Auxiliary ventilation operation practices

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ABSTRACT: A series of visits to underground operations have been performed to identify installation and maintenance practices in auxiliary ventilation systems. This paper presents industry trends in duct ventilation practice and a series of guidelines are introduced for ventilation operators to follow when performing installations and inspections. This paper presents information with which mines could train their personnel on effective operational procedures to maximize the performance and guarantee compliance of their installations.

1 INTRODUCTION

Auxiliary ventilation is used to augment the primary ventilation system in supplying adequate quantities of fresh air to inadequately ventilated workplaces. Typical applications of auxiliary ventilation underground include the ventilation of development headings, and the ventilation of stopes and raises. Auxiliary ventilation systems must be designed to supply a sufficient quantity of air to provide a healthy, safe and comfortable environment in the workplace.

When designing a system one must consider government regulations which typically prescribe that 'in an underground mine, a development, exploration or production work place shall be ventilated throughout by an auxiliary ventilation system for any advance in excess of sixty metres (two hundred feet) from a mechanical mine ventilation system; and a continuous supply of fresh air shall be provided and used to dilute and remove contaminants, in a raise, and in a sub-drift for any advance in excess of ten metres (thirty feet) from a mechanical mine ventilation system, to prevent exposure of a worker to contaminants in excess of maximum allowed values (threshold limit values). The fresh air supply shall be independent of the air supplied by any drill or machine used; controlled only at the beginning of the raise or sub-drift; and operating when a blast is detonated'.

This paper presents the design aspects of auxiliary ventilation and, based on a series of visits to underground operations, introduces typical operating practices and provides guidelines to determine the most efficient ventilation system for a particular project.

2 TYPICAL AUXILIARY VENTILATION SYSTEMS

The range of auxiliary ventilation systems found in the mines ranged from 30 m (100 ft) to some 1000 m (3280 ft). Of the different categories of auxiliary systems the most common systems used are the force system, in which the intake air is led to the face through the duct, and the exhaust system, in which the air is drawn from the face through the duct.

The force system is the most commonly used method in metal mines due to its simplicity of operation and relative economical attributes. The force system supplies good quality air, at high velocity, to the face and allows a quicker clearing of the face, but sends a plug of blasting gases up the development drift, towards the main airway. Depending on the installed system, long re-entry periods after blast may be necessary. The end of the ventilation column is kept as close to the face as possible during working operations and should not exceed some 30 duct diameters away from the face (Figure 1). In general, the ventilation tubing is located at a distance between 5 and 12 m (15 and 40 feet) from the face in horizontal headings and not more than 2.5 m (8 feet) from the back in raises. Also, the tubing is installed as close as possible to the back of the drift to ensure the air sweeps downward across the working face from roof to floor (Figure 2). This method assures the airflow to pass over the workers and equipment operating in the heading, thus carrying the contaminants from the face below the worker's breathing zone. Specific design considerations are also followed in order to avoid build up of gas and dust concentrations through recirculation of air. The fan is installed in an adequate fresh intake air base and is positioned to eliminate the possibility of recirculation. The fan is installed at a point at least 10 m (33 feet) upstream in the general mine air circuit (Figure 3). The volume of intake air available should be 2.5 times the fan capacity. In order to avoid damage when blasting, the last section of tubing (at least 15 m - 50 ft) is taken down to a safe distance from the blast. The last section of duct is advanced with the face until it has to be replaced; the pressure is lowest in this section of duct and minor mechanical damage due to blasting will not result in too great an air loss.

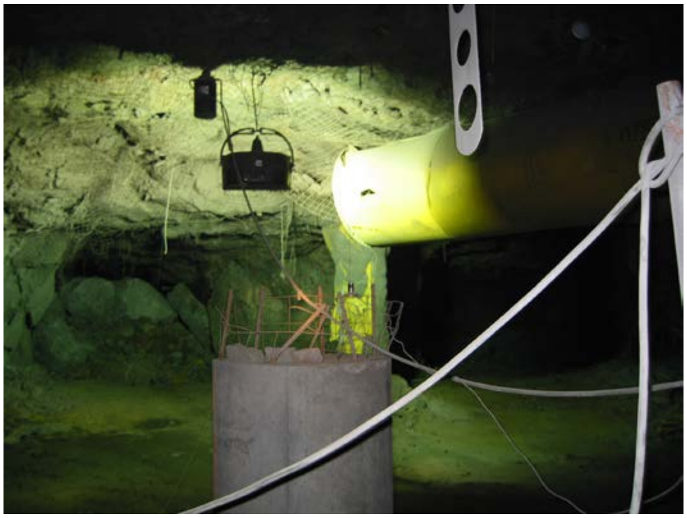

Figure 1. The end of the ventilation column should be kept as close to the face as possible.

Figure 2. The end of the ventilation column is positioned at the centre of the drift and high at the back to provide adequate dilution of contaminants.

The exhaust system incorporates an exhausting fan and uses rigid ducting (Figure 4). Spiral wire reinforced flexible tubing may be used for short lengths and low pressures. In this method a single fan and column are installed to exhaust contaminated air from a point as close to the face as practical and discharge it downstream in the nearest through ventilation. The

Figure 3. The fan should be positioned upstream in the main ventilation circuit to eliminate recirculation.

fan in this system provides a continuous, negative pressure in the tubing, and brings in fresh air through the drift, and removes it from the face and workplace through the tubing. The fan can be installed anywhere along the duct. The exhaust end of the duct is installed in an adequate exhaust air base and is positioned so there is no possibility of recirculation. The duct has to be carried to the face before drilling and mucking and the last section (15m, 50 ft) must be removed before blasting. The advantages of this system include quick removal of smoke and gases after blasting, specially in long headings and the contaminated air from the face is removed without affecting workers in the travel way. Some disadvantages of this method include: the air enters the end of the duct at low velocity and will not sweep the face of the heading and the higher costs involved if rigid tubing is used.

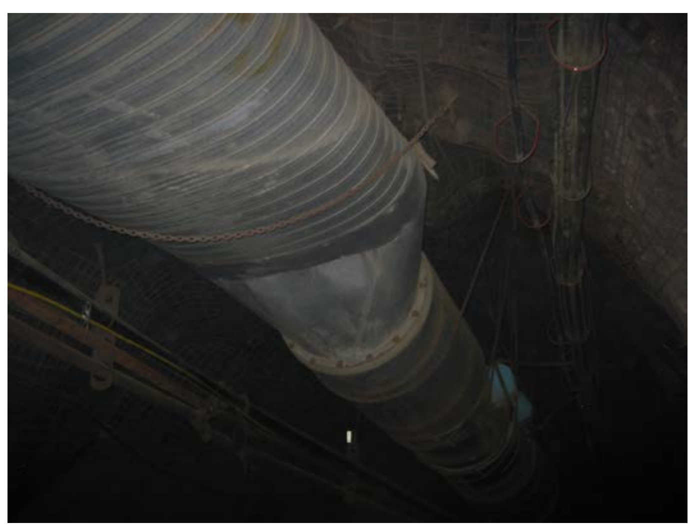

Figure 4. Circular and oval rigid duct in an exhaust system.

The selection of the type of auxiliary ventilation system depends on the amount of air and air quality conditions required, the size and type of fan required and the size and type of duct necessary. Acceptable working conditions determine the required airflow quantities which in term specify equipment requirements and ventilation tubing size. The main factors considered when selecting a specific auxiliary ventilation system include:

- The type of heading, i.e. drifts, ramps, raises, shafts, etc.
- The length of heading. Longer headings may require more sophisticated systems.
- The heading cross-sectional area. Larger headings require considerably higher airflows than smaller ones. This is based on a minimum air velocity requirement of 2.75 m/s per m^2 of face area (50 ft/min per ft^2 of face area).
- Equipment used to drive the heading. Headings driven by diesel powered equipment require higher air quantities than other types of equipment.
- The local temperature. In situations where high rock temperature and high humidity exist, fresh cool air must be supplied to the face via ducting in order to reduce the temperature in the working area.
- Allowed re-entry times. The time allowed to clear the heading after the blast is critical in the selection of an auxiliary ventilation system. For continuous drifting operations, where crew changes may occur at the face, any lost re-entry time is detrimental to the advance of the heading.
- Cost. The effectiveness of an auxiliary ventilation system should not be judged by cost alone. The additional cost of installing a more complicated system must be balanced against the benefits this system will provide as compared to a simpler system.

3 AUXILIARY VENTILATION DESIGN PROCEDURE

The following steps are normally followed when designing and auxiliary ventilation system:

- step 1 - Air volume calculations. This is generally based on diesel equipment operating in the heading. The following factor is considered: 100 cfm per brake horsepower (0.0633 m^3/s per kilowatt) of operating or installed diesel equipment.
- step 2 - Air leakage estimations. Leakage may be assumed to range between 20% and 30%. Calculate the flow required at the fan using: $Q_{fan} = Q_{face}/(1 - \text{leakage})$.
- step 3 - Ventilation system selection. The type of auxiliary ventilation system, the size and type of fan required and the size and type of duct necessary are decided based upon the type of heading, the length of heading, the heading cross-sectional area, the development method, allowed re-entry times, and cost considerations.
- step 4 - Airflow resistance calculations. The contribution of each component of the column to the head loss must be determined. Atkinson's equation can be used to estimate the friction head loss in the duct. The friction head loss contributed by each coupling has an equivalent length of 1.8 m (6 feet). This is multiplied by the number of couplings and added to the length of duct. Elbow losses are estimated using standard shock loss equations. If tubing larger than the fan is used, the losses (including conversion of velocity to static pressure) associated with the transition cone must be considered. Entrance and exit losses must also be included into the calculations. In all calculations appropriate airflow volumes must be used for each section of the column. The flow at the fan is different from the flow at the face and will decrease as it moves along the column.
- step 5 – Fan sizing. Fan curves are analysed to match with the system requirements of head and flow. The fan selection should be based on total pressure. The fan blade pitch and motor size are determined in this step.

A number of design factors (rules of thumb) used by mines in ventilation design calculations are listed below. It must be emphasized however, the danger of basing air requirements on ventilation factors as it may result in under designed or over designed ventilation systems.

- air velocities to obtain gas dispersion from 0.25 to 0.30 m/s (50 to 60 ft/min).
- 0.25 to 1 m/s (50 - 200 ft/min) design face velocity.
- 0.25 m/s (50 ft/min) air velocity for headings which are not governed by diesel requirements.
- Minimum quantity of air per worker underground of 0.01 m^3/s (21.2 cfm).
- 0.014 to 0.028 m^3/s of air per square metre of face area (30-60 cfm per square foot of face area).
- 0.095 m^3/s (200 cfm) per worker at a minimum air velocity of 0.15 m/s (30 ft/min) required to dilute fumes and dust.
- 100 cfm per brake horsepower (0.0633 m^3/s per kilowatt) of operating or installed diesel equipment.
- 9290 to 13935 m^3 (100000 to 150000 ft^3) of air per imperial gallon of diesel fuel consumed.
- 0.014 m^3/s (30 cfm) of fresh air per pound of explosive used will permit re-entry in 20 minutes.

The above design steps are described in more detail in the following sections.

4 FACE AIR VOLUME REQUIREMENTS

Air quantity is governed by federal and provincial regulations. Auxiliary ventilation is required to dilute the fumes from blasting and diesel exhaust to a safe concentration required to maintain acceptable working conditions, to dilute any harmful or dangerous strata gases to safe, acceptable concentrations and to replace the oxygen used up by the workers and diesel equipment. It is also required control airborne dust and to control the temperature and humidity of the air in the working area. All these factors are considered when determining air volume requirements at the face. Some systems operate at flows as low as 1.4 m^3/s (3,000 cfm) and as high as 28 m^3/s (60,000 cfm).

Air quantity is dependent on the advance distance and dimensions. The estimation of air volume requirements is normally based on the minimum amount of airflow required at the heading during the final stages of development or at the stope face during the final stages of production; i.e. when the ventilation tubing is at its maximum length.

In the majority of cases diesel exhaust dilution requirements are used to determine the airflow volume at the face. When utilizing diesel units in development headings one must ensure the air requirements for diesel equipment are met, 0.0633 m^3/s per kilowatt (100 cfm per brake horsepower) of operating or installed diesel equipment. For example, an 8 yard scooptram with rated brake power of 179 kW (240 HP) will require 11 m^3/s (24,000 cfm) and a bolt platform with rated brake power of 63 kW (84 HP) will require 4 m^3/s (8,400 cfm).

When considering mine gases, typical regulations require that all active workings underground be ventilated by an air flow with a minimum oxygen content of 19.5% and not more than 0.5% carbon dioxide. The threshold limit values of common gases encountered in headings are: Carbon Monoxide 0.0025%; Carbon Dioxide 0.5%; Nitrogen Oxide 0.0025%; Nitrogen Dioxide 0.0003%; Hydrogen Sulphide 0.001%; Sulphur Dioxide 0.0002% and Methane 1%. Such values are used to estimate the volume flow of fresh air required for appropriate dilution ventilation.

Because the fumes produced by blasting are produced only once in each drill-blast-muck cycle, and are cleared before any of the diesel equipment are employed, the volumes of fresh air required to clear the blasting fumes from the face and to dilute the diesel fumes are not added together; the air volume requirements is based on whichever amount is greater.

5 AUXILIARY FANS AND FAN REQUIREMENTS

The size of the fan is dependent on the air volume requirements, on the head losses in the tubing and air leakage in the system. Air leakage is always present in auxiliary ventilation, it is minimized when good ventilation practices are followed, and must always be incorporated during system design and fan selection. Air leakage is dependent on duct conditions, installation practices and on the static air pressure in the duct.

Under normal conditions, small fans are used in auxiliary ventilation systems. Airflow capacities range from 1.0 to 14.2 m^3/s (2,000 to 30,000 cfm), and may reach some 28 m^3/s (60,000 cfm) and static pressures normally vary between 0.25 kPa (1" w.g.) and some 2 kPa (8" w.g.), but may reach as much as 3.7 kPa (15” w.g.). The electric motors running these fans normally range from 4 kW (5 HP) to 75 kW (100 HP). Larger motors, reaching 150-185 kW (200-250 HP) may be required depending on conditions. Typical fan sizes are 24, 30, 36, 42 and 48 inches (610, 760, 915 and 1220 mm).

Mines normally select fan sizes based on experience. Fan requirements for mechanized headings depend on the length of the heading and flow requirements. For example, for a short heading, 38 m (125 ft) long, requiring a flow of 14 m^3/s (30,000 cfm), a 76 cm (30”) fan with a 29 kW (40 HP) motor would be selected. A longer heading, 137 m (450 ft) long, requiring a flow of 14 m^3/s (30,000 cfm), a 91 cm (36”) fan with a 45 kW (60 HP) motor would be selected. For a flow of 21 m^3/s (45,000 cfm), a 96.5 cm (38”) fan with a 75 kW (100 HP) motor would be selected.

Typically, auxiliary axial flow fans are designed based on the final length of the drift, and the blade pitch is initially set for this requirement. Normally, instead of adjusting the blade pitch during the various phases of heading development, flow control is achieved with the use of regulators. A common method of regulating electrical fans, although improper, is by constricting the duct by means of a cord tied around it.

In long ductwork installations, booster fans are normally spaced at intervals along the auxiliary ventilation system (staged fans), rather than positioning all the system static pressure requirements (one high pressure booster or several fans in series) at the start of the column. This is done to reduce high pressures in the column thus minimizing system leakages.

6 VENTILATION TUBING AND TUBING SELECTION

The selection of the ventilation tubing is crucial in system design. In order to assure maximum air delivery to the heading, the resistance of the duct system should be minimized. The tubing resistance is governed by its size, type, length, layout and efficiency of installation and maintenance. In order to minimize resistance to flow, the tubing must be stretched tight during installation and possess good alignment and be free of unnecessary sinuosity. The type of tubing depends on the ventilation system (blowing, exhaust), the drift and workplace requirements and somewhat on personal preference. Duct diameters are generally selected to match the fan diameter. However, when sizing the ventilation column, the size of the drift and equipment are considered to allow for sufficient clearance between the ducting and mobile diesel equipment (Figure 5).

Figure 5. Sufficient clearance between ducting and mobile equipment should be provided to prevent damage to column.

Three general types of tubing are commonly used to ventilate working faces: rigid, flexible and flexible wire-reinforced tubing (Figure 6). Typical tubing internal diameters range between 610 mm (24") and 1220 mm (48") but can go as large as 1960 mm (78"). Oval ducting is also used, and selected to have an equivalent round duct diameter. Ducting is available in various lengths, generally in 3-9 m (10-30 ft) lengths or longer.

Flexible tubing are very popular because they are lightweight, easy to handle and install and have low capital cost. They are commonly used for temporary systems and in short headings (up to 180 m, 600 ft). Their main disadvantage is their susceptibility to damage. Flexible tubing is useful in headings in which room is restricted or in headings which are not straight. Resistance characteristics are fair when hung straight and well maintained. They can only be used for blowing systems as the static pressure holds the tubing open. When abrupt changes in drift direction are encountered, the use of spiral tubing may be necessary to eliminate the possibility of crimping of the column. Flexible wire reinforced tubing are light, and easy to handle. They have poor resistance to flow unless if stretched tight during installation.

Figure 6. Flexible and rigid tubing used in the same column.

Rigid ducting are rugged, have low resistance to flow both under blowing and exhausting conditions and low maintenance costs for long, permanent systems. They are bulky, heavy, difficult to handle and install and have high capital cost. Rigid ducting can be built underground (Figure 7) thus making it competitive with flexible ducting. Although steel tubes offer extremely low leakage, they are susceptible to rust. Fiberglass tubing are smoother and have a coefficient of friction of approximately 12% less than metal tubing.

Figure 7. Underground manufacturing of rigid tubing.

Ducting accessories include rigid and flexible elbows, end caps, T's, Y's, reducers and transition pieces.

Every duct column leaks at seams and joints. Air leakage is dependent on duct conditions, installation practices and on the static air pressure inside the duct. Air leakage can, in many cases, be very significant and must be incorporated into the ventilation balance. Leakage increases with the static pressure, which, in turn increases with the length of the column, and the volume of air flow. As a rough guide: doubling the length of column, trebles the leakage for a given volume of air flow; doubling the volume of air flow increases the leakage two and a half fold for a given length of duct; approximately 0.09 m^3/s (190 cfm) of air leakage occurs per joint in the column. For these reasons, in long drifts, fans spaced at intervals along the column prove more satisfactory than positioning one (or more) high pressure fan(s) at the start of the tubing system. In general, the amount of leakage from normal ducting installations is very high. Leakage values exceeding 30-50% are not unusual due to poor maintenance practices and due to damage by blasting and equipment (Figure 8).

Figure 8. Severe leakage due to damage by equipment.

7 INSTALLATION PRACTICES

The proper installation and maintenance of tubing is of great importance to assure efficiency in system performance. Leakage should not exceed 10% the initial flow volume, although leakage above 50% is frequently observed due to poor installation and maintenance practices. The following installation procedures are normally followed at the mines:

- The support cable and tubing are hung and carried as straight and tight as possible with a minimum of bends.
- Proper fan adaptors are used to connect the duct to the fan in order to avoid leakage.
- Duct couplings, tight clamps and clips are used to assure good duct connection and avoid leakage.
- Ducts, in particular flexible ducts, are hung with hooks attached to messenger cables. Steel ducts are hung with the use of chains (Figure 6). Hooks are also directly attached to bolts, straps and screens used for strata support.
- In order to minimize damage to the column by mobile equipment, the ducting is suspended as high as possible against the back, in particular at intersections and low-lying areas.

8 PRACTICAL DESIGN AND OPERATIONAL CONSIDERATIONS

The following design and operational aspects were found to be implemented in a number of mines:

- A fan should be installed in such a manner that a sufficient quantity of air reaches it at all times so as to ensure that it does not recirculate air.
- Fan installation should be conducted so as to eliminate the risk of the air which it draws being contaminated by toxic fumes and dust.
- The volume of air a fan will handle must always be less than the quantity of air passing in the airway in which the fan is installed. The capacity of the fan should not be more than one half of the quantity of air passing in the airway where the fan is situated.
- When installing fans spaced in series, at intervals along the auxiliary ventilation system, it is common to leave a gap of approximately 15 cm (6") between the end of the column and the booster fan to prevent collapse of the column. One should however be aware of the potential for excess recirculation of contaminated air.
- When sizing the ventilation column, the size of the drift and equipment must be considered. Sufficient clearance between the ducting and mobile diesel equipment must be allowed to prevent damage to the duct. Personnel should be advised of the importance of avoiding causing damage to the column when utilizing transport and haulage equipment.
- Fans should be turned off during blasting. This step will prevent damage to the impeller blades by air blast.
- The ventilation tubing should be maintained in a condition such that air leakage is minimized. For economic operation, leakage should not exceed 10%. For design purposes, leakage may be assumed to range between 10 and 30% of the fan supply flow.
- Minor damage to tubing at different segments of the column will have a cumulative contribution to leakage. As such, even minor damage should be readily repaired during normal inspection. Simple techniques such as stitching or patching can be employed (Figure 9). The use of 'zipper tubing' may save considerable repair time.

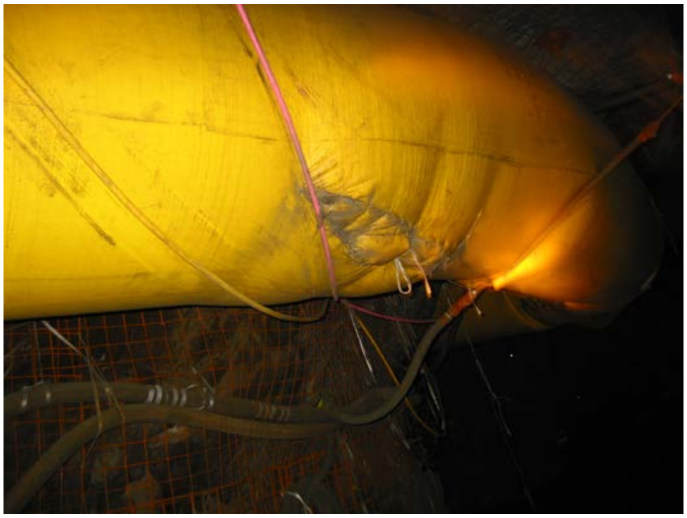

Figure 9. Stitching used to repair damage to tubing.

- The last 30-45 m (100-150 ft) of tubing should be removed (or protected) prior to a blast to minimize damage.
- The end of the column should be closed prior to a blast. This will prevent or minimize the accumulation of dust and debris in the column, as such collection and build-up of material will increase the resistance to flow.
- As additional lengths of new ducting are added to the column with the advance of the heading, the last section of ducting (which is subjected to most damage) is always maintained at the end of the column.
- Adequate air delivery to within 5 m (15 ft) of the face should be maintained.
- 0.09 m^3/s (190 cfm) of air leakage per joint in a ventilation column.
- The friction head loss contributed by each coupling has an equivalent length of 1.8 m (6 feet).
- Friction factor of 0.0028 $N.s^2/m^8$ (15 x 10^{-10} $lb.min^2/ft^8$) for fiberglass duct, 0.0037 $N.s^2/m^8$ (20 x 10^{-10} $lb.min^2/ft^8$) for canvas duct and 0.00111 $N.s^2/m^8$ (60 x 10^{-10} $lb.min^2/ft^8$) for spiral-type canvas.
- One velocity pressure for discharge (exit) loss.
- Daily inspection for column damage should be performed.
- Standard ventilation surveys (with vane anemometers or pitot tubes) should be performed weekly to verify if sufficient air is reaching the face and to verify that recirculation is not developing. If the airflow is too high, the use of regulators may be required. Factors that should be included during a survey are motor amperage, fan pressure, air volumes at fan and at exit of column, gas levels, straightness of column, condition of ducting, condition of couplings, distance of last duct section from face.

9 CONCLUSIONS

This paper was presented to provide, for the ventilation operator and practising engineer, design guidelines and operational procedures which would maximize the performance of auxiliary ventilation systems. The contents of this paper are based on a series of visits to underground operations and represent standard techniques practised in such operations.

REFERENCES

Bossard, F.C., LeFever, J.J., LeFever, J.B. & Stout, K.S. 1983. *A Manual of Mine Ventilation Practices*. Second edition. F.C. Bossard and Associates, Inc.

Burrows, J., Hemp, R., Holding, W. & Stroh, R.M. 1989. *Environmental Engineering in South African Mines*. Mine Ventilation Society of South Africa.

Flexible Ducting Ltd. 1957. *Tunnel Ventilation*. Maryhill:Glasgow.

Hall, C.J. 1981. *Mine Ventilation Engineering*. The American Institute of Mining, Metallurgical and Petroleum Engineers, Inc.

Hartman, H.L. (ed.), Mutmansky, J.M. & Wang, Y.J. (co-eds.) 1982. *Mine Ventilation and Air Conditioning*. Second edition. John Wiley & Sons.

Misra, G.B. 1986. *Mine Environment and Ventilation*. Oxford University Press.

National Coal Board. *The Ventilation of Headings*. Information Bulletin No. 52/74.

Notley, R.K. 1983. *Mine Ventilation Manual*. Queen's University.

Roberts, A. 1960. *Mine Ventilation*. Cleaver Hume Press Ltd.

Sandkuhler, T. et. al. 1998. *Auxiliary Ventilation Systems*. Queen’s University.

The Mine Ventilation Society of South Africa (1990) *Le Roux's Notes on Mine Environmental Control*. CPT Book Printers.

Thompkins, R.W. *Manual on Mine Ventilation*. Queen's University.