[How Much Air?](#)
[Planning](#)
[Planning Considerations](#)
[Factors](#)
[What do we have?](#)
[What do we require?](#)

[How Do I Get More Air?](#)
[Never what they seem](#)
[The Problems](#)
[Solutions](#)

ventilation

Ventilation - How much air do I need?

Author - P T Gardner

In 1988 I had been employed as a mine ventilation practitioner for 10 years and while attending the "Fourth International Mine Ventilation Congress" in Brisbane a delegate at the end of a session asked the presenter...

"*How much air do I need for my mine*?"

The reply was a simple "That depends" however this only further frustrated the delegate and he repeatedly asked this question of each presenter in turn and received the same basic reply.

In 1996 after 17 years involved in mine ventilation I have found this question to be singularly the most puzzling ventilation question for mining production personnel and the most daunting question asked of mine ventilation engineers.

top

Ventilation Planning

Some consider "that many ventilation systems have been poorly designed and in some cases poor design still continues today."

If poor design is to be recognised how is it recognised and what then is good ventilation design? Until we can define a good ventilation system then it is very difficult to define a poor ventilation system?

Words like good and poor are at best subjective and usually based on the opinion of the person making the evaluation and therefore making it impossible for another person to compare one mine with another.

Mine ventilation is about providing a quality of mine air to ensure to health and safety of mine workers as well as providing a suitable atmosphere for the safe and effective operation of mining plant and equipment.

Of the many definitions for quality Phillip Crosby(1) provides a definition of quality as "conformance to requirements" and in all mining operations the operators must meet the requirements of:

1. the mine owners to ensure that production schedules are met within the design criteria of grade, tonnes and costs

2. the mine workers, to ensure that personnel working within the mine will provide maximum productivity with out detriment to their health and well being, and

3. the legislators to ensure present (and foreseeable future) contaminant and airflow requirements are met and maintained.

Until the requirements of all three groups are recognised and satisfied then ventilation systems can best be described as "non conforming" and once we have met the requirements of these parties we can say we have a quality ventilation system.

Mine ventilation planning can only be as good as the mine production scheduling:

Life Of Mine (LOM) usually the conceptual resource,

- 5 yearly, or in some cases if the grades are difficult to determine, eg gold mines, this is reduced to 3 years, and is based on the proven/probable reserve,

- Yearly plan which is based on the proven reserve usually with access development complete, and

- Weekly

Mine ventilation planning must eventually consider all of the above schedules along with the capital expenditure requirements and limitations of the site, provide the quality of air necessary to ensure the occupational health and safety of employees and the necessary return on the capital expenditure.

Many attempts have been made to produce ventilation plans for the LOM but because the ventilation plan is directly tied to the mine production schedule then by definition after 5 years this planning can at best only be conceptual.

With the ever increasing need to establish International Best Mining Practise to remain competitive, we must be continuously redefining our goals and objectives as far to many times ventilation plans fail to meet the production requirements after periods of less than five years from establishing the initial ventilation circuits.

top

Planning Considerations

Ventilation planning is the optimisation of many variables and at the end of the day effective mine ventilation will be achieved as a result of compromise between production schedules, plant and equipment maintenance, mining services, industrial relations and economics.

Of the many variables for consideration are included:

- Mine heat sources both natural and artificial
- Equipment in use and to be used
- Radioactive and combustible gas emissions
- Harmful substance exposure
- Re-entry times
- Residence times of contaminants
- Fire control
- Requirements for servicing eg rockbreaking, crushing, hoisting, maintenance workshops, haulage routes, fuel-up points, etc.
- Complexity of circuit and cost of development
- Flexibility of circuit control
- Auxiliary ventilation systems
- Velocities in shafts and haulage accesses
- Legislation requirements
- Comfort levels (Industrial Relations component)
- OH&S, and
- Production location and development location schedules.

top

Ventilation Factors

I have seen a number of attempts to provide final air flow requirements by equating legislative requirements ie the minimum standard method where the Airflow requirement for the mine(m3/s) = Sum of the power rating of the diesel engines underground (kW) * Specified airflow specified in the respective legislation (m3/s per kW).

Others have developed factors and empirical equations based on production methods and production rates.

Some factors used for ventilation planning include:

- m3/s per k tonnes mined per year
- m3/s per kW of installed diesel power
- m3/s per kW of operating diesel power
- m3/s per litre of diesel fuel consumed underground
- m3/s per person underground
- the time to complete one change of air within the mine workings

A survey of 33 metal mine sites and 23 collieries in Australia produces the results shown in Figure 1 and Figure 2. If we accept a band from 0.10 to 0.15 m3/s per 1000 tonnes mined per year, which could be considered acceptable ventilation, then from the above 11 (48%) of these collieries could be said to be over ventilated, 5 (22%) are under ventilated with 7 (30%) acceptable.

Similarly if we accept a band for metal mines of 0.40 to 0.50 m3/s as acceptable ventilation then from the above 14 (43%) metal mines could be said to be over ventilated, 13 (39%) under ventilated with only 6 (18%) acceptable.

Does this then mean that only 13 (23%) of sites have acceptable ventilation or, does it mean that the low airflow factor is the Australian Best Practice in Mine ventilation and we should all be attempting to achieve this result or, is it simply a matter of meeting requirements for each site?

Planning Mine ventilation requirements on factors derived from operating mines and utilising this factor for a new mine has the potential to be a very costly exercise. However there may be some basis to extrapolate existing conditions for use when expanding production in the same operating mine (eg in uranium mines where the requirement is for a specified airflow for each m2 of exposed rock) or when attempting to get an estimate of ventilation requirements during the initial stages of a project.

Design of ventilation systems must be based on sound engineering principles and although past experiences cannot and must not be ignored reliance on rule of thumb principles or empirical ventilation factors alone can and have led to both under designed and over designed systems both of which have the consequential result of adding extra cost to a project.

top

What do we have?

"*to start at the start is not a bad place to start*" Unknown.

What do we have, either:

- to work with (eg existing mine , ventilation equipment , climate etc.) or
- to comply with (eg legislation, budget, time frame for completion)?

It is the completeness of the answer to this question which can determine the effectiveness of the final plan . Often this question is not asked early enough in any problem solving exercise as we all tend to assume the answer or we have some preconceived idea as to what we want the answer to be . Understanding what we have to work with generally helps to make the solution clearer earlier and a review of what has been done in the past may prevent us from making the same mistakes in the future.

A review of mining legislation is necessary as it varies from country to country and in Australia from state to state (although in recent years there has been an effort to provide standard requirements in all states this has not yet come to fruition but the process, at the time of this writing, was continuing.)

Although variable most mining legislation will provide a airflow requirement based on specific contaminants eg diesel exhaust emissions, radon daughters, methane, carbon dioxide, dust(s) etc. and mine operators are expected to maintain these airflow requirements as a minimum operating standard.

Other specific requirements may be placed on the allowable concentrations of atmospheric contaminants including gases and particulate matter and are expressed in the form of Time Weighted Averages (TWA) and Short Term Exposure Limits (STEL) as described by the National Occupational Health and Safety Commission in the Standard produced by Worksafe Australia.

It is also usual for legislation to place allowable concentrations of gases and particulate matter from diesel engines, although not purely a ventilation problem but rather a mechanical maintenance procedure, however the results of these gases and particulates in the mine atmosphere must be considered and allowed for during planning.

A review of the legislation applicable to your mine site is the first step to be taken in your determinations for total mine airflow sadly it is sometimes used as the only criteria for primary mine airflow determination.

Sources of heat in mines can be categorised as either natural (eg rock temperatures, ambient air temperatures and humidity, autocompression) or artificial (eg diesel and electrical powered equipment) and need to be considered at the early stages of any project as the proportions of each component will vary greatly the total mine heat load.

For example a mine in Australia which required refrigeration found the heat sources to come from three primary sources, autocompression which contributed 42% of the total mine heat load, diesel engines contributed 29%, rock surfaces which contributed 21% and miscellaneous sources such as electrical equipment and surface temperatures and humidity contributed the remaining 8% of a total heat load approaching 7000kW.

Heat load and exhaust emissions from mining equipment and in particular mobile diesel powered equipment has a considerable influence on total airflow requirement for a mine. However equipment size (physical dimension) is a major considerations in mine design layout, as it will help determine the physical dimensions of access and haulage routes which turn affects the air velocities and thus residence times of contaminants in the mine.

Although the mining method employed in one mine may be a similar method as to that employed in other mine, ventilation requirements cannot be simply extrapolated as many geological and geotechnical variables will determine differing mine layouts and scheduling. For these reasons ventilation control requirements may be considerably different based upon the number of production, development and servicing areas open and/or operating at any point in time and it is the flexibility of ventilation circuits and controls which will eventually determine to effective ventilation and total airflow requirement.

The importance of effective ventilation has long been recognised however it is the failure to recognise the need to include ventilation planning and scheduling as an integral part of the mine production and development schedules that mine ventilation engineers are continuously searching for quick solutions to problems which occur as a result of changes in schedules, technology, legislation or philosophy of mine owners/operators which have occurred since the original mine ventilation system and circuits were established.

Many problems occur as a result of contamination of intake air and the use of series ventilation circuits rather than single pass ventilation circuits. Servicing facilities such as workshops, diesel fuel supply areas, pumping stations, rockbreaking and crushing equipment are more than often located at or near shafts or main decline access for many obvious reasons usually related to convenience and economics. The location and contaminant control measures for these areas should be seriously considered when designing ventilation circuits as although it is accepted practice to ventilate these areas with primary air and in series with other operational areas the potential is to produce high levels of contaminants eg dust, welding/cutting fumes, and products of combustion should a fire occur in any one of these areas.

Failure to consider the cost both present and future for the supply of electricity until final plans have been developed and approved can significantly affect the final project costs. Time spent reducing the actual cost of securing power, reducing mine resistance and optimising the utilisation of available mine air is far more beneficial than attempting to purchase the most energy efficient fan available from fan manufacturers. (Fan selection will be the subject of a future note.)

Finally a comprehensive review of existing ventilation circuits and equipment will complete the understanding of what is existing although at this point we are only addressing the total airflow requirement this information will be required for final system design. This review may also assist in the understanding of any existing problems and in some cases will identify solutions to existing problems other than increased airflow.

1. Fan

- Air flow
- Fan total pressure
- Input power
- Insitu spare capacity
- Mechanical condition
- Maintenance costs (preventative and breakdown)
- Available spares

2. Air circuit

- air utilised effectively
- air not utilised effectively
- Structural condition of ventilation controls
- Booster fan (condition and siting)
- Problem areas (type and frequency)

3. Primary Intake

- Physical dimensions
- Equipment in shaft
- Airflow in each section
- Pressure drop in each section

4. Primary exhaust

- Physical dimensions
- Equipment in shaft
- Airflow in each section
- Pressure drop in each section

top

What do we require?

What we have now and what we will have in the future will vary considerably with time and the purpose of ventilation planning and scheduling is to ensure the most effective use of the available mine air.

Having determined what we have we should be well on the way to determining what we require. The next process is to work with the designers and schedulers to allocate air flow and with consideration to predicted heat loads, gas emissions, legislation, OH&S and Industrial relations to allocate airflow requirements for;

1. Scheduled production areas

 - Equipment in use in each area
 - Dimensions and layout of access and loading routes

2. Scheduled development areas

 - Equipment in use in each area
 - Dimensions and layout of access and loading routes
 - Auxiliary ventilation system

3. Haulage routes

 - Equipment in use in each area
 - Dimensions and layout of access and haulage routes

4. Rockbreaking

5. Crushing

6. Loading stations

7. Hoisting

8. Servicing areas

 - Maintenance workshops
 - Electrical sub-stations
 - Pumping stations
 - General maintenance and construction work areas
 - Refrigeration plants

9. Storage and supply areas

 - Explosive
 - Diesel fuel
 - General consumables and stores

10. Lunch rooms and waiting areas

Circuit design is ultimately determined by the production schedule, the siting of dedicated ventilation airways will be determined by mining methods and production design layouts, and the determination of total mine airflow is only the first step toward a mine ventilation system and requires the most attention because it is at this point that the final and cost to the operation will be determined.

Ventilation planning and design is complicated and those who are responsible for ventilation and believe otherwise have the potential to cost their organisation a great deal of money.

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top

How do I get More air?

I can probably count on one hand the number of times someone has approached me with the information that the ventilation in their workplace has improved.

However, I couldn't count the number of times someone has approached me with the information"....the ventilation was OK yesterday but today it is terrible. How can we get more air to the job?" In each case they were correct because there had been a change to the quality of air. In fewer cases there had also been a change to the quantity of airflow.

For each and every situation there was a different problem and therefore a different solution. However, irrespective of their perception as to the degree of the problem, one thing was certain, there was a problem, and it needed to be rectified.

top

Things are never what they seem

I recall being telephoned one morning at approximately 2.00am to be told that a section of the mine had been smoked out since the firing at the end of the previous shift (11.00pm). In efforts to clear the smoke a couple of ventilation controls had been altered. This had not improved the situation, in fact"......even with the increased airflow it had become worse". A supervisor had reported smoke and a strange smell coming from a ladderway to an old worked out area. He suspected there may be a fire and had called out the FRES (Fire Rescue Emergency Service) team.

Arriving at the mine I checked the remote gas monitoring system for the area. I noted that the concentrations of Carbon Monoxide (CO) being reported were zero, and had been since a little after midnight. This did not unduly alarm me as the system in use at that time was a tube bundle system. The tube was possibly cut (this is one of the problems with tube bundle monitoring systems because you never know until you visually inspect the line). I then donned my compressed air breathing equipment, proceeded to the area of concern and re-established the ventilation controls. I have always considered this to be good practice as it should establish the design circuits. I knew what the ventilation design flows should be and therefore could help me to predict what areas should be affected by smoke. This would help me to direct FRES members to the suspect area with a greater degree of confidence.

In this type of situation I am always interested in the concentrations of CO, and after testing the atmosphere I was confused when my tests showed zero concentrations of CO. Moving to a position near the ladderway where I felt the concentrations should be greater, I tested again with the same results, zero.

While this testing was being carried out the affected area had very quickly cleared.

Investigations of the old workings revealed that the area was being hydraulically sandfilled, and the design ventilation flow was very low. This combined with high temperatures had produced a mist of water. When the ventilation controls were altered to increase the ventilation flow, and hopefully clear the blasting fumes, it had also increased the flow through the old workings. This caused the water mist to flow out giving the impression of smoke. The smell associated with the mist was the normal smell associated with hydraulic fill, and was not recognised at the time by the supervisor who had reported the "smoke".

top

more

ventilation

...continued...
Ventilation - How do I get more air?

The Problems

"*The problem of Quality Management is not what people don't know about it. The problem is what they think they do know*"
-Philip Crosby

Of all the ventilation problems I have encountered the vast majority have been caused by higher than acceptable concentrations of smoke, dust and heat. Very few could be attributed to lack of available air. Those which fell into this category were most often caused by changes to design ventilation circuits either intentionally or unintentionally, and leaking ducts in development headings.

Smoke reported during the shift is generally from poorly tuned and/or maintained diesel engines. Dust is almost always from handling of dry broken rock, seldom from drilling operations. Increases in temperature are due to change in ambient surface conditions or ventilation flows being reduced (changes due to rock temperatures should be well recognised long before they cause problems). Identification of the source of the contaminant provides the opportunity to control the problem at this point. However solutions of this type are more often than not met with resistance from production and maintenance personnel. Most cases are resolved by a compromise between removing the source and increasing the airflow.

In those situations where the source cannot be successfully controlled, for whatever reason, then rescheduling of activities may remove the symptoms and allow work to continue.

As it is generally considered by production and maintenance personnel that all ventilation problems in mines are due to insufficient airflow to the workplace, then their only solution is to increase the airflow. In most instances, observations of contaminant problems are subjective and based upon comfort levels or disruption to production. Nevertheless they are very real and need to be dealt with.

Initial reaction to these problems is "lets turn up the surface fans" or "lets put in another fan" or "lets knock down a wall or open a door". It is usually never considered to close a door or turn off a fan, and very seldom with any recognition as to the consequences of these temporary solutions. In some instances these temporary solutions must be put in place to ensure continuity of production. However, we should always attempt to identify the source of the problem to enable the opportunity for a permanent solution to be put in place.

Some identified sources of ventilation problems in mines are:

- Lack of maintenance to ventilation equipment and controls
- Lack of ventilation controls
- Excess number of controls
- Rock stacked in return airways
- Poor location of secondary fans (circuit or development) causing recirculation or reuse of air
- Leaking ducting to development headings
- Short circuiting of air through ore passes, stopes and

damaged ventilation controls

- Low velocities in workshops, crushers and loading stations

- Poor tuning and maintenance of diesel engines

- Lack of dust control measures when loading and transporting broken dirt

- Poor design of dust and fume extraction systems

- Poor design and schedule of ventilation circuits

Increasing airflow to the workplaces is a very expensive exercise and design for increasing ventilation systems must be based on sound engineering principles.

Methods for increasing airflow to sections (and whole) of mine may be achieved by;

- alteration to ventilation controls (this also has the effect of reducing airflow to other parts of the mine and therefore must be carefully designed and scheduled)

- the lowering of mine resistance which subsequently moves the operation of the fan to a point which requires less pressure and therefore increased airflow, and

- the use of fans

The most widely used method for increasing airflow is to do it with fans either by the installation of another fan or by alteration to the existing fan.

Fans used in mines are:

- Primary

- Circuit (sectional ventilation)

- Development heading, and

- Special application eg dust extraction, man cooler, etc.

In all cases additional fans may be installed in either series or parallel.

One of the most common request for more air will come from development miners because "there is no air being delivered to the face". In many instances they have previously, and mistakenly, resolved this problem by reducing the delivery area of the duct. This then increased the velocity and, because they felt cooler, believed they had increased the amount of air delivered.

The recommended first step toward solving this type of problem is to determine why the air is not being delivered.

- Inspect the ventilation ducting to ensure that there is no leakage from holes in the ducting. This should also include those areas not clearly visible. In many cases when using flexible ducting the constant rubbing of the flex against such items as rockbolts may have caused large holes and therefore high leakage rates.

- Inspect the ducting material. Some materials have been found to leak through the weave and although most suppliers are aware of this problem it still remains a possibility.

- Inspect the material seams for leakage. Some manufactures still use machine stitching methods rather than welded seams. Depending on material type, and the stitching practice used, this is still a potential area for leakage. It also provides a point that may assist tearing of the material.

- Inspect the method used to join the lengths of ducting. The potential for leakage at this point is very high and other than a hole in the material it is the area of highest leakage.

- Inspect the fan inlet to ensure it is not obstructed and therefore affecting the fan performance.

- Inspect the impeller to ensure it is correctly mounted on the shaft, it is clean and all blades are intact and set at the correct pitch angle.

- Check the fan speed to ensure it is running at design speed

- Check direction of rotation (centrifugal fans will continue to deliver air when running backwards; a common occurrence because the motor is incorrectly wired)

- Inspect the mechanical operation of the fan to ensure bearings are running freely, and finally

- Inspect the fan to ensure it is operating at design pressure and quantity.

The effect of one or more of the above has the potential to significantly decrease the quantity of air delivered to the end of the duct.

In recognition of duct leakage it is now usual to allow for a leakage when selecting a fan for a development heading. To help with this process, software has been developed to determine leakage factors.

Solution - Fans for increased airflow

Figure 1 shows the effect of installing like fans in series. For this example, the system characteristic has been calculated, given the following duct dimensions:

- diameter 1200 mm
- length 450 m
- k factor 0.004 Ns2/m4

which can be found in a typical development heading in many underground mines.

The fan shown would typically be fitted with a 55 kW electric motor.

Assuming no leakage adding a like fan in series would have the effect of increasing the airflow from 21.0 m3/s to a little over 26.2 m3/s or 23%. However the most significant increase is in the power that would jump from approximately 54 kW to 104 kW ie 93%.

Despite the obvious costs of this method for increasing pressure and the subsequent increase in airflow continues to be used.

The leakage factor component is some times improved when considering the installation of another fan in series. When installed, the airflow actually delivered to the end of the duct is found to be less that which was calculated or expected and in some cases there has been no increase in flow.

The use of fans in series in any application needs to be fully investigated. The consequences need to be fully understood as this method has the potential to increase costs significantly for little increase in airflow . It is, however, a very necessary procedure for maintaining airflow with an increasing system resistance and the subsequent increasing pressure requirement.

There are many operational restrictions that need to be considered when making decisions to install a fan in series. Although a parallel system (ie another similar fan and duct line) would increase the airflow from 21.0 m3/s to 42.0 m3/s ie 100%, it is very seldom used.

Parallel systems and fans in parallel should not be confused.

figure 2 shows the original fan and system and the combined characteristic of a second fan in parallel. In this case the system would be very unstable and the fan(s) would be operating in their stall zone. Therefore in this particular case the only possible means to increase airflow would be another fan in series or another parallel fan and duct system.

Any consideration for the operation of primary fans in parallel must include the determination of the existing mine system resistance. I have seen many mining operations consider the insitu spare fan to be insitu extra capacity. They then find that any attempt to turn this fan on or increase the speed causes the system to operate in the stall zone.

top

The Solution-Lowering Resistance for Increased Airflow

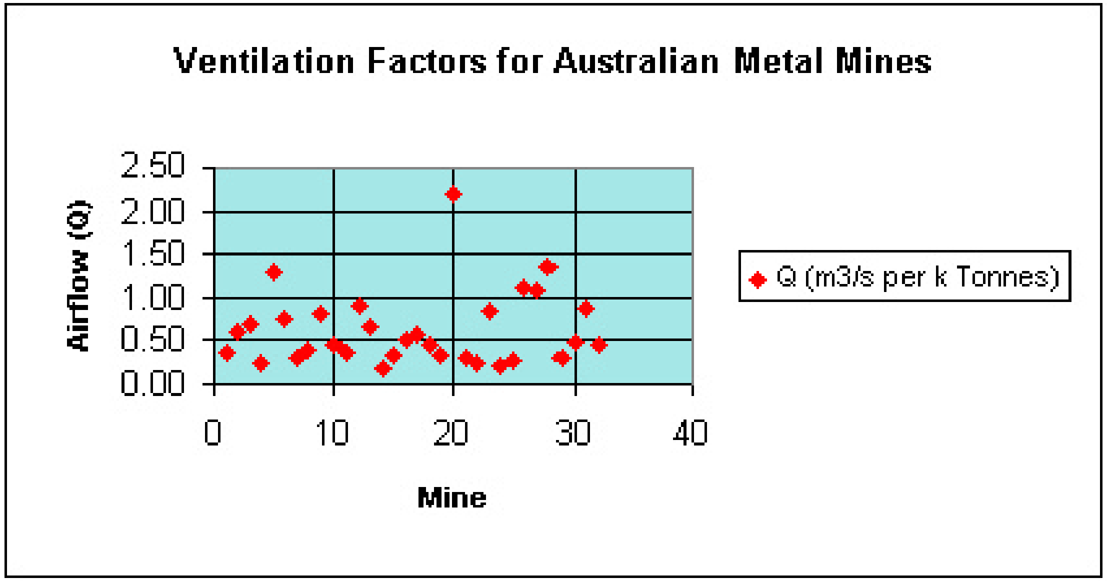
Figure 3 shows the result of increasing the duct diameter from 1.220m to 1.550m. This would effectively reduce the total system resistance from 4.6908 Ns2/m8 to 1.300 Ns2/m8. This decrease in resistance would cause the system operating point to change from 21.0 m3/s to 30.0 m3/s for the single fan. This would also allow for the installation of another fan in parallel and the subsequent increase in airflow to 40.0 m3/s which is comparable to the parallel system. Only the cost of the ducting and operational restrictions would determine the cost effectiveness of this method for increasing airflow.

This method for reducing resistance in development ducting is seldom used because the larger duct diameter required generally restricts the use of mining equipment by lowering the back height. It is used more readily for primary ventilation where the power cost is much higher.

Resistance reduction must not be overlooked when attempting to increase airflow to sections of a mine. The simple removal of obstructions in airways will have the same affect as the opening of a regulator with the result depending upon the size of the obstruction . In many instances where low pressure circuit fans are installed, the same airflow could be achieved by enlarging the airway. This removes the costs associated with the need for extra power, purchase and maintenance for the fan. Mine production objectives are usually placed above non-productive activities including ventilation and as a consequence most decisions of this type are based upon convenience of operation rather than cost.

With the current philosophies of continuous improvement and goals for achievement of international best practice mine operators need to become more aware of the cost to production for increased ventilation. This will happen once it is accepted that ventilation problems in mines are usually symptoms of a different problem, and although increasing the airflow may help the relieve the symptoms, it seldom removes the problem.

top



Airflow	m^3/s per 1000 tonnes mined
Average	1.74
Median	0.45
High	2.20
Low	0.19

Back

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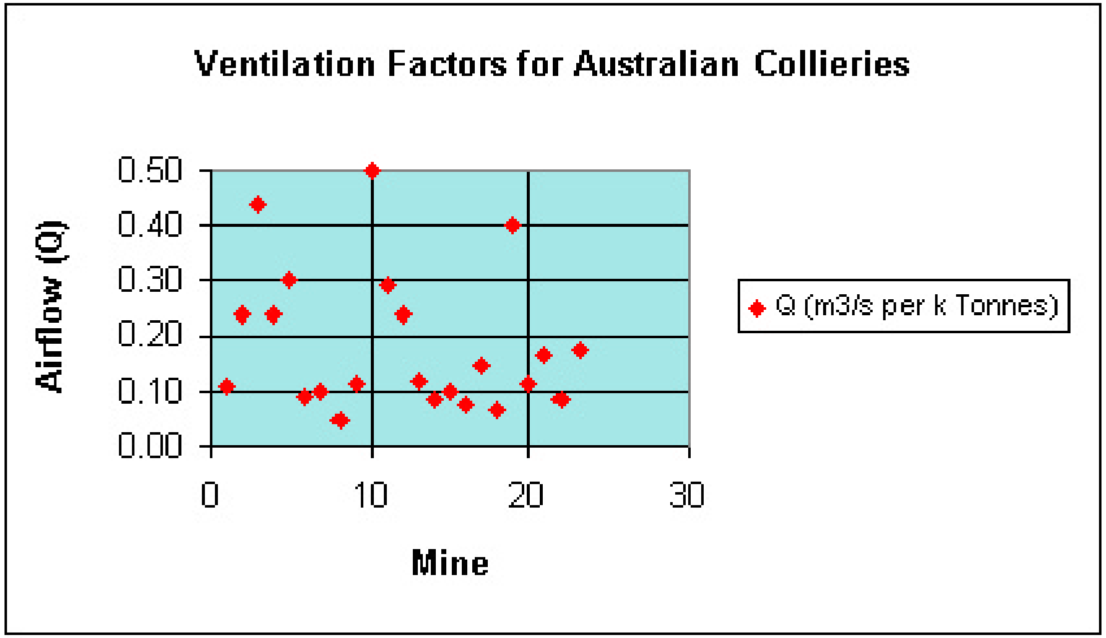
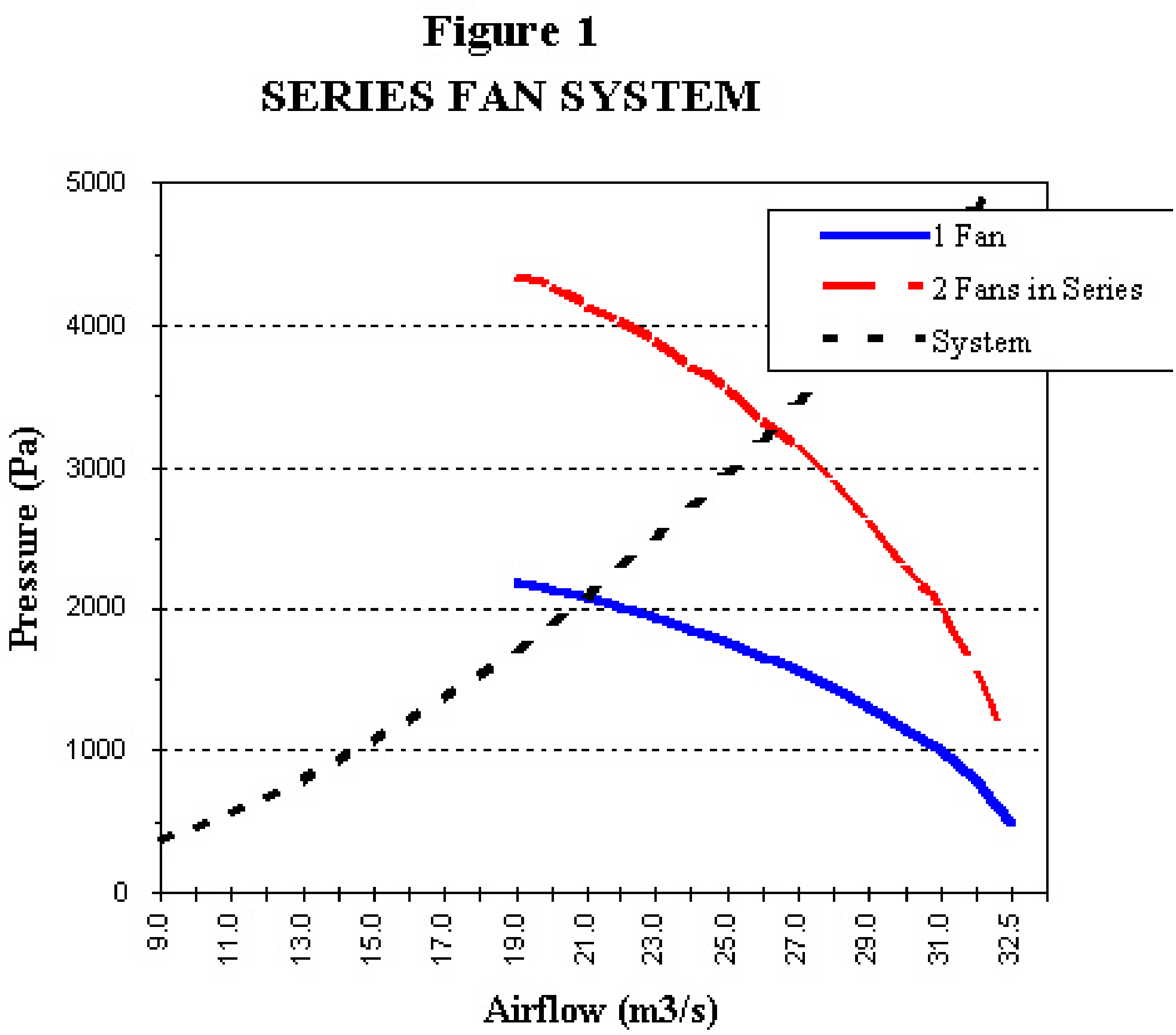
By LJ Stevens



Airflow	m^3/s per 1000 tonnes mined
Average	0.19
Median	0.12
High	0.50
Low	0.05

Back



Back

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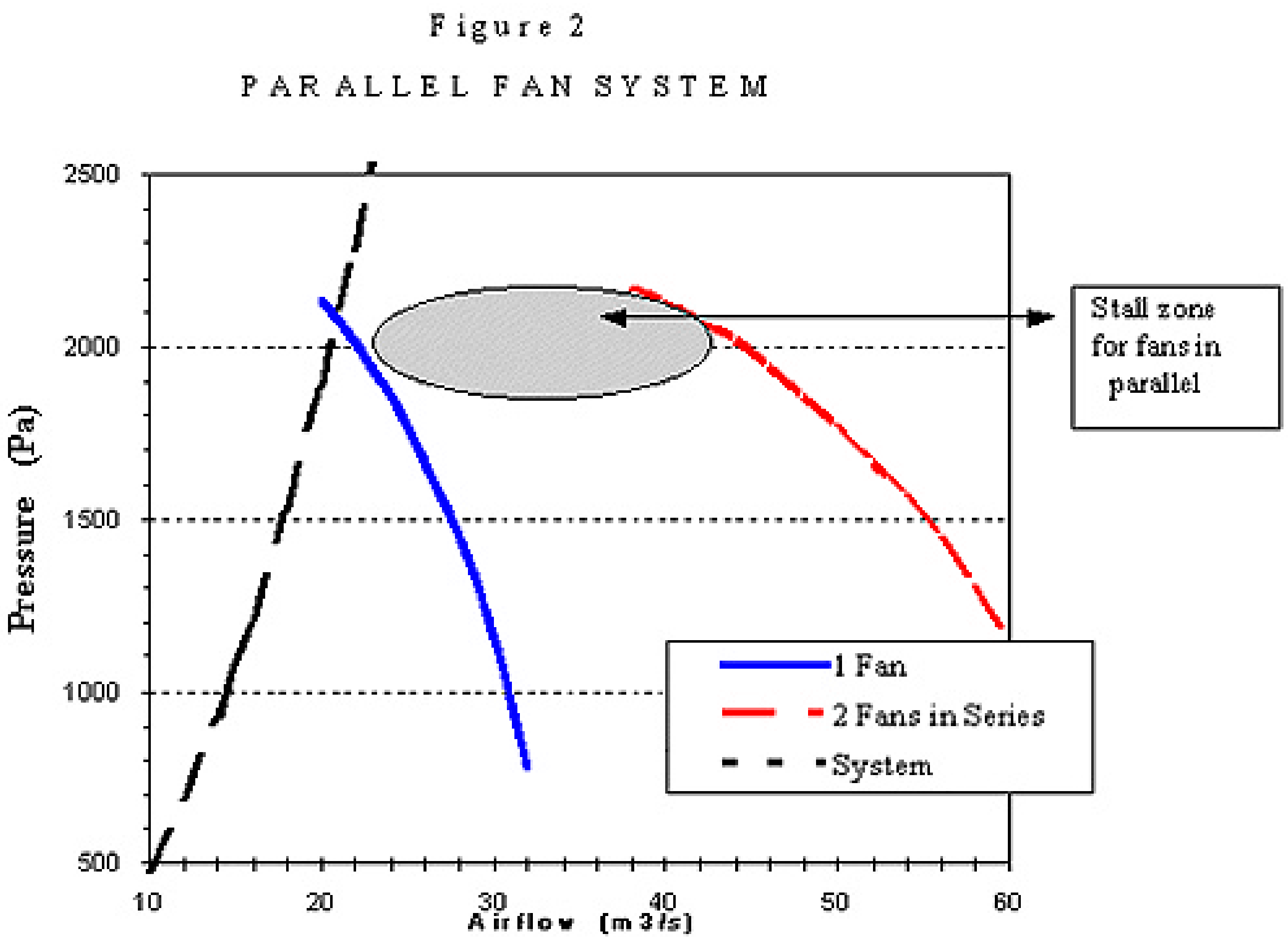

Back

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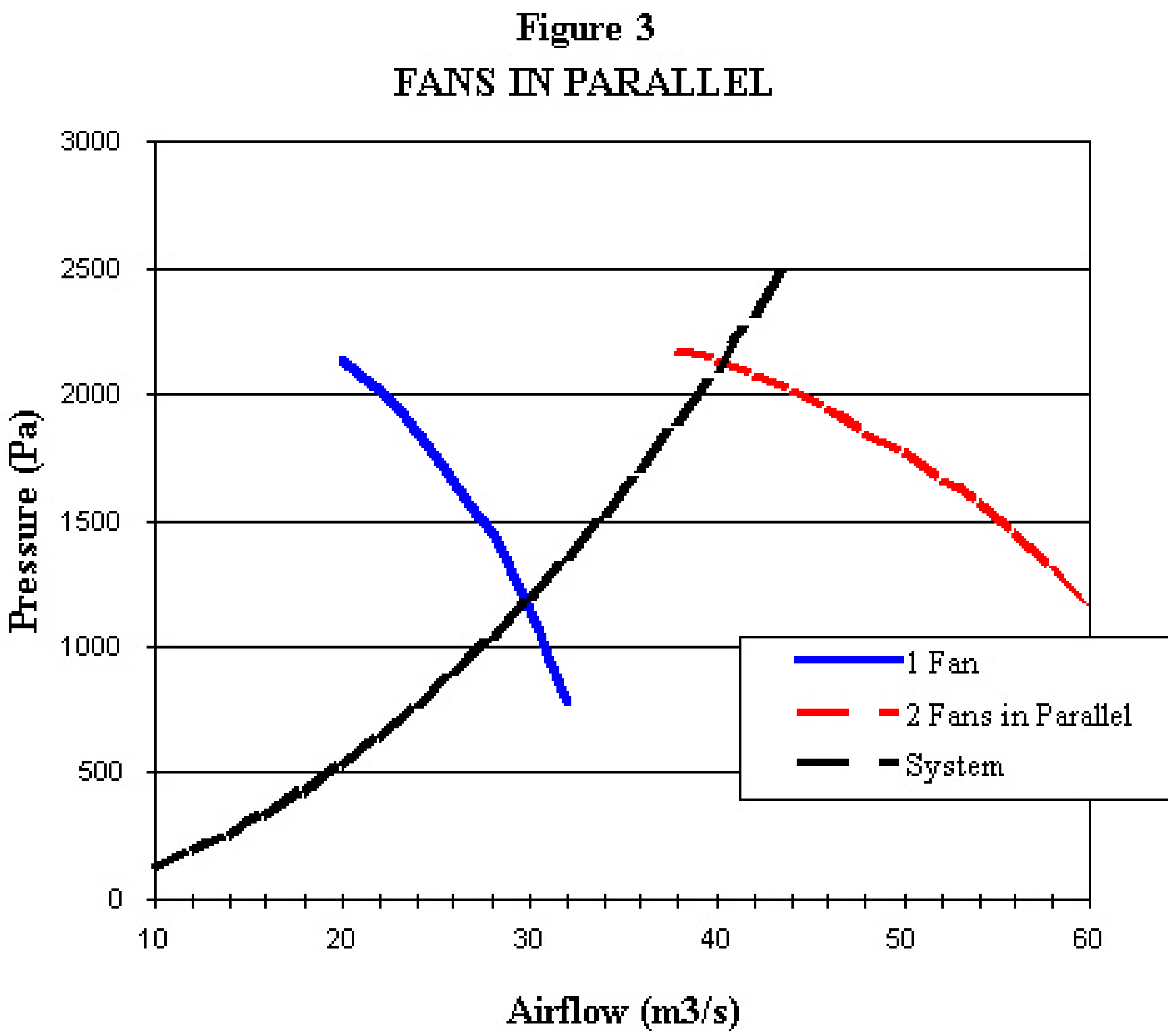

Back

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