Computer aided coal mine ventilation planning

A vital component in the design of a new underground mine is the quantified planning of the distribution of airflows, together with the locations and duties of fans and other ventilation controls required to achieve acceptable environmental conditions throughout the system. Similarly, throughout the life of an underground operation, it is necessary to plan ahead in order that new fans, shafts or other airways are available in a timely manner for the efficient ventilation of extensions to the workings. As any operating mine is a dynamic system with new workings continually being developed and older ones coming to the end of their productive life, ventilation planning should be a continuous and routine process.

Ventilation network analysis is concerned with the interactive behaviour of airflows within the connected branches of a complete and integrated network. The questions addressed by ventilation network analysis may be formulated quite simply. If we know the resistances of the branches of a ventilation network and the manner in which those branches are interconnected then we can predict, quantitatively, the distribution of airflow for given locations and duties of fans.

Various softwares are used to simulate underground mining environments for planning and verification of the environmental performance parameters of operational and future mines.

This paper describes the step by step procedure involved in planning the ventilation system of an underground coal mine as well as the usage of software packages in design of the same.

1. Introduction

The ultimate goal for ventilation planning is to design a system that will be capable of adequately ventilating all working faces, airways, and areas underground at minimum costs. A good mine ventilation system always begins with the initial development of the mining plan, which should always have alternatives. A well-thought out ventilation system can minimize long-term problems, builds in flexibility for expansion without exorbitant cost, reduces up-front capital expenditures, and phases in capital outlay over the life of the project. Air volume requirements can be substantial in some operations. The presence of diesel, gaseous products, strata gases, heat and humidity, and large openings all require a significant increase in the minimum air velocity required, and hence a higher air volume requirement. Since energy requirement is proportional to the cube of air volume circulated, optimization between air volume and resistance must be considered. Other factors also must be factored in, such as environmental requirements and available resources. Although many factors enter into an ultimate ventilation planning scheme, minimizing friction and shock losses are the two most important among all the items considered.

The main objective of mine ventilation is the provision of sufficient quantities of air to all the working places and travel ways in an underground mine to dilute to an acceptable level those contaminants which cannot be controlled by any other means. Where depth and rock temperatures are such that air temperatures are excessive, mechanical refrigeration systems may be used to supplement the beneficial effects of ventilation.

The following general design principles are to be adapted, while planning the mine ventilation system.

1. Select main ventilation inlets and outlets.
2. Determine airflow requirements.
3. Specify fan locations.
4. Determine air flow resistance for all branches.
5. Build and run a computer model of the mine ventilation system.
6. Adjust system layout, design parameters, and equipment operating characteristics and rerun computer code until a viable system results.
7. Review the plan with operating personnel.

2. Air quantity requirements

The composition of the gaseous envelope encircling the earth varies by less than 0.01% from place to place and the constitution of "dry" air is usually taken as 78.09% nitrogen,

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20.95% oxygen, 0.93% argon and 0.03% carbon dioxide. Water vapour is also present in varying amounts depending on the air temperature and pressure and the availability of free water surfaces. As ventilation air flows through a mine, the concentration of water vapour may change significantly and this variation is the subject of the separate study of psychrometry. To define the state of a water vapour and dry air mixture at a particular point requires the three measurable independent properties of barometric pressure, dry bulb and wet bulb temperatures.

The contaminants to be controlled by dilution ventilation are primarily gases and dust. The amount of air required for dilution control will depend on both the strength of the contaminant source and the effectiveness of other control measures such as water for dust suppression or methane drainage systems in coal mines. The minimum dilution air flow rate is determined by the contaminant requiring the greatest dilution quantity with due cognizance of the possible additive effects of mixtures and synergism, where one contaminant can increase the effect of another. Overriding this value could be a minimum air velocity requirement, increasing as air temperatures also increase.

3. Airway resistance and shock losses

The resistance to airflow of a mine opening is a function of its size and surface roughness and the resultant pressure loss depends on this resistance and the square of the air velocity. By adding energy to the system, a pressure can be generated which then overcomes the pressure loss. This may occur naturally where the energy is provided by heat from the rock and other sources (natural ventilation). Although this used to be the main method of providing ventilation, only 2 to 3% of the energy is converted and, during hot summers, the rock may actually cool the intake air resulting in flow reversals. In modern mines a fan is normally used to provide energy to the air stream which then overcomes the pressure loss although the effects of natural ventilation can either assist or retard it depending on the time of year.

With a limited number of intake and return airways between the workings and surface, a large proportion (70 to 90%) of the total mine pressure loss occurs in them. Airway pressure losses also depend on whether there are any discontinuities causing shock losses such as bends, contractions, expansions or any obstructions in the airway. The losses resulting from these discontinuities such as bends into and out of airways, when expressed in terms of the losses which would be produced in an equivalent length of straight airway, can be a significant proportion of the total and need to be assessed carefully, particularly when considering the main intakes and exhausts. The losses in discontinuities depend on the amount of boundary layer separation; this is minimized by avoiding sudden changes in area.

4. Main and booster fans

Axial flow fans are used to provide air circulation in mine ventilation systems, with fan efficiencies of over 80% being achievable. In mines where a fan failure may result in dangerous methane accumulations, additional fan capacity is installed to ensure continuity of ventilation. Where this is not so critical and with a twin fan installation, about two-thirds of the mine airflow will continue if one fan stops. Vertical axial flow fans installed over the airways have low costs but are limited to about 300 m^3/s. For larger air quantities, multiple fans are required and they are connected to the exhaust with ducting and a bend.

It is rare that a main fan is required to operate at the same duty point over the life of the mine, and effective methods of varying fan performance are desirable. Although variable speed results in the most efficient operation for both axial and centrifugal fans, the costs, particularly for large fans, is high. The performance of an axial flow fan can be varied by adjusting the blade angle and this can be carried out either when the fan is stopped or, at a significantly higher cost, when it is rotating. By imparting a swirl to the air entering a fan using variable inlet vanes, the performance of a centrifugal fan can be varied while it is running.

The position of the main fan in the overall system is normally on surface at the exhaust airway. The main reasons for this are simplicity where the intake is often a hoisting shaft and the exhaust is a separate single purpose airway and minimization of the heat load by excluding fans from intake airways. Fans can be installed at hoisting shafts either in forcing or exhausting mode by providing a sealed headframe. However, where workers, materials or rock also enter or leave the shaft, there is a potential for air leakage.

Underground booster fans, because of space limitations, are almost always axial flow and they are used to boost flow in the deeper or more distant sections of a mine. Their main drawback is the possibility of recirculation between the booster fan exhaust and the intake airways. By only providing a boost to the smaller airflows where they are required, they can result in a lower main fan pressure for the full mine airflow and a consequent reduction in total fan power required. The evaluation of a mine ventilationn system can be best expresses by calculating the volumetric efficiency. It relies on the simple formula as given below:

Ventilation efficiency (%) = 100 × total quantity of air 'usefully employed'/total quantity of air supplied through the main fan(s)

5. Secondary ventilation

Secondary ventilation systems are required where through ventilation is not possible, such as in development headings. Four arrangements are possible, each having its own advantages and disadvantages.

The forcing system results in the coolest and freshest air reaching the face and allows cheaper flexible duct to be used. The high velocity of the air issuing from the end of the supply duct creates a jet which entrains additional air and helps sweep the face of contaminants and provide an acceptable face velocity. Its main drawback is that the rest of the heading is ventilated with air that is contaminated with the gases and dust produced by mining operations in the face. This is particularly a problem after blasting, where safe re-entry times are increased.

An exhausting system allows all the face contaminants to be removed and maintains the rest of the heading in intake air. The drawbacks are that heat flow from the surrounding rock and moisture evaporation will result in higher face delivery air temperatures; operations in the heading back from the face, such as rock removal using diesel-powered equipment, will contaminate the intake air; there is no air jet produced to sweep the face; and more costly duct which is capable of sustaining a negative pressure is required.

In an exhaust-overlap system the problem of clearing the face with an air jet is overcome by installing a smaller fan and duct (the overlap). In addition to the extra cost, a disadvantage is that the overlap needs to be advanced with the face.

In a reversing system, the forcing ventilation mode is used, except during blasting and the re-entry period after blasting, when the airflow is reversed. Its main application is in shaft sinking, where re-entry times for deep shafts can be prohibitive if a forcing only system was used. The air reversal can be obtained by either using dampers at the fan inlet and outlet or, by taking advantage of a feature of axial flow fans, where changing the direction of blade rotation results in a flow reversal with about 60% of the normal flow being delivered.

The fans used for secondary ventilation are almost exclusively axial flow. To achieve the high pressures necessary to cause the air to flow through long lengths of duct, multiple fans with either contra-rotating or co-rotating impeller arrangements may be used. Air leakage is the greatest problem in auxiliary fan and duct systems, particularly over long distances. Rigid ducts fabricated from galvanized steel or fibreglass, when installed with gaskets, have suitably low leakage and may be used to develop headings up to several kilometres in length.

Flexible ducts are considerably cheaper to purchase and easier to install; however, leakage at the couplings and the ease with which they are ripped by contact with mobile equipment results in much higher air losses. Practical development limits using flexible duct rarely exceed 1.0 km, although they can be extended by using longer duct lengths and ensuring ample clearances between the duct and mobile equipment.

6. Ventilation controls

Both through ventilation and auxiliary fan and duct systems are used to provide ventilation air to locations where personnel may work. Ventilation controls are used to direct the air to the working place and to minimize the short circuiting or loss of air between intake and exhaust airways.

A ventilation door is needed where pedestrian or vehicular passage is required. The materials of construction, opening mechanism and degree of automation are influenced by the pressure difference and the frequency of opening and closing. For high pressure applications, two or even three doors may be installed to create air locks and reduce leakage and the loss of intake air. To assist in opening air lock doors, they usually contain a small sliding section which is opened first to allow equalization of the pressure on both sides of the door to be opened.

A regulator is used where the amount of air flowing through a tunnel is to be reduced rather than stopped completely and also where access is not required. The regulator is a variable orifice and by changing the area, the air quantity flowing through it can also be changed.

7. Monitoring and emergencies

Ventilation surveys which include airflow, contaminant and temperature measurements are undertaken on a routine basis to meet both statutory requirements and to provide a continuing measure of the effectiveness of the ventilation control methods used. Where practical, important parameters such as main fan operation are monitored continuously. Some degree of automatic control is possible where a critical contaminant is monitored continuously and, if a pre-set limit is exceeded, corrective action can be prompted.

More detailed surveys of barometric pressure and temperatures are undertaken less frequently and are used to confirm airway resistances and to assist in planning extensions of existing operations. This information can be used to adjust the network simulation resistances and reflect the actual airflow distribution.

The emergencies that may affect or be affected by the ventilation system are mine fires, sudden gas outbursts and power failures. Fires and outbursts are dealt with elsewhere in this chapter and power failures are only a problem in deep mines where the air temperatures may increase to dangerous levels. Generally, when an emergency such as a fire occurs underground, it is better not to interfere with the ventilation while personnel who are familiar with the normal flow patterns are still underground.

8. Ventilation network analysis

Primary ventilation systems or networks are concerned with ensuring the flow of air through interconnected mine openings. The overall ventilation network has junctions where three or more airways meet, branches that are airways between junctions and meshes which are closed paths traversed through the network. Although most mine ventilation networks are ramified with hundreds or even thousands of branches, the number of main intake (branch between surface and the mine workings) and return or exhaust (branch between the workings and surface) airways is usually limited to less than ten.

With large numbers of branches in a network, determining a flow pattern and establishing the overall pressure loss is not straightforward. Although many are in simple series or parallel arrangement which can be solved algebraically and precisely, there will be some compound sections requiring iterative methods with convergence to an acceptable tolerance. Analogue computers have been successfully used for network analysis; however, these have been superseded by less time-consuming digital methods based on the Hardy Cross approximation technique developed to solve water flow networks.

Gustav R. Kirchhoff (1824-87) was a German physicist who first recognized the fundamental relationships that govern the behaviour of electrical current in a network of conductors. The same basic relationships, now known as Kirchhoff's Laws, are also applicable to fluid networks including closed ventilation systems at steady state.The simplest statement of Kirchhoff's second law applied to ventilation networks is that the algebraic sum of all pressure drops around a closed path, or mesh, in the network must be zero, having taken into account the effects of fans and ventilating pressures. This can be quantified by writing down the steady flow energy equation (3.25), initially for a single airway. If we consider a number of such branches forming a closed loop or mesh within the network thenthe algebraic sum of all ΔZ must be zero and the sum of the changes in kinetic energy, $\Delta u2/2$, is negligible summing each of the remaining terms.

Traditionally, a mine ventilation network is solved by means of iterative techniques using Kirchoff's current and voltage laws. The most popular one of these methods is the Hardy Cross algorithm. A number of computer programmes based on this algorithm have been developed. Despite their popularity, the Hardy Cross method and its modifications have some disadvantages. They have uncertain convergence characteristics, convergence to optimal solution and solution time are highly dependent on the initial arbitrary air quantities assigned for all branches. In order to overcome these difficulties, some different solution procedures based on several mathematical methods like linear programming, non-linear programming and network analysing techniques have been proposed by several investigators.

9. Softwares for ventilation planning

Various softwares are used to simulate underground mining environments for planning and verification of the environmental performance parameters of operational and future mines.

Softwares have been developed to include heat modelling, and takes into account the dynamics present inside the production zone within the mine itself. The algorithms have been developed over a period of 30 years, and are based on measurements in local deep hot mines that are calibrated to give us specific solutions.

Further, the system is able to include variables such as heat from broken rock, advancing faces, configurations of working areas, and production zones when determining the heat balance of an underground working environment, and can be used to ensure underground legislative adherence.

The software enables the mine to specify its own design criteria to meet current underground ventilation legislation, and will notify the user when there is noncompliance within the model. The feature will compare the mine results against the mine standard and identify any discrepancies.

In addition, mining operators appear to be showing increased commitment to ventilation and airflow standards. Mine operators are taking ventilation far more seriously than in the past and are using sophisticated software to do their planning. During feasibility studies, ventilation and cooling engineering is a priority.

Long-term plans include combining a number of programmes into one package that will allow water and ventilation simulation networks to be based on a shared database. An important feature offered by these software codes is simulation - of mine fires, gas outbursts like methane, carbon monoxide, etc.

Given data that describes the geometry of the mine network, airway resistance or dimensions, and the location and characteristic curves of fans, the programme will provide detailed listings and graphical representations of:

- Branch airflows.
- Frictional pressure drops.
- Airway resistance.
- Air power losses in airways.
- Ventilation cost of each airway.
- Fan operating points (pressures and airflows).
- Duties of required regulators and booster fans

Few softwares allow the user to simulate fires, heat flow, contaminant flow, and/or natural ventilation in underground ventilation networks using the familiar graphical and tabular interfaces. Results are displayed both symbolically and numerically on the schematic. It provides a new user-friendly, cost-effective tool to quickly design, model, and analyze proposed or existing duct systems ranging from small secondary fan/duct installations to large series-fan systems.

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Summary and conclusion

Disposal of CO_2 in an abandoned coal mine appears to be promising after the successful experience of storage of natural gas in the mines. Preventing leakage of CO_2 by maintaining the cap rock stability and integrity over a large period sometimes for several decades is a big challenge. However since in the nature many CO_2 repositories exist, it is believed that mines can be good sinks. Using selection criteria potential mines can be identified and the feasibility of CO_2 storage in such mines shall be studied before any sequestration operation is carried out in practice.

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According to input data, the user is able to construct models and optimize them by considering duct type and diameter, shock losses, and the number, type and spacing of fans. The programme may be used for initial design, or to help trouble shoot and improve existing duct installations. It is useful in showing personnel the reasons behind a poor installation and ways to improve the system, resulting in safer working conditions.

Few computer software programmes have been designed to aid mine ventilation and environmental engineers in the prediction of the thermodynamic and psychrometric properties of air as it flows through underground airways. The programme takes into account geothermal gradient, rock thermal conductivity and diffusivity, airflow, air quality, age of the excavation, wetness of the rock surfaces and the siting and capacity of machinery, heat exchangers or other local or disseminated sources of heat and humidity.

10. Conclusion

Softwares have proved to be essential tool in underground coal mine ventilation planning and monitoring.The views expressed in this paper are of the author and not necessarily of the organization, he belongs to.