# ENGINEERING ASPECTS OF COAL MINE VENTILATION SYSTEMS

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## INTRODUCTION

The single most critical factor affecting the health and safety of workers engaged in the coal-winning process is the mine environment; which is broadly defined as the space in which man works when underground and includes the physical and chemical conditions of the surrounding enclosure and the nearby mining equipment. A fundamental objective of a mine ventilation system is to supply this environment with an adequate and sufficient quantity of uncontaminated fresh air. It is the largest single logistics application in health and safety for underground coal mining operations. It is sometimes necessary to course intake air through several miles of underground airways in order to achieve this purpose. Leakages will be severe and yet an adequate supply of fresh air must be delivered to the last open cross-cut outby of the active face. This process is identified as quantity control. Equally important, if not more crucial, is the quality control process dealing with the control of respirable contaminants liberated during mining operations.

The Federal Coal Mine Health and Safety Act of 1969, Sec. 303(b), stipulates that the primary ventilation system must deliver at least 9,000 cfm of uncontaminated fresh air to the last open cross-cut. Auxiliary ventilation systems are required to supply 3,000 cfm to the coal face. Sec. 202(b), (2), of the 1969 Act states that each mine operator shall continuously maintain an average concentration of respirable dust in the mine environment during each shift at or below 2.0 $mg/m^3$. Respirable dust can be defined as solid coal particles in the minus 10 micron range which become airborne and do not settle easily.

With respect to gaseous concentration, the 1969 Act states that no working section of the mine shall contain more than 0.5 percent carbon dioxide and no harmful quantities of other noxious or poisonous gases such as the oxides of nitrogen. The concentration of methane should at all times be maintained below one percent. A split of air returning from any working section shall contain no more than 1.5 percent of methane and air that has passed by an opening of any abandoned area shall not be used to ventilate any working place in the coal mine if such air contains more than 0.25 percent methane. Methane concentration in the returns from the bleeder entries should not exceed 2.0 percent, and no air that has passed through an opening which is inaccessible for examination shall be used to ventilate any active areas. While the air quantity requirements alone can easily be met, the governing condition in most mines is the dilution requirements for quality control. A sufficient quantity of air is required to render harmless and carry away noxious and respirable pollutants.

Good ventilation is essential for efficient mine operation. On one hand, available ventilation facilities place certain limitations on production level. On the other hand, ventilation possibilities and requirements cannot be defined other than in relation to a production plan. Thus, ventilation and production planning are interdependent. Experience

in the last decade has shown that the development of larger and more powerful machines for higher production rates calls for increased sophistication in ventilation planning. Over the last twenty years, ventilation standards have risen steadily and stringent regulations have been enacted. It is also evident that in the near future, ventilation requirements will become increasingly more demanding. The trend is a consequence of change in both mining conditions and equipment. These changing conditions, such as higher production from fewer mines, extraction of thinner seams, increasing depth of workings and additional installed horsepower, influence the planning and design of ventilation systems. It is, therefore, becoming increasingly important that ventilation requirements should be adequately assessed at the planning stage.

## COMPUTERS IN MINE VENTILATION STUDIES

The role which computers can play in evaluating ventilation parameters and processes is tremendous. During the past decade, the role of the digital computer has expanded in an unprecedented manner from purely commercial applications to problems involving the design, maintenance, and control of technical systems. Major development of computer applications for mine ventilation has been in the field of ventilation planning. When an enormous amount of data has been collected, a computer can be used advantageously to relieve the ventilation engineer from the tedium of routine repetitive calculations. In addition, digital data processing has both short and long term significance. Long range data processing involves such observations which are routine and are being continually recorded. An accumulation of such data could be tested for statistically significant trends (6). This information could then be used in planning the ventilation of new sections or adjacent mining operations. Short term data processing involves spot testing and checking of such parameters as fan performance, optimum roadway sizes, air horsepower losses, and statistical examination of information surveys.

Development of computerized methods of calculations is only one aspect of the use of digital machines by research personnel. An example of ventilation research which is completely computer dependent is the theoretical investigations to study the patterns of methane flows and rates into the mine openings from the roof, sides, and floor. Mathematical models have been developed which enable the computer to simulate gas flow rates while varying such parameters as the position and emissivity of the gas sources, boundary pressures, and the permeabilities of the intervening strata.

The application of energy and mass transport phenomena, or more appropriately, physico-chemical principles, to quantify mining engineering parameters for quality and quantity control of the mine environment has taken an unprecedented outlook since the advent of digital computers. These machines enable complex problems in ventilation to be modeled and solved numerically. It is, therefore, not surprising that solution of problems of temperature and humidity, fluid flow dynamics, and toxic emission dilution in the mine environment are being attempted through mathematical models and computers. The parameters obtained from such numerical estimation can then be utilized in engineering and process control.

Today, more than ever, much attention is being focused on the development of a system of remote monitoring and control of environmental parameters. Significant progress is being reported in remote sensing

and monitoring of environment. Some work has already been done in the United Kingdom on automatic monitoring of a methane drainage system. Such automatic controls can be extended to other environmental parameters such as heat and humidity, temperature and dust levels. As studies are perfected in the determination of suitable parameters for control, their range of operation and choice of monitoring sites, these advances can eventually be used to develop on-line computer control systems of the complete mine environment.

## VENTILATION NETWORK ANALYSIS

The theory of network analysis has long played an important role in many branches of engineering sciences. Transportation and other distribution problems have been solved by applying tools of network analysis. Literature review reveals that the application of this theory to mine ventilation planning and network analysis is a recent development. There has, however, been a growing awareness in recent years that certain concepts of network theory can be successfully applied in many other fields as well. It is, therefore, not surprising that in the last ten years, these tools have found increasing application in mine ventilation network analysis.

The major advance in ventilation network analysis in the last decade has been, therefore, the development of computer programs capable of developing and solving the systems of equations defined by the junction and pressure laws. Ever since Hardy-Cross iterative technique (4) was adapted and modified by Scott and Hinsley (13) for the solution of ventilation network problems, several programs have been developed to solve for mine ventilation parameters. A brief description of most of the quantity flow mine ventilation programs is presented by Geiger (5).

## METHANE GENERATOR MODELS

The quantity of methane emitted into the mine atmosphere and the movement of gas through solid coal and the adjoining country rock are dependent on gas emissivity, boundary conditions, and the initial gas distribution pressures and the combination of natural and mining factors. Functional relationships between these factors are not yet known. Consequently, the development of rigorous mathematical equations to simulate methane flow into the mine air is difficult, and to date, no model has been reported which is capable of such a function. Several researchers in many parts of the world have attempted to quantitatively describe the pattern of gas emission in mines as functions of seam characteristics and the confining gas pressure (1,2,9), none with complete success.

Thus far, empirical formulas available for the calculation of gas released from underground sources appear amenable to analytical computation. These estimations are at best only crudely approximate. The numerical methods available have not been made practical enough for use in the industry. Therefore, a relationship amenable to numerical analysis and practical enough for application in the industry would provide the flexibility lacking in analytical approaches. The mathematical model developed and presented by Owili-Eger (10) is yet another attempt to correlate as many flow governing parameters in a single equation. This model solves gas flow-rates into mine workings from coal seams and intervening layers of rocks and is designed to handle only two dimensional steady state flow systems. It represents a modified gas diffusion system

for flow through porous media. Mathematical considerations and derivation of the flow equation are presented in the reference.

Various investigators have shown that temperature also affects the rate of gas flow. However, at temperatures usually encountered in mines, methane has a very low rate of diffusion. As long as shallow deposits are being extracted, the effect of temperature on the rate of gas flow will remain insignificant. At great depth where rock temperature will be high, temperature will affect flowrate of gas and has to be considered. The chemistry of multi-component multi-phase systems has also been considered in a recent report on methane flow modelling (12). It has been pointed out that the presence of water affects the migration characteristics of methane in coal seams even though the two fluids are said to be chemically unreactive.

## HEAT AND HUMIDITY CONTROL

Temperature and humidity control is important in the face area, or more generally, any active section of the mine where men are exposed to the environment for as long as a shift. Factors that affect the temperature of the ventilating air in such areas are the presence of men and machines, the temperature of the incoming air, chemical oxidation of coal, evaporation of water which may extract part of the latent heat from the air and the heat transfer from the surrounding strata. This last factor is very significant especially in deep mines where wall rock temperature is much higher than that of the incoming ventilation stream. In the U.S. coal mines today, rise in temperature and humidity as a result of heat transfer from the wall rock is not significant because coal seams being mined presently are very shallow - less than 1500 feet. However, these coal reserves are being depleted at a very fast rate. It is only logical to say that operation at great depth in the near future is inevitable. In deep metal mines, heat transfer from the enclosing strata can be significant and, consequently, techniques for predicting air temperatures have been developed. The first requirement in mathematically formulating heat transfer problems is knowledge of the thermal properties of the strata surrounding the roadway or model area. Jones (7), Jordan (8), and Paulin (11) have presented details of mathematical considerations which can be taken to estimate such parameters if the thermal history of the region is unknown. Extensive work in this area is reported in South Africa and in Japan, Amano and Shigeno (3) and Vance and Kathage (15).

## DUST IN COAL MINES

Coal dust is defined as any solid coal particles smaller than 100 microns (1 micron = $10^{-4}$cm) which become airborne when disseminated. During the coal winning process, dust is inevitably generated by the mining machines. Transfer points and transport systems, and high air velocities, contribute to the dust problem in the mine roadways. Inadequate suppression of coal dust can lead to explosion hazards and the coal workers' pneumoconiosis. Pneumoconiosis is supposed to be caused by the inhalation of respirable coal dust (-10 micron) for extended periods of time.

In addition to the human suffering, cost of compensating pneumoconiosis victims is high. For example, in the fiscal year 1972, the Department of HEW provided $384 million for this cause which marked an increase of $142 million over the 1971 budget (14). This cost is expected

to rise even more steeply in the next few years as more and more coal workers become eligible for compensation benefits.

In the light of economics of remedial actions due to dust hazards, the prediction of dust content in air is very necessary from health and safety points of view. The amount of coal dust deposited along the mine roadways is of paramount importance because it serves as the assessment of the dust explosion hazard, and it can be used to calculate the amount of incombustible dust required for rock-dusting. Mechanisms of dust deposition and quantity estimations have been discussed at length (5). Two processes have been employed to control dust levels at the working face. These are 1) water sprays, and 2) face ventilation to reduce the concentration of respirable coal dust. Although water sprays reduce dust load handled by ventilation systems, the current spray techniques are not effective in the control of respirable dust (5). Currently, face ventilation is the most commonly used procedure.

A dust control program should, therefore, be able to deal effectively with both the fine and ultra-fine dust sizes. Work in the area of dust characterization, particularly with respect to the size-consist, chemical properties is reported (14). Under the Coal Mine Health and Safety Act of 1969, research on dust control has accelerated.

## HAZARDS FROM DIESEL EQUIPMENT

The principal hazards of using diesels underground have been identified as:

1) The transportation and storage of a highly flammable and volatile fuel with resultant hazards of fire and/or explosions.
2) Unhealthy conditions caused by the discharge of toxic substances from the engine exhaust.
3) Ignition of flammable atmospheres by hot surfaces of the engine, such as exhaust manifold or by burning particles of carbon from the exhaust gas.

It has been long established from engineering tests that diesel exhaust quantities are related to displacement and speed characteristics of the engine, the design of the engine, and the fuel-air ratio needed to produce useful power. It has also been recognized that diesels under proper control produce only minor amounts of toxic and noxious fumes although there is an irreducible limit for the exhaust gases. The contaminants that are released into the mine atmosphere must be diluted immediately to minimize local concentrations. Furthermore, since multiple units usually will be operating in the same air stream, there is a cumulative effect on contaminant concentrations. The rate of contamination, therefore, is related to the volume and velocity of the ventilating air, frequency and duration of engine operations, and engine load and location. Ventilation, in addition, affects the rate at which the contamination moves through the workings. Because of Threshold Limit Values (TLVs) and excursion rates allowed on some of the contaminants, the calculations for ventilation requirements must take into account the time variant characteristics of the contaminant concentrations and average them over the entire operating period of the mine. The objective of a research program at Penn State is the development of a digital simulation model to study the effect of using diesels underground on mine ventilation systems (16).

## SUMMARY

In its most elementary form, coal mining is materials handling and consists of removing in-situ coal from multiple mine origins to final destinations. There are certain special environmental considerations peculiar to underground mining. These include the problems of toxic, noxious, and explosive atmospheres caused by gases and dust. A fundamental objective of a mine ventilation system is to supply the mine environment with an adequate quantity of uncontaminated fresh air to deal with the control of respirable and explosive contaminants and to provide for the health and safety of the workmen. This paper has briefly reviewed some recent research programs presently underway in the mine ventilation area.

It is difficult to quote an average cubic feet per minute ventilation figure for coal mines. The weighted figure is unknown and really has no significance. However, in a modern coal mine, for each ton of coal produced each day, on an average, 4-6 tons of air is circulated. Similarly, cost figures are very difficult to obtain from the industry because of the concern for releasing proprietary information. Also, accounting principles vary from one mine to another to make comparisons less meaningful. However, as a typical figure for a group of mines, operating costs are 15¢ per ton and capital costs 25¢ per ton, accounting for about 6% of the total costs. However, the indirect costs of mine ventilation, though difficult to ascertain, can be quite high. Severe disruption of work and losses in production cannot be ruled out. In any case, the end results of inadequate control in mine ventilation can be sudden and catastrophic e.g., explosions, ignitions, fires, suffocations, etc.

Much research - theoretical, empirical, laboratory, and field studies - has been done and is being done toward the identification and quantification of the hazards posed by inadequate ventilation. Model studies of gas and heat flow problems provide the necessary input parameters to sophisticated quantity and quality control models. Research efforts are also aimed at the determination of suitable parameters for process control, their range of operations, the development of remote sensing and monitoring equipment, choice of monitoring sites, etc. In the future, it is not difficult to foresee a highly sensitive monitoring system coupled to computers that are programmed for automatic corrective action.

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