USING MINE PLANNING AND OTHER TECHNIQUES TO IMPROVE VENTILATION IN LARGE-OPENING MINES

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Abstract

The National Institute for Occupational Safety and Health (NIOSH) has conducted research to improve the ventilation of large-opening mines. The research has demonstrated that the ventilation of large-opening mines improves significantly by including ventilation requirements in the mine planning process and implementing some practical techniques during mining. Planning the location of long pillars to reduce the number of crosscuts between intake airways and return airways, positioning auxiliary fans in their proper locations, and establishing ventilation stoppings with minimal leakage all significantly improve the ventilation of large-opening mines. Mine operators that adopt these techniques in the mine ventilation plan will reduce mineworkers' exposure to airborne contaminants.

Introduction

This paper discusses methods to improve ventilation in large-opening mines. Utilizing engineering controls is the primary strategy many operators use to reduce workers' exposure to contaminants. The controls include increasing the air quantity entering the mine, using stoppings and auxiliary fans to direct airflow to faces, and improving mine planning layouts (Grau et al., 2004a, 2006a, 2006b; Krog et al., 2004) to direct airflow to the face areas.

The ventilation demands of a fleet of diesel powered equipment that is to be operated in an underground stone mine should be incorporated into the mining plans (Head, 2001; Grau, et al., 2002; Krog, et al., 2004). During this planning session, special thought should be given to the length and orientation of stone pillars and to a plan to divide the mine into smaller units such that the ventilation flow to active face areas is increased by eliminating the need to ventilate old works. The ventilation plan should also include the type and location of main mine fans, auxiliary fans, and stoppings as well as considerations for face areas, maintenance shops, crusher areas, and truck haulage routes.

Ventilation plans must be developed on the premise of the mine fan developing enough air to adequately dilute airborne contaminants and delivering sufficient air to the face to dilute and render harmless airborne contaminates. In previous studies, NIOSH has shown that a large percentage of air that is produced by the main mine fan can reach the face best by using long stone pillars that form walls and reduce crosscuts between intake and return airways (Grau et al., 2006a). However, even with large air quantities reaching the face area, the methods that are used to distribute the air within the face area can significantly improve ventilating the working areas.

The Application of Long Stone Pillars

The rectangular stone pillars, shown in figure 1, are named "long pillars" because they are over 10 times longer than wide. The long pillars create a continuous wall that separates intake airways from return airways as well as course and direct the intake airflow. Air is delivered to the face area which is located beyond the last open crosscut of a long pillar, as shown in figure 1. Long stone pillars provide more resistance to leakage between adjacent entries than fabric stoppings. Using long stone pillars significantly increases airflow to face areas by reducing the number of crosscuts between intake and return airways.

The mine illustrated in Figure 1 incorporates a blowing ventilation system utilizing long stone pillars to direct the ventilation air to the face area. The mine advanced about 550 m (1,800 ft) while having only four crosscuts between intake and return entries that were separated by fabric stoppings. Using this technique, about 74% of the air produced by the main mine fans was delivered to the face area. From observations of the stoppings in the mine, an even greater air quantity could be delivered to the face area by improving the four stoppings and thus reducing leakage.

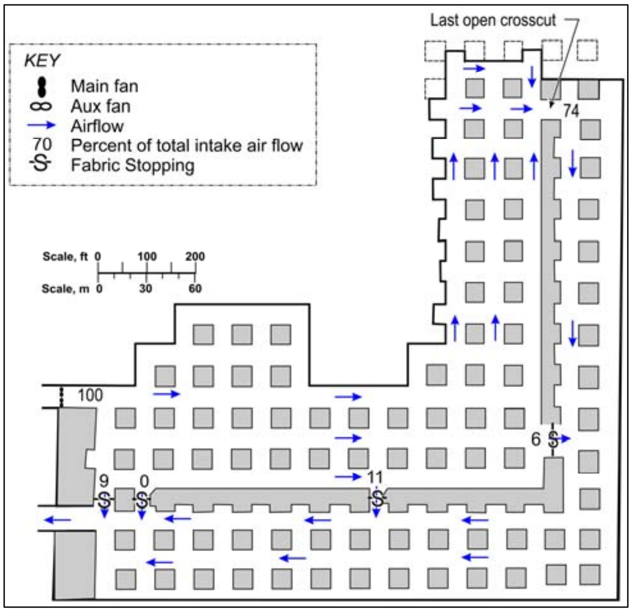

Figure 1. Using long pillars to maintain a high percentage of air reaching the last open crosscut.

Although using long pillars enables a high percentage of main mine air to reach the last open crosscut, a disadvantage is that at times, the last open crosscut may be 150 m (500 ft) or more from the face. This distance can create difficulty to adequately ventilate the face. Without using a properly positioned auxiliary fan, the ventilation air will short circuit the face and feed directly into the return entry through the last open crosscut in the long pillar. A strategically positioned auxiliary fan located outby the last open crosscut that blows fresh air to the face will reduce the air quantity that is short circuited. Various factors affect how much air quantity is moved to the face, and include the mine entry grade at the face, the amount of equipment moving in the face area, and most importantly, the auxiliary fan type, fan nozzle, location and orientation (Dunn et al, 1983).

Moving More Fresh Air to the Face

Although using a long pillar air wall will deliver large air quantities to the last open crosscut, the correct placement of auxiliary fans plays a vital role in moving the air from the last open crosscut to the face. NIOSH performed in-mine tests to determine how face ventilation is affected by the placement of an auxiliary fan. The percentage of air at the last open crosscut that is used at the face represents *face ventilation efficiency* and is calculated by dividing the airflow at the face by the airflow at the last open crosscut and multiplying by 100. Ventilation efficiency is a means to normalize results obtained for different mines having different air quantities. The ventilation efficiency represents how much air at the last open crosscut is effectively being used at the face. The results in this report present the face ventilation efficiency at a set distance from the last open crosscut for comparing one system to another.

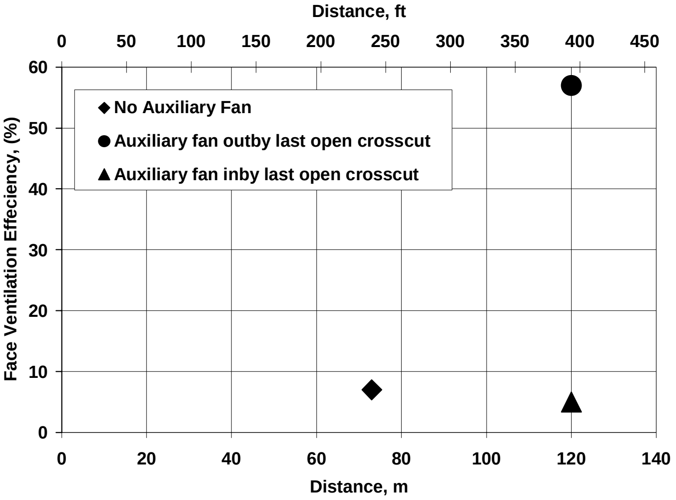

Figure 2. Face ventilation efficiencies of fan locations and distances from last opening in pillar.

Figure 2 shows graphically how air at the last open crosscut was found to be effectively used at the face for three different scenarios. The scenarios include ventilating with no auxiliary fan, positioning the auxiliary fan inby the last open crosscut, and positioning the fan outby the last open crosscut blowing through the intake air stream. Different results were found with each scenario, but the best results were found when the auxiliary fan is positioned in the intake blowing through the main air flow.

Figure 3 shows the least efficient face ventilation scenario of the three scenarios with the face being ventilated without using an auxiliary fan. With this scheme, about seven percent of the intake air that was available at the last open crosscut was measured at a distance of about 73 m (240 ft) inby from the last open crosscut. A small amount of face ventilation is achieved because the air mass moving down the intake entries carries momentum which pushes it a short distance into the face area before eventually being turned and moving through the last open cross cut. Also, a small amount of ventilation arises from the motion of both the loader and trucks at the face. However, even with these factors, the face ventilation in this scheme is minimal.

Using Fan Airflow Characteristics to Improve Face Ventilation Efficiency

Fan characteristics such as entrainment and intake air velocity common to most fans can impact the fresh air quantity moved to the face. The fan used in the scenarios shown in Figures 4 and 5 is a free-standing vane-axial fan with a diameter of 0.91 m (36 in). It was powered by a 19kW (25 hp) motor, and mounted with a reducer at the outlet with discharge diameter of 0.58 m (23 in). Figure 6 shows comparisons of air quantities flowing through an entry from the 3-ft vane-axial fan as well as a 8-ft propeller fan (Krog et al., 2006). For both fans, due to the fan entrainment properties, the maximum air quantity produced occurs some distance away from the fan. The total flow produced by these free-standing fans is the sum total of the air produced by the fan, the air entrained around the fan and by the air plume leaving the fan. Figure 6 shows that the vane axial fan's high exit velocity causes air entrainment for a distance slightly less than 90 m (300 ft) from the fan. The actual volume passing through the fan was 10.4 m^3/s (22,000 cfm) however due to entrainment and air moving around the fan, the fan eventually moved about fifteen times the original air volume that passed through the fan. The ability of the fan to entrain such large amounts is partly due to momentum. The 19 kW (25 hp) fan by itself is not well suited to move large amounts of air and without a reducer it would operate at a very low efficiency. The reducer forces the fan's airflow to pass through a small 0.58 m (23 in) diameter nozzle, which creates the higher exit velocity and therefore a higher momentum. Entrainment by free-standing fans in other cases has been documented to be quite high. Dunn et al, (1983) found an entrainment ratio ranging from 9 to 15. Also, Kissell (2006) reported several studies that showed ventilation efficiencies in dead head entries were improved when jet fans were equipped with a nozzle and were tilted slightly to the roof.

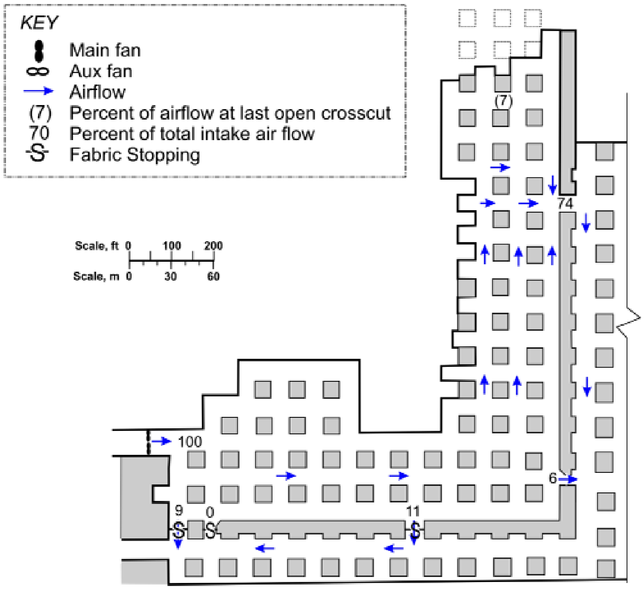

Figure 3. Least efficient face ventilation with no fan.

The other fan characteristic to consider is the fan intake. For all practical purposes, as shown in Table 1, air motion is negligible only a few distances away from a fan intake. A free standing fan placed a few crosscuts inby the last open crosscut will only intake air that is recirculating from the face and will not pull in fresh intake air from several crosscuts away. Since the face ventilation efficiency is a percentage of air at the last open crosscut that is moved to the face, with a 100 pct recirculation, no airflow at the last open crosscut is moved to the face area; consequently, the face ventilation efficiency is zero.

Figure 2 shows that an improperly placed fan inby the last pillar opening provides only marginal improved ventilation than if an auxiliary fan is not present. Figure 4 shows a plan view of this scenario where a fan is positioned inby the last opening in the long pillar resulting in poor face ventilation. In this scenario, only about five percent of the air available at the last opening in the long pillar was measured 120 m (400 ft) from the last open crosscut.

The fan position located inby the main ventilation air stream increases recirculation while providing minimal fresh intake air to the face. Furthermore, the position of the fan in the middle entry as shown tends to promote excessive recirculation as the air reverses both in entry “A” and “B” and the recirculated air acts as a substitute for fresh air. It should be noted that not all recirculation is detrimental, as previous studies have shown that recirculation is a problem only when it is substituted for fresh air rather than be added to fresh air (Kissell et al., 1975).

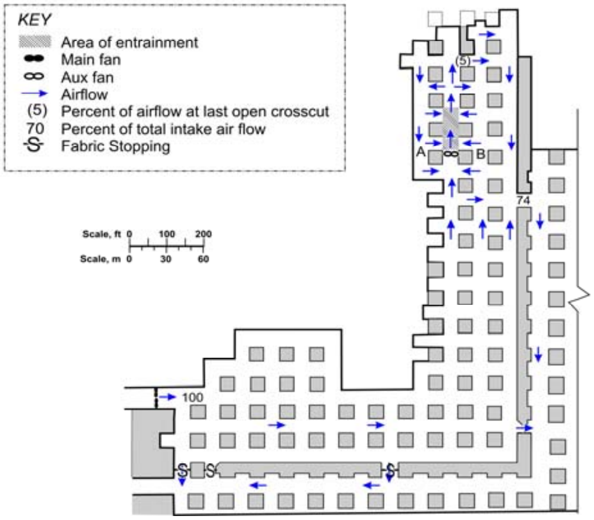

Figure 4. An improperly located fan reduces ventilation efficiency and increases recirculation.

Table 1. Diminishing air velocity with distance from end of ventilation pipe, 0.30-m (1-ft) diameter (Hartman, 1961).

Distance, diameters	Velocity, percent at fan
0.25	60
0.50	27
0.75	14
1	7

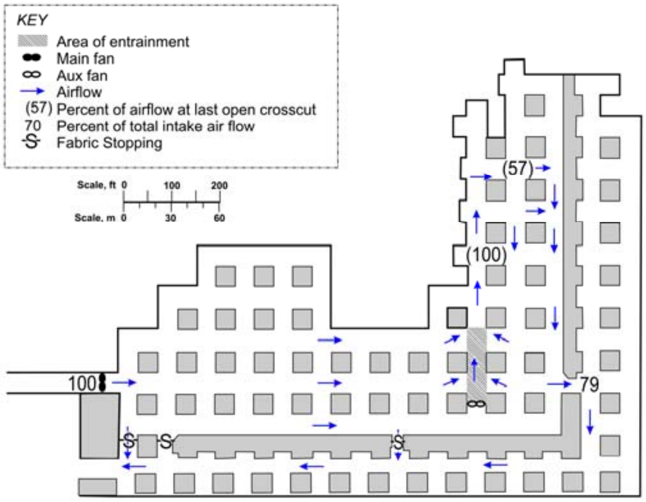

Figure 5. A properly located auxiliary fan increases ventilation efficiencies.

The correct auxiliary fan location, as shown in figure 5, should be outby the last open crosscut where it can entrain and blow fresh air into the face area. The fan should also be positioned in the furthest upstream entry (in this case left) to create air movement that is moving in the same general direction as the air being moved by the main mine fan. Being in the left most entry, recirculation is reduced and the air sweeps along the face. Using this configuration, virtually all of the air that was moved by the fan was intake air and 57 pct of the air at the last open cross cut was available at 120 m (400 ft) from the last open crosscut as described in Figures 2 and 5. There are two positive factors at work in this scenario. First, with the fan blowing down the left entry, the air recirculation is reduced and the energy is used to deliver air to the face rather than creating recirculation. Second, the fan is positioned properly to maximize intake air to the fan and maximize the entrainment of fresh air. It should be considered that moving the fan further from the face, outby the last open in the long pillar, does not increase the airflow at the face, but increases the percentage of air available at the last open cross cut to be moved to the face.

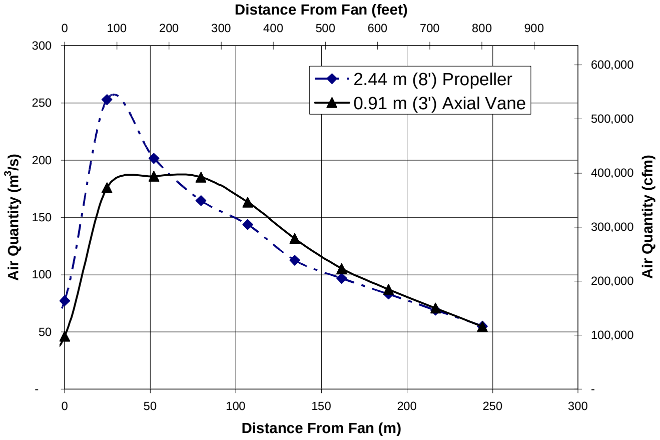

Figure 6. Air flow at center of entry compared to distance from fan for two fan types.

Considering the Floor Grade

In some instances, the floor grade has an influence on the ventilation and air quality in the face areas (figure 7). Mining downgrade has a tendency to improve ventilation and air quality. From observation alone, a slight increase in efficiency was observed while mining downgrade with no auxiliary fan. Generally, from observations and discussions with mine operators, mining up grade, as shown in Figure 7, is more difficult to ventilate since the hot exhaust fumes rise and accumulate in the upper face corner. Conversely, mining down grade enhances air quality as hot exhaust fumes rise and follow the roofline to the return entry. Fans blowing into a face with an upslope would have less efficiency as fans blowing downgrade into a face.

Summary

This paper discusses methods to improve the ventilation in large-opening mines such as utilizing mine planning layouts that use long stone pillars along with using stoppings and auxiliary fans to direct airflow to the face areas. The use of long stone pillars is particularly effective in reducing leakage between intake airways and return airways, thus allowing the maximum amount of air produced by the main mine fan to reach the face area. Although, various factors can impact the effectiveness of the face ventilation, the best method to ventilate the face is to position an auxiliary fan outby the last open crosscut, in the furthest upstream entry, such that it blows through the intake entry. Auxiliary fans blowing through an entry entrain considerably more air quantity than the actual rated air quantity of the fan. This entrainment leads to larger fresh air quantities moving toward the face. The fan should be positioned so all entrainment occurs in intake air. To reduce recirculation, the fan should also be located in the furthest upstream entry to create air movement that is moving in the same general direction as the air being moved by the main mine fan. Using this method, 57 pct of the available air reaching the last open crosscut was moved 120 m (400 ft) inby the last open crosscut.

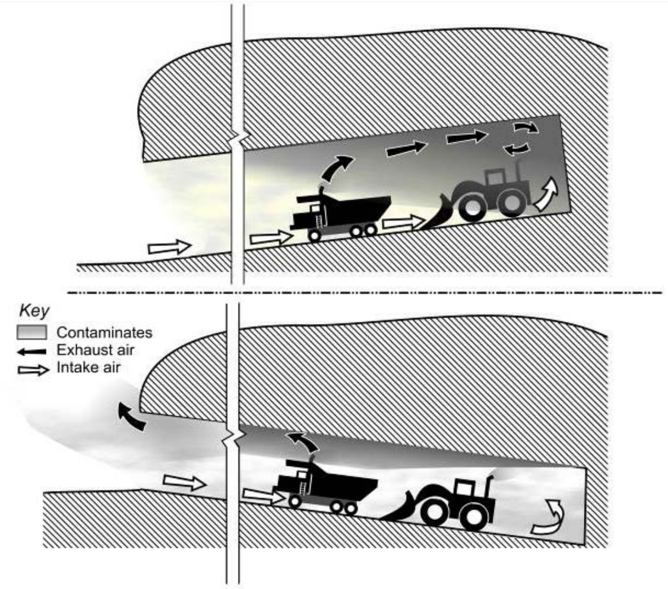

Figure 7. Air quality variations when mining up and down dip.

Disclaimer

The findings and conclusions in this report have not been formally disseminated by the National Institute for Occupational Safety and Health and should not be construed to represent any agency determination or policy.

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