimensions of the unit are 1.3 m in length, 0.66 m in depth, and 0.72 m in height. The intake side of the unit is 0.61 m by 0.61 m through which dust-laden air is drawn using a direct-drive centrifugal blower. The dust is then filtered in two stages. The first filter or prefilter is a 0.61 m by 0.61 m by 0.10 m multi-vee high-capacity pleated filter. This filter media is composed of continuous, synthetic, and hydrophobic fibers and is 60% efficient for particle sizes > 1.0 microns. The second filter or primary filter is a 0.61 m by 0.61 m by 0.53 m vee-bag filter composed of ultra-fine glass fiber media. It is approximately 92% efficient at particle sizes > 1.0 microns. The filtered air is then exhausted through the back of the unit via a 0.36 m by 0.19 m (0.068 m^2) louvered opening. The prefilter extends the life of the primary filter, but both filters require replacement, depending upon dust loading conditions.

Figure 2 shows the floor plan for the processing shop and the location of six air cleaning units suspended approximately 1m from the shop ceiling. These air cleaners are equipped with a 0.56 kw, 120 Volt AC motor and direct drive blower. Fan curves show that the motor and blower should operate at an air volume of approximately 1.70 m^3/s at zero Pa static pressure (no filters installed), to an air volume of 0.94 m^3/s at a static pressure of 622 Pa. However, measurements in the shop showed that the air volume, with no filters installed, was approximately 1.22 m^3/s or 0.48 m^3/s less than the air volume indicated by the fan curve. These initial dust surveys also found that air volume cleaned by the units decreased rapidly under dust concentrations between 0.75 mg/m^3 and 1.3 mg/m^3 in the shop. Ventilation measurements at the exhaust louvers showed that the air volume was 0.94 m^3/s when new pre- and primary filters were installed and decreased to 0.24 m^3/s after approximately six shifts of operation.

NIOSH and plant personnel decided to retrofit one of the air cleaning units in the shop with an upgraded motor and blower combination that would provide additional air volume. This would improve performance by overcoming the pressure increase as both the pre- and primary filters were loaded with dust generated by the cutting and polishing of stone in the shop.

To quantify this upgrade, both the off-shelf unit and upgraded unit were tested and evaluated at the NIOSH laboratory and then in the processing shop to assess their dust capture and air flow characteristics. First, tests were conducted in the laboratory on the off-shelf unit equipped with a 0.56 kw, 120 Volt AC motor and direct drive blower. The unit was then retrofitted with a 2.24 kw, 240 Volt AC motor and direct drive blower also rated at 1.70 m^3/s at zero Pa static pressure (no filters installed) and 1.42 m^3/s at 622 Pa static pressure. The higher air volume at 622 Pa static pressure would improve the air flow through the unit and consequently, the dust capture performance of the unit.

3 Laboratory Comparison

The air cleaner was tested by enclosing the intake and exhaust ends of the unit in ductwork as shown in Figure 3. This ensured that the dust introduced on the intake side would pass through the unit and be collected by the filters. The feed material was a standard limestone rock dust (40% of the feed > 250 microns), which was introduced into the intake side of the ductwork with a vibrator screw and compressed air feed to separate dust particles and minimize agglomeration.

Several types of instruments were used to monitor dust concentration, pressure, and velocity during the tests. Dust concentrations were monitored on the intake side and exhaust sides of the air cleaner using a real-time aerosol monitor, called a Personal DataRam (pDR), manufactured by Thermo Anderson Inc.[1] The pDR measures and records the concentration of respirable airborne dust using a light-scattering technique. Light-scattering instruments offer only a relative measure of concentrations; however they also provide a continuous record of dust levels so that concentrations can be evaluated over any time interval during the sampling period. A useful feature of this instrument is that dust concentrations can be viewed in real-time via laptop computer. Two pDRs were used in the tests, one was located at the intake side of the air cleaner and the other at the return side by the exhaust louver. A recording micromanometer was used to monitor pressure drop across the primary filter as it loaded with dust. Air velocity at the exhaust louver was measured using a recording vane anemometer so that the volume of air cleaned could be calculated. All instruments were set to display values each second and record the average at one-minute intervals.

To limit the time of the tests in the laboratory, dust was introduced into the air cleaner at a much higher level than actual field conditions so that both filters would load in a reasonable timeframe. Dust was introduced at a rate to cause similar air volume loses observed in the processing shop. Shakedown tests with limestone dust showed that respirable dust concentrations ranging from 40 to 50 mg/m^3, measured at the intake side of the air

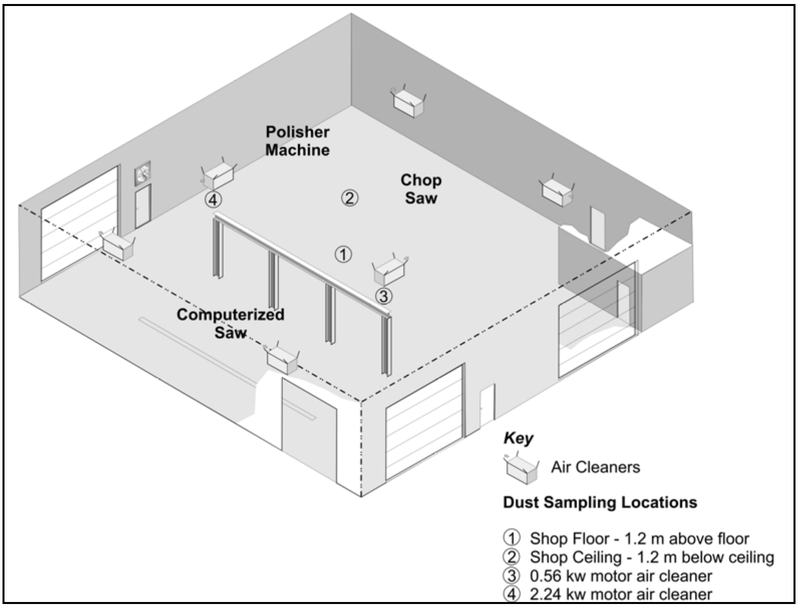

Figure 2. Shop floor plan with sampling locations.

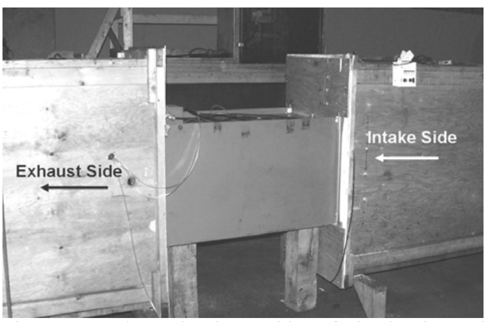

Figure 3. Intake and exhaust sides of air cleaning unit enclosed in ductwork for laboratory tests.

cleaning unit by the pDR, would yield similar air volume losses as observed in the processing shop in about 150 minutes of testing. Based on this, the criteria selected for testing was an initial air volume of approximately 0.90 m^3/s and a final air volume of between 0.10 and 0.35 m^3/s. The dust concentrations, as observed on the pDRs located on the intake and exhaust sides, were used to determine the length of each test. When the pre- and primary filters were loaded to capacity, pDR concentrations on both the intake side and exhaust side began to increase rapidly, indicating that the filters were no longer cleaning the intake air. The dust and air volume ranges were used for all the tests, however the average concentrations as logged by the pDRs did vary slightly, most likely due to variations in feed rate and air turbulence.

Five tests were first conducted with the 0.56kw motor and blower. The unit was then retrofitted with the 2.24 kw motor and blower and five tests conducted with the upgrade. Both the pleated filter (prefilter) and vee-bag (primary filter) were changed after each test.

Table 1 compares the performance of the 0.56 kw and 2.24 kw motor as volume of air cleaned per test. The "Initial Air Volume" and "Final Air Volume" are calculated by taking the initial and final velocities from the recording vane anemometer and multiplying these values by the area of the louvered opening which is 0.068 m^2. The average of the values is then multiplied by the test time, in seconds, to calculate the volume of air cleaned.

The graph in Figure 4 compares the vee-bag pressure and the air velocity losses for an average test for each motor type. A comparison of results from table 1 and Figure 4 reveals the following:

1) From Figure 4, the final pressure drop across the v-bag for the 0.56 kw motor was approximately 570 Pa versus 820 Pa for the 2.24 kw motor.
2) From Figure 4, the final air velocity measured at the 0.068 m^2 louvered opening for the 0.56 kw motor was 2.1 m/s versus 4.2 m/s for the 2.24 kw motor.
3) From table 1, the average filter loading time was 132 minutes for the 0.56 kw motor versus 283 minutes for the 2.24 kw motor.

The upgraded air cleaner was installed at the processing shop and sampling surveys were conducted during the winter months when the shop doors were closed. Sampling surveys were conducted for eight shifts for

Table 1. Comparison of motors in laboratory tests.

0.56 kw Motor						
Test	Test Time Minutes	Initial Air Volume m^3/s	Final Air Volume m^3/s	Average Air Volume m^3/s	Volume of Air Cleaned m^3	Average pDR Concentration mg/m3
1	152	0.89	0.17	0.53	4834	42.0
2	132	0.90	0.15	0.53	4198	41.5
3	135	0.94	0.13	0.53	4293	40.9
4	143	0.90	0.19	0.54	4633	35.9
5	97	0.96	0.22	0.59	3434	44.2
Average	132	0.92	0.17	0.54	4278	40.9
2.24 kw Motor						
1	370	0.88	0.22	0.55	12210	48.9
2	208	0.91	0.27	0.59	7363	51.4
3	317	0.91	0.33	0.62	11792	52.3
4	261	0.84	0.28	0.56	8770	53.2
5	260	0.92	0.33	0.63	9828	51.8
Average	283	0.89	0.29	0.59	9993	51.5

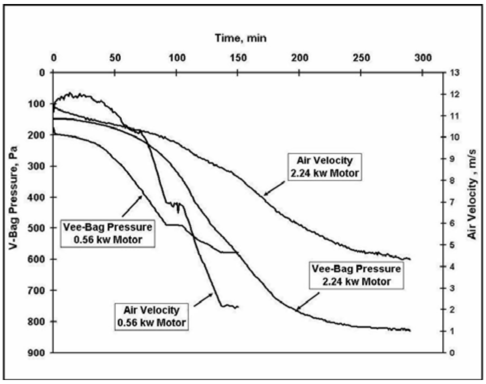

Figure 4. Pressure and air velocity characteristics for an average test for each motor.

approximately seven hours per shift. Figure 2 shows the locations of the two units compared in the study as well as the location of the four other 0.56 kw motor air cleaners in the shop. The location of the air cleaners in the shop were chosen because of their proximity to highest dust-generating source, the computerized cutting saw. Two types of instruments were used to compare the performance of the units: 1) gravimetric samplers, placed at four locations as shown in Figure 2 to measure respirable dust concentrations, and 2) recording vane anemometers, mounted at the discharge of each collector, to calculate the volume of air cleaned by each unit. Figure 5 shows the positioning of these instruments on the two air cleaning units. Each air cleaner had the same instrument setup.

Table 2 shows the average respirable dust concentrations measured at the four sampling locations for each sampling day. The concentrations show that dust levels at the shop floor and upper bay area were fairly consistent for each day of sampling. This would suggest

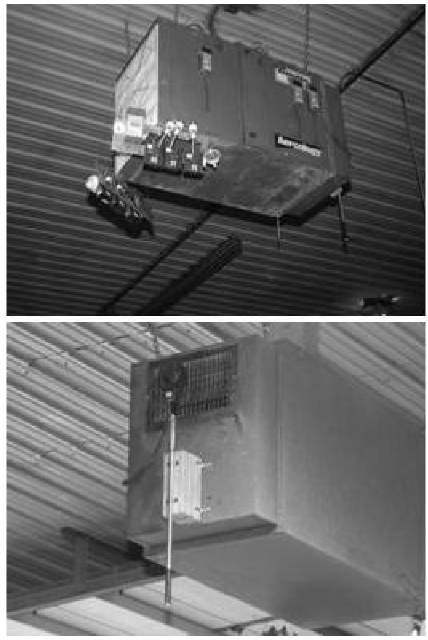
Figure 5. Location of gravimetric samplers at the intake side and the recording vane anemometer at the louver exhaust side.

that the arrangement of the units has resulted in a uniform mixing of the air within the shop. The shop floor had the lowest average concentration at 0.382 mg/m^3, while the 2.24 kw unit had the highest average concentration at 0.444 mg/m^3. Although this is only a 16% increase in concentration, dust levels would be somewhat higher in the upper bay than near the shop floor since the units are pulling airflow toward them. Also, natural airflow currents of heated air would move dust upward in the shop.

Table 2. Dust concentrations measured at sampling locations for each shift.

	Respirable Dust Concentration mg/m^3			
Shift	Shop Floor	Shop Ceiling	0.56 kw Motor	2.24 kw Motor
1	0.311	0.388	0.365	0.382
2	0.139	0.183	0.188	0.182
3	0.807	0.848	0.734	0.899
4	0.364	0.412	0.399	0.433
5	0.351	0.436	0.404	0.443
6	0.431	0.532	0.484	0.500
7	0.228	0.348	0.331	0.359
8	0.423	0.279	0.303	0.367
Average	0.382	0.428	0.401	0.444

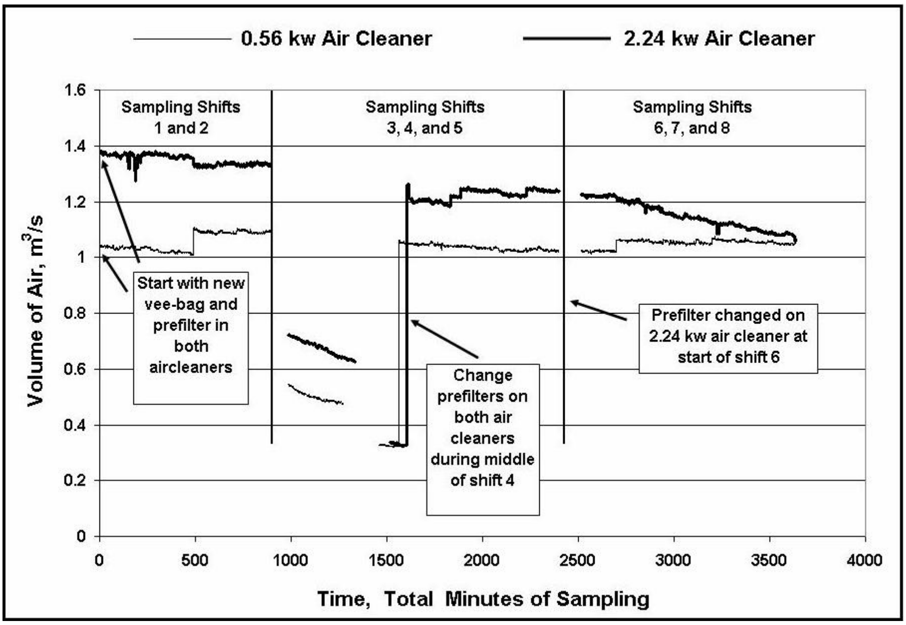

Figure 6. Comparison of 0.5 6 kw and 2.24 kw motors for 8 sampling shifts in processing shop.

The graph in Figure 6 compares the airflow performance measured in m/s^3 for the 0.56 kw and 2.24 kw motors. The air volume data show each unit's performance as a timeline based on total minutes of sampling over eight sampling shifts. A description of the sampling history is as follows:

1) A new vee-bag and prefilter were installed in both units, followed by NIOSH sampling for shifts 1 and 2.
2) The units operated for seven shifts with no NIOSH sampling. Prefilters were not changed during this time.
3) When sampling resumed at the start of shift 3, a large decrease in air volume for both units was measured resulting from the prefilters becoming loaded with dust. Also, airflow data are missing from the 1300 to the 1450 minute mark due to low batteries in both recording units, but this did not affect the results of the tests.
4) Prefilters were changed in the middle of shift 4 as air volume on both units began to decrease. As a result, new gravimetric samplers were used for the second half of the shift on each unit. This scenario is represented in table 3 with shift 4 being split into two sampling times. Figure 6 and table 3 show that changing the prefilter resulted in a substantial increase in air flow for both units.
5) Sampling continued for the remainder of shifts 4 and 5 with no significant changes in air volume.
6) The units were operated for 12 shifts with no sampling.
7) NIOSH sampling resumed for shift 6, during which time it was learned that the prefilter had been changed on the 0.56 kw unit by shop personnel the previous day. In order to ensure that both units were operating under equivalent conditions, NIOSH also changed the prefilter on the 2.24 kw unit.
8) Sampling continued for shifts 6, 7, and 8 without any additional changes to the units.

The graphs in Figure 6 show that the 2.24 kw motor outperformed the 0.056 kw motor by cleaning more air during the sampling time. Table 3 compares the performance of the two motors as volume of air cleaned per sampling day. Using the same method as in the laboratory tests, the volume of air cleaned was calculated by multiplying the shift sampling time, in seconds, by the average air volume calculated for that shift.

Using the information from table 3, the percent increase in air volume cleaned and amount of respirable dust captured, can be estimated using the average gravimetric concentration. For the 0.56 kw motor, the total volume of air cleaned and the average shop respirable dust concentration was 217817 m^3 and 0.401 mg/m^3, respectively. For the 2.24 kw motor, this is 259570 m^3 and 0.444 mg/m^3, respectively. Based on this information, the 2.24 kw motor cleaned 19 percent more air and captured 32 percent more respirable dust than the 0.56 kw motor during the 3915 minutes of dust sampling in the shop.

Table 3. Performance of each unit as volume of air cleaned per sampling day.

Shift	Action	Sampling Time Minutes	Initial Air Volume m^3/s	Final Air Volume m^3/s	Average Air Volume m^3/s	Volume of Air Cleaned m^3	Gravimetric Concentration mg/m3
			0.56 kw Motor				
1	New Vee-bag & Prefilter	491	1.04	1.01	1.03	30344	0.365
2		464	1.11	1.08	1.09	30346	0.188
3		464	0.55	0.36	0.45	12528	0.734
4		289	0.35	0.32	0.34	5896	0.399
4	New Prefilter	226	1.01	1.02	1.02	13831	0.399
5		467	1.05	1.03	1.04	29141	0.404
6	New Prefilter	465	1.06	1.02	1.04	29016	0.484
7		538	1.06	1.05	1.06	34217	0.331
8		511	1.07	1.05	1.06	32500	0.303
		Total 3915 minutes				Total 217817 m^3	Average 0.401mg/m^3
			2.24 kw Motor				
1	New Vee-bag & Prefilter	491	1.38	1.35	1.37	40360	0.382
2		464	1.33	1.33	1.33	37027	0.182
3		464	0.75	0.62	0.69	19210	0.899
4		289	0.38	0.33	0.35	6069	0.433
4	New Prefilter	226	1.26	1.18	1.22	16543	0.433
5		467	1.22	1.20	1.21	33904	0.443
6	New Prefilter	465	1.25	1.22	1.23	34317	0.500
7		538	1.23	1.15	1.19	38413	0.359
8		511	1.14	1.06	1.10	33726	0.367
		Total 3915 minutes				Total 259570 m^3	Average 0.444 mg/m^3

4 Summary and Conclusion

Stand-alone fan-powered dust collectors can be a feasible method to lower dust levels in small dimension stone processing shops. However, this requires that air cleaning units be properly sized to clean the anticipated dust loads and keep overall shop levels at acceptable levels during the winter months. Both laboratory and field testing demonstrated that a 2.24 kw motor improved the performance of a cleaning unit over the original 0.56 kw motor when considering the volume of air cleaned by each of these units. The study also showed that cost-effective retrofit options are available if the dust collector is under- performing. The cost of the upgraded motor and blower was $1,100 and took 8 man-hours to install.

Laboratory tests showed that, on average, the 2.24 kw motor cleaned over twice the amount of air as the 0.56 kw motor for the five tests conducted--4278 m^3/s versus 9993 m^3/s. This improvement is because the upgraded air cleaner was able to clean air for a longer time before the final air volume criteria (0.15 and 0.3 m^3/s) was reached. From table 1, the average time for a test was 132 minutes for the 0.56 kw motor and blower versus 283 minutes for the 2.24 kw motor and blower. As a result, this additional performance would extend the life of both filters, requiring them to be changed less often under normal operating conditions.

Results from the processing shop tests, conducted under normal dust loads, showed a similar trend as in the laboratory tests. This resulted in more dust being cleaned from the ambient air in the shop. The 2.24 kw motor cleaned 19 percent more air and captured 32 percent more respirable dust than the 0.56 kw motor during the eight shifts of sampling.

The survey data also show that the vee-bag filter can be used much longer than prefilters. As shown in Figure 6, when the prefilters were changed in the middle of shift 4, the airflow increased to levels near those observed at the start of shift 1. This demonstrates that the airflow reductions observed within the units resulted from dust loading on the prefilter. Therefore, to effectively achieve the air moving capacities of these units, it is critical to replace the prefilters on a regular basis.

Based on these study results and observations, an optional design change to consider would be collector position and/or location. With all the dust collectors mounted at the roof, it would be expected that higher dust levels would be measured near the roof, with lower dust levels at the floor around the shop workers. The relatively uniform dust levels measured at the different sampling locations in this study would suggest that the units are mixing air within the shop, but not pulling dust-laden air from the breathing zone of the workers. If feasible, a more effective use of the collectors may be achieved by changing spacing and orientation of the units mounted at the shop ceiling, extending intake ducting toward the floor to improve dust pickup, or moving the collectors closer to the dust-producing sources.

References

Cecala AB, Klinowski GW, and Thimons ED, 1993. Reducing respirable Dust Concentrations at Mineral Processing Facilities Using Total Mill Ventilation Systems. US Bureau of Mines RI 9469. 11 pp.

Cecala, A.B., Zimmer J.A., and Timko, R.J., 2006. Lowering Respirable Dust at an Iron Ore Plant Through Improved Ventilation Practices. *Proceedings of the 11th US/North American Mine Ventilation Symposium*, The Pennsylvania State University, University Park, Pennsylvania, June 5-7, 2006, pp. 189-196.

Mine Safety and Health Administration (MSHA), 2000-2004, Metal/Nonmetal Mine Inspection Data (MNMID), available from the MSHA Metal and Nonmetal Safety and Health Office in Arlington, Va.

NIOSH 2002. NIOSH Hazard Review – Health Effects of Occupational Exposure to RespirableCrystalline Silica. US Dept of Health and Human Services, Centers for Disease Control and Prevention. DHHS (NIOSH) Publication No. 2002-129. 127 pp.

[1] Mention of any company name or product does not constitute endorsement by NIOSH.