Impact of fan type for reducing respirable dust at an underground limestone crushing facility

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ABSTRACT: Researchers from the National Institute for Occupational Safety and Health have demonstrated that mine-wide ventilation in large-opening stone mines can be improved by using low-pressure, high-volume propeller fans and constructing stoppings in key locations to direct and control airflow. In light of these findings, a comparative study was conducted to determine if a portable diesel-powered propeller fan could perform more efficiently for dust dilution and transport than an axial vane fan for localized ventilation. The objective of this study is to evaluate both fan types for ventilation efficiency at an underground dump/crusher facility in a limestone mine. Results showed an improvement with the propeller fan to dilute both the respirable dust and the respirable silica dust around the dump/crusher facility. Overall, an average reduction of 20% in respirable dust and silica was observed at the dump/crusher location with the propeller fan.

1 INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) at the Pittsburgh Research Laboratory is currently involved in various research projects related to worker health and safety in underground metal/nonmetal mines. A primary area of research involves health issues in underground stone mines, a growing segment of the aggregates industry. Methods for reducing worker exposure to noise, silica dust, and diesel particulate matter are being addressed through various research programs. One approach to reducing worker exposure to silica dust in large-opening mines is to adopt ventilation practices that will increase airflow and dilute and transport harmful particulate from major dust sources.

Baseline sampling surveys have shown that underground dumps and crushers in limestone mines can be a significant source of dust generation (Chekan et al, 2002). Inhalation of excessive levels of respirable silica dust can lead to the development of silicosis in mine workers. Although the health hazards from silica dust have been well documented for many years, the problem of overexposure still persists for a number of job occupations in both underground stone and metal/nonmetal mining operations. Compliance sampling from the Mine Safety and Health Administration (MSHA) database, for a 5-year period from 2000 through 2004 shows that, on average, 14% of all occupational samples exceed the permissible exposure limit. Occupations that exceed the average include mobile workers, crusher operators, and front end loader operators (MSHA, 2000 – 2004).

Typically, underground stone operations are drift mines developed after the economical quarry reserves have been exhausted. Room-and-pillar mining methods are utilized, with pillars of either square or rectangular dimensions ranging from 10.6 to18.3 m (35 to 60 ft). The entries are considered large mine openings with entries widths ranging from 9.1 to 18.3 m (30 to 60 ft) and entry heights on development ranging from 4.9 to 13.8 m (16 to 45 ft). After benching, entries can be over 18.3 m (60 ft) high. Due to these large openings, ventilation fan pressure is very low, even if significant quantities of air move through the mine. Ventilation pressures of less than 24.9 Pa (0.1 in w.g.) are common whether airflow is induced by fans, natural ventilation pressure, or a combination of both (Grau et al, 2002a). Depending on the extent of the workings, air velocities less than 0.13 m/s (25 fpm) are common, or in some idle areas of the mine, virtually nonexistent. In addition, airflow in the entries can be stratified, multi-directional, or readily affected by the movement of mine equipment.

These large-opening mines require ventilation systems that are designed to effectively dilute airborne particulate by supplying sufficient ventilating air to primary locations, i.e., working faces, worker locations, etc. To accomplish this, studies show (Grau et al, 2002a; Grau et al, 2002b; Head, 2001; Kissell and Volkwein., 2002; Timko, and Thimons, 1987; Chekan et al, 2004a). that three key parameters should be included in the mine ventilation plan to improve airflow: (1) a main mine fan to establish air circuits on a mine-wide scale; (2) either permanent or brattice stoppings in key locations throughout the mine to more efficiently direct and control the airflow; and (3) the application of booster fans, to improve local ventilation in areas requiring a more direct and controlled volume of airflow to remove harmful particulate. These fans include axial vane fans, jet fans, and more recently low-pressure, high-volume propeller fans. Studies comparing fan performance have shown that propeller fans are more efficient at lower pressures and can produce larger air quantities at lower horsepower than axial-vane fans (Grau et al, 2002a; Grau et al, 2002b; Krog and Grau, 2006). In addition, because of operational characteristics related to lower fan pressure and larger diameter, propeller fans provide better regional air coverage in large- opening mines than axial vane fans. In light of these findings, a study was conducted at an underground dump/crushing site to compare the effectiveness of an electric-powered axial vane fan versus a diesel-powered propeller fan for the dilution and transport of respirable dust from this facility.

Figure 1. Axial vane fan and propeller fan used in study

2 FAN CHARACTERISTICS AND SAMPLING STRATEGY

The two fans compared in the study are shown in figure 1. Air volume for each fan was measure using a moving traverse immediately downstream of the exhaust opening with a 10 cm (4 in) Davis vane anemometer. Both fans had approximately a 23.6 m^3/s (50,000 cfm) output, keeping this operational parameter constant in the study. The axial vane fan is Joy Model AMF-100-50-26H. It is 460 volts, 37.1 kw (50 hp) with a 0.91 m (3 ft) outlet opening and equipped with a flow straightener. The propeller fan is a Spendrup Model 152-764-HVLD. It has a 20.0 kw (27.2 hp) Duetz Model F2L1011F diesel engine. The fan is belt driven with a 1.52m (5 ft) diameter outlet opening. Figure 2 is a plan view of the study area showing information concerning the location of the fans, the dump and crusher, the operator control booth, ventilation stoppings, and dust sampling stations.

The fans were positioned in the same location, on the left side of the haul road entry, approximately 30.3 m (100 ft) from the dump/crusher. The fan discharge blew across the haul road entry and was oriented toward the center of the dump area and crusher. The width and height of the entry at the dump were 13.7 m and 18.3 m (45 ft and 60 ft), respectively. Generated dust was diluted and transported away from the crusher via the belt entry, into a return airway, and out of the mine. The belt entry is isolated from the main developments using both permanent and curtain stoppings in crosscuts along its entire length of approximately 152 m (500 ft) as shown in figure 2. The crusher is a 222.6 kw (300 hp) jaw type rated at 907 metric tph (1000 short tph).

The dust survey consisted of two parts. The dust survey was first conducted with the axial vane fan, routinely used by the mine to ventilate the facility. After completion of the survey, the axial vane fan was replaced by the propeller fan which was positioned in the same location. The sampling survey was then repeated. As shown in figure 2, the sampling strategy was to collect dust samples at six key locations around the dump/crushing facility. This sampling array provided dust concentrations at the same locations to determine the effectiveness and performance of each fan as it relates to the dilution

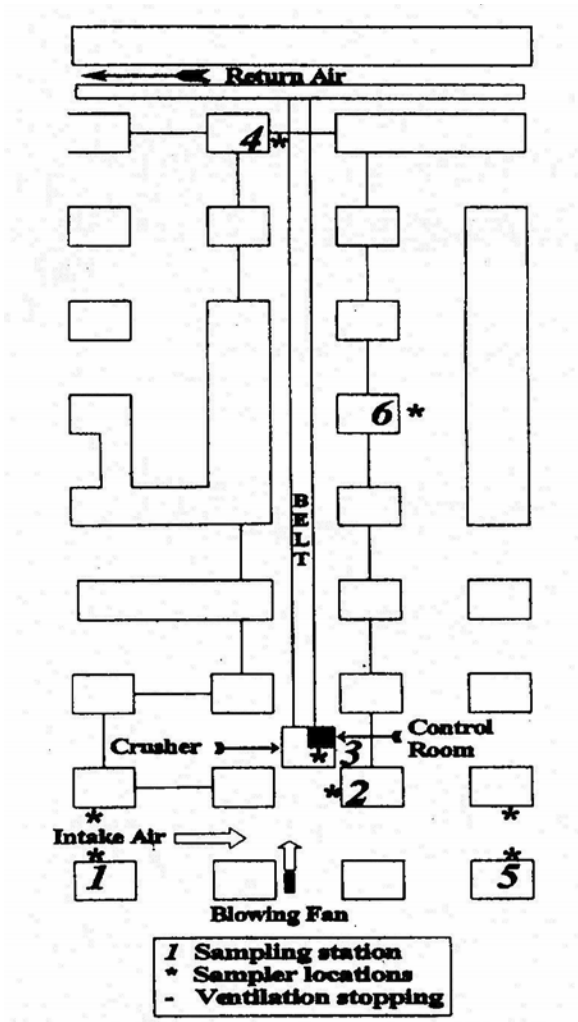

Figure 2. Plan view of the study area showing the location of the blowing fans (axial vane or propeller), the dump and crusher, the operator control booth, ventilation stoppings, and dust sampling stations.

and transport of respirable dust and respirable silica dust.

The instrument package at each sampling location varied depending on the information required at each location. Two types of instruments were used. The first instrument type that was used for measuring respirable dust was the gravimetric sampler operated at 1.7 liters/minute which complies with MSHA requirements for metal/nonmetal sampling. The respirable fraction of the airborne dust (<10 microns) was obtained with a 10 mm Dorr-Oliver cyclone and deposited onto a 37 mm PVC filter. The filters used for dust were weighed before and after sampling to calculate overall respirable dust concentrations (which includes all dust types and particulate) based on the sampling rate and time. The filters were then analyzed by an independent laboratory for silica using NMAM-Method 7500 to determine the silica weight. From this information, silica concentrations could be calculated.

The second type of sampling instrument was the MIE personal DataRAM (pDR). The pDR measures and records the concentration of respirable airborne particulate from 0.1 to 10 microns (which includes all dust types, DPM, and water mist) using a light scattering technique. Light-scattering instruments offer a relative measure of concentrations, but provide a continuous record of particulate levels so that concentrations can be evaluated over any time interval during the sampling period.

Table 1 identifies the types and numbers of dust samplers that were positioned at each location. Sampling packages on the ribs were positioned about 1.82 m (6 ft) above the floor. Figure 2 shows a plan view of the location of these sampling stations. Samples for both parts of the study were collected on 3 consecutive days for an average sampling time of about 5 to 6 hrs per shift. Other information related to dust production and migration was collected each day during the sampling period. During this time, the number of trucks that dumped and the tonnage processed through the crusher were recorded.

Table 1. Dust samplers used in study.

		Sampling Instruments	
Site	Location	Gravimetric	pDR
1	Intake Entry	4	0
2	Dump	2	1
3	Crusher	2	1
4	Belt	2	1
5	Return Entry	4	0
6	Adjacent Entry	2	0

To monitor airflow from the crusher to the return airway, vane anemometer readings were taken at the end of the belt entry (site 4 in figure2) at a 0.91m by 2.3m (3 ft by 7.5 ft) regulator in a permanent stopping leading to the return. Vane anemometer readings of the air velocity were also taken in front of the dump to compare the ventilation coverage provided by each fan. To determine the bulk percentage of silica in the rock, samples were collected from the belt during both parts of the study and sent to an independent laboratory analysis. Percentages of silica in the rock ranged from 37.8% to 44.4%.

3 GRAVIMETRIC SAMPLING

Figures 3 and 4 summarize the concentrations based on filter weights from gravimetric sampling at all six locations for the 3 sampling days for the respirable dust and silica dust, respectively. Both the respirable and silica dust concentrations were examined to determine if fan effectiveness varied depending on the type of dust. In figure 3, the respirable dust concentration is most likely composed of three main

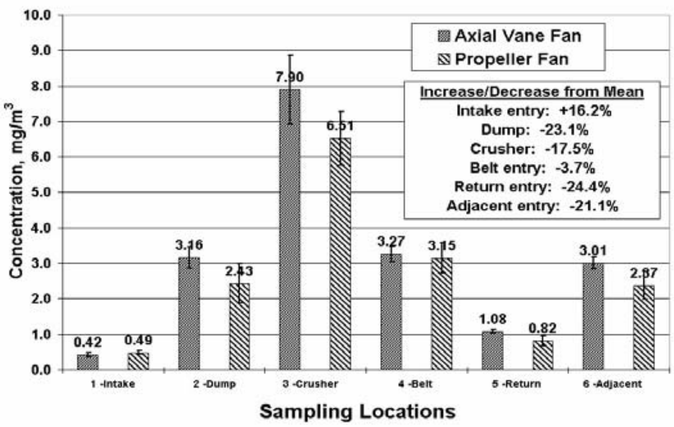

Figure 3. Average respirable dust concentrations from gravimetric sampling at all six locations for the 3 sampling days.

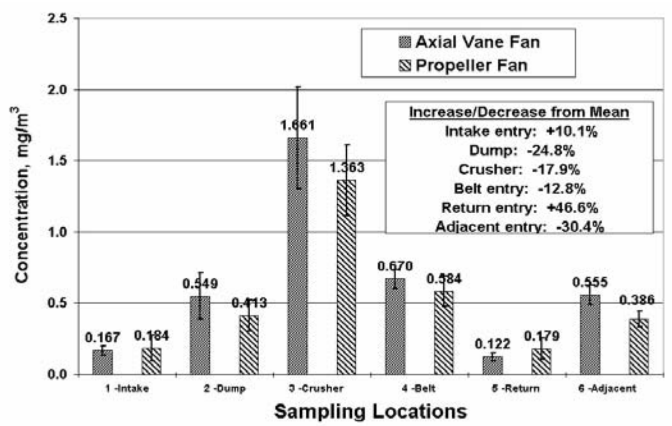

Figure 4. Average respirable silica dust concentrations from gravimetric sampling at all six locations for the 3 sampling days.

components: inert limestone dust or calcite, diesel particulate, and silica. Filters were sent to an independent laboratory for XRD silica analysis of three primary mineral components: quartz, cristobalite, and tridymite. The analysis only found quartz mineral on the filter. Figure 4 shows the concentrations of silica at the six locations around the crusher.

For each sampling location, the mean and 95% confidence interval were calculated using a t-distribution. The graphs in figures 3 and 4 plot the mean concentration and the upper and lower confidence limit (UCL and LCL) for each sampling location. In examining all locations, the following is notable in comparing the axial vane to the propeller fan:

Site 1- Intake: Gravimetric sampling showed a slight increase in both respirable dust and silica dust. This station was not influenced directly by the fans, but the low dust levels indicate that very little if any dust is migrating from the dump and crusher back into the main developments on the intake side. Observed concentration increases are most likely related to dust generated from vehicle traffic in the area.

Site 2 - Dump: This station recorded a reduction in both respirable and silica dust of 23.1% and 24.8% respectively, with the propeller fan. When compared to the crusher, the dump has low respirable and silica concentrations. This suggests that both fans are preventing dust rollback from the crusher as the trucks dump.

Site 3 - Crusher: This location had the highest concentrations of both respirable and silica dust. Of interest is the fact that respirable concentrations increase threefold from the dump to the crusher location, a distance of roughly 18.2 m (60 ft). This station recorded a reduction in both respirable and silica dust of 17.5% and 17.9% respectively, with the propeller fan. Observation from inside the operator's booth showed that a large plume of dust was created as trucks dumped regardless of the fan in use. The propeller fan appeared to be more effective in diluting the dust than the axial vane fan. Stratification or layering of the air may be causing this effect as both fans are lifting and entraining the dust, but the propeller fan is more effective in dust transport.

Site 4 - Belt: Both the respirable and silica dust concentrations at the belt location are less than half of the levels at the crusher, at a distance of approximately 152 m (500 ft). Dust reductions were 3.7% and 12.8% for the respirable and silica dust, respectively. However since the concentrations mean values show little change, this confirms that the dust is well diluted and uniform when it reaches the end of the belt before it passes through the regulator in the stopping. This indicates that both fans are slowly moving the air down the entry with about the same efficiency.

Site 5 - Return: This location behaved much the same as the intake location with low respirable and silica concentrations showing that very little dust is migrating from the dump/crusher back into the main developments. This site is the only station to record conflicting concentration levels in that the respirable dust decreased with the propeller fan but the silica dust increased. Similar to site1 intake, this station was not directly influenced by the fans and observed concentration increases are most likely related to dust generated from the tramming of haulage trucks past the sampling station.

Site 6 – Adjacent Entry: Since dust concentrations were similar to the dump and the belt locations, this indicates that considerable air leakage is occurring through the line curtains along the belt entry. As a result, dust is being transported through the stopping line and has the potential to be carried toward the working faces. Reductions in both respirable and silica dust were recorded when the propeller fan was in use but dust concentrations in this adjacent entry can easily be reduced by tightening the curtain line to prevent the escape of dust.

Figures 3 and 4 show that the propeller fan outperformed the axial vane fan in the dilution of respirable dusts as evidence for the lower mean values at sampling sites most influenced by the fans. This includes the dump and crusher, belt, and the adjacent entry. However, since at all sampling sites the error bars (upper and lower confidence intervals) overlap, the dust reductions are not statistically significant for the amount of data collected. For larger dust particles or nuisance dust (>10 microns), visible dust from the crusher still appeared to linger in the air with relatively slow removal from this area regardless of fan type. Although total dust measurements were not collected, the primary reason for this observation is that the area of the entry at the dump increases dramatically at the crusher, which results in a significant drop in air velocity.

4 PERSONNEL DATA RAMS

The pDR graphs in figures 5 and 6 illustrate the difference in dust patterns between dump, crusher and belt for a typical day of sampling. These graphs

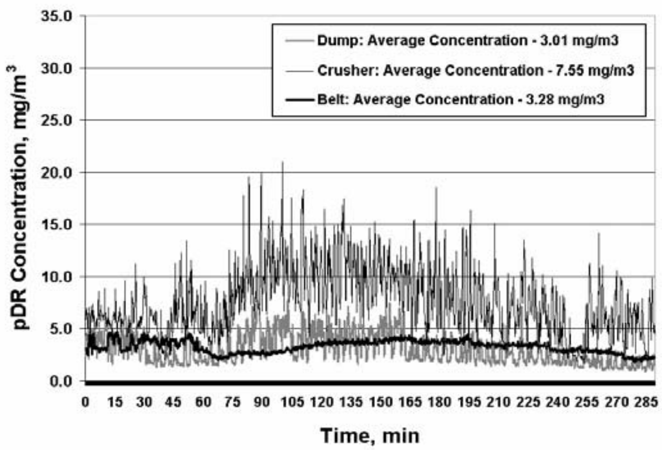

Figure 5. Dust patterns for axial vane fan at the dump, crusher, and belt for a typical day of sampling.

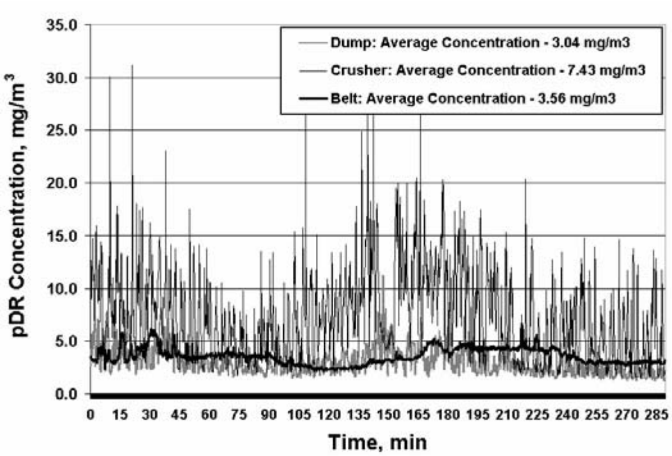

Figure 6. Dust patterns for propeller fan at the dump, crusher, and belt for a typical day of sampling.

compare pDR data from the third day of sampling with the axial vane fan, and the first day of sampling with the propeller fan. These days were select because tonnage processed through the crusher those days were similar at 3890 metric tons (4290 short tons) and 3820 metric tons (4210 short tons), respectively. The pDR concentrations in the figures have been corrected to the average gravimetric concentrations at those locations. This is simple correction by calculating a ratio of average gravimetric concentration divided by the average pDR concentration for the entire sampling period. This ratio is then used to adjust each individual concentration in the pDR log. The pDR was configured to log a concentration every 10 seconds over a 285-minute sampling period. This equates to 1710 sampling points.

Two primary observations can be made from these graphs. First, unlike the concentrations from the gravimetric samplers (figure 3), the average concentrations at each of these three locations were similar, regardless of fan type. These results are not uncommon, since the pDR a light scattering instrument which yields a relative concentration value depending on the aerosol being sampled. Differences in the content of the aerosol, (in this case limestone dust, silica dust, and diesel particulate matter) can vary during the sampling period and may account for the similarity in corrected concentrations.

Second, although these light-scattering instruments offer only a relative measure of concentrations, they provide a continuous record of dust levels so that concentrations can be evaluated over any time interval during the sampling period. Examining concentration trends over this time period is the most useful way to interpret the data. In comparing the two graphs, concentration trends both the dump and belt sampling stations tend to have a similar pattern during the dump and crushing cycle. What is most notable in the figures is the differing trend at the crusher. The peak and valley concentrations are consistently higher and lower with the propeller fan. The dump and crushing cycle was a continuous process with only about a 30-second delay between trucks arriving to dump. The crusher was usually behind the dump cycle and trucks had to wait for the crusher to process most of the rock before dumping into the hopper. The trucks would idle at the dump before being signaled to dump. Figure 7 inset picture shows a truck waiting at the dump.

Figure 7 compares the three-shift average of anemometer readings taken directly in front of the dump. The three fixed point measurements were spaced approximately 4.6m (15 ft) apart and 1.5 m (5 ft) above the floor. These reading were taken before the shift or when no trucks were at the dump. Due to the operational characteristics of each fan, the axial vane fan did not provide air coverage at the center and right side of the dump as did the propeller fan. As a result, with a truck waiting at the dump, it is likely that the airflow became more turbulent with the propeller fan. As airflow moved around the truck, increase turbulence may have entrained more

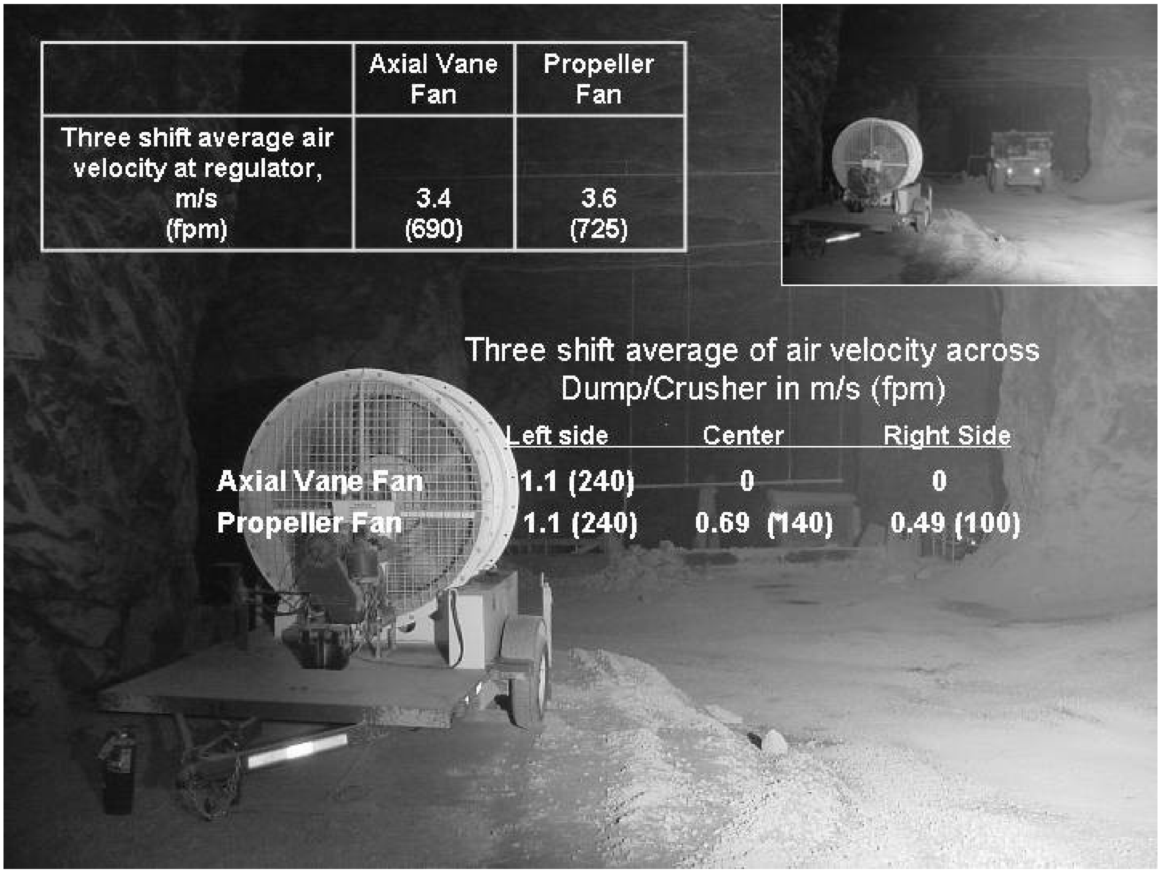

Figure 7. 1) Three shift average of anemometer readings taken across the dump; 2) three shift average air velocity at the regulator at the end of the belt; 3) inset picture showing a truck waiting at the dump.

Table 2. Daily production for each sampling shift.

	Axial Vane Fan			Propeller Fan		
Shift number	1	2	3	1	2	3
Gravimetric Sampling time, min	216	322	298	325	312	297
Number of trucks dumped	55	110	110	108	107	108
Measured tonnage, metric tons (short tons)	1945 (2145)	3890 (4290)	3890 (4290)	3820 (4210)	3785 (4170)	3820 (4210)

dust, leading to higher concentration values logged by the pDR (Chekan et al, 2004b; Xu and Bhaskar, 1995). When the truck left the dump, the airflow provided by the propeller fan diluted the dust produced by the crusher more effectively, as evident by the immediate reduction in dust levels.

Figure 7 also shows the three-shift average air velocity at the regulator at the end of the belt. The air flows are comparable, indicating that air losses through the brattice stoppings isolating the belt are similar for each fan. Figures 5 and 6 show that dust levels at site 4 (belt) are comparable in trend and concentration. This indicates that both fans are equally effective in transporting the dust once it has been diluted at the dump/crusher area.

5 RESPIRABLE DUST GENERATION AND PRODUCTION

Another method to evaluate the data, other than concentration, is to calculate dust generated based on the tonnage produced during the sampling period. This will normalize dust generation to production, and offer an alternative approach to compare the effectiveness of each fan. This value is calculated by taking the average milligram weight gain collected on the filter for a shift, and dividing it by the metric tons processed through the crusher for the duration of the sampling period. It is expressed as milligrams of respirable dust per metric ton of rock crushed per minute. Table 2 provides specific details about sampling time and tonnage processed by the crusher for each sampling shift. For this analysis, the following four sampling sites most influenced by fan airflow were examined: the dump, the crusher, the belt, and the adjacent entry.

Figures 8 and 9 compare the 3 shift average of both the respirable dust and the respirable silica dust for each fan. The decrease in respirable dust based on tonnage is apparent when the propeller fan was used. These results are similar to the percent decease in dust concentrations at the dump, crusher, belt, and the adjacent entry shown in figures 3 and 4 and offer further evidence that the propeller fan outperformed the axial vane fan for dust dilution.

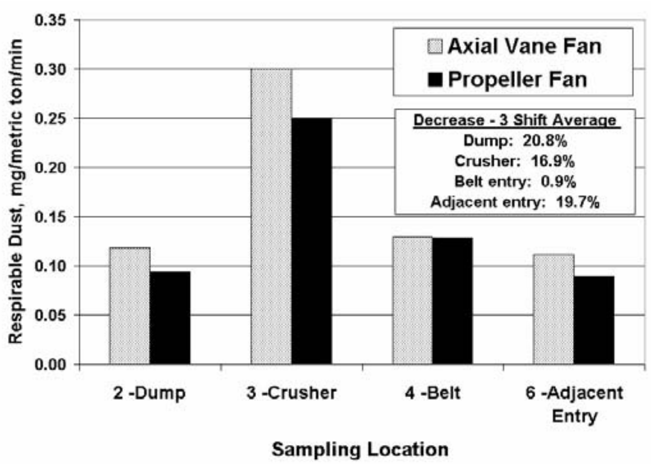

Figure 8. Three-shift average comparing respirable dust generated based on the tonnage produced during the sampling period.

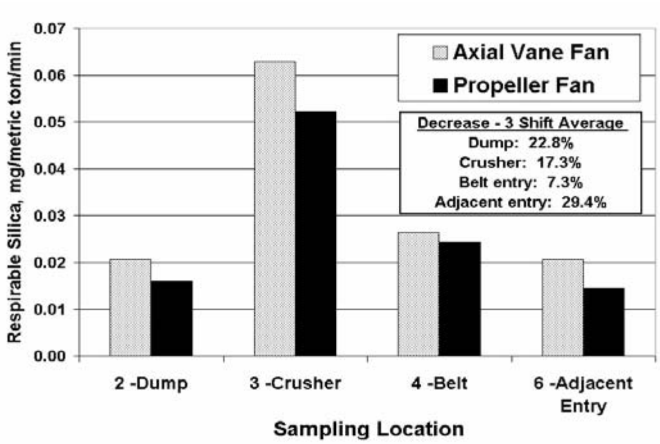

Figure 9. Three-shift average comparing respirable silica dust generated based on the tonnage produced during the sampling period.

6 CONCLUSIONS

Based on gravimetric sampling, the study showed an improvement with the propeller fan to dilute both the respirable dust and the respirable silica dust around the dump/crusher facility. Although the dust reductions are not statistically significant at a 95% confidence, concentration values show that the propeller fan outperformed the axial vane fan in the dilution of respirable dusts as evident by the percent reduction in mean concentration values at sampling sites most influenced by the fans (i.e., the dump, the crusher, the belt, and the adjacent entry). In addition, when examining dust generation as it related to production the percent reductions offer further support that the propeller fan outperformed the axial vane fan. Since reductions for both the respirable dust and the respirable silica were approximately the same whether comparing concentrations (figures 3 and 4) or production (figures 8 and 9), this shows that the propeller fan's effectiveness did not vary depending on dust type.

However, one observation needs to be addressed. For larger dust particles or nuisance dust (> 10 microns), visible dust from the crusher still appeared to linger in the air with relatively slow removal from this area regardless of fan type. The reason for this observation is that the area of the entry at the dump increases dramatically at the crusher, which results in a significant loss of air velocity.

The pDR concentration showed that concentration trends at the dump and belt sampling stations tended to have a similar pattern during the dump and crushing cycle. However, when comparing the concentration trends at the crusher, the peak and valley values are consistently higher and lower with the propeller fan. Due to the operational characteristics of each fan, the axial vane fan did not provide air coverage at the center and right side of the dump as did the propeller fan. As a result, with a truck idling at the dump, it is likely that the airflow became more turbulent with the propeller fan. When the truck left the dump, the airflow provided by the propeller fan diluted the dust produce by the crusher more effectively, as evident by the immediate reduction in dust levels. Data indicates that both fans are equally effective in transporting the dust once it has been diluted at the dump/crusher area. This is based on similar air velocities measured at the regulator and comparable concentration values and trends from the gravimetric and pDR samplers.

This survey was conducted to evaluate two different types of fans for dust dilution and transport from an underground crushing facility during normal production activities. Dust concentrations around the crusher and down the belt entry were higher than desired for either fan and could be reduced with improved dust capture. The current fan location, approximately 30.3 m (100 ft) from the dump/crusher, is performing a function by diluting the dust at the dump and keeping it from recirculating back to the main developments. The use of brattice around the crusher to better direct and increase airflow would provide an inexpensive method to possibly reduce dust levels. Another alternative to consider would be to increase fan capacity using either a push-pull system with two auxiliary fans or a fan-powered dust collector. The push-pull system would require an axial vane fan to be placed outby the crusher in the belt entry with exhaust tubing positioned as close to the crusher as possible to maximize dust capture. Tubing would then be attached to the exhaust side of the fan to transport captured dust directly to the return airway. The second alternative would involve the installation of a fan-powered dust collector with filtration system to remove airborne dust and discharge clean air. With the additional fan capacity, either system should increase dust capture at the crusher, thus lowering dust levels at the crusher and in the belt entry.

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