AUSTRALIAN MINE EMERGENCY EXERCISES AIDED BY FIRE SIMULATION

By

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ABSTRACT

The structure of a comprehensive research project into mine fires study applying the Ventgraph mine fire simulation software, preplanning of escape scenarios and general interaction with rescue responses is outlined. Some outcomes from a project funded by the Australian Coal Association Research Program and substantial mining company site support are described. Mine site testing has allowed the approach to be introduced in the most creditable way. The project has assisted the Australian coal mining industry to attain an improved position in their understanding of mine fires and the use of modern advances to preplan actions to be taken in the advent of mine fires and possible emergency incidents. Work undertaken at individual mines is discussed as examples. Most Australian mines of reasonable size currently use a ventilation network simulation program. Under the project a small subroutine has been written to transfer the input data from the existing mine ventilation network simulation program to Ventgraph. This has been tested successfully. To understand fire simulation behaviour the mine ventilation system must first be understood correctly. The simulation of safe escape scenarios as part of emergency evacuation is described. Approaches to improving the ability of all levels of the mine workforce to evacuate mine workings in the safest way are examined, developed through pre-learning of appropriate escape strategies. The effect of use of a GAG inertisation unit to smother a fire after personnel have been withdrawn is examined.

Work undertaken with appropriate bodies during preplanning and subsequently during the course of a mine rescue and recovery emergency exercise is discussed. Some comments have been made on the ventilation aspects of the emergency exercise from observations made during the course of the incident. Some of these are set down as observations and some were personal comments from participating individuals. A key aspect of the software is the ability to model fires in a mine and the consequent effects of control measures such as ventilation changes and the introduction of inertisation using the GAG engine. Management is provided with a pre-emptive tool that gives ability to have control measures such as emergency seals or doors in place, as well as a predictive tool for analysing actions prior to implementation in the event of a fire.

INTRODUCTION

Mine fires remain among the most serious hazards in underground mining. The threat fire presents depends upon the nature and amount of flammable material, the ventilation system arrangement, the duration of the fire, the extent of the spread of combustion products, the ignition location and, very importantly, the time of occurrence. The response to the fire by mining personnel will depend upon all of these factors.

There is a lack of knowledge about fire/heat dynamics, some unproven technology in the field of

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gas sensors and no general agreement on appropriate alarm response systems and measures to be taken in the event of a significant incident. There is a need to couple the detection system with the response system. A research project and a number of mine site exercises has been undertaken focused on the application of mine fire and ventilation software packages for contaminate tracing and fire modelling in coal mines and validation of fire modelling software against real mine incidents to reduce the effects of fire incidents and possible consequent health and safety hazards.

With the increasing complexity of technological and managerial development of mines, the effects of mine fires must be better understood. Task Group No 4 Report arising out of the Moura No 2 coalmine disaster of August 1994 in Australia made a number of recommendations including that,
"*the capability to model ventilation and the mine environment following an incident should be available at mines*".

Following these recommendations, sub-committees were formed in 1997 to further progress various findings with Sub-Committee 5 – Incident Management given certain tasks including the question,
"*that there is a need for a wider appreciation of current knowledge and improved capability of ventilation management at mines for both routine as well as emergency conditions; guidelines for modelling should include……..*

- *Computer modelling of post incident mine ventilation and atmosphere to be a required element in mine safety management plans,*
- *Models interface with standard mine planning packages and be kept up-to-date, and*
- *Development of learned ventilation and fire control responses occur for different incident scenarios and locations, pre-determined for each mine and with plans prepared and personnel trained in appropriate action plans".*

A primary objective of the study has been to implement a program of research into this complex area utilizing the recently upgraded Polish mine fire simulation software, Ventgraph. There is a need to understand the theory behind the simulation program and to allow use by those already familiar with the main existing mine ventilation analysis computer program currently popular within the Australian industry, "Ventsim", as an aid to incident and emergency management. "Ventsim" was not designed to handle fire simulation or in fact compressible flow effects in mine networks.

When a fire occurs outbye the working section, the immediate safe evacuation of miners from these areas should always be the first action during the rescue operation. Usually, the intake entries are dedicated as the primary escapeways from the working section. In many cases, the dedicated escapeways are contaminated with fire by-products from abutting entries (eg, belt entry) due to interconnection or leakage through stoppings. It is important to keep these escapeways unobstructed and free from contamination.

It is difficult to predict the pressure imbalance and leakage created by a mine fire due to the complex interrelationships between the mine ventilation system and a mine fire situation. Depending on the rate and direction of dip of the entries (dip or rise), reversal or recirculation of the airflow could occur because of convection currents (buoyancy effect) and constrictions (throttling effect) caused by the fire. This reversal jeopardizes the functioning of the ventilation system. Stability of the ventilation system is critical for maintaining escapeways free from contamination and therefore available for travel.

Simulation software has the great advantage that underground mine fire scenarios can be analysed and visualized. Details of the Ventgraph program have been described by Trutwin, Dziurzynski and Tracz (1992). The software provides a dynamic representation of the fire's progress (in real-time) and utilizes a colour-graphic visualization of the spread of combustion products, O_2 and

temperature throughout the ventilation system. During the simulation session the user can interact with the ventilation system (eg, hang brattice or check curtains, breach stoppings, introduce inert gases such as those generated by a GAG unit and change fan characteristics). These changes can be simulated quickly allowing for the testing of various fire-control and suppression strategies. Validation studies on Ventgraph have been performed using data gathered from a real mine fire as undertaken by Wala, et al (1995).

A major part of the paper examines a comprehensive emergency training exercise held at an operating colliery incorporating a fire incident. The Ventgraph simulation software was used to model the fire and mine conditions as various mitigation strategies were assessed. A number of viable and non viable alternatives were examined to achieve rescue. This incident and its outcome are examined. Some comments have been made on the ventilation aspects of the emergency exercise from observations made during the course of the incident. Some of these are set down as observations and some were personal comments from participating individuals.

The main purpose of this paper is to examine the effects of fires on mine ventilation systems using numerical fire simulation software such as Ventgraph. Various case studies based on the modelling of fire scenarios in a number of different mine layouts are discussed.

EFFECTS OF FIRES ON MINE VENTILATION

An open fire causes a sharp increase in the temperature of the air. The resulting expansion of the air produces a number of distinct effects. First the expansion attempts to take place in both directions along the airway. The tendency to expand against the prevailing direction produces a reduction in the airflow. Secondly, the expansion in volume increases air velocity downwind from the fire causing additional pressure loss This is known as the choke or throttle effect. Finally, the decreased density results in the heated air becoming more buoyant and causes local effects as well as changes in the magnitudes of natural ventilating energy.

The Choke or Throttling Effect

This effect results from an increase in volume of air as it passes through the fire. This increase in volume is due to gas expansion as well as the addition of combustion products such as fire gases and evaporated water. As a result the velocity of air downwind from the fire is increasing and additional pressure loss following the square law results.

The choke effect is analogous to increasing the resistance of the airway. For the purposes of ventilation network analyses based on a standard value of air density, the raised value of this “pseudo resistance”, R_t, can be estimated in terms of the air temperature as followed (McPherson,1993).

$$R_t \propto T^2$$

The value of R_t, increases with the square of the absolute temperature (T). However, it should be recalled that this somewhat artificial device is required only to represent the choke effect in an incompressible flow analysis.

Buoyancy (Natural Draft) Effects

Local or Roll Back effect

The most immediate effect of heat on the ventilating air stream is a very local one. The reduced density causes the mixture of hot air and products of combustion to rise and flow preferentially along the roof of the airway. The pronounced buoyancy effect causes smoke and hot gases to form

a layer along the roof and, in a level or descentional airway, will back up against the direction of airflow.

Whole mine Natural Ventilation Pressure effects

A more widespread effect of reductions in air density is the influence felt in shafts or inclined airways. The conversion of heat into mechanical energy in the ventilation system is called the buoyancy (natural draft, natural ventilating pressure or chimney) effect. The effect is most pronounced when the fire itself is in a shaft or inclined airway and promoting airflow if the ventilation is ascentional and opposing the flow in descentional airways. In addition, in the latter case, flows can reverse in all parallel airways to the airway with fire. Indeed, in this case, the airflow may be reversed in the airway with fire, bringing combustion products into adjacent parallel airways and also resulting in non-steady state flow of toxic atmospheres.

Natural ventilating pressure always exist in a mine and its magnitude mostly depends on the mine's depth and difference in air density in the inclined and horizontal airways. In the case of fire, this effect is magnified due to high temperatures leading to unpredictable changes in air density and the airflow distribution.

If the air temperatures can be estimated for paths downstream of the fire then it is possible to determine the modified natural ventilating pressures. Those temperatures vary with respect to size and intensity of the fire, distance from the fire, time, leakage of cool air into the airways affected and heat transfer characteristics between the air and the surrounding strata.

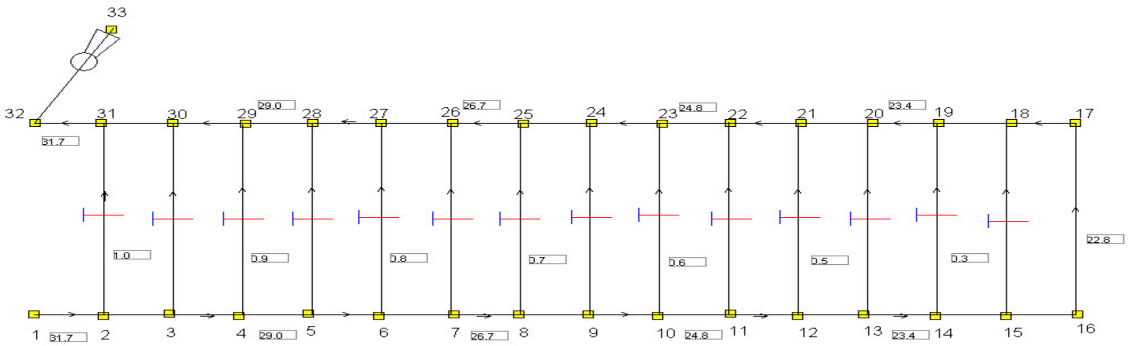
CASE STUDIES OF AUSTRALIAN LONGWALL DEVELOPMENT PANELS

One of the major goals of the study is to examine the effects of fires on mine ventilation systems. To demonstrate how the choke or throttling and buoyancy effects influence the mine ventilation system, a number of fire scenarios were simulated as described by Gillies, Wala and Wu, 2004.

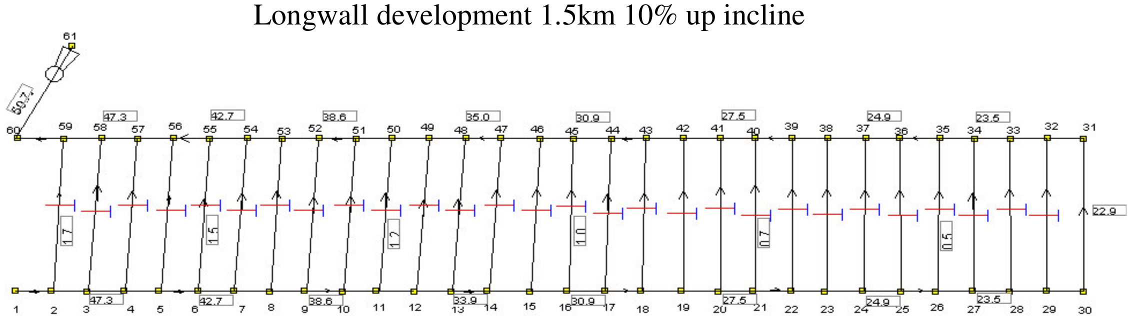
Several case studies have been examined based on a typical Australian two entries longwall development panel with various panel configurations. Panel configurations varied in the case studies covered panel lengths of 1.5 km or 3 km with panel dipping angles of plus and minus 5 degrees and 10 degrees. To generate an uniform ventilation airflow of 22.8 m^3/s through the panel at the working face, a differential pressure equal to 70 Pa was introduced across the stopping at the first cut-through between intake and return entries for the 1.5 km panel length cases studied and a differential pressure of 235 Pa was used for the 3 km panel cases studied.

Figure 1 shows typical two–entry longwall development panel ventilation systems with various panel lengths of 1.5 and 3 km. The fresh air reaches the face though one intake entry and exhausts from the face through the other, which is the belt entry and return. The fresh air intake entry is isolated from the return entry by a series of short life stoppings.

Table 1 shows a summary of the simulation results with diesel fires set in the middle of the development panel for each case study at either intake or return airways. The fire has a 5m fire zone length, a fire intensity of 10 and a time constant 120 seconds. There were two cases under which that the face airflow almost reversed. One is observed when the diesel fire is set in the middle of the return airway at nodal points 24-25 in the 1.5 km longwall development panel mining on a 10% incline upward.



Longwall development 1.5km 10% up incline



Longwall development 3.0km 10% up incline

Figure 1. Two-Entry Longwall Development Panels.

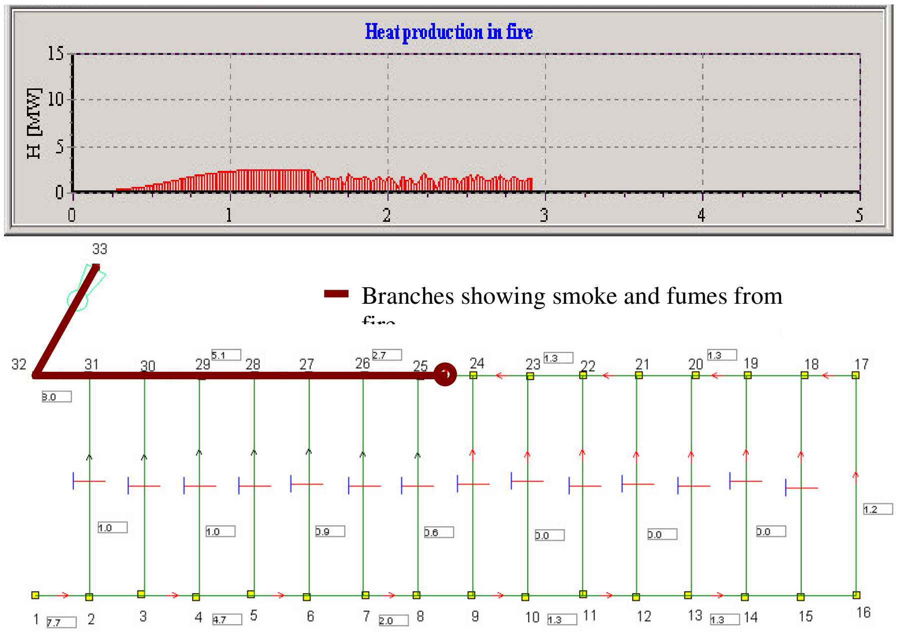
Table 1. Summary of simulation results for 5m-fire zone.

Panel Length	Panel Inclination		Face Q m^3/s		Air Reversal
			Initial	Final	
Fire at return airways (branch 24-25 or 45-46)					
1.5km	5%	Up	22.8	16.1	No
1.5km	5%	Down	22.8	25.7	No
1.5km	10%	Up	22.8	1.3	Almost
1.5km	10%	Down	22.8	30.2	No
3.0km	5%	Up	22.8	21.3	No
3.0km	5%	Down	22.8	24.4	No
3.0km	10%	Up	22.8	20.1	No
3.0km	10%	Down	22.8	24.5	No
Fire at intake airways (branch 8-9 or 14-15)					
1.5km	5%	Up	22.8	26.7	No
1.5km	5%	Down	22.8	16.2	No
1.5km	10%	Up	22.8	29.3	No
1.5km	10%	Down	22.8	1-1.3	Almost
3.0km	5%	Up	22.8	24.3	No
3.0km	5%	Down	22.8	21.4	No
3.0km	10%	Up	22.8	25.7	No
3.0km	10%	Down	22.8	19.4	No

In this case the buoyancy effect of the fire acted against the fan pressure but was not enough to overtake the fan pressure to reverse the airflow. As the airflow reduced, the O_2 supplied to the fire is decreased. This caused a significant reduction in the magnitude of the fire and thus the buoyancy effect of the fire working against the fan pressure is reduced. There is more air available to the fire so the fire starts to grow again (non-steady state).

This can be observed in the fire simulation output graphic and is illustrated in Figure 2 showing

the heat production of the fire during simulation. It can be noted from the figure that the fire causes a sharp reduction in the airflow entering the development panel. In the case of a mine with high seam CH_4 levels this will lead to higher gas levels in the mine air.



Longwall development 1.5km 10% up incline

Figure 2. Smoke progressions and heat production for 5 m long fire zone in return roadway.

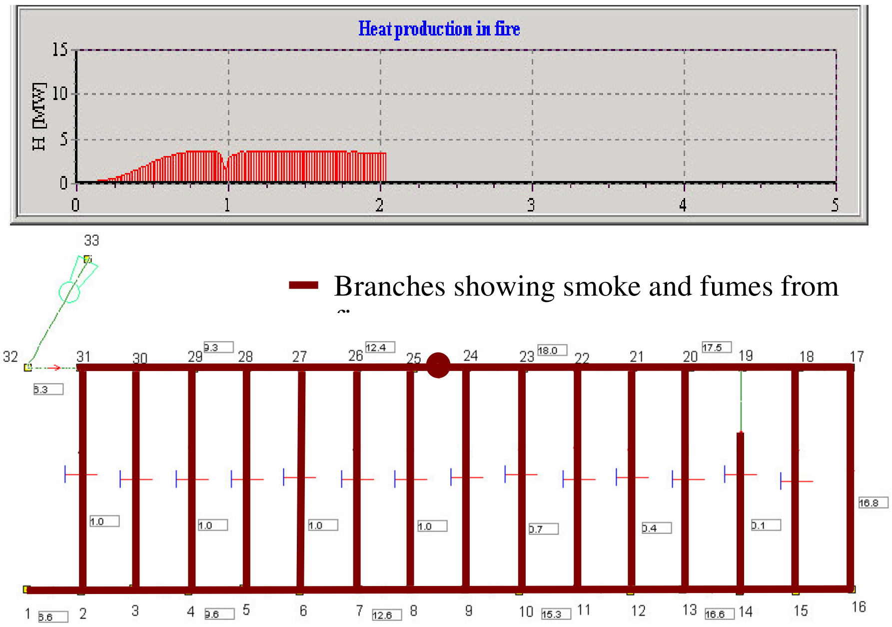
A similar situation was observed in the second case of reversal almost occurring when the fire was in the intake airway at nodal points 8-9 in the 1.5 km longwall development panel mining at a 10% decline down. Again, the buoyancy effect of the fire acted against the fan pressure was not enough to overtaken the fan pressure to reverse the airflow. The airflow at the faces in both cases was drastically reduced to approx. 1-1.3 m^3/s.

Table 2. Summary of simulation results for 10m-fire zone.

Panel Length	Panel Inclination		Face Q m^3/s Initial	Face Q m^3/s Final	Air Reversal
Fire at return airways (branch 24-25 or 45-46)					
1.5km	5%	Up	22.8	4.1	No
1.5km	5%	Down	22.8	29.0	No
1.5km	10%	Up	22.8	16.8*	Yes
1.5km	10%	Down	22.8	33.4	No
3.0km	5%	Up	22.8	20.9	No
3.0km	5%	Down	22.8	24.6	No
3.0km	10%	Up	22.8	18.4	No
3.0km	10%	Down	22.8	26.2	No
Fire at intake airways (branch 8-9 or 14-15)					
1.5km	5%	Up	22.8	28.1	No
1.5km	5%	Down	22.8	3.5	No
1.5km	10%	Up	22.8	36.6	No
1.5km	10%	Down	22.8	1.5-4.5*	Yes
3.0km	5%	Up	22.8	24.9	No
3.0km	5%	Down	22.8	20.6	No
3.0km	10%	Up	22.8	27.4	No
3.0km	10%	Down	22.8	16.0	No

** Air flows in opposite direction to initial flow direction.*

Simulations were re-run for these cases with a 10m fire zone length instead of 5m and a summary of results is shown in Table 2. Airflow reversals at the face were observed in the 10% incline case with fire in return airway and also with 10% decline with fire in the intake air. Figure 3 shows how the smoke progresses and the amount of heat produced during different stages of the fire simulated in the 10% incline case with fire in return air.



Longwall development 1.5km 10% up incline

Figure 3. Smoke reversal and heat reduction observed during simulation for 10m long fire zone in return roadway.

It is noted that a reduction in heat production from the fire was observed before the airflow reversal occurred. As the products of fire are forced passed or over the fire at the moment when airflow reversal occurs, the amount of O_2 available to the fire is drastically decreased.

EFFECTS OF MINE FIRE IN GASSY MINES

Effects from mine fires on ventilation system in gassy mine situations were also investigated in this study. The development panel studies were used to demonstrate the effects of mine fires in gassy mines. All panel parameters remain the same as previously stated. A CH_4 source of 230 l/s was placed at the development face to given approximately 1% ($0.23m^3/s$ / $22.8m^3/s \approx 1\%$) CH_4 concentration in the return air in the development panel.

Table 3 shows a summary of the simulation results with diesel fires set in the middle of the development panel in either intake or return airways for each of the two case studies.

The fire has a 10m fire zone length, a fire intensity of 10 (on a scale of 1-10) and a time constant 120 seconds (time taken to build up to full size). There were two cases under which that the face airflow reversed as observed previously. It should also be noted that there were two cases (that of a 1.5km panel with 5% incline up with fire in return air and secondly a 1.5km panel with 5% decline down with fire in intake air) under which the face airflow was drastically reduced to less than 4.5 m^3/s due to the effects of buoyancy from the fire.

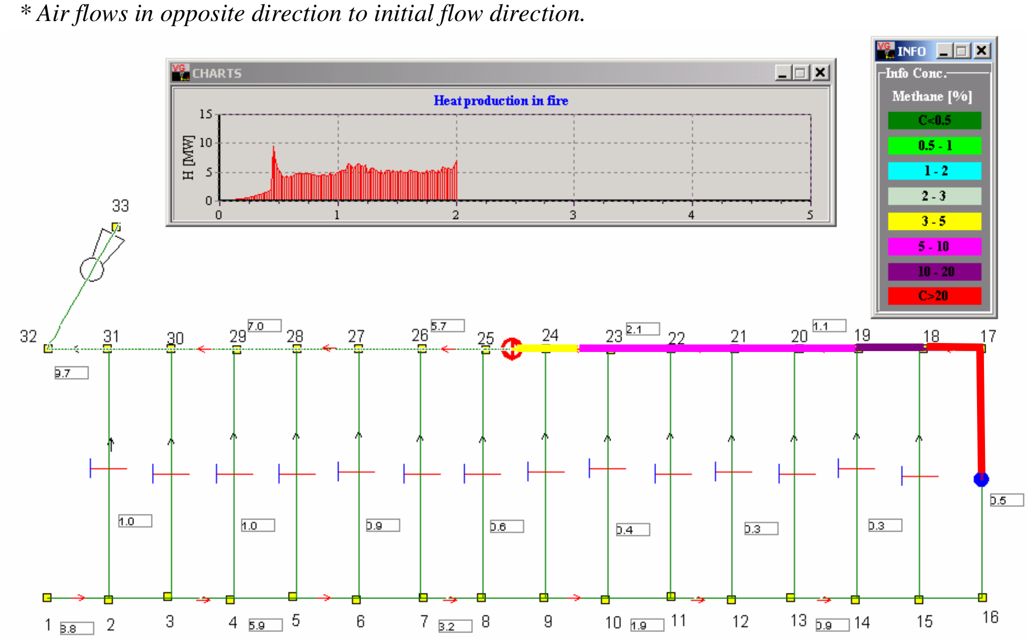
In these two cases, the CH_4 source at the face will cause gas concentration to increase from 1% to

over 5%, which means the mine atmosphere became explosible or potential explosible. It is a very dangerous situation as it is very easy to think that with no ventilation reversal resulting from the fire the ventilation system is still intact and safe. However, the reduction of fresh airs to the face in these gassy mine situations results in the mine atmosphere at the face becoming potentially explosible. The gas laden face air quickly passes to return and over the fire ignition source. Figure 4 shows the CH_4 levels at the face and the amount of heat produced during different stages of the fire simulated in the 1.5km panel length 5% incline up case with fire in return air.

Table 3. Summary of simulation results for 10m-fire zone in gassy mine situation.

Panel Length	Panel Inclination		Face Q m^3/s Initial	Face CH_4% Initial	Face Q m^3/s Final	Face CH_4% Final	Air Reversal
Fire in return airways (branch 24-25 or 45-46)							
1.5km	5%	Up	22.8	1.0	0.6	38.3%	No
1.5km	5%	Down	22.8	1.0	29.0	0.78%	No
1.5km	10%	Up	22.8	1.0	16.8*	1.34%	Yes
1.5km	10%	Down	22.8	1.0	33.4	0.67%	No
3.0km	5%	Up	22.8	1.0	20.9	1.08%	No
3.0km	5%	Down	22.8	1.0	24.6	0.91%	No
3.0km	10%	Up	22.8	1.0	18.4	1.22%	No
3.0km	10%	Down	22.8	1.0	26.2	0.86%	No
Fire in intake airways (branch 8-9 or 14-15)							
1.5km	5%	Up	22.8	1.0	28.1	0.80%	No
1.5km	5%	Down	22.8	1.0	1.5	15.3%	No
1.5km	10%	Up	22.8	1.0	36.6	0.61%	No
1.5km	10%	Down	22.8	1.0	1.5-4.5*	5-15%	Yes
3.0km	5%	Up	22.8	1.0	24.9	0.90%	No
3.0km	5%	Down	22.8	1.0	20.6	1.09%	No
3.0km	10%	Up	22.8	1.0	27.4	0.82%	No
3.0km	10%	Down	22.8	1.0	16.0	1.41%	No

** Air flows in opposite direction to initial flow direction.*



Longwall development 1.5km 10% up incline

Figure 4. CH_4 level and heat reduction observed for 10m long fire zone in return roadway.

LONGWALL VENTILATION CASE STUDIE

Typical Aspects of Australian Longwall Mining

A typical layout of an Australian longwall mine is shown in Figure 5. In terms of ventilation nomenclature intake roadways are shown as solid, single arrow roadways whereas return roadways are shown as dashed, double arrow roadways.

In this case a raise borehole exists behind the current goaf and is shown as a circle with an intake roadway connecting to the longwall face roadway (Mayes and Gillies, 2002). Australian longwalls at present normally use only two roadway maingate developments and have typically between five and seven Mains' roadways. In development, A Heading (as shown in Figure 6) is an intake roadway with B Heading the return roadway through which the panel conveyor runs.

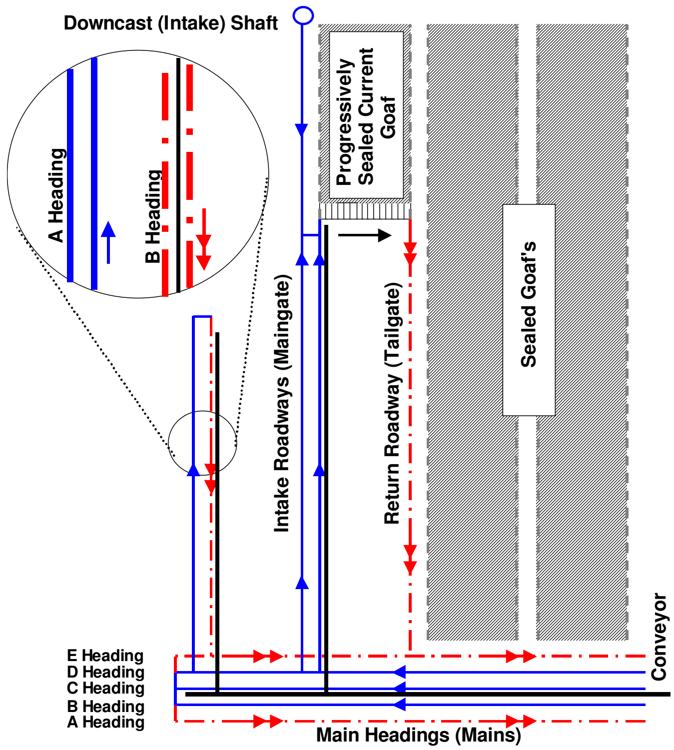


Figure 5. Typical Layout of Australian Longwall Mining (After Mayes and Gillies, 2002).

In the Mains, B, C, and D Headings are typically intake with flanking return roadways, A and E Headings. When all longwalls are being extracted on one side of the Mains only, D and E Headings may be used as return roadways with A, B and C Headings as intake roadways. The conveyor runs in the intake headings, typically in C Heading. In Queensland this roadway is generally segregated from either one or both of the other intake roadways.

Simulation of Inertisation Usage

Inertisation has been accepted to have an important place in Australian mining. The two GAG units purchased by the Queensland government in the late 1990s have been tested and developed and mines made ready for their use in emergency and training exercises. Various incidents in 2003 underlined the need for more information on their use and application. The NSW Mine Shield nitrogen apparatus dates to the 1980s and has been used a number of times. The Tomlinson boiler has been purchased by a number of mines and is regularly used as a routine production tool to reduce the time in which a newly sealed goaf has an atmosphere within the explosive range.

Pressure Swing Adsorption units are available and in use. Each of these approaches puts out very different flow rates of inert gases. Each is designed for a different application. Background information is needed to allow their use in pre-training and emergency risk management assessments exercises.

Because of complex interrelationships between the mine ventilation system and a mine fire it is difficult to predict the pressure imbalance and leakage created by a mine fire. Depending on the rate and direction of dip of incline of the entries (dip or rise), reversal or recirculation of the airflow could occur because of convection currents (buoyancy effects) and constrictions (throttling effects) caused by the fire. This reversal jeopardizes the functioning and stability of the ventilation system. Addition of the gas stream from the unit adds another level of complexity to the underground atmosphere behaviour. Should the main mine fans be turned off so as not to dilute the inert gas or will this action cause, in conjunction with buoyancy effects, airflow reversal and the drawing of combustion products or seam gases across a fire leading to an explosion?

Simulation of the introduction of the GAG or other apparatus has indicated that there is a substantial lack of knowledge on use of these facilities. The Queensland GAG unit was used successful in a mine fire incident in the Loveridge mine in the USA in early 2003. A fire in West Virginia in late 2003 attempted to use a Polish owned GAG unit without success. The Queensland GAG unit was called to the Southland, NSW mine fire at the end of 2003 but not utilised in full.

Simulations using Ventgraph were undertaken to gain better understanding of how inertisation units such as GAG interact with the complex ventilation behaviour underground during a substantial fire. Aspects worthy of examination include

- Location of the unit for high priority fire positions; eg portal docking position, special boreholes
- Time required for output to interact with and extinguish a fire.
- Effects of seam gas on fire behaviour with present.
- Changes which can be safely made to the ventilation system during including switching off some or all fans.
- Complications caused by underground booster fans.
- Spontaneous combustion issues

Operation of a unit requires preplanning in terms of infrastructure requirements for a surface portal docking station and access for operating personnel, jet fuel, water and other operating requirements, The following examples were undertaken simulating the effects of GAG usage.

Positioning of Inertisation Units

Studies were also carried out to examine usage of interisation tools and particularly application of the GAG jet engine. The best surface portal location placement for the GAG for most efficient suppression of a fire has been examined. Case studies of the typical Australian longwall examples in previous section were modified. The length of Mains was extended to 2 or 4km. A 1 m diameter borehole was connected to the back of longwall panel about 400m from the longwall panel.

Two GAG jet engine positions were investigated. The first position is at the portal B heading and the second position is at the top of the borehole located at the back of the longwall panel. A diesel fire with a 30m length of fire zone, a fire intensity of 10 and a time constant of 120 seconds is started 50m outby of the current longwall face was simulated.

Procedures to implement the GAG for both positions are as follows.

1. Start the simulation and let the fire run for 1 hour.

2. Start the GAG after 1 hour and close the emergency door at portal B Heading just outby the GAG.
3. Shut off the fan and close off the other two emergency doors located at C and D heading.
4. Let the GAG run till the heat production from fire is minimal and the fuel temperature is less than 250°C.

It was found that it made no difference for the second case study GAG position whether the emergency doors at the portal was closed or not.

When the length of the Mains is 2 km, the time it takes to have the GAG put the fire out was similar whether the GAG unit is at the Mains portal or at the top of longwall back borehole. However, when the length of the Mains is increased to 4 km, it was found that a GAG unit located at the back borehole has significant advantage in terms of time in reducing the fire to significantly reduced state (see Figures 6 and 7).

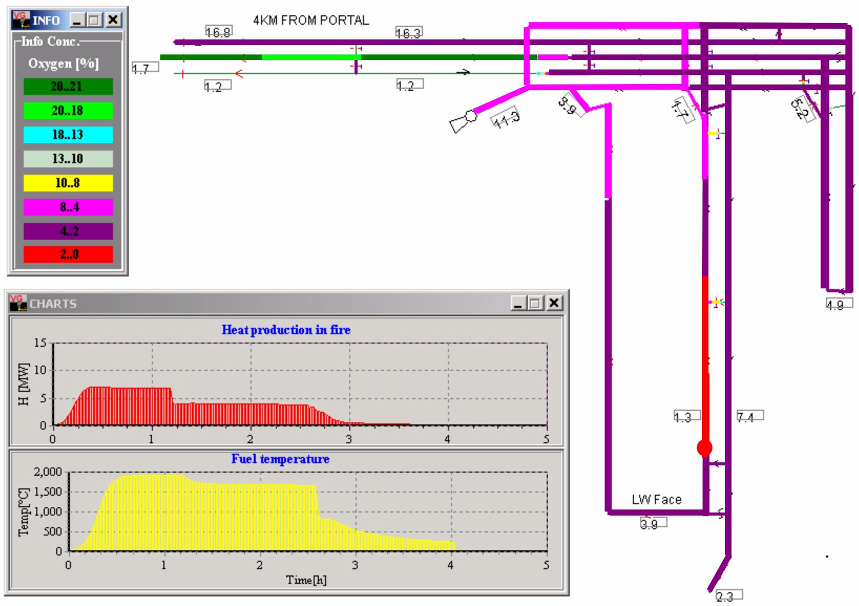


Figure 6. GAG position at the portal B heading for 4km Mains length

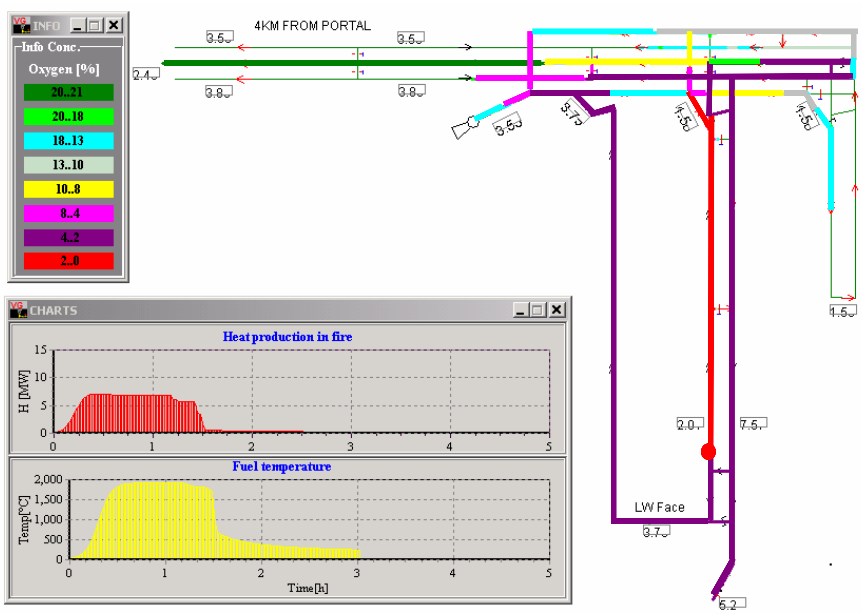


Figure 7. GAG position at the top of back longwall borehole for 4km Mains length.

It should be noted that the advantages can be gained from use of various GAG positions depends on a number of considerations including the location of the fire, the relative distance from the GAG placement portal location and the attributes and complexity of the mine ventilation network Operation of a GAG unit requires preplanning in terms of infrastructure requirements for a GAG surface portal docking station and access for operating personnel, jet fuel, water and other operating requirements.

The same conclusion from GAG studies also applies to use of other tools such as the Nitrogen Shield in New South Wales. It would be advantageous for investigations to be undertaken by any mine contemplating use of inertisation devices. This requires a detailed study of each mine's ventilation and fire simulation model to identify optimum unit position placement for various fire locations.

Fire with High Gas Level at Face

Investigations were also carried out to examine usage of interisation tools and particularly application of the GAG jet engine in a mine with high gas emission level at the longwall face. Case studies of the typical Australian longwall examples used in previous section were modified. A seam gas face source of CH_4 of 400litres/s was introduced in the middle of the longwall face line in the model to simulate this case. This gives a CH_4 concentration level of about 1% on the return side of the longwall face. In the simulation a diesel fire of 10m length of fire zone, a fire intensity of 10 and a time constant of 120 seconds was started 50m inbye the maingate end of the current longwall face.

The Longwall face was examined under two situations of dip angles of 2.5% and 5% (-6 and -12m respectively on a longwall face 240m long) down from maingate to tailgate. This gives descentional ventilation effects as discussed earlier in the paper. The fire in this situation will work against the main ventilation direction along the longwall face. The GAG unit is positioned at the portal B heading.

Procedures to implement the GAG for both positions were as follows.

1. Start the simulation and let the fire run for 1 hour.
2. Start the GAG after 1 hour and close the emergency door at portal B Heading just outby the GAG.
3. Close off the emergency door located at C, Shut off the fan and then close off the emergency door located at D heading.
4. Let the GAG run till the heat production from fire is minimal and the fuel temperature is less than 250^{o}C.

It was found that when the longwall is dipping at 2.5%, the GAG unit is successful in reducing the fire to minimal heat production and fuel temperature of less than 500^{o}C around 4 hours after the GAG was started as indicated in Figure 8. No airflow reversal was observed at the longwall face.

However, when the dipping angle increased to 5% for the same fire situation, as soon as the fan is turned off, the airflow on the longwall face reversed. This leads to the high concentration of face CH_4 flowing back across the fire with high likelihood of an explosion occurring as shown in Figure 9. A sharp drop of the heat produced from the fire is observed.

As soon as an explosion "occurs" in the Ventgraph simulation program, the program will no longer simulate the heat production from fire.

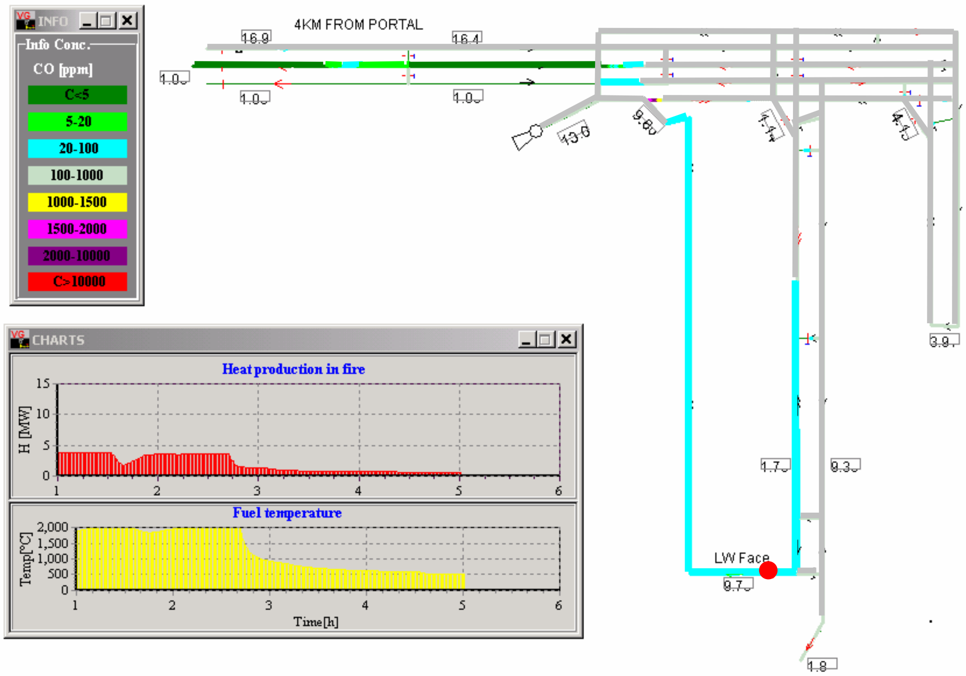


Figure 8. Gassy longwall dipping at 2.5% from Maingate to Tailgate.

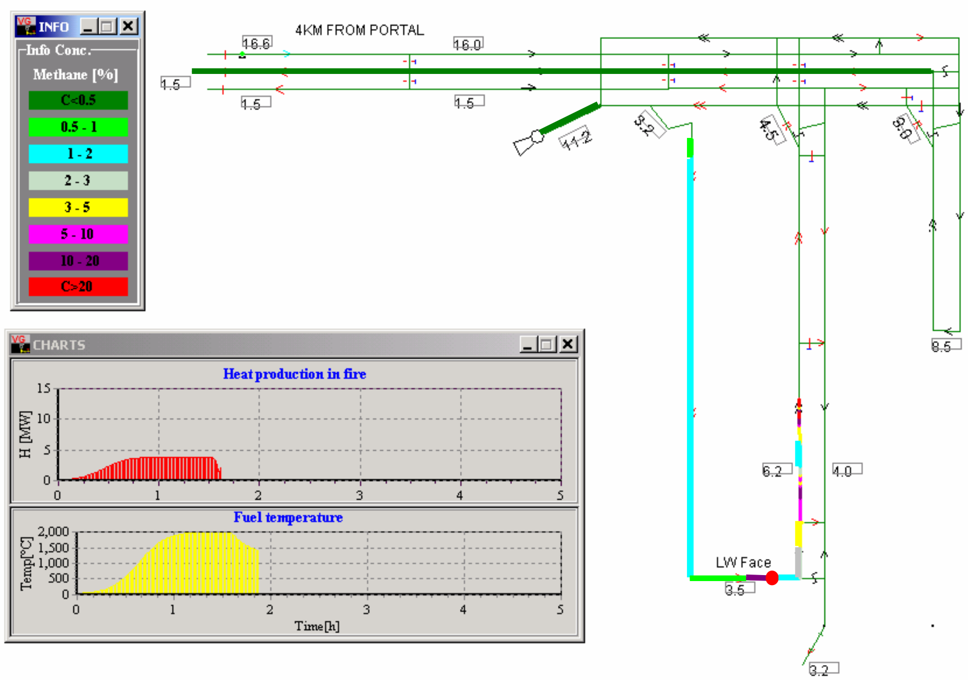


Figure 9. Gassy longwall dipping at 5% from Maingate to Tailgate.

Addition of the inert gas stream adds another level of complexity to the already complicated interrelationships between the mine ventilation system, the presence of seam gases and a mine fire. Should the main mine fans be turned off to reduce dilution of the inert gas, or will this action cause, in conjunction with fire induced buoyancy effects, airflow reversal and the drawing of combustion products or seam gases across a fire leading to an explosion?

EMERGENCY EXERCISE

Emergency training exercises have been undertaken in Queensland since implementation of the recommendations of the Inquiry Report from the Moura No 2 coalmine disaster of August 1994. Oaky North Coal Mine in May 2004 continued an emergency response exercise from the previous State Level 1 Emergency Exercise held at Crinum Mine. A simulated fire was burning in an intake airway with two miners trapped inbye the fire. They were barricaded in a cut-through where a 500mm ballast borehole was providing fresh air from the surface.

The Ventgraph ventilation and fire simulation software was used to model the fire and mine conditions as various mitigation strategies were assessed. This assisted in determining the ultimate best solution to the problem. The mine used the GAG inertisation unit to reduce the intensity of the fire, whilst theoretically extricating the miners via the borehole and single rope and harness rescue. A borehole camera was used to view the men and the surrounding area. At the same time actions were taken to control the fire by drilling a series of boreholes from the surface to seam level, just outbye (in the same roadway) the last known position of the fire as well as in cut-throughs around the expected perimeter; then dropping flyash into the roadways. This was to be undertaken to block off the air to these roadways and starve the fire of O_2.

The previous Crinum incident had tested the mines ability to respond *unaided* to an emergency incident – initial detection, interpretation, personnel evacuation and first response to control the incident, primarily utilising the mine's internal resources.

The Oaky North incident tested the mines *aided* response capability. That is, following on from first response principles, personnel had been evacuated, as far as possible and the Incident Management Team must bring the situation under control utilising any resources that may be available – Mines Rescue Services, GAG Inertisation Unit, other Emergency Service Organisations, SIMTARS and any relevant subject matter experts. The assessment covered not only the mines response capability but also those of the respective agencies that were called upon.

The Oaky North scenario commenced with a fire burning at 51 cut-through (c/t) B heading Mains. Two miners were trapped (barricaded) at 61 c/t Mains, between A heading return and B heading intake (transport), at a ballast borehole site. This cut-through has a stopping between A and B Headings and a set of double doors on the intake side of the borehole. This facilitated the opportunity for the miners to take refuge in relatively fresh air – one of the miners was injured and having difficulty evacuating the mine. The GAG inertisation unit was at the minesite but had not been connected or activated. Mines rescue teams were also on site but not operational, due to the mine measured gas levels from products of combustion approaching 80% of the Lower Explosive Limit (LEL).

For the purposes of the exercise, the mine was advised of these details three days prior to the event, in order to replicate some degree of preparation – as if the incident had happened a day or so beforehand. The mine were also advised that the Emergency Exercise Management Team (EEMT) would be utilising the Ventgraph software and that as the mine also had access to this software it would be able to utilise both the model and operators from the University of Queensland (who were present at the mine) to model the situation.

This paper focuses only on the fire simulation modelling during the exercise. Examples from the concise scenario development and simulation results is set down.

Scenario

Fire in Oaky North Mains inbye 51c/t B Heading caused by collision of two diesel vehicles with acetylene diesel ignition and subsequently ignition of standing coal. The mine has been evacuated except for two miners (one with a suspected broken lower arm) who have barricaded themselves at 61c/t A-B Hdg at the (600mm) ballast borehole. Attempts were made by evacuating personnel and a mine rescue team (using high expansion foam) to extinguish the fire but these were unsuccessful.

- The fire has been burning for 6 hours with no other intervention.
- All mine fans are operating as normal and entries to mine have not been altered.
- The atmosphere inbye of the fire at nearest monitoring point indicates that fire gases are approx. 80% of LEL and therefore re-entry, at this time, has been precluded.
- The GAG unit is on site but is still on the truck.
- Mine rescue volunteers from the surrounding mines are on site but unable to enter the mine.

Assumptions Made

CH_4 output of 1,000 litres/s at fire from fire cracking coal.

Prior to running fire simulation pre-enter some of the controls that may be required e.g.

- Initiation of GAG set at the Intake Drift.
- CO Gas sensors set at a point inbye fire in B Heading. There is no sensor here in reality.
  CO Gas sensors set at South MG LW1 at point Outbye 1 c/t.
  CO Gas sensor on Mains C Heading 63 c/t MG.
- O_2 Gas sensors set at a point inbye fire in B Heading. There is no sensor here in reality.
- O_2 Gas sensor on Mains C Heading 63 c/t MG.
- CH_4 Gas sensor on Mains C Heading 63 c/t MG.

Fire is fuel rich with 30% CO in combustion gases.

Simulation

Fire is already burning. Assume at steady state after 6 hours. Assume GAG has been called to pit.

Two miners have escaped to 61 c/t B-A Heading at bottom of 600 mm road base drop hole. There is no refuge chamber in the mine. There is perceived to be thick smoke throughout the pit.

Step 1 Time 0 – 6 hours. Coal burning. Simulate as 100 m entry length coal fire developing, time constant 21,600 seconds, intensity 10, CO % = 30 (assume H_2 = CO level).

Figure 10 shows part of Oaky North pit plan with fire location and data input window. Figure 11 shows the mine plan with extent of Ventgraph simulation of smoke travel through workings after 1 hour.

Observation

Fire out of control at Time 6 hours. Air quantity outbye the fire is 55 m^3/s and 0.3 m^3/s of fresh air is flowing down the borehole but contaminated air is leaking into the refuge from B Heading. Figure 12 shows part of Oaky North pit inbye fire showing CO levels after 6 hours of fire burning.

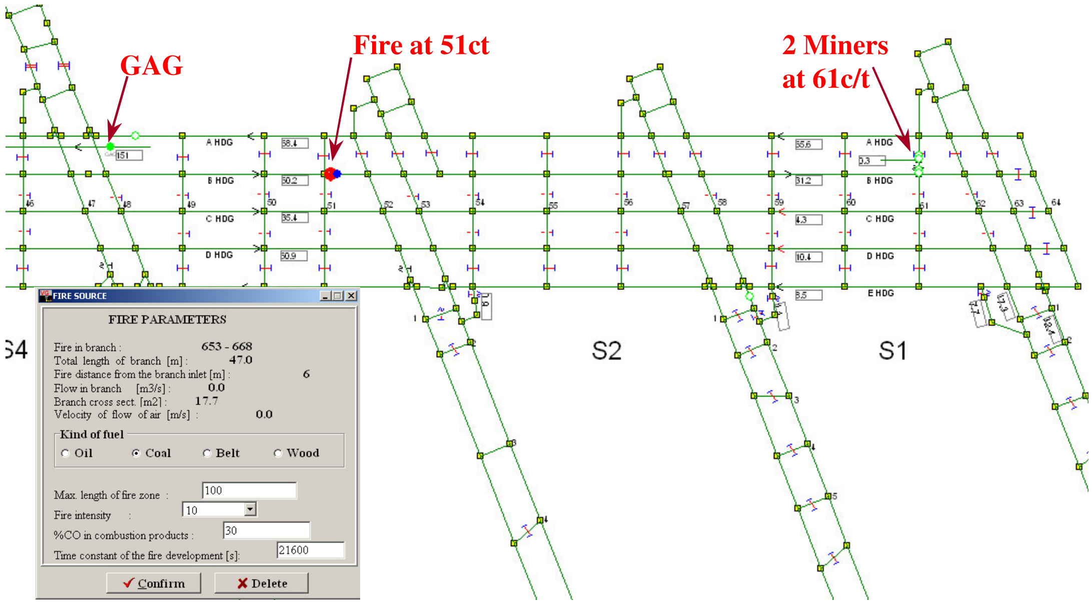


Figure 10. Part of Oaky North pit plan showing fire location, docking point for GAG and data input window.

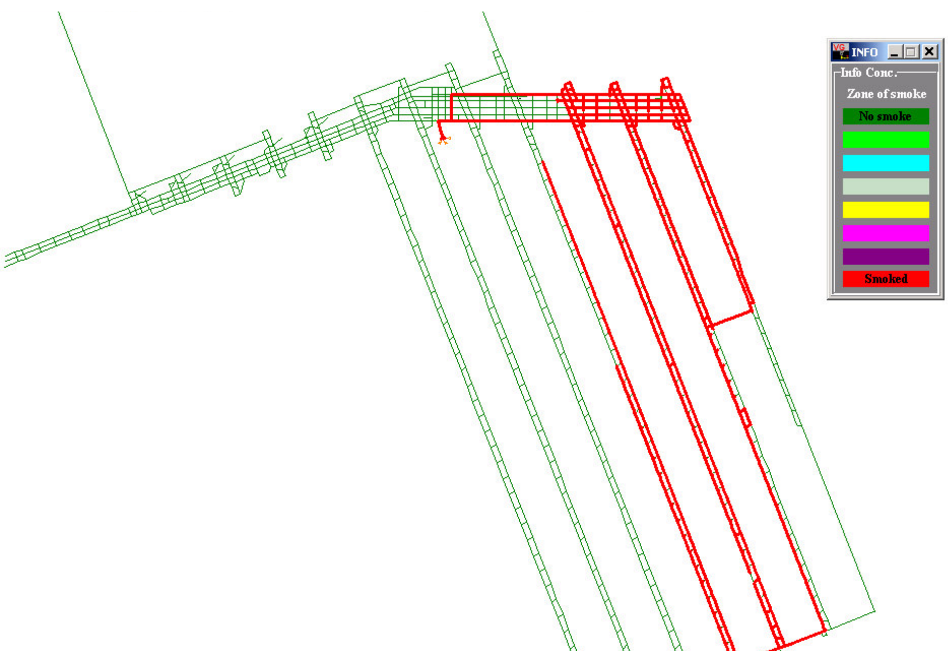


Figure 11. Oaky North pit plan showing extent of Ventgraph simulation of smoke travel through workings after 1 hour.

Control Action

Seal off Drift Portal (R=100), Start up the GAG. GAG running at 11,000 rpm and maximum efficiency of 10.

Consequence

Air quantity outbye the fire is reduced to 50 m^3/s (O_2 is 17%). No contaminated air is leaking into the refuge from B Heading. Lower O_2 supply to the fire has reduced the fire intensity. This has stabilised the situation for attempts to be made to evacuate the two trapped miners through the 600mm borehole.

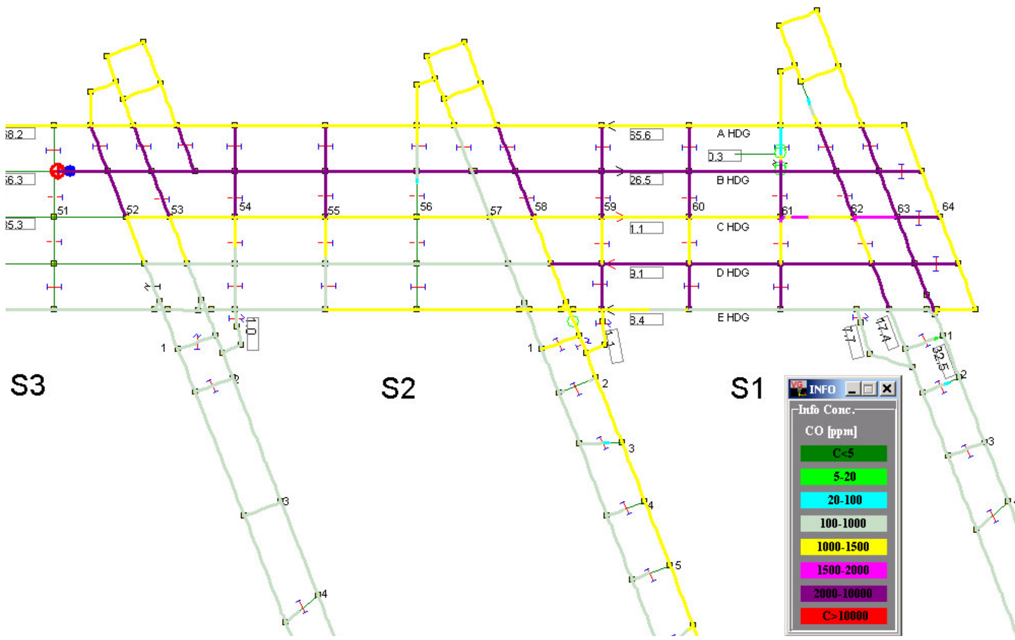


Figure 12. Part of Oaky North pit inbye fire showing CO levels after 6 hours of fire burning. This shows air quantity outbye the fire of 55 m^3/s, 0.3 m^3/s of fresh air flowing down the borehole and contaminated air is leaking into the refuge from B Heading.

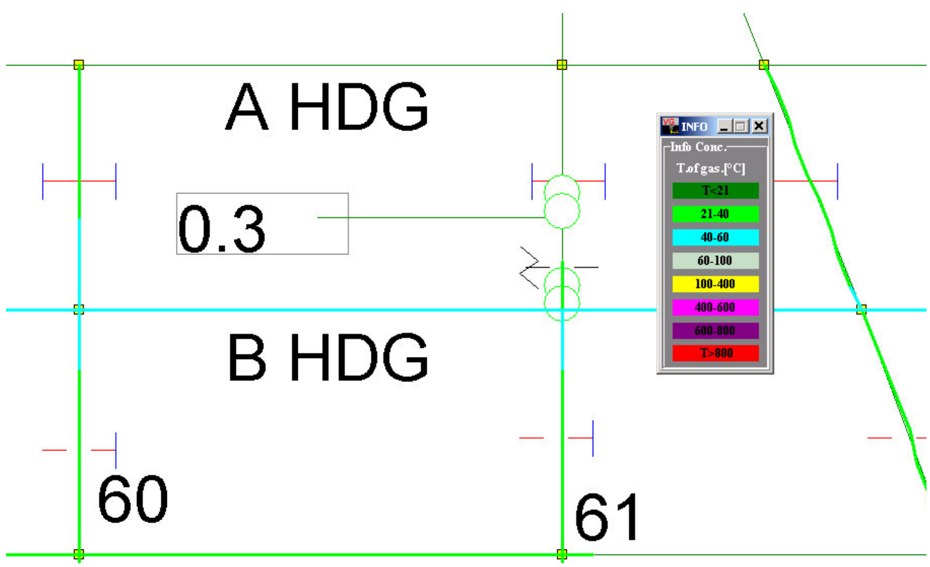


Figure 13. Part of Oaky North pit inbye fire after sealing Drift Portal showing air temperature. 0.3 m^3/s of fresh air flowing down the borehole. No fire contaminated air is leaking into the refuge from B Heading.

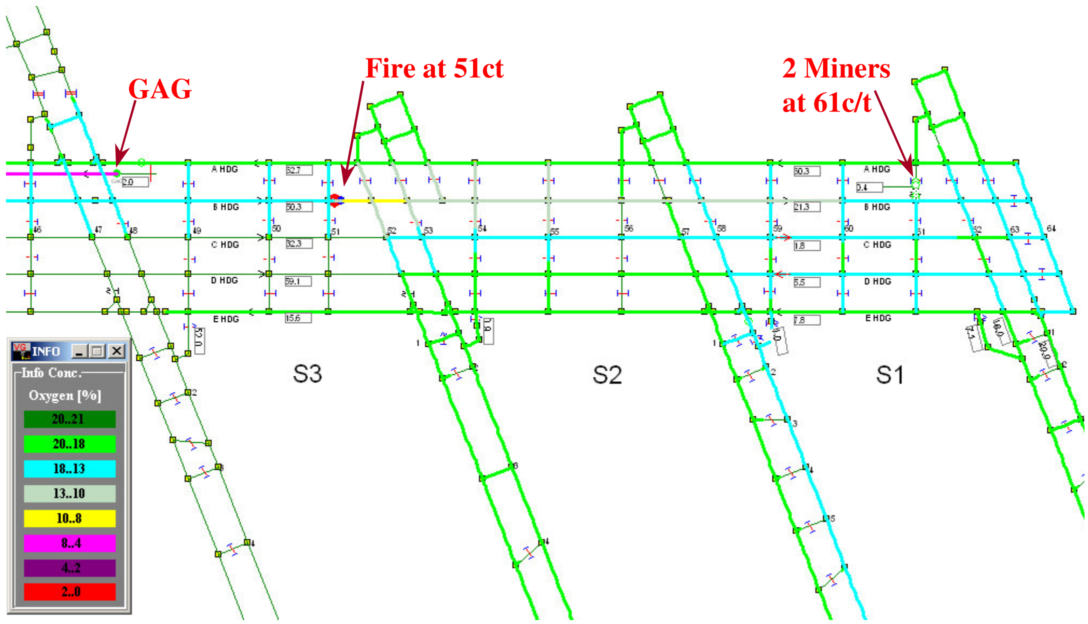


Figure 14. Part of Oaky North pit plan with simulation of fire burning and with GAG in action and O_2 levels.

Simulation

Drilling of borehole into B Heading outbye of the fire is proposed and will take up to 12 hours to complete.

Step 2 Time 6 –18 hours Coal burning, fire largely unchanged.

Control Action

First borehole drilled into B Heading outbye of fire and fly ash used to obstruct the airway (R=5). Figure 14 shows part of Oaky North pit commencing to place flyash outbye fire. GAG operating at Drift Portal showing CO levels.

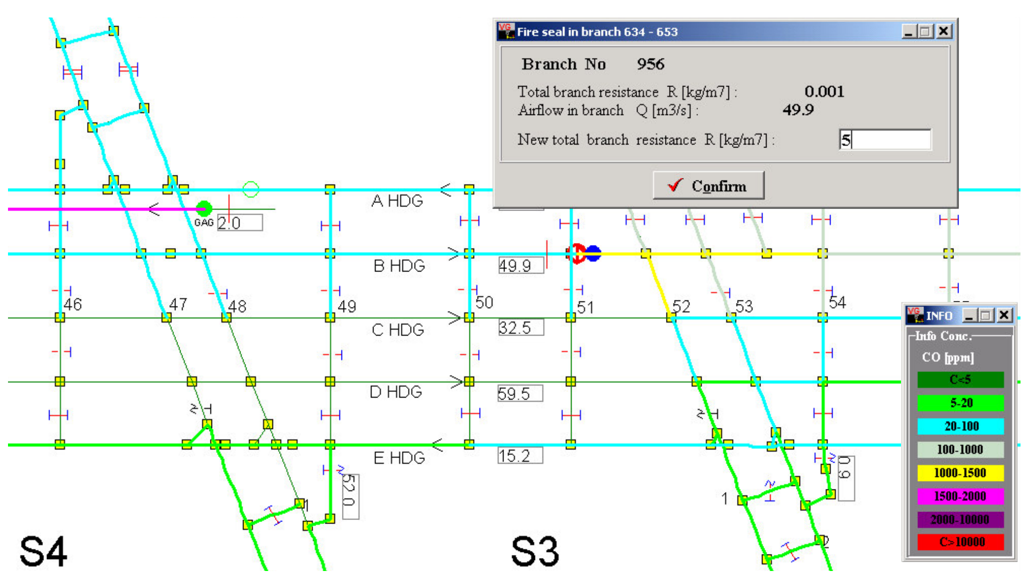


Figure 15. Part of Oaky North pit commencing to place fly ash outbye fire and GAG operating at Drift Portal showing CO levels.

Air quantity in B heading outbye the fire is further reduced to 3.6 m^3/s (O_2 is 12%) and the heat output from fire reduced to around 5 MW. The fire is now controlled and small enough to fight with foam or water. Figure 15 shows part of Oaky North pit 12 hours after placement of flyash outbye fire GAG operating at Drift Portal showing CO levels.

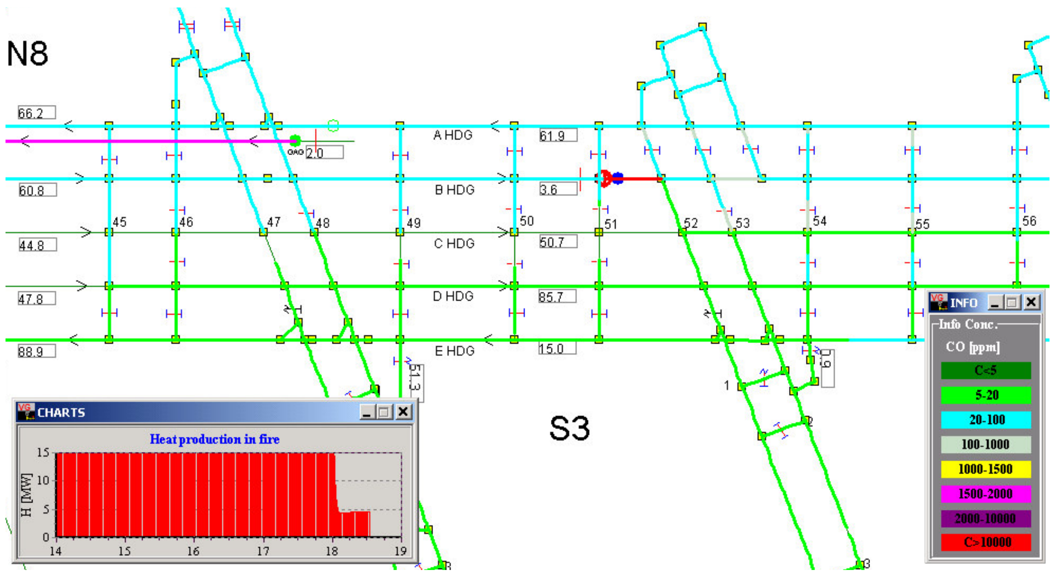


Figure 16. Part of Oaky North pit 12 hours after placement of flyash outbye fire GAG operating at Drift Portal showing CO levels. Air quantity outbye the fire is reduced to 3.6 m^3/s (O_2 is 12%, very high CO levels) and the heat output from fire reduced to 5 MW.

Alternative Rescue Approaches Simulated

A number of alternative scenarios were simulated. The mine normally has three fans running

1. After starting up the GAG, an attempt was made to gradually shut off fans to reduce the O_2 supply to the fire. It was found that after shutting off the second fan (with the third fan still running), the airflow is reversed at the fire site and an explosion may occur. This is an unsatisfactory solution. This simulation can be seen in Figure 16.
2. After starting up the GAG, an attempt was made to shut off one fan and then progressively close off two of the highwall entries to reduce the O_2 supply to the fire. Shutting off one fan successfully reduced the airflow to the fire but due to a lack of segregation, closing off the highwall entries had no effect in further reducing the flow to the fire. This alternative approach did not appear to cause a situation under which a gas explosion would be likely. However it is not effective as the fire would not be starved from lack of air. These simulations can be seen in figures 17 and 18.

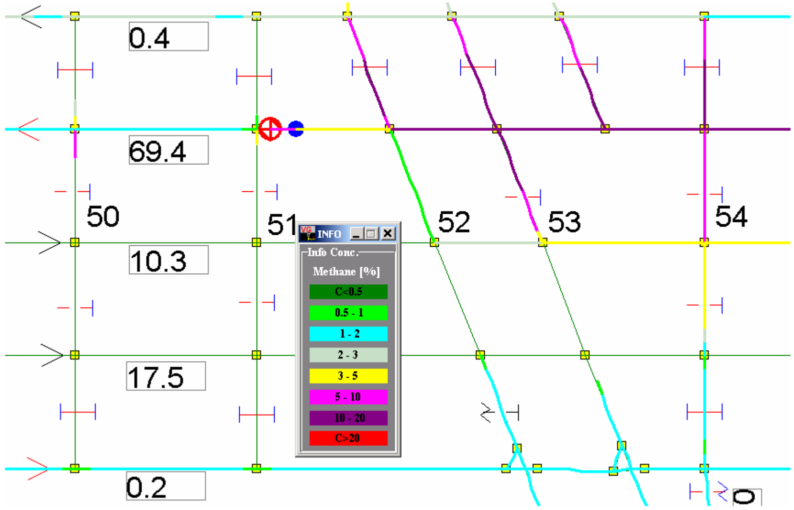


Figure 17. Part of Oaky North pit showing airflow and CO levels at time 13 hours and 22 minutes. Airflow reversal has occurred across the fire.

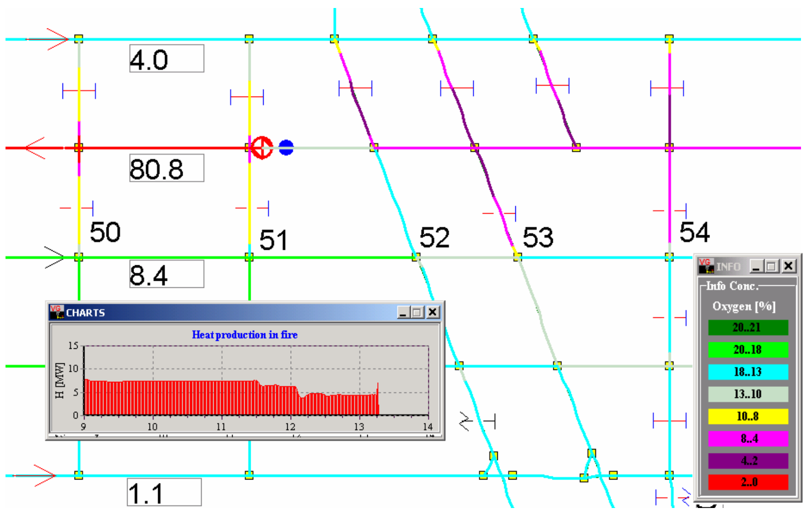


Figure 18. Part of Oaky North pit showing airflow and O_2 levels at time 13 hours and 31 minutes. Airflow reversal has occurred across the fire. Fire is in an O_2 lean state with reduction in heat output.

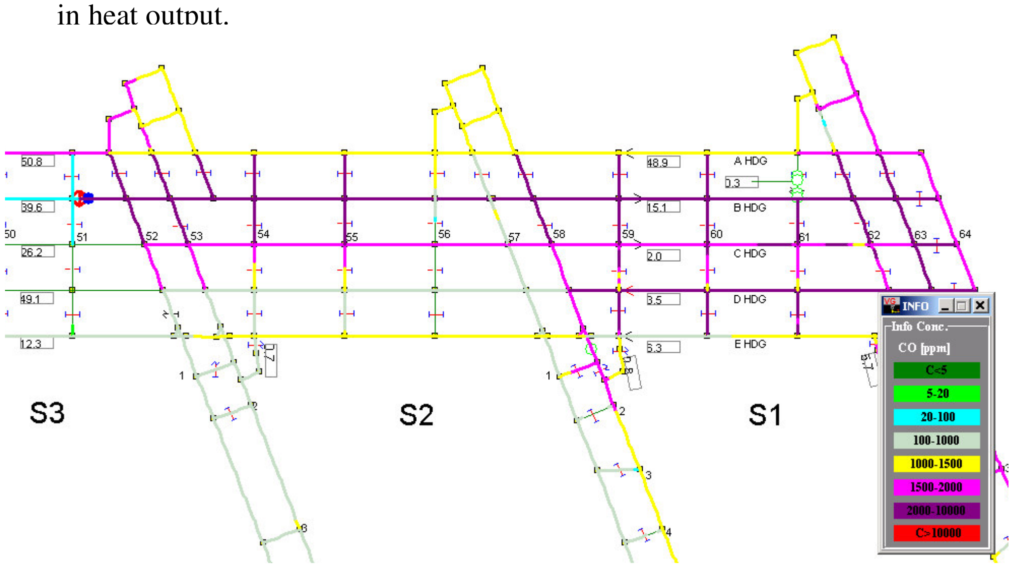


Figure 19. Part of Oaky North pit showing airflow with one fan off.

Scenarios Summary

Table 4 gives a summary of key information from the scenarios tested. The scenario which was considered to be the best option is laid down in three sequences in the first three rows of the table. The other two alternatives tested that gave unsatisfactory outcomes are included in the last three rowsTable 4 Summary of the various emergency exercise simulations.

Steps in Scenario	Q in B, C & D Hdg at 50ct outby (m^3/s)	Q at 61ct Refuge through borehole (m^3/s)	Gas and Temperature Conditions				Comments
			Into Fire O_2 (%)	At 61ct Refuge			
				CO (ppm)	Temp (^oC)	O_2 (%)	
Before fire started	B 60.0 C 36.0 D 61.0	0.3	21.0	0	25	21	
6 hrs after fire started	B 55.0 C 35.4 D 63.8	0.3	21.0	100	21	20.4	Leakage from B to A Hdg via doors observed at 61 ct Refuge
Drift protal sealed, GAG started	B 50.2 C 32.6 D 59.0	0.4	17.6	0	<20	21.0	Improve flow from borehole and no leakage from doors into Refuge
Turned off 1st fan	B 37.6 C 25.7 D 48.7	0.3	16.8	0	<20	21.0	Flows into fire reduced but not enough to starve the fire out
Turned off 2nd fan	B -33.7 C 27.7 D 45.5	0.2	16.4	0	<20	21.0	Reversal of airflow at B Hdg with 8.4% CH_4 into fire - explosion

Observations on the Emergency Exercise

The following comments on the ventilation aspects of the emergency exercise summarise observations made by participants during the course of the incident. Some comments are set down as observations and some were personal comments from participating individuals.

1. It was clear that the purpose, capabilities and limitations of Ventgraph were not fully understood by Oaky North mine staff. This may in part be due to the short lead time and also limited training in its operation by the software supplier.
2. A lot more work needs to be done to adequately incorporate Ventgraph into the mine ventilation analysis system and current ventilation models should be integrated into Queensland Mines Rescue Service functions as part of GAG operations. Difficult to evaluate operation of GAG without this. The Ventgraph suppliers need to provide a lot more training and particularly that targeted to dealing with scenarios – for example case studies of past incidents. In addition the suppliers need to be very clear defining to mines what Ventgraph can and cannot do. There is no doubt that using Ventgraph will significantly enhance the ability of the Incident Management Team (IMT) to deal with mine fires.
3. There is a need to refresh key personnel understanding of mine fires and their characteristics, - for example the effect of reducing O_2 whilst maintaining airflow and effects of recirculation. This should be interfaced with actual examples of mine fires and successful and unsuccessful treatment of them.
4. The evaluation of the various fire control options on Ventgraph had resolved that the optimum solution was to drill a borehole from the surface and block B Heading using a

medium such as flyash. The singular use of the GAG was ineffective without positive control over the ventilation quantity but did have an impact on the intensity of the fire. This is worth noting as a "buy time" option or to reduce fire effects and assist with escape. Armed with this information, the IMT split into small teams to detail the respective activities. The activities covered were to facilitate the escape of the trapped miners via the borehole and drill a borehole and place flyash.

5. The Ventilation Officer (VO) was directed to analyse a number of potential solution options utilising Ventgraph for the IMT. This process was to take significant time mainly due to the need to carefully document each step as it was modelled so that an effective plan was generated and key activities were not missed.
6. Acceptance of the solution of drilling a series of boreholes from the surface and introducing flyash was a practical solution to the fire control issue following the provision of a clear and practical plan for achieving the objective. Details included having a drill rig available on site, estimated drilling time, a plan showing the locations of five boreholes in total to completely control the suspected fire area, experience with other boreholes that indicated expected deviation that could be allowed for and the provision of flyash for filling the roadway from a local supplier.
7. VO was close to the IMT (in an adjacent room) but in effect was sufficiently removed from view that the IMT didn't adequately utilise the Ventgraph model.
8. The Ventgraph model was not well understood and as a result was very underutilised as a conceptual aid and management tool. Had it been better utilised, decisions and actions may have been more quickly and freely flowing. There is a clear benefit for mine management and VO's to have modelled the principal hazards for their individual mine as well as assessing and establishing fundamental control techniques. This will aid on two fronts – (i) to respond quickly to an incident and (ii) to reduce the stress levels improve thinking capability and thereby improve the response times and actions. There was no clearly structured process that the IMT followed. This includes information gathering, decision making, action planning, operational processes.
9. The ventilation models and options being run in another room were effective in that this positioning allowed ventilation experts to concentrate on developing options unencumbered. However the drawback was that it became disconnected from the IMT processes.
10. A number of key functions such as data entry and validation were under resourced . Time had not been devoted to understanding Ventgraph or preparing the IMT room for operation. Ventgraph is a very recent addition to site capabilities and therefore no doubt will take time to be assimilated. The assimilation process may require much more extensive training by the providers including scenario training.
11. There is a need to objectively demonstrate the behaviour of mine fires including their products and how they are influenced – effects of air flow, O_2 concentration, inert gas.
12. There is a need to develop Ventgraph so that the fire is an integral part of the simulation and not artificially specified so it can dynamically adapt to the changes and potential changes in ventilation etc. The chemistry of mine fires needs to be included in the model to enable prediction of gaseous products including O_2 deficiency, H_2, CO, CO_2 and CH_4 to be simulated as the conditions in the mine vary or are varied in an effort to control the fire. The IMT was not aware of the capabilities of Ventgraph. VO did not have sufficient familiarity with Ventgraph to use effectively. Ventgraph was newly acquired and key personnel were not familiar with it.
13. Ventgraph was not as useful as hoped by some. Time taken to do simulations restricted number that could be done and value of applying it. There was no recognition of what Ventgraph can do well – simulate buoyancy effects and what it does not do – it does not simulate gas production – CH_4 has to be input, CO to CO_2 ratio has to be externally specified as does size and intensity of fire. Model does not predict any of these.

14. Ventgraph modelling was a valuable tool but became intense due to the number of options being run – the IMT with more experience should ask for a prioritised assessment of the key options.

DISCUSSION AND CONCLUSIONS

To understand fire simulation behaviour on the mine ventilation system, it is necessary to understood the possible effects of mine fires on various mine ventilation systems correctly first. Case studies demonstrating the possible effects of fires on some typical Australian coal mine ventilation circuits have been examined. The development panel situation presents a variety of situations and some cases where fire can cause reversal have been highlighted. The situation in which there is some gasmake at the face and effects with fire have also been developed to emphasise how unstable and dangerous situations may arise.

Case studies have been developed to examine usage of inertisation tools and particularly application of the GAG unit. One example has focused on selection of the best surface portal location for placement of the GAG for most efficient suppression of a fire. A second has examined a situation with significant seam gas being emitted on the face. This has shown that under certain face dip angles switching off the mine surface fan to reduce dilution of GAG exhaust gases will cause reversal of face air and consequent mine explosion as gas laden air is drawn across a fire.

A comprehensive emergency training exercise held at an operating colliery incorporating a fire incident has been examined. Two miners trapped inbye the fire and were barricaded in a cut-through with a 500mm borehole providing fresh air. The Ventgraph simulation software was used to model the fire and mine conditions as various mitigation strategies were assessed. This assisted in determining the ultimate best solution to the problem. The mine used the GAG inertisation unit to reduce the intensity of the fire while theoretically extricating the miners via the borehole. Actions were taken to control the fire by drilling a series of boreholes and dumping flyash outbye of the fire. This was undertaken to block off the air to these roadways and starve the fire of O_2 and achieved success. The mine normally uses three main surface fans. A number of alternatives were investigated for switching these off to reduce flow to the fire. These were not considered to be viable alternatives as they could not reduce flow sufficiently and in some cases reversed flow and brought fire fumes back across the fire with potential for explosion

Use of the Ventgraph simulation approach highlights actions that mine management can undertake to improve their position in the event of a fire. Examples of these include the following.

1. Many fires occur associated with conveyor belts. Segregation of belt headings assists in preventing fumes ingressing escape intake roadways. Ventgraph give a clear indication of poor or non-existent segregation stoppings.
2. Short circuiting of fire fumes to return can keep escape ways open. This could be achieved by opening stopping man doors or vehicle doors. This can be very difficult if these are inbye a fire source. Remote control of these doors from a surface mine control room can overcome this difficulty..
3. Many mines have change over locations (or refuge chambers). Ventgraph simulation can assist in determining the optimum location for these.

Some comments have been made on the ventilation aspects of the emergency exercise from observations made during the course of the incident. Some of these are set down as observations and some were personal comments from participating individuals.

Mine fires are recognized across the world as a major hazard issue. New approaches allowing improvement in understanding their consequences have been developed and tested as an aid in

handling this complex area.

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