Application of propeller fans at Wisconsin Industrial Sand — a case study

A. ADU-ACHEAMPONG, B. MCGUNEGLE AND T. STAUFFER

A. Adu-Acheampong and **B. McGunegle**, member SME, are project engineer and senior associate, respectively, with Agapito Associates Inc., Grand Junction, CO; **T. Stauffer**, member SME, is regional manager with Wisconsin Industrial Sand, Maiden Rock, WI.
Paper number TP-06-035. Original manuscript submitted online October 2006. Revised manuscript accepted for publication March 2007. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to Dec. 31, 2007

Abstract
Fairmount Minerals' Maiden Rock underground sand mine historically delivered air to ventilate diesel-powered equipment at its working faces through high-resistance, 380-mm- (15-in.-) diameter PVC distribution lines. In support of plans for expanded production, three new, low-resistance ventilation design alternatives were analyzed. The study determined that adequate ventilation for expanded production was possible with various commercially available, high-volume/low-pressure fans combined with a systematic layout of control structures. The recommended redesign was implemented in 2001, resulting in a significant increase in flow volumes and a noticeable improvement in the mine environment.

Background
The Maiden Rock Mine is located adjacent to the Mississippi River at Maiden Rock, WI, near the north end of Lake Pepin (Fig. 1). The mine extracts sandstone underground using drill-and-blast mining methods. Mining operations employed a more or less regular room-and-pillar mining pattern. In the 1950s, rooms were approximately 6 m (20 ft) wide by 4.5 m (15 ft) high, but the rooms mined since 1991 are approximately 9 m (30 ft) wide and range from 6 to 9 m (20 to 30 ft) high, and the rooms are driven on varying centerlines.

The roof in several areas, particularly in the currently active mining area, is mined with the intent of leaving an arched roof, but this results in peel-outs extending upward 0.3 to 1.8 m (1 to 6 ft) through the sandstone-dolomite transition. These peel-outs presented a more complex perimeter profile, thus increasing the complexity of construction of the ventilation control structures.

Blasted sand is mucked from the faces by rubber-tired loaders and delivered to a grizzly located in close proximity to the active mining faces. The scalped sand was conveyed to a surge tank and subsequently slurried for transportation to a wash plant located near the current mine main access portal. Sand from the wash plant was passed through cyclones to separate the desired product, with the cyclone underflow placed on the mine floor to allow draining of the contained water. Drained sand was loaded by a rubber-tired loader into 27-t (30-st) trucks for transportation to the surface plant.

To meet MSHA ventilating requirements, it was necessary to base the quantities of air required on the size of the underground equipment fleets, the types of equipment and the sizes of the diesel engines used. From a ventilation perspective, the Maiden Rock Mine most closely resembles underground limestone mines in that the openings are relatively large with generally low mine resistance. Most losses were associated with the fan, connecting ductwork and ventilation control structures.

Ventilation system
The ventilation system previously employed by the Maiden Rock Mine included a 1.68 m (66-in.-) diameter Buffalo Forge Company vane axial fan that discharged to a distribution box fitted with four, 380-mm- (15-in.-) diameter PVC distribution lines. Mine intake air for ventilating the workings was passed to the working faces through PVC conduits to isolate the openings from variations in temperature and humidity common in the mid-western climate. The main fan was located at the intake of the mine, and auxiliary fans, if needed, are located within the mine workings.

The fan blades were reportedly set at the 32-position and capable of producing just over 47 m^3/s (100,000 cfm) of air at a total pressure of about 750 Pa (3 in.) water gage (w.g.) under free discharge conditions (according to the fan curves). However, by restricting the airflow to the four ducts, there was an increase in the resistance to airflow and a reduction in the fan capacity to approximately 7 to 9 m^3/s (15,000 to 20,000 cfm).

Equipment and volume requirements
The diesel-powered underground equipment fleet used at the mine consisted of two CAT 966F face loaders, a CAT 950D stockpile loader and a CAT D30D haul truck. In addition, a diesel-powered drill jumbo was used at the mining face. The estimated ventilation air-volume requirements for each of the equipments are shown in Table 1. The MSHA-approved quantity for the equipment listed in Table 1 were increased by 50 percent (to account for leakage) before adjusting it by the corresponding utilization factors and the number of pieces of each equipment type in the fleet. The resistances in the mine were estimated using a Microsoft Excel spreadsheet. Drift heights and widths of 6 and 9 m (20 and 30 ft), respectively, were modeled. The overall resistances of the mine were estimated by summing the intake and return mine resistances (Ramani, 1992). An additional 7.1 m^3/s (15,000 cfm) was added to account for the volume required at the wash plant area. The total air required to ventilate the mine was estimated to be around 44.3 m^3/s (93,900 cfm) at less than 100 Pa (0.4 in.) w.g. The low

mine resistance was a result of the large mine openings, while the high resistance was attributed to the small or obstructed openings.

Ventilation system alternatives

Three ventilation system alternatives were considered applicable for the Maiden Rock Mine. Alternative 1 employed ducting to carry ventilating air to the mine operating areas, Alternative 2 utilized the mine openings as air passages, while Alternative 3 established an intake ventilating air shaft or raise near the mine working face using a low-pressure/high-volume fan. Three circuits were proposed to the mine. One circuit, or split, would provide air to the sand stockpile area where a loader and haulage trucks would operate. A second split would supply a modest quantity of air to the wash plant. The third split would ventilate the working faces where two loaders would normally operate. All three system alternatives described below could furnish three air splits.

Ducted system. The ducted system, as shown on the mine plan map in Fig. 2, included a new fan at the current intake fan location. Air would be ducted into the mine through a 1.2-m- (4-ft-) diameter fiberglass, reinforced pipe paralleling the present ventilation pipeline route. Leakage was minimized with a ducted system, and the mine air volume required for this case was 44.3 m^3/s (93,900 cfm). At Point D3 (shown in Fig. 2), the airflow was split and two booster fans were employed to force the air to the face split and to the split serving the stockpile and wash plant areas of the mine. A total of three fans were required to ventilate the current mine. The extension of mining activities beyond the mining locations shown in Fig. 2 would require the addition of more fans as the tubing run was extended by advancing the face of the production area. These systems required extensive runs of tubing or ducting, and booster fans are often required to maintain airflow volumes. The placement of booster fans is dictated by head losses in the tubing. These losses are reduced when tubing diameters are increased to the extent possible consistent with tunnel or mine opening dimensions and equipment clearance needs. Exhaust air would exit the mine primarily through the south portal.

North intake system. Alternative 2 anticipated bringing air into the mine from the existing north portal or portals. A low-pressure/high-volume fan could be installed in a bulkhead in one portal and the remaining openings to surface at this location sealed to prevent return of the air to the outside. Man doors would be included to preserve the mine escape way. Air would be controlled by stoppings and coursed to the south along existing drift entries to a point just north of the stockpile area. The air volume required for this option was 68 m^3/s (144,000 cfm). The first split of air at N8 in Fig. 3 would be regulated to flow through the stockpile area to exhaust via the main access portal. A second split (at point N40 in Fig. 3) would be regulated and directed by stoppings to flow through the wash plant area. The third split would be unregulated, or free, and be directed by stoppings to the active mine working faces. Exhaust air from the wash plant and mine working faces would commingle with air from the stockpile area and leave the mine through the south main access portal. Figure 3 illustrates the locations of the mine fan, stoppings, regulators and doors for this option.

Future mine expansion was not expected to require additional fan capacity, due to the low resistance to airflow in the mine openings. However, the advance of the mine face would result in the construction of additional stoppings to maintain the flow of air to the working faces.

Utilization of the existing mine access portal as intake airway for the preferred system alternative was discounted because of the adverse effects of cold winter temperatures on the wash plant and stockpile areas. Introduction of the ventilating air through the north portal provides for some tempering of the air before it reaches the stockpile and plant areas.

Shaft intake system. Alternative 3 employed a new intake airshaft, as shown on the mine plan map in Fig. 4. The intake shaft would be 3 m (10 ft) in diameter to accommodate a low-pressure fan application. Air from the shaft would be directed to the face area, as well as the wash plant and stockpile areas, along routes delineated by stoppings. The air volume required for this option was 68 m^3/s (144,000 cfm) and accounted for leakage through ventilation control structures. Regulators were used to control airflow volumes to the plant and stockpile areas.

FIGURE 1

Maiden Rock Mine location.

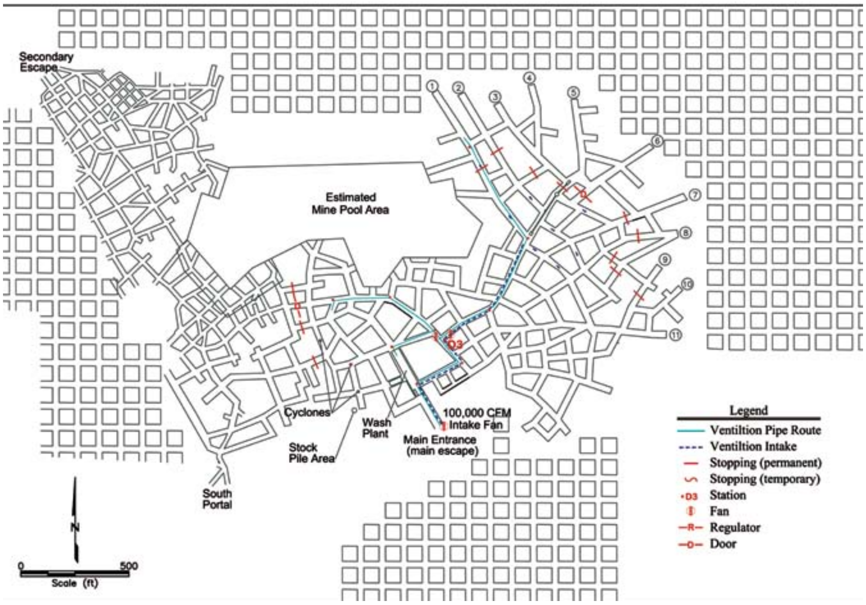
Table 1

Ventilation volume requirements for diesel equipment.

Engine make	Unit	Air required m^3/s (cfm)	Adjusted air required, m^3/s (cfm)
Caterpillar	D30D Haul Truck	7.1 (15,000)	6.4 (13,500)
Caterpillar	950 D Loader	5.7 (12,000)	7.2 (15,300)
Caterpillar	966 Loader	11.3 (24,000)	14.4 (30,600)
Deutz	Drill Jumbo	9.4 (20,000)	9.2 (19,500)

FIGURE 2

Mine plan map.



Exhaust air from these splits will commingle and exit the mine through the south main access portal. Future mine expansion considerations for the shaft intake system are similar to Alternative 2 (north intake system).

Propeller fans. Unlike most underground coal mines and many metal mines, moving adequate fresh air volumes in large-opening, room-and-pillar mines presents several challenges due to the large open-space volume of the mine and the extremely low airflow resistance. Propeller fans are the preferred choice based on the following: lower noise levels, capital and operating costs. Propeller fans are primarily suitable for low static and high-volume applications — conditions at the Maiden Rock Sand Mine.

Ventilation control structures

It was envisaged at the time of the study that the distribution of ventilating air in the Maiden Rock Mine would require the construction of either air walls (stoppings) or the installation of tubing, depending on which system was employed to best address the mine ventilation needs. In addition to the air walls, it was anticipated that doors to allow movement of vehicles and personnel in the mine and regulators (dampers) to apportion the airflow to the various circuits in the mine would be required.

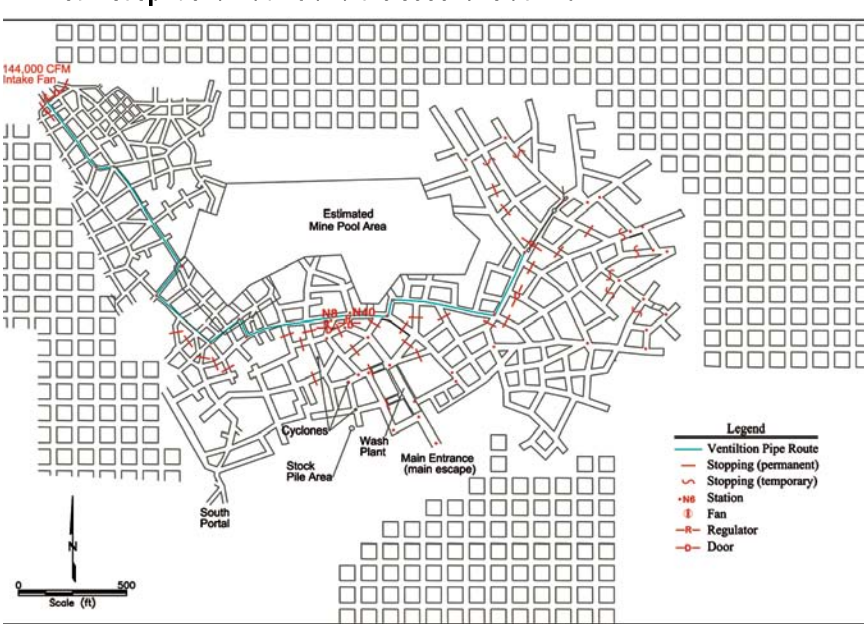
Several alternatives were available for the construction of ventilation control structures, but the simplicity of the Maiden Rock Mine would probably not require the construction of ventilation overcasts to allow the crossing and separation of intake and return air streams. The two alternatives considered the most likely to provide adequate ventilation to the face of the mine, while minimizing costs, are broken ore or rock stoppings near the face and foam block stoppings in the outby areas of the mine where blasting influences were expected to be reduced. In addition, foam blocks are easy to handle, could be readily cut and formed and are not destroyed if subjected to blasting forces, as can be the case, especially with cinder block stoppings. Adding 2.4- by 2.4-m (8- by 8-ft) timbers could provide additional rigidity to the Styrofoam block stoppings. Stopping lines would have to be close to the face to direct sufficient air through the last open crosscut.

Cost estimates

Rough-order-of-magnitude (ROM) costs were estimated for the three alternatives described in this paper and are summarized in Table 2. The north intake system (Alternative 2) has the lowest initial cost similar to the shaft intake system (Alternative 3). The ducted system (Alternative 1) can be deployed for the short term, but will result in future costs for additional booster fans, as well as higher operating costs as the mine and the ventilation systems are advanced as a result of high resistance and two booster fans required to provide the required volume of air to ventilate the mine. Alternative 3 has the highest initial cost, which is attributed to the cost of the shaft. However, operating costs are expected to be similar to Alternative 2 as a result of the low resistance, hence, the smaller horsepower required. The ducted system resistances are significantly higher, requiring 340 fan horsepower for the current mine configuration, compared to 25 fan horsepower for current and future operation of the mine.

FIGURE 3

First first split of air at N8 and the second is at N40.



Current ventilation system

In 2005, as a result of mine advancement and a shallow depth of cover of about 24 m (80 ft), the mine adopted Alternative 3 with a 90-m^3/s (191,000-cfm) booster fan to circulate air around the east side to the north of the mine while a 137-m^3/s (290,000-cfm) exhaust fan lifts the air through a 24-m- (80-ft-) long shaft.

Table 2

Summary of costs.

Component	Ducted (Alternative 1)	North intake (Alternative 2)	Shaft intake (Alternative 3)
Shaft	–	–	$500,000
Fans:			
Main (hp)	$63,9530 (300)	$10,000 (25)	$10,000 (25)
2 Boosters (hp)	$25,520 (20)	–	–
Ducting	$27,399	–	–
Stoppings:			
Temporary	$11,250	$7,500	$8,750
Permanent	$12,800	$96,000	$86,400
Permanent w/doors	$10,000	$25,000	$25,000
Total	**$150,922**	**$138,500**	**$630,150**

Conclusion and recommendations

- Utilization of the existing mine access portal as an intake airway for the preferred system alternative was discounted because of the adverse effects of cold winter temperatures on the wash plant and stockpile areas.
- The placement of booster fans would be dictated by head losses in the tubing; these losses are reduced when tubing diameters are increased to the extent possible consistent with tunnel or mine opening dimensions and equipment clearance needs.
- Stopping lines would have to be maintained close to the face to direct sufficient air through the last open crosscut. Portable auxiliary fans could be a freestanding duplicate of the main mine fan for the face air system cases and represents an additional cost if applied.
- The north intake system (Alternative 2) has the lowest initial and operating costs similar to Alternative 3; as a result, it is the preferred option. The air volume requirements are expected to be adequate if engines are maintained in accordance with the manufacturers' recommendations and fuel quality and the integrity of the ventilation system are maintained. Changes in the composition of the underground equipment fleet will have an impact on air quality.
- The ducted system (Alternative 1) can be deployed for the short term, but it will result in future costs for additional booster fans, as well as higher operating costs as the mine and the ventilation systems are advanced. For these reasons, it was not the preferred option.
- The shaft intake system (Alternative 3) has the highest initial cost, which is attributed to the costs of the shaft. However, the operating costs are expected to be similar to Alternative 2 (preferred option).
- The operating cost differences were as a result of the resistance to airflow for each system. The ducted system resistances are significantly higher, requiring 340 fan horsepower for the current mine configuration compared to 25 fan horsepower for current and future operation of the mine.
- Large mine openings provide low resistance to mine ventilating airflow and low flow velocities. These factors allow utilization of industrial ventilating fans that employ high volumes, low pressures at lower operating costs compared to conventional mine ventilating fans. Control of the ventilating air and direction of air to working areas of the mine, however, will require the construction of ventilation control structures.
- Prior to 2001, the fan was operating at a very low efficiency and well off the fan curves provided by the manufacturer, with probably a great deal of recirculation around the fan. As a result, the previous system was incapable of providing adequate ventilation. The use of vent lines to deliver air closer to the face only increased resistance. Ultimately, Alternative 2 was selected to replace the existing ventilation system, including the PVC vent line. Flow volumes increased and the mine environment was significantly improved following the start-up of the new ventilation system (Alternative 2). ■

Reference

Ramani, R.V., 1992, "Chapter 11.6 —"Mine ventilation," Mining Engineering, H.L. Hartman, ed., Vol. 1, Littleton, CO, pp. 1052–1121.

FIGURE 4

Alternative 3 employed a new intake airshaft.