# VENTILATION

# MINE ENVIRONMENTAL CONTROL

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## COMPOSITION OF AIR

Air is composed of a mixture of gasses of which the two dominant ones are the elements Nitrogen at 78% by volume and Oxygen at 21%. The remaining 1% is made up predominantly of Argon. In the un-polluted atmosphere carbon dioxide forms only 0.04% of the total, but in an industrial environment it may reach the percent range. Water vapour is always present and when the air becomes saturated liquid water will precipitate out as droplets.

## PHYSICAL PROPERTIES OF AIR

A column of air has a measurable mass and the weight of the overlying gas causes the pressure to increase with increase of depth. Near sea level the atmospheric pressure approximates to 1 bar which equals 100 kilopascals which is the accepted unit for recording pressure. Under stable atmospheric conditions, the pressure gradient with depth is approximately 10 kilopascals per 1000 metres. This increase in pressure with depth is accompanied by an increase in temperature which is known as the lapse rate and is found to be 6.5°C per 1000 metres.

Air which is moved vertically, such as down a shaft, is compressed and thereby heated. Dry air is warmed by 10°C for every 1000 metres it descends. This adiabatic lapse rate is 3.5°C more than the static lapse rate, and air drawn down a mine shaft is significantly warmed by compression.

## NATURAL VENTILATION

As warm air is less dense than cold air it will tend to rise allowing colder air to displace it. Water vapour is also less dense than air, so air which is closer to saturation will rise through dry air at the same temperature. Open shafts leading to mine workings will normally circulate air as warm moist air from wet hot working areas will upcast and allow dryer cool air to downcast down shafts into de-watered sections of the mine.

## MECHANICAL VENTILATION

The mechanical movement of air requires the use of fans to provide fresh un-polluted air to the working places and travelling ways in an underground mine. It should be noted that any ventilation system should where possible assist the flow of gas due to natural ventilation. A fan working against the natural pressure gradient will expend energy counteracting the natural ventilation before it can do useful work in ventilating the mine.

There are two types of fan used for mine ventilation. The centrifugal fan is the most efficient relying on the normal centrifugal forces which surround a rotating shaft. Impellers or paddles are fixed to the shaft which is enclosed in an aerodynamic housing or volute. As these fans, which are also known as radial flow or paddle fans, have a greater diameter than the vent pipe, they are best sited on surface at the collars of up-casting ventilation shafts. Paddle fans run at a slower speed than axial flow fans and are subject to far lower operating stresses. They also consume less power for the same amount of work done and efficiencies of more than 90% are normal. Manufacturing tolerances are less critical than for axial flow fans, and the design and fabrication of all but the largest centrifugal fans can be carried out in a conventionally equipped mine workshop. The motor driving the fan is external and is therefore not subjected to corrosive fumes during use. A belt drive to a pulley on the impeller of the fan allows for simple replacement should the motor burn out.

The axial fan is designed to be the same diameter as the ventilation column and is used to force air through a vent pipe. These should be used principally in sections undergoing development to provide temporary ventilation until connections are made to the nearest return airway. In local zones of dead air, it is often necessary to install boosters in the form of a length of ventilation pipe containing an axial fan. This configuration is used to provide the necessary pressure gradient to move any foul air towards a return airway. The design of the axial flow fan necessitates the motor being enclosed within the fan housing which restricts the cross sectional area of the airway. For this reason the fan needs to operate at a high speed and the balance of the shaft and the aerofoil profile of the impeller blades requires a very sophisticated fabrication plant. Some makes of fan incorporate variable pitch blades for differing operating conditions.

NOISE

Sound is propagated as pressure waves through an elastic medium; either solid, liquid or gas. In air the speed of sound is approximately 1200 kilometres per hour or 344 metres per second. Propagation through liquids and solids is between four and 12 times faster. Wave frequencies between 20 hertz and 20000 hertz can be detected by the human ear, and it is the pressure variation or amplitude of these waves which are related to the loudness of the sound produced.

The unit of measurement for noise levels is the decibel which is a function of the logarithm of the square of the pressure caused by the sound source. The logarithmic scale means that an increase of one decibel is equivalent to an output of almost twice the sound energy.

1 decibel is below the hearing threshold

70 dB is comfortable

80 dB is uncomfortably noisy

120 dB is past the threshold of pain

Exposure to constant noise at more than 80 decibels causes permanent ear damage accompanied by hearing loss.

Sound emission in the work-place can be contained either by eliminating or moderating the source, or by isolating the noise from the ears of the workers. The loudest sounds heard underground are the exhaust from pneumatic rock drills, explosions in secondary blasting and excess sound from machinery, principally axial ventilation fans.

All primary development within a mine, ie. shafts, travelling ways and workshops, should not be subject to severe noise. Pumps, fans and other machinery should be maintained so that there are no loose panels or covers to vibrate. Fans which persist in humming can be acoustically damped by enclosing them with absorbent lagging. It may be possible to eliminate secondary blasting on grizzleys by the installation of hydraulic rammers. Grizzleys should be screened behind sound deadening blast curtains.

Personnel working at the face and using hand held pneumatic drills need to be compelled to wear ear protectors in conjunction with ear plugs. Most workers in this environment have suffered some degree of permanent hearing loss because of not using ear protectors. It should be enforced by all overseers and instilled into the workers during training, that the wearing of protective gear is mandatory.

TEMPERATURE CONTROL

It has already been noted that the adiabatic lapse rate of down-casting air is an additional 3.5°C per vertical kilometre, over the static lapse rate, so that air drawn down a mine shaft is significantly warmed by compression. Mines which operate at depths below two kilometres normally require some form of temperature control in order to maintain an environment in which people are able to work. Surface air is often refrigerated to ten degrees or so below the ambient temperature to compensate for the inevitable warming due to compression.

Water has a far greater thermal capacity than has air. As water needs to be introduced into a mine for services such as dust prevention, it has been found that chilling this service water before it enters the descending main helps to cool all working places where the water is discharged. The latent heat of water melting from solid ice to liquid is 80 calories per gram. This means that if a ton of ice were transported to the hot working places underground, 80 million calories of heat would be removed from the environment before the temperature of the water rose above the freezing point. The most efficient method of cooling the working places of deep hot mines is by adding ice to the chilled service water which is pumped underground to a transfer chamber which behaves as a heat exchanger, where fresh downcast air is cooled and the ice in the service water is allowed to melt.

## MECHANISED MINING

All large scale underground mining operations require a level of mechanisation in order to maintain the efficiency and cost per man hour within profitable limits. The chief phases of underground mining are; establishing access to the ore-body, extracting the ore and transporting the ore to surface.

Access is normally via a shaft or decline, or where the topography is favourable, by way of a horizontal adit. Mechanised shaft boring and raise boring are well established techniques. These rely on electric power input and therefore do not require additional ventilation. The same criteria applies to the use of tunnel boring machines.

The mechanisation of ore extraction has made significant advances since the middle of the twentieth century. It is this phase of mining which is the most dangerous and any reduction of the work-force in this area is of benefit to the safety of the mine as a whole. Mechanical shearers are only of practical use in soft rock environments such as salt, potash and coal mines.

Elsewhere drilling and blasting remains the only option for liberating ore from its surroundings. Some work is being done in hydraulic mining and impregnated wire cutting, but this remains experimental.

Diesel powered loaders and trucks were popularised for underground use during the 1950's and early 1960's when very large high performance pneumatic tyres were first developed and diesel fuel was cheap and readily available. The tenfold rise in the price of petroleum fuels in the early 1970's, plus subsequent price increases has made trackless mining less attractive. The range of available equipment developed for this type of mining has meant that in situations where flexibility is important there remains a place underground for rubber tyres and diesel engines.

Large diesel engines working under fluctuating load place heavy demands on the ventilation system of a trackless mining section. The heat given off from the vehicle's radiator as well as its exhaust will rapidly raise the temperature of a working place to dangerous levels unless a constant supply of cool fresh air is available. The direction of flow should, as always be so that hot, dust and exhaust laden fumes are drawn up draw points or parts of stopes previously worked out. Personnel and machinery should only be exposed to cool fresh air. A diesel engine which is exposed to exhaust fumes is unable to operate efficiently and will produce dense particulate smoke. This will rapidly render the work-place uninhabitable.

# DESIGN

DESIGN

FUNDAMENTALS

The movement of air requires work to be done to combat inertia and to overcome frictional forces opposing the movement. A pressure gradient will ensure the free movement of air but the rate of movement will be dependant on the frictional resistance. The greater the speed of the air being moved the greater will be the frictional forces opposing that movement. It is more efficient for the air speed to be maintained at a minimum by using the maximum practical cross sectional area for all ventilation columns.

Ventilation pipes are commonly supplied in the following Imperial sizes; 11 inch, 16 inch, 22 inch and 31 inch. It will be noted from the table below that the cross sectional area doubles between sizes, so that two 11 inch vent pipes can feed a single 16 inch pipe with no volume loss.

The resistance due to friction is inversely proportional to the diameter of the ventilation column whereas the volume of contained air is proportional to the cross sectional area. In the instance where two 11 inch vent pipes feed a 16 inch vent pipe of the same carrying capacity it will be noted that the surface area per metre of the 16 inch vent pipe is less than for the two 11 inch feeder pipes in the proportion 0.4 : 2x0.28. Thus the friction will be greatest where the diameter of the pipe is smaller although the total combined cross sectional area is the same. This effect is very significant where air speeds are high.

| diameter inches | diameter metres | cross section area $m^2$ |
|---|---|---|
| 11 | 0.28 | 0.06 |
| 16 | 0.40 | 0.12 |
| 22 | 0.56 | 0.25 |
| 31 | 0.79 | 0.49 |
| 44 | 1.12 | 0.98 |
| 62 | 1.58 | 1.96 |
| 88 | 2.24 | 3.92 |
| 124 | 3.16 | 7.85 |
| 176 | 4.47 | 15.70 |
| 248 | 6.32 | 31.39 |

From the above table it can readily be seen that a 20 foot diameter circular vent shaft can serve four ten foot diameter return airways each of which can handle the air from four five foot diameter grizzley ventilation drives. By the same convention a working stope which is serviced by a single 2.24m diameter vent shaft requires man-ways box-holes or draw-points with a combined cross sectional area of $3.93m^2$ to avoid pressure losses and maintain ventilation efficiency.

## VENTILATION NETWORKS

In any ventilation layout all sections of the mine in which personnel work or travel through, must never be exposed to foul air from other sections. Ideally stopes should be connected to main return airways which are in turn served by up-casting ventilation shafts. In this way stopes in which primary blasting takes place, are maintained at negative water gauge so that fresh air from surface is drawn into the mine through the service shafts which carry men and materials. It is reticulated along the main haulages towards the working places. Draw-points and box-holes are sources of excessive amounts of dust and must up-cast into the stope. Where secondary blasting takes place auxiliary return airways may be necessary to clear toxic fumes. Long finger raises used to draw ore from stopes are choked with broken rock and grizzley ventilation drives are required to remove foul air from behind each grizzley. These GVD's must be connected to an up-casting vent shaft by way of a main return airway.

## VENTILATION SHAFTS

When any mine reaches a certain size it becomes necessary for shafts to be set aside exclusively for the transport of air. Air is a viscous fluid and is subject to the effects of friction due to obstacles and irregularities in its path. A shaft which is to be converted from a hoisting and access shaft to one used only for ventilation, should be stripped of all buntons, platforms and other fittings which would hinder the free movement of air. The surface area of the shaft walls exert a frictional drag on moving air. The walls of a circular shaft have a smaller surface area compared to those of an elongate rectangular shaft with the same cross sectional area.

## RE-CIRCULATION

The air at any working place underground should be freshly sourced from the main downcast system with no contamination from stale air derived from adjacent working places. Foul air re-circulating through a mine should be contained behind barricades and diverted to the nearest suitable up-cast return airway. Ventilation barricades and doors are used to isolate sections of the mine which are worked out but whose primary development is still in occasional use, such as by maintenance crews and for the movement of equipment. The seepage of air past barriers is usually sufficient to maintain air quality to acceptable standards. Frequent inspection by ventilation staff is necessary to ensure that no toxic build-up is taking place in any section of the mine.

PRESSURE GRADIENTS

A difference in air pressure will cause the bodily movement of air from a location of higher pressure to one of relative lower pressure. The absolute pressures are most easily measured by an aneroid barometer which can be carried into any part of a mine and is simple to read. It should be calibrated against a mercury column on surface before and after any survey and the results corrected for drift. The deeper levels of a mine will record higher absolute pressures than the shallower but these variations will not cause air to flow. Differences in temperature and humidity will also affect the absolute pressure readings in a mine.

Relative pressures can be measured by various commercially available instruments, but the simplest is a water manometer made from a metre of transparent plastic tubing bent into a "U" tube supported on a rigid board. These may be permanently fixed to ventilation doors with one arm in open connection to the opposite side. These should be read at the start of each shift to reassure the person in charge that the ventilation system is working properly.

A manometer reading of 150mm (6 inches) water gauge is characteristic and is usually a suitable pressure gradient to keep air circulating through the average mine section.

## POLLUTION CONTROL

Various activities during the normal operation of a mine will generate gasses which are toxic to health. The most obvious are the products of explosives due to primary and secondary blasting. Underground welding is the source of hazardous fumes especially when high alloy welding rods are being used. All routine welding underground should be carried out in a designated workshop provided with a connection to a return airway. All welding should be carried out where the air speed is sufficient to prevent the operator or any other person coming in contact with welding fumes.

## BASIC ECONOMICS

The maintenance of a safe working environment is a factor as important as keeping the fine ore bin filled. The latter is an obvious first target of the whole mining operation, but down-time and lost shifts due to accidents and workers ill-health can have a ruinous effect on the overall viability of any mine.

The supply of fresh air to all travelling ways and working places is the major cost of environmental control. Some very deep mines retain an up-casting compartment within their hoisting or men and materials shafts in order to contain capital expenditure while commissioning a new mine or section. This requires airtight bratticing to separate the up-casting foul air from the down-casting air in the men and materials compartment. The volume of air is necessarily restricted and the necessary high air speeds to compensate, lead to large friction losses. This very deep mining is typical of the Witwatersrand but is makes better economic sense to sink the production shaft on the down dip part of the ore-body, with a separate dedicated ventilation shaft up-dip to take advantage of the small natural ventilation component. These shafts are usually sunk by specialist sinking contractors and the capital costs are necessarily high.

The ventilation of mines operating at moderate depths (100 to 500m) is best carried out with many smaller ventilation shafts which can be commissioned and abandoned in sequence as the working faces advance. The expense of sinking these shafts can be contained by sinking from surface to 25 metres depth using low cost well sinking technology. A circular shaft with a diameter of two metres or less is inherently stable, even through soil and decomposed rock. A smooth concrete lining integral with a raised shaft collar can be cast using inexpensive shuttering. Mounting bolts for the fan installation can be incorporated into the concrete collar. At 25 metres depth the ground can be expected to be competent and a holing made from the underground return airway system using any suitable inclined raising technique. If a raise borer is available this is both speedy and safe and provides a smooth bore which will provide minimum friction to the exhausting air.

It has been found advantageous to sink a ventilation shaft on the site of a vertical surface drill hole for the following reasons. Geotechnical information will be available from the logging of the hole so zones of poor ground conditions can be avoided. The location of the hole where it intersects the ore-body will have been established so the starting point for the connecting raise can be planned with accuracy. Water which would accumulate in the shaft bottom during sinking will drain down the drill hole into the mine so the necessity for pumping is eliminated.

ILLUMINATION

Good lighting in the work place has been shown to both increase productivity and reduce the accident rate. This is true of underground mining which relies on the supply of artificial lighting more than any other occupation.

The minimum amount of underground lighting is that supplied by the cap lamps worn be each person. These provide light for the work and importantly illuminate the worker so that his presence is always registered. Good maintenance of cap lamps is an essential factor in accident prevention.

Light is a very small part of the electromagnetic spectrum to which our eyes are sensitive. The whole spectrum ranges from radio waves to gamma and cosmic waves and these waves are a medium for transporting energy across a void.

The candela has replaced the standard candle as a measurable light source. The luminous flux is the radiant energy which flows from a light source. This is measured in lumens. The illumination of a surface by a light source is measured in lux, which are equal to one lumen per square metre. A point source of light of one candela will produce illumination of one lux on a surface one metre away provided that the source is perpendicular to the surface. Illumination from a non-perpendicular source is calculated by multiplying by the cosine of the deviating angle. This is known as the cosine correction.

The most common light sources in use are the filament lamp which employs an incandescent tungsten wire surrounded by an inert gas, usually argon, protected by a glass bulb. The filament glows at a bright white heat, at temperatures over 1500°C and only some 10% of the energy radiated is in the form of useful light. The electric cap lamp uses this type of bulb.

The fluorescent lamp is a hollow glass tube coated with a fluorescent powder which emits light when excited by ultraviolet radiation produced by passing a current down the partly evacuated tube. As less heat energy is produced the fluorescent light is some six times more efficient than the filament lamp.

The mercury arc lamp is similar gas discharge lamp which does not use a fluorescing powder, emitting white light directly. It is a more efficient light source with a long service life and is most suitable for illuminating large bays where an intense light source is required.

A cap lamp produces from 2 to 4 candela of illumination normally providing a focused beam of 45 lumens.

A 40 watt tungsten filament lamp produces 35 candela

A 100 watt tungsten filament lamp produces 130 candela

A 40 watt fluorescent lamp produces 200 candela

The use of reflectors, and simply by whitewashing the surroundings of a light source increases the available illumination significantly.

The recommended levels of illumination for underground mines in South Africa are as follows:

Stations and areas where machinery is used 100 - 200 lux.
Junctions and hazardous areas 50 lux.
Travelling ways 20 lux.

# MONITORING

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## SAFETY

The principal reason for environmental monitoring is to maintain a level of safety in which all work may be carried out with minimum risk. It is universally accepted that opencast mining is intrinsically safer than underground mining. The main reason is that the whole operation is constantly visible to the supervisor, and any infringement of safety regulations can be immediately rectified. In an underground operation there is no substitute for constant vigilance on the part of the supervisory staff. Numerous accidents have been caused by workers unlawfully resting in what they thought to be an unused development end, and falling asleep. Video monitors are not usually practical in an underground environment, so constant training and re-training of workers together with regular inspections by senior personnel is the only proven method of maintaining a safe mine.

## AIR QUALITY

In ideal circumstances the men and material shafts of an underground operation will constantly downcast fresh air which is then drawn along the main haulages and travelling ways into the stopes. These are held at negative relative pressure by a return airway connected to an up-casting ventilation shaft.

Gasses injurious to health are generally oxides of carbon and oxides of nitrogen. The former are derived from the complete and incomplete combustion of organic matter. Carbon dioxide, like nitrogen is a suffocating inert gas, but carbon monoxide is a dangerous poison, they are found in both blasting fumes and diesel exhaust. Prolonged exposure to concentrations of only 0.1% of CO can be fatal. Portable electronic CO detectors are available for testing for traces of this gas. These should be available in trackless mining sections. Fixed audio visual alarms can be set to trigger at pre-set levels.

The oxides of nitrogen make up part of the fumes formed as a product of blasting. These have an irritating smell and are therefore easily detected. Prolonged exposure to very dilute concentrations of these gasses will cause permanent lung damage.

The average underground blast using 100Kg of explosive will produce approximately:

3 cubic metres carbon monoxide

20 cubic metres carbon dioxide

2 cubic metres of nitrous fumes

Electronic multi gas testers have been developed to be used both as fixed installations and as portable hand held devices for spot checks. These can monitor levels of $O_2$, NO, $NO_2$, $CO_2$, CO, $SO_2$ as well as smoke levels and temperature.

HOUSEKEEPING

A clean and uncluttered environment underground is an essential requirement for the maintenance of a safe and productive work-place. Travelling ways should be free of projecting pipes and electric cables. The rungs on ladder-ways must be properly fastened and an exact distance apart (30cm). Bins must be provided in stations for the accumulation of rubbish such as empty boxes, rope fragments, timber off-cuts and broken drill steels, and these must be cleared on a daily basis. This can only be achieved by regular visits to all sections of a mine by the overseer who must maintain records of conditions.

COMPUTERISATION

The advent of less expensive and portable computers in the work-place has made the interactive monitoring of most types of instrumentation possible. With a networked system it is possible to have all sensors in the mine linked to a surface control room where constant displays show the condition of all sections of the mine in real time. Simple manually operated processors allow daily, weekly and monthly graphs to be speedily and accurately prepared to reveal any trends developing in the quality of the environment underground.

# REFERENCES

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