2002 SME Annual Meeting
Feb. 25 - 27, Phoenix, Arizona

Preprint 02-187

NIOSH VENTILATION RESEARCH ADDRESSING DIESEL EMISSIONS AND OTHER AIR QUALITY ISSUES IN NONMETAL MINES

R.H. Grau III, S. B. Robertson, T.P. Mucho, F. Garcia, A.C. Smith
NIOSH
Pittsburgh, PA

ABSTRACT

Researchers working for the National Institute for Occupational Safety and Health (NIOSH) at the Pittsburgh Research Center are developing ways to protect the health of miners. Part of that effort is improving the air quality in metal/nonmetal mines by developing proper ventilation techniques. The air quality of large opening nonmetal mines can be greatly improved by using engineering controls of contaminant prevention and proper ventilation techniques. Contaminant prevention includes methods to reduce contaminants from entering the mine air. Ventilation can be improved with appropriate fan selection and fan operation used in conjunction with air coursing using manmade and insitu rock stoppings.

INTRODUCTION

The National Institute for Occupational Safety and Health (NIOSH) conducts research into various mining health and safety issues to improve working conditions for the U.S. miner's health and safety. To achieve this goal, researchers at the NIOSH Pittsburgh Research Laboratory (PRL) are developing methods and technologies to improve the air quality in nonmetal mines particularly large entry mines. This effort is also directed to increase the knowledge base concerning the ventilation science of the mining industry. This paper discusses current NIOSH research to improve the mine ventilation and mine air quality, particularly for large opening mines. The paper covers methods to estimate air quantity requirements for effective dilution of diesel particulate emissions (DPM,) choosing appropriate fans, air coursing methods and mine layouts particularly for mines having entries with large cross sectional areas. The most common type of mine with large entries are stone mines followed by rock salt mines. Surveillance data from the Mine Safety and Health Administration (MSHA) for the year 2000 shows that there were 162 active underground nonmetal mines in the United States, of which, 117 were stone mines and 13 were rock salt mines.

The continuing and emerging air quality issues in metal/nonmetal mines include silica dust, DPM, fog and face shot fumes. The concentration of these contaminants can be effectively reduced by utilizing preventive measures along with proper ventilation. A growing concern by various health agencies is the health risks associated with exposure to diesel particulate matter (DPM). Various regulatory agencies, ACGIH (2001), NIOSH (1988), EPA (2000), have confirmed the health hazards of exposure to DPM. As this concern increases, the mining community is confronted with DPM exposure limits. MSHA recently addressed this health concern by promulgating underground diesel regulations for coal and metal/nonmetal mines, MSHA (2001). The law was meant to reduce the health risks associated with DPM exposure. Regulations will force the use of some form of ventilation improvement and/or emissions control technology to both dilute and reduce workplace DPM concentrations and DPM emissions from equipment. Most of the common ventilation knowledge and techniques which are utilized in some nonmetal mines are not readily adaptable to large opening nonmetal mines. The large entries reduces the ventilation resistance and permits large air quantities to flow under extremely small mine static pressures. Mine designers should incorporate this small pressure loss, large air quantity relationship into their mine design plans.

CONSIDERATIONS TO IMPROVE UNDERGROUND MINE AIR QUALITY

Various mining activities such as blasting, welding, operating diesel engines and in some cases emissions from the ground strata, create contaminants that enter the mine atmosphere and need to be diluted. From these activities, a growing concern is with the mine workers' exposure to DPM emitted from the diesel engines operating in the mine. The research at NIOSH indicates that there is no single fix to reduce DPM concentrations within the large opening mines. As will be shown in this report, most underground mine operators will need to substantially increase air quantity to effective dilute DPM. In addition to the large air requirements, effective planning for the placement of ventilation equipment and control devices, such as fans and stoppings are necessary to effectively ventilate the large opening mines. The mine operators will also probably need to replace a few diesel engines that have high DPM emissions with cleaner burning engines. Other DPM control measures such as planning haulage routes and reducing diesel engine idling times should also be considered. All these measures will reduce DPM concentrations in the mine. We assume that all mine operators will not replace all the diesel engines operating in their mine. Under those circumstances, the air requirements needed to dilute DPM concentrations to comply with the proposed regulatory standards will also dilute all other contaminants to compliance concentrations. The ventilation and DPM control approaches need to be developed simultaneously as an overall strategy to reduce DPM concentrations. Although many options need to be considered on a mine by mine basis, core ideas such as documented in the following sections can be implemented by all underground large opening mine operators.

DPM AND OTHER AIR CONTAMINANT CONTROL APPROACHES

The air contaminant control approach is to reduce as much as feasible the contaminants from entering the mine or from entering where miners are working. This is accomplished by utilizing a variety of prevention techniques. Control techniques are the first step in keeping DPM and other contaminants in the mine air to acceptable concentrations.

Once the contaminants are liberated into the mine atmosphere, the two remaining choices are to dilute the contaminants or isolate the mine worker from the environment. Contaminant control techniques include implementing proper blast procedures, improving engine maintenance, utilizing diesel exhaust filters and catalytic converters, using low sulfur fuels, alternate fuels and fuel additives, replacing engines and placing haulage routes in return air. The extent or success of implementing these techniques should be at least briefly examined by the mine operator to determine which technique would have the most impact on improving the air quality in the mine.

Table 1. Typical Diesel-Powered Equipment Data for an Underground Stone Mine Producing 1.25 Million tons/year

Type of diesel-powered equipment	Number of vehicles	Total kw (hp) per vehicle type (Installed)	Pct of total kw and/or hp per vehicle type (Installed)	Total kw (hp) per vehicle type (Utilized)	Pct of total kw and/or hp per vehicle type (Utilized)
Rock Truck	5	2,136 (2,864)	39	1,301 (1,745)	34
Front End Loader	4	1,025 (1,375)	18	1,006 (1,350)	25
Drills	4	619 (830)	11	511 (685)	15
Scaler	2	261 (350)	5	261 (350)	6
Pickup	3	447 (600)	8	56 (75)	6
Mechanic Truck	2	373 (500)	7	37 (50)	5
Water Truck	1	172 (230)	3	120 (161)	4
Dozer	1	306 (410)	6	15 (20.5)	2
Powder Truck	1	101 (135)	2	20 (27)	2
ANFO Loader	1	50 (67)	1	45 (60)	1
Total	24	5,490 (7,361)	100	3,372 (4,524.5)	100

Two important DPM prevention techniques are utilizing cleaner burning engines and planning haulage routes to keep haul trucks in air that is moving out of the mine. Using cleaner burning engines makes a significant improvement in DPM emissions. As will be described later, the air quantity required for adequate DPM dilution varies significantly between clean and dirty burning engines. Table 1 provides a general list of the diesel powered equipment and the corresponding horsepower as well as the percent of actual operating time during a typical shift for an underground limestone mine that is producing about 1.13 million metric tons (1.25 million tons) per year. As shown in Table 1, truck haulage is the single largest source of DPM in this underground stone mine, and probably all other stone mines utilizing truck haulage. Thirty-four percent of the total utilized diesel engine kW (hp) operating in this underground stone mine comes from haulage (rock) trucks. Therefore, reducing the trucks operating time or adjusting their haul routes can have a major impact on the amount of DPM released into the mine air or mine workers exposure. Besides switching to cleaner burning engines, DPM from truck haulage can be reduced in several ways. Converting to belt haulage in the mine reduces underground truck haulage. However, consideration must be given to the fact that associated with belt haulage is an underground crusher. The situation should be evaluated, since nuisance dust or silica dust may be introduced into the mine air from an underground crusher as shown by Chekan et al., (2001). A separate ventilation split for the belt line, along with other control techniques at the crusher, should be provided to reduce dust exposure.

Another important consideration to reducing DPM concentrations in the mine air is to locate truck haulage routes in air that has already ventilated the face. This permits fresh air to first enter the working face and reduces DPM exposure to workers at the face. Using this ventilation scenario, the haul trucks should be equipped with a positive pressure filtered cabs to protect the truck driver from DPM. Also, some mines may be able to create alternate truck haulage routes using surface routes to reduce underground haul roads. The combined effects of implementing some or all of these preventive methods will reduce DPM in the mine.

VENTILATION APPROACH

Many large opening mines rely on a combination of natural ventilation and strategically placed auxiliary fans for ventilation. Natural ventilation is created by differences in the densities of air columns between the mine air and the ambient outside air. Since these densities are temperature dependant, natural ventilation changes frequently, both in magnitude and direction. Therefore, natural ventilation alone is unreliable for establishing a steady air quantity to the underground workings. The mines that depend upon natural ventilation also have an unreliable ventilation system. Nevertheless, in large entry mines with drift openings, even small differences in elevation, can cause large volume air movement and mine air exchange although in an uncontrolled manner. In benched areas of the mine, where conventional ventilation must overtake such large volumetric space, natural ventilation is helpful. In these areas, the large void may actually create an “air reserve.” Although this air reserve can gradually be contaminated with DPM, the natural ventilation does provide some ventilation relief during working hours and cleans out the system during off shift times.

To effectively improve the mine air quality, ventilation techniques throughout the entire mine ventilation system should be considered. The system consists of combining mechanical main mine fans, auxiliary fans, and mine layouts using devices such as air walls to direct and control the air. Criteria for proper fan selection, installation and operation for both main mine fans and booster fans should be considered. Fan characteristics of static pressure and quantity should be matched for the operation. The use of air walls helps control the mine ventilation flow, i.e., efficiently directing the air to where its most needed and separates the intake and return airways. Developing air walls includes making stoppings from man-made materials or leaving rock intact to act as stoppings.

Designing for the mine layout includes long-term planning for proper air distribution. This includes methods to have air sweep the active faces and also ventilate bench areas with strategically placed auxiliary fans. Proper planning of haulage routes and directions as well as drive through stopping locations are also important.

ESTIMATING VENTILATION AIR REQUIREMENTS

Mine ventilation systems are designed according to the air quality required to dilute contaminants to safe concentrations. Once the required air quantity is determined, the ventilation planner can determine the air quantity that will be required to be moved by the fan after taking into consideration leakage and pressure losses. The ventilation engineer can select the correct fan for the job needed. As previously discussed, a result of the new DPM regulations will be that the overriding ventilation design parameter is for the dilution of DPM. In addition, even though the total theoretical air quantity needed to dilute these contaminates can be estimated, the actual conditions may require a booster fan in selected locations to adequately mix the air with the DPM at the source.

In order to determine the air required to dilute the DPM, estimates must be made as to the DPM emitted by the diesel engines operating in the mine. In order to do this, estimates of the running percent of each vehicle must be made. Referring again to Table 1, 24 different engines operate in the mine with a total of 5,489 kW (7,361 hp). After considering the percent operating time of each engine in the mine, the actual engine kW (hp) running in the mine is reduced by about 39% to 3,373 kW (4,524 hp). The percent operating time takes into account the fact that not all the diesel engines are operating in the mine 100 percent of the time.

MSHA evaluates diesel engines and provides data for determining the air required to dilute diesel exhaust gases and diesel particulate matter concentrations to suggested levels (MSHA, 2001). For each engine tested by MSHA, the approval number, engine specifications and model number, engine rating (horsepower and rpm) and ventilation and diesel particulate indices are available. The result of the tests provides two indices, a gas index and a particulate index. The diesel particulate index is the estimated air flow needed to dilute the weighted average DPM emitted during the MSHA test to a concentration of 1,000 ug/m3. Starting on July 19, 2002, the metal/nonmetal regulations will limit workers' exposer to a DPM concentration of 400_{TC} μg/m^3 and a further limit on January 19, 2006 to 160_{TC} μg/m^3. At the allowable DPM concentration of 160_{TC} μg/m^3, the DPM index will be the more stringent requirement and the suggested ventilation needed to achieve those DPM concentrations are far greater than needed to dilute diesel exhaust gasses.

The air quantity required for a mine can be determined using a cookbook approach. A list of engines operating in the mine should be created in tabular form. The list should contain important information about each vehicle such as the equipment, and engine type (New Direct, Old Direct or Indirect Injection), year of manufacturer, model, age, size, percent operating time, catalytic efficiency and filter efficiency and finally the engine emission. The suggested air quantity from any engine nameplate should not be used as this value is for diesel exhaust gases and it is generally lower than needed for DPM dilution. Each specific diesel engine and its associated parameters should be cross-referenced with the engines tested by MSHA. The engine emission per vehicle is then documented for each respective engine found on the MSHA list. Since many commercially available engines have not been tested by MSHA, it is unlikely that all engines in the mine will be found on the MSHA list. The air requirements for those engines not tested by MSHA are determined in one of three ways and listed in order of preference: from the Environmental Protection Agency (EPA) testing data (EPA, 2001), from the manufacturer, or from estimates. The EPA has been regulating off-road vehicles since 1996 and their engine test data provides information for newer engines. Also, the manufacturer's specifications are generally available for each engine type manufactured. If the air requirements are not available from these sources, the estimated air requirements can be calculated from specifics of each engine such as the model, the age, the injection method and the catalytic efficiency of DPM control devices (MSHA, 1999). Once this information is compiled, the estimated total mine air is the sum of the engine air quantity requirements operating in the mine. This technique assumes that all of the mine air will be efficiently used to dilute the DPM and that the air exiting the mine will be at the regulatory limit. Mine planners should generally design for the lower concentration limit of 160_{tc} μg/m^3 when planning their ventilation system even though that concentration limit is not yet in law. Using this cook book approach, the estimated air quantity required for the mine represented in table 1 is 401 m^3/s (850,000 cfm) to dilute to a 400_{TC} μg/m^3 concentration and 990 m^3/s (2,100,000 cfm) to dilute to a 160_{TC} μg/m^3 concentration given the current equipment, controls etc. These air quantities may be too high for practical mine ventilation, however, the required air quantity is highly dependent upon the engines in use. Mine operators can dramatically decrease air requirements by selectively replacing some engines that have higher DPM emissions. Also, as previously described, the extremely large volumetric size of bench areas may reduce the actual air quantity required.

THE IMPACT OF SELECTING CLEANER BURNING EQUIPMENT

Past studies such as Schnakenberg, 2001, Haney, 1998 and McPherson, 1982, have found it convenient to describe ventilation air volume required in relation to diesel engine power that are operating in the mine. Using this concept, mine planners can quickly arrive at estimates of the air requirements for specific mines. Figure 1 shows the air quantity requirements from diesel engines that have been approved by MSHA. The results shown are from non-permissible diesel engines greater than 75 kW (100 hp). Although MSHA has tested a wide range of diesel engine sizes, engines less than 75 kW (100 hp) are generally uncommon in underground stone mines. Therefore, that size group has an insignificant impact on the mine air requirements.

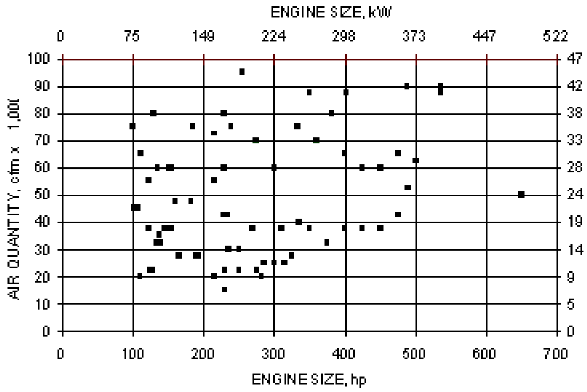

Figure 1. MSHA diesel engine test data showing air required for each engine.

The average air quantity suggested of all the diesel engines shown in Figure 1 to achieve a DPM of less than160 μg/m^3 is 0.142 m^3/s per kW (220 cfm per hp). This air quantity is less than the air quantity calculated using the previously described cookbook approach method for the diesel engines used in the stone mine listed in table 1. Using that method, the suggested air volume required was 0.183 m^3/s per kW (285 cfm per hp.) More air quantity is needed in this latter calculation because it is a more accurate account of the operating diesel engines in the mine and it takes into consideration that many of

Table 2. Ventilation data for a typical underground coal and stone mine.

Mine type	Friction factor, K ($\times 10^{-10}$)	Airway perimeter, O, m (ft)	Entry length, L m (ft)	Air quantity, Q m^3/s (cfm)	Cross-sectional area, A m^2 (ft^2)	Pressure loss, H Pa (in w.g.)
Coal	70	15.2 (50)	1,524 (5,000)	11.8 (25,000)	9.3 (100)	52.3 (0.2103)
Stone	70	42.7 (140)	1,524 (5,000)	42.7 (100,000)	38.1 (1,125)	1.64 (0.0066)

the engines are not new and are not MSHA approved engines. Not only are engines of an older vintage less efficient, as engines age, the combustion process degrades. This lowers the fuel economy and promotes higher DPM emissions. This significant difference defines why additional research is needed to define more accurate estimates of engine emissions during a normal duty cycle in an underground stone mine.

The MSHA data in Figure 1 shows there is a wide range of air required for nearly identical engine horsepower. This highlights the importance of choosing equipment with clean burning engines. The air quantity required to dilute the DPM from cleaner burning engines is significantly less than that required for the dirty burning engines. From the MSHA test data in Figure 1, the range of difference in required air volumes to dilute the DPM emission between dirty and clean engines is about 9.0 m^3/s to 142 m^3/s (21,000 to 90,000 cfm) per engine. The engines approved in Part 7 emit fairly low DPM relative to many EPA approved engines. Unlike coal mines, stone mines were not required to use Part 7 engines and as a result many of the engines they use emit more DPM and have not been tested by MSHA. Considering the mine described in table 1, if all 24 engines were in the higher range of emissions in Fig. 1, the total mine air quantity required to dilute the DPM emissions would be much higher than if cleaner burning engines were used.

FAN SELECTION

Mine fans utilized in underground stone mines are usually of the axial vane type although centrifugal and propeller fans are occasionally used. The three fan types are each designed for specific applications and the proper fan selection depends upon the ventilation application. Namely, the fan needs to overcome the mine static air pressure from resistance and develop the required air quantity. Many underground limestone stone mines are drift mines developed from quarry operations. Typically, these room and pillar mines feature entries that are 6.1 m (20 feet) or higher and at least 12.2 m (40 feet) wide. These dimensions are significantly larger than the typical coal mine in the United States where the average dimensions are 1.5 m(5 ft) high by 6.1 m (20 ft) wide. The large dimensions in stone mines contribute to a low static head loss while moving large air quantities through the entries. The static head pressure loss can be expressed in the common pressure-loss formula for mine ventilation which is:

$$H = \frac{KLOQ^2}{5.2A^3}$$

where: H = pressure loss, Pa (in of H^2O w.g.)
K = friction factor for air of standard density
O = perimeter of the airway, m (ft)
L = entry length, m (ft)
Q = air quantity, m^3/sec (cfm)
A = entry cross-sectional area, m^2 (ft^2)

Therefore, in calculation, the static head loss is based upon the reciprocal of the cube of the entry cross-sectional area. As shown in Table 2, the typical pressure loss through large entries such as underground stone mines is considerably lower than what would be encountered in a coal mine. The fan static pressure required to move 47 m^3/s (100,000 cfm) through one typical underground stone mine entry is about 1.64 Pa (0.0066 in) of water gauge versus 52.3 Pa (0.2103 in) of water gauge (32 times that of a stone mine) required to move 47 m^3/s (100,000 cfm) through four typical parallel coal mine entries. Fan static pressure readings from four underground limestone mines were taken and the results are shown in table 3. All fan static pressure readings were extremely small unless a shaft or slope were present. This small difference in static pressure should be considered during fan selection for mines of this type with large cross-sectional airways. In most cases, large opening room and pillar mines with drift openings exhibit static pressure losses significantly less than 248.8 Pa (1 in) w.g.

Axial vane fans are the most widely used fan type we have encountered in underground large opening stone mines. Axial vane fans have the capability to develop higher pressure than that created by propeller fans. Propeller fans are designed for a smaller range and lower potential for static head but have more potential for higher air volumes than an axivane fan. Although numerous fan designs are available for both fan types, Figure 2 shows a fan pressure-quantity curve for two typical axial vane fans and one typical propeller fan. With the current diesel particulate concerns, large entry nonmetal mines particularly drift portal stone mines will need large air volumes that can be delivered at very small static pressure losses. To date, only three underground stone mines that are using large propeller fans have been identified. However, due to the low static pressure and high air volume requirements, other underground stone drift mines could benefit from their use. Also, mines with air shafts less than 30.5 m (100 ft) in length and at least 3.6 m (12 ft) in diameter may also benefit from propeller fans. In those cases, if large diameter propeller fans are used, larger diameter shafts will be needed. Figure 3 shows the relationship between static pressure loss and shaft diameters of 2.4 m to 6.1 m (8 ft to 20 ft) at air quantities of 165 m^3/s (350,000 cfm.) The static pressure losses ranges from 2.8 kPa (11.4 in w.g.) for a 2.4-m (8-ft) diameter shaft to 28.9 Pa (0.12 in w.g.) for a 6.1-m (20-ft)-diameter shaft. The pressure loss through a shaft or a slope in large opening mines dictates the fan selection. Corresponding to this information, a large opening mine with drift openings or a with large shaft 6.1 m (20 ft) or more in diameter, can possibly use a high air volume-low pressure propeller type fan. However, a mine that has a smaller diameter shaft would have to use a higher pressure axivane fan delivering a lower air quantity.

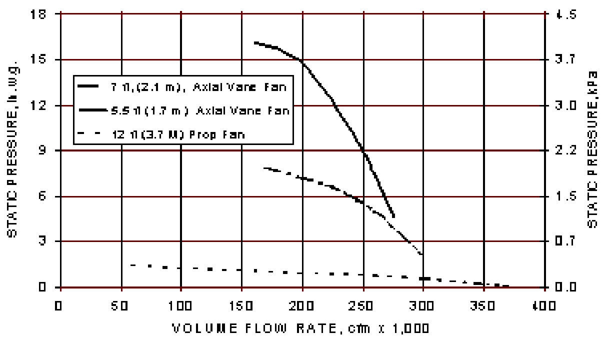

Figure 2. Fan Curves of Axivane and Propeller Fan.

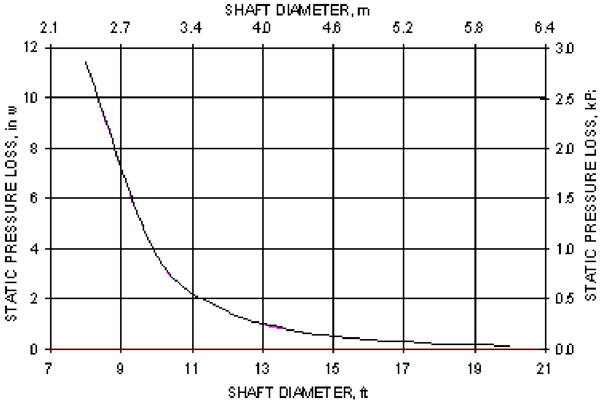

Figure 3.Static pressure loss through various size shafts at 165 m^3/s (350,000 cfm).

From Table 3, Mine C is an example of a lower volume, higher pressure axivane fan being used in a 4.0-m (13-ft) diameter air shaft. This particular mine needed significantly higher air volumes to dilute DPM concentrations. One option would be to increase the air quantity by adding a second fan in parallel. However, using two conventional high pressure axial vane fans in parallel to increase the air quantity in a low resistance application is not practical when compared to a large, high flow/low pressure propeller fan. Two large axial vane fans would require a high initial capital and operating cost, and the fans would operate inefficiently at of very low static pressure. A propeller fan may be a better choice in this application. For planning purposes, if stone mines are to utilize the low pressure/high volume fan concept, they must have air shafts large enough to reduce head loss. The development cost of a large diameter shaft generally overrides the fan choice. However, shaft development costs for a large diameter shaft in a stone mine will be lower than mines that require a smooth lined air shaft to reduce friction. Realizing those cost reductions, the reduced savings in both the capital and operating costs of a large diameter fan should be considered.

AIR COURSING

Air flows through a mine due to differential static pressure between locations. The air flow is always in the direction from a higher to a lower pressure, disregarding pressure differences due to elevation. The pressure is developed from either natural ventilation or from mechanical fan pressure. Natural ventilation pressure is created by differences in the air density of air columns because of the combination of elevation changes and temperature differences between the surface and inside the mine. Unfortunately, natural ventilation pressure and the subsequent natural ventilation are unreliable. The airflow may change daily, and it is often in the direction opposite of that desired. However, natural ventilation does offer some exchange of mine air with outside air, albeit in a very uncontrolled manner. A much more practical and efficient method is to ventilate using mechanical fans to develop a pressure difference throughout the mine. In conjunction with the fans, an integral part of the ventilation system is to distribute mine air using stoppings between high and low pressure airways. This concept is used in virtually all types of mechanically ventilated mines. The unique characteristic of underground stone mines is their large cross-sectional area which allows the mines to be ventilated with high air quantities at low static pressures. Although this small pressure difference is a benefit to minimizing air leakage between intake and returns, many mines avoid the use of stoppings due to the cost and the problems of constructing and maintaining a stopping in a large entry. Instead, these mines rely on auxiliary fans that are positioned by trial and error at strategic locations. Although very small mines may stay in compliance with a few strategically placed jet fans, as the physical size of the mine increases, moving adequate quantities of air throughout the mine becomes more difficult.

CONSTRUCTED STOPPINGS

NIOSH scientists are evaluating the use of stoppings in large opening mines. A variety of materials have been used for stopping construction in large opening mines. Steel sheeting, cementious-covered fiber, mine brattice, used mine belting and piled waste stone have all been used with varying degrees of success. Unfortunately, expense, construction, and maintenance problems have been barriers to stoppings gaining wide acceptance by the stone mining industry, particularly in larger more established mines. Two stopping design criteria are: to prevent leakage and the capability to withstand the pressure from face production shots and the static pressures created by the fans. Some mines have had success in developing stoppings designed to provide relief during face production shots. Techniques such as leaving the brattice loose at the floor, using VELCRO strips, or using a combination of used mine belt and brattice have been effective.

INSITU ROCK STOPPINGS

Rock stoppings that connect pillars can be strategically oriented to direct the ventilation air. These rock stoppings are created by eliminating at least the last face shots that would normally break through two adjoining entries, thus keeping a natural connection between two pillars. In order to direct the air, the rock stoppings are oriented parallel to the ventilation flow. Rock stoppings can later be mined through for optimum stone recovery and bench mining can proceed if desired. The long unbroken rib (air wall) utilizing stone stoppings are an effective and practical method to direct ventilation air. This technique reduces maintenance and the expense of building stoppings. Stone production may be temporarily compromised because the stone in the rock stopping is not immediately mined. However the stone can eventually be mined when the stoppings are no longer needed or when a new air wall is constructed past the original stopping line.

Table 3. Measured air quantities and static pressure through underground stone mines

Mine	Airway length, m (ft)	Shaft length, m (ft)	Shaft diameter, m (ft)	Slope length, m (ft)	Slope cross sectional area, $m^2(ft^2)$	Air quantity m^3/s(cfm)	Fan static pressure, Pa (in w.g.)
A	731 (2,400)	None	None	None	None	165 (350,000)	29.9 (0.12)
B	2,134 (7,000)	None	None	None	None	132 (280,000)	14.9 (0.06)
C	1,463 (4,800)	23 (75)	4.0 (13)	None	None	59 (125,000)	59.7 (0.24)
D	464 (5,000)	14 (150)	3.0 (10)	244 (800)	14 (156)	130 (275,000)	671.8 (2.7)

MINE LAYOUTS USING VENTILATION IDEAS

The concept of incorporating mine planning and ventilation ideas together is an important step in improving the ventilation in the mine. By strategically planning stopping and auxiliary fan locations, stopping types, and truck haulage routes, the mine ventilation efficiency and air quality will be improved. By increasing the mine ventilation efficiency, the air quantity needed from the fan is reduced because a higher percentage of air reaches the face sections. A mine ventilation system that has high efficiency means less leakage and less recirculation. Also, by increasing the efficiency, the air exchange rate in the mine is also increased. In any case, mine operators should strive for fresh, uncontaminated intake air to the working faces. To help accomplish this goal, truck haulage should be primarily routed in air that has already ventilated the working faces (return). Haulage trucks are the major single source of DPM. Keeping truck haulage from entering the working face sections is an important concept to prevent excessive DPM concentrations at one location of the mine. Although planning of haulage routes reduces mining flexibility, the benefit received in reduced DPM concentrations should outweigh the reduced flexibility.

The concept of increasing the air exchange rate to mining activities is also important. On a typical working day, the first shift follows several hours of down time proceeding the completion of the night shift. If the mine air turns over before the workers on the new shift arrive, they will enter the mine in fresh uncontaminated air. Also if the exchange rate is quick enough, some air can be recirculated in a controlled manner from the bench areas to the development areas.

Considering the above criteria, NIOSH researchers have identified three different ventilation concepts for ventilating large underground stone mines: perimeter ventilation, unit ventilation and split mine ventilation. Real working experiences are needed to verify the successfulness of each concept. We have observed mines incorporating at least some parts of these concepts in daily practice, however no real data exists as to the successfulness of the methods.

The goal of all three concepts is to supply fresh uncontaminated air to the faces. Each method is defined by a unique mining layout that is advantageous for different mine applications. To properly choose the correct ventilation plan, the size and extent of the mine should be considered. All the methods utilize a main mine fan to move the air, and they all utilize air walls to direct and course the air. In most cases, jet auxiliary will be required to address the ventilation needs for localized areas where diesel equipment concentrated. Auxiliary ventilation fans should be positioned to work in conjunction with main mine fans and not directed in an opposing direction.

During the planning process, considerations need to be given as to the choosing between a blowing or exhaust system. Either method is capable of diluting contaminants in the mine and each method has it's pros and cons. One advantage of a blowing system is the elimination of the need for check curtains on the truck haulage routes as the trucks leave the mine. Other considerations are the circumstances that develop when the intake air enters the mine. Air entering on slope declines may creates hazardous conditions with icy roadways during the winter season. Also, shaft air intakes may have considerable condensation present during the summer months. This could promote ground control problems near the shaft. These criteria should be fully considered for all three ventilation methods.

PERIMETER VENTILATION

The perimeter ventilation system is particularly applicable to existing large mines. The perimeter ventilation system is designed to keep the active faces, or the outside perimeter of the mine, always under intake air as shown in figure 4. This is accomplished by separating the developing active mining areas from the rest of the mine by an air wall. Ventilation is provided to the area by utilizing a bulkheaded main mine fan. Since the mining front continually expands, a second air wall is developed at least four entries beyond and parallel to the first air wall. In an older developed mine, the first air wall needs to be developed by creating stoppings. However, the second air wall could be developed using insitu stone. A check curtain every third or fourth crosscut through the air wall allows for equipment haulage. As mining progresses beyond the second air wall, and a third air wall is developed, the second air wall can be mined through and the stone recovered. By alternating in this manner, the working faces will always remain in adequate ventilation. In many of large mines, extensive benching areas will be already developed, these areas can normally be ventilated by the combination of natural ventilation and auxiliary fans.

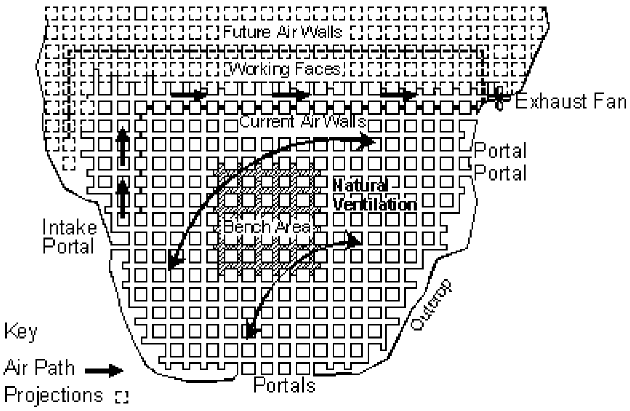

Figure 4 Perimeter Ventilation.

UNIT VENTILATION

Figure 5 describes the unit ventilation method in which a series of "units" or "sections" are created which are the active mining areas. The unit ventilation plan is applicable to newer mines especially if air shafts are present. The units described in this method are a planned mining block of significant size (several pillars) that contain the working faces and that is surrounded on four sides by long air walls incorporating stone stoppings. The air walls have only a few openings or check curtains which allow for ventilation control and haulage. One advantage of this method is that it allows for these units to be at least partially removed from the main mine ventilation circuit when mining development is completed. The method is also less dependent upon one mining front which can be a problem if poor roof conditions are encountered. In the unit ventilation method it may be possible for one auxiliary fan to provide the ventilation for that separated section. The size and capacity of the fan will be dictated by the section size.

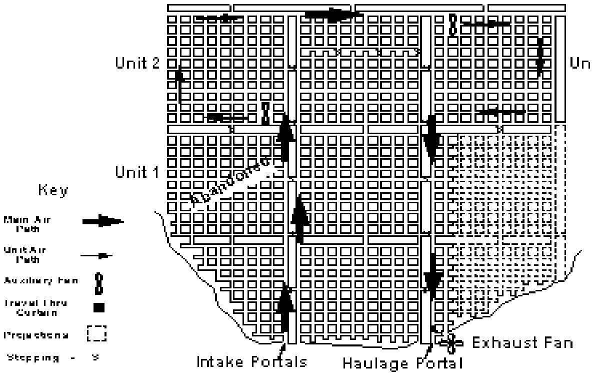

Figure 5. Unit ventilation.

SPLIT MINE

Split mine ventilation, shown in figure 6, is designed to split the mine into two parcels, intake and return, separated by an air wall. The face ventilation using this system is similar to the perimeter ventilation method in that air is coursed by air walls. However the system uses a air wall that is built as a permanent structure. Like the unit ventilation, the split mine ventilation is particularly good for newer mines. The method is also effective for utilizing truck haulage in return air and for a developing mine with drift openings. Like the other ventilation methods, this system keeps the working faces in fresh air.

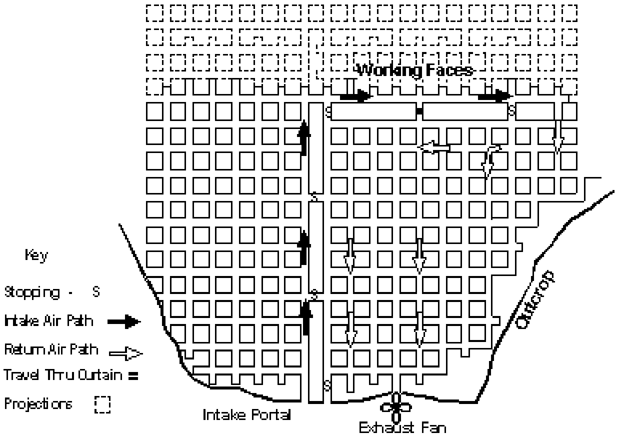

Figure 6. Split mine ventilation.

CONCLUSIONS

NIOSH is researching various ways to improve ventilation in large opening mines and is currently focusing on contaminant prevention, fan applications, air coursing and implementing mine ventilation techniques into the mine layout. Prevention techniques include implementing proper blast procedures, improving engine maintenance, using exhaust filters, higher quality low sulfur fuels, fuel additives and locating truck haulage routes in return air.

Two very important prevention techniques are utilizing cleaner burning engines and better planning of haulage routes to reduce haul time in the mine. Truck haulage is the single largest source of diesel particulate in an underground stone mine. Mine operators can dramatically decrease air requirements by selectively replacing engines or adding control measures to engines that emit the most DPM. Ventilation techniques which can be used in underground stone mines are the proper use of mechanical fans, and developing air walls and mine layouts incorporating ventilation concepts. Underground stone mines are large opening mines that feature a small head loss for ventilation air. Propeller fans should be suited to produce large air quantities under low static head loss conditions. The use of stone stoppings is being researched particularly as to how they can be implemented in the mine layout. Three mine layouts incorporating ventilation have been identified: perimeter ventilation, unit mine ventilation, and split mine ventilation. All three methods keep the working face in fresh air. Operators of all underground stone mines should find that these recommendations will improve their ventilation in the underground workings.

REFERENCES

American Conference of Governmental Industrial Hygienists (ACGIH), 2001, “Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices."

Chekan, G. J., Colinet, J. F., Grau III, R. H., 2001, “Silica Dust Sources in Underground Metal/Nonmetal Mines - Two Case Studies,” In publication for 2002 SME Annual Meeting, Phoenix AZ.

Haney, R., Saseen, G., 1998, “Estimation of diesel particulate concentrations in underground mines,” Preprint 98-146 for presentation at the SME-AIME Annual Meeting Orlando, FL, March 9-11,.

McPherson, M. J., 1982, “The Environmental Aspects of Diesels in Underground Mines,” IM & EJ, April.

Mine Safety and Health Administration (MSHA), U.S. Department of Labor, 2001, “MSHA Web Site, Nonpermissible diesel engines approved under Part 7", http://www.msha.gov/S&HINFO/DESLREG/1909a.HTM

Mine Safety and Health Administration (MSHA), U.S. Department of Labor, 2001, “Final Rule 30 CFR Part 57," January.

National Institute for Occupational Safety and Health (NIOSH), Department of Health and Human Services, 1988, “Carcinogenic Effects of Exposure to Diesel Exhaust,” Publication 88-116, 30 pp.

U.S. Environmental Protection Agency (EPA), 2000, “Health Assessment Document for Diesel Exhaust,” Report EPA/600/8-90/057E, July.

U.S. Environmental Protection Agency (EPA), http://www.epa.gov/otaq/certdata.htm#largeng

Schnakenberg, Jr., G. H., 2001, "Estimate of Technically Feasible Dpm Levels for Underground Metal and Nonmetal Mines," Mining Engineering, Sept.