Improving Ventilation in Underground Stone Mines

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The new MSHA diesel rules have stone mine operators looking hard at possible upgrades to their ventilation systems. There are existing methods to reduce diesel engine emissions (MSHA, 2001)(Head, 2001b), but many operators will decide that a ventilation upgrade is necessary as well. NIOSH has several stone mine ventilation projects underway, but in the meantime a good information resource is the work done by the U.S. Bureau of Mines in the 70's and 80's on ventilation for oil shale mines. The Bureau conducted this research because oil shale mines were projected to be gassy and would, therefore, require a lot of ventilation air. The focus of this oil shale work was on the use of jet fans for face area ventilation, and on stoppings that would be low cost and leak-tight. The work also considered changes in mine design to reduce the number and size of stoppings. The findings are still applicable to stone mines.

JET FANS FOR FACE AREA VENTILATION

A jet fan is a free-standing fan designed to induce additional air movement through a mine airway. Typically, no duct work is attached to the fan, and the exhaust jet from the fan entrains additional air from around the fan and pushes it forward. Usually jet fans do not outperform those fans with attached ductwork. However, for duct work to be effective, it must be extended close to the working face, and, at this location, duct work is subject to blast damage. Jet fans are located farther away and can always be moved around a corner to avoid the direct path of a blast.

Jet fans have two applications. They are used to ventilate a straight single heading provided it is not too long, and they are used to ventilate a portion of the mine a few crosscuts away from the main pathway of fresh air. Jet fans cannot be used to ventilate an entire mine nor even to move air more than a few crosscuts. The fans used in the oil shale research were the typical vane-axial mine fans used in auxiliary ventilation applications, so they were not specifically designed for low-pressure jet fan use.

Jet fan ventilation of single headings. Figure 1 shows a jet fan placed to ventilate a straight single heading. It is placed at the entrance of the heading, on the intake air side. It must be close to the rib, pointed straight ahead and with the inlet extended slightly into the crosscut. Performance inevitably suffers when other locations are used. Keeping the fan within a foot or two of the rib ensures that the jet expands only on one side, increasing its penetration. Extending the inlet into the crosscut reduces recirculation.

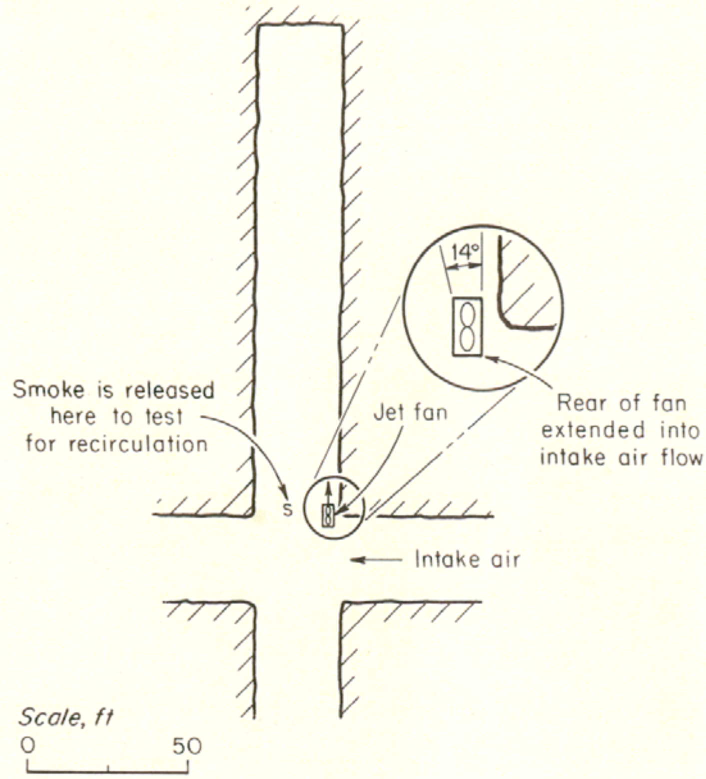

Figure 1. Jet fan ventilating a straight single heading.

Several studies have measured the performance of fans located as shown in Figure 1. Matta et al. (1978) used a 20,000 cfm fan to ventilate a heading 28 ft. wide by 165 ft. long. The height ranged from 17 ft. at the crosscut to 9 ft. at the face. Tracer gas tests showed that 5,000 cfm of fresh air was reaching the face at 150 ft. A smaller 12,000 cfm fan with a 3-ft. outlet nozzle pushed 6,000 cfm of fresh air to the face, and a 10,000 cfm compressed air-powered venturi air mover gave 3,500 cfm of fresh air to the face. The airflow in the crosscut was 57,000 cfm.

Matta et al. got better results when the fan had a nozzle attached, and Goodman (1992) and Foster-Miller (1980) obtained similar findings. Foster-Miller achieved the best air jet penetration when the nozzle was a truncated cone attached to a 1-ft. long straight section at the outlet. The sides of the cone were sloped at 18° from the axis, and the ratio of the outlet diameter to the fan diameter was 0.68.

Agapito (1985) tested a jet fan in a larger heading, 55 ft. wide by 30 ft. high by 320 ft. long. An 88,000 cfm jet fan was surprisingly effective, with 66,000 cfm of fresh air reaching the face, according to the tracer gas dilution tests. Airflow in the crosscut was 124,000 cfm.

Engineers International (1983) tested jet fans in two different sizes of headings. Both were wide relative to their depth, probably the major factor leading to the high ventilation efficiencies. For example, in a heading of medium cross-section, 45 ft. wide by 21 ft. high by 115 ft. long, a 7,000 cfm fan inclined up at 10° forced

6,700 cfm of fresh air to the face. There was 14,000 cfm in the crosscut. In another heading with a large cross-section, 52 ft. wide by 38 ft. high by 150 ft. long, a 14,000 cfm jet fan inclined upwards at 12° forced all of the 14,000 cfm of fresh air to the face. The baseline ventilation with no fan was 4,500 cfm. A larger fan performed no better because only 15,000 cfm of fresh air was available in the crosscut.

In other work, Goodman et al. (1992) tested a jet fan in a coal mine-sized entry 7 ft. by 16 ft. by 90 ft. long. The system was prone to recirculation and yielded low values for face ventilation effectiveness, probably because of the small entry area relative to its length.

Table 1 shows the results of all of the large-entry tests. The face ventilation effectiveness is the fresh air delivered to the face divided by the fan quantity, expressed as a percentage.

Overall, these results show that jet fans can work reasonably well in a dead heading, if the heading is large enough, the fan is properly located and enough fresh air is provided to the fan inlet. The best results were obtained when the heading area to length ratio was high. A nozzle should be used to improve the jet penetration. Also, it may help to angle the fan upwards by 10° per the Engineers International findings.

Jet fans in dead headings should always be tested for recirculation by releasing smoke at location S in Figure 1 and observing whether any travels back to the fan inlet. If recirculation to the fan inlet is present, it may help to attach a short length of ventilation duct to the inlet and then extend the other end of the duct upwind in the crosscut.

Researcher	Cross-sectional Area (sq. ft.)	Length (ft.)	Area to Length Ratio	Fan size (cfm)	Face Ventilation Effectiveness (%)
Matta	476 - 252	165		approx. 20,000	30
Matta	476 - 252	165	2:1	12,000 w/nozzle	50
Matta	476 - 252	165		10,000 venturi	35
Agapito	1,650	320	5:1	88,000	75
Eng. Intl.	945	115	8:1	7,000 up 10°	96
Eng. Intl.	1,976	150	13:1	14,000 up 12°	100

Table 1. Large-entry test results.

Jet fan ventilation of areas a few crosscuts away from fresh air pathway. Jet fans have great potential for moving air short distances. However, ensuring an adequate quantity of fresh air can be difficult. Figure 2 shows a jet fan placed in the center of an airway and indicates how the air jet spreads as it moves away from the fan. This jet spreading results from the entrainment of the air next to the jet, and the amount of air entrained can be surprisingly high —nine to 15 times the air quantity passing through the fan (Dunn et al., 1983). Air can also be entrained from crosscuts ahead of the fan, as indicated in Figure 2. Unfortunately, much of the entrained air is contaminated air that is recirculated back from the face, not fresh air.

The challenge is how to place the fan to maximize the amount of fresh air. Having some recirculated air is not necessarily a problem. Studies have shown that recirculated air becomes a problem only when it is substituted for fresh air rather than added to a fixed quantity of fresh air (Kissell and Bielicki, 1975).

As an example of how recirculated air can substitute for fresh air, Figure 3 shows a portion of a mine a few crosscuts away from a fresh air pathway. Without a jet fan in operation, the mine air circulation in this portion of the mine was directly from location 1 to location 2. A 14,000 cfm jet fan was placed close to a pillar at location A and directed toward the face area (Engineers International, 1983). In this location, the fan worked well since the air movement it generated brought an average of 10,000 cfm of fresh air to faces FA through FD. Location B, close to the opposite side of the pillar, was almost as effective in relation to fan placement.

However, when the fan was placed at either of the two locations close to the adjacent pillar, marked X and Y, fresh air delivery was cut by 40 percent and 80 percent, respectively. Even though the distance from A and B is less than 100 ft., X and Y are too far from the intake air source, permitting recirculated air to return on both sides of the fan and diminish the fresh air. However, for fan locations A and B, the recirculated air returns only on one side, the left side, since the rib on the right side serves as a natural barrier. Figure 4 shows the airflows obtained with the jet fan in operation at location A. The airflow directions show that all of the fresh air was being directed toward the working faces, even though there was also a large amount of recirculated air.

Important conclusions from this work conducted by Engineers International were that fans must be placed in the incoming fresh airflow. In the larger airways, it helped to angle the fan upwards

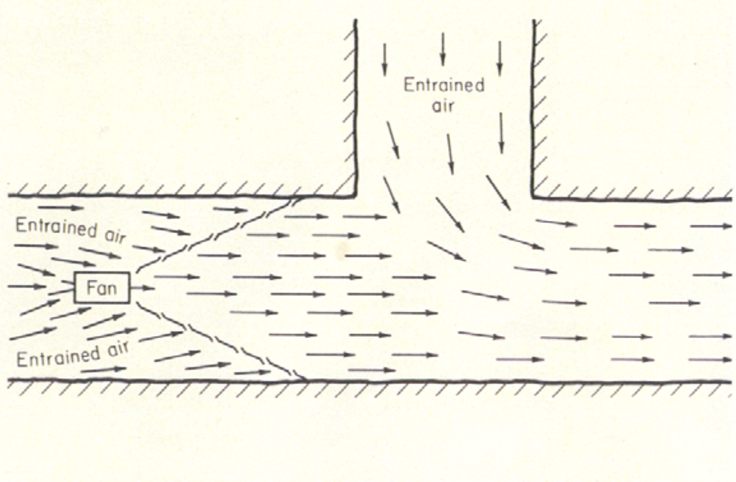

Figure 2. Jet fan entrainment of mine air.

by 10°. Also, as part of this work, it was concluded that larger capacity fans ventilate more effectively if enough intake fresh air is available.

IMPROVED STOPPINGS

In addition to jet fans, improved stoppings were seen as essential for good oil shale ventilation. The Bureau awarded a contract to Agapito (1986) to study alternative stopping designs for large mine openings. This work was undertaken to develop construction techniques and cost data, and to measure leakage rates on full-scale structures in an oil shale mine where the entries were 30 ft. high by 55 ft. wide. Six full-size stoppings and one overcast were built. Leakage was measured before and after a full-scale face blast. The lessons learned are applicable to today's stone mines.

Muckpile stoppings elicited the most interest from mine operators. These were simply piles of waste material stacked in crosscuts. However, the air leakage from this type of stopping was far too high, possibly because there were not many fines in the waste. Agapito's recommendation for achieving less leakage was to use a pipe and sheeting stopping in main entries and a brattice and wire mesh stopping in individual panels.

The pipe and sheeting stopping is formed on 5- and 6-in. telescoping, 1/4-in. wall, square section steel tubes. These tubes were set into shallow holes that had been drilled into the floor on 7.5-ft. centers. At the roof, directly above each floor hole, an 8-in. long, 3 by 3 by 3/8-in. piece of angle iron was attached using a 2 ft. resin roof bolt. The top of each telescoping member was welded to a roof angle. The connection between the two tubes was also welded. Corrugated metal sheets were then fastened to the vertical support members on the high pressure side using self-drilling screws. All sheeting seams and the stopping perimeter were then sealed with a polyurethane foam.

To build a brattice and wire mesh stopping, short pieces of threaded rod, 2-in. diameter by 4 in. long, were first welded every 2 ft. to a section of angle iron 4 by 4 by 1/4 in. by 10 ft. long. This angle iron was then bolted to the roof and floor using 2-ft. resin bolts on 3-ft. centers. Next, a wire fencing layer was placed across the opening and each panel of fence was attached to the angle base on the roof and floor. Then, brattice with velcro strips sewn down the vertical edges was attached to the angle bars on the high pressure side. The velcro seams were then fastened to create a sealed wall of brattice. Following the brattice installation, a sec-

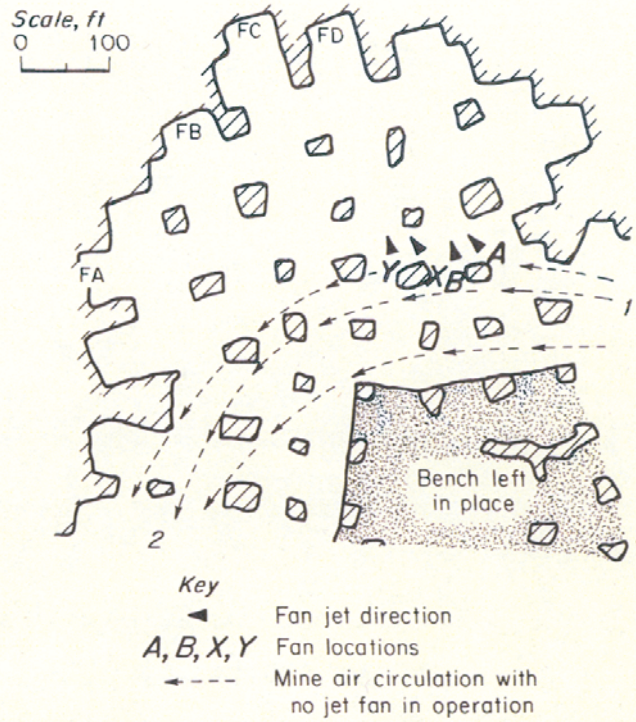

Figure 3. Portion of a mine a few crosscuts away from a fresh air pathway.

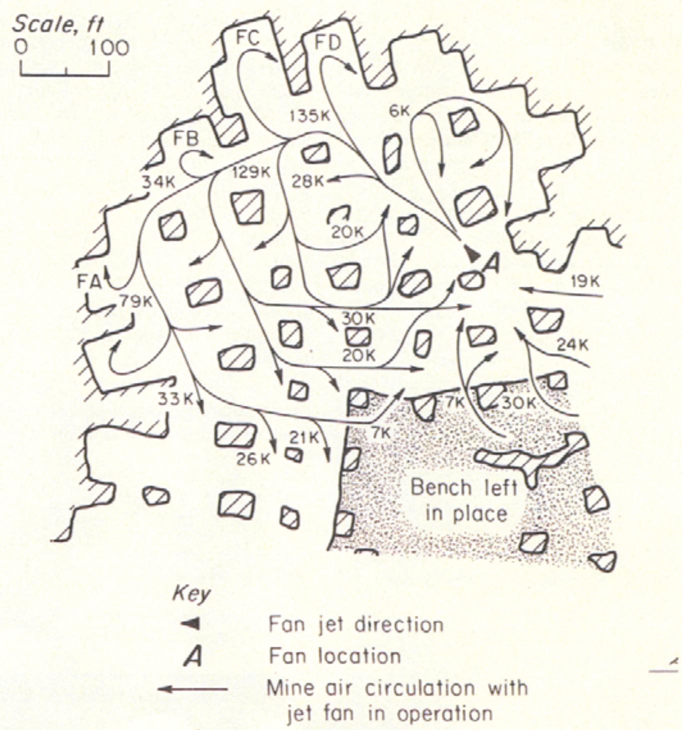

Figure 4. Airflows obtained with jet fan in operation.

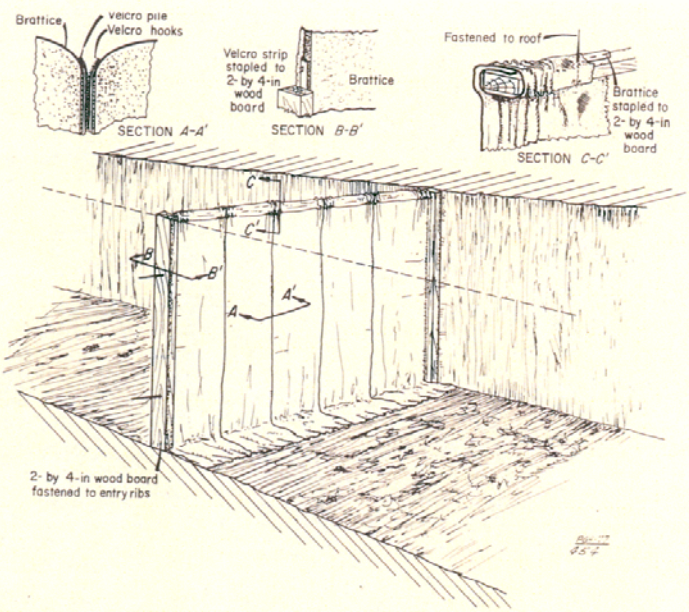

Figure 5. Stopping constructed from damage-resistant brattice.

ond layer of wire fence was attached across the drift in a fashion similar to the first. The two layers of fence sandwiching the brattice were then securely fastened to the threaded rod with roof bolt plates, washers and nuts. Finally, all velcro seams and the stopping perimeter were sealed with polyethylene foam.

Close to the face, some blast relief is needed. So, a stopping of damage-resistant brattice (Figure 5) can be used (Thimons et al., 1978). Damage-resistant brattice consists of vertical brattice panels joined by velcro seals. To form a stopping of damage resistant brattice, a strip of velcro is sewn to each edge of a roll of brattice cloth, on the same side of the fabric. The end of the roll is wrapped around a wooden 2 by 4 that is slightly shorter than the width of the roll. The 2 by 4 is then bolted to the roof, with the brattice hung down to the floor. The operation is repeated to extend a curtain all the way across the entry. Adjacent cloth panels are sealed to each other with the velcro. The velcro strips are sewn to the same side of adjacent panels so that they separate by peeling rather than shearing. Next, other wood 2 by 4s are bolted to the ribs. Velcro is then stapled on and the adjacent brattice curtain attached. Blast forces can split the seams between the panels and at the ribs, but they can easily be reattached. When blast forces are no longer a concern at that location, adjacent panels can be stapled together. Also, wire mesh can be placed on either side to make a more pressure-resistant brattice and wire mesh stopping.

Table 2 shows the leakage and cost of the three types of stoppings, along with two types of muckpile stoppings. With the exception of the muckpile stoppings, the leakage values were reasonable. However, the costs were high because there were such large entries to be sealed.

Because of the high stopping costs, Agapito also considered a wide variety of alternatives in the room and pillar layout to reduce the number and size of stoppings required. Typical alternatives were longer pillars along a stopping line, development of bleeder entries, ventilation from adjacent panels and reduced-width hourglass crosscuts that were widened on the retreat benching operation. These alternatives were then weighed in a cost-efficiency model that considered the volume mined per unit stopping area, the haulage distance and the equipment tram distance. Agapito concluded that stopping size and cost could be reduced by any of several cost-effective alternatives.

Table 2. Leakage and cost for stoppings.

Type of Stopping	Cost (1986 prices)	Leakage in cfm/1000 sq. ft. at 0.10 in. w.g.
Pipe and sheeting	$8,900	80
Brattice and wire mesh	$3,000	160
Damage-resistant brattice	$2,400	200 (before blast)
Muckpile stopping	$5,800	5100
Muckpile and brattice stopping	$2,400	2200

ONGOING WORK IN STONE MINE VENTILATION

Very recently, Head (2001, 2001a, & 2001b) has published several helpful papers dealing with stone mine ventilation. NIOSH also has stone mine ventilation projects underway. Some of these have investigated the possibility of using large diameter propeller fans as jet fans instead of the vane-axial fans employed in the oil shale research (Grau et al., 2002) (Grau et al., 2002a). Since jet fans have no ductwork attached, they are a low-pressure application, and so propeller fans could be a more appropriate type of fan to use.

NIOSH will continue to provide stone mine operators with the information they need to control diesel emissions. However, the oil shale work done by the Bureau of Mines in the 70's and 80's is still relevant and helpful to stone mines in achieving the airflows necessary for a big reduction in diesel particulate. ▲

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