Coal Mine Ventilation Systems in the United States of America

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SYNOPSIS

The favorable mining conditions in the United States of America that resulted in the development of the highly productive room and pillar systems are largely disappearing. Increasing mechanization, power natural conditions, and greater concern for health, safety and environment gave impetus to the enactment of the Federal Coal Mine Health and Safety Act of 1969. These regulations prescribe more stringent requirements for face ventilation and mine air distribution, necessitating significant changes in existing ventilation systems. Stricter mandatory standards were applied to replaceable dust control for the first time, and simultaneous control of both gas and dust has affected the face as well as primary distribution, most notably on haulage entries.

The size and complexity of the present-day mining operations, and the need to evaluate various system changes in a limited time, call for scientific methods in mine planning. In this paper, the authors trace the previous applications of computers to mine ventilation planning and discuss the results of their work in applying a ventilation simulator developed at Penn State. The paper includes an analysis of current trends and suggestions for future research and development.

INTRODUCTORY HISTORY OF U.S. COAL MINING

The United States Geological Survey estimates the coal reserves of the U.S.A. at $4 \times 10^12$ tons—close to 3 000 years reserve at today's production rate. The above represents all seams greater than two feet thick and extending to a depth of 3 000 ft, but even under today's technical limitations and costs, there is probably at least a 500-year reserve. In any event, the coal reserves of the U.S.A. are huge and represent the single highest energy source. Over one-half of the nearly 600 million tons annually goes to the production of electricity, more than the combined total electricity produced from oil, gas, water power and nuclear energy.

While the production of anthracite continues to decline, bituminous coal mining is currently experiencing an unprecedented boom. Future annual demands are estimated at between 700 and 800 million tons by 1980, and anywhere from 1 000 to 3 000 million tons by the end of the century. While it is difficult to extrapolate the national needs very accurately because of many imponderables, it would appear that a vigorous expansion of coal production will be necessary during the remainder of this century.

In 1970, underground mining accounted for about 62 per cent of the total production, and while strip mine production has shown a steady rise during the last decade, it is probably near its maximum percentage share. A 60:40 per cent distribution between underground and surface mining is a great probability for the remainder of the century, taking into account the reserve picture, economic conditions and environmental considerations.

While coal is mined under a variety of natural conditions, single-seam mining of a four-foot thick horizontal bed less than 1 000 ft deep might be considered an average U.S. condition. There are a number of new mines being developed in the 1 000 to 1 500-ft depth range and the projection of at least one mine is under covers of 3 000 to 4 000 ft. The trend is definitely to deeper and more gassy seams, with ground conditions more difficult than in the past. For these reasons, as well as other economic considerations, longwall applications have been viewed with greater interest, although at the end of 1970 there were only 37 longwall installations with the combined production of less than four per cent of the underground total. There is no question about the growth potential of longwall mining in the U.S., but it must be kept in mind that it is still applied on only a minor scale.

MINE VENTILATION SYSTEMS

Whether the room and pillar or longwall system is used, certain basic principles apply to mine ventilation systems. Figure 1 shows a typical Pittsburgh block system representative of the six-to-eight-foot thick seam that is mined extensively in southwestern Pennsylvania and northern West Virginia at average depths of approximately 1 000 ft. Since the seam is highly gaseous, a considerable volume of air is required to dilute the methane gas emitted from the coal, so as to render it harmless and sweep it away from the working places. This typical mine map will be used to illustrate common ventilation practices in the past, and the changes required under the recently enacted Federal Coal Mine Health and Safety Act of 1969.

In general, this legislation promulgated much more restrictive ventilation requirements and removed the classification of non-gassy mines.

Good ventilation practice has dictated the use of the two-split system on each single unit section; in this way a separate split can be obtained for the working machine as well as for the preparation crew. In the past, 6 000 ft³/min was the minimum quantity specified in the last open crosscut, with no specified volume requirement in the face except that no place could be worked in a methane concentration above one per cent. This latter requirement had necessitated quantities far in excess of the minimum quantity in most instances and therefore it was not uncommon to have 20 000 to 25 000 ft³/min of air in each split, or a total section requirement of 40 000 to 50 000 ft³/min.

Beyond the last open crosscut, blind entries and rooms have been ventilated by both line brattice and auxiliary fans. Blowing line brattice dominated, and no specific volume had to be met at the face. Under the new provision, a minimum quantity of 3 000 ft³/min is specified at the face and the average maximum dust requirement of 3 mg/m³ of respirable dust has practically precluded a blowing system, whether line brattice, or fan and vent tube. With a two-split system, line brattice systems are being designed so that equipment does not have to pass through the brattice at any time. Also, with auxiliary fans, exhaust fans and tubing are employed in each working place and a diffuser fan (blowing) is mounted on the machine with a hydraulic take-off to sweep the blind.

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corner of the gas that would otherwise accumulate in a single exhausting fan situation.

Haulage provisions have also been revamped drastically under the new regulations. While some states have required a neutral split for belt conveyors in the past, most have not, and even with the former, the leakage air was permitted to join the intake air in the face area. Under the new provisions, this is not allowed and the air passing over the belt must be placed directly into return. This will require that a regulator be placed in by the doors at the head end (permanent) or the regulator must be maintained just out by the tailpiece which means constant moving with extensions and contractions of the belt. Preliminary studies reveal that neither system is completely adequate and perhaps both approaches will be necessary, regulators utilized near the head end at the beginning and ending on the panel, and tail regulators required near the furthest extension of the panel.

A probably even more stringent requirement is a velocity restriction on trolley haulage to a value of less than 250 ft/min. With sidetracks normally swinging right and left, this means a volume restriction on as many as three intake airways. This restriction is to minimize the fanning of any fire that may develop on the haulage. There have been frequent fires on trolley haulage in the United States and therefore stringent measures are undoubtedly called for. Most countries have banned the use of trolley haulage in underground coal mines entirely in recognition of this great fire and explosion hazard. With irregular roof profiles on haulage due to past caving, however, this regulation could constitute a gas explosion hazard. Bleder systems, when employed with exhaust fan ventilation, offer improved safety and are required.

Because coal seams have been relatively horizontal and continuous, and roof conditions at the shallower depths have been good to fair, multiple entries have been utilized primarily, with relatively little brushing or dinting to secure additional areas. As shown in Fig. 1, the mine entry system with five center intakes and two returns on each side is quite common. However, it might be added that as mining has proceeded to depth and ground conditions have deteriorated there has been an increasing application of the 'pressure arch' to minimize the adverse affects of long spans. Fig. 2. Figure 2 also reflects built-in flexibility to meet mine expansion. The single eight-entry system is used at the early stages of life of a large mine that is to be extended over a large area. At some future date, another eight-entry parallel set will be driven. At that time the metal stoppings on the left side of the original entry set will be removed and the right side will become intake (all except No. 8 entry) and the eight entries on the left side will be made returns. Since there will be a considerable acreage of virgin coal on the right of entry No. 8, there would be too much gas contamination of intake air on the solid rib to make all eight entries intake. A new look is being taken at the use of a large number of multiple entries, however, because of the great difficulty of maintaining long spans. A number of companies are utilizing machines to lift bottom or take top, or both, to increase airway areas with fewer entries and, hopefully, to provide shorter and thus more stable spans.

However, even with the multiple-entry provisions and allowing for expansion, or the use of larger airways, one-point intakes with a single exhaust fan are inadequate for the long-life high-tonnage mines that exist in the United States. Therefore, multiple shafts and fans are common with as many as seven large exhausting fans providing between two and three million ft³/min of air. Figure 3 shows schematically what might be expected with air shafts generally arranged with a curtain wall to provide both intake and return and spaced on 12,000- to 14,000-foot centers. Velocities of 2,000 to 2,500 ft/min are found in shafts with 700 to 800 ft/min on intake entries. Generally speaking, these velocities are too high and do not provide optimum overall cost. Also, drilled shafts are producing changes in economic considerations where fewer entries are developed and maintained in favor of more drilled shafts. The possibility of employing such shafts in rescue and
survival systems provides even greater impetus in that direction.

![Diagram of multiple shaft and fan arrangement for a large mine.](image)

Each shaft and fan generally has its own zone of influence, with no attempt being made to isolate one zone from another. This has contributed to some real problems in trying to obtain the desired distribution of air in the working places and especially on rail haulage. Without prior analysis of what will occur with a fan or shaft change, certain portions of the mine may not be properly ventilated and therefore require costly remedial actions. To provide flow on a rail haulage segment, quite frequently stoppages between intake and return in the dead air segment must be bridged and large quantities of air ‘dumped’ to obtain proper air flows.

Since the average mine ventilation system is far too complex to allow a manual calculation of air distribution and fan pressure requirements, there is a great need for computer applications of mine ventilation network analysis. Because ventilation requirements have been restricted largely to gas control, and conditions at relatively shallow depths have been good, there has been little impetus to seeking greater use of the computer for this purpose. However, because both natural conditions and regulatory requirements have recently changed drastically, the computer offers the greatest hope for network analysis. A few words will be said first about ventilating longwall faces.

It has been said many times that the collateral benefits with respect to services with a longwall system may tip the balances in favor of this system, and this is true especially if one compares the ease of ventilation of a longwall (Fig. 4) with that of a room and pillar system. The three-entry system shown in Fig. 4 was applied most commonly during the introduction of self-advancing longwall mining systems in the U.S. during the early 1960's. However, even independent of the 1960 Act, this three-entry system has now largely given way to a four-entry system. As can be seen in Fig. 4, with the three-entry system, two of the three entries are lost during mining, the first with the retreat of the preceding panel mined and the second with the active panel. With the small pillars, even the third remaining entry cannot be relied upon to remain open sufficiently to provide proper bleeding, and the roof conditions in the tail entry (because of the two superposed abutment zones) generally were intolerable. With either a two- or three-entry system, the velocity of the air on the supply track generally located in the tail entry will be too great to meet the new regulations. However, to the authors' knowledge, no one has gone to a five-entry system yet. It has been difficult for mines to maintain adequate development using the three- and four-entry systems without going to five entries. In fact, there have been a number of two-entry systems and presently a single-entry, center-cribbed and partitioned, is being worked experimentally with a longwall system in Utah.

In any event, the major portion of intake air generally sweeps down one set of entries, usually the tail, but head intakes are also common across the face, returning partly on the other set of entries or bled through the gob to the bleeder system. Theoretically at least, a large volume of air can be provided at the face with relative ease. However, with the requirement of 100 000 ft³/min for each longwall face in a deep mine in Virginia, production has of necessity been curtailed because of an inability to provide enough air for the very gassy conditions encountered.

**COMPUTER APPLICATIONS**

Since the advent of computers about two decades ago, the number of scientific applications has increased tremendously. Although their use in many mineral industries is established practice, extensive application in mine atmospheric environmental control is long overdue. The size and complexity of present-day mining operations, and the need to evaluate various systems in a limited time, call for scientific methods in planning and for more rapid and effective techniques to evaluate proposed changes. Except for some small-scale ventilation problems, most mines will require a high-speed digital computer for ventilation solutions. The changes that have to be made to existing ventilation systems and the necessity for rapid and accurate solutions are such that these problems necessitate use of the computer.

A computer can be used purely as a rapid calculating machine to manipulate the enormous arithmetical operations that have to be performed in a mine ventilation analysis, but this is too restrictive a use. Its great power as a planning tool lies in the ability to input empirical or projected data into programs with predicting ability. Network analysis of mine ventilation systems is not new, having been traced back to 1854. Scott et al (1951 and 1952) presented a detailed mathematical analysis. Since then work has been done in adapting this technique to analog, and within the last few years, to digital computers. Several authoritative papers in a Committee Report (1970) described the considerable work done in this respect in the United Kingdom, Japan, U.S.S.R., South Africa, United States and other countries. Wang et al (1970) developed a mine ventilation simulator which is an improvement over the earlier one developed by Wang et al (1967). The present program incorporates many novel features that have increased considerably its utility value to the industry. This program has the capabilities of free-splitting, internal or external fans, natural ventilation pressure and allows for specifying fixed quantity branches. The operational details of the program and the program itself are presented in the references.

While this program has existed now for some years, its application in the U.S.A. has not been very extensive. Many ventilation engineers who have solved complex problems by
long-hand with simplistic assumptions have little or no computer background and are not familiar with the computer program. The process of moving from a mine map to a desired network to the generation of computer input data from a ventilation survey is also not widely understood. The need to establish confidence in the computer program is of paramount importance. The undergraduate mining engineering students at Penn State are taught the use of the Wang program. The Continuing Education group of the University, actively supported by the Department of Mining and the state agency, has offered a short course on the applications of the program. The Department of Mining has welcomed and actively assisted ventilation engineers in their efforts to computerize their ventilation networks. In addition, the United States Bureau of Mines has been using this program (with modifications) for analyzing some of its mine ventilation surveys.

Lastly, most coal companies have been utilizing computer facilities for data processing, but usually do not have a computer suitable for scientific calculations. In the past, the cost of installing a versatile scientific computing facility might have been too high to justify the investment for the benefit to be derived from it. However, today management has available remote-entry terminals through which time can be rented on the most modern of computing facilities. In many cases, all programming can be internal to the system and the input to the program, on a pre-assigned format, can be fed through the terminal. Also, the report-writing programs are such that the computer output is in a format familiar to operating personnel. In addition, at the very outset, most input data can be stored in readily accessible data banks to minimize the input necessary each time a solution is sought. Nevertheless, except for a few of the larger coal mining companies in which recent applications have begun to appear, computer application to mine ventilation analysis in the United States is rare.

The purpose of the program is to serve as an experimental mine to be used to analyze proposed alternatives for ventilation planning and to choose the best for the required conditions. Therefore, the simulation of existing or historical operating conditions is generally done for checking the input values. However good a computer program is, unless fairly accurate input information is available, the output will be suspect.
Therefore, when future operating policies are to be evaluated, the expected parameters of the physical system must be read in.

At present, work is being done in a number of areas for the purpose of modifying the program to make it simpler and more easily applied. Research is also underway to include a methane emission and distribution subroutine. Acceptance by ventilation engineers of these models is likely to depend more on their tested performance in the field than on validity aspects of the models as reported from programs of research and development. However, the latter must continue.

The extremely small time lapse in the system from inquiry to receipt of information, and the large information records that are available from computer systems have opened up many areas for research. The use of computers to verify relationships developed earlier with simplifying assumptions, for development of new theories, and for optimization of ventilation systems requires greater attention. The fundamental approach to providing good atmospheric environmental control in underground coal mining is a well-engineered ventilation system. Distinctly apart from this, there is the necessity to identify and define dangerous situations and to allow for the establishment of safe operating and emergency procedures. Planning for ventilation during emergencies, heretofore all but dependent on experience, can be attempted on the computer although the associated changes in the physical system (high temperatures, cave-ins, etc.) may make such analysis difficult. Significant progress is being reported in remote sensing and recording of environment. As studies are perfected in the determination of suitable parameters for control, their range of operation, choice of monitoring sites, etc., these advances could lead eventually to on-line computer control of the complete mine environment.

CONCLUSIONS

The greater demands for coal in the energy market, the more difficult mining conditions, and the influence of greater social concerns about regulations have contributed additional problems for the ventilation engineer in the U.S. Unfortunately, because of a manpower shortage there are also fewer engineers available to help with these additional problems. In any event, even with stable manpower it would be impossible to project complex ventilation systems as well as make necessary modifications to existing plans manually, and therefore the computer becomes increasingly important.

There have developed in the U.S. two ventilation groups who generally do not communicate with one another. The practical "by the seat of the pants" engineer keeps the ventilation system going on a routine basis but generally does very little planning ahead and, as a result, the mine goes from one ventilation crisis to another. The other group consists of theoreticians who have developed computer programs for hypothetical mining systems that may or may not bear any resemblance to an actual mine. Unfortunately, they have not gone one step further and shown how a typical mine ventilation network can be solved. The authors have attempted to correct this situation in the U.S.A. in a recent paper.

Because of the lack of understanding of the other group's problems and limitations, real world situations are not simulated on the computer. It is exceedingly important for each group to understand the basic principles of mine ventilation systems and to be able to transform a mine map into a network schematic that can then be solved by computer. This aspect of the problem has received hardly any attention at all in the U.S.A., although it is difficult to see how the computer will otherwise become anything but an interesting potential application.

Also, computer output is only as good as the input data; to simulate properly one must have a good indication of leakage and friction factors. Yet relatively little work has been done in the past three decades to determine these more realistically, although within the last year several people have directed their attention to this aspect of the problem.

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REFERENCES


