ACARP

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Report

INERTISATION AND MINE FIRE SIMULATION USING COMPUTER SOFTWARE

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ABSTRACT

Inertisation is a technique that has been used around the world to enhance the safety of underground coal mine areas either to avoid the potential for a combustion event or to stabilise a situation after an ignition, fire or heating. The term normally refers to the fact that the atmosphere in the area is such that it cannot sustain combustion, including ignitions, and is therefore "inert".

The primary objective of the study is to review coal mine inertisation in Australia. In particular it is to focus on use of the Polish mine fire simulation software "VENTGRAPH" to gain better understanding of how inertisation (GAG, Mineshield, Nitrogen Pressure Swing Adsorption (Floxal) and Tomlinson Boiler) units interact with the complex ventilation behaviour underground during a substantial fire. Most emphasis has been given to understanding behaviour of the GAG unit because of its high capacity output. Critical aspects targeted for examination under the project grant include location of the unit for high priority fire positions, size of borehole or pipe range required, time required for inertisation output to interact with and extinguish a fire, effects of seam gases on fire behaviour with inertisation present and main fan management. The project aims to increase understanding of behaviour of mine fires in modern mine ventilation networks with the addition of inert gas streams.

A second major aim of the project has been to take findings from the simulation exercises tied to the above objectives to develop inertisation related modifications to the program in conjunction with the Polish program authors.

Computer simulation of mine fires and effects on ventilation networks has been introduced in recent years to the industry with considerable interest and success. This has already put a significant number of mines in an improved position in their understandings of mine fires and the use of modern advances to preplan for mine fires and the handling of possible emergency incidents. Mine exercises have been built around the use of the fire simulation computer program "VENTGRAPH" and modelling of fire scenarios across the mine layouts. A coding system has been developed to assist interpretation within the audit exercises.

Simulation software has the great advantage that underground mine fire scenarios can be analysed and visualised. The software provides a dynamic representation of a fire's progress in real time and utilises a colour-graphic visualisation 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 (e.g. hang brattice or check curtains, breach stoppings, introduce inert gases and change fan characteristics). These changes can be simulated quickly allowing for the testing of various fire control and suppression strategies.

Inertisation has been accepted to have an important place in Australian mining emergency preparedness. The two jet engine exhaust GAG units purchased from Poland by the

Queensland government in the late 1990s for the Queensland Mines Rescue Service have been tested and developed and mines made ready for their use in emergency and training exercises. Their use in real and trial mine fire incidents has underlined the need for more information on their application.

The NSW Mineshield (liquefied nitrogen) apparatus dates to the 1980s and has been actively used a number of times particular in goaf heating incidents. The Tomlinson (diesel exhaust) 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" and for goaf spontaneous combustion heatings. Nitrogen Pressure Swing Adsorption (Floxal) units are available and in use both for reducing time in which goafs are "within the explosive range" and for goaf spontaneous combustion heatings. Each of these facilities puts out very different flow rates of inert gases. Each is broadly designed for a different application although there is some overlap in potential usages.

Case studies have been developed to examine usage of the GAG inertisation unit. One section examined seam gas emissions in the face area; 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. Another section has focused on selection of the surface portal location for placement of the GAG for effective fire suppression. The difficulties that some current approaches present are highlighted.

Priority fire locations at a wide selection of mines with a developed and current Ventgraph simulation model have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage. In the study it was assumed that the GAG would be docked at a prepared position designated by the mine (most commonly the current fabricated docking installation). The conclusion is that the current situation is not well placed to effectively inert most colliery priority fires.

These simulation exercises undertaken with a wide range of Australian mines focused attention to the situation that many potential underground mine fire sources cannot be successfully inertised with the GAG docked at the current specified point. This inability to deliver GAG output is particularly so for fires in extended areas of workings or in panels. Two important conclusions are

- Successful delivery of GAG output from units on the surface must consider other (that is alternative to Mains Travel or Conveyor Heading portals) delivery conduits directly into workings near the fire through existing or purpose drilled boreholes.
- During a fire the stopping of the main surface fan or fans will lead to rebalancing of pit ventilation and in some cases potential explosions through air reversals bringing poorly diluted explosible seam gases or fire products across the fire site.

Another section has looked at inertisation and dilution issues in Mains headings. These present a complex ventilation network and with additional interference from a fire, maintaining control of the movement of inert gas is more difficult than elsewhere in the mine. Even good quality segregation stoppings allow significant dilution of inertisation flows over relatively short distances. There is a section that has examined considerations presented by "punch" mines layouts. A number of recent punch longwall mines are accessed off highwalls. These mines have some provision for GAG docking from within the highwall pit but all have put down boreholes to workings which enable the GAG team to operate the engine from the surface.

A calibration exercise on the VENTGRAPH software has occurred in two parts. Back analysis of the gas monitoring data during a fire at the US Pattiki Mine showed that a VENTGRAPH model could be established to simulate satisfactorily this incident. The inertisation exercise during part sealing of the Newlands South highlighted a number of findings. The GAG quantity measured exhausting from the mine area being sealed was at first considered to be unrealistically low. However further analysis, as detailed in Chapter 10 of this report, indicates that accounting for temperature and moisture mass changes explains any differences. The hypothesis that some of the GAG exhaust, with diurnal pressure changes, will flow into and out of goafs is of interest and needs to be accounted for. Further monitoring of mine site GAG exercises are warranted to give greater understanding to this complex system.

A brief overview of the VENTGRAPH simulation software is given. It has highlighted the new features that have been added to the software as a consequence of this inertisation project and in particular the ability to use up to four different types of inertisation gases (at varying flow rates) across a mine layout simultaneously and the ability to include carbon dioxide and nitrogen seam gases as well as methane.

Exercises based on Oaky North and Oaky No 1 mines have involved "evaluation or auditing" of ability to deliver inert gases generated from GAG units to high priority underground fire locations. These exercises have been built around modelling of fire scenarios across the mine layouts. A coding system, A to E, has been developed to assist interpretation within the audit exercises. The principal sections focused on the development of scenarios for examining priority 15 fire locations across both mines and firstly their effect on the mine ventilation system and secondly the influence of introducing inertisation gases to stabilise the fire. Inertisation outcomes in all case scenarios have been examined through introduction through the mine's present docking point. Each scenario has then been re-examined one or more times to establish if a different docking point, altered underground ventilation segregation or other approach would be more effective in stabilising the simulated fire.

Five major case study scenarios based on the modelling of fires with introduced inertisation in a number of high priority different points geographically spread within the Oaky North longwall mine layout have been discussed. Possible alternative strategies for successfully inerting the fires have been examined and conclusions drawn to the success or otherwise of these approaches. Approaches focus on use of alternative portal docking points, increased underground segregation and possible use of boreholes to delivery GAG exhaust directly to the fire seat.

These fire simulation exercises have shown that some priority fires at Oaky North and Oaky No 1 mines can be stabilised through GAG inertisation strategies. One scenario goaf fire strategy developed is a case in point where use of a panel borehole with careful segregation allowed a relatively fast outcome to be achieved. Another scenario development heading fire was similar in that a borehole GAG delivery gave the best outcome. Both these were achieved with one surface fan operating and maintaining minimum pit ventilation and seam methane dilution. A third scenario fire, a Mains belt fire, utilised the GAG positively through use of an alternative Portal for docking. These examples showed that the audit was a success in that it highlighted successful approaches to use of inertisation where the previous approach was inadequate.

On the other hand Mains belt and Development heading belt scenario fires were placed such that alternative approaches to inertisation were ineffective because pit layout means excess dilution affects the GAG exhaust quality which can be brought to the fire.

Recommendations arising from the Oaky North and Oaky No 1 mines exercises were as follows:

1. GAG docking stations should be fabricated for all ventilation intake openings to both mines. The existing facilities should be supplemented by docking points at all Highwall or Drift portals, any pit boreholes of appropriate diameter and future main shafts. In effect each docking point can deliver to a restricted geographic zone within the pit; multiple points allow the appropriate point to be utilised.
2. Segregation strategies have shown that distribution of inert gases to separate Mains headings can be improved. Current segregation is less effective for fires located a long way inbye the mine and in the longwall production and development panels (due to increasing dilution through stoppings).
3. Borehole with a diameter of at least 1 m should be considered at the beginning of each panel for delivering inert gases to each longwall production or development face. These boreholes can also be used for other purposes such as delivery of ballast or emergency extraction of people out of the mine. They may be used for other services. Incorporation of remote controlled doors should be considered to give control over which gateroad should be used to carry the inert gases into the panel.
4. Scenarios in which no satisfactory inertisation strategy was apparent should be further examined to determine the merits of locating a borehole or shaft in the vicinity of the fire to enable satisfactory outcomes.

The fire simulation exercises at Oaky North and Oaky No 1 mines demonstrated that it is possible to efficiently evaluate possible inertisation strategies appropriate to a complex mine layout extracting a gassy seam and determine which approach strategy (if any) can be used to stabilise a mine in a timely fashion.

A final chapter has focused on borehole design parameters. Analyses have been established applicable to Australian conditions based on the complex fluid flow theory that describes the dynamic, hot, pressurised exhaust carrying a superheated vapour. Determinations have been made of the relationships between borehole back pressure and GAG thrust relationships and the best approach to vary the jet engine thrust to overcome this bask pressure. These mathematical relationships can now be applied to investigate the possibility of using GAG in small diameter boreholes for either production inertisation or fire fighting purposes. This would be a verification exercise taking the equations describing GAG exhaust fluid behaviour based on the steady flow energy equation and comparing the theoretical predictions of GAG exhaust fluid behaviour with actual measurements of pressure, quantity and temperature at various locations downstream from GAG exhaust trials proposed.

To support the report’s main findings some concluding discussions on borehole delivery of inert gases and aspects of Mains segregation have been included. Some considerations for selecting the best surface portal location placement for the inertisation unit for most efficient suppression of a fire have been examined. There is a brief examination of the possibility of a wider and proactive application of GAG in Australian mines responding to or recovering from mine fires or spontaneous combustion heatings or elimination of the potential explosibility of newly sealed goafs is examined. The primary focus here is on systems involving delivery of GAG exhaust through docking to surface boreholes connecting into underground workings. Attainable designs for panel boreholes and how GAG docking to boreholes can improve delivery of GAG exhaust are discussed. Introduction of inert gases can present difficult emergency management decision making. 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?

The report has recommended some addition studies that may be undertaken based on the findings from this project. It is proposed that a study on production or proactive use of inertisation and particularly the GAG inertisation unit should be undertaken. The study should aim to examine the possibility of a wider and proactive application of GAG in Australian mines responding to or recovering from mine fires or inertisation of sealed mine workings or spontaneous combustion heatings or elimination of the potential explosibility of newly sealed goafs.

In conclusion the main conclusions from this project are:

- Positioning of the GAG inertisation units is a major determinant of potential success for

most efficient suppression of a specific fire. Studies undertaken with most Australian underground collieries have concluded that the current situation is not well placed to effectively inert most colliery priority fires.

- There is a need to examine attainable designs for GAG inerting using panel boreholes under Australian conditions with current drilling technology. Part of this is to calculate design considerations to overcome back pressure. There is a limit to the ability of the GAG jet engine to deliver exhaust down smaller dimension borehole. The objective will be to define the
  - Hole designs (diameters and depths) that can deliver directly without assistance of any fan,
  - Hole designs that can deliver with modifications to the jet engine to improve thrust to overcome back pressure required for this delivery to be attained, and
  - Specifications of boreholes design parameters that cannot achieve delivery even with full GAG jet thrust.
- There is a need to examine the use of the GAG for production or proactive uses in a wider application in Australian mines responding to recovering from mine fires, spontaneous combustion heatings, elimination of the potential explosibility of newly sealed goafs or inert mines or mine sections on closure. Some of the current uses of low flow inertisation facilities could be more effectively undertaken with the GAG unit.

Mine fires and heatings are recognised across the world as a major hazard issue. New approaches allowing improvement in understanding their use of inertisation techniques have been examined. The outcome of the project is that the mining industry is in an improved position in their understanding of mine fires, use of inertisation and the use of modern advances to preplan for the handling of possible emergency incidents.

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1. INTRODUCTION

Inertisation is a technique that has been used around the world to enhance the safety of underground coal mine areas either to avoid the potential for a combustion event or to stabilise a situation after an ignition, fire or heating. The term normally refers to the fact that the atmosphere in the area is such that it cannot sustain combustion, including ignitions, and is therefore “inert”.

This can be accomplished by reducing the oxygen component of the atmosphere to a level that will not sustain combustion of a gas or of a solid, such as coal, or by increasing the amount of an existing flammable gas, such as methane, to an atmospheric concentration above which it becomes non-flammable relative to the oxygen level of the atmosphere. The oxygen level can be lowered to levels below that of normal air through consumption by slow or fast oxidation processes or by the addition of inert gases such as nitrogen or carbon dioxide which do not participate in the oxidation or combustion processes. The technique enhances safety to the extent that should an ignition source be present in an inert atmosphere, combustion would not occur. Additionally, as will be discussed here, creating such an inert atmosphere in an area of a coal mine where combustion is ongoing, can extinguish the combustion process.

Use of inertisation techniques is very common in coal mining regions around the world with the use of bleederless ventilation systems in active areas of coal mines. Bleederless ventilation is generally used where the prevention of spontaneous combustion is a key parameter for the ventilation design of an active panel. Bleederless ventilation is an attempt to render the goaf inert in that it permits the accumulation of methane and other non-flammable gases, while limiting the introduction of oxygen. This creates an inert atmosphere that will not sustain the self combustion of coal and, therefore, limits the potential for these types of hazardous fire events or as a potential ignition source for an explosion.

Seals are ventilation structures that are designed to prohibit, or at least greatly minimise, the exchange of atmosphere between an abandoned area with any adjacent ventilated areas and are therefore often a key component of inertisation methods. Well constructed seals are also designed to limit the potential that an explosion in a sealed area could impact the active mine areas or the safety of the mine workforce. Seals, Even those seals that are virtually airtight, do not ensure that the entire atmosphere in the sealed area is inert. Research and investigations have shown that the surrounding strata can permit an exchange of atmospheres between the sealed area and adjacent ventilated areas of a mine (Garcia, et al. 1995). Recent case study modelling work by Gale (2005) has likewise shown that strata interaction to mining can produce hydraulic conductivity changes in the strata and provides insight to the mechanism for these mine atmosphere exchanges. The sealed area most susceptible to not being inert is the periphery of areas adjacent to ventilated areas. The concern from the inertisation standpoint is mainly that oxygen from the ventilated area will enter the sealed area and make the atmosphere flammable or capable of sustaining combustion, although the reverse flow of methane or oxygen depleted air from the sealed area can also be a safety concern.

The primary objective of the study is to review coal mine inertisation in Australia. In particular it is to focus on use of the Polish mine fire simulation software “VENTGRAPH” to gain better understanding of how inertisation (GAG, Mineshield, Nitrogen Pressure Swing Adsorption (Floxal) and Tomlinson Boiler) units interact with the complex ventilation behaviour underground during a substantial fire. Most emphasis has been given to understanding behaviour of the GAG unit because of its high capacity output. Critical aspects targeted for examination under the project grant include location of the unit for high priority fire positions, size of borehole or pipe range required, time required for inertisation output to interact with and extinguish a fire, effects of seam gas on fire behaviour with inertisation present and main fan management.

A second major aim of the project has been to take findings from the exercises tied to the above objectives to develop inertisation related modifications to the program in conjunction with the Polish program authors.

Inertisation systems for handling underground fires, use in sealing old mines or mine sections, spontaneous combustion heatings and elimination of the potential explosibility of newly sealed goafs have been accepted as important safety approaches within the Australian industry. Computer simulation of mine fires and effects on ventilation networks has been introduced to the industry over the last few years and particularly under ACARP grant 12026 . This has already put about 20 Australian underground coal mines in an improved position in their understanding of mine fires and the use of modern advances to preplan for mine fires and the handling of possible emergency incidents. The fire program VENTGRAPH allows simulation of the introduction of an inertisation gas stream to the ventilation network and understanding of its effect in fire suppression. This study has investigated application of the program in relation to the utilization of available inertisation units. The interaction of inertisation with a mine's ventilation system during an underground fire requires further investigation and the program simulator has capability to assist mining personnel to understand the critical issues.

The theory of fire behaviour and fire control in the underground mine environment is complex. Application of the simulation software package to the changing mine layouts requires experience to achieve realistic outcomes. A comprehensive research project into mine fires study applying the Polish derived VENTGRAPH mine fire simulation software, preplanning of escape scenarios and general interaction with rescue responses was undertaken in 2003 and 2004 following the awarding of an ACARP grant entitled “Mine Fire Simulation in Australian Mines using Computer Software”. The approach has been introduced to the majority of Australian mines in New South Wales and Queensland mines through on site development of fire scenarios, escape strategies and recovery planning. Initial work under this grant involved acquiring the program and development of a bridging sub-program to allow conversion of VENTSIM mine network lay-outs to the mine layout required in VENTGRAPH. Other preparatory work included reviews of fire thermodynamics, escape approaches and discussions with mine rescue management on applications of the program. Two Polish or Polish/American people with experience in the development and use of the VENTGRAPH program, Dr Waclaw Dziurzynski of the Polish Academy of Sciences, Krakow, Poland and Dr Andrzej Wala of the University of Kentucky, USA have visited Australia during the project and given support. Recommendations have been made to the Polish software authors on improvements to the program to make it easier to set up mine simulations, mine model editing, tracing of other gases and related issues. Many or these were adopted and this cooperation was greatly appreciated.

To ensure credibility the work program then turned to implementation of the approach to mines across Queensland and NSW and on-site use of the program at individual mine sites. Inspectorates in both states have been very supportive of use of the simulation approach to improve understanding in this very important area. The Queensland Mine Rescue Service purchased the VENTGRAPH program and have had training undertaken with all their permanent managerial staff. Furthermore the researchers have been asked by both the Inspectorate and a number of operating mines to assist in the design and implementation of Level 1, 2, 3 and 4 emergency exercises. These exercises have allowed a large number of people to become familiar with some of the capabilities of this approach to fire simulation. Invitations were received to speak on the results of the project to groups such as the Queensland Chief Inspector’s CEO’s meeting, Regional Inspectors’ meetings, the Mine Managers Association of Australia, the annual GAG Inertisation seminar in Queensland and a number of professional institution conferences in Australia and overseas. A number of refereed papers have been published in international journals and conference proceedings.

Simulation software has the great advantage that underground mine fire scenarios can be analysed and visualised. The software provides a dynamic representation of a 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 (e.g. hang brattice or check curtains, breach stoppings, introduce inert gases and change fan characteristics). These changes can be simulated quickly allowing for the testing of various fire control and suppression strategies.

A number of the mine site fire scenario exercises undertaken have addressed the issue of mine recovery. Simulated introduction of the GAG or other inertisation apparatus has indicated that there is a substantial lack of knowledge on the interaction of these facilities with the mine ventilation system. This question formed the principal basis for this inertisation project.

The Queensland GAG unit was purchased in the late 1990s following a recommendation from the Moura Number 2 mine disaster. It was first used actively in 1999 at the Blair Athol mine to handle a spontaneous combustion issue in old underground working that were about to be mined by surface extraction. The Queensland GAG unit was subsequently used successful in an underground mine fire incident in the Loveridge mine, West Virginia in early 2003. On this occasion the GAG ran for approximately 240 hours over 13 days and was successful in stabilising the mine so that rescue teams could enter the mine and seal and fully extinguish the fire-affected zone. Much was learnt about the ventilation network behaviour and the need to have an upcast shaft open. Observations were made on the effects of natural ventilation pressure, barometric changes and rock falls on the backpressure experienced by the operating GAG.

A fire at the Pinnacle mine, also in West Virginia in October 2003 attempted to use a Polish owned GAG unit without success. Following these experiences the US Micon company has purchased a GAG unit and is developing a commercial mine emergency and recovery business. A fire in the Dotiki mine, Kentucky in early 2004 was stabilised using a Nitrogen Pressure Swing Adsorption unit. The Queensland GAG unit was called to the Southland, NSW mine fire at the end of 2003 but not utilised in full.

The primary objective of the study is to use the Polish mine fire simulation software VENTGRAPH to gain better understanding of how inertisation particularly that generated by a GAG unit interact with the complex ventilation behaviour underground during a substantial fire.

An introductory section examines different available mine inertisation sources. Some considerations for selecting the best surface portal location placement for the inertisation unit for most efficient suppression of a fire have been examined. Introduction of inert gases can present difficult emergency management decision making. 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?

This section also examines the possibility of a wider and proactive application of GAG in Australian mines responding to or recovering from mine fires or spontaneous combustion heatings or elimination of the potential explosibility of newly sealed goafs is examined. The primary focus here is on systems involving delivery of GAG exhaust through docking to surface boreholes connecting into underground workings. Attainable designs for panel boreholes and how GAG docking to boreholes can improve delivery of GAG exhaust are discussed.

The section also examines the vital aspect of airway segregation and stopping leakage. Mains headings present a complex ventilation network with often numerous parallel headings, hundreds of cut throughs and a variety of ventilation control devices. In such a complex system (with additional interference from a fire), maintaining control of the movement of inert gas is more difficult than elsewhere in the mine. Some illustrations of this issue are given.

Another section examines attempts to examine calibration exercises that have been undertaken to verify the ability of VENTGRAPH to accurately simulate mine fire situations over time and the impact of introduction of inertisation gases ion the mine ventilation system.

A chapter discusses the VENTGRAPH fire simulation software and applications. This includes discussion on recent additions to the original VENTGRAPH software to allow incorporation of a variety of inertisation unit types and a greater variety of seam gas types.

This major section of the study is devoted to examination of the effects of fires and introduced inertisation on the Oaky North Mine and Oaky No1 Mine ventilation systems using fire simulation software VENTGRAPH. Fifteen major case study scenarios based on the modelling of fires with introduced inertisation at a number of high fire priority different points geographically spread within the longwall mine layouts are discussed. Inertisation outcomes in all case scenarios have been examined through introduction through the mine’s present docking point at the Transport Drift or the highwall down cast main shaft. Each scenario has then been re-examined one or more times to establish if a different docking point, altered underground ventilation segregation, use of boreholes to delivery GAG exhaust directly to the fire seat or other approaches would be more effective in stabilising the simulated fire.

Results have been analyses in detail, conclusions drawn and recommendations made. The fire simulation exercises have demonstrated that it is possible to efficiently evaluate possible inertisation strategies appropriate to a complex mine layout extracting a gassy seam and determine which approach strategy (if any) can be used to stabilise a mine in a timely fashion.

The outcome of the project will be that the Australian mining industry is in an improved position in their understanding of mine fires and the use of inertisation units following the very substantial work already undertaken and built around the introduction of the modern fire simulation computer program VENTGRAPH and the consequent modelling of fire scenarios at a substantial number of mines in Queensland and NSW.

Simulation software has the great advantage that underground mine fire scenarios can be analysed and visualised and actions planned to control fire contaminants, maintain safe escapeways and develop approaches to recovery. The VENTGRAPH software provides a dynamic representation of the fire's progress (in real-time) and utilises a colour-graphic visualisation of the spread of combustion products, oxygen, and temperature throughout the ventilation system. During the simulation session the user can interact with the ventilation system (e.g., hang brattice or check curtains, breach stoppings, introduce inert gases such as those generated by a GAG and other units and change fan characteristics). These changes can be simulated quickly allowing for the testing of various fire control and suppression strategies.

Because of complex interrelationships between the mine ventilation system and a mine fire it is difficult to predict the pressure unbalance 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 inertisation 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?

The project has increased understanding of these and other questions in the use of inertisation units. It also has reviewed in detail all types of inertisation units available in Australia and discussed how each can be utilised in a fire emergency. Simulations have been undertaken of the effects of common fire causes and fire progress rates. Inertisation units have been simulated at more than one mine “docking” surface point to help mines decide on optimal portal placement.

The Polish program authors have accepted recommendations for changes and have undertaken inertisation related modification to the VENTGRAPH software from the project findings. These improvements will be available free of charge or at cost price to all Australian mines that have already purchased the VENTGRAPH program as part of earlier mine site fire scenario exercises.

The exercise to introduce simulation of fires and their effects on mine ventilation networks supported by ACARP in 2003 and 2004 has been highly successful. Technology transfer from this project has occurred both to individual mines and in a large number of industry and professional forums. It is considered that the outcomes from this complimentary simulation project aiming to understand inertisation will be similarly received and be considered to be of great benefit to the mining industry.

Successful attainment of goals involved commitment of a number of parties. The research program led by a team consisting of experienced researchers with significant mine ventilation experience. The support of operating mines to allow examples of testing of fire scenarios incorporating inertisation in various mine layouts has been essential. Linkage with Mines Rescue Bodies and related parties was also essential. Some of the investigations were undertaken on site at mines. The research program involved a number of interlinked stages.

2. INERTISATION IN AUSTRALIAN COAL MINES

2.1. Overview of Mine Inertisation Systems

Successful underground mine inertisation is fundamentally dependent on being able to dilute or displace oxygen in the presence of an inerting agent to less than combustible levels.

A number of factors contribute to the success of underground inertisation:

- Flowrate of the inert gas
- Pressure of the inert gas
- Density of the inert gas
- Continuity of the inert gas supply

Low flow inertisation systems have been successful in the proactive inertisation of goaf areas and have the ability for total mine inertisation. A substantial period of time is required due to their low flow rates. To put it simply, large-volume units take less time to achieve the results of the smaller capacity systems, but consideration must be given to relative cost factors. Experience to date has shown that, where large volumes of inert gases are required, the GAG 3A system can deliver these large volumes on a lower cost per cubic metre of inert gas than many of the low-flow methods for which total cost information is available.

Each inertisation system has an optimum application dependent on the site-specific variables existing at a mine at the time of a combustion event. Experience has indicated that a risk based logic approach will aid in the selection and determination of the appropriate system for a particular application. To assist with selection of an inertisation system of choice Table 2.1 indicates both positive and negative variables for consideration prior to application.

Table 2.1 Comparison of inertisation methods (after Mucho et al, 2006)

Inertisation Methods	Advantages	Disadvantages
GAG 3A Jet Engine Inertisation System	▪ Large Volume ▪ Low cost per m^3 ▪ Mobility ▪ Access to the mine ventilation system ▪ Self Contained	▪ Manpower required ▪ Support Materials/Supplies ▪ Transport and Availability ▪ Training ▪ Higher O_2 (than CO_2 and N_2) ▪ Fire gas ratios unstable (due to CO & H_2 production)
Tomlinson Boiler	▪ Versatility ▪ Manpower (2 people/24 hrs) ▪ Portability	▪ Low Flow ▪ Time Duration ▪ High Maintenance

	▪ Minimal support materials/supplies	▪ Fire gas ratios unusable
CO_2 Liquid and/or Gaseous	▪ Cool ▪ Denser than air (can be advantage application dependent) ▪ Ease of movement ▪ Detection relatively easy	▪ Low Flow ▪ Method of application ▪ Transport and Availability ▪ Fire gas ratios unusable
N_2 Liquid and/or Gaseous	▪ Cool ▪ Lighter than air (can be advantage; application dependent) ▪ Non-toxic ▪ Injection ability ▪ Operational logistics relatively simple	▪ Low Flow ▪ Method of application ▪ Transport and Availability ▪ Fire gas ratios unusable

This section reviews the principal categories of inertisation systems in use in Australian coal mines. It also gives some application of the use of each approach.

2.2. Flue Gas Generator (Tomlinson Boiler)

The Tomlinson Inert Gas Generator has been developed primarily for use within the coal mining industry. It grew from large scale hot water heater systems used in institutions such as hospitals. The main application is to inertise underground mined areas to sealing from the mine ventilation system to minimise the possibility of methane gas explosions.

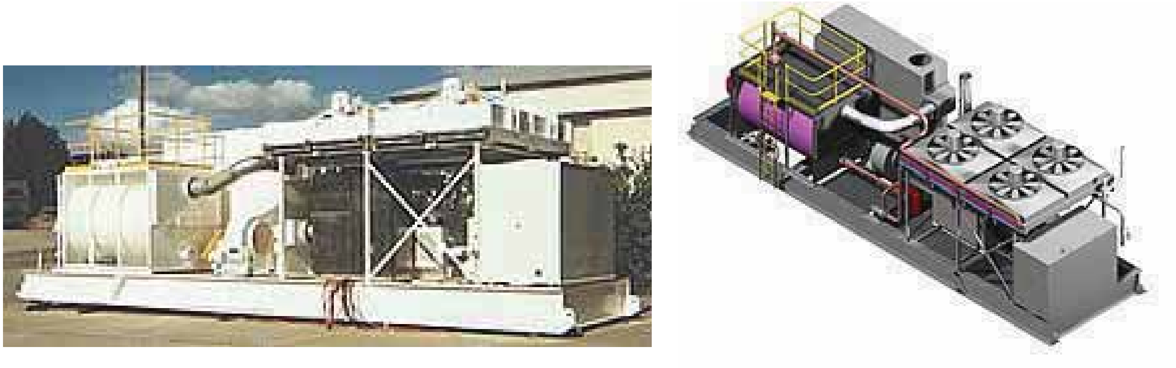


Figure 2.1 Photographic Views of Tomlinson Inert Gas Generator (after Tomlinson Boilers, 2004)

Figure 2.2 Tomlinson unit on mine site

2.2.1. Specification and current applications

Typical inert gas specifications produced by a Tomlinson Inert Gas Generator are:

- Gas volume - 1,800 m^3/hour or 0.5 m^3/s
- Delivery pressure - 100 kPa
- Oxygen content (O_2) - less than 2%
- Nitrogen content (N_2) - 75%
- Carbon dioxide (CO_2) - 12.5%
- Gas temperature - ambient + 20°C

Other possible applications for the Tomlinson Inert Gas Generator include:

- Purging LP gas storage vessels prior to internal inspections
- Purging sewerage digesters prior to internal maintenance
- Purging fuel storage tanks prior to internal inspections
- Dilution of process gas streams to adjust calorific value or chemical composition

Current users include many underground coal mines in the Queensland Bowen Basin.

2.2.2. Tomlinson application - ACARP Project C6002

ACARP funded research project C6002 titled "Sealing, Monitoring & Low Flow Inertisation of a Goaf" undertaken by Cook Resources Mining Ltd (CRM) tested the feasibility of this low flow inertisation concept and successfully demonstrated that the Tomlinson Inert Gas

Generator has considerable potential for the elimination of potential explosion hazards which may exist in some circumstances when areas of a mine containing flammable gases are sealed.

The aims and objectives of this project were:

- To develop, test and refine a sealing management plan.
- To identify gas monitoring protocols which occur in a goaf, before, during and after sealing.
- To demonstrate that low flow inertisation provided by a Tomlinson Inert Gas Generator of a sealed area will:
  - prevent the atmosphere behind the seals from entering the explosive range;
  - be achieved without interruption to the normal production cycle;
  - be cost effective.
- To develop a computer model which enabled future predictions for the inertisation of mine areas using either external inert gas generation, natural processes or a combination of both.

The low flow inertisation concept was successfully demonstrated at Cook Colliery during May/June 1997 and the overall result was very encouraging. In the project CRM confirmed that the Tomlinson Inert Gas Generator is capable of eliminating potential explosion hazards and possible business interruptions when areas of a mine containing flammable gas are sealed.

It must be recognised that the make or volume of flammable gas found in the 9 West Waste Workings at Cook and the 2 South District at Laleham Collieries prior to the inertisation trials was relatively low. However in the case of Cook the make or liberation of methane into the workings should have been sufficient for an explosive mixture to occur before the zone could self inert.

In both cases, the make or liberation of methane was much lower than expected and this raised a number of interesting points. The Tomlinson Inert Gas Generator produced a positive pressure in the sealed area of about 300 Pa at Cook and about 650 Pa at the seals for the 3 South District at Laleham.

It was noticed that this pressure increase was maintained regardless of diurnal variations in the barometer of up to 900 Pa and it would appear that provided the ventilation pressure across the seals has been balanced effectively the barometric pressure has little if any effect.

There was no evidence to support a hypothesis that this overpressure suppressed the release or desorption of seam gas and in particular methane.

There is also no evidence to support a hypothesis that the methane was in fact, displaced. Rescue Team personnel could find no evidence of layering or stratification of gases and this was confirmed by numerous spot tests and bag samples taken from the floor, roof and mid seam heights in a number of roadways.

2.2.2.1. Sealing issues

Good sealing practice dictates that ventilation should be maintained throughout the panel until the intake and return airways are blocked off or sealed simultaneously. In the past the mines had attempted to achieve this by sealing non-critical intake and return airways first and then coordinate the sealing of the main intake and return airways.

When two seals are to be erected simultaneously major challenges are faced. Seals require some time to cure in addition to the timing and resource problems before they are subjected to the low pressure produced by an Inert Gas Generator. The opinion was formulated that for the inertisation process, in any form, to be successful, maintenance of a ventilation circuit until the latest possible time was necessary. This may be some time after the actual inertisation process or injection of inert gas has commenced.

There needs to be an ability to close off the mine ventilation rapidly and to remove the mine's ventilation pressure from the seals.

The inertisation of CRM’s 9 West Waste Workings at Cook Colliery was a success, in that:

- the oxygen in the sealed area atmosphere was reduced to a level below 12%;
- the methane level in the sealed area atmosphere did not reach the lower explosive limit for that gas.

There is no doubt that this project and in particular the inertisation trials broke new ground and the overall results were very encouraging. CRM is confident that low flow inertisation has considerable potential for the elimination of potential explosion hazards and business interruptions in some mines which contain flammable gas.

The trial at Cook Colliery lasted about 236 hours with 181 hours of effective pumping or inertisation time and this equates to an overall unit efficiency of about 77%. It should be recognised that the Inert Gas Generator was new and in fact commissioned on site during the early days of the trial. The methods employed were new and the operators were to a degree, self trained on the job.

2.2.3. Advantages and disadvantages

Advantages of Tomlinson use

- Well known to industry
- Inert gas is generated continuously

Disadvantages

- Requires a continuous feed of fuel and water
- Requires operator supervision
- Delivers inert gas at low pressure
- Combustion flue gas used for inerting is acidic
- Nameplate performance very difficult to verify on site
- No capable of large peak flows of inert gas
- High initial capital outlay

2.3. Mineshield Liquid Nitrogen System

The Mineshield system was developed by the NSW Mines Rescue Board and gas providers CIG in 1985 in response to the frequency of heatings in underground mines and the Appin explosion in 1979. The system works by ‘boiling off’ liquid nitrogen to generate inert gas.

The unit can be operational within 4 hours from the initial call. Liquid nitrogen which is supplied by BOC gases is delivered by tanker from their facilities in Wollongong, Newcastle and Brisbane and stored onsite tanks to be used between deliveries (Mines Rescue, NSW 2007).

The plant heats liquid nitrogen to convert it to nitrogen vapour which is then introduced into the problem area by a bore hole. Up to 17 tonne per hour of liquid nitrogen per hour can be used to lower the oxygen content of the problem atmosphere to less than 2%.

Figure 2.3 Mineshield inertisation unit on mine site

Figure 2.4 Mineshield on mine site, pump and vaporisation unit

2.3.1. Specification and current applications

The components of the Mineshield unit are:

- 40 tonne Storage Tanker
- Vaporizer trailer
- Pump trailer
- LPG supply tanker

Additional requirements are:

- Site pad capable of bearing 5.7 t/m^2
- Water (10,000L at start-up, plus ongoing supply)
- A 400 kVA power supply; provided by grid or generator
- Site lighting
- Phone lines
- Four operators (provided by BOC)
- Road access and turning facility for B-double tankers.

An example site layout for Mineshield is shown in Figure 2.5. The unit consumes between 1t and 17t of liquid nitrogen per hour. One tonne of liquid nitrogen equates to 860m^3 of inert nitrogen gas. Thus the unit can produce up to 4 m^3/s of inert gas. It is believed that an output of only 2 m^3/s can be sustained over a long period. Current supplies of liquid nitrogen are limited to 400 t/day at Port Kembla and 100 t/day at Brisbane. Transport of liquid nitrogen involves significant logistical difficulties due to restrictions on movement of dangerous goods and the limited number of suitable rigs.

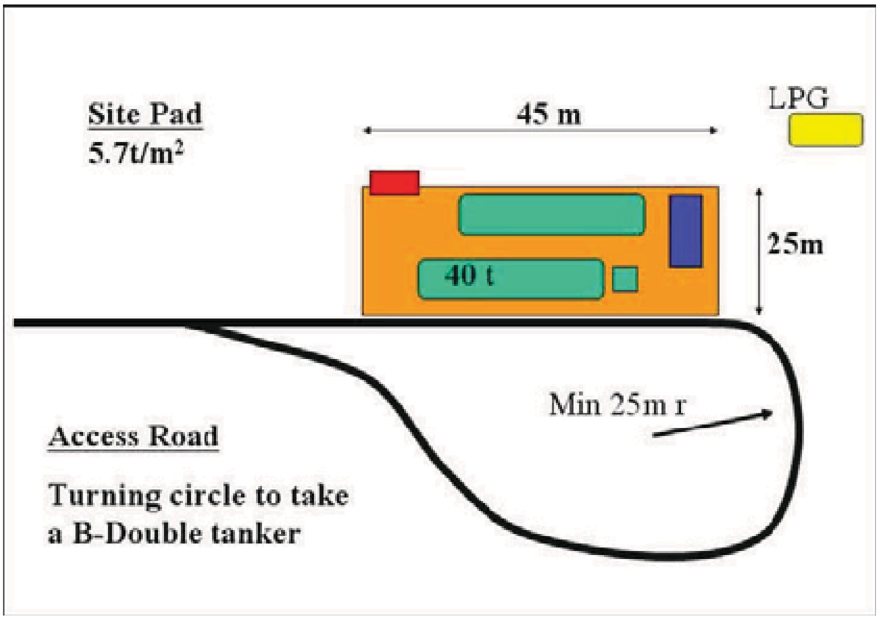


Figure 2.5 Mineshield plant layout.

Liquid carbon dioxide can be used in place of nitrogen but is only suited to a limited number of scenarios as it is heavier than air and tends to sink to the bottom of the mine. This greater density also results in a lower volume of gas per tonne.

Advantages of the Mineshield unit over the GAG are:

- Greater control of low oxygen content in output.
- Nitrogen from Mineshield can be distributed to boreholes using flexible hosing. Thus multiple holes can be injected at once, or injection points can be changed by simply reconnecting hoses. Hoses can also be used to distribute the inert gas underground.
- Inert gas from Mineshield also has a cooling effect.

Disadvantages are:

- Higher operating cost
- Lower flow rates
- Greater demands on infrastructure

Mineshield has been used at five mines in NSW and at Moura No. 4 in Queensland. The most recent operation was at Dartbrook in the Hunter Valley during 2002 when inert gas was injected into the goaf behind the longwall face over five months (Coal Service, 2003). This case was a success with production maintained and all face equipment safely recovered.

2.3.2. Mineshield application - 1986 Moura No. 4 underground mine inertisation

Shortly after the disaster borehole drilling was commenced to facilitate further sampling, water injection into the goaf and nitrogen injection into the workings. At approximately 8:00 a.m., Sunday 20th July, the Mineshield equipment, technical personnel and four tankers containing a total of 64 tonnes of liquid nitrogen arrived on site (Lynn, 1986). However, the propane gas tanker which contained fuel for the vaporising unit was delayed.

Attempts were made to inject liquid nitrogen directly down two boreholes. These attempts proved unsuccessful as back pressure in the bore holes caused the liquid nitrogen to force its way back to the surface via cracks in the subsoil. This eventually froze the ground and blocked the borehole. Water injection was also proving difficult through blockages in the uncased boreholes. Both operations were abandoned and recovery of the blocked holes by reaming and casing was commenced in anticipation of the nitrogen vaporising unit becoming operational and the arrival of further quantities of liquid nitrogen.

Bore hole recovery and mine atmosphere sampling continued into Monday 21st July, when sample results determined at 10:00 a.m. from bore holes indicated the mine atmosphere about the Main Dips Section was not explosive. Further samples 1 hour later provided similar information.

As a result, rescue team 9 accompanied by a District Union Inspector, The Mines Rescue Superintendent and the Government Mines Inspector entered the mine. During this inspection concern arose about the accuracy of sample results received up to that time because a thick bluish smoke and a "fire stink" were detected. These signs indicated the existence of an active fire inbye of 22 Cut Through (Lynn, 1986).

Further exploration attempts were suspended and attempts were made to inject nitrogen gas. The first significant injection rate of 5 tonnes per hour was achieved at approximately 6:00 p.m. This rate was increased gradually to 14 tonnes per hour at 8:00 p.m. causing the oxygen levels to be slightly reduced. However, this rate could not be maintained due to the difficulties of getting sufficient nitrogen to the site. It was evident that the natural ventilation flow in the unsealed panel was diluting the nitrogen and it was calculated that to reduce the atmosphere to 12% oxygen would require an injection rate of 18 tonnes per hour which could not be guaranteed.

On Tuesday, 22nd July, water injection to the goaf area was recommenced to reduce the area to be inertised by nitrogen.

Rescue teams 10 and 11 entered the mine to locate the source of smoke and to erect brattice seals to reduce the quantity of airflow in the panel. While these teams were underground, the nitrogen injection rate was set at 10 tonnes per hour.

A large area of smouldering floor coal as well as evidence of burnt out props was discovered in 24 Cut Through between 2 and 3 Headings. A new sample tube point was established inbye and all roads were sealed by brattice.

Drilling of a borehole was commenced directly over the heating to allow the injection of nitrogen vapour into the area. On Wednesday, 23rd July, at 8:20 a.m., the hole was completed and nitrogen at the rate of 3 tonnes per hour was pumped through the drill stem. With sufficient quantities of nitrogen on site and additional supplies in transit, it was decided to attempt to recover the bodies.

The nitrogen injection rate was increased and five rescue teams were prepared for the recovery operation. By 1:00 p.m., oxygen levels had been reduced sufficiently to allow the operation to commence. Rescue teams 12, 13, 14, 15 and 16 were to prepare and remove the bodies to the fresh air base.

Physical conditions were extremely arduous with high temperature and humidity, very poor visibility and extensive blast debris. However, in spite of these conditions all of the bodies which had been previously located were recovered together with the two bodies which had not previously been located. One of these was located wedged beneath the outbye section of Shuttle Car No. 31.

The last of the bodies was transported to the surface by 5:15 p.m. The Mineshield equipment was shut down at approximately 5:30 p.m. It appeared that inertisation of the sealed area had been successful in that the oxygen level had remained outside the explosive range (Lynn, 1986).

2.3.3. Mineshield application - 2002 Dartbrook mine heating inertisation

On the 16th May 2002 the Hunter Valley Station responded to a spontaneous heating in the longwall goaf at Dartbrook Colliery (Coal Services, 2003). The Mineshield Inertisation Plant was activated to pump an average of 4 tonne/hour of liquid nitrogen into the area. The longwall equipment had been removed and, by 30 September, the goaf area sealed and inerted. During the whole operation approximately 10,500 tonnes of liquid nitrogen had been used. The Plant remained on standby at the mine until 8th October 2002.

This protracted utilisation of the Mineshield Plant put a strain on the pumps and the electrical systems which were only designed for short intense usage of up to 18 tonne/hour of liquid nitrogen. Following a review of the performance of the Mineshield Plant, it was decided to undertake a capital upgrade of the plant to ensure it remained operative and effective for the next 15 years. The upgrade was completed late in 2003.

2.3.4. Advantages and disadvantages of Mineshield

Advantages:

- Utility requirements are relatively minor
- Can deliver large amounts of inert gas in a short time

- Can deliver inert gas at pressure
- Gas 100% inert
- Good solution for limited use applications

Disadvantages:

- High set up cost
- Requires set-up of liquid nitrogen vessel on-site
- Requires a continuous fleet of liquid nitrogen tankers to maintain inert gas supply
- High specific cost of inert gas

2.4. GAG 3A Jet Engine Inert Gas Generator

The GAG-3A Jet Engine Inert Gas Generator consists of a modified jet engine which no longer produces thrust. The engine was originally built for use in a Polish military training aircraft and has subsequently been adapted to generate inert combustion products (Prebble and Self, 2000). The stages within the engine are:

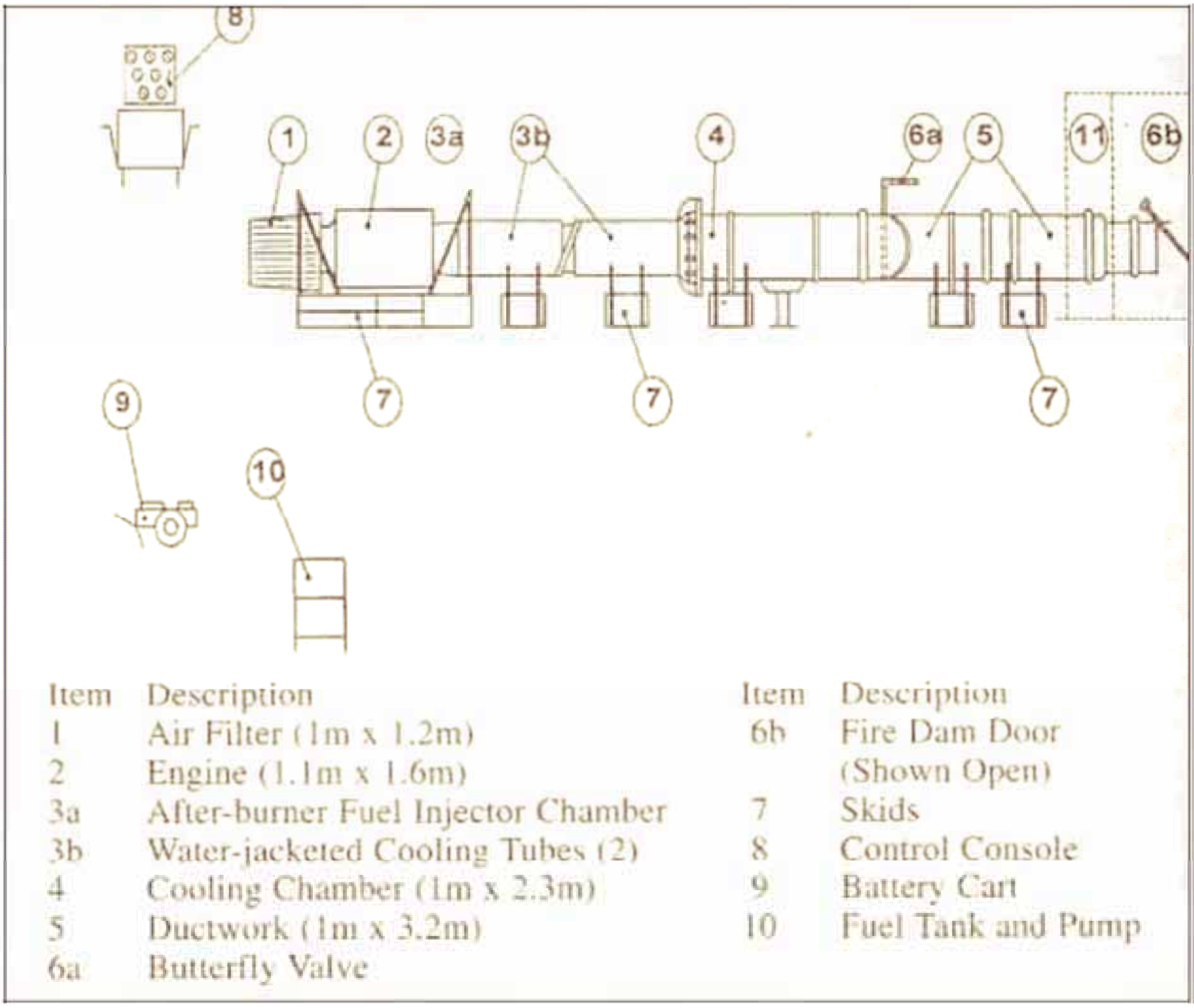
- Compressor
- Combustion chamber
- Turbine
- Afterburner and mixing chamber
- Cooling

A photo of the assembled unit is shown in Figure 2.6. The length of the unit is approximately 12m (Parkin, 2005).

Figure 2.6 One of the Queensland Mines Rescue Service GAG-3A inertisation units

The engine can operate at speeds up to 11,000 rpm, with a standard operating speed of 8000 rpm. The unit produces approximately 25 m^3/s of moisture saturated gas at 85°C, equivalent to 10 m^3/s dry gas. Claims of the oxygen content in the exhaust gas vary from 0.1% to 5% and 2-3% is a realistic target while the unit is running smoothly. There may be a relationship between oxygen in the combustion products and other operational factors. The unit requires up to 2000 L/hr jet fuel and 40,000 L/hr of water for cooling during operation.

The Queensland Mines Rescue Service owns and operates two GAG units that were purchased in 1998 (Parkin, 2005). These units are currently stationed in the Bowen Basin. The unit is transported by truck and setup time for operation is approximately three hours once equipment is on site. The GAG inert gas generator has also been used in Poland, the US, Kuwait (for oil well fires), the Czech Republic and South African gold mines (Page, 2003 and Parkin, 2005).



Item	Description
1	Air Filter (1m x 1.2m)
2	Engine (1.1m x 1.6m)
3a	After-burner Fuel Injector Chamber
3b	Water-jacketed Cooling Tubes (2)
4	Cooling Chamber (1m x 2.3m)
5	Ductwork (1m x 3.2m)
6a	Butterfly Valve
6b	Fire Dam Door (Shown Open)
7	Skids
8	Control Console
9	Battery Cart
10	Fuel Tank and Pump

Figure 2.7 Schematic of GAG-3A inert gas generator.

Figure 2.8 Assembled GAG engine (after Romanski, 2004).

2.4.1. Specification and current applications

Some operational parameters are given in the following table.

Table 2.2 Operation Parameters of the GAG-3A Inert Gas Generator.

	Parameter	**Unit**	**RPM**	
			7200	**11000**
1	Flow	m^3/s	13.95	33.25
2	Mass of inhaled air	kg/s	5.48	10.76
3	Fuel Consumption	litres/min	approx. 17	approx 32.5
4	Oil use	litres/hour	1.3	1.3
5	Cooling Water for afterburner at 70kPa Range 60kPa to 90kPa	litres/s	5	5
6	Water cooling system exhaust gas cooling at 350kPa Range 200kPa to 450kPa	litres/s	7.5	7.5
7	Inert gas temperature on GAG-3A exit	°C	approx. 85	approx. 85
8	Min. water pressure Afterburner Tubes Diffusive Cooler	kPa	70 350	70 350
9	Approx gas make: Oxygen Carbon Dioxide Nitrogen Carbon Monoxide	% % % ppm	0 to 0.5 13 to 16 80 to 85 approx. 3	0.5 to 2 13 to 16 80 to 85 approx. 3

2.4.2. GAG-3A application - ACARP Project C6019 and Collinsville mine trial

Surface and underground trials of the GAG-3A jet inertisation device were held at the Collinsville No 2 underground coal mine from 7th to 18th April 1997 (Bell et al, 1997).

The selection criteria for the trial developed by the Moura related Task Group 5 Committee were met with the exception that output flow rates were slightly below the levels predicted

(19 m^3/s against an expected 20-25 m^3/s). This diminution in flow rates was attributed to higher ambient air and water temperatures.

The unit operated safely during all aspects of the trial and no mechanical problems were encountered. Over 100 industry stakeholders visited the demonstration and feedback questionnaires were generally positive. The demonstration supported the view that the device was suitable for coal mine use. No external flame was visible on the device.

The unit produced noise levels in excess of 124 dB(A) (when measured 1 m from the jet) in both surface and underground operations. Environmental noise levels measured 2.3 km from the GAG-3A were not impacted by the operation of the unit. The limited stratification experiment conducted indicated that the gas produced by the GAG-3A tended to move closer to the roof than the floor (Bell et al, 1997).

The trial demonstrated that the GAG-3A device has applications in underground coal mines and that it outperformed all other available technologies with respect to volume of inert gas produced. It is clear that the GAG-3A produces a low oxygen level output and has a wide range of applications. The device produces a large volumes of low oxygen inert gas which can be used to replace a potentially explosive atmosphere in an underground coal mine.

The GAG-3A inert gas generating device was developed in Poland in the early 1970's and has been used extensively in Poland, Czech Republic, CIS, China, and more recently, to combat frequent and extensive gold mine fires in South Africa. A variation of this device was used, mounted on a remotely controlled tank, to extinguish the oil well fires in Kuwait following the Gulf War. The GAG-3A has been used for tens of thousands of operational hours with no serious accidents reported to date. The device was brought to Australia by the Polish Mines Rescue Service with SIMTARS providing operational support for this ACARP and industry-funded project.

Following the explosion at the Moura No 2 coal mine in 1994, the subsequent inquiry recommended that various forms of inertisation be investigated with regard to their suitability for use in Queensland coal mines.

Task Group 5 under the auspices of the Moura Implementation Committee was formed with two main foci, inertisation and the suitability of the current sealing strategies in use in underground coal mines. This project focussed on the demonstration of one particular inertisation strategy

The GAG-3A jet inertisation device was trialled under a variety of circumstances at the Collinsville No 2 Mine. The device produced large volumes of inert gas and complied with the criteria set down by Task Group 5 with the exception that due to site-specific conditions at

Collinsville No 2 Coal Mine, relating to water and ambient temperatures the flow rate of inert gas was 19 m^3/s rather than 20 m^3/s nominated in the Task Group 5 selection criteria.

This compares very favourably to the only other significant trial of inertisation in Queensland, at Moura No 4 in 1986, where 700 tonnes of liquid nitrogen were injected into a mine area over a period of 5 days to produce an oxygen level of less than 10%.

The GAG-3A achieved similar results in 6 hours at a fraction of the cost - $600,000 liquid nitrogen versus $4,500 Jet A fuel (Bell, et al, 1997).

In the mine the device operated faultlessly although there was one minor stoppage due to dirty fuel filter problems. The jet was re-started in less than 10 minutes. The operation of the device should be supervised by a competent ventilation engineer. It is clear that the GAG-3A produces lowered oxygen levels over a wide range of excess air conditions and therefore has a wide range of applicability.

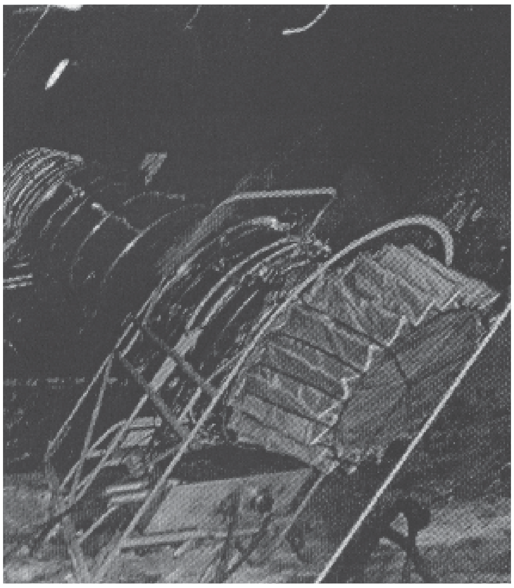


Figure 2.9 Demonstration of the GAG-3A jet inertisation device at the Collinsville No. 2 Coal Mine April 1997 ACARP Project 6019

On the basis of the trials conducted at Collinsville No 2 Coal Mine the GAG-3A device was concluded to be is applicable with respect to conducting relatively high quantity inertisation in underground coal mines. It was also concluded that each usage of the device would be dependent upon site-specific factors and the GAG-3A may not be suitable for every mine situation (Bell et al, 1997).

2.4.3. GAG-3A application - Blair Athol open cut mine, 1999

Blair Athol is an open cut mine in Queensland's Bowen Basin, 25km north west of the town of Clermont. The Number 3 seam mined at Blair Athol contains old underground workings from several collieries originally mined between the 1890s and 1960. As the old workings were exposed there had been a history of heatings but all had been easily treated (Prebble and Self, 2000).

However in July 1999 a new strip was commenced and the problems encountered were much greater than previously experienced. Coal in the strip rapidly heated and open fires formed in many areas. The propensity of this coal to self-heat presented two major risks for mining of the strip:

1. Smoke coming out of the old workings contained toxic levels of carbon monoxide, up to 1200ppm.
2. The possibility of an explosion in the old workings, fuelled by hydrogen, methane and carbon monoxide produced by oxidation of the coal.

Eight boreholes were drilled into the old workings to determine the atmosphere within the abandoned colliery. Results showed high concentrations of explosive gases and low oxygen, typically 10% CO, 12% hydrogen, 4% methane, and less than 1% oxygen (Prebble and Self, 2000).

To disperse this mixture of explosive gases it was decided to displace the explosive gases with inert gas. The GAG-3A inert gas generator was chosen to flush out the workings and then a Tomlinson boiler and/or Floxal nitrogen unit was used to maintain the inert state in the colliery. To provide access for the GAG into the old workings a 900mm borehole was sunk (to approximately 50m depth). Typical running times for the GAG at Blair Athol were 1-4 hours and in total five campaigns were run. Experiences stowed that it was highly effective in flushing out explosive gases although some teething issues with equipment and labour problems occurred.

2.4.4. GAG-3A application - Loveridge Mine, West Virginia, 2003

The Loveridge No.22 mine is operated by Consol Energy Inc. Following a fire in February 2003 the mine was evacuated and sealed. Shortly afterwards Consol contacted QMRS about the possibility of using one of the GAG units to extinguish the fire as shown Figure 2.10.

Two teams of operators were invited to assist Loveridge. The GAG ran for approximately 240 hours over 13 days and was successful in inertising the fire area. Following this success the mine could be re-entered by rescue teams and the mine could be unsealed.

Parkin (2005) also observed the effects of natural ventilation pressures, barometric changes, and rock falls on the backpressure experienced by the GAG. This was a key issue as high ventilation system backpressure resulted in a number of operational delays.

Figure 2.10 GAG-3A inertisation unit in use at the Loveridge mine, 2003

On February 13, 2003 a fire began in a trash car near the bottom of the slope in the Sugar Run area of this longwall mine, The mine was evacuated after some direct fire fighting attempts, the mine openings sealed and six boreholes drilled in and around the fire area for monitoring and water pumping.

By March 2003, attempts to suppress the fire with water pumped from the surface had not been fully successful. A decision was then made to attempt to inert the fire area using the GAG 3A jet engine technology. The QMRS was contacted to deploy an engine and operating personnel in a joint collaboration with Consol Energy (Parkin, 2005).

A ventilation simulation of the inertisation situation at Loveridge Mine was done by the operator, which concluded that it was feasible to inert the whole mine. On March 8, 2003, preliminary plans for a means (a docking facility) to connect the GAG 3A system to the existing slope entrance structure were discussed and the design of the necessary components was begun. The slope, initially sealed with a make-shift seal, would permit the inert gases to travel to the fire area near the slope bottom and continue through the main entries of the mine to the other shaft areas.

On April 4, 2003, the GAG 3A system had arrived at the Loveridge Mine site and, after some maintenance to the jet engine and its components; the system was commissioned for inertisation operations. Following the first 12 hours of engine operation, the unit was shut down due to overheating.

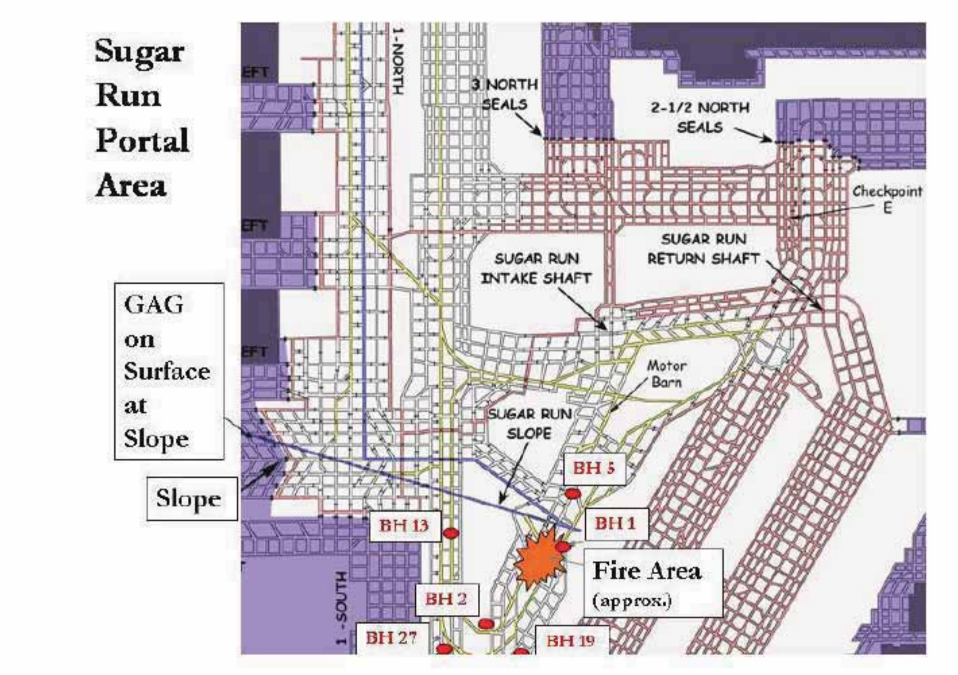


Figure 2.11 Fire area at Loveridge Mine (after Mucho et al, 2005).

On April 5, 2003, after 16 hours of run time, the plywood slope seal was leaking steam and the outer connection to the slope as shown in Figure 2.12 developed gaps and was leaking badly. The engine was shut down while repairs were made to the slope seal. Leaks in the ductwork attached to the slope were sealed with polyurethane foam and sand bags.

Figure 2.12 GAG 3A jet engine system interface with Sugar Run Slope. Note steam indicating exhaust gas leakage.

By April 9, 2003, boreholes and shafts in the Sugar Run area were out-gassing and readings indicated the presence of the exhaust gases. Examples of the presence and effectiveness of the engine exhaust gases in the Sugar Run bottom area, indicated by the presence of exhaust gases (CO_2 as the identifier) and the decrease in O_2 are shown in figures 2.13 and 2.14.

To facilitate movement of the exhaust gases throughout the entire mine, the seal of the St Leo Return Shaft, located at the opposite end of the mine was breached. After 5 days of operation, the jet exhaust gases had reached St Leo shaft and by April 13, 2003, St Leo and Miracle Run fans were first started, which helped to pull inert gases through the mine from the Sugar Run bottom area.

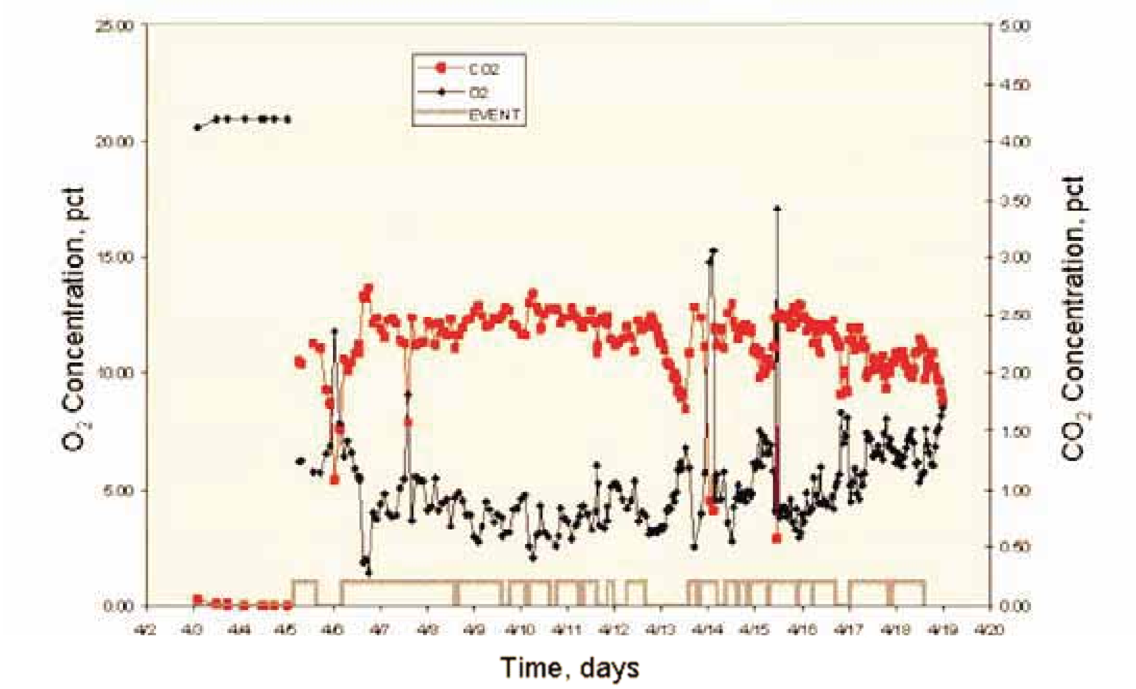


Figure 2.13 CO2 and O_2 concentrations in Sugar Run Slope, Loveridge Mine. "Event" as shown on the graph indicates GAG 3A operation (on/off) (after Mucho et al, 2005).

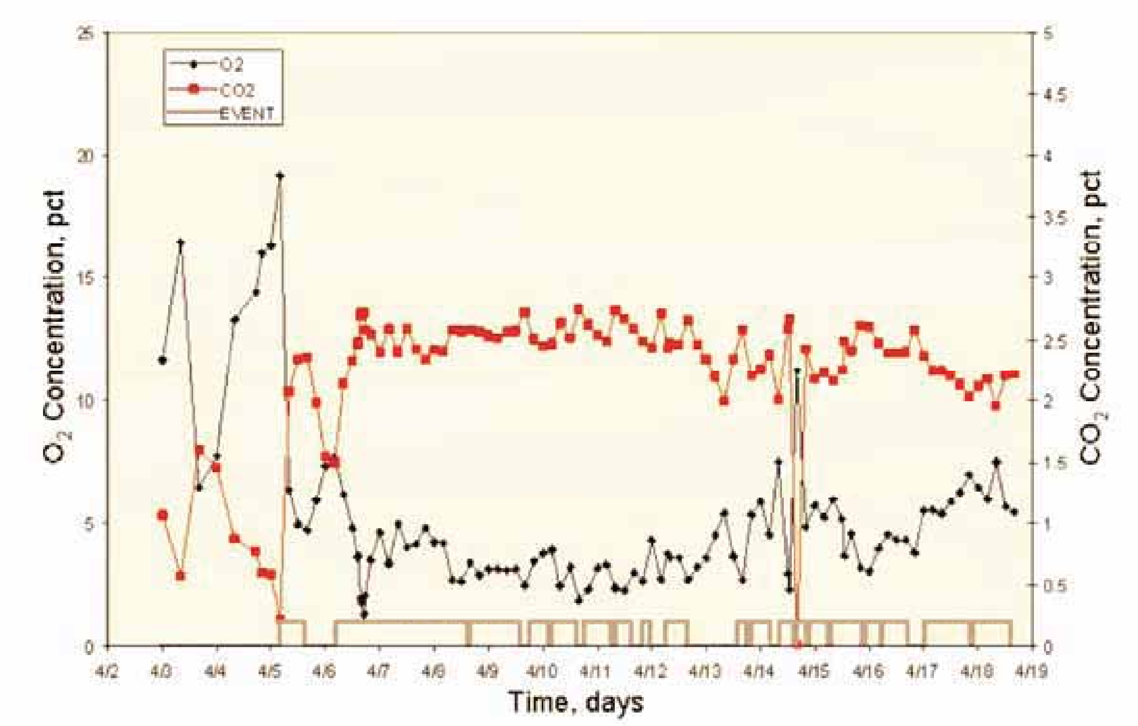


Figure 2.14 CO_2 and O_2 concentrations at borehole #1, Loveridge Mine. "Event" as shown on the graph indicates GAG 3A operation (on/off) (after Mucho et al, 2005).

At 8 pm on April 15th, 2003, the first rescue team re-entered Loveridge, 61 days after the mine was sealed and 10.5 days after the GAG engine was started. The GAG 3A system was operated intermittently during the mine rescue re-entry operations until April 21, 2003, when operations were terminated. In total, the engine operated for 270 hours with minor servicing and replacement of consumable parts and the engine consumed an average of 1,600 litres of fuel per hour and 18,500 litres of water per hour.

During its 17 days of operation at the Loveridge Mine, the GAG 3A system was able to render inert the Sugar Run bottom area and the over 9.5 miles of passageways at the Loveridge Mine by reducing the O_2 concentrations (Conti and Lazzara, 2003). As a result, the mine rescue teams were able to safely re-enter the mine to explore and ultimately isolate the fire area, which still had indications of active combustion, and was further inerted with N_2 injection and permanently sealed. At the time, this was the longest that the jet engine had operated for a mine inertisation application and some system components failed, but these occurrences were handled without major impact to the overall inertisation process. The potential benefit of more positive sealing of connections, ports, and mine seals was also recognized. Finally, the Loveridge Mine experience also provided a learning process for those involved and demonstrated that the GAG 3A system would be a valuable tool for fighting mine fires in the U. S.

2.4.5. GAG-3A application - Pinnacle Mine, West Virginia, 2003 and 2004

A series of four explosions between August 31 and September 16 2003 occurred at the Pinnacle Mine, Pineville, WV, in the active #8 longwall district shown in Figure 2.15. Mine gas readings from the various monitoring boreholes indicated that there was active combustion ongoing at an unknown location in the longwall district. The operator began drilling additional boreholes into the longwall gateroads to detect the heat source. Phoenix First Response was contacted by the operator and arrangements were made to utilize the GAG 3A jet engine in an attempt to inert the approximately 3 km by 3 km longwall district to extinguish the fire. Arrangements were also made to have trained GAG operators from Poland man the operation of the jet engine (Mucho et al, 2005).

By October 1st, the engine had been set up at the 8A bleeder shaft and the operators had arrived. The engine was started late in the day after a crane had removed the bleeder fan elbow conduit from the shaft and replaced it with a specially designed GAG docking hood that was then fastened to the shaft coping. This system had considerably less leakage issues than the Loveridge slope structure and temporary seal which were not as amenable to a pressurized, leak-proof connection.

The GAG 3A system ran successfully through October 7th with only occasional operational or maintenance issues. S. Fork fan was operated and ventilation adjustments made to assist in drawing the inert exhaust gases toward the active longwall. Even so, as occurred at the Loveridge Mine, there were periods when the engine would see more or less backpressure from the mine. Theories as to why this was occurring abounded and included flow restrictions, barometric pressure influences, and an "air bubble". Obviously, the exact cause could not be determined, but perseverance in terms of continuous operation of the engine seemed to overcome the variable backpressure problem.

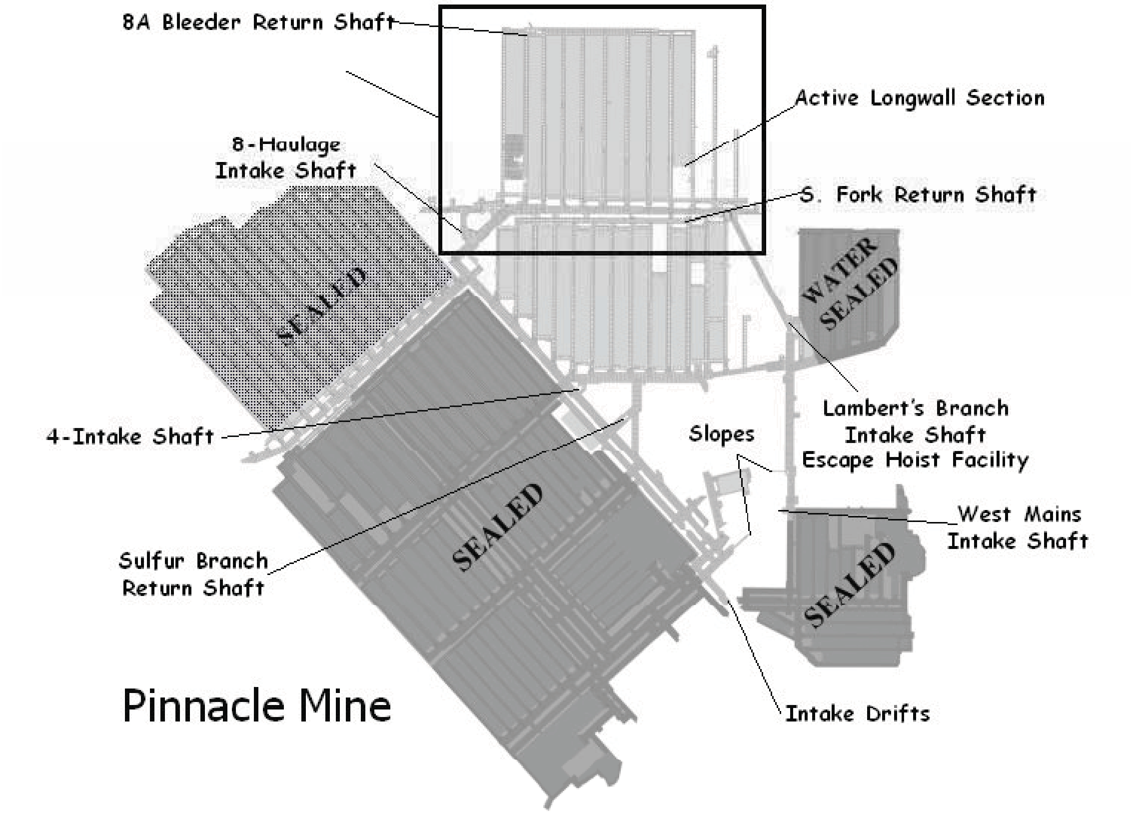


Figure 2.15 Pinnacle Mine showing #8 Longwall District, 8A Bleeder fan, and active longwall.

Tracking the underground movement of the exhaust gases via the monitoring boreholes in the #8 longwall district indicated that the exhaust gases initial migration was generally down-dip from the 8A shaft bottom, i.e., the structurally low northwest corner of the district inerted first and then the inerted zone gradually moved up-dip. Gravity (their higher density) may have been a reason for this, although ventilation (the operating S. Fork fan), ventilation controls, water accumulations, or goaf resistance could also have been reasons in whole or in combination (Mucho et al, 2005).

By October 8th, the inert gas front was approaching the active 8I longwall area and the five pressure monitoring borehole sensors measured a sudden pressure increase attributed to a gas ignition or explosion. The time to initially inert the desired area of the mine took approximately 7 days, which is the length of time that the mine had originally estimated.

The GAG 3A engine continued to be operated through October 19th in an attempt to maintain the inert area near the active longwall face. During this time, the pressure transducers measured another, much lower magnitude and less sudden, pressure increase on October 14th, indicating a possible explosion. Also during this time period, the mine operator, using a compressor, brought inert gases out of a borehole in the lower elevation area of the longwall district, transported the gases overland via a pipeline, and pumped the inert gases into boreholes closer to the area of the suspected ignition source in the goaf behind the active longwall face (Mucho et al, 2005).

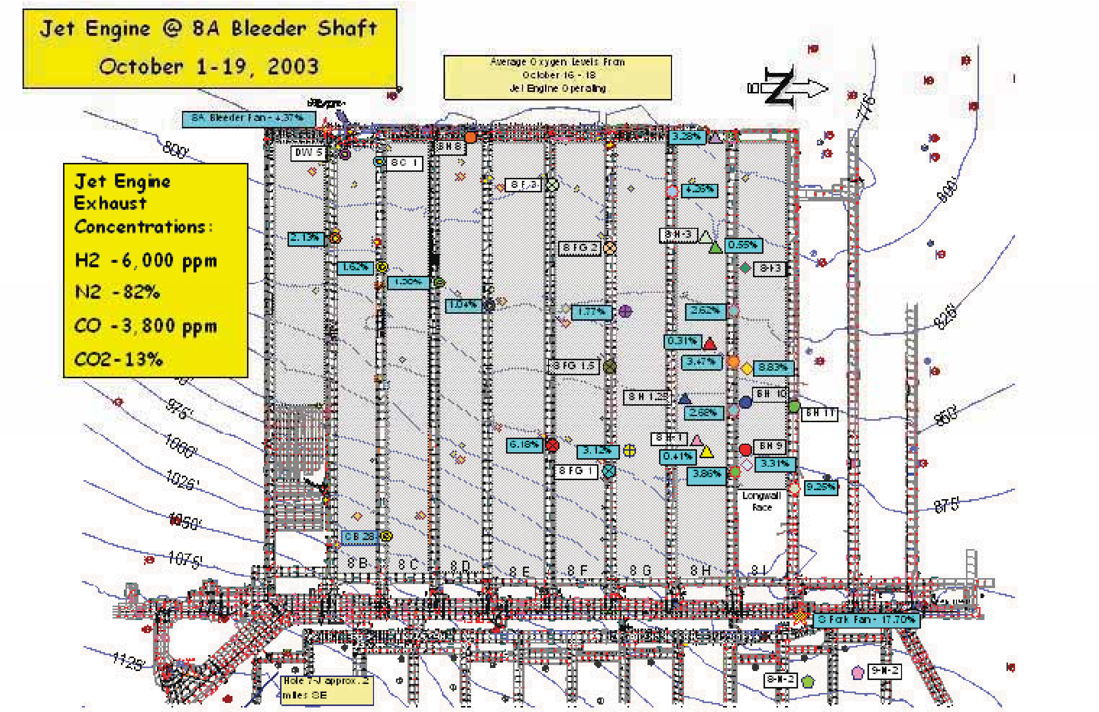


Figure 2.16 Pinnacle #8 Longwall District depicting bottom of coal elevation contours, 8I active longwall face, monitoring boreholes and GAG exhaust gas levels.

In the time period following the inertisation process, a more extensive array of pressure monitoring was installed in the longwall district and the mine was alternately ventilated using different ventilation scenarios. This ventilation process was an attempt to determine whether the ongoing ignition source had been successfully and completely extinguished by the inertisation process. While gas readings did not show conclusively that combustion was ongoing in the area, concerns about the presence and interrelationship of relatively small amounts of H_2, CO, and CH_4 delayed re-entry until a localised inertisation plan was instituted early in 2004. This re-entry plan is presented by Smith (Smith et al., 2005). The #8 longwall district was first temporally sealed and then permanently sealed in February and March of 2004, permitting continuous miner production to resume on April 7, 2004. Following re-ventilation of the 8I longwall panel in May, longwall production resumed on May 17, 2004.

2.4.6. GAG-3A application - Southland colliery December, 2003

Southland Colliery is located near Cessnock in the Hunter Valley. The mine, which was owned by Gympie Gold Ltd, was sealed following the fire but has since been reopened. It was concluded that the fire was started by spontaneous combustion in the goaf adjacent to the longwall face, and was unable to be contained.

Romanski (2004) gives an account of the use of the GAG at Southland. The initial callout came on the evening of the 24th of December 2003. The GAG unit and operators were mobilized on the 25th, and all necessary work before operation could commence was completed on the 26th. Operation commenced on the 27th and the engine ran almost continuously for over 43 hours.

Figure 2.17 GAG 3A Jet Engine set up at Southland Colliery, 2003

On the 29th Gympie Gold elected to halt the inertisation operation and the GAG was dismantled. During the operation the GAG unit consumed 65,000l of jet fuel, equating to approximately 1.4 million m^3 of dry inert gas. The effect of the inert gas on the fire was difficult to judge as the injection point was a long way from the fire site causing a long delay before inert gas could have reached the fire, and the lack of information available about the state of the mine following sealing.

2.4.7. Global Steamexfire Inertisation Services (GSIS) jet unit

The Global Steamexfire Inertisation Services unit operates in a very similar way to the GAG-3A jet engine and is purpose designed for mine fire inertisation. Owned by a Dutch company, GSIS launched its technology in 2005 and has been involved in the successful stabilisation of a coal mine fires at the Anglo Coal Goedehoop Colliery in South Africa in April in 2005 and the Svea Nord longwall coal mine in Spitzbergen, Norway in September 2005 (GSIS, 2007).

The company is reported to be working on offering more advanced technology. One of their upcoming releases will be a software inertisation program that will allow mines to run experimental exercises in real time, such as deciding the best possible inert site for a mine fire, goaf inertisation during longwall changeouts and experiments showing contaminate distribution underground and Steamexfire's inertisation effects.

2.4.8. Advantages and disadvantages of the GAG-3A

Advantages

- Well known to industry
- High volume inert gas generation

Disadvantages

- High set-up cost
- Requires a continuous feed of fuel and water
- Requires intense operator supervision
- Deliver inert gas at low pressure

2.5. Membrane Nitrogen Filter Units

The nitrogen production from an on-site generator is derived through a hollow fibre membrane separation process. It is the property of the membrane fibre that certain gases pass more quickly through the wall of the fibre than others. Filtered compressed air is introduced at the inlet of the bundle. As air (approximately 78% nitrogen, 21% oxygen, 1% other) passes through the hollow fibres, water, carbon dioxide, and oxygen molecules permeate through the wall of the fibre more quickly than nitrogen molecules. In this way, atmospheric nitrogen is concentrated as it passes along the membrane fibre. The process is continuous – this means there are no pressure swings. The inherent design of the membrane system means that systems are modular (allowing expansion of existing systems for more capacity as opposed to installing a larger unit), and that nitrogen production turndown is possible on larger systems.

A typical membrane system is comprised of:

- a 13 or 15 bar (g) single stage lubricated rotary screw air compressor/compressors with integral air drier,
- a membrane cabinet which includes compressed air filtration and membrane bundles,
- a mass flow meter and totaliser for performance monitoring and complete transparency,
- a downstream receiver to act as nitrogen buffer and source of peak nitrogen gas.

The entire system can be run automatically and remotely and is self monitoring. Similar units are available from other manufacturers in Australia.

2.5.1. Specification and current applications of the Floxal AMSA units

The AMSA's systems for underground inerting have been purpose built for the Australian coal mining industry. They have been designed as a complete, portable, skid mounted package. The primary components of the AMSA system are (Sajimon, 2005):

- Lubricated screw air compressor/compressors
- Air drying and filtration skid
- Nitrogen membrane air separation modules
- Nitrogen buffer/receiver
- Transportation skid/frame
- PLC control system and TeleFlo wireless communications computer

Figure 2.18 Floxal membrane inertisation unit at mine site

Atmospheric air is filtered and compressed in a standard air-cooled single stage lubricated screw air compressor/compressors. Compressed air is cooled with an air-to-air heat exchanger and dried with a refrigerated air drier. A condensate drain and two coalescing filters remove the liquid carryover entrained in the compressed air. An activated carbon filter removes hydrocarbons that may carryover past the filters. The clean dry air is then heated to ensure a uniform feed air temperature into the nitrogen membrane modules. As air passes through the membrane modules, oxygen and remaining water vapour are vented (discharged through the waste gas header) and nitrogen gas is concentrated. An oxygen analyser continuously monitors the produced nitrogen to ensure that oxygen levels are maintained at all times. Nitrogen gas is discharged from the AMSA at 9 bar pressure (Sajimon, 2005).

The operation of the AMSA system is monitored and controlled by a PLC. Interfacing with the PLC is TeleFlo – Air Liquide’s proprietary telemetry and communications computer. Teleflo is Air Liquide’s facility management system based on a robust combination of industrial PC hardware and software specific to Air Liquide’s Floxal systems.

The TeleFlo system includes a GSM wireless link to interrogate the Floxal system at any moment and observe all process parameters. Conversely the Floxal system is able to ‘call out’ to signal routine maintenance for example or to issue alarms if necessary.

Technical staffs in all regions carry pagers which the Floxal units TeleFlo system can 'call' day and night. On being paged they are able to connect to the site with portable computers, and to investigate the nature of the problem. The TeleFlo system is powered by an un-interruptible power supply so that it can proceed with calling out to signal alarms as necessary and may still be interrogated remotely.

Floxal AMSA for goaf inertisation performance specifications (AMSA Floxal Unit, 2006):

- Nitrogen flow: 1934 m^3/hr
- Nitrogen gas pressure: 9 bar
- Residual oxygen: 3%
- Design availability: 98%/annum

Floxal AMSA utility requirements:

- Water: none
- Fuel oil: none
- Operators: none
- Electricity: 3 phase 415VAC, 805 kW, 981 kVA
- Surface Preparation: Level packed earth; sleepers may be used to distribute skid load and aid levelling.
- Telemetry connection: phone line, reliable GSM network reception, or satellite phone connection.

Footprint and weight:

- A standard AMSA 3000 series (with 14 x 12''Modules) nitrogen generation unit with after cooler and refrigerated drier, skid mounted. (L: 14.5m x W: 3.5m, Wt: 20 T)
- A Compressor skid having 3 x Kaeser ESD 441 air compressors with MCC. (L: 14.5m x W: 3.5m, Wt: 25 T)
- One 8 KL nitrogen buffer vessel mounted on the AMSA Skid.
- The ancillary equipment necessary to ensure the stable and reliable operation (control panel, PLC, Teleflo, interconnecting piping and wiring) of the Floxal and compressor.

2.5.2. Advantages and disadvantages

Advantages

- No CO, therefore no masking of spontaneous combustion heatings
- No toxic gas introduced
- Low set-up cost and easy set-up
- Can deliver gas at pressure
- Possible of centralized "fixed" positioning of the unit
- Inert gas generated continuously
- No need for operator supervision

- No requirement for fuel or water
- System and Performance is monitored
- 1934 m^3/hr of nitrogen from a single AMSA system can be delivered over 12.5 km through a 4" pipeline.

Disadvantages

- Requires a continuous supply of 415 VAC electricity
- High cost for electricity usage
- Relative new to the industry

2.6. Summary of Inertisation Systems

Inertisation has been accepted to have an important place in Australian mining emergency preparedness. The two jet engine exhaust GAG units purchased from Poland by the Queensland government in the late 1990s for the Queensland Mines Rescue Service have been tested and developed and mines made ready for their use in emergency and training exercises. Their use in real and trial mine fire incidents has underlined the need for more information on their application.

The NSW Mineshield (liquefied nitrogen) apparatus dates to the 1980s and has been actively used a number of times particular in goaf heating incidents. The Tomlinson (diesel exhaust) 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" and for goaf spontaneous combustion heatings.

Nitrogen Pressure Swing Adsorption (Floxal) units are available and in use both for reducing time in which goafs are "within the explosive range" and for goaf spontaneous combustion heatings. Each of these facilities puts out very different flow rates of inert gases. Each is broadly designed for a different application although there is some overlap in potential usages.

Table 2.3 examines some typical simplified characteristics of the outlet flow of examples of these four units.

Some recent Australian incidents have utilised more than one form of inertisation to stabilise an incident. Table 2.4 lists the systems used at the Dartbrook Colliery 2006 goaf heating.

Table 2.3 Characteristics in simplified form of the outlet flow of the GAG-3A, Mineshield, Tomlinson and Floxal inertisation units.

	Flue Gas[1] Generator (Tomlinson Boiler)	Mineshield[2] Liquid Nitrogen System	GAG unit[3]	Membrane[4] System (AMSA Floxal Unit)
Inert Output Range, m^3/s	0.5	0.2 – 4.0	14 – 25	0.12 – 0.7
Default Quantity, m^3/s	0.5	2.0	20	0.5
Delivery Temperature, ^{o}C	54	Atmospheric	85	20
Oxygen, %	2	0	0.5	3
Nitrogen, %	81.5	100	80 – 85	97
Carbon Dioxide, %	15.3	-	13 – 16	-
Carbon Monoxide, ppm	0	-	3	-
Water Vapour, %	1.2	-	some	-
Water droplets			significant	

Table 2.4 Systems used at the Dartbrook Colliery 2006 goaf heating (after Sykes and Packham, 2006)

System	Capacity l/s	Installed	Removed
Floxal AMSA 16	120	Pre 19/01/2006	
Floxal AMSA 17	120	Pre 19/01/2006	
Tomlinson 1	300	Pre 19/01/2006	11/02/2006
Tomlinson 2	500	24/01/2006	
Tomlinson 3	500	11/02/2006	
Air Liquide nitrogen	300 (up to 500)	12/02/2006	
BOC nitrogen	300 (up to 1200)	18/02/2006	

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[1] Tomlinson Boilers, 2004

[2] Mines Rescue, NSW, 2007

[3] Bell, et al, 1997

[4] Sajimon, J. 2005 and AMSA Floxal Unit, 2006

2.7. CONCLUSION

The chapter has examined types of inertisation systems currently available and in use in Australian coal mines for sealing mines or mine sections, for elimination of the potential explosibility of newly sealed goafs, for combating goaf spontaneous combustion heatings or for stabilising fires in high priority locations. Systems have been compared in a number of tables to allow evaluation of the advantages and disadvantages of each approach.

3. SOME ISSUES OF IMPORTANCE IN MINE INERTISATION

3.1. Introduction

Underground mine fires lead to complex interrelationships with airflow in the mine ventilation system. Addition of the gas stream from an inertisation unit adds another level of complexity to the underground atmosphere behaviour. Important questions are raised such as 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? This chapter examines simulation exercises on mine examples of inertisation usage to focus on a number of issues raised in introduction of the additional gas flow to the mine ventilation network.

3.2. The GAG and the Mine Ventilation Systems

Simulation exercises on the introduction of the GAG or other apparatus to a mine ventilation system have indicated that there is a substantial lack of knowledge on use of these facilities. The Queensland GAG units were first used actively in 1999 at the Blair Athol mine to handle a spontaneous combustion issue in old underground workings that were about to be mined by surface techniques as described by Prebble and Self, 2000. The GAG unit was subsequently used successfully in an underground mine fire at the Loveridge mine, West Virginia in early 2003 (Urosek et al, 2004). On this occasion the GAG ran for approximately 240 hours over 13 days and was successful in stabilising the mine so that rescue teams could enter the mine and seal and fully extinguish the fire affected zone. Much was learnt about the ventilation network behaviour and the need to have an upcast shaft open. Observations were made on the effects of natural ventilation pressure, barometric changes and rock falls on the backpressure experienced by the operating GAG.

A fire which was suspected to have been caused by lightening strike at the Pinnacle mine, also in West Virginia, was out of control from October 2003 to May 2004. A Polish owned GAG unit was successfully used to stabilise the situation although there were a number of underground gas explosions during the course of the incident (Campbell, 2004). Following these experiences the US Micon company has purchased GAG units and has developed a commercial mine emergency and recovery business.

New and innovative approaches to mine recovery are occurring. In the US an equipment unit fire in the Dotiki mine, Kentucky, in early 2004 was stabilised using a Nitrogen and Carbon Dioxide (Wesley et al., 2006). Also in early 2004 carbon dioxide was used to stabilize a goaf spontaneous combustion heating in the West Ridge mine in Utah (Stoltz et al., 2006).

Simulations using the fire simulation software VENTGRAPH can be undertaken to gain better understanding of how inertisation units or systems interact with the complex ventilation behaviour underground during a substantial fire or hating. Aspects worthy of examination include:

- Location of the introduction point for inert gases for high priority fire positions; e.g. portal docking position, special boreholes;
- Size (diameter) of borehole or pipe range required to deliver inert gases and back pressure issues;
- Time required for inertisation output to interact with and extinguish a fire;
- Effects of seam gas on fire behaviour with inertisation present;
- Changes which can be safely made to the ventilation system during inertisation including switching off some or all fans;
- Need for remote controlled underground doors to channel inert gases to the fire location;
- Complications caused by underground booster fans; and
- Spontaneous combustion issues.

3.3. Effects of Positioning of Inertisation Units on Fires and the Mine Ventilation System

An ACARP research project entitled “Mine Fire Simulation in Australian Mines using Computer Software” incorporating a number of mine site exercises to reduce the effects of fire incidents and possible consequent health and safety hazards has been undertaken focused on the application of mine fire simulation software packages for contaminate tracing and fire modelling in coal and metalliferous mines (Gillies, Wala and Wu, 2004). Broad conclusions from work undertaken at individual Australian coal mines are discussed as examples. The effort is built around the introduction of the fire simulation computer program ‘VENTGRAPH’ to the Australian mining industry and the consequent modelling of fire scenarios in selected different mine layouts.

Generic case studies have been developed to examine usage of inertisation units and particularly application of the GAG jet engine 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 stopping 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 third examines inertisation and dilution issues in mains headings. Mains headings present a complex ventilation network with often numerous parallel headings, hundreds of cut-throughs and a variety of ventilation control devices. In such a complex system (with additional interference from a fire), maintaining control of the movement of inert gas is more difficult than elsewhere in the mine. Some illustrations of this issue are given.

3.3.1. Positioning of inertisation units

Studies were 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. A generalised longwall mine layout was used with the length of Mains was set at 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 outbye 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 outbye 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 3.1 and 3.2).

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.

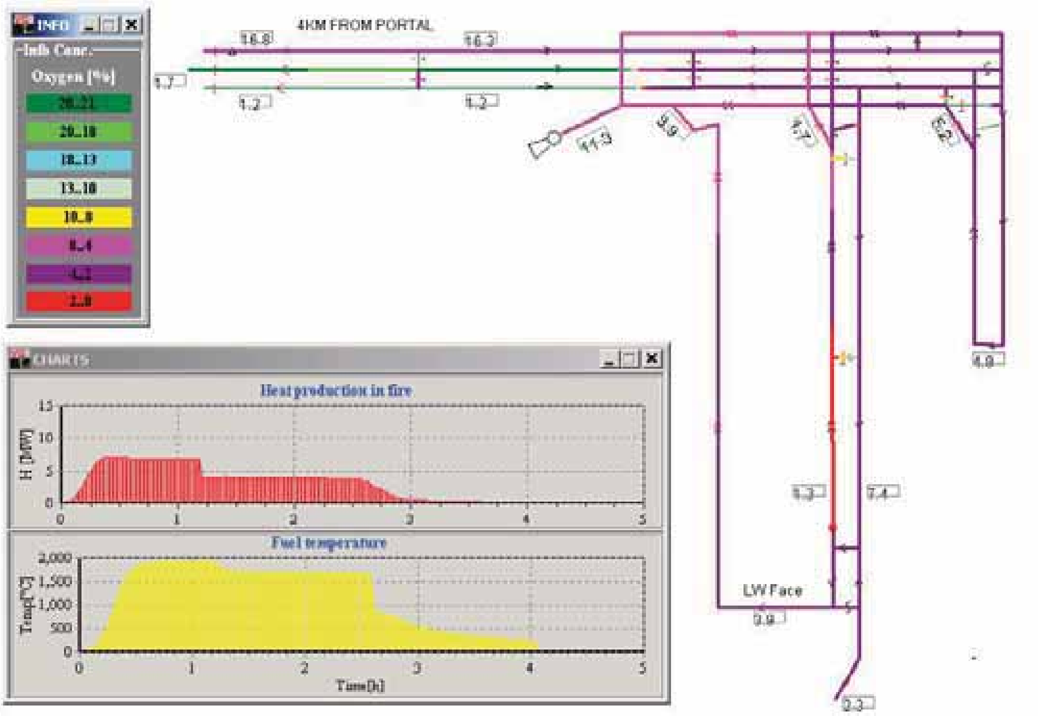


Figure 3.1 GAG position at the portal B heading for 4km Mains length

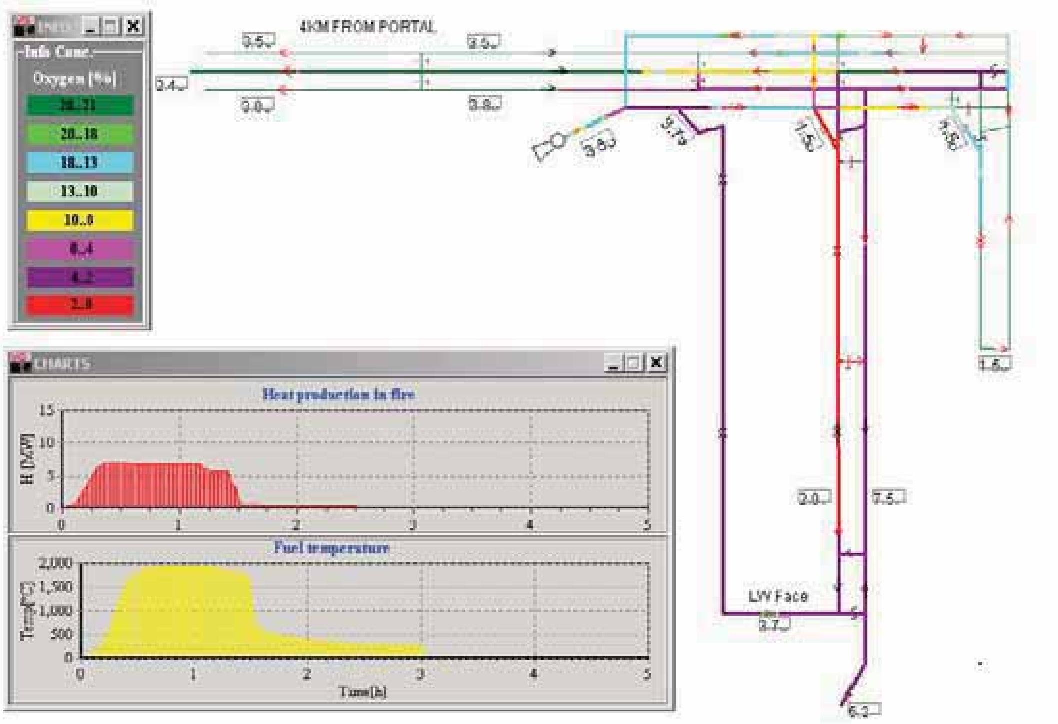


Figure 3.2 GAG position at the top of back longwall borehole for 4km Mains length.

The same conclusion from GAG studies also applies to use of other tools such as the Nitrogen Shield in New South Wales. Any evaluation of this kind requires a detailed study of each mine's ventilation and fire simulation model to identify optimum unit position placement for various fire locations.

3.3.2. 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 Mains travel road 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 outbye 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°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°C around 4 hours after the GAG was started as indicated in Figure 3.3. 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 3.4. A sharp drop of the heat produced from the fire is observed.

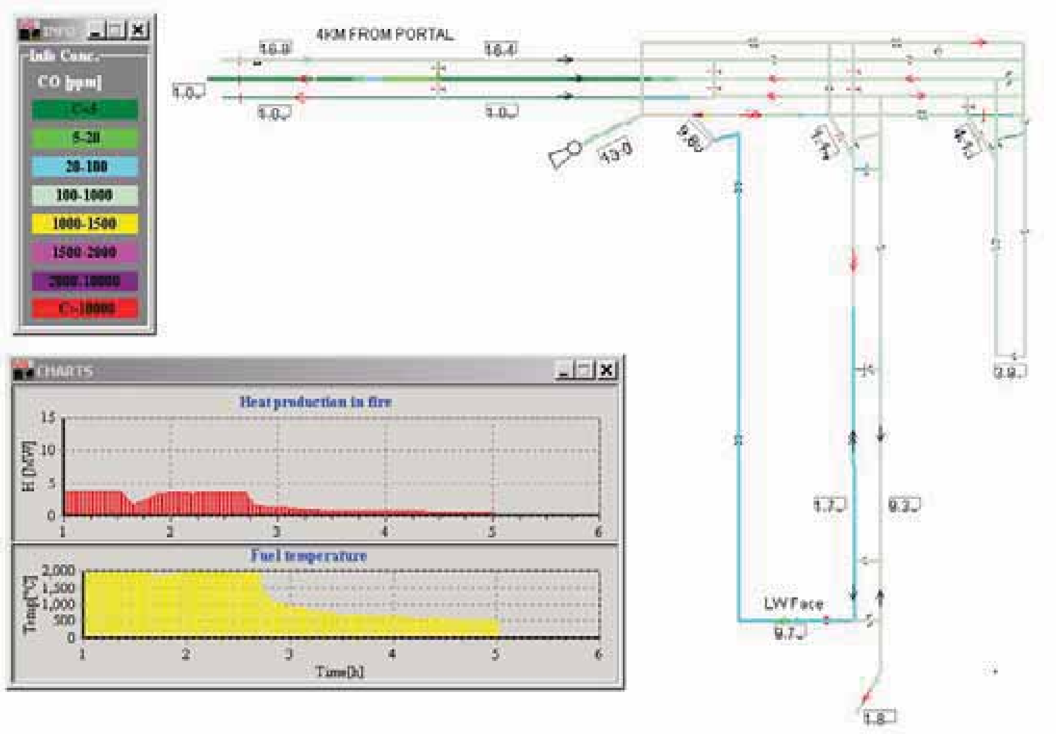


Figure 3.3 Gassy longwall dipping at 2.5% from Maingate to Tailgate.

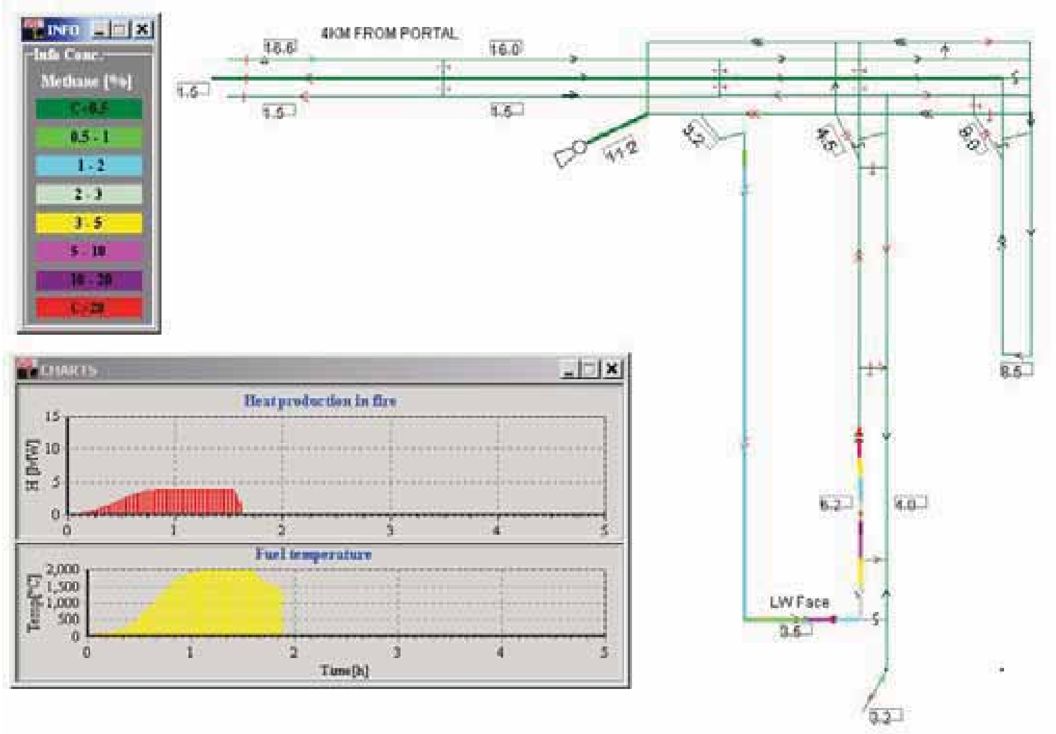


Figure 3.4 Gassy longwall dipping at 5% from Maingate to Tailgate.

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

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?

3.4. Effective Docking Positioning of Inertisation Units

Positioning of the inertisation units is a major determinant of potential success for most efficient suppression of a specific fire. Traditionally in Queensland docking points have been placed on intake ventilation headings (either travel or conveyor belt roads). Some mines have prepared docking points on boreholes of about 1.0 to 2.0m diameter placed at the back of longwall panels.

The advantages that can be gained from use of various inertisation docking positions depends on a number of considerations including the location of the fire, the relative distance from the inertisation docking 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, fuel, water and other operating requirements.

Priority fire locations at mines with VENTGRAPH simulation models developed in an ACARP research project entitled “Mine Fire Simulation in Australian Mines using Computer Software” have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage. In the study it was assumed that the GAG would be docked at a prepared position designated by the mine (most commonly the current fabricated docking installation; in most mines this is at the portal of a Mains travel or belt heading).

A system was derived for categorising mines’ principal inertisation docking points as to their ability to inert a priority fire location as set down.

- Category A covers fire in which the inertisation product is directed fully over the fire. No mine priority fire examined achieved the situation in which the simulated fire is directly stabilised to aid recovery in a timely manner.
- Category B covers situations in which the inertisation product goes straight to the fire but there is significant dilution from other ventilation air or leakage through stoppings. Because of dilution stabilisation of a fire through inertisation can only be achieved with some main surface fan changes. 20 percent of mines are in this category and under these situations the fire should, over time, be abated or stabilised to a point where conventional recovery approaches can be initiated.
- Category C covers priority fires in which the GAG output will never reach the fire location without stopping of one or more main surface fans to rebalance ventilation within the pit. In many of these cases requiring fan changes to put GAG output across the fire location

effective ventilation air velocity has been reduced to the extent that local reversal across the fire occurs and fire fumes are pulled across the fire. This is an unsatisfactory situation as fire smoke and fumes can carry combustible products. This situation broadly prevails for 46 percent of the cases examined

- Category D covers priority fires in which the GAG output will never reach the fire location even if surface main fans are altered. These are fire locations within panel sections in which either the fire behaviour stops normal intake ventilation flow into the section headings or the GAG docking point is in an airway that is isolated from the section. This situation is seen in 14 percent of the cases examined.
- Category E covers priority fires in gassy mines in which section production gas make has been included in the simulation modelling. GAG exhaust will never reach the fire location without stopping of one or more main surface fans to rebalance ventilation within the pit. However this change in ventilation causes working section methane and ventilation air (incl. fire fumes) to reverse across the fire. This is clearly a potentially dangerous situation. This situation was found in 20 percent of the cases examined.

A total of 71 potential priority mine fire locations that have had scenarios simulated were reviewed. From these 35 scenarios were considered worthy of incorporating utilisation of the GAG as an exercise in recovery of a mine following a major fire. Table 3.1 shows results of the outcome of the 35 scenarios from the study.

These simulation exercises undertaken with a wide range of Australian mines focuses attention to the situation that many potential underground mine fire sources cannot be successfully inertised with the GAG docked at the current specified point.

This inability to deliver GAG output is particularly so for fires in extended areas of workings or in panels. Two important conclusions are

  - Successful delivery of GAG output from units on the surface must consider other (that is alternative to Mains Travel or Conveyor Heading portals) delivery conduits directly into workings near the fire through existing or purpose drilled boreholes.
  - During a fire the stopping of the main surface fan or fans will lead to rebalancing of pit ventilation and in some cases potential explosions through air reversals bringing poorly diluted explosible seam gases or fire products across the fire site.

The next section examines some considerations in use of boreholes for delivery of inertisation products.

Table 3.1 Effectiveness of GAG delivery

Code	Description	Results out of 35 scenarios simulated	Percentage %
A	GAG exhaust delivered efficiently (without significant dilution) to fire.	0	0
B	GAG exhaust reaches fire but diluted and not fully effective. Fan change needed to allow inertisation stabilisation of fire.	7	20
C	GAG exhaust reaches fire only after fan change and potentially effective after local reversal of ventilation air (incl. fire fumes) across fire.	16	46
D	GAG exhaust will never reach fire even with fan changes.	5	14
E	GAG exhaust only reaches fire after fan change. Reversal of working section methane and ventilation air (incl. fire fumes) across fire.	7	20

3.5. Inertisation Effectiveness in Mains Heading Fires

Mains headings present a complex ventilation network with five or more parallel headings, numerous cut-throughs and a variety of ventilation control devices. In such a complex system with additional interference from a fire, maintaining control of the movement of inert gas is more difficult than elsewhere in the mine. There is added emphasis in Queensland where most mines have inertisation injection portals (docking stations) connected to Mains entries. At present most Australian collieries have limited control over flow of air in Mains intakes. The quality of segregation stoppings and doors varies greatly between sites. Some states have legislative requirements regarding segregation.

Causes of fires in mains headings include:

- Belt fires (including transfer points and motors)
- Vehicle fires
- Spontaneous combustion in pillars (particularly pillars with large pressures differences across them)

It is not always practical, or safe, to turn off the main fans and flush the mine with inert gas in the event of a fire. Given this limitation, use of segregation can allow fans to be kept on while inert gas is delivered to a particular fire site without dilution and without losing inertising gases in the other airways. On the other hand, without adequate segregation inert gas will spread between all intake airways and be diluted by fresh air. It will also leak to returns.

To determine the impact of the quality of segregation (stopping resistance) on GAG effectiveness in a quantitative manner, Hosking (2004) undertook VENTGRAPH simulations using a fully segregated belt heading with a range of segregation stopping resistance values. The belt way carries intake air and had a regulator placed outbye to reduce airflow and cause leakage flow into it from adjacent intake headings A GAG unit was connected to the beltway drift and run at 11 000 rev/min to give an exhaust stream with an oxygen level less than 5 per cent. The oxygen level found at each cut-through was then measured for each stopping resistance. To keep the scenario simple no doors were included and no fire was actually placed in the drive. The mine fans were kept on throughout the simulations. Existing overcasts in the model were retained and cut-throughs were spaced at about 50 m intervals.

Figure 3.5 shows the results as a set of contour lines for oxygen concentrations. It can be seen that on a log-log plot the dilution rates form a clear relationship with stopping resistance and distance. As would be expected higher resistance segregation stoppings will maintain a reduced atmospheric oxygen content at fixed sensor points in the belt road, and the oxygen content increases with distance from the drift (as the number of leakage paths increases). As the pressures across stoppings are lower further inbye, the leakage rate drops and the contours become steeper.

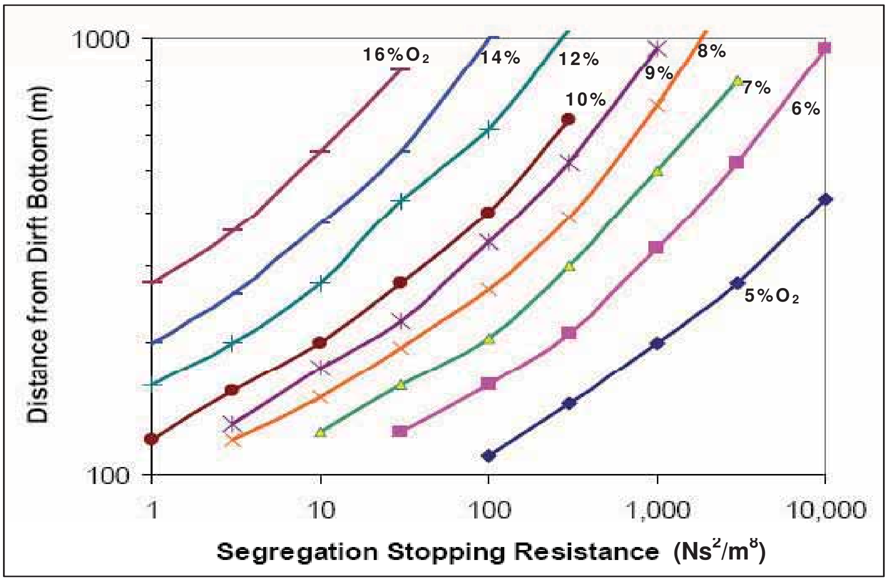


Figure 3.5 Dilution of inert gas at varying segregation qualities and distance

Considering the contour for 10 per cent oxygen (a level below which open flames will not occur), the quality of segregation has a dramatic effect on the range of the inert gas. If flaps/used conveyor belt are used for segregation (resistance less than10 Ns^2/m^8) this concentration of inert gas will only travel 200 m – the first four cut-throughs after the drift bottom. On the other hand a quality stopping that is well maintained (resistance of 100 Ns^2/m^8) will keep the oxygen level at 10 per cent for the first 400 m of the mains.

Figure 3.6 illustrates how effectively the ventilation network can deliver inert gas to a fire at 1.0 km distance. Stopping resistances less than 10 Ns^2/m^8 are unable to stop dilution of the heading air at this distance. Above 10 Ns^2/m^8, the oxygen content steadily declines with higher quality segregation.

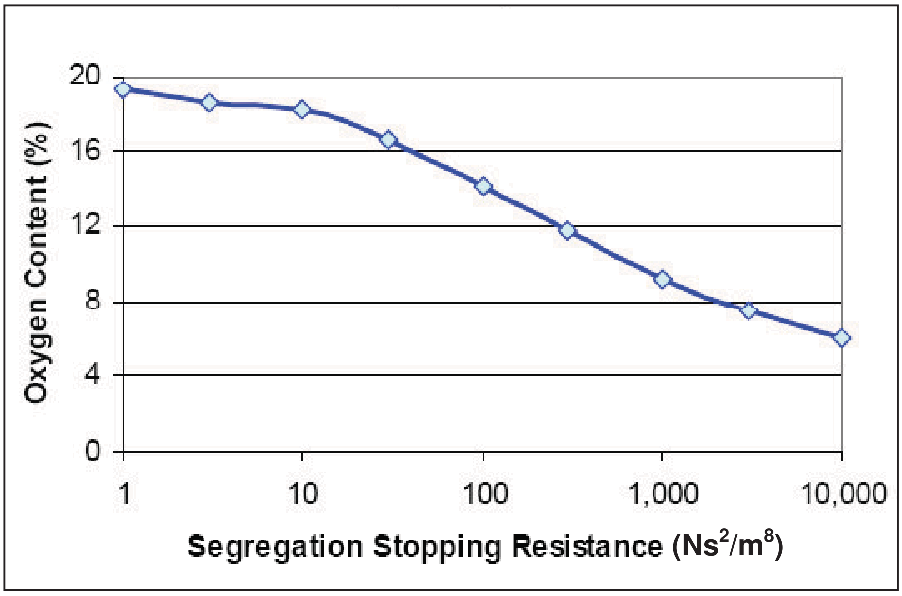


Figure 3.6 Dilution of inert gas at 1.0 km from drift bottom.

These plots are relatively simple to generate for a ventilation network once the model exists. While it may be technically unrealistic or impractical to consider changes to segregation stoppings in an existing mine, diagrams of this form are useful as a planning tool for future developments. Good quality segregation restricts the spread of contaminants (heat, dust and gas on a routine basis and smoke and fire products in an emergency) in addition to assisting the movement of inert gases.

3.6. Inertisation of Highwall Punch Mines and Use of Boreholes

A number of Australian mines have adopted “punch” mine layouts with access to workings through the highwall of a box cut. Many of these have no conventional Mains. Practical options for inertisation of punch mine longwall workings are required. Borehole docking and delivery of inert gases may be required for fires in some sections of the mine if the open cut is not available for GAG action because of

- Geometry of the open cut,
- Open cut road access issues,
- Open cut roads pass in front of open portals,
- Potential of fume build up in the box cut

There is a debate on whether a borehole into punch mine workings should be placed near the front of the mine workings (close to and within a few hundred metres of the highwall portal) or at the back of the mine behind the longwall installation road. These alternatives of use of a front or back borehole have various advantaged and disadvantages that are often mine layout specific.

The use of a back borehole to conventional longwall panels in Queensland is becoming very common. Examples are for instance in use or planned at Crinum, North Goonyella, Moranbah North, Grasstree, Oaky Creek No 1, and Kestrel collieries. Other mines such as Bundoora and Aquila have put in boreholes for potential inertisation use. The punch mines of Newlands North, Broadmeadow and Crinum East have examined the competing merits of use of different location boreholes for inertisation use.

A back borehole in a punch mine can be useful for the following.

- Borehole downcast air can be used at start of extraction of LW panels to ventilate Main Gates if development slows over life of mine and there is no hole through to the next planned panel. It provides a form of ventilation insurance.
- Borehole downcasts clean air that provides some additional ventilation throughout LW panel lives.
- Chilled air can be downcast through the borehole throughout LW panel lives with positional advantage for delivery when longwall face is farthest inbye and often at greatest depth.
- Borehole can be used for services and communication links.
- Borehole delivery of GAG inerts is generally equal to or advantageous (in terms of GAG operating time to inert a fire) for back half of mine compared with docking at front boreholes or highwall portals.
- Borehole can be used for emergency man escape if it is considered too far to walk from back of LW panels to open cut portals.

Front boreholes can be developed earlier than back boreholes. However they do not generally have the positional advantage in relation to providing extra production face air (chilled or normal) or emergency man escape. Efficiency of inert gas delivery through a front borehole will partly depend on mine layout and whether the mine longwall panels are progressing from right to left or left to right. Extra overcasts or remote operation of a VCD door or regulator may be required to direct borehole inert gases to the fire site.

The use of highwall portals for delivery of GAG inerts to longwall panels is the simplest and most direct approach. No extra development of borehole drilling is needed. All new development immediately inbye a new Portal requires this approach for delivery of inert gases until a borehole (if one exists) is holed into. The docking approach is essential for the first part of any new Development headings.

Many punch mines are currently being developed with provision for inertisation docking at both the highwall and boreholes to allow efficient inertisation of fires across a variety of priority locations.

3.7. Conclusions

The potential for simulation of the effects of inertisation on fires within a mine ventilation network was examined. The project involved applying the VENTGRAPH mine fire simulation software to preplan for mine fires. Work undertaken to date at some Australian coal mines is discussed as examples. The effort has been built around the modelling of fire scenarios in selected different mine layouts.

Case studies have been developed to examine usage of the GAG inertisation unit. One section examined seam gas emissions in the face area; 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?

Another section has focused on selection of the surface portal location for placement of the GAG for effective fire suppression. The difficulties that some current approaches present are highlighted. The advantages that can be gained from use of various inertisation docking positions depends on a number of considerations including the location of the fire, the relative distance from the inertisation docking 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, fuel, water and other operating requirements.

Priority fire locations at a wide selection of mines with a developed and current Ventgraph simulation model have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage. In the study it was assumed that the GAG would be docked at a prepared position designated by the mine (most commonly the current fabricated docking installation). Many mine layouts were reviewed and from these 35 scenarios were considered appropriate for use of the GAG. These fires were categorised A to E in terms of ability of the GAG exhaust to effectively stabilise and extinguish the fire. As examples of results no fires met the category A description, 14 percent met category D and 20 percent met category E. The conclusion is that the current situation is not well placed to effectively inert most colliery priority fires.

These simulation exercises undertaken with a wide range of Australian mines focused attention to the situation that many potential underground mine fire sources cannot be successfully inertised with the GAG docked at the current specified point. This inability to deliver GAG output is particularly so for fires in extended areas of workings or in panels. Two important conclusions are

- Successful delivery of GAG output from units on the surface must consider other (that is alternative to Mains Travel or Conveyor Heading portals) delivery conduits directly into workings near the fire through existing or purpose drilled boreholes.
- During a fire the stopping of the main surface fan or fans will lead to rebalancing of pit ventilation and in some cases potential explosions through air reversals bringing poorly diluted explosible seam gases or fire products across the fire site.

Another section has looked at inertisation and dilution issues in Mains headings. These present a complex ventilation network and with additional interference from a fire, maintaining control of the movement of inert gas is more difficult than elsewhere in the mine. Even good quality segregation stoppings allow significant dilution of inertisation flows over relatively short distances

A final section has examined considerations presented by “punch” mines layouts. A number of recent punch longwall mines are accessed off highwalls including Broadmeadow, Carborough Downs, Newlands North and Crinum East. These mines have some provision for GAG docking from within the highwall pit but all have put down boreholes to workings which enable the GAG team to operate the engine from the safety of the surface.

4. GAG-3A INERT GAS GENERATOR CALIBRATION EXERCISES

4.1. Introduction

Two validation studies of the mine fire simulation program VENTGRAPH using data gathered from an actual mine fire or other real exercises have been examined. One involved examination of data from a large mine fire and the other use of the GAG-3A inertisation unit as an exercise in making safe old mine workings on mine closure.

4.2. Validation Study of the Mine Fire Simulation Model against Pattiki Mine, Kentucky 1991

Validation studies of the mine fire simulation program VENTGRAPH using data gathered from an actual mine fire which occurred in November 1991 at the Pattiki Mine, Kentucky in US were undertaken by Wala et al (1995). The study evaluated the suitability of the simulation software for modelling an underground fire.

The study simulated a fire as written up in the major event publication listed in the MSHA District #8 Accident Report, 1992. Throughout the fire CO concentration at the mine exhaust fan station was continuously measured and recorded by the mine control and monitoring system and this data stream was used as indicator to compare the VENTGRAPH simulated fire with the real fire.

The simulation processes involved the following steps,

- modelling of the ventilation system prior to the fire,
- modelling of the fire source,
- simulation of the actual fire according to the major event record.

A series of simulations were undertaken using a trial and errors method. The reason for this approach was to obtain a match with the CO data recorded at the fan station and to determine a time sequence for the fire area growth and for parameters which characterise dynamics of fire development. A comparison of the simulated and actual CO levels at fan station is shown in Figure 4.1. The thin solid line represents the simulated CO level and the thick line represents the actual CO level recorded. It can be seen that there is a very close correlation between the simulated and actual CO levels. The time axis of the figure presents real time and descriptions of the particular actions that took place during the fire.

The study shows the VENTGRAPH mine fire simulation model is able to simulate the documented scenario of mine fire at the Pattiki Mine with great confidence. Consequently the calibrated model can be used to perform a number of simulation exercises to test different fire frighting and sealing strategies. The study also shows the importance of the real time atmospheric monitoring system for the validation process.

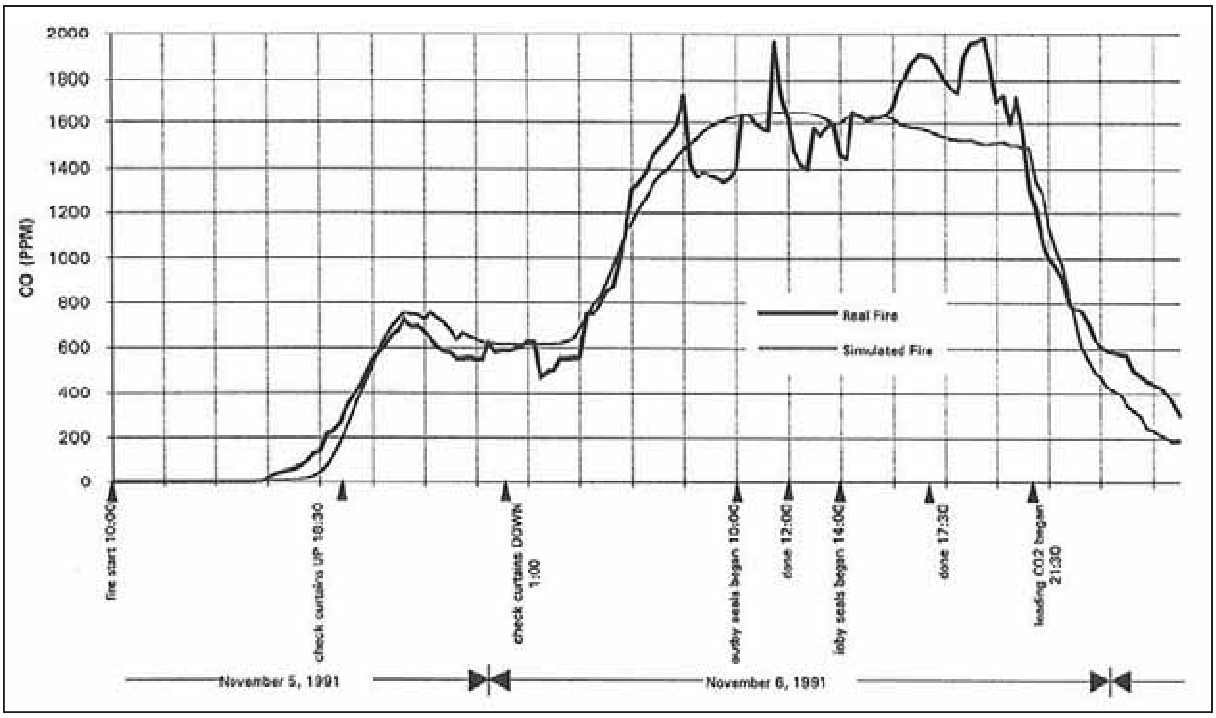


Figure 4.1 Simulated and measured CO levels at Fan Station.

4.3. Validation Study of the Mine Fire Simulation Model against the Newlands Southern Operation, Queensland, 2005

During December 2005 the Xstrata Newlands Southern Underground operation used the Queensland Mine Rescue Service (QMRS) GAG jet engine inert gas generator to inertise its Southern underground workings to reduce the potential risk of an explosive atmosphere after closure of this mine.

The mine operators worked together with the Queensland Mines Rescue Service (QMRS) staff in inertising a section of the mine over a 24 hours period. The trial was also used as a calibration exercise to validate pre-planned VENTGRAPH models and assist with planning for the application of the GAG at the Northern Underground.

The cooperation of Mine Manager Mr David Stone (Stone, 2006) and Mine Technical Services Superintendent Mr John Phillips (Phillips and Hanrahan, 2006) in sharing information and answering questions on the inertisation exercise is acknowledged.

4.3.1. Sealing and re-entry process at Newlands' Southern operation

Figure 4.1 shows the location of the sealing and re-entry strategy used by Newlands' Southern Operation during the inertisation operation.

The strategy focused on reversing mine ventilation by removing the main surface fans and forcing GAG exhaust down what had been the return shaft. Some seals were prepared as shown at the pit bottom area. As the GAG forced air out of the Mains and production panels final seals were completed while airflow and gas concentrations were monitored.

The Aim:
Safe and effective two-stage sealing of the Southern Underground Mine

Figure 4.2 Sealing Strategy in Newlands Southern Underground Operation (after Phillips and Hanrahan, 2006).

A policy has been in place of using 350 kPa seals to separate old goafs from Mains, new workings and potential reserves. This had in the past reduced requirements for injecting Tomlinson boiler gas once sealing has been completed. Appropriate risk assessment with sound atmospheric testing and goaf seal integrity testing had allowed the workforce to remain underground at all times.

The system required no major dewatering and U tubes were left open to drain water through the Micon seals and allow flow down dip to a water storage point at the bottom of the mains. This management approach has bee relatively low cost compared to traditional re-enter and re-establish operations with minimal belt, ventilation and other preparation costs relative to recoverable coal reserves.

The arrangement allowed for the retreating salvage of gear required for the start of the new Northern Operation but still provided for the option for the extraction of coal at the Southern in the future.

4.3.2. Start of the Newlands exercise

The main mine fans were turned off at 8:30am on December 15 and ventilation was basically suspended in the mine workings whilst the shaft cap was fitted. The GAG port was fitted to the top of the shaft to allow the GAG hook-up to take place later in the day. The following

Figures 4.2 and 4.3 shows the main fan removal, shaft capping and GAG alignment; as exercise that took less than one hour.

Figure 4.3 Removed Main Fan Dividing Breach on top of shaft.

Figure 4.4 Positioned shaft cap, injection elbow and flexible elbow to GAG and aligning GAG flexible connection.

4.3.3. Seal up strategy

A primary objective was to safely and effectively seal the mine. The GAG provided a means of rapid, safe and effective inertisation. The exercise also provided a valuable training opportunity for Newlands personnel and a commissioning trial for the new GAG trailer without the pressures found in a real emergency.

The pit bottom area was ventilated for this exercise by an 80m^3/s Portal fan located at the top of the old belt drift and the outbye part of the mine was effectively ventilated at the same time. This was used for maintaining ventilation during the sealing process and also enabled continuation of seal construction while the GAG injected exhaust underground.

The mine had VENTSIM and VENTGRAPH models. The Southern Underground's VENTGRAPH model was updated to reflect the most recent VENTSIM model, and scenarios run to simulate the most effective means of inerting the mine. VENTGRAPH modelling indicated it would be possible to reduce the mine's O_2 concentrations to below 8% (an effectively inert atmosphere) in approximately 8 or 9 hours as shown in Figure 4.5.

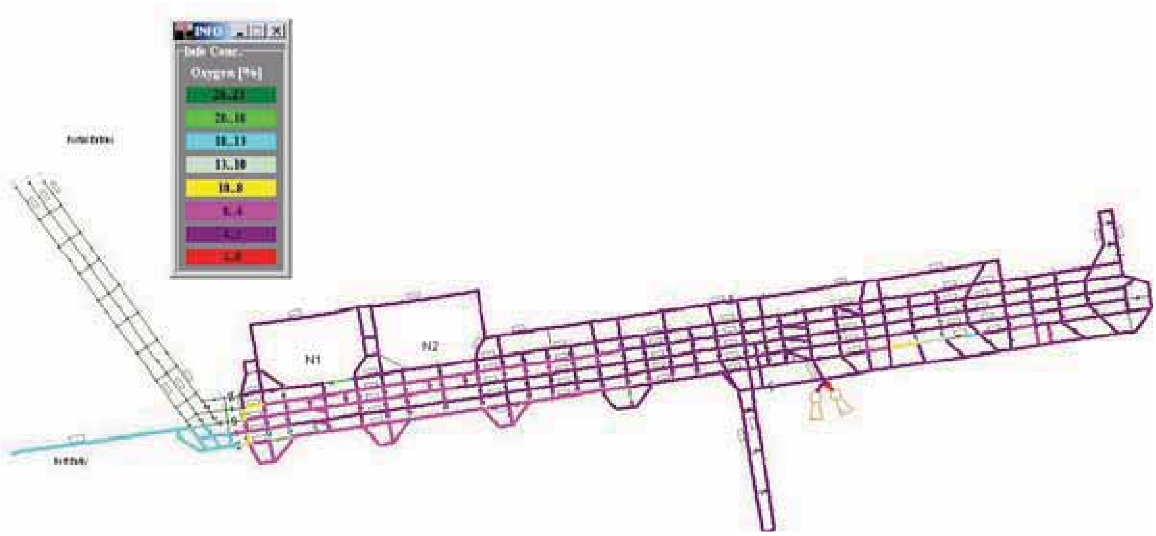


Figure 4.5 Oxygen distribution at 8.5 hours from VENTGRAPH simulation.

A "ventilation change" procedure was prepared with the aim of reversing the mine returns so that the inert gas was directed towards the bottom of the dips (to overcome buoyancy) and then purged out through the mine.

Managing possible CO hazards at the seal construction site was another important consideration. The VENTGRAPH model indicated that the 80m^3/s of auxiliary fan ventilation was capable of safely diluting the expected CO levels as shown in Figure 4.6. Additional gas monitoring and temporary stoppings were installed to manage this risk.

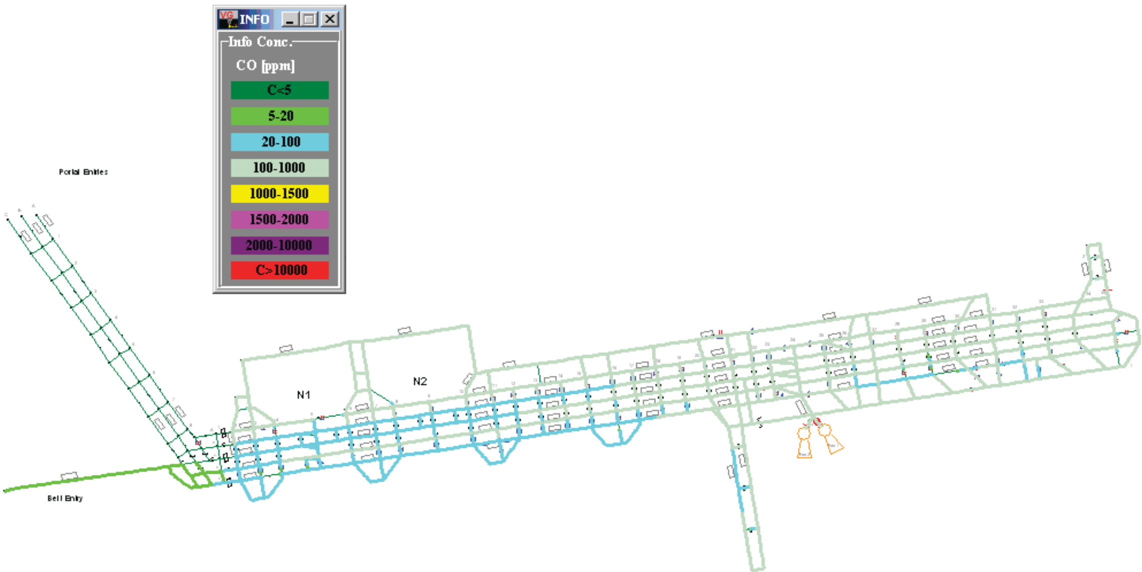


Figure 4.6 CO distribution at 8.5 hours from VENTGRAPH simulation.

4.3.4. GAG operation

The GAG injection process commenced at 4:30pm the same day (December 15) as shown in Figure 4.7 and products of GAG combustion were noted on the mine monitoring system at the bottom of the shaft around 45 minutes later.

Figure 4.7 GAG operation at Newlands South.

Injection continued until around 2:40am on December 16 when the GAG was stopped due to a minor mechanical failure. During GAG injection the quantity of atmosphere exiting the workings at the D heading seal site was measured at around 6.5m^3/s. This perceived low flow was in fact due to a combination of contraction of the exhaust gas due to cooling, the loss of water vapour out of the mixture, the flow of some air and exhaust into the sealed areas due to a barometric high and the effect of turning off the main mine fans. A theoretical analysis of flow behaviour is given in Chapter 10 and data from the Newlands exercise used as a case study.

The door in the temporary seal was closed at 4:30am on December 16 and final sealing continued at that site until the D heading seal was completed at around midday on December 17. At 6:30pm on December 18, the underground atmosphere was showing a gradual increase in methane throughout the workings. At no point had the atmosphere become explosive. The methane concentration had been steadily rising and it appeared if it did become explosive, it might just pass through the bottom corner of the Coward’s triangle.

4.3.5. Comparison of predicted and measured GAG outputs

During the operation, underground gas readings were taken with a tube bundle system. They showed that the shaft bottom area inertised within a suitable time frame, but the gas did not migrate throughout the remainder of the mine as predicted (Phillips and Hanrahan, 2006).

Figure 4.8 shows that at tube bundle station 24 at D-E Hdg 24 c/t Shaft Bottom after 8 hrs O_2 level was reduced to 5% compared to the prediction form VENTGRAPH model of 4% and CO level measured was100 ppm compared to predicted levels of 100 to 1000ppm at the same location.

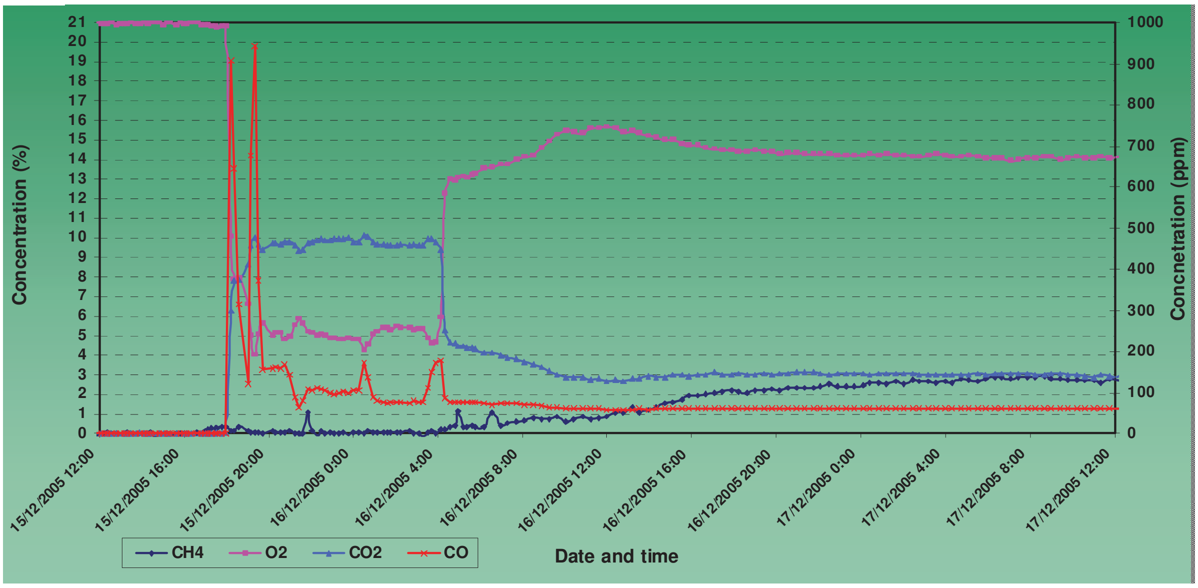


Figure 4.8 GAG outputs from mine monitoring system at D-E Hdg 24 c/t.

After the first two to three hours the gas monitoring system clearly showed that the GAG gas was effectively reporting to the Northern Goafs as shown in the Figure 4.9.

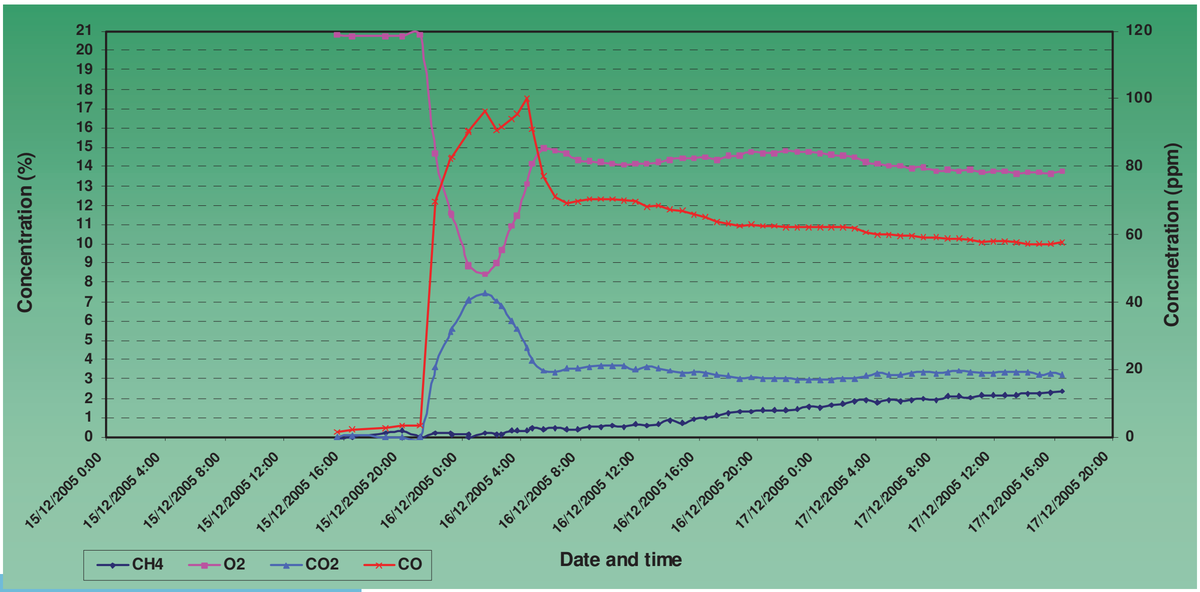


Figure 4.9 GAG outputs from mine monitoring system N1 TG Chute road.

However, the GAG exhaust gas was taking considerable time to report to pit bottom at Mains D Hdg 34 ct as shown in Figure 4.10.

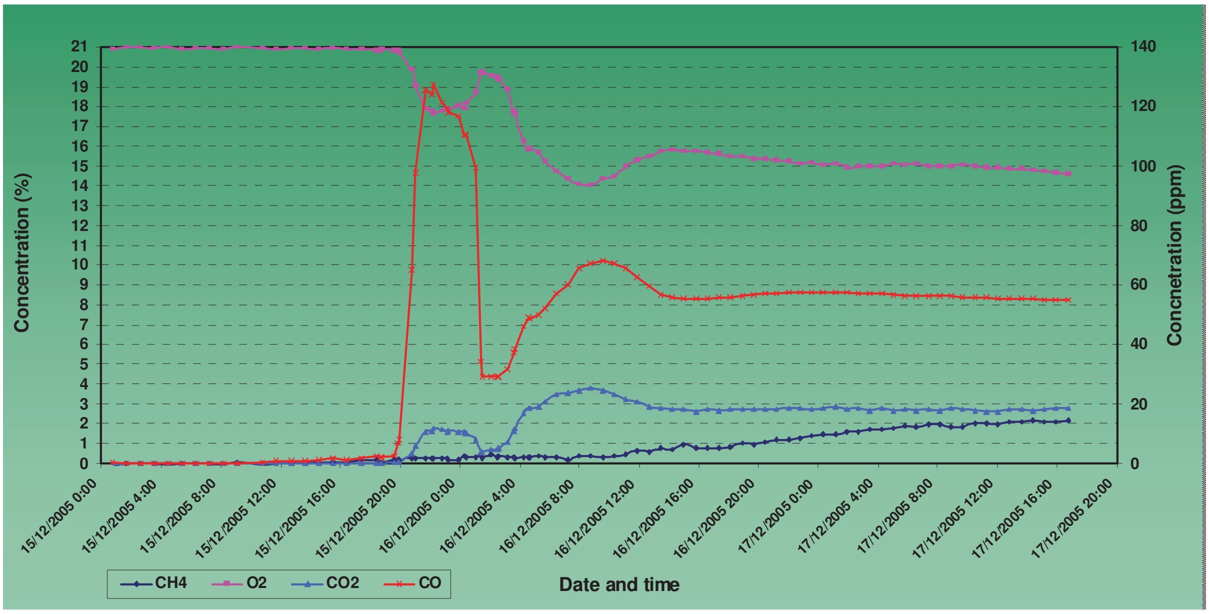


Figure 4.4.10 GAG outputs from mine monitoring system at pit bottom.

Summary of some observations by mine personnel were as follows.

- The resistance of the appliances setup as part of the "ventilation change" could not be measured and validated. Therefore it is difficult to assess the accuracy of the VENTGRAPH model. The injected O_2 levels were 2 to 3 percent higher than the levels modelled in VENTGRAPH.
- At the morning debrief the decision was made to remove a regulator in the northern seal returns as part of the ventilation change. This was a risk-based decision was based on:
  - The barometer was rising steeply and the northern Goafs were prone to oxygen ingress.
  - The Tomlinson boiler could only deliver limited amounts of gas to the area due to requirement to inject elsewhere.
  - The low CH_4 levels in the northern goafs meant the atmosphere could rapidly progress towards an explosive range.
- The product from the GAG did report to the northern returns as expected, however in a higher proportion than expected.
- The output from the GAG was measured a 7m^3/s at the Main Dips D reading return. This is inline with conventional literature after taking into account moisture condensation and cooling effects.
- Buoyancy and the small amount of ventilation pressure from the portal fan did act to draw the gas towards the D Heading return as modelled.
- Injecting down the mineshaft did not unduly hinder the GAG.

- The CO levels at the job site were acceptable (despite one scare from a false reading).
- O_2 levels at pit bottom continued to drop after the GAG was switched off and the CO_2 settled to pit bottom.

4.3.6. Issues and findings

The main issues found during the operation identified by Newlands Underground operations manager, Mr Dave Stone (Stone, 2006) were

- cooling of the gas (80^{o}C to 35^{o}C) which reduced the quantity of GAG output,
- leakage into the goaf and backpressure from buoyancy of the gas in the shaft.

The manager at this point said he were still undecided whether they would use the GAG method of mine sealing in future. "The use of the GAG appears to be very situational specific. All factors are required to be analysed prior to the use of the GAG. The Northern Underground operation is currently assessing various scenarios for which the GAG would be applicable".

GAG operations are very situation specific. For its use careful consideration of the following is required;

- Time to inertise area,
- Effective dilution rates and flows.

Fighting fires with the GAG may be the most effective usage and best suited to long term resource recovery.

4.4. Conclusions

The back analysis of the gas monitoring data during a fire at the US Pattiki Mine showed that a VENTGRAPH model could be established to simulate satisfactorily this incident. The inertisation exercise during part sealing of the Newlands South workings (without a fire present) highlighted a number of findings.

- The GAG quantity measured exhausting from the mine area being sealed was at first considered to be unrealistically low. However further analysis, as detailed in Chapter 10 of this report, indicates that accounting for temperature and moisture mass changes explains any differences. The GAG jet exhaust (as with any combustion exhaust) puts out a lot of moisture and the cooling water usage adds a lot more. This exhaust product flow mass is lost from the system as it condenses and “wets” the mine workings. Temperature reductions leads to no mass change but “lower” quantity measured.
- The hypothesis that some of the GAG exhaust, with diurnal pressure changes within the workings, will flow into and out of goafs is of interest. This is very likely and

means that both goaf voids should be taken into account in calculating mine excavation volume and that the cyclic pattern of this in and out flow needs to be accounted for.

Further monitoring of mine site GAG exercises are warranted to give greater understanding to this complex system.

5. VENTGRAPH FIRE SIMULATION PACKAGE

5.1. Introduction

The VENGRAPH package is an integrated set of computer programs providing mine ventilation engineers with efficient tools for solution of complex ventilation problems. Its Australian application has been particularly focused to situations with the potential for fires. Difficult and hazardous mine operating conditions necessitate the continuous development of methods of assistance to ventilation service personnel. This contributes to increased work safety and improves economic performance both during normal mining operation and in case of emergency situations such as underground fires or the presence of gas sources (CH_4, CO_2 and N_2) in uncontrolled situations. Interdisciplinary combinations of various branches of science have enabled scientists to formulate a mathematical description of airflow in a complex mining excavation system.

The software focuses on phenomena influencing unsteady processes of flow of air and mixtures of air and CH_4, CO_2 and N_2 or fire gases. The program's graphical capabilities, sufficient computational power and user-friendly interfaces allow a fast and detailed interpretation of calculations.

The concept of the VENTGRAPH ventilation engineering software system was developed in the late 1980s. The presentation method of information about a ventilation network adopted in VENTGRAPH software requires prior preparation of two types of data. These are data about the network structure and the three-dimensional diagram of the ventilation network presented on the screen. This software, which was originally based on a DOS platform, was imported into a WINDOWS environment in 2002.

The VENTGRAPH package is a tool that may assist Ventilation Engineers and others in design and maintenance of ventilation networks including hazard prevention and suppression. Applications include

- Constant control of the non-stationary ventilation process,
- Computer assisted detection of dangers in the mine ventilation network,
- Forecasting of new ventilation arrangements,
- Reconstruction of the non-stationary ventilation process particularly after occurrence of disasters in the mining network (fire, discharge of methane etc).

The package uses opportunities offered by the graphical multitask environment MS WINDOWS, including:

- Enhanced user interface of the software based on system of windows with active boxes which facilitates the operation of this type of programs and is relatively user-friendly in the calculating process,

- Possibilities of using any printers, plotters, monitors and video cards that are WINDOWS compatible,
- Use of full capabilities of editors at any time during the running of a simulation exercises,
- Addition of other newly developed ventilation engineering software that makes use of a common database such as gas sensors in the monitoring system.

5.2. VENTGRAPH Package

The basic VENTGRAPH package consists of the following programs with features described below:

5.2.1. Input database and ventilation network graphic diagram

EDTXT A special full-screen text editor has been developed for inputting data. This enables preparation of data and supports some basic calculations including verification of the correctness of network structures, calculation of resistance values of branches on the basis of measurements conducted in the ventilation network and the approximation of characteristics of fans. This division of data into groups related to branches, measurements at nodes and data for fans allows convenient and fast inputting of large quantities of measurement data.

EDRYS A graphic editor that is designed for drawing three-dimensional diagrams. Knowing the structure of connections between branches, it is possible to draw a 3-D diagram of a multi-level, three-dimensional network. Each branch and node are assigned with selected flow parameters, including air velocity, static pressure, pressure loss and other parameters, such as the node's position with regard to depth, pressure, potential variation from the isentropic pressure distribution. These parameters can be displayed on the screen. Sometimes it is necessary to draw diagrams of selected network regions or simplified diagrams, where a selection of branches is replaced by one equivalent branch. Using the computer keyboard, mouse or digitiser diagrams consisting of branches, nodes, information boxes, symbols of fans, dams, arrows showing the flow direction and boxes with data for individual branches can be drawn.

5.2.2. Simulation software – steady state

Air parameters in the situation of stationary distribution in a ventilation network are constant for a given place in a branch. Taking advantage of this fact, we can restrict the presentation of results on the screen to results in a numerical form displayed next to branch symbols. However, the basic problem is the large amount of results rather than the method of their presentation. An extensive ventilation network in a mine may include several hundred branches; therefore a legible presentation of the whole system on the screen together with results of calculations is not feasible. The solution presented offers a possibility to display the network at any scale and to show any marked part of the network. Calculations of parameters in branches are placed in rectangular boxes adjacent to drawings of branches. It is also possible to present characteristic parameters for network nodes (pressure, elevation, potential). Documentation of the computing conducted is produced both in a traditional tabular form and graphic one (Dziurzyński, et al, 1988).

GRAS GRAS allows for calculation of the steady air distribution in a mining excavation network in normal and emergency conditions. This can be achieved due to the following features of this software:

- The possibility of changing resistance values of selected mining excavations;
- The possibility of building a constriction for a specific resistance value;
- The possibility of introducing air pressure drops due to a fire;
- The possibility of changing the type of branch, including:
    a) a normal branch, without any change in parameters;
    b) a branch with a fan, with the possibility to change the characteristics of the fan;
    c) air supply, change in the flow rate;
    d) methane supply, change in the flow rate;
    e) regulator (fixed flow branch), the calculation of ventilation door resistance or changed operating conditions of a fan.

5.2.3. Simulation software – the unsteady state

Transients generated by fires or outbursts of gas and rocks in a ventilation network lead to a complex distribution of parameters which vary both in time and space. The presentation of this type of distribution requires substantial resources. In simulation software of this type of phenomena a range of 32 colours available in PCs are used. In contrast to computing in stationary states, information about individual colours for presentation is displayed (e.g. distribution of oxygen concentration levels in fire gases). This solution allows the observation of fluctuations in this distribution during simulation. Another advantage is the possibility of obtaining time diagrams of observed parameters in selected network points. The application of a solution with a legible colour screen makes the interpretation of phenomena occurring in the network much easier and assists decision-making during simulated rescue actions.

FIRE FIRE allows the simulations of unsteady distribution of air and gases in a mining excavation network after occurrence of an underground fire. The fire can be simulated by:

- calculating the flow rate of air and fire gases in each ventilation route;
- identification of the current depression of fans, thermal depression and natural depression;
- calculation of temperature as a function of time and location;
- computing the propagation of gases and concentration levels of individual gases as a function of time and location;

- calculation of time and zone where reversion occurs.

The capabilities of this software listed above enable the prediction of possible effects on the use of various fire fighting tactics or elimination of the potential danger might be faced by various working areas. Multi-variant simulations allow responses of the ventilation network during a fire before a real danger occurs. This is the basis of prevention training of mine ventilation service personnel.

5.3. Preparation of Data

The value of a computer model of a ventilation system in a mine is dependent on data about its structure and accuracy of measurements of ventilation parameters in branches and at fans.

5.3.1. Representation of the ventilation network diagram

It is possible to draw a 3-D diagram of a multi-level, three-dimensional network knowing the structure of connections between branches, Each branch and node can be assigned with selected parameters of flow (flow rate, static pressure) or other values such as a node elevation or branch length.

VENTGRAPH system includes EDRYS, a special graphic editor designed for drawing three-dimensional diagrams. It is possible to draw a diagram consisting of branches, nodes, information boxes, symbols of fans, dams, arrows showing the flow's direction and boxes where data for individual branches are displayed. EDRYS offers also a possibility of assigning sensors of the monitoring system to the three-dimensional diagram.

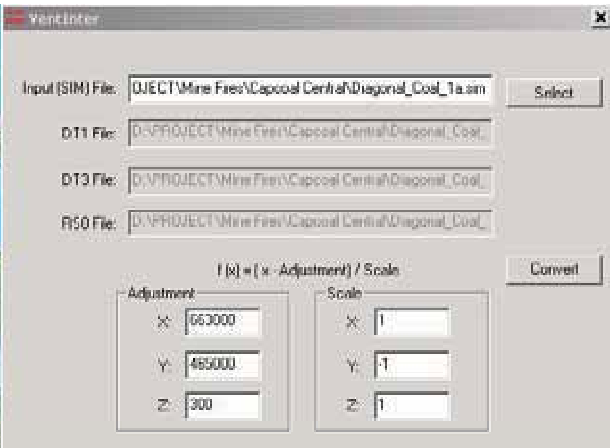
5.3.2. Ventilation measurements

To prepare an accurate model it is necessary to conduct what is generally referred to as a “Pressure Quantity” survey in a mine. The measuring procedure is performed by the specialists teams equipped with instruments for measurement of air velocity, static pressure and temperature measured by a dry and wet bulb thermometer. Accuracy is needed while measuring the barometric pressure and the flow rate (measured as an average flow rate across the mining excavation diameter). It is necessary to know the average cross sectional area of branches, lengths of branches and elevations of nodes.

The results of measurements and data about the structure (i.e. connections between branches) are put in by means of EDTXT, a full-screen network data editor. In addition, this software enables verification of the correctness of the structure and supporting calculations. Other programs of the VENTGRAPH system use databases prepared by EDTXT.

5.4. VentInter Conversion Program

A conversion program, VentInter, has been developed by the authors of this report to convert a VENTSIM data file into 3 VENTGRAPH data files, namely, DT1, DT3 and RS0. The program is written in Visual C^{++} and its main purpose is to build a window interface so that the ventilation data can be imported from VENTSIM into VENTGRAPH. It contains one interface window that requires the user to select the VENTSIM model file and its location as the source and to generate the three VENTGRAPH data files at the same directory at default as shown in Figure 5.1.



Input (SIM) File: OJECT\Mine Fires\Capcoal Central\Diagonal_Coal_1a.sim
DT1 File: D:\PROJECT\Mine Fires\Capcoal Central\Diagonal_Coal_
DT3 File: D:\PROJECT\Mine Fires\Capcoal Central\Diagonal_Coal_
RS0 File: D:\PROJECT\Mine Fires\Capcoal Central\Diagonal_Coal_
Adjustment X: 663000
Adjustment Y: 465000
Adjustment Z: 300
Scale X: 1
Scale Y: -1
Scale Z: 1

Figure 5.1 Interface window in the VentInter conversion program.

It allows the user to input adjustment factors to convert the mine X, Y and Z coordinates into appropriate screen true coordinates so the network model can be fitted into the VENTGRAPH screen display for easier manipulations. Scales factors are also included in the program so that depending on the network model size; the user can re-size the model to fit the display area. By using negative numbers, the model can be flipped in 3-D so the user can determine the best viewing setting for the model.

5.5. New Inert Unit and Gas Source Functions

Under this ACARP supported project the Polish program authors kindly undertook inertisation related modification to the VENTGRAPH program from the project findings. The modifications are as follows.

1. New inertisation units. The original program only allowed use of a GAG form of inertisation unit within the ventilation network. The modified version includes additional units. An additional pull down menu “Inert Units” has been included. Under the “Inert Units” submenu a selection of inertisation units namely GAG, Mineshield, Tomlinson Boiler and Membrane Filter can be included. Once the unit or system is selected, a pop up window shows up with the operating parameters and outputs parameters displayed. The users can then accept the default parameters or opt for changes if the operating or output parameters are different from the default parameters.

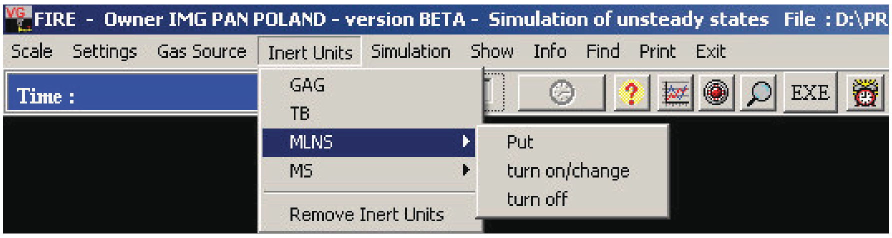


Figure 5.2 New Inert Units Pull down Manu in VENTGRAPH

2. Including extra mine gas sources. The original VENTGRAPH version only allowed the seam gas of CH_4 to be included. The new version allows in addition CO_2 and N_2 to be placed in the model. A new pull down menu facilitates this.

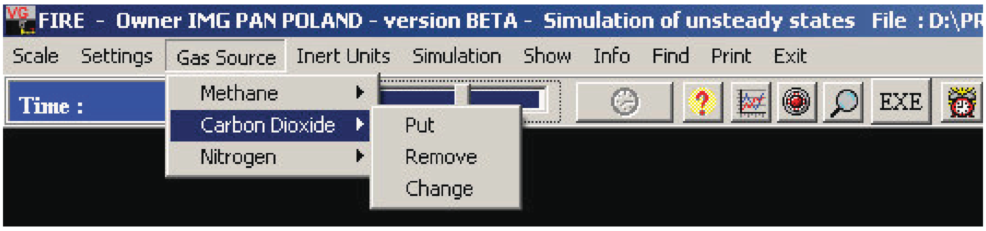


Figure 5.3 New Gas Source Pull down Manu in VENTGRAPH

As part of the ACARP funded project a Beta version of the new form of VENTGRAPH was created and tested. The new additions were trialled and tested on various mines' VENTGRAPM models and as a result and a list of suggested improvements to the Beta version was sent to the authors of VENTGRAPH for consideration. All recommendations were accepted and VENTGRAPH is now significantly more useful for use in a mine inertisation study.

5.6. Application of VENTGRAPH to Mines

The introduction of a fire simulation computer program relies on the modelling of fire scenarios on accurate mine layouts. It is most important for running VENTGRAPH that the mine has an accurate, timely, and calibrated ventilation network model such as the Australian VENTSIM software or equivalent. It is necessary to have the VENTSIM model of the mine being studied in an appropriate state to act as a foundation to build mine fire simulation models. Basically the VENTSIM model must be up to date, calibrated and incorporate depth coordinates. It is recommended that as a minimum the model's calibration be checked. It is assumed that mine planning software data and mine survey measurements are available (AutoCAD style DXF format) in readily transferable form. A small amount of additional extra data for fire simulation modelling also needs to be collected. In particular relevant information on underground heat sources and air temperatures may be needed.

Once an updated VENTSIM model from the mine is established the model can be transferred to VENTGRAPH graphic model. This has been undertaken using the VentInter conversion program developed for transfer and building the five data files required for VENTGRAPH. The major time factor here is constructing and validating the file which controls the program graphics interface. Building the graphics file from scratch would be most inefficient.

Mine fire scenarios based on fire sources common to all mines have been simulated. Ventilation engineers or other engineering and safety staff at each mine involved were given an overview of how to use the VENTGRAPH program. The teaching effort emphasised to mine staff the need to have an accurate VENTSIM model in a form to serve as the base for initiating the fire simulation process. Information was given on how to undertake file transfer to VENTGRAPH so that at a later stage as the mine progresses a new VENTSIM model can be transferred. Experiences were shared on how to undertake fire simulations.

Fire simulation programs rely on the modelling of fire scenarios across actual mine layouts. The exercises undertook simulations of the effects of common open fire causes and fire progress and intensity rates. Examples studied across various locations included fires initiated by for instance vehicles, stationary installations (fuel containers, transformers, equipment containing hydraulic fluids, etc) gas sources and conveyors. Considerable effort went into correct modelling of the thermodynamics characteristics of the various fire sources modelled. Fires from vehicles, fuel, belting coal and so on all develop at different rates and different intensities. Much work had been done to calibrate fire types and this was used to give “best representation”. As far as possible these simulation scenarios were developed working directly alongside mine Ventilation Officers and other technical staff.

Some simulations of safe escape scenarios from a pit affected by fire as part of emergency evacuation were also undertaken. These simulations involved for instance installation of temporary stoppings, removal of stoppings or doors, changes to mine fan duty and possibly use of interisation. These were done with mine staff principally based on the scenarios the mine already has in place in its emergency evacuation plan. Fires and application of inertisation scenarios developed during the studies are described and discussed in the following chapters 6 to 9.

5.7. Conclusions

This section has given a brief overview of the VENTGRAPH simulation software. It has highlighted the new features that have been added to the software as a consequence of this inertisation project and in particular the ability to use up to four different types of inertisation gases (at varying flow rates) across a mine layout simultaneously and the ability to include carbon dioxide and nitrogen seam gases as well as methane.

6. CASE STUDIES OF FIRE SCENARIOS AT OAKY NORTH MINE

6.1. Introduction

Scenarios developed for Oaky North Colliery have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage following a fire.

A total of five scenarios were simulated for Oaky North Colliery based on the mine fire simulation model developed from the ventilation arrangements in July and October 2005 as shown in Figure 6.1. These scenarios are as follows.

1. Belt Fire in Mains C Hdg conveyor at 39ct.
2. LW goaf fire. Spontaneous Combustion in goaf behind South Longwall 3 face currently at 15ct. Spon comb potentially spread over 600m (modelled by development of spider web arrangement.
3. Belt Fire in South LW 4 MG 22CT Tripper drive.
4. Belt tripper drive Mains 11ct C Hdg.
5. Dev in 7 MG at 26 ct (100m pillar). Eimco vehicle fire at 500m outbye of the face. Face 2.2 m^3/tonne CH_4.

Each of these three scenarios are described and discussed in the following section.

6.2. Scenarios for Xstrata – Oaky North Colliery

Exploration at Oaky Creek began in 1977. MIM acquired its majority stake in the Oaky Creek project lease in 1981, becoming project manager, and the mine was officially opened in 1983. Initially an open cut dragline operation, underground mining was later introduced to increase coal production as the open cut mine became deeper and stripping ratios increased.

As part of the Oaky Creek project, the Oaky North underground mine was developed from 1995. Oaky North Longwall underground mine went into production in 1998 at a cost of $213 million. A move to more economical coal recovery through the two underground operations saw the wind up and closure of the open cut operation during 1999. However, changes in exchange rates and coal prices saw the open cut operation become economical again and reopen with two draglines in the high quality Aquila seam in July 2001.

Developed as a major longwall mine, Oaky North is generally a larger scale operation than the Oaky No 1 mine, with a greater seam thickness, wider longwall blocks and bigger more powerful mining equipment. In Oaky North, continuous miners develop the blocks for longwall extraction maintaining minimum developed longwall inventories of at least two blocks at all times. It has generally good working conditions with stable roof, floor and coalface and an above average seam thickness.

Xstrata acquired the MIM operations in mid 2003.

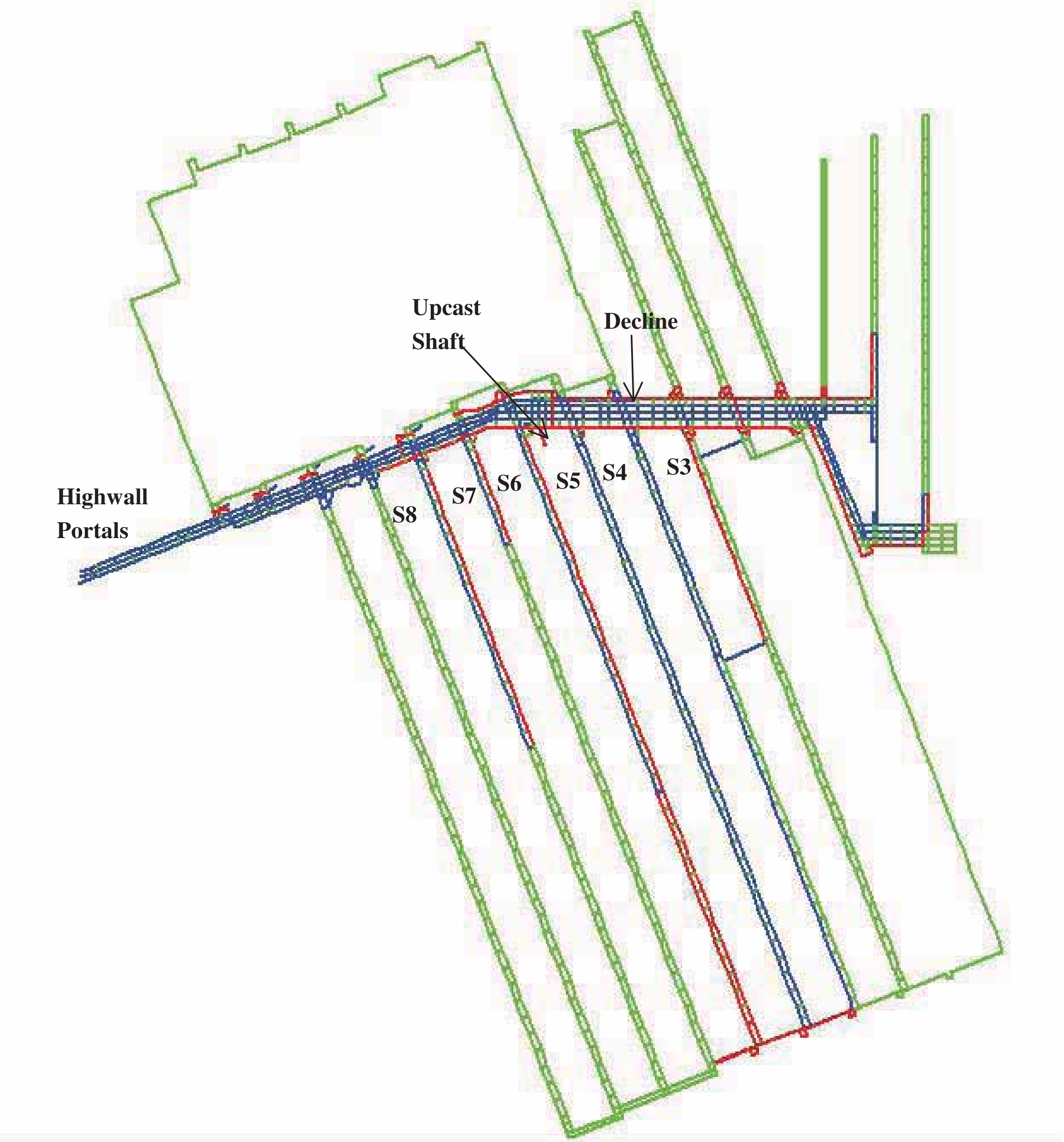


Figure 6.1 Ventilation arrangements at Oaky North Colliery in October 2005

6.3. Oaky North Fire Scenario 1

Scenario: *Belt Fire in Mains C Hdg conveyor at 39ct*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s

Gas emission levels from measurements in mine November 2005.

CH_4 source of 600 litres/s from LW goaf at TG end of face

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

- CO Gas sensors set at points before and after fire, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.

  CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 15 minutes: 30 litres oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10 CO: CO2 = 0.1. (assume H_2 = CO level).

Step 2 Time 15 - 30 minutes: 230 litres oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Step 3 Time 30 – 120 minutes: Oil consumed. 50 m entry length coal develops. time constant 14,400s, intensity 5.

Control: At 120 minutes decision made to introduce high flow inertisation – GAG

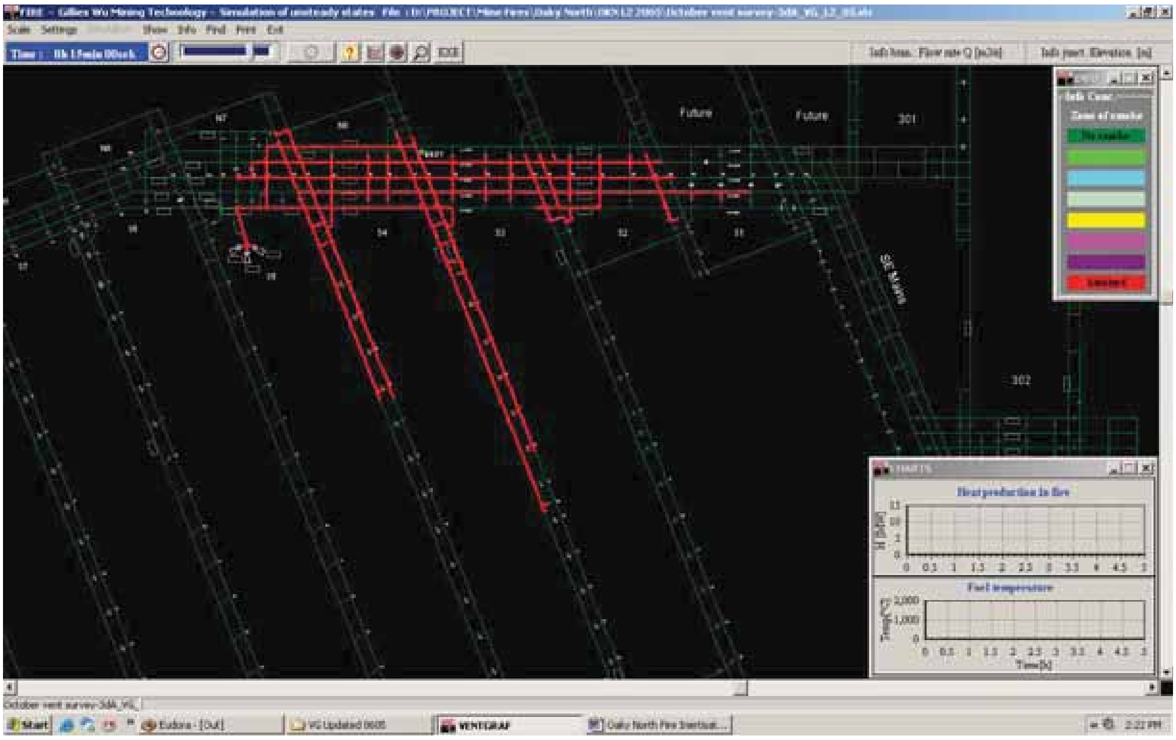


Figure 6.2 Smoke distribution after 15 minutes

Step 4 Time 120 – 300 minutes: 100 m entry length coal fire develops. time constant 14,400s, intensity 5.

Step 5 300 minutes: Segregation devices (e.g. prep seals, brattice, remote controlled doors or manually controlled doors) installed. Segregation for pit bottom required at the following points. For delivering into

B Hdg

- Close machine door at 37ct B – C
- Prep seal B Hdg 35 – 36

C Hdg

- Prep seal at B Hdg 35-36
- Open machine door at 37ct B-C
- Brattice around belt structure C Hdg 36 – 37ct
- Brattice around belt structure 37ct C - D
- Prep seal at B Hdg 37-37A ct

D Hdg Must turn at least one main fan off

- Close B Hdg, C Hdg & D Hdg, 35 – 36ct
- Close B Hdg & C Hdg 37 - 37A ct
- Open machine door at 37ct B-C

Step 6 Time 300 minutes: GAG has been set up at the Intake Drift Close emergency door R=10; Start GAG

Examine all three main fan curve operating points; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 330 minutes: Shut down No 1 fan; fan louvre doors closed R=20
Examine No 2 and No 3 fan curve operating points
Reversal of air in pit has occurred
Fire unstable and erratic local air reversals over fire.

Step 8 390 minutes: install brattice stopping in Belt drift C heading R = 1

Step 9 420 minutes: Shut down No 2 fan; fan louvre doors closed R=20

Examine No 3 fan curve operating point

Step 10 450 minutes: Close Mains Portal D Heading Emergency Door R = 20

Step 11 480 minutes: Shut down No 3 fan

Step 12 540 minutes: Close Main Portal B Heading Emergency Door R = 20

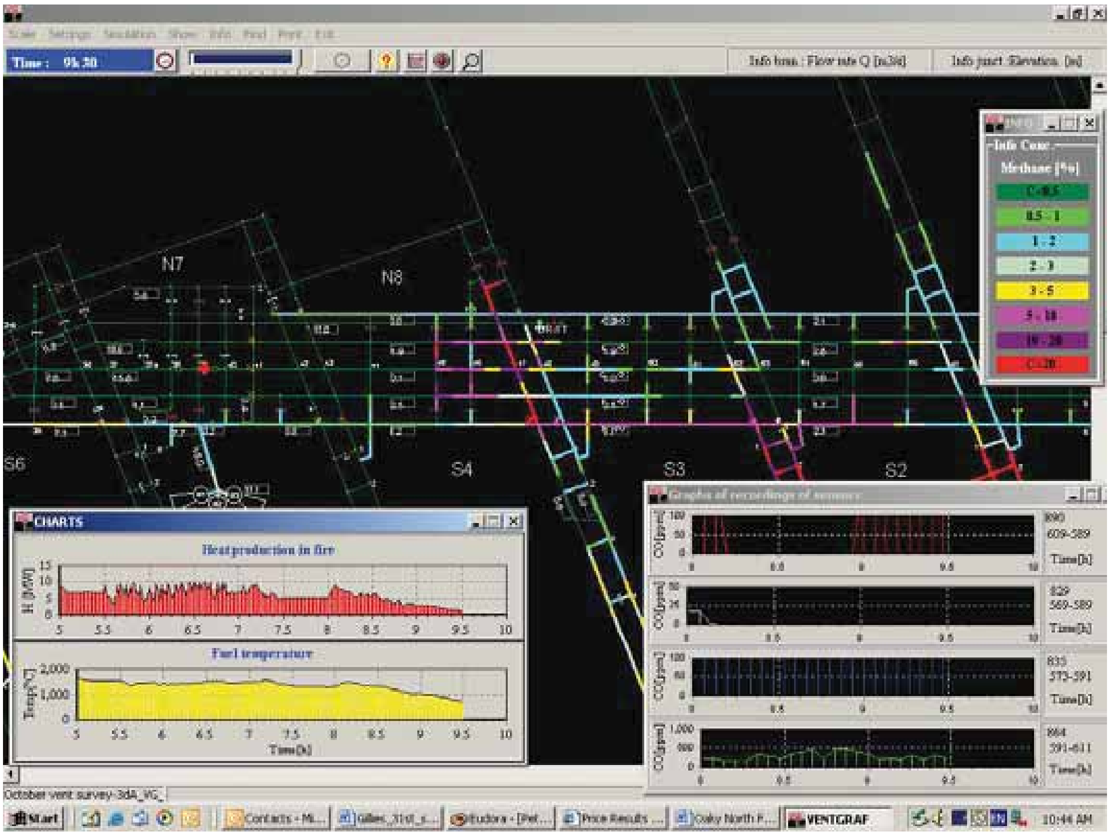


Figure 6.3 Methane distribution after 570 minutes

Summary *With GAG running Fire intensity insignificant at 10 hours and oxygen level outbye fire at less than 2.9 percent.*

6.4. Oaky North Fire Inertisation Scenario 2

Scenario: LW goaf fire - analysis of goaf needing understanding of caved material permeability and methane emissions. Spontaneous combustion in goaf behind South Longwall 3 face currently at 15ct. Spontaneous combustion potentially spread over 600m.

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
- Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO Gas sensors set at points either side of bottom of Ventilation Shaft.
- CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- O_2 sensor in the LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 360 minutes: 1 m entry length coal fuel in 18 c/t MG edge of goaf burning; time constant 14400s, intensity 1 $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control.

Step 2 Time 360– 720 minutes: 5 m entry length coal burning with gas continuing to burn; time constant 14400s, intensity 2.

Step 3 Time 720 – 1080 minutes: Continue coal fire 25 m entry length coal burning; time constant 14400s, intensity 4.

Step 4 Time 1080 - 1440 minutes: Continue coal fire 100 m entry length coal burning; time constant 14400s, intensity 8. Fire very unstable and not under control.

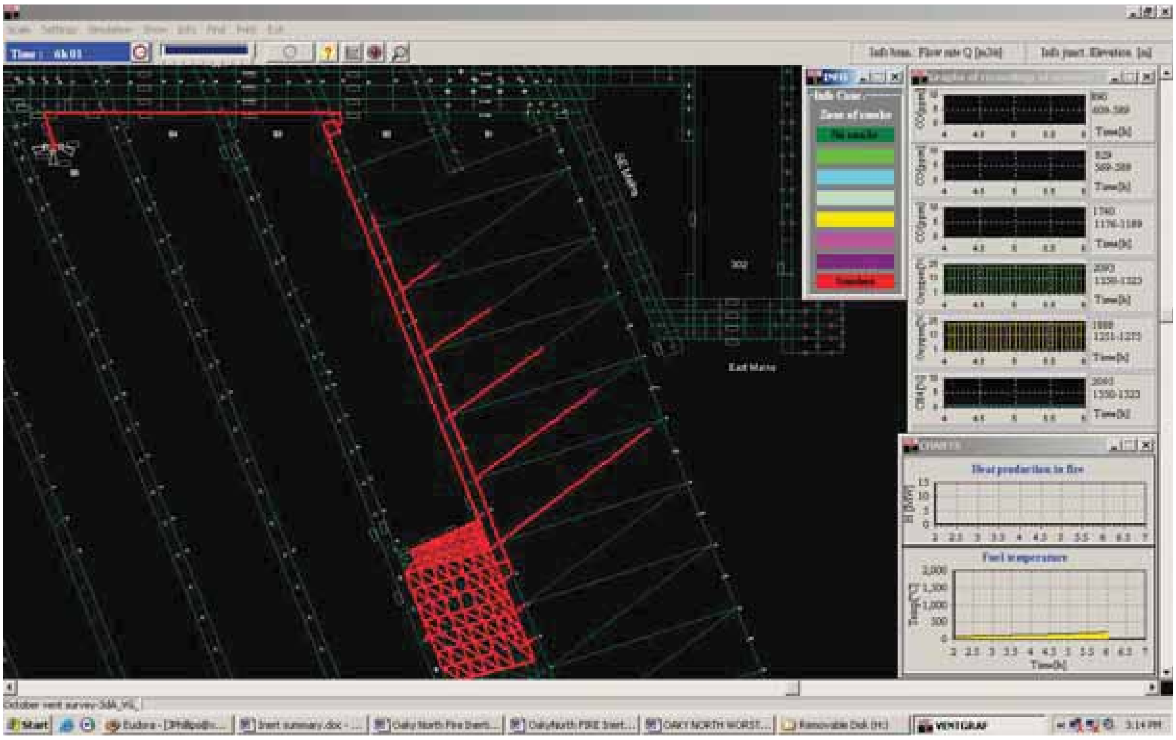


Figure 6.4 Smoke distribution after 360 minutes

CO concentration at 19 hours sets off alarm at bottom of vent shaft.

Step 5 Time 1440 - 1800 minutes: Continue coal fire 200 m entry length coal burning; time constant 14400s, intensity 10.

Step 6 Time 1440 minutes: GAG has been set up at the Intake Drift Close emergency door R=10; Examine all three main fan curve operating points; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 1500 minutes: Shut down No 1 fan; fan louvre doors closed R=20
Examine No 2 and No3 fan curve operating points

Control Assess effectiveness of GAG

Step 8 1560 minutes: Install brattice stoppings Belt drift C heading R = 1

Step 9 1590 minutes: Shut down No 2 fan; fan louvre doors closed R=20
Examine No 3 fan curve operating point

Step 10 1620 minutes: Close Main Portal D Heading Emergency Door R = 20

Step 11 1680 minutes: Shut down No 3 fan. Close main portal B Emergency Door R=20

At 34 hours local reversal occurred to produce a minor methane burn-off.

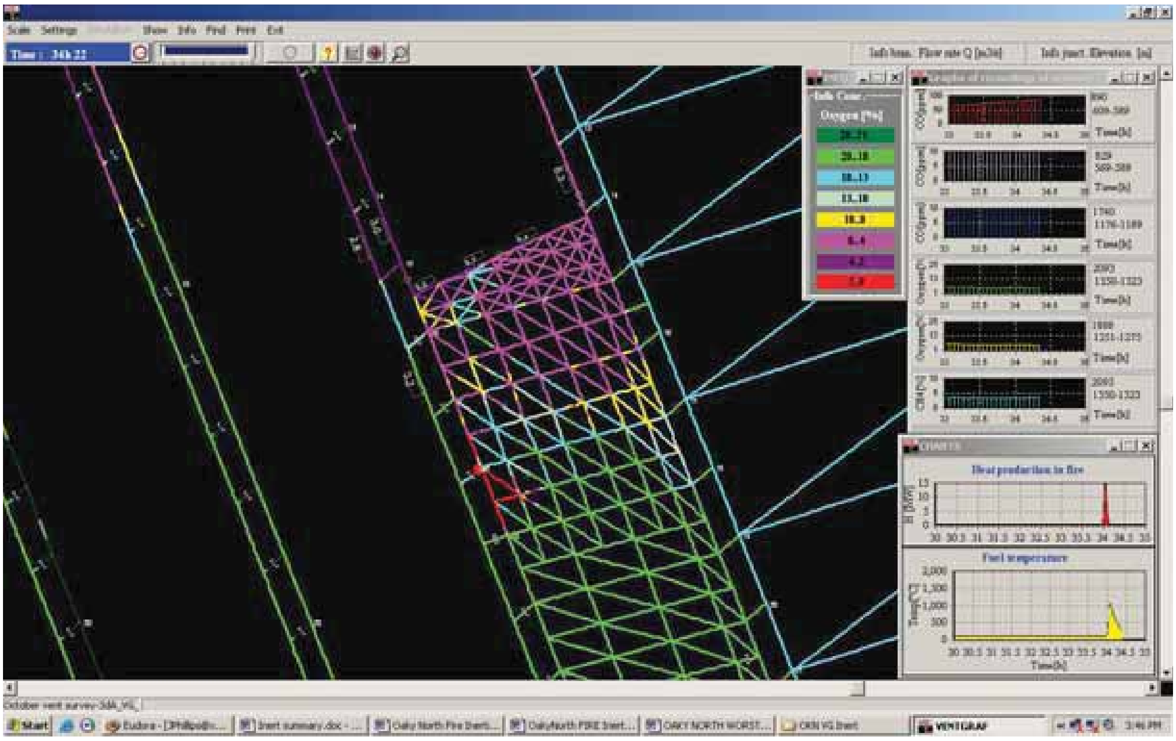


Figure 6.5 Oxygen distribution after 7200 minutes

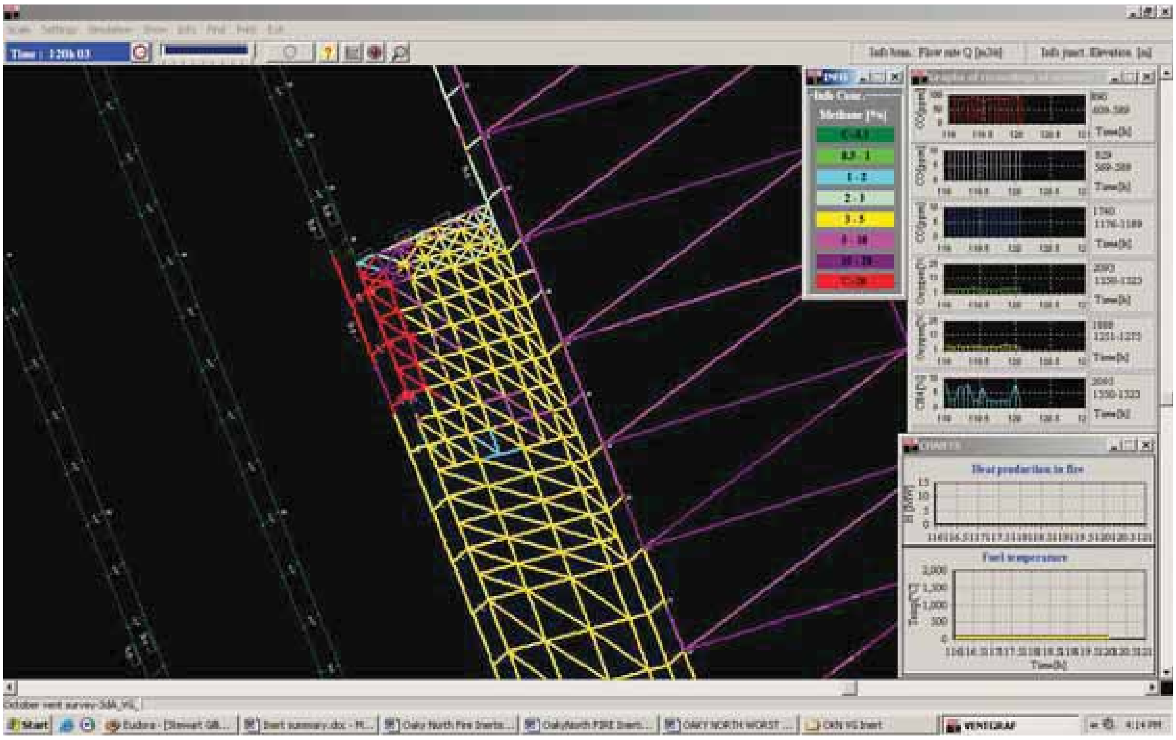


Figure 6.6 Methane distribution after 7200 minutes

Summary *With the GAG running after 5 days there is no significant fire. Outbye the fire oxygen is 0.1 percent.*

6.5. Oaky North Fire Inertisation Scenario 3

Scenario: *Belt Fire in South LW 4 MG 22CT Tripper drive.*

Sections

1. *LW 4 at 37ct 3/06*
2. *Dev 301 MG at 10ct 3/06*
3. *Dev South MG 7 at 28ct 3/06*
4. *Dev Stone Development road header (contractor) MG6 at 8ct at 3/06*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.
- CH4 source of 600 litres/s from LW goaf at TG end of face
- CO Gas sensors set at points before and after fire, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.

  CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 30 minutes, Spillage coal burning. Simulate 1 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control Fire fighting control commences with hoses; ineffective.

Step 2 Time 30 – 120 minutes, Spillage coal burning. Simulate 5 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control At 120 minutes decision made to introduce high flow inertisation – GAG

Step 3 Time 120 – 300 minutes, Spillage coal burning. Simulate 10m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 4 Time 300 – 360 minutes, Spillage coal burning. Simulate 25m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

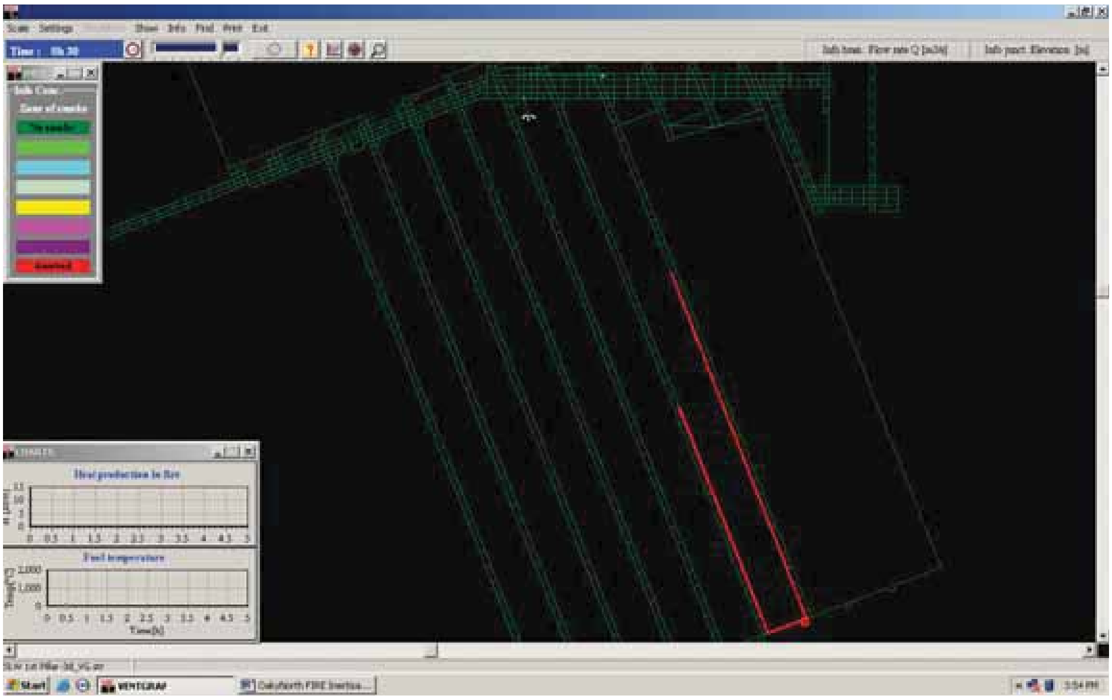


Figure 6.7 Smoke distribution after 30 minutes

Fire is constrained but still burning

At 300 minutes GAG has been set up at the Intake Drift Close emergency door R=10

Examine all three main fan curve operating points; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 5 After 360 minutes shut down No 1 fan; fan louvre doors closed R=20
Examine No 2 and No 3 fan curve operating points

Control Assess effectiveness of GAG

Step 6 After 390 minutes install brattice stoppings Belt drift C heading R = 1

Step 7 After 420 minutes Shut down No 2 fan; fan louvre doors closed R= 10

Examine No 3 fan curve operating point; Localised reversal occurs over fire

Step 8 After 435 minutes Close Main Portal D Heading Emergency Door R = 10

Control Assess effectiveness of GAG

Step 9 After 450 minutes Shut down No 3 fan; fan louvre doors left open
Close Main Portal B Heading Emergency Door R = 10

After 8 hours, reversal brings methane over the fire and causes a large explosion.

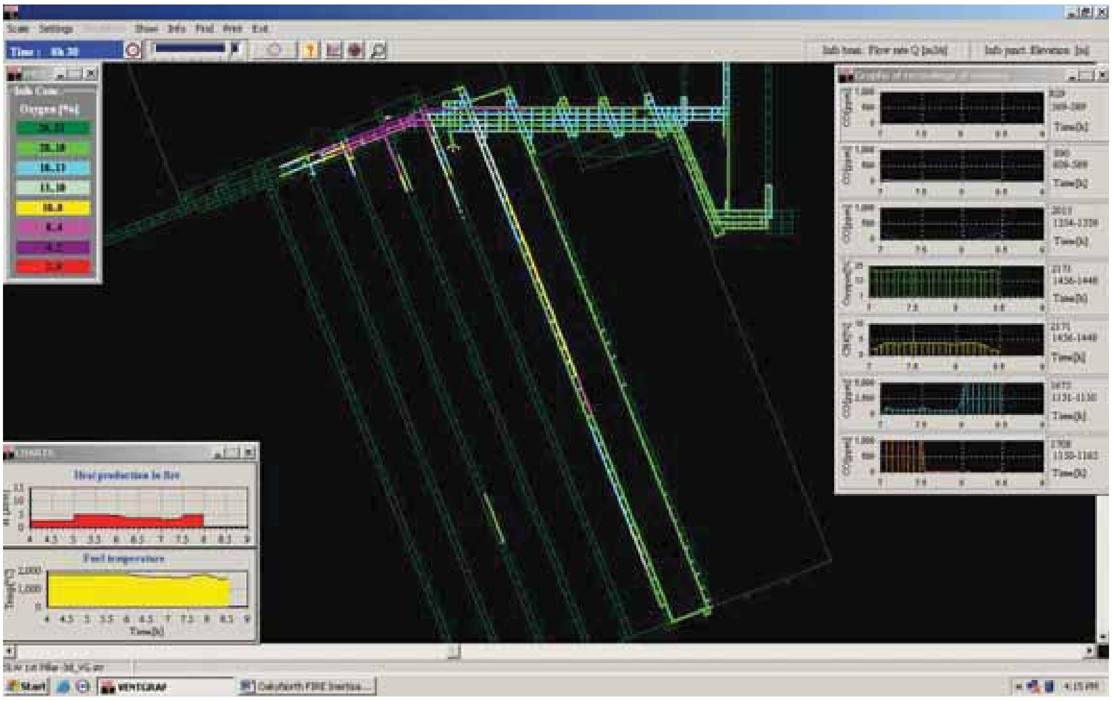


Figure 6.8 Oxygen distribution after 510 minutes

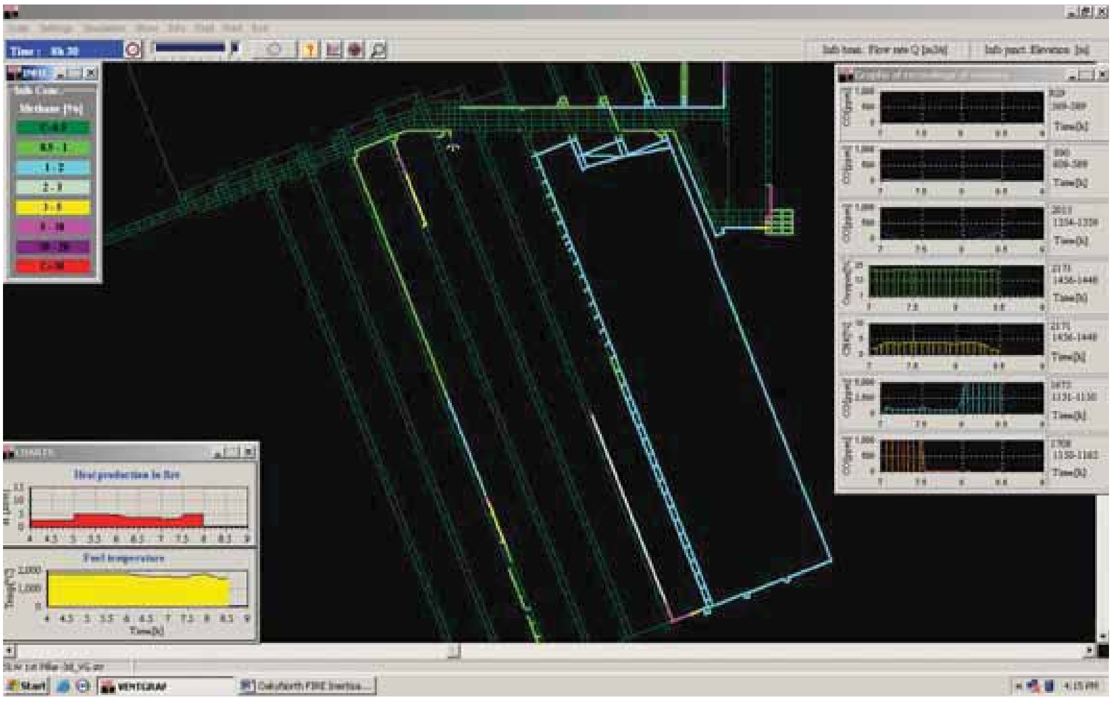


Figure 6.9 Methane distribution after 510 minutes

Control Assess effectiveness of GAG

Summary *Explosion occurred as soon all fans were turned off due to an airflow reversal across fire.*

6.6. Oaky North Fire Inertisation Scenario 4

Scenario: *Belt tripper drive Mains 11ct C Hdg*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.

CH_4 source of 600 litres/s from LW goaf at TG end of face

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

- CO Gas sensors set at points before and after fire, and
- CO Gas sensors set at points either side of bottom of Ventilation Shaft.

Simulation

Step 1 Time 0 – 30 minutes, Spillage coal burning. Simulate 1 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control Fire fighting control commences with hoses; ineffective.

Step 2 Time 30 – 120 minutes, Spillage coal burning. Simulate 5 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control At 120 minutes decision made to introduce high flow inertisation – GAG

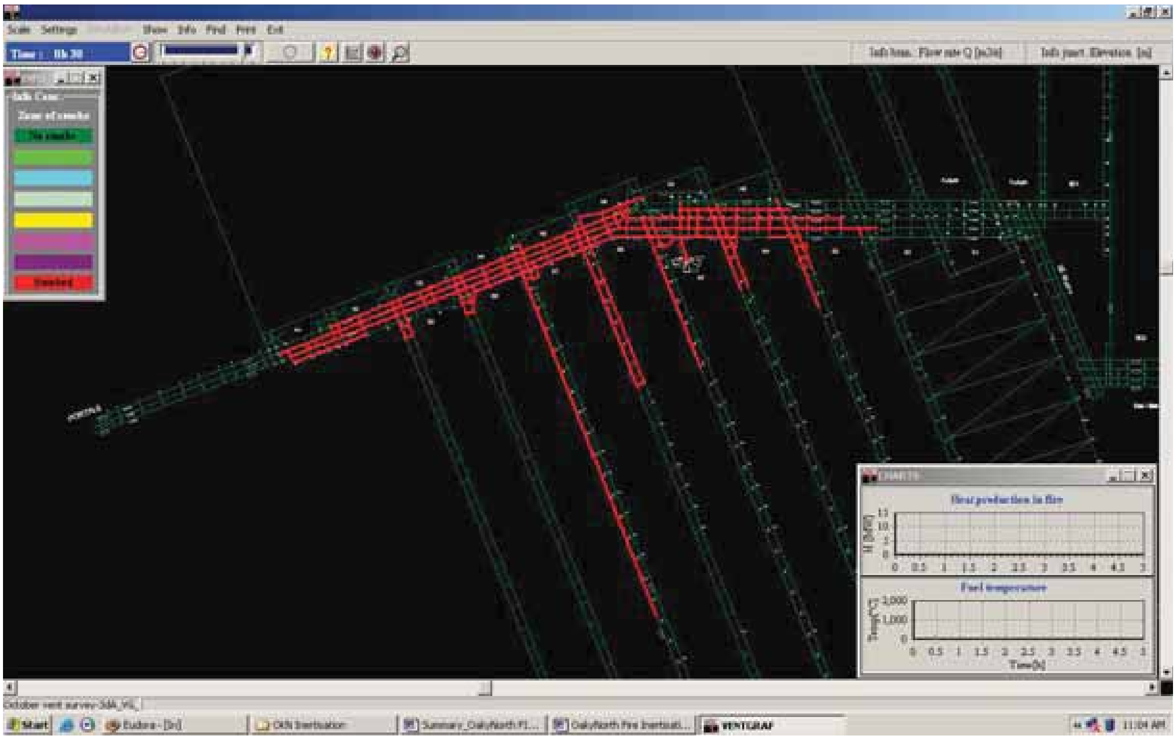


Figure 6.10 Smoke distribution after 30 minutes

Step 3 Time 120 – 300 minutes, Spillage coal burning. Simulate 10m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 4 Time 300 – 330 minutes, Spillage coal burning. Simulate 10m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

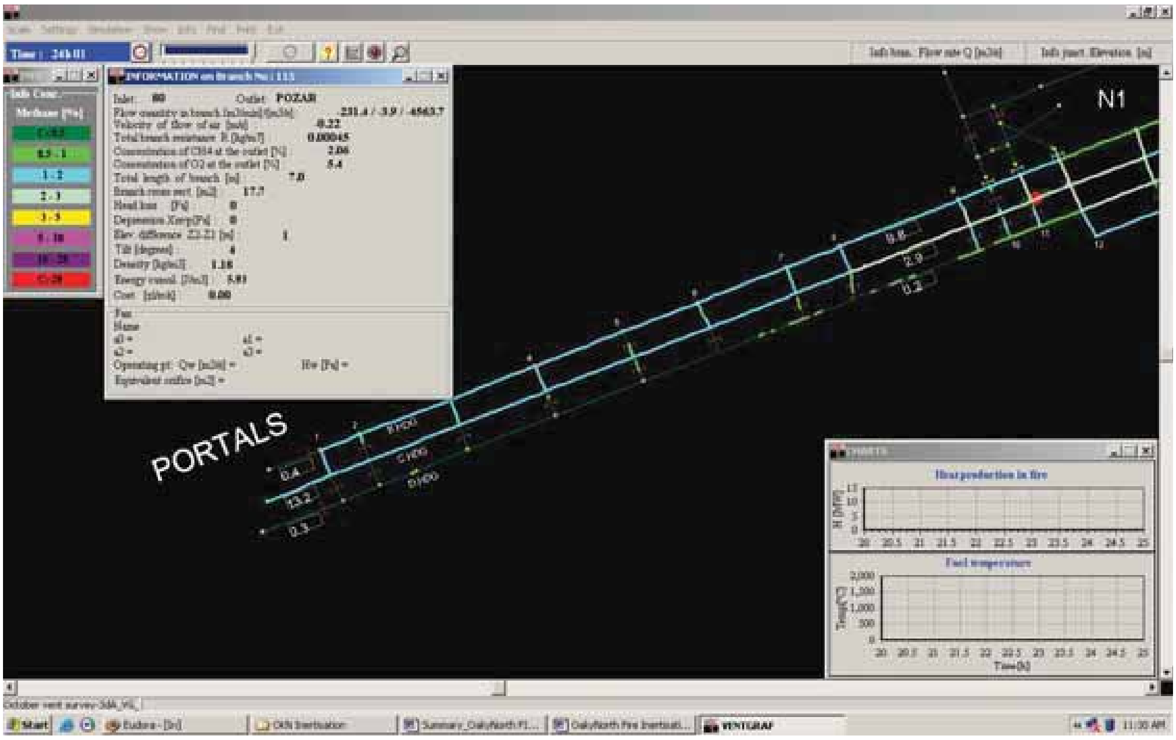
Fire is constrained but still burning

At 300 minutes GAG has been set up at the Intake Drift Close emergency door R=10

Control Assess effectiveness of GAG

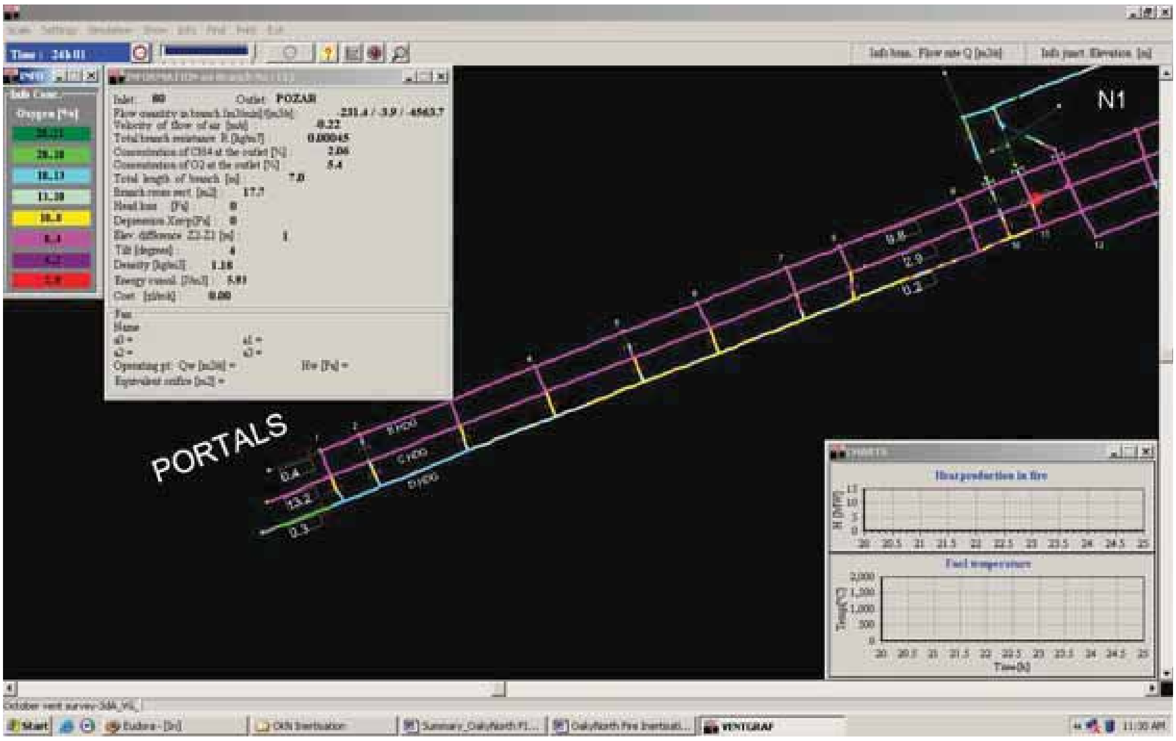
Examine all three main fan curve operating points; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 5 330 minutes, Shut down No 1, No 2 and No 3 fans; fan louvre doors closed R=20
Close Main Portal D Heading Emergency Door R = 10
Close Main Portal B Heading Emergency Door R = 10



Inlet: 80 Outlet: POZAR
Flow quantity in branch [m3/min]/[m3/s] 231.4 / 3.9 / -4563.7
Velocity of flow of air [m/s] 0.22
Total branch resistance R [kg/m7] 0.00045
Concentration of CH4 at the outlet [%] 2.06
Concentration of O2 at the outlet [%] 5.4
Total length of branch [m] 7.0
Branch cross sect. [m2] 17.7
Head loss [Pa] 0
Depression Xerp[Pa] 0
Elev. difference Z2-Z1 [m] 1
Tilt [degree] 4
Density [kg/m3] 1.18
Energy consd. [J/m3] 5.81
Cost [zl/m3] 0.00
Fan
Name
a0 = a1 =
a2 = a3 =
Operating pt: Qw [m3/s] = Hw [Pa] =
Equivalent orifice [m2] =

Figure 6.11 Methane distribution after 1440 minutes



Inlet: 80 Outlet: POZAR
Flow quantity in branch [m3/min]/[m3/s] 231.4 / 3.9 / -4563.7
Velocity of flow of air [m/s] 0.22
Total branch resistance R [kg/m7] 0.00045
Concentration of CH4 at the outlet [%] 2.06
Concentration of O2 at the outlet [%] 5.4
Total length of branch [m] 7.0
Branch cross sect. [m2] 17.7
Head loss [Pa] 0
Depression Xerp[Pa] 0
Elev. difference Z2-Z1 [m] 1
Tilt [degree] 4
Density [kg/m3] 1.18
Energy consd. [J/m3] 5.81
Cost [zl/m3] 0.00
Fan
Name
a0 = a1 =
a2 = a3 =
Operating pt: Qw [m3/s] = Hw [Pa] =
Equivalent orifice [m2] =

Figure 6.12 Oxygen distribution after 1440 minutes

Control Assess effectiveness of GAG

Summary *With GAG running fire intensity insignificant at 24 hours and oxygen level outbye fire at less than 5.4 percent. Face methane passing over fire potentially causing explosions.*

6.7. Oaky North Fire Inertisation Scenario 5

Scenario: *Development in 7 MG at 26 ct (100m pillar). Eimco vehicle caught fire at 500m outbye of the face. Face 2.2 m^3/tonne CH_4. October 2005*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO and CH_4 Gas sensors in Dev 7 TG 2-3 ct panel returns, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.

Simulation

Figure 6.13 Fire location at initiation

Step 1 Time 0 – 15 minutes: 200 litres diesel fuel is burning; Simulate 7m length fire over entry width; time constant 120s, intensity 10 $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 2 Time 15– 30 minutes: Simulate 7m length fire over entry width; time constant 120s, intensity 10 $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 3 Time 30 – 60 minutes: 200 litres fuel is burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control

Step 4 Time 60 – 120 minutes: an additional 20m length of coal pillar equivalent of a total 47m additional burning; Simulate 47m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control

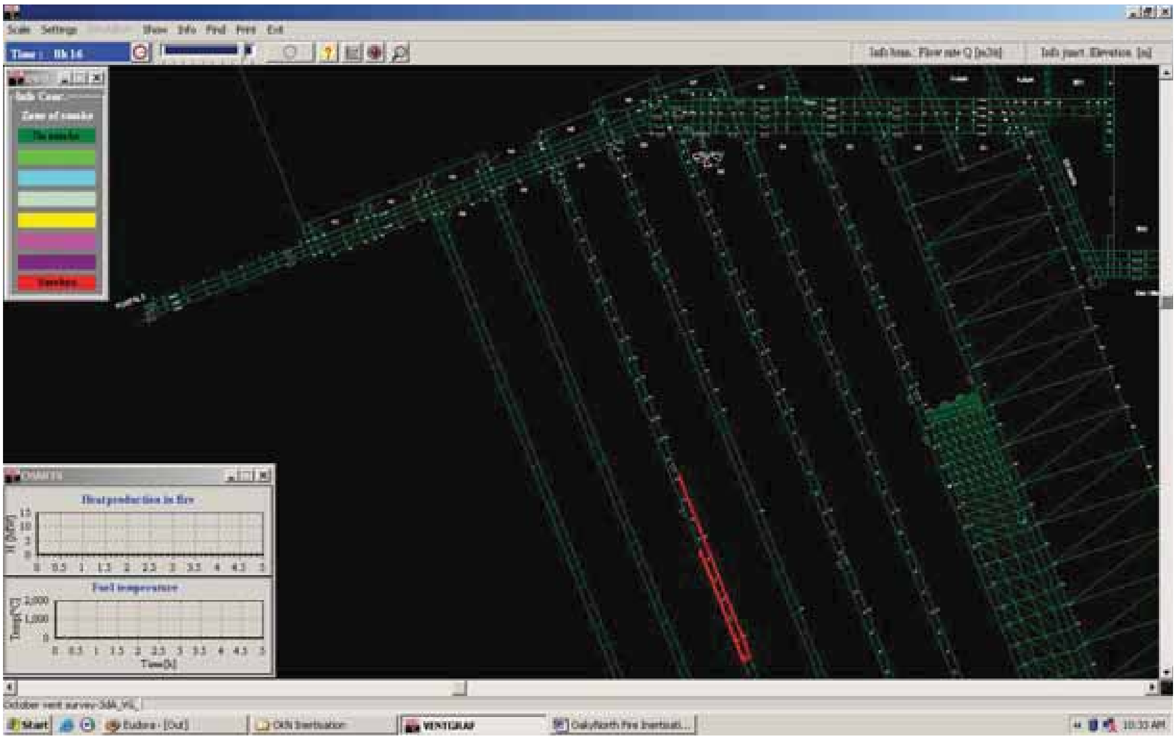


Figure 6.14 Smoke distribution after 15 minutes

Control Assume all mining crewmembers out of mine.

IMT team formed; Decision made to introduce high flow inertisation – GAG as soon as all crews evacuated out of mine.

Step 5 Time 120 – 300 minutes: Additional 20 m entry length coal caught on fire. Simulate 67m length oil fire over entry width; time constant 120s, intensity 7. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control.

Step 6 Time 300 - ? minutes: Continue simulating 67m length fire over entry width; time constant 120s, intensity 7 $CO:CO_2 = 0.1$. (assume H_2 = CO level); Fire out of control.

Control High flow inertisation GAG unit has arrived and is set up

At 300 minutes: GAG has been set up at the Drift Transport Portal entry and emergency door closed, R=10; Initiate GAG.

At 330 mins shut down one main fan; fan louvre doors closed R=20
At 360 mins shut down second main fan; fan louvre doors closed R=20
At 360 B and C Hdg portal doors closed R = 10 and R = 1 respectively.
Due to less ventilation air methane levels have increased in the return air up to 3.5%.

At 390 mins shut down the third main fan
At 390 D Hdg portal doors closed R = 10.

Explosion occurs due to localised reversal of methane over fire in SMG7.

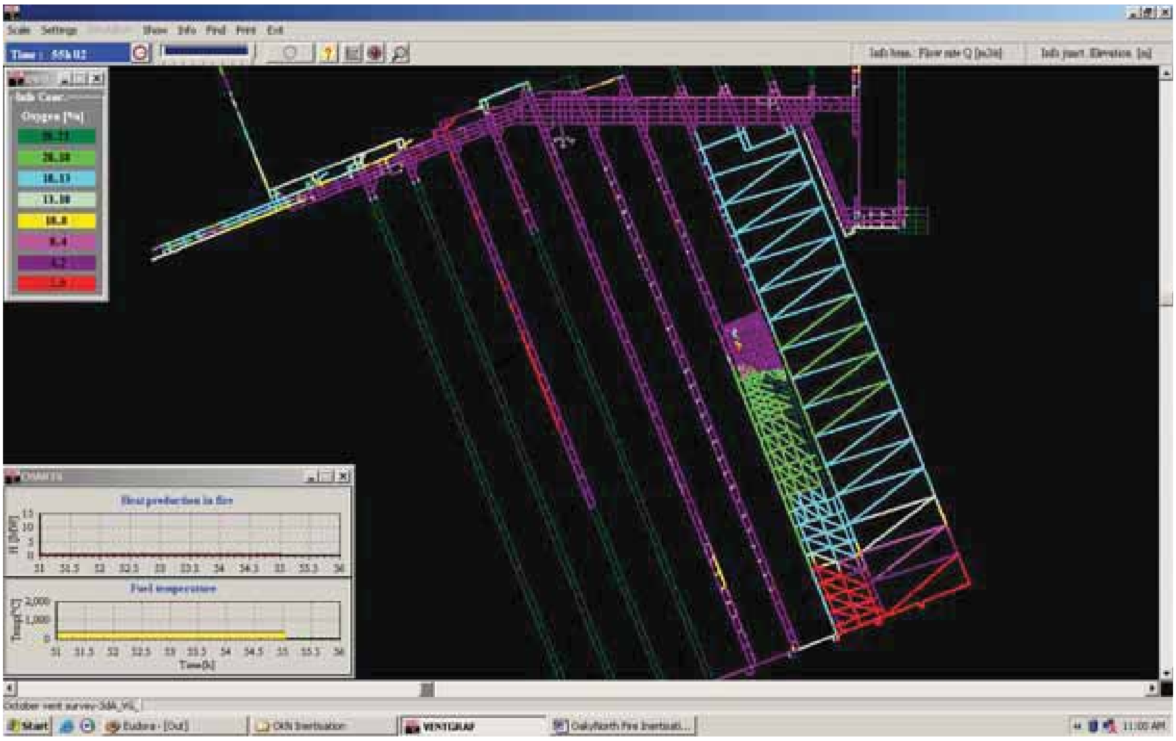


Figure 6.15 O_2 distribution at 3300 minutes

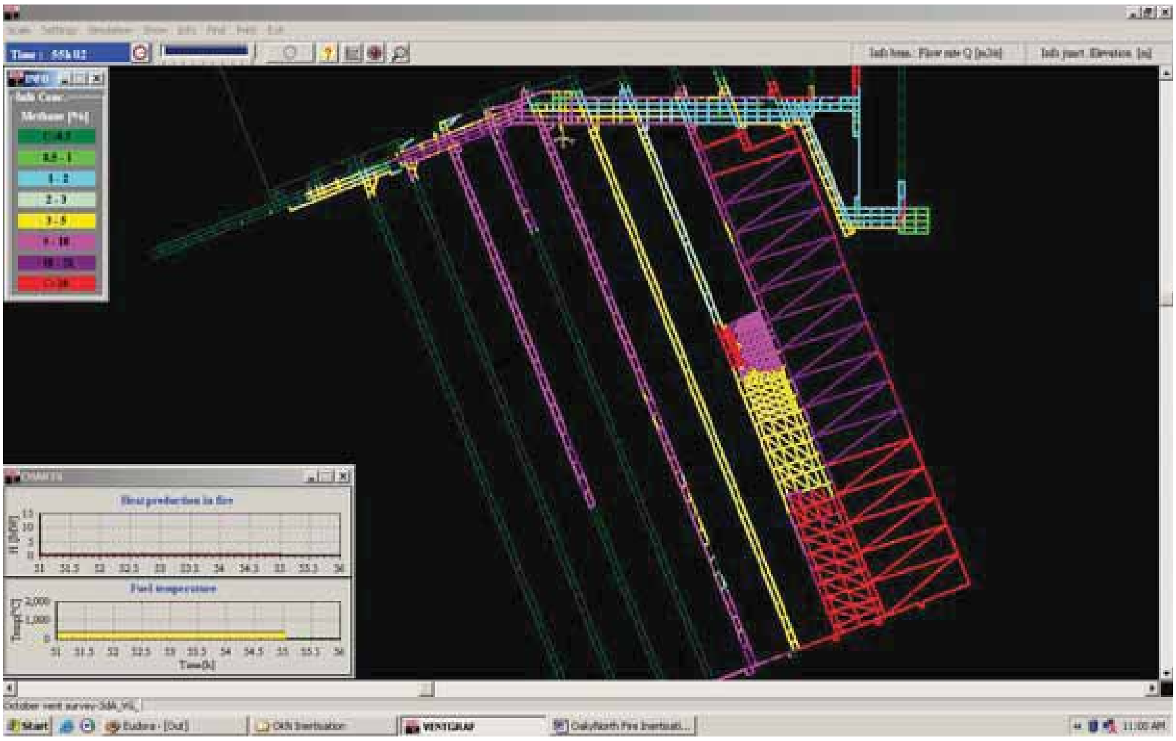


Figure 6.16 Methane (from other sources) distribution at 3300 minutes

Summary Inertisation and extinguishment of fire eventually occurs over a long period of time, but with several methane explosions.

7. REVIEW OF OPTIONS FOR IMPROVING ABILITY TO INERTISE PRIORITY FIRES AT OAKY NORTH MINE

As mentioned in Section 3.3, location position of the inertisation unit's point of coupling to the mine, or the docking point, is a major determinant of potential success for most efficient suppression of a specific underground fire. Traditionally in Queensland docking points have been placed on intake ventilation headings (either travel or conveyor belt roads). Some mines have prepared docking points on boreholes of about 1.0 to 2.0m diameter placed at the back of longwall panels.

Scenarios developed for Oaky North Colliery have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage following a fire. Table 7.1 shows results of the outcome of the five scenarios investigated in Chapter 6.

Analysis of these five scenarios leads to the following comments.

- Category A covers fire in which the inertisation product is directed fully over the fire. None of the five mine priority fires examined achieved the situation in which the simulated fire is directly stabilised to aid recovery in a timely manner.
- Category B covers situations in which the inertisation product goes straight to the fire but there is significant dilution from other ventilation air or leakage through stoppings. Because of dilution stabilisation of a fire through inertisation can only be achieved with some main surface fan changes. One scenario is in this category. Under these situations the fire should, over time, be abated or stabilised to a point where conventional recovery approaches can be initiated.
- Category C covers priority fires in which the GAG output will never reach the fire location without stopping of one or more main surface fans to rebalance ventilation within the pit. In many of these cases requiring fan changes to put GAG output across the fire location effective ventilation air velocity has been reduced to the extent that local reversal across the fire occurs and fire fumes are pulled across the fire. This is an unsatisfactory situation as fire smoke and fumes can carry combustible products. This situation broadly prevails for 40 percent (two scenarios) of the cases examined.
- Category D covers priority fires in which the GAG output will never reach the fire location even if surface main fans are altered. These are fire locations within panel sections in which either the fire behaviour stops normal intake ventilation flow into the section headings or the GAG docking point is in an airway that is isolated from the section. There is no such case in the five scenarios examined.
- Category E covers priority fires in gassy mines in which section production gas make has been included in the simulation modelling. GAG exhaust will never reach the fire location without stopping of one or more main surface fans to rebalance ventilation within the pit.

However this change in ventilation causes working section methane and ventilation air (incl. fire fumes) to reverse across the fire. This is clearly a potentially dangerous situation. This situation was found in 40 percent (two scenarios) of the cases examined.

It was determined that Oaky North is not in the best prepared position to undertake efficient GAG inertisation in the event of a major fire

Recommended general actions that can be undertaken to improve the effectiveness of inertisation in an underground ventilation network can be drawn from the following.

1. Maintain use of existing docking station but with additional underground segregation to control the delivery of inert gas.
2. Try alternative Portal docking station locations.
3. Try alternative Portal docking station locations with additional underground segregation.
4. Drill new borehole to deliver inert gas more directly to the fire site.

The five scenarios have been re-simulated using appropriate actions from the above approaches. These new scenarios are described in the following sections.

Table 7.1 Summary of Scenario Outcomes on the Effects of Inertisation

Scenario No	Fire Location	Fire Type	GAG Location	Segregation actions	Fan Actions	Outcomes
1	Mains C Hdg conveyor at 39ct	Belt (oil)	Transport Drift Portal	None; Only external sealing required for GAG operation.	All shut down	With fans still running, GAG exhaust was diluted significantly. After all fans off, fire insignificant at 10 hours and oxygen level outbye fire less than 2.9 percent. ***(Category B)***
2	Behind South Longwall 3	Goaf spon combustion	Transport Drift Portal	None; Only external sealing required for GAG operation.	All shut down	At 34 hours local reversal occurred to produce a minor methane burn off. With the GAG running after 5 days there is no significant fire. Outbye the fire oxygen is 0.1 percent. ***(Category C)***
3	South LW 4 MG 22CT Tripper drive	Belt Fire	Transport Drift Portal	None; Only external sealing required for GAG operation.	All shut down	Explosion occurred as soon as all fans were turned off due to a reversal. ***(Category E)***
4	Belt tripper drive Mains 11ct C Hdg	Spillage Coal	Transport Drift Portal	None; Only external sealing required for GAG operation.	All shut down	With GAG running Fire intensity insignificant at 24 hours and oxygen level outbye fire at less 5.4 percent. Face methane passing over fire potentially causing explosions. ***(Category C)***
5	Dev in 7 MG at 26 ct B Hdg	Eimco vehicle fire (diesel)	Transport Drift Portal	Close Main Portal B Heading Emergency Door Close Main Portal C Heading Emergency Door Close Main Portal D Heading Emergency Door	All shut down	Explosion occurs due to localised reversal of methane over fire in SMG7. Inertisation eventually occurs over a long period of time, but with several methane explosions. ***(Category E)***

7.1. Oaky North Fire Inertisation Scenario 1A

Scenario *Belt Fire in Mains C Hdg conveyor at 39ct*

Inertisation Strategy *The pit bottom area is very open. Various forms of segregation are introduced to reduce GAG exhaust dilution with intake air in the pit bottom area. GAG remains docked at the Decline Portal.*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.

CH_4 source of 600 litres/s from LW goaf at TG end of face

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

- CO Gas sensors set at points before and after fire, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.
  CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 15 minutes: 30 litres oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10 $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 2 Time 15 - 30 minutes: 230 litres oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Step 3 Time 30 – 120 minutes: Oil consumed. 50 m entry length coal fire develops. time constant 14,400s, intensity 5.

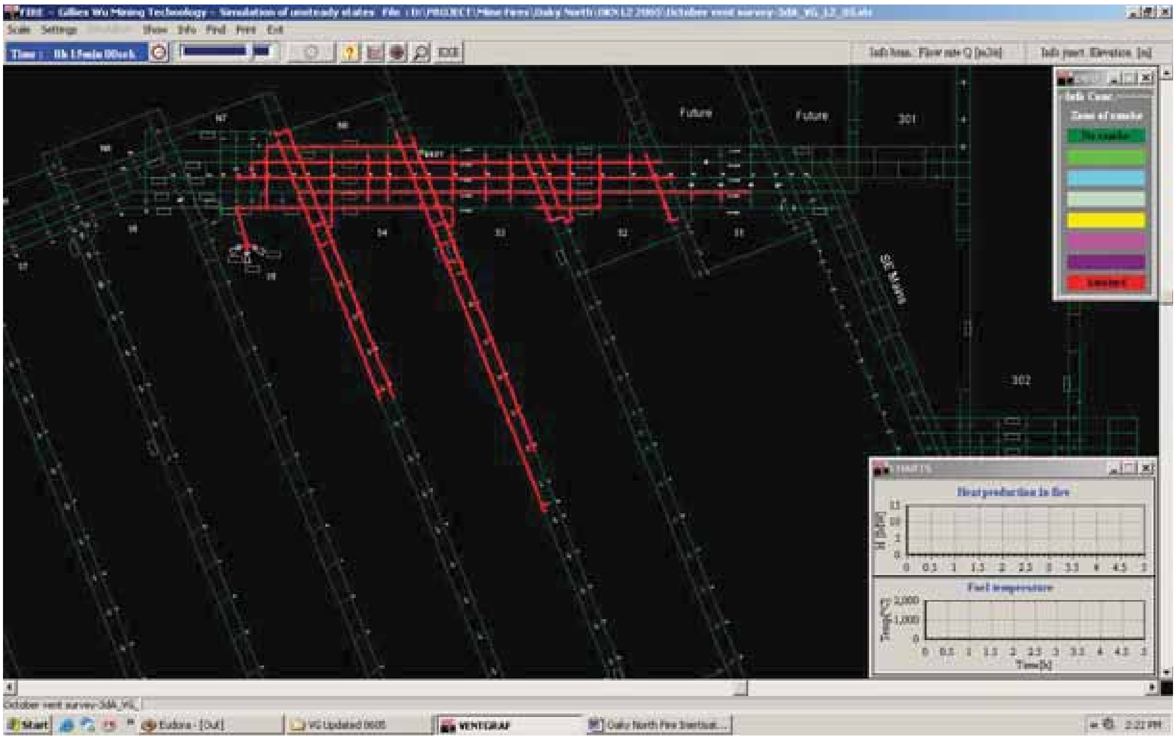


Figure 7.1 Smoke distribution after 15 minutes

Control At 120 minutes decision made to introduce high flow inertisation – GAG

Step 4 Time 120 – 300 minutes: 100 m entry length coal fire develops. time constant 14,400s, intensity 5.

Step 5 300 minutes: segregation devices (e.g. prep seals, brattice, remote controlled doors or manually controlled doors) installed to assist segregation of inert gases. Segregation for pit bottom required at the following points. For delivering of GAG exhaust into

B Hdg
- Close machine door at 37ct B – C
- Prep seal B Hdg 35 – 36

C Hdg
- Prep seal at B Hdg 35-36 R=2
- Open machine door at 37ct B-C
- Brattice around belt structure C Hdg 35 – 36ct R=1
- Brattice around belt structure 37ct C – D R=1
- Prep seal at 36ct C - D R=2
- Prep seal at B Hdg 37-37A ct R=2
- Segregation stopping 38ct, 39ct and 40ct C-D

D Hdg Must turn at least one main fan off
- Close B Hdg, C Hdg & D Hdg, 35 – 36ct
- Close B Hdg & C Hdg 37 - 37A ct
- Open machine door at 37ct B-C

Step 6 Time 300 minutes: GAG has been set up at the Intake Drift Close emergency door R=10; Start GAG. Undertake pit bottom segregation strategy for inertisation of fire in C Heading.

Control Assess effectiveness of GAG

Examine all three main fan curve operating points; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 330 minutes Shut down No 1 fan; fan louvre doors closed R=20

Fire unstable and erratic local air reversals over fire.

Step 8 345 minutes: Shut down No 2 fan; fan louvre doors closed R=20
Examine No 3 fan curve operating point

Step 9 390 minutes: Shut down No 3 fan

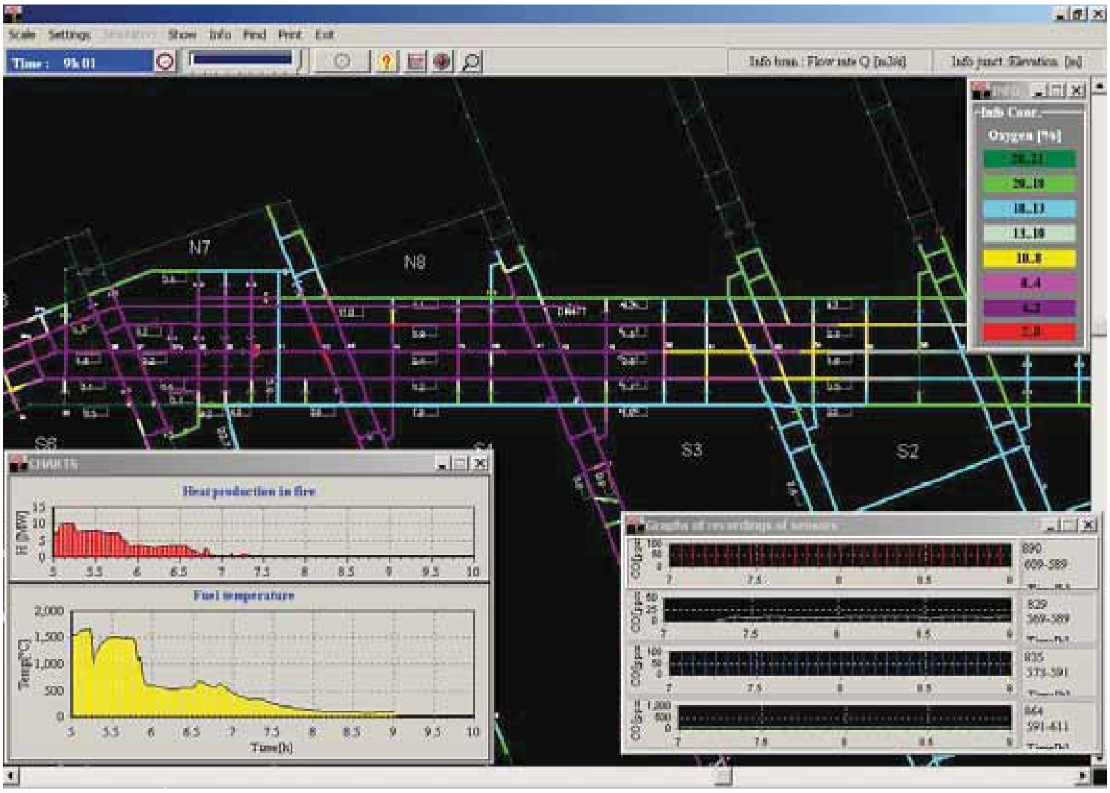


Figure 7.2 Oxygen distribution after 540 minutes

Summary *With GAG running fire intensity insignificant at 9 hours and oxygen level outbye fire at less than 2.5 percent. There is only a slight reduction in the time needed to achieve satisfactory inertisation of the mine with extra segregation.*

7.2. Oaky North Fire Inertisation Scenario 2A

Scenario *LW goaf fire - spider web arrangement. Spontaneous Combustion in goaf behind South Longwall 3 face currently at 15ct. Spontaneous Combustion potentially spread over 600m (Model: October vent survey-3dA_VG_Goaf_BH).*

Inertisation Strategy: *Close Mains C Hdg 35 – 36, Mains B Hdg 35 – 36 and Mains D Hdg 35 – 36; Shut down all fans.*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
- Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO Gas sensors set at points either side of bottom of Ventilation Shaft.
- CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- O_2 sensor in the LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 360 minutes: 1 m entry length coal fuel in 18 c/t MG edge of goaf burning; time constant 14400s, intensity 1 $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control.

Step 2 Time 360– 720 minutes: 5 m entry length coal burning with gas continuing to burn; time constant 14400s, intensity 2.

Step 3 Time 720 – 1080 minutes: Continue coal fire 25 m entry length coal burning; time constant 14400s, intensity 4.

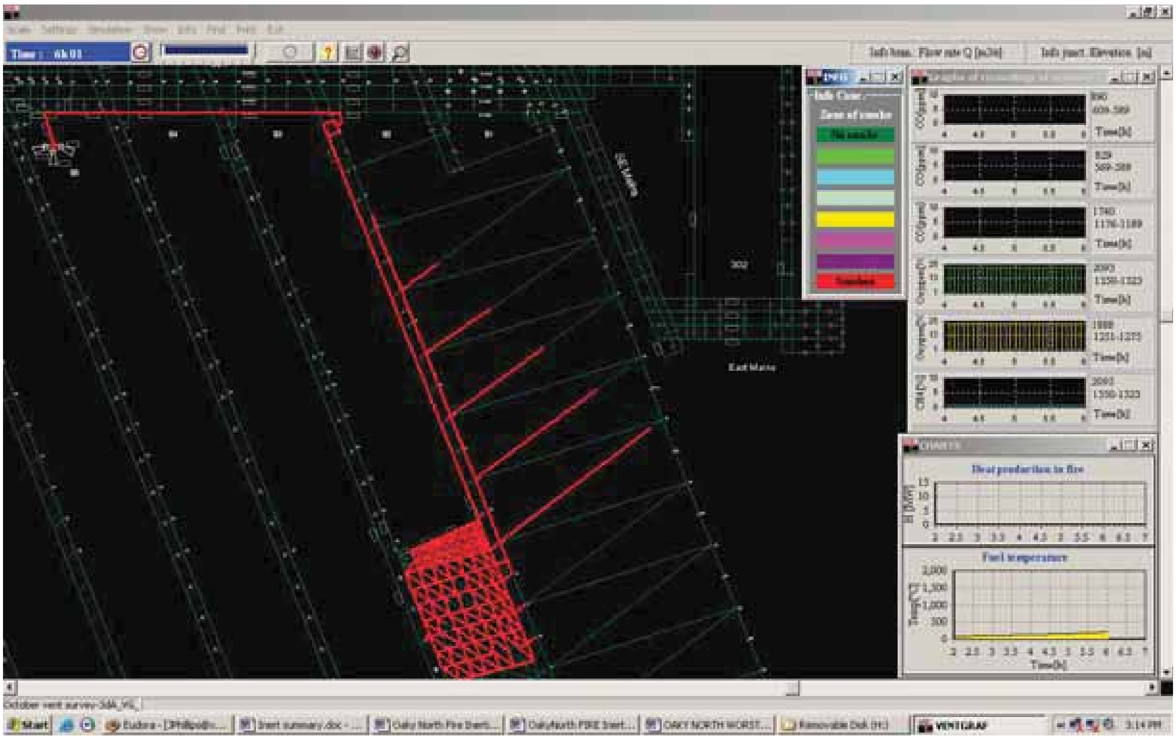


Figure 7.3 Smoke distribution after 360 minutes

Step 4 Time 1080 - 1440 minutes: Continue coal fire 100 m entry length coal burning; time constant 14400s, intensity 8. Fire very unstable and not under control.

CO concentration at 19 hours sets off alarm at bottom of vent shaft.

Step 5 Time 1440 - 1800 minutes: Continue coal fire 200 m entry length coal burning; time constant 14400s, intensity 10.

Step 6 Time 1440 minutes GAG has been set up at the Intake Drift Close emergency door R=10

Close C Hdg 35 – 36 Brattice seal R=1
Close B Hdg 35 – 36 Prep seal R=2
Close D Hdg 35 – 36 Prep seal R=2
Shut down No 1 fan; fan louvre doors closed R=20
Shut down No 2 fan; fan louvre doors closed R=20
Examine No 3 fan curve operating point

Step 7 1680 minutes: Shut down No 3 fan. Close main portal B Emergency Door R=20

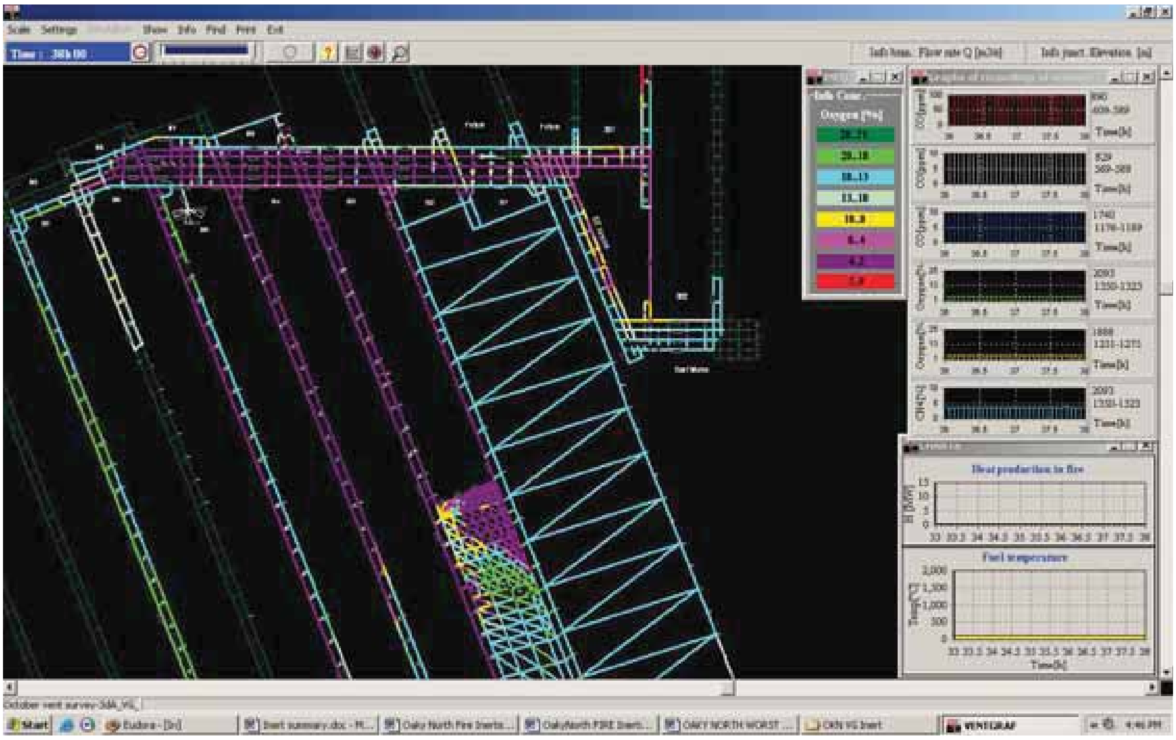
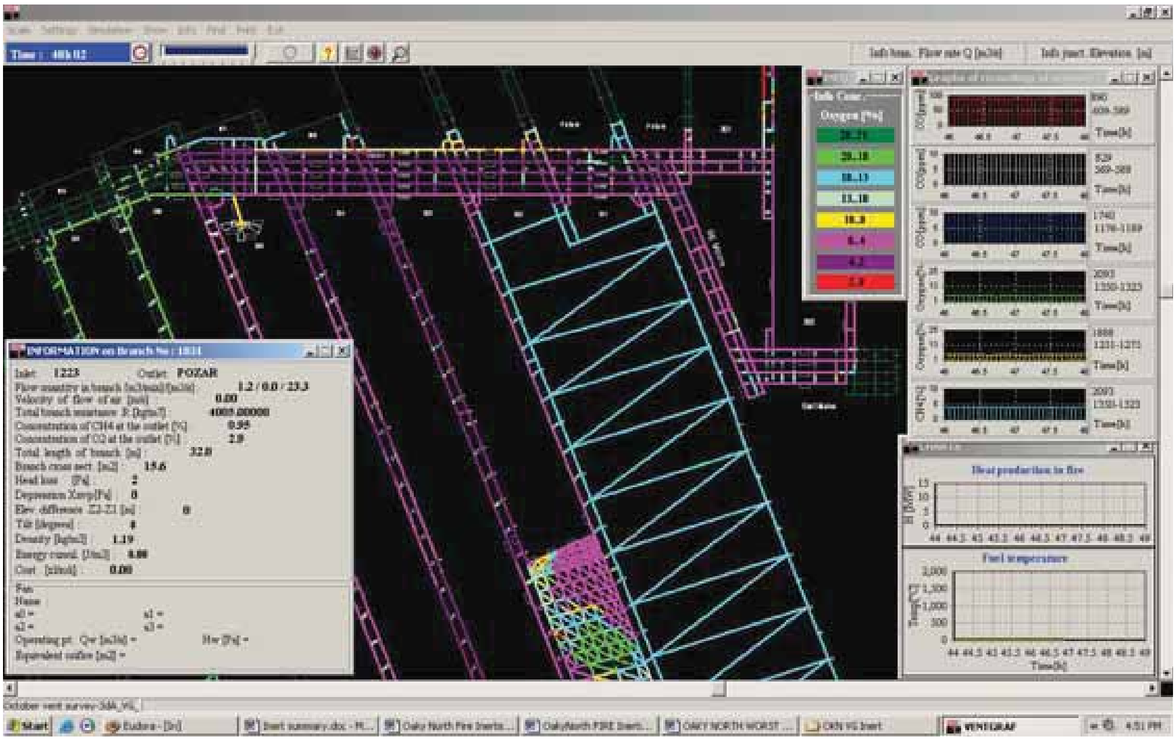


Figure 7.4 Oxygen distribution after 2280 minutes



INFORMATION on Branch No : 1811

Inlet 1223 Outlet POZAR
Flow quantity in branch [m3/min]/[m3/s] 1.2 / 0.0 / 23.3
Velocity of flow of air [m/s] 0.00
Total branch resistance R [kg/m7] 4005.00000
Concentration of CH4 at the outlet [%] 0.99
Concentration of O2 at the outlet [%] 2.9
Total length of branch [m] 32.0
Branch cross sect. [m2] 15.6
Head loss [Pa] 2
Depression Xavg[Pa] 0
Elev. difference Z2-Z1 [m] 0
Tilt [degree] 8
Density [kg/m3] 1.19
Energy consd. [J/m3] 0.00
Cost [zl/m3] 0.00
Fan
Name
a0 = a1 =
a2 = a3 =
Operating pt. Qw [m3/s] = Hw [Pa] =
Equivalent orifice [m2] =

Figure 7.5 Oxygen distribution after 2880 minutes

Summary *After 2 days with the GAG running, there is no significant fire. Outbye the fire the oxygen is 2.9 percent.*

7.3. Oaky North Fire Inertisation Scenario 2B

Scenario *LW goaf fire - spider web arrangement. Spontaneous Combustion in goaf behind South Longwall 3 face currently at 15ct. Spontaneous Combustion potentially spread over 600m (Model: October vent survey-3dA_VG_Goaf_BH).*

Inertisation Strategy: *GAG on Panel Borehole; Close Mains C Hdg 35 – 36, Mains B Hdg 35 – 36 and Mains D Hdg 35 – 36; Shut down all fans*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Borehole at MG 2 ct LW.
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
- Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO Gas sensors set at points either side of bottom of Ventilation Shaft.
- CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- O_2 sensor in the LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 360 minutes: 1 m entry length coal fuel in 18 c/t MG edge of goaf burning; time constant 14400s, intensity 1 $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control.

Step 2 Time 360– 720 minutes: 5 m entry length coal burning with gas continuing to burn; time constant 14400s, intensity 2.

Step 3 Time 720 – 1080 minutes: Continue coal fire 25 m entry length coal burning; time constant 14400s, intensity 4.

Step 4 Time 1080 - 1440 minutes: Continue coal fire 100 m entry length coal burning; time constant 14400s, intensity 8. Fire very unstable and not under control

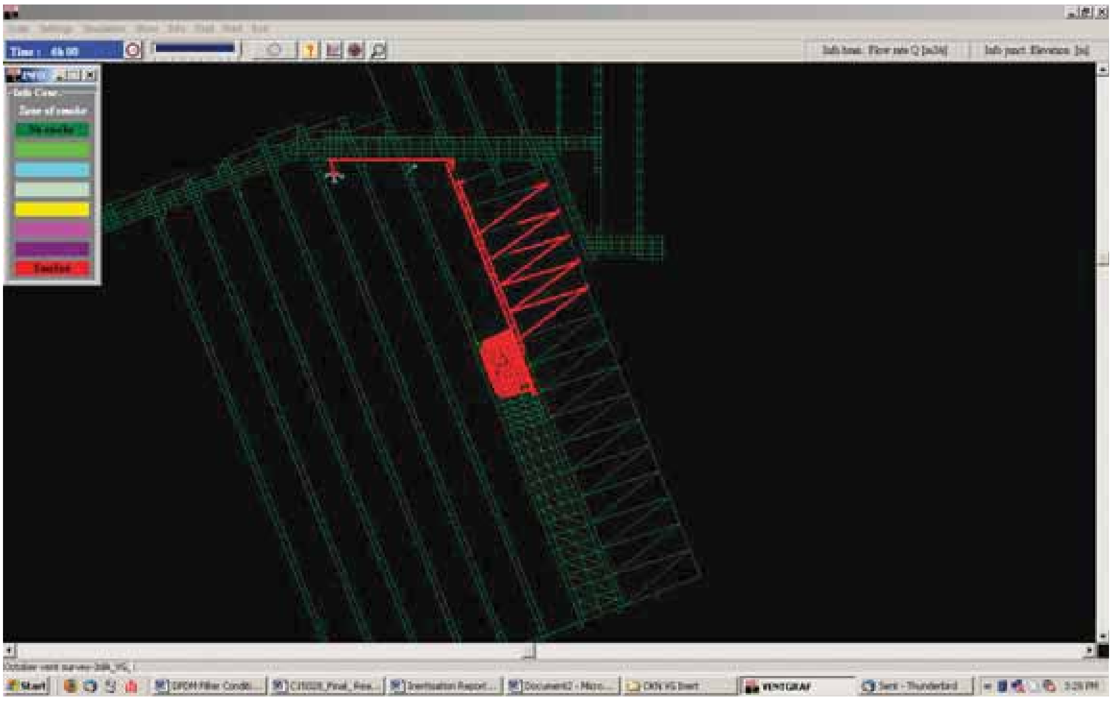


Figure 7.6 Smoke distribution after 360 minutes

CO concentration at 19 hours sets off alarm at bottom of vent shaft.

Step 5 Time 1440 - 1800 minutes: Continue coal fire 200 m entry length coal burning; time constant 14400s, intensity 10.

Step 6 Time 1440 minutes GAG has been set up at the Borehole at LW3 MG 2 ct.

Seal LW3 MG A (R = 1) and B Hdg (R = 5) 1-2ct
Borehole R = 2.3 to represent Borehole open resistance

Close Mains C Hdg 35 – 36 Brattice seal R=1
Close Mains B Hdg 35 – 36 Prep seal R=2
Close Mains D Hdg 35 – 36 Prep seal R=2

Shut down No 1 fan; fan louvre doors closed R=20
Shut down No 2 fan; fan louvre doors closed R=20
Shut down No 3 fan

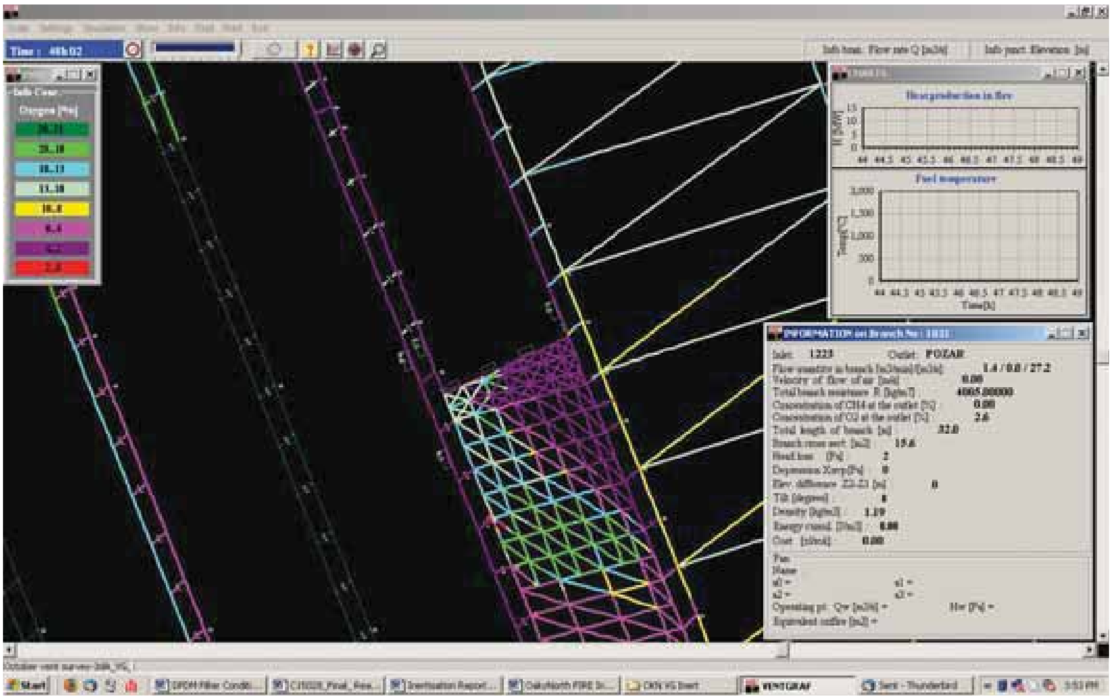


Figure 7.7 Oxygen distribution after 2880 minutes

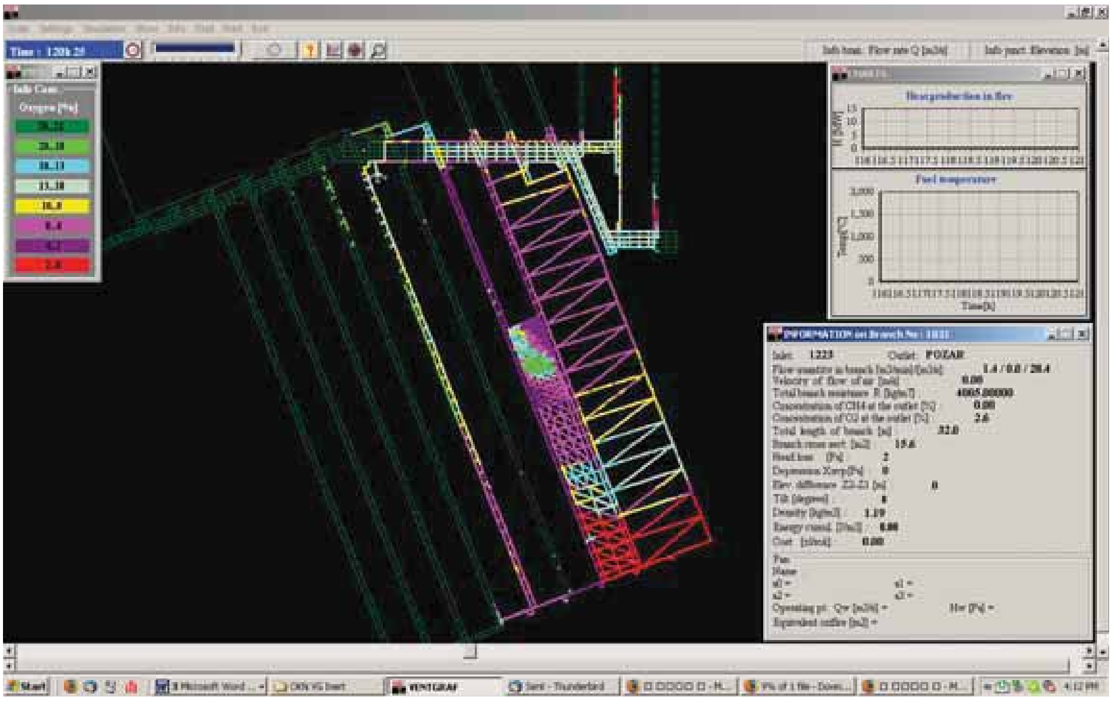


Figure 7.8 Oxygen distribution after 2880 minutes

Summary *After 2 days with the GAG running, there is no significant fire. Outbye the fire the oxygen is 2.6 percent. After 5 days with the GAG running, there is no significant fire. Outbye the fire the oxygen is 2.6 percent.*

7.4. Oaky North Fire Inertisation Scenario 2C

Scenario *LW goaf fire - spider web arrangement. Spontaneous Combustion in goaf behind South Longwall 3 face currently at 15ct. Spontaneous Combustion potentially spread over 600m (Model: October vent survey-3dA_VG_Goaf_BH).*

Inertisation Strategy: *GAG on Panel Borehole; Close Mains C Hdg 35 – 36, Mains B Hdg 35 – 36 and Mains D Hdg 35 – 36; Shut down fans 1 and 2. Close Transport Drift.*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Borehole at MG 2 ct LW.
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
- Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO Gas sensors set at points either side of bottom of Ventilation Shaft.
- CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- O_2 sensor in the LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 360 minutes: 1 m entry length coal fuel in 18 c/t MG edge of goaf burning; time constant 14400s, intensity 1 $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control.

Step 2 Time 360– 720 minutes: 5 m entry length coal burning with gas continuing to burn; time constant 14400s, intensity 2.

Step 3 Time 720 – 1080 minutes: Continue coal fire 25 m entry length coal burning; time constant 14400s, intensity 4.

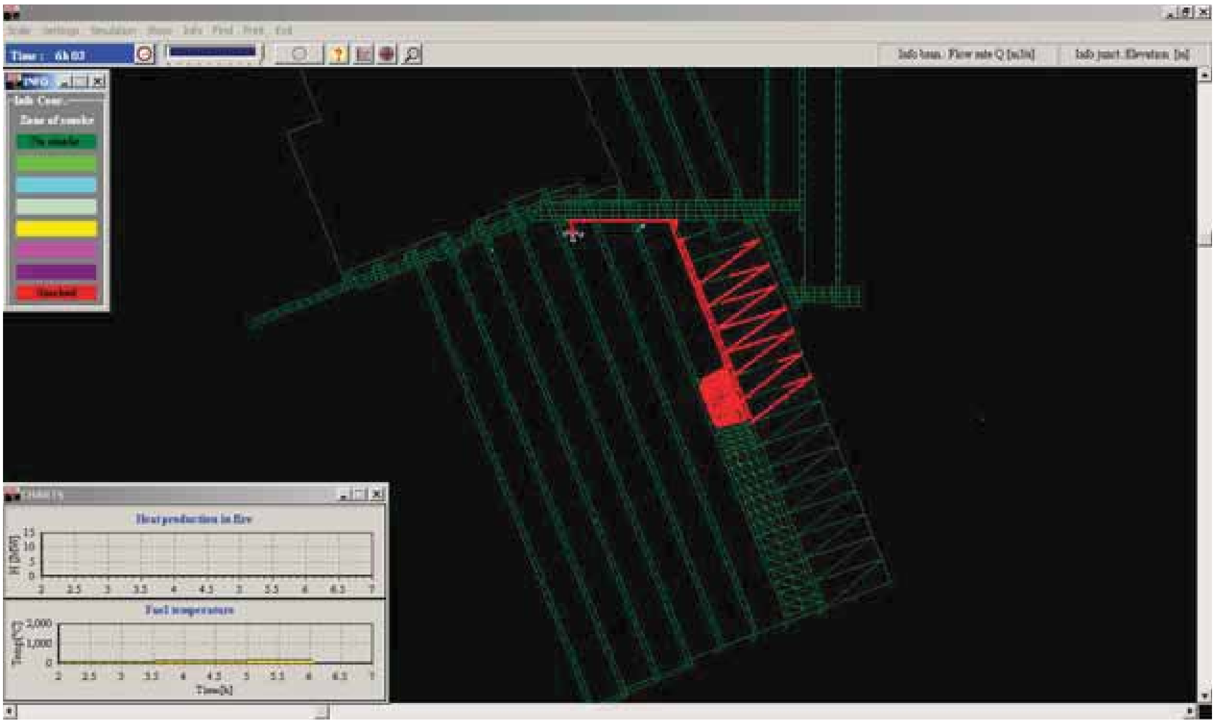


Figure 7.9 Smoke distribution after 360 minutes

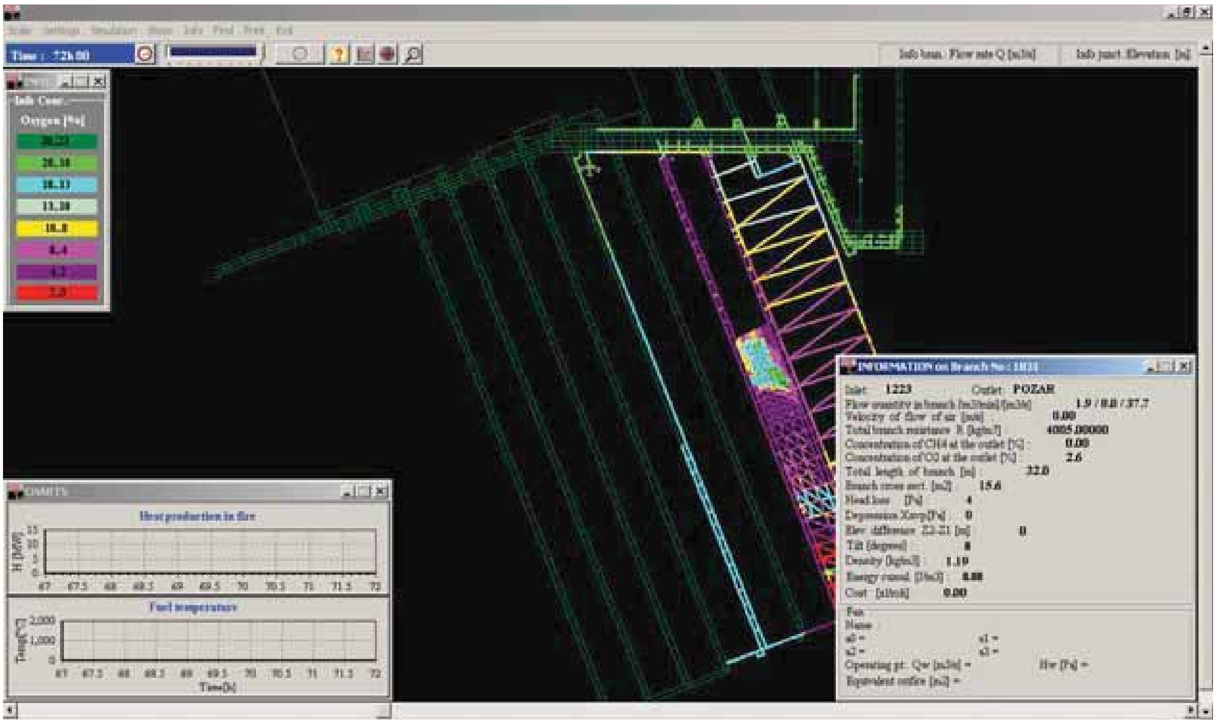
Step 4 Time 1080 - 1440 minutes: Continue coal fire 100 m entry length coal burning; time constant 14400s, intensity 8. Fire very unstable and not under control

Step 5 Time 1440 - 1800 minutes: Continue coal fire 200 m entry length coal burning; time constant 14400s, intensity 10.

Step 6 Time 1440 minutes GAG has been set up at the Borehole at LW MG 2 ct
Seal LW3 MG A (R = 1) and B Hdg (R = 5) 1-2ct
Borehole R = 2.3 to represent Borehole open resistance
Close Mains C Hdg 35 – 36 Brattice seal R=1
Close Mains B Hdg 35 – 36 Prep seal R=2
Close Mains D Hdg 35 – 36 Prep seal R=2
Shut down No 1 fan; fan louvre doors closed R=20
Shut down No 2 fan; fan louvre doors closed R=20
Examine No 3 fan curve operating point (Q = 138m^3/s, P = 267 Pa)

Step 7 2880 minutes Close Drift Transport Portal emergency door R=10.

Examine No 3 fan curve operating point (Q = 132m^3/s, P = 499 Pa)



INFORMATION on Branch No : 1831

Inlet 1223 Outlet POZAR
Flow quantity in branch [m3/min] [m3/s] 1.9 / 0.0 / 37.7
Velocity of flow of air [m/s] 0.00
Total branch resistance R [kg/m7] 4005.00000
Concentration of CH4 at the outlet [%] 0.00
Concentration of O2 at the outlet [%] 2.6
Total length of branch [m] 32.0
Branch cross sect. [m2] 15.6
Head loss [Pa] 4
Depression Xsrp[Pa] 0
Elev difference Z2-Z1 [m] 0
Tilt [degree] 0
Density [kg/m3] 1.19
Energy consd. [J/m3] 0.00
Cost [$/h] 0.00
Fan
Name
a0 = a1 =
a2 = a3 =
Operating pt: Qw [m3/s] = Hw [Pa] =
Equivalent orifice [m2] =

Figure 7.10 Oxygen distribution after 2880 minutes

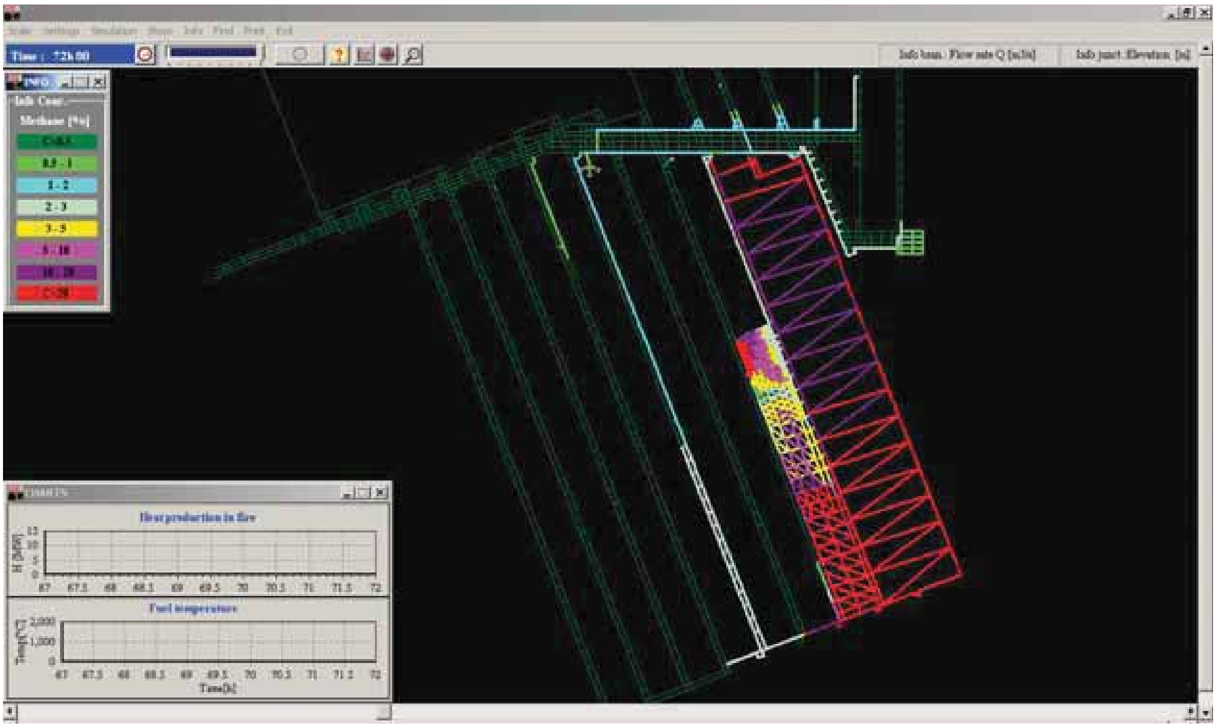


Figure 7.11 Methane distribution after 2880 minutes

Summary *After 2 days with the GAG running, there has been no significant fire. Outbye the fire the oxygen is 4.2 percent. However, by closing the Drift Transport Portal emergency door with the third fan still running, the oxygen level outbye the fire is reduced to 2.6 percent in less than 12 hours. Majority of the mine has methane level of less than 3 percent except the sealed longwall panels and goaf.*

7.5. Oaky North Fire Inertisation Scenario 3A

Scenario *Belt Fire in South LW 4 MG 22CT Tripper drive (Model: March 2006 SLW4).*

Inertisation Strategy: Segregation of Mains B, C and D Headings to assist delivery of GAG inert gases to fire site.

Sections

1. *LW 4 at 37ct 3/06*
2. *Dev 301 MG at 10ct 3/06*
3. *Dev South MG 7 at 28ct 3/06*
4. *Dev Stone Development road header (contractor) MG6 at 8ct at 3/06*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.
- CH4 source of 600 litres/s from LW goaf at TG end of face
- CO Gas sensors set at points before and after fire, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.

  CO sensor on MG leading onto LW face
- O_2 sensor at TG end of LW face
- CH_4 sensor at TG end of LW face

Simulation

Step 1 Time 0 – 30 minutes, Spillage coal burning. Simulate 1 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control Fire fighting control commences with hoses; ineffective.

Step 2 Time 30 – 120 minutes, Spillage coal burning. Simulate 5 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control At 120 minutes decision made to introduce high flow inertisation – GAG

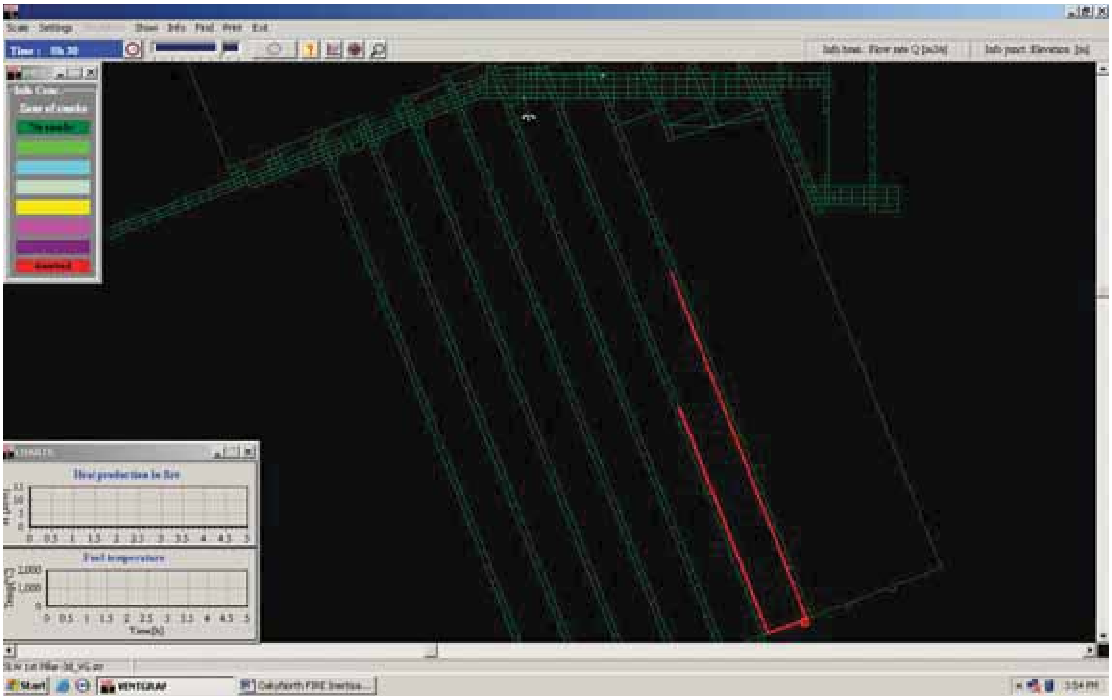


Figure 7.12 Smoke distribution after 30 minutes

Step 3 Time 120 – 300 minutes, Spillage coal burning. Simulate 10m length fire over entry width; time constant 7200s, intensity 7 and CO:CO_2 = 0.1. (assume H_2 = CO level).

Step 4 Time 300 – 360 minutes, Spillage coal burning. Simulate 25m length fire over entry width; time constant 7200s, intensity 7 and CO:CO_2 = 0.1. (assume H_2 = CO level).

Fire is constrained but still burning

At 300 minutes GAG has been set up at the Intake Drift Close emergency door R=10

Close C Hdg 35 – 36 Brattice seal R=1
Close B Hdg 35 – 36 Prep seal R=2
Close D Hdg 35 – 36 Prep seal R=2

Shut down No 1 fan; fan louvre doors closed R=20
Shut down No 2 fan; fan louvre doors closed R=20
Examine No 3 fan curve operating point

Reversal occurs, but no methane passes over the fire

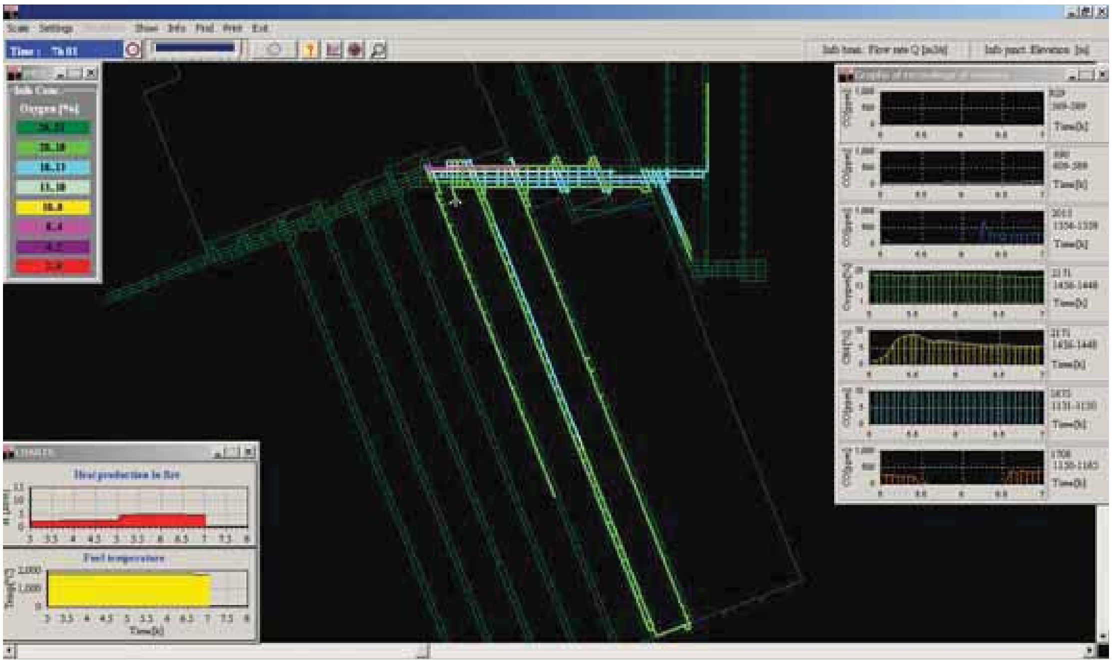


Figure 7.13 Oxygen distribution after 420 minutes

Step 5 Tighten Mains seals. After 420 minutes:
Close C Hdg 35 – 36 Brattice seal R=5
Close B Hdg 35 – 36 Prep seal R=10
Close D Hdg 35 – 36 Prep seal R=10

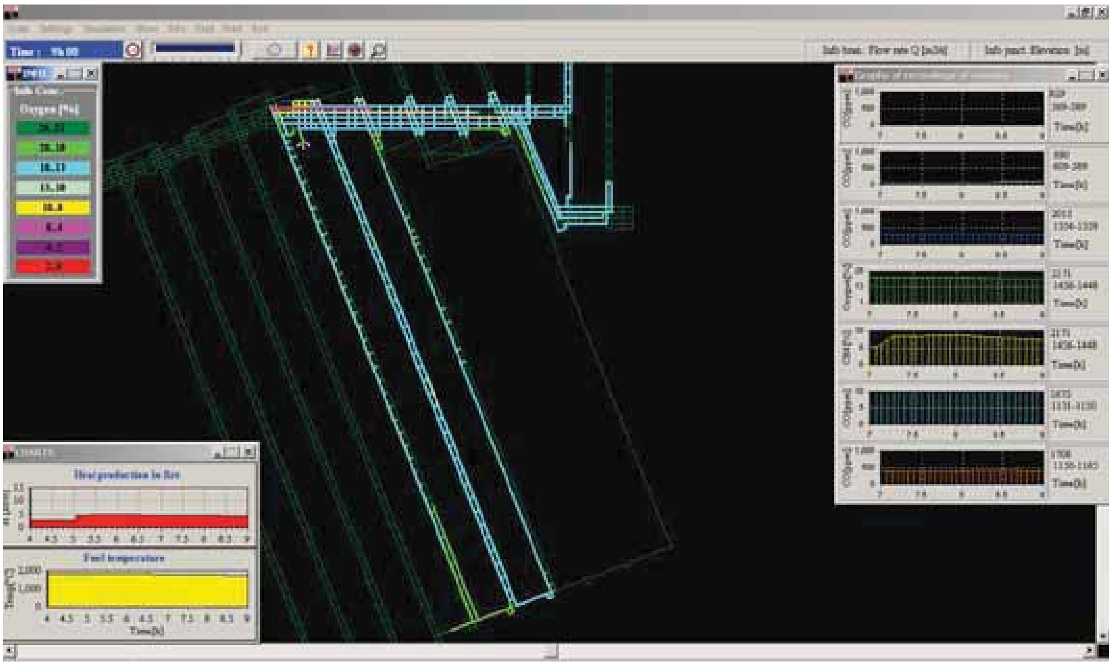


Figure 7.14 Oxygen distribution after 540 minutes

Summary *New segregation strategy does not improve inertisation strategy.*

7.6. Oaky North Fire Inertisation Scenario 4A

Scenario *Belt tripper drive Mains 11ct C Hdg*

Inertisation Strategy Set up GAG at highwall B Heading Portal. Close B, C and D Headings to assist delivery of GAG inert gases to fire site. Seal transport Drift.

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Drift Transport Portal entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.

CH_4 source of 600 litres/s from LW goaf at TG end of face

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

- CO Gas sensors set at points before and after fire, and
- CO Gas sensors set at points either side of bottom of Ventilation Shaft.

Simulation

Step 1 Time 0 – 30 minutes, Spillage coal burning. Simulate 1 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control Fire fighting control commences with hoses; ineffective.

Step 2 Time 30 – 120 minutes, Spillage coal burning. Simulate 5 m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Control At 120 minutes decision made to introduce high flow inertisation – GAG

Step 3 Time 120 – 300 minutes, Spillage coal burning. Simulate 10m length fire over entry width; time constant 7200s, intensity 7 and $CO:CO_2 = 0.1$. (assume H_2 = CO level).

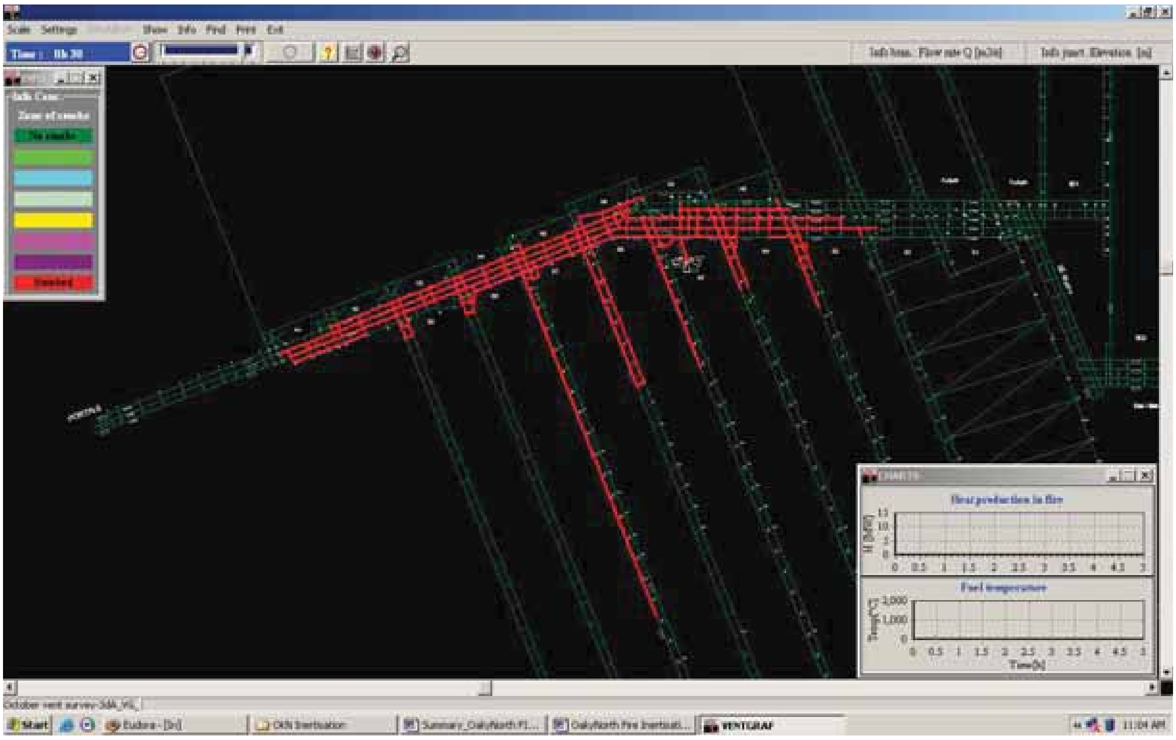


Figure 7.15 Smoke distribution after 30 minutes

Step 4 Time 300 – 330 minutes, Spillage coal burning. Simulate 10m length fire over entry width; time constant 7200s, intensity 7 and CO:CO_2 = 0.1. (assume H_2 = CO level).

Fire is constrained but still burning

At 300 minutes GAG has been set up at the Portal B Emergency door R=10
Close Main Portal B Heading Emergency Door R = 10

Control Assess effectiveness of GAG

Examine all three main fan curve operating points
NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 5 330 minutes, Shut down No 1 fan; fan louvre doors closed R=10
Close Main Portal C Heading Emergency Door R = 1

Step 6 390 minutes, Shut down No 2 fan; fan louvre doors closed R=10
Close Main Portal D Heading Emergency Door R = 10

Step 7 390 minutes, Shut down No 3 fan
Close Intake Drift Heading Emergency Door R = 10

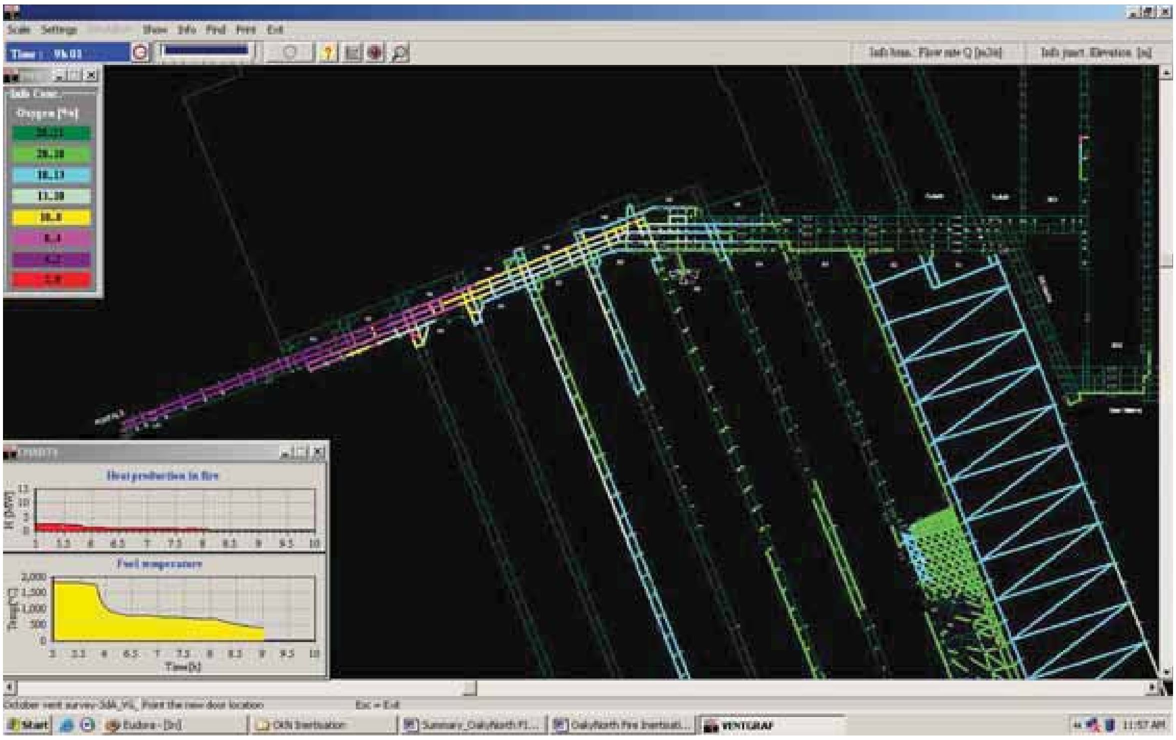
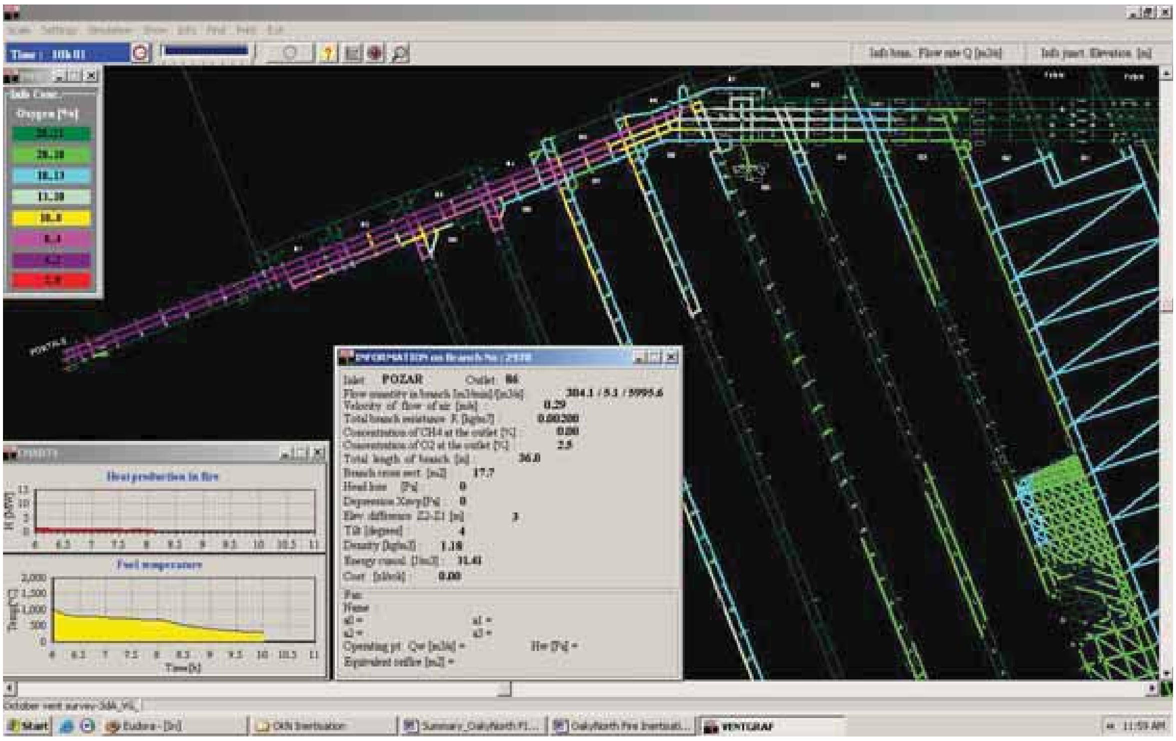


Figure 7.16 Oxygen distribution after 540 minutes



INFORMATION on Branch No : 2978

Inlet POZAR Outlet 86
Flow quantity in branch [m3/min]/[m3/s] 304.1 / 5.1 / 5995.6
Velocity of flow of air [m/s] 0.29
Total branch resistance R [kg/m7] 0.000200
Concentration of CH4 at the outlet [%] 0.00
Concentration of O2 at the outlet [%] 2.5
Total length of branch [m] 36.0
Branch cross sect. [m2] 17.7
Head loss [Pa] 0
Depression Xavy[Pa] 0
Elev. difference Z2-Z1 [m] 3
Tilt [degree] 4
Density [kg/m3] 1.18
Energy consd. [J/m3] 31.41
Cost [$/kwh] 0.00
Fan
Name
a0 = a1 =
a2 = a3 =
Operating pt. Qw [m3/s] = Hw [Pa] =
Equivalent orifice [m2] =

Figure 7.17 Oxygen distribution after 600 minutes

Summary *With GAG running Fire intensity insignificant at 10 hours and oxygen level outbye fire at less 2.5 percent.*

7.7. Oaky North Fire Inertisation Scenario 5A

Scenario *Dev in 7 MG at 26 ct (100m pillar). Eimco vehicle fire at 500m outbye of the face. Face 2.2* m^3*/tonne* CH_4*. (Model: October 2005).*

Inertisation Strategy GAG placed on 1 m dia. Borehole at MG7 2 ct. Seal off SMG7 A and B Hdg 1-2ct. Close Highwall B and C Hdg portal doors. Close C Hdg 35 – 36 Brattice seal, B Hdg 35 – 36 Prep seal and D Hdg 35 – 36 Prep seal.

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ct at 11/05*

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

- Initiation GAG set at Borehole at MG7 2 ct
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO and CH_4 Gas sensors in Dev 7 TG 2-3 ct panel returns, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.

Simulation

Step 1 Time 0 – 15 minutes: 200 litres diesel fuel is burning; Simulate 7m length fire over entry width; time constant 120s, intensity 10 CO:CO_2 = 0.1 (assume H_2 = CO level).

Step 2 Time 15– 30 minutes: Simulate 7m length fire over entry width; time constant 120s, intensity 10 CO:CO_2 = 0.1. (assume H_2 = CO level).

Step 3 Time 30 – 60 minutes: 200 litres fuel is burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, CO:CO_2 = 0.1. (assume H_2 = CO level); fire very unstable and not under control

Step 4 Time 60 – 120 minutes: an additional 20m length of coal pillar equivalent of a total 47m additional burning; Simulate 47m length fire over entry width; time constant 120s, intensity 7, CO:CO_2 = 0.1. (assume H_2 = CO level); fire very unstable and not under control

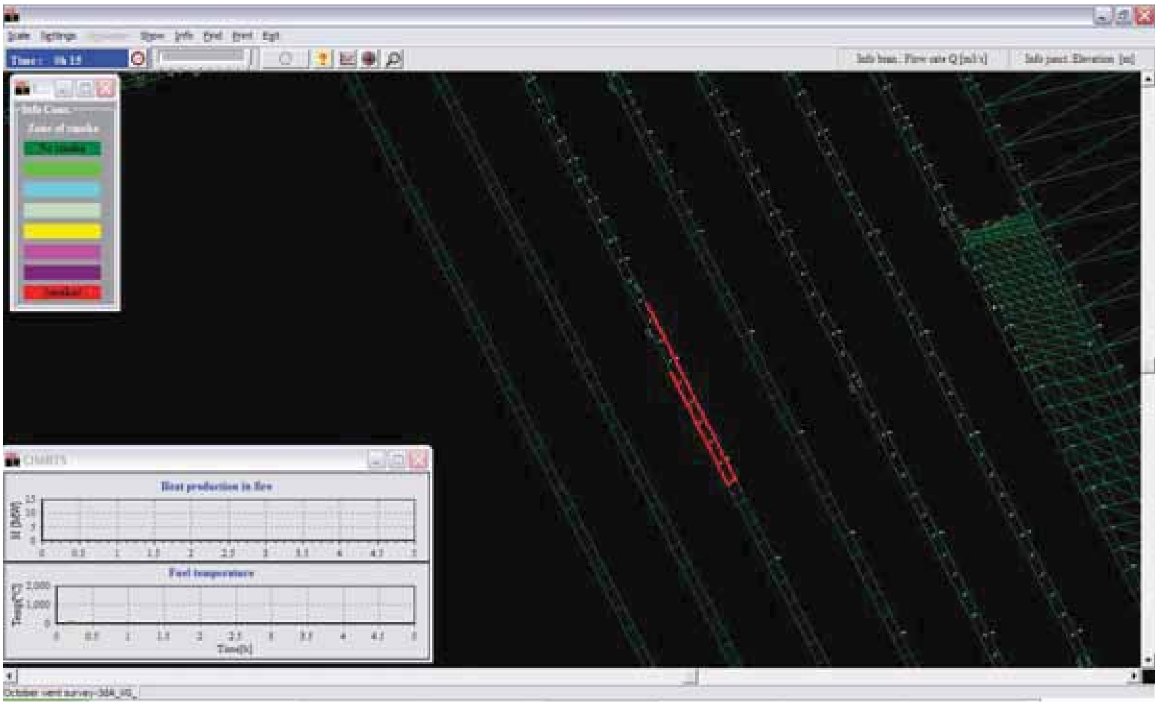


Figure 7.18 Smoke distribution after 15 minutes

Control Assume all mining crewmembers out of mine.

IMT team formed; Decision made to introduce high flow inertisation – GAG as soon as all crews evacuated out of mine.

Step 5 Time 120 – 300 minutes: Additional 20 m entry length coal caught on fire. Simulate 67m length oil fire over entry width; time constant 120s, intensity 7. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control.

Step 6 Time 300 - ? minutes: Continue simulating 67m length fire over entry width; time constant 120s, intensity 7 $CO:CO_2 = 0.1$. (assume H_2 = CO level);

Fire out of control

Control High flow inertisation GAG unit has arrived and is set up

At 300 minutes: GAG has been set up at the Borehole at MG7 2 ct and seal off MG7 A (R = 1) and B Hdg (R = 5) 1-2ct - Change BH R = 2.3.
Highwall B and C Hdg portal doors closed R = 10 and R = 1 respectively.
Close C Hdg 35 – 36 Brattice seal R=1
Close B Hdg 35 – 36 Prep seal R=2
Close D Hdg 35 – 36 Prep seal R=2
Shut down No 1 fan; fan louvre doors closed R=20
Shut down No 2 fan; fan louvre doors closed R=20
Examine No 3 fan curve operating point; Initiate GAG.

After 570 minutes improve C Hdg portal seal to R=10

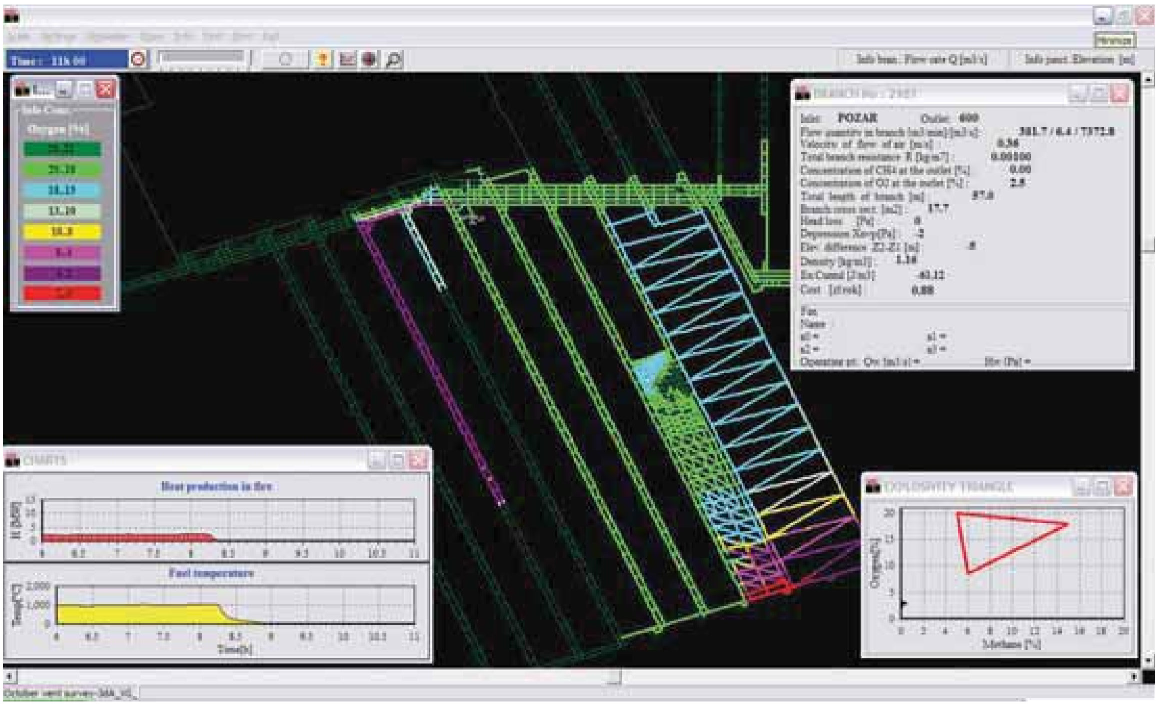


Figure 7.19 O_2 distribution at 660 minutes

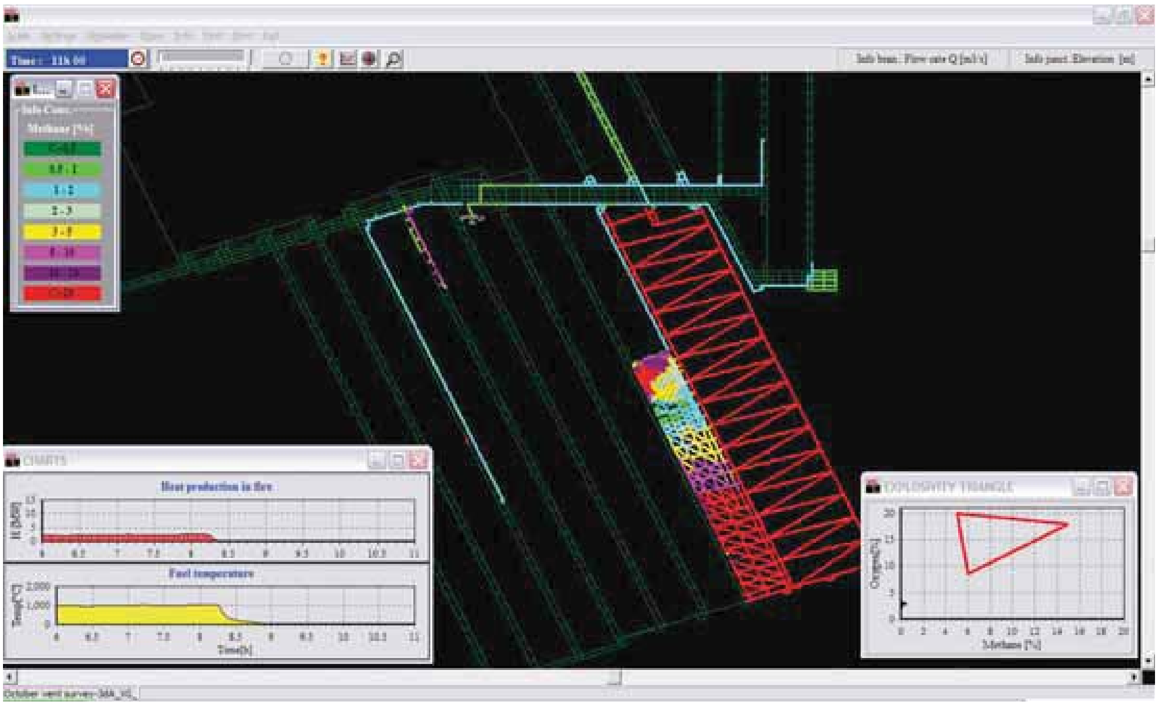


Figure 7.20 Methane (from other sources) distribution after 660 minutes

Summary *With GAG running Fire intensity insignificant and oxygen level outbye fire at less than 2.5 percent at 11hours.*

7.8. Oaky North Fire Inertisation Scenario 5B

Scenario *Dev in 7 MG at 26 ct (100m pillar). Eimco vehicle fire at 500m outbye of the face. Face 2.2 m^3/tonne CH_4. October 2005*

Inertisation Strategy *GAG at Highwall Portal D; Close Highwall B and C Hdg portal doors; Close B Hdg 35 – 36, C Hdg 35 – 36 and D Hdg 35 – 36; Seal transport drift*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Highwall Portal D entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO and CH_4 Gas sensors in Dev 7 TG 2-3 ct panel returns, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.

Simulation

Step 1 Time 0 – 15 minutes: 200 litres diesel fuel is burning; Simulate 7m length fire over entry width; time constant 120s, intensity 10 $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 2 Time 15– 30 minutes: Simulate 7m length fire over entry width; time constant 120s, intensity 10 $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 3 Time 30 – 60 minutes: 200 litres fuel is burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control

Step 4 Time 60 – 120 minutes: an additional 20m length of coal pillar equivalent of a total 47m additional burning; Simulate 47m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control

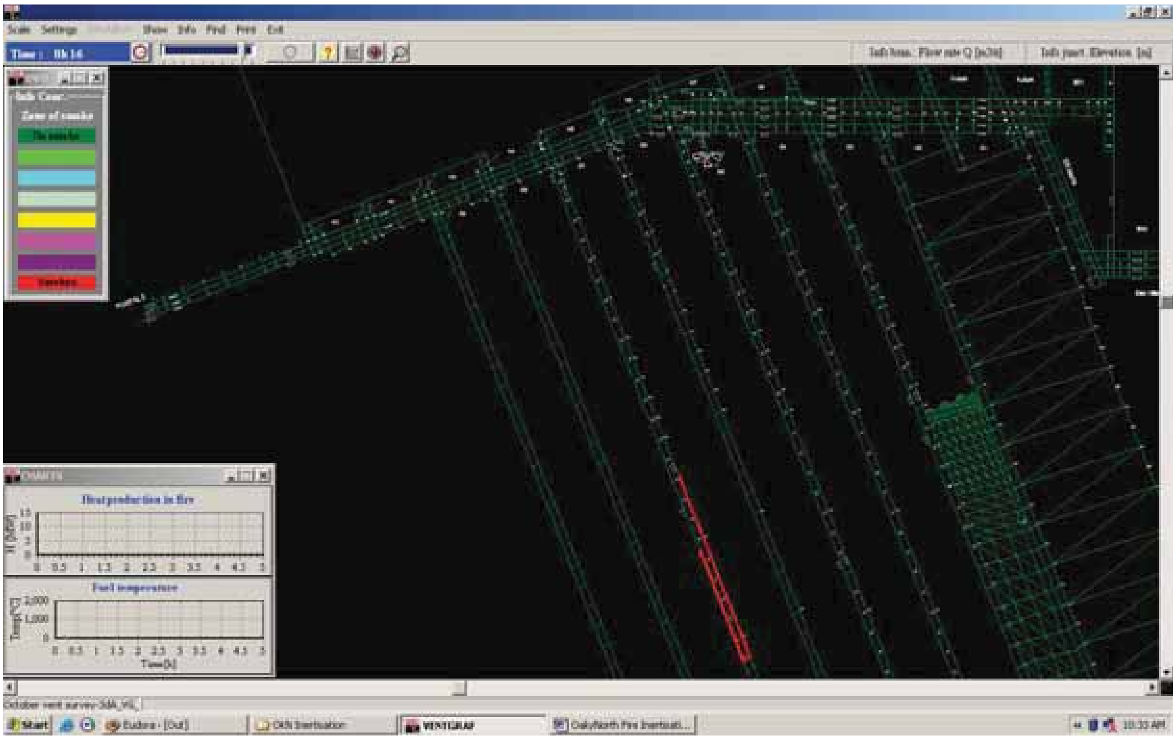


Figure 7.21 Smoke distribution after 15 minutes

Control Assume all mining crewmembers out of mine.

IMT team formed; Decision made to introduce high flow inertisation – GAG as soon as all crews evacuated out of mine.

Step 5 Time 120 – 300 minutes: Additional 20 m entry length coal caught on fire. Simulate 67m length oil fire over entry width; time constant 120s, intensity 7. $CO:CO_2 = 0.1$ (assume $H_2 = CO$ level). Fire very unstable and not under control.

Step 6 Time 300 - ? minutes: Continue simulating 67m length fire over entry width; time constant 120s, intensity 7 $CO:CO_2 = 0.1$. (assume $H_2 = CO$ level);

Control High flow inertisation GAG unit has arrived and is set up

At 300 minutes: GAG has been set up at the D Portal entry and emergency door closed, R=10. B and C Hdg portal doors closed R = 10 and R = 1 respectively.

Close C Hdg 35 – 36 Brattice seal R=1; Close B Hdg 35 – 36 Prep seal R=2

Close D Hdg 35 – 36 Prep seal R=2; Shut down No 1 fan; fan louvre doors closed R=20; Shut down No 2 fan; fan louvre doors closed R=20 and examine No 3 fan curve operating point; Initiate GAG.

After 570 minutes improve C Hdg portal seal to R=10;

Fire not able to be extinguished.

After 720 minutes shut down No 3 fan.; Seal transport drift R=10;

Soon after, explosion occurs.

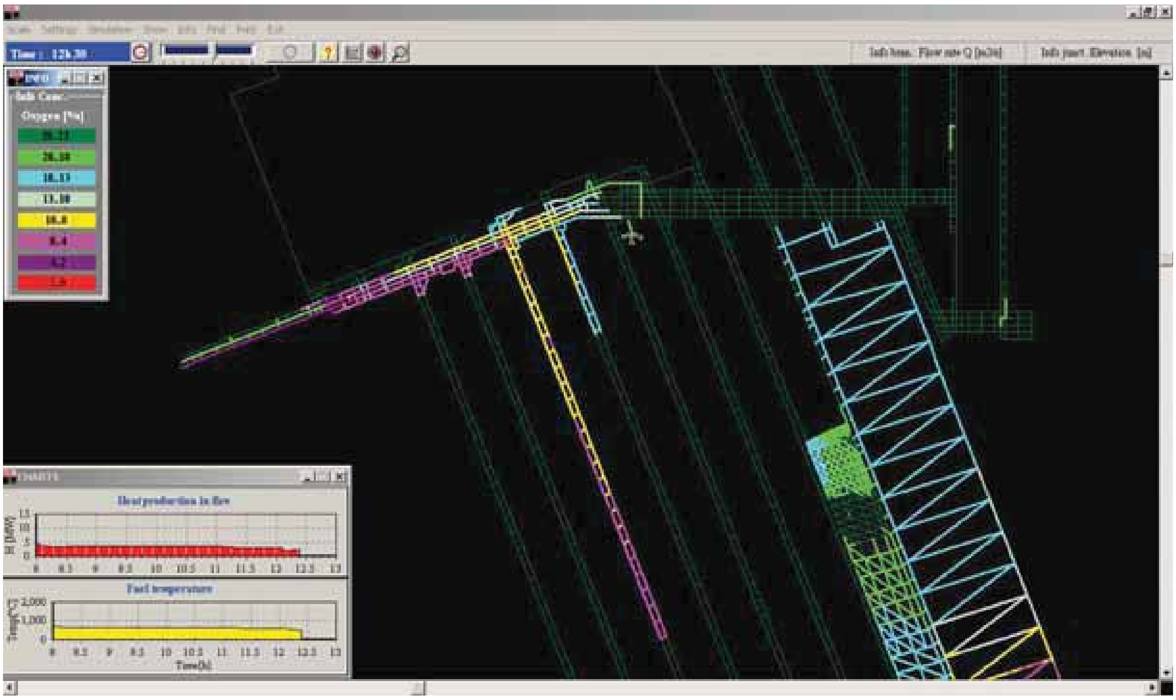


Figure 7.22 O_2 distribution at 750 minutes

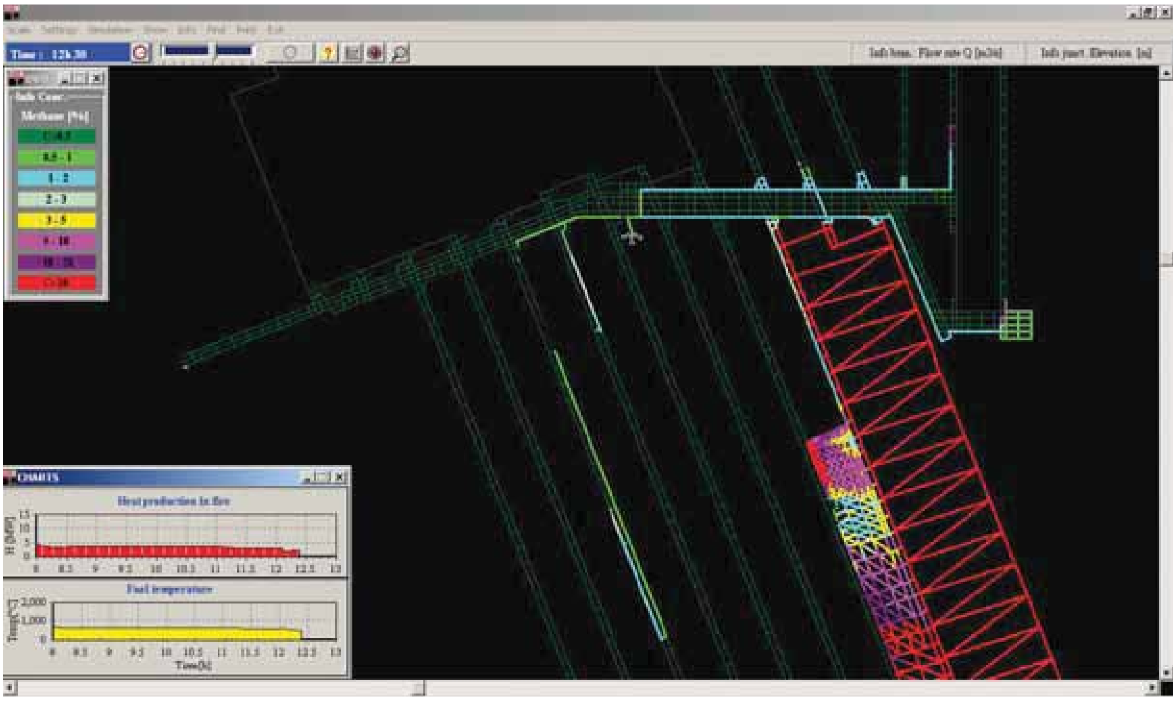


Figure 7.23 Methane (from other sources) distribution after 750 minutes

Summary *Inertisation strategy not effective. Explosion occurred soon after No 3 fan was shut down.*

7.9. Oaky North Fire Inertisation Scenario 5C

Scenario *Dev in 7 MG at 26 ct (100m pillar). Eimco vehicle fire at 500m outbye of the face. Face 2.2 m^3/tonne CH_4. October 2005*

Inertisation Strategy *GAG at Highwall Portal D; Close Highwall B and C Hdg portal doors*

Sections

1. *LW 3 at 13ct11/05*
2. *Dev 301 MG at 5ct 11/05*
3. *Dev South MG 7 at 26ct 11/05*
4. *Dev Stone Development road header (contractor) MG6 at 8ctat 11/05*

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

- Initiation GAG set at Highwall Portal D entry
- CO alarms set at 4.4ppm high alarm and 8.8ppm high high alarm.
- Methane sources on LW face of 160 x 3 litres/s simulated as sources at 20, 74 and 128 chocks.
- Negligible intake methane.
- Methane output at 301 Dev face of 200 litres/s
- Methane output at South MG 7 face of 100 litres/s.
- Methane from 302 MG standing face of 100 litres/s
  Levels from measurements in mine November 2005.
- CH_4 source of 600 litres/s from LW goaf at TG end of face
- CO and CH_4 Gas sensors in Dev 7 TG 2-3 ct panel returns, and
  CO Gas sensors set at points either side of bottom of Ventilation Shaft.

Simulation

Step 1 Time 0 – 15 minutes: 200 litres diesel fuel is burning; Simulate 7m length fire over entry width; time constant 120s, intensity 10 $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire is very unstable and not under control.

Step 2 Time 15– 30 minutes: Simulate 7m length fire over entry width; time constant 120s, intensity 10 $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 3 Time 30 – 60 minutes: 200 litres fuel is burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control

Step 4 Time 60 – 120 minutes: an additional 20m length of coal pillar equivalent of a total 47m additional burning; Simulate 47m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control

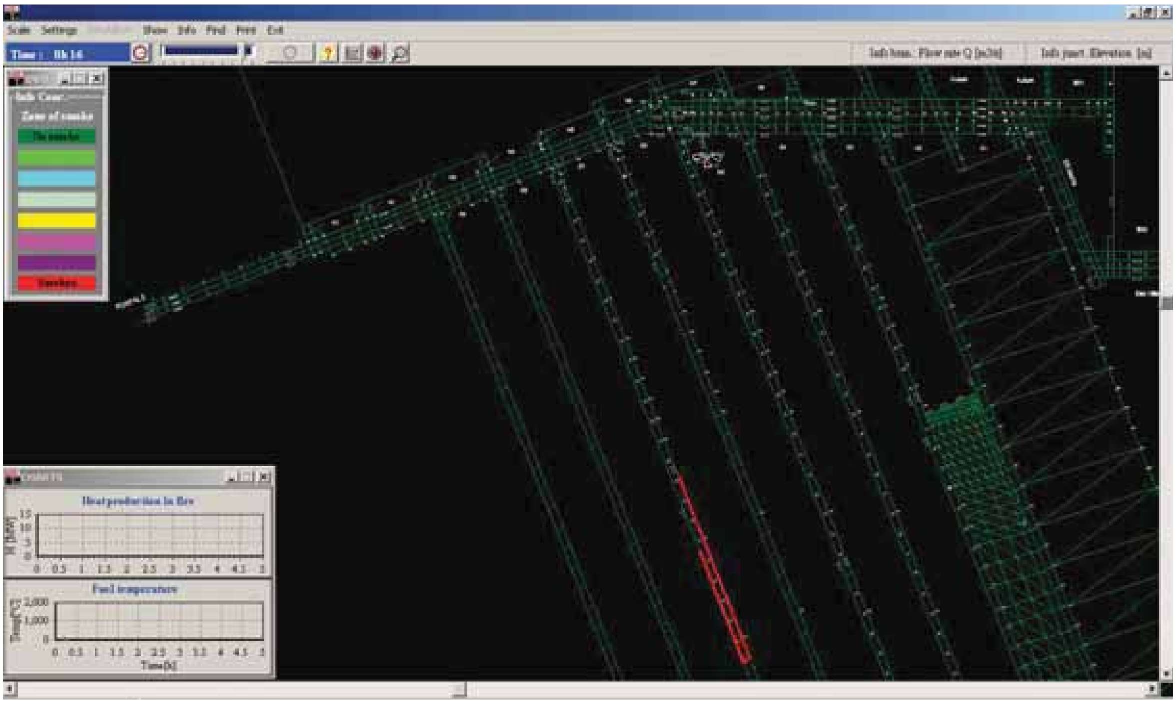


Figure 7.24 Smoke distribution after 15 minutes

Control Assume all mining crewmembers out of mine.

IMT team formed; Decision made to introduce high flow inertisation – GAG as soon as all crews evacuated out of mine.

Step 5 Time 120 – 300 minutes: Additional 20 m entry length coal caught on fire. Simulate 67m length oil fire over entry width; time constant 120s, intensity 7. $CO:CO_2 = 0.1$

Step 6 Time 300 - ? minutes: Continue simulating 67m length fire over entry width; time constant 120s, intensity 7 $CO:CO_2 = 0.1$. (assume $H_2 = CO$ level); Fire out of control

Control High flow inertisation GAG unit has arrived and is set up; At 300 minutes: GAG has been set up at the D Portal entry and emergency door closed, R=10. Initiate GAG.

At 330 mins shut down one main fan; fan louvre doors closed R=20
Due to less ventilation air methane levels have increased in the return air.
At 360 mins shut down second main fan; fan louvre doors closed R=20
At 360 B and C Hdg portal doors closed R = 10 and R = 1 respectively.

Due to less ventilation air methane levels have increased in the return air up to 3.5%.

Oxygen level in Mains high due to air through intake drift, decision made to close the third fan to reduce oxygen level in air across fire.

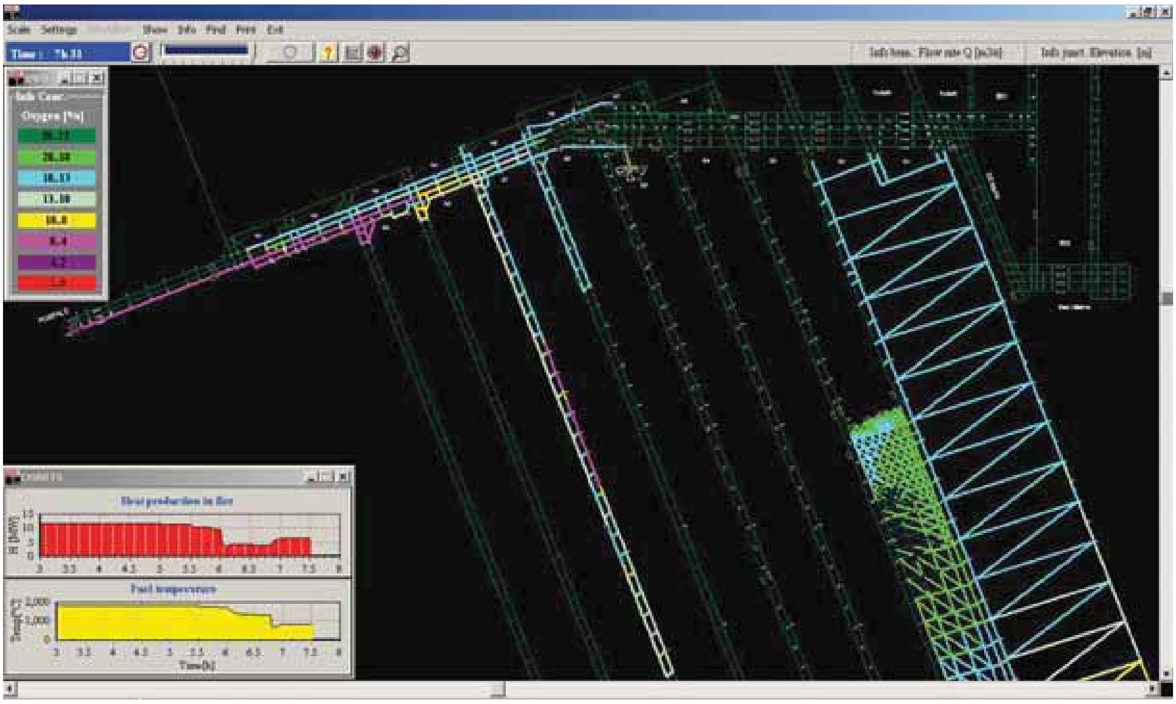


Figure 7.25 O_2 distribution at 450 minutes

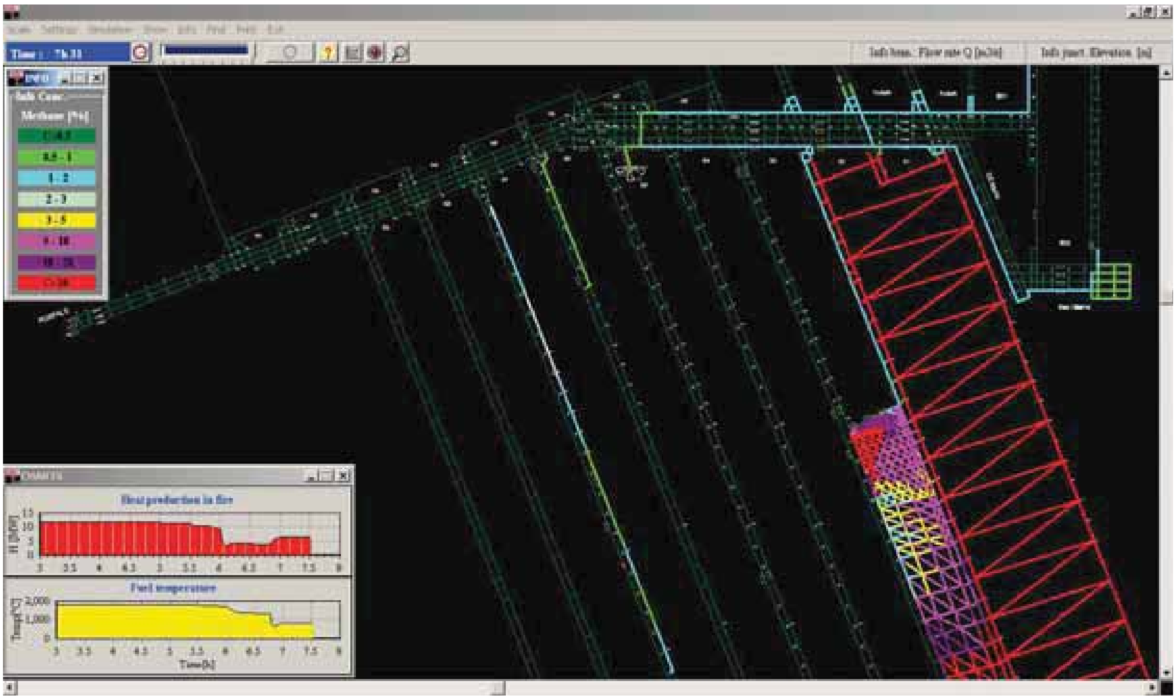


Figure 7.26 Methane (from other sources) distribution after 450 minutes

At 450 mins shut down the third main fan; soon after, explosion occurs as methane reverses flow across fire

Summary *Explosion occurred soon after No 3 fan was shut down.*

Table 7.2 Comparison of inertisation effects between original GAG operation and new segregation and/or GAG Docking Positions.

Scenario No	Fire Location	Fire Type	GAG Location	Segregation actions	Fan Actions	Outcomes
1 (original)	Mains C Hdg conveyor at 39ct	Belt (oil)	Transport Drift Portal	None	All shut down	With GAG running Fire intensity insignificant at 10 hours and oxygen level outbye fire at less than 2.9 percent. ***(Category B)***
1A	Mains C Hdg conveyor at 39ct	Belt (oil)	Transport Drift Portal	Mains C Hdg • Prep seal at B Hdg 35-36 R=2 • Open machine door at 37ct B-C • Brattice around belt structure C Hdg 35 – 36ct R=1 • Brattice around belt structure 37ct C – D R=1 • Prep seal at 36ct C - D R=2 • Prep seal at B Hdg 37-37A ct R=2 • Segregation stopping 38ct, 39ct and 40ct C-D	All shut down	With GAG running Fire intensity insignificant at 9 hours and oxygen level outbye fire at less than 2.5 percent. There is only a slight reduction in the time need to achieve satisfactory inertisation of the mine with extra segregation. ***(Category B)***

Scenario No	Fire Location	Fire Type	GAG Location	Segregation actions	Fan Actions	Outcomes
2 (original)	Goaf behind South Longwall 3	Goaf spon comb	Transport Drift Portal	None	All shut down	At 34 hours local reversal occurred to produce minor methane burn off. With the GAG running after 5 days there is no significant fire. Outbye the fire oxygen is 0.1 percent. (***Category C***)
2A	Goaf behind South Longwall 3	Goaf spon comb	Transport Drift Portal	Close C Hdg 35 – 36 Brattice seal Close B Hdg 35 – 36 Prep seal Close D Hdg 35 – 36 Prep seal Shut down all fans at the same time; fan louvres for No1 & 2 closed.	All shut down	After 2 days with the GAG running, there is no significant fire. Outbye the fire the oxygen is 2.9 percent. (***Category B***)
2B	Goaf behind South Longwall 3	Goaf spon comb	Borehole (1m dia.) at MG 2 ct LW	Seal off SMG3 A and B Hdg 1-2ct Close C Hdg 35 – 36 Brattice seal Close B Hdg 35 – 36 Prep seal Close D Hdg 35 – 36 Prep seal Shut down all fans at the same time; fan louvres for No1 & 2 closed.	All shut down	After 2 days with the GAG running, there is no significant fire. Outbye the fire the oxygen is 2.6 percent. (***Category B***)
2C	Goaf behind South Longwall 3	Goaf spon combustion	Borehole (1m dia.) at MG 2 ct LW	Seal off SMG3 A and B Hdg 1-2ct Close C Hdg 35 – 36 Brattice seal Close B Hdg 35 – 36 Prep seal Close D Hdg 35 – 36 Prep seal Shut down No 1 & 2 fans; fan louvres closed. Close Transport Drift Doors after 2 days.	Shut down 2 fans with 1 fan running	After 2 days with the GAG running, there is no significant fire. Oxygen is 4.2 percent outbye the fire. By closing the Transport Drift Portal door, the oxygen level outbye the fire is reduced to 2.6 percent. A majority of the mine has methane levels of less than 3 percent except the sealed longwall panels and goaf. (***Category B***)

Scenario No	Fire Location	Fire Type	GAG Location	Segregation actions	Fan Actions	Outcomes
3 (original)	South LW 4 MG 22ct Tripper drive	Belt Fire	Transport Drift Portal	None	All shut down	Explosion occurred as soon all fans were turned off due to a reversal. ***(Category E)***
3A	South LW 4 MG 22ct Tripper drive	Belt Fire	Transport Drift Portal	Close C Hdg 35 – 36 Brattice seal Close B Hdg 35 – 36 Prep seal Close D Hdg 35 – 36 Prep seal Shut down No 1 fan; fan louvre closed Shut down No 2 fan; fan louvre closed Shut down No 3 fan	All shut down	No improvement; Explosion occurred as soon all fans were turned off due to a reversal. ***(Category E)***
4 (original)	Belt tripper drive Mains 11ct C Hdg	Spillage of Coal	Transport Drift Portal	None	All shut down	With GAG running fire intensity insignificant at 24 hours and oxygen level outbye fire at less 5.4 percent. Face methane passing over fire potentially causing explosions. ***(Category C)***
4A	Belt tripper drive Mains 11ct C Hdg	Spillage of Coal	Highwall Portal B	Close Portal B Heading Emergency Door Close Portal C Heading Emergency Door Close Portal D Heading Emergency Door Seal transport drift	All shut down	With GAG running Fire intensity insignificant at 10 hours and oxygen level outbye fire at less 2.5 percent. ***(Category B)***

Scenario No	Fire Location	Fire Type	GAG Location	Segregation actions	Fan Actions	Outcomes
5 (original)	Dev in 7 MG at 26 ct B Hdg	Eimco vehicle fire (diesel)	Transport Drift Portal	Close Portal B Heading Emergency Door Close Portal C Heading Emergency Door Close Portal D Heading Emergency Door	All shut down	Explosion occurs from localised reversal of methane over fire in SMG7. Inertisation eventually occurs, but with several methane explosions. ***(Category E)***
5A	Dev in 7 MG at 26 ct B Hdg	Eimco vehicle fire (diesel)	Borehole (1 m dia.) at MG7 2 ct	Seal off SMG7 A and B Hdg 1-2ct Close Portal B Heading Emergency Door Close Portal C Heading Emergency Door Close Portal D Heading Emergency Door Close C Hdg 35 – 36 Brattice seal Close B Hdg 35 – 36 Prep seal Close D Hdg 35 – 36 Prep seal Shut down No 1 fan; fan louvre closed Shut down No 2 fan; fan louvre closed Improve C Hdg portal seal	Fans 1 and 2 shut down.	With GAG running fire intensity insignificant at 11 hours and oxygen level outbye fire at less than 2.5 percent. ***(Category B)***
5B	Dev in 7 MG at 26 ct B Hdg	Eimco vehicle fire (diesel)	Highwall Portal D	Close Highwall B and C Hdg portal doors Close C Hdg 35 – 36 Brattice seal Close B Hdg 35 – 36 Prep seal Close D Hdg 35 – 36 Prep seal Shut down No 1 fan; fan louvre closed Shut down No 2 fan; fan louvre closed Shut down No 3 fan. Seal transport drift	All Shut down	At 720 mins shut down the third main fan and soon after, explosion occurs ***(Category E)***
5C	Dev in 7 MG at 26 ct B Hdg	Eimco vehicle fire (diesel)	Highwall Portal D	Close Highwall B and C Hdg portal doors Close C Hdg 35 – 36 Brattice seal Close B Hdg 35 – 36 Prep seal Close D Hdg 35 – 36 Prep seal Shut down No 1 fan; fan louvre closed Shut down No 2 fan; fan louvre closed Shut down No 3 fan.	All shut down	At 450 mins shut down the third main fan and soon after, explosion occurs ***(Category E)***

7.10. Summary of Scenarios Examined and Alternative Inertisation Strategies

A study has examined the potential for simulation of the effects of inertisation on fires within a mine ventilation network. The project involved applying the VENTGRAPH mine fire simulation software to preplan for situations created by mine fires. As an introduction some general conclusions from relevant work undertaken to date at a range of Australian coal mines is discussed.

Priority fire locations at mines with VENTGRAPH simulation models developed in an ACARP research project entitled "Mine Fire Simulation in Australian Mines using Computer Software" have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage. In the study it was assumed that the GAG would be docked at a prepared position designated by the mine (most commonly the current fabricated docking installation). A review of 35 scenarios showed that there was no fire examined that achieved the situation in which GAG docking inerted the simulated fire to aid recovery in a timely manner. Further, only 20 percent of scenarios showed a situation in which while the inertisation product went straight to the fire site even though it arrived with significant dilution from other ventilation air or leakage through stoppings.

Other introductory sections examined issues with borehole location and sizing for delivery of GAG output and the influence of stopping leakage on GAG exhaust dilution in parallel intake airways

The principal purpose of this study is examination of Oaky North case study priority fires selected from across the pit layout with two in the mains, two in longwall panel gateroads and one in the newly formed longwall goaf. GAG inertisation strategies were examined for the five cases and details of the development of the individual scenarios are set down in chapter 4. Following this in chapter 5 each case scenario study was re-examined to evaluate whether a better inertisation strategy was possible through adoption of either use of additional underground segregation to control the delivery of inert gas, or GAG relocation to an alternative portal docking station locations or the drilling of a new borehole to deliver inert gas more directly to the fire site.

7.10.1. Scenario 1

Scenario 1 examined a Mains belt fire. It was considered as an inertisation partial success (Category B) in that use of the GAG did cause some early stabilisation of the fire. Progressive turning off of the three main surface fans did in time cause the fire to be extinguished through combustion caused reduction of oxygen aided by the addition of inert gases. Seam methane emissions caused gas levels to build up in the panels however these did not recirculate across a Mains located fire.

The Scenario 1A reassessment of approaches to improve the inertisation strategy led to the decision to add segregation to the pit bottom area at the base of the Decline travel road. This area was very open and the objective was to channel inert gases from the travel road docking point into C Heading without loss into and mixing from Mains B and D Headings. The result was that with the GAG running and addition segregation stoppings and doors there was only a slight reduction in the time needed to achieve satisfactory inertisation of the mine with extra the additional segregation. Leakage through the significant number of additional doors and stoppings prevented a better outcome. The question of how these stoppings and doors could be installed or closed in the event of a major fire was not addressed. There was still a need to turn off the fans to achieve stabilisation. Turning off main surface fans in a gassy mine with a major fire is not a question to be decided lightly due to the complexity of the situation.

The alternative strategies of or GAG relocation to an alternative portal docking station locations or the drilling of a new borehole to deliver inert gas more directly to the fire site were not considered to be likely to give an improved situation. GAG docking at highwall portals B or C or D placed the unit further from the fire with more leakage and dilution through stoppings. A borehole into the Mains without significant segregation in the pit bottom area would not achieve advantage.

7.10.2. Scenario 2

Scenario 2 examined a spontaneous combustion fire in the longwall panel goaf on the MG side a few cut throughs back from the face It was considered as a situation where inertisation by itself would not help extinguish the fire in the goaf (Category C). Progressive turning off of the three main surface fans did after much time cause the fire to be extinguished through combustion caused reduction of oxygen aided by the addition of inert gases which reach the fire after alteration of the pit ventilation. With fans off seam methane emissions caused gas levels to build up in the panels and although the VENTGRAPH simulation did not show these recirculating across the fire this could be a dangerous situation.

The alternatives examined for improved inertisation focused on utilisation of underground segregation, use of a borehole for GAG docking and surface segregation. The aim was to review various possible alternative strategies to establish the optimum approach.

The first alternative (Scenario 2A) examined the effect of stopping air from Highwall Portals B, C and D entering the pit and diluting the GAG exhaust coming down the Transport Drift. This was achieved by closing Mains headings and at the same time stopping all surface main fans. At least some fan stoppage was necessary or stalling would have occurred. This strategy improved the stabilisation of the goaf (Category B) significantly although with fans off seam methane emissions caused gas levels to build up in the panels which could potentially lead to a dangerous situation.

The second alternative (Scenario 2B) examined the effect of placing a borehole near the beginning of MG3 leading to the goaf with the fire. The GAG was docked on the borehole and doors closed on the Main Gate headings. As in Scenario 2A Highwall Portal air was closed off at the same time as all fans were stopped. This strategy improved the stabilisation of the goaf (Category B) significantly and marginally better than that achieved in Scenario 2A although the issue of having fans off needs to be recognised.

The third alternative (Scenario 2C) again examined the effect of placing a borehole near the beginning of MG3 leading to the goaf with the fire and with the GAG was docked on the borehole and doors closed on the Main Gate headings. Again as in Scenario 2A and 2B Highwall Portal air was closed off but this time only two fans were stopped with one still operating to keep seam gas accumulations diluted. A Category B outcome was achieved but marginally less efficiently than in Scenarios 2A or 2B. The scenario fire simulation was then continued with a final step of closing the Transport Drift Emergency Door. A Category B outcome was still achieved and with less air in the pit the air reaching the goaf heating had reduced oxygen to the level achieved in Scenario 2B but with the added advantage that one fan was still operating to keep seam gas accumulations diluted. Scenario 2C was the best outcome of this progressive sequence as with one fan still operating seam methane emissions were not observed to build up in the panels and so a potentially dangerous situation was avoided.

7.10.3. Scenario 3

Scenario 3 examined a fire in Longwall 4 MG at a 22 cut through tripper drive. It was considered as an inertisation failure (Category E) in that use of the GAG did not cause stabilisation of the fire, as with dilution of inert exhaust at pit bottom little low oxygen air will effectively reach the fire. Progressive turning off the three main surface fans led, after 8 hours, to reversal of face air carrying explosible concentrations of methane over the fire which caused a large explosion.

Scenario 3A reassessment of approaches to improve the inertisation strategy led to the decision to examined the effect of stopping air from Highwall Portals B, C and D entering the pit and diluting the GAG exhaust coming down the Transport Drift. This was achieved by closing Mains headings and at the same time stopping all surface main fans. This did not improve the situation and it was still considered as an inertisation failure (Category E) as reversal of face air carrying explosible concentrations of methane over the fire still caused a large explosion.

7.10.4. Scenario 4

Scenario 4 examined a fire in the Mains at 11 cut through C Heading tripper drive. The scenario was found to be a situation where inertisation would not help extinguish the fire

(Category C). The fire is ventilated by intake air from the Highwall portals and inert gases added at the Decline Travel Heading docking point will not reach the fire location. Progressive turning off of the three main surface fans did not alter this situation. Seam methane emissions caused gas levels to build up in the panels however these did not recirculate across this Mains located fire.

The Scenario 4A reassessment of approaches to improve the inertisation strategy led to the decision to dock the GAG unit at the Highwall Portal B Heading. This position could direct inert gas directly into B and C Headings and onto the fire and led to a satisfactory outcome (Category B). To avoid dilution portal doors in B, C and D were progressively closed and to avoid stalling Main surface fans were progressively turning off. The emergency door on the Decline Travel Heading was also closed to achieve the minimum time for stabilisation of the fire.

7.10.5. Scenario 5

Scenario 5 examined a vehicle fire in Development MG. It was considered as an inertisation failure (Category E) in that use of the GAG did not cause stabilisation of the fire before several methane explosions with reversal of face air carrying explosible concentrations of methane over the fire. Closure of emergency doors on Highwall portals B, C and D was needed to rebalance the pit ventilation to bring the inert gases to the entrance to the panel. To avoid stalling fans needed to be turned off progressively as with dilution of inert exhaust at pit bottom little low oxygen air will effectively reach the fire.

The alternatives examined for improved inertisation focused on use of alternative docking points. The aim was to review various possible alternative strategies to establish the optimum approach.

The first alternative (Scenario 5A) examined moving GAG docking from the Transport Drift to docking at a Borehole at the beginning of the Development panel MG. Doors at entry to the Panel MG were closed. Highwall Portals B, C and D were closed as well as possible to stop air entering the pit and diluting the Borehole GAG exhaust. At the same time Mains headings were sealed underground and two surface main fans stopped. At least some fan stoppage was necessary or stalling would have occurred. This strategy forced borehole inert gases across the fire. Additional sealing of the Conveyor drift at Portal C was required and as a consequence with minimum air being able to leak into the panel successful stabilisation of the fire occurred (Category B).

The second alternative (Scenario 5B) examined the effects of docking the GAG at Highwall D Heading Portal. The Emergency doors were closed at Highwall B and C Portals as well as further inbye in the Main Gate headings. Progressive turning off the three main surface fans, with the third stopped when the Transport Drift was sealed, led, after 12 hours, to reversal of face air carrying explosible concentrations of methane over the fire which caused a large explosion. This approach was considered as an inertisation failure (Category E) in that use of the GAG did not cause stabilisation of the fire before several methane explosions with reversal of face air carrying explosible concentrations of methane over the fire.

The third alternative (Scenario 5C) was similar to Scenario 5B as it examined the effects of docking the GAG at Highwall D Heading Portal. As before Emergency doors were closed at Highwall B and C Portals as well as further inbye in the Main Gate headings. However the transport drift remained open as all three main surface fans were progressively turned off. This led, after 7.5 hours, to reversal of face air carrying explosible concentrations of methane over the fire which caused a large explosion. This approach was again considered as an inertisation failure (Category E) in that use of the GAG did not cause stabilisation of the fire before several methane explosions with reversal of face air carrying explosible concentrations of methane over the fire.

7.11. Conclusions and Recommendations

The principal part of this study of inertisation strategies has been to examine priority fire locations and best approaches to stabilising of fires. It was determined that Oaky North has a mine layout under which some improvements could be made to inertisation strategies in the event of a major fire

Based on the results from the actions described in Chapter 6 scenarios have been re-simulated with new approaches to inertisation. Outcomes for these re-simulated alternative scenarios were compared with the original simulation results as described in previous sections. A summary of the comparisons is shown in Table 7.3.

General actions that can be undertaken to improve the effectiveness of an existing inertisation situation in an underground ventilation network, apart from general improvement to ventilation control devices, can be drawn from the following.

1. Maintain use of existing inertisation docking station but with use of additional underground segregation to control the delivery of inert gas.
2. Try alternative Portal docking station locations through use of existing portals or installation of new.
3. Try alternative Portal docking station locations with additional underground segregation.
4. Drill new borehole to deliver inert gas more directly to the fire site.

The best inertisation strategy as determined from alternative simulation exercises for the five priority fire locations is summarised in Table 7.3.

Fire Number 1 gave an outcome in which this Mains fire was stabilised by turning off fans and allowing oxygen to be consumed to eventually lead to extinguishment. The mine's pit bottom area is very open. The alternative strategy simulated of segregating various headings in the pit bottom area was complicated by the number of actions required. Placement of stoppings and closing of underground doors is only mildly effective as all these structures will leak and so allow a fire to keep burning. Turning off all fans poses high risk issues in a gassy mine; however in this scenario the fire is in the Mains and so panel flow reversals of methane laden air was not presented as an issue. The conclusion was that GAG inertisation of this fire did not present a satisfactory strategy, not was the approach of placement of ventilation control devices. The traditional approach of sealing the mine after turning off fans provided a solution.

Table 7.3 Summary of optimum outcomes from the five fire simulation exercises

No	Fire Location	Fire Type	GAG Location	Fan Action	Outcome	Category
1	Mains C Hdg conveyor at 39ct	Belt (oil)	Transport Drift Portal	All shut down	Fire stable at 10 hours	B
1A	Mains C Hdg conveyor at 39ct	Belt (oil)	Transport Drift Portal	All shut down	Fire stable at 9 hours	B
2	Goaf behind SLW3	Goaf spon comb	Transport Drift Portal	All shut down	Fire stable at 120 hours, gas over fire possibility	C
2C	Goaf behind SLW3	Goaf spon comb	Borehole (1m dia.) at MG3 2 ct	2 down 1 running	Fire stable at 48 hours	B
3	South LW 4 MG 22ct Tripper drive	Belt (oil)	Transport Drift Portal	All shut down	Reversal, gas explosion	E
3A	South LW 4 MG 22ct Tripper drive	Belt (oil)	Transport Drift Portal	All shut down	Reversal, gas explosion	E
4	Belt tripper drive Mains C Hdg, 11ct	Coal spillage	Transport Drift Portal	All shut down	Fire stable at 24 hours, gas over fire possibility	C
4A	Belt tripper drive Mains C Hdg, 11ct	Coal spillage	Highwall Portal B	All shut down	Fire stable at 10 hours	B
5	Dev in 7 MG at 26 ct B Hdg	Eimco vehicle (diesel)	Transport Drift Portal	All shut down	Reversal, gas explosion	E
5A	Dev in 7 MG at 26 ct B Hdg	Eimco vehicle (diesel)	Borehole (1m dia.) at MG7 2 ct	2 down 1 running	Fire stable at 11 hours	B

Fire Number 2 examined how a longwall goaf fire could be stabilised by use of a borehole which delivered directly to the fire seat. A good quality seal was needed to avoided dilution of the GAG exhaust. In effect the fire affected panel was segregated from the rest of the mine which allowed one fan to continue operating (use of more led to excessive leakage into the panel) maintaining safe ventilation of the mine. Sealing of Mains headings and the Transport Drift assisted the process. Other alternatives could eventually stabilise the fire but required turning off of all main surface fans.

Fire Number 3 was another example where GAG inertisation was not effective. Direct delivery of exhaust to the site was not effective due to dilution; segregation remediation did not materially assist because of leakage. Turning off fans led immediately to ventilation reversal in various panels due to air buoyancy and explosions form face gas flowing under natural ventilation pressure across the fire.

Fire Number 4 examined a fire which could not be inertised using the traditional Travel Drift GAG docking point. It focused on how a Mains heading fire could be stabilised by use of an alternative GAG docking portal. Appropriate segregation allowed direct delivery of exhaust to the fire location. However because the fire was in the Mains effective segregation was not easy and so all surface main fans had to be turned off to give a timely result.

Fire Number 5 again examined a fire which could not be inertised using the traditional Travel Drift GAG docking point. The fire was in a development heading and the best outcome was to use a panel borehole to direct exhaust directly to the fire seat. A good quality seal was needed to avoided dilution of the GAG exhaust. As with Fire Number 2 the fire affected panel was segregated from the rest of the mine which allowed one fan to continue operating (use of more led to excessive leakage into the panel) maintaining safe ventilation of the mine. Sealing of all Portals assisted the process. Other alternatives could eventually stabilise the fire but required turning off of all main surface fans.

In conclusion these fire simulation exercised have shown that some priority Oaky North fires can be stabilised through GAG inertisation strategies. The Number 2 goaf fire strategy developed is a case in point where use of a panel borehole with careful segregation allowed a relatively fast outcome to be achieved. The Number 5 development heading fire was similar in that a borehole GAG delivery gave the best outcome. Both these were achieved with one surface fan operating and maintaining minimum pit ventilation and seam methane dilution. The Number 4 fire, a Mains belt fire, utilised the GAG positively through use of an alternative Portal for docking.

However Number 1 (a Mains belt) and Number 3 (Development heading belt) fires were placed such that an inertisation strategy was not effective because pit layout means excess dilution affects the GAG exhaust quality which can be brought to the fire.

Recommendations arising from the analyses are as follows:

- GAG docking stations should be fabricated for all ventilation intake openings to the mine. The existing apparatus at the Travel Decline should be supplemented by docking points at the Highwall portals, any pit boreholes of appropriate diameter and future main shafts. In effect each docking point can deliver to a restricted geographic zone within the pit; multiple points allow he appropriate point to be utilised.
- Segregation strategies simulated at pit bottom areas have shown that distribution of inert gases to separate Mains headings can be improved. They were useful for fires located inbye from the pit bottom in the Mains but were less effective for the fires located a long way further inbye and in the longwall production and development panels (due to increasing dilution through stoppings).
- It is recommended that a borehole with a diameter of at least 1 m should be considered at the beginning of each panel for potential delivery of inert gases to each longwall production or development face. These boreholes can also be used for other purposes such as delivery of ballast or emergency extrication of people out of the mine. They may be used for other services. Incorporation of remote controlled doors should be considered to give control over which gateroad should be used to carry the inert gases into the panel.

These fire simulation exercises have demonstrated that it is possible to efficiently evaluate possible inertisation strategies appropriate to a complex mine layout extracting a gassy seam and determine which approach strategy (if any) can be used to stabilise a mine in a timely fashion.

8. CASE STUDIES OF FIRE SCENARIOS AT OAKY NO 1 MINE

Scenarios developed for Oaky Creek No 1 Colliery have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage following a fire.

A total of ten scenarios were simulated for Oaky Creek No 1 Colliery based on the mine fire simulation model developed from the ventilation arrangements in December 2005 as shown in Figure 8.1. These scenarios are as follows.

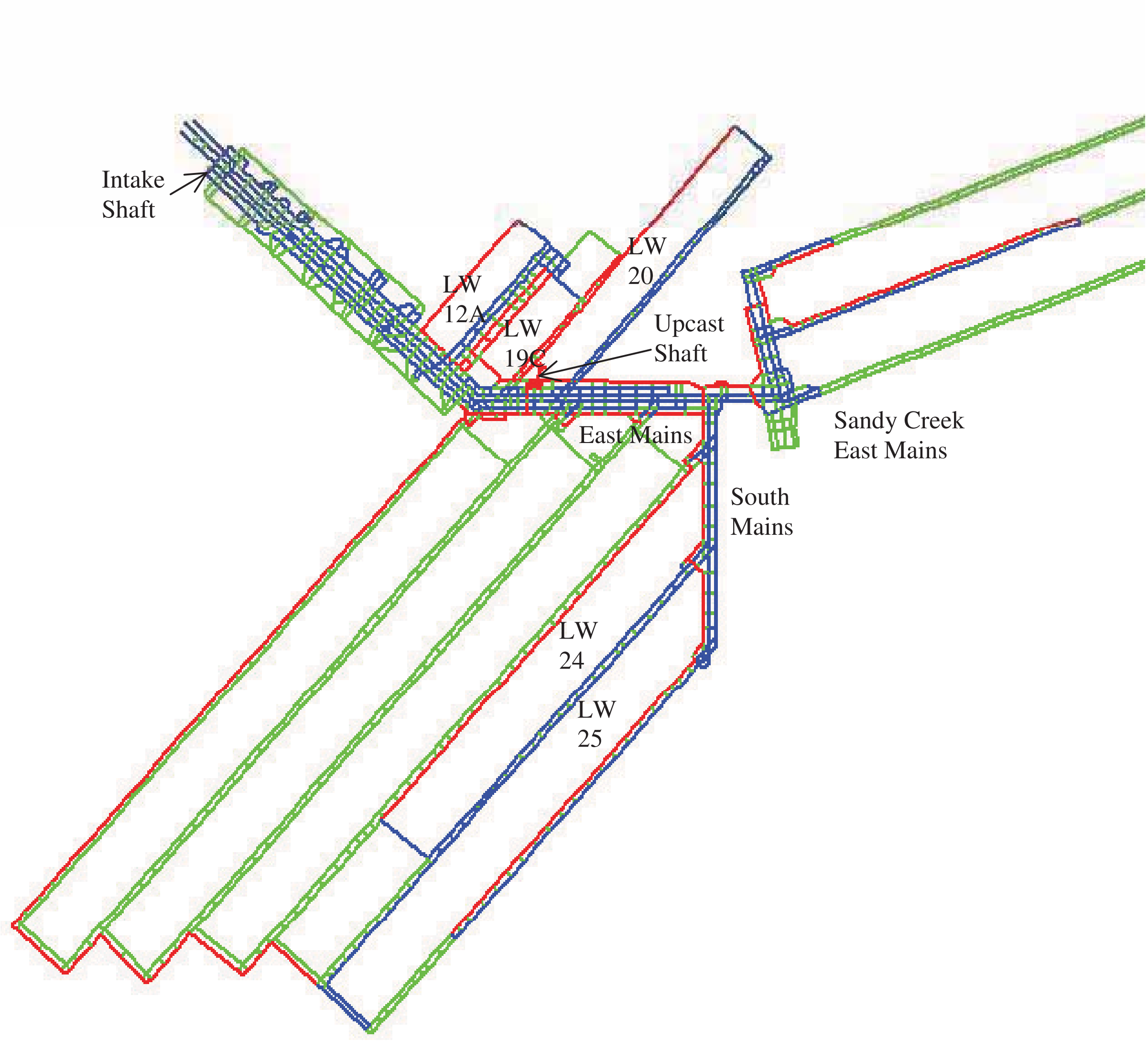


Figure 8.1 Ventilation arrangements at Oaky Creek No 1 Colliery in December 2005

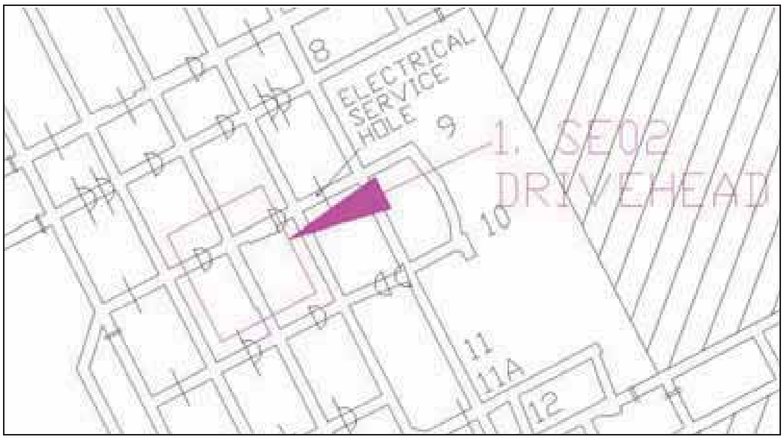
1. SE02 Drivehead - Main Dips C9-C10 - Belt Drivehead area that is segregated. This is modelled as an oil fire that develops into a coal fire.
2. SE03 Drivehead - Main Dips C21-C22 - Belt Drivehead area that is segregated. This is modelled as an oil fire that develops into a coal fire.
3. SE04 Drivehead - East Mains C5-C6 - Belt Drivehead area that is segregated. This is modelled as an oil fire that develops into a coal fire.

4. SE05 Drivehead - South Mains C5-C6 - Belt Drivehead area that is segregated. This is modelled as an oil fire that develops into a coal fire.
5. LW Drivehead - South Mains D8 to MG24 C2 - Belt Drivehead area that is segregated. This is modelled as an oil fire that develops into a coal fire.
6. LW Face Friction Ignition - Longwall 24 face. This is modelled as an oil fire that develops into a coal fire.
7. LW Goaf Spontaneous Combustion - Longwall 24 Goaf heating.
8. MG25 Drivehead - South Mains D14 to MG25 C2 - Belt Drivehead area that is segregated. This is modelled as an oil fire that develops into a coal fire.
9. MG26 Drivehead - Sandy Creek East Mains D6 to MG26 C1 - Belt Drivehead area that is segregated. This is modelled as an oil fire that develops into a coal fire.
10. Jiffy Drive 1 Drivehead - Sandy Creek East Mains C13 to C12 - Belt Drivehead area, which is segregated. This is modelled as an oil fire that develops into a coal fire.

Each of these scenarios is described and discussed in the following section.

8.1. Oaky Creek No 1 Fire Scenario 1

Scenario *In the "C" main dips at bottom of main dips at the C9-C10 (belt drive head area), hydraulic oil has caught on fire. SE02 Drivehead - Main Dips C9-C10 - Belt Drivehead area that is segregated.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW12A 80 l/s, LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume $H_2 = CO$ level).

Smoke reaches surface at 22 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Smoke reaches Longwall face at 50 minutes

Control Fire fighting control is suppressing oil fire

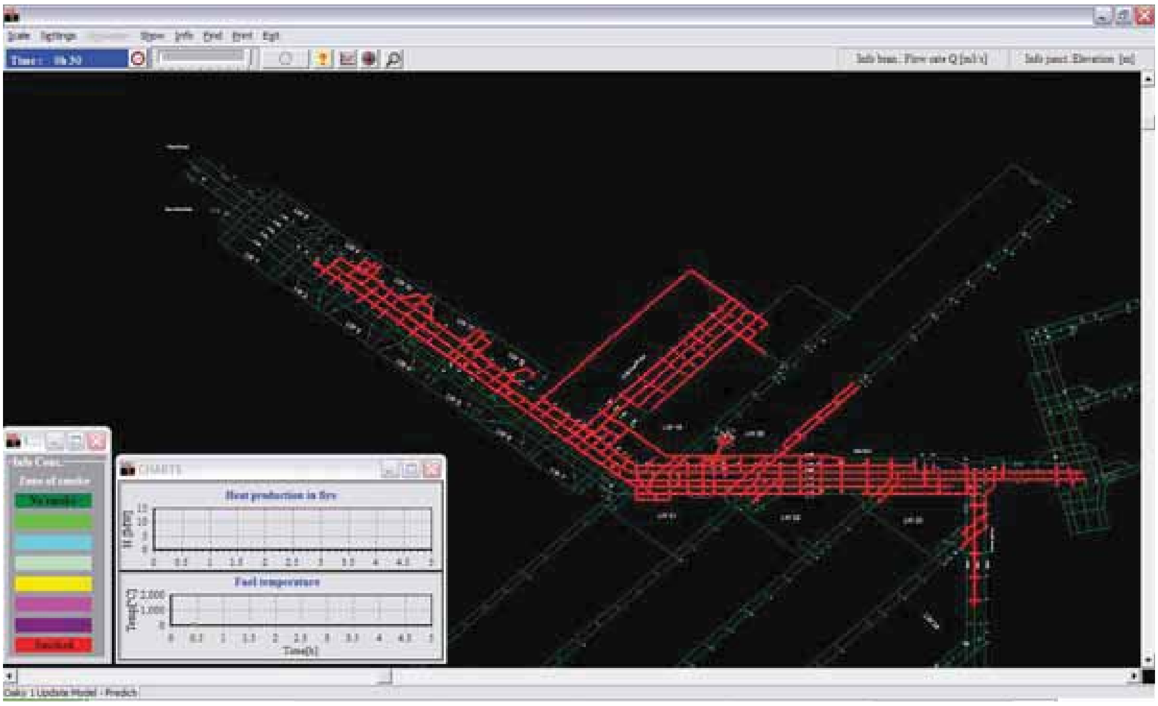


Figure 8.2 Smoke distribution after 30 minutes.

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, CO:CO_2 = 0.1. (assume H_2= CO level); fire very unstable and not under control.

Control Fire fighting ineffective within 120 minutes

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. CO:CO_2 = 0.1 (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

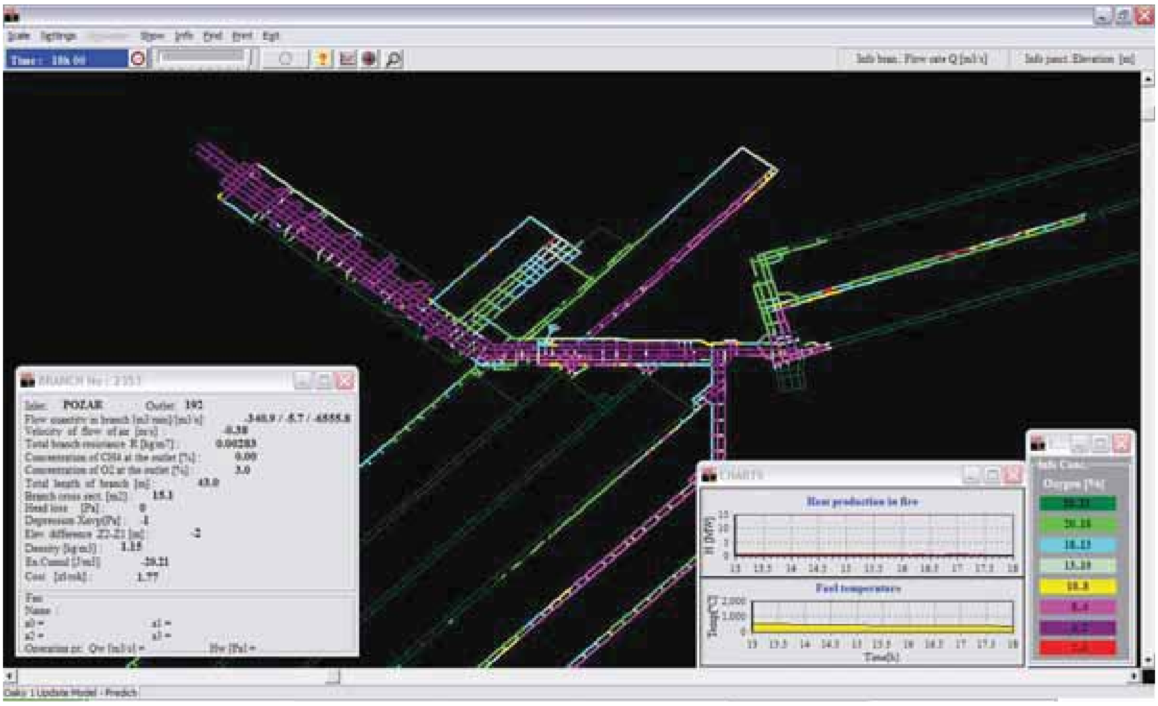
Examine fan curve operating point ; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 At 330 minutes: Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Step 7 At 360 minutes: Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip B Heading Emergency Door R=10

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 8 At 390 minutes: Shut down No 3 fan; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1



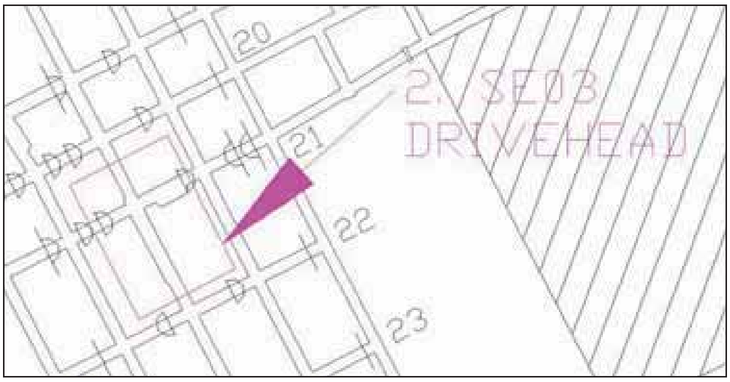
Inlet: POZAR Outlet: 192
Flow quantity in branch [m3/min]/[m3/s]: -340.9 / -5.7 / -4555.8
Velocity of flow of air [m/s]: -0.38
Total branch resistance R [kg/m7]: 0.00283
Concentration of CH4 at the outlet [%]: 0.00
Concentration of O2 at the outlet [%]: 3.0
Total length of branch [m]: 43.0
Branch cross sect. [m2]: 15.1
Head loss [Pa]: 0
Depression Xavg[Pa]: 1
Elev. difference Z2-Z1 [m]: -2
Density [kg/m3]: 1.15
En.Consul [J/m3]: -20.21
Cost [zl/mh]: 1.77

Figure 8.3 Oxygen distribution after 1080 minutes.

Summary *With GAG running Fire intensity insignificant at 18 hours and oxygen level outbye fire at less than 3.0 percent. However ventilation air reversal occurred across the fire after all fans stopped but no methane reversed across the fire.*

8.2. Oaky Creek No 1 Fire Scenario 2

Scenario *In the "C" main dips at bottom of main dips at the C21-C22 (belt drive head area), hydraulic oil has caught on fire. SE03 Drivehead - Main Dips C21-C22 - Belt Drivehead area which is segregated.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

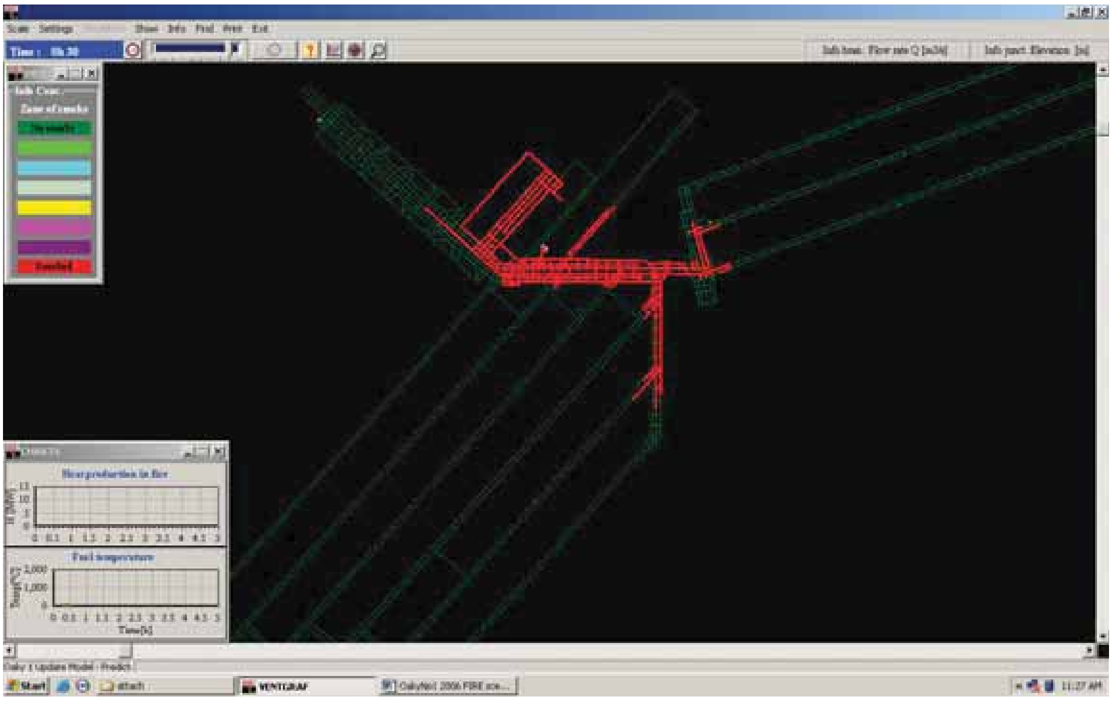


Figure 8.4 Smoke distribution after 30 minutes.

Smoke reaches surface at 15 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator.
Simulate 7m length fire over entry width; time constant 120s, intensity 10.
Smoke reaches MG26 face at 45 minutes
Smoke reaches Longwall face at 47 minutes
Smoke reaches MG25 face at 54 minutes

Control Fire fighting control is suppressing oil fire

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

East Main CO concentration is less than 50ppm throughout.

Control Fire fighting ineffective within 120 minutes.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Examine fan curve operating point; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 After 330 minutes Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Step 7 After 360 minutes Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip B Heading Emergency Door R=10

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 8 Shut down No 3 fan; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1

Reversal of air occurs across fire once the final fan is turned off.

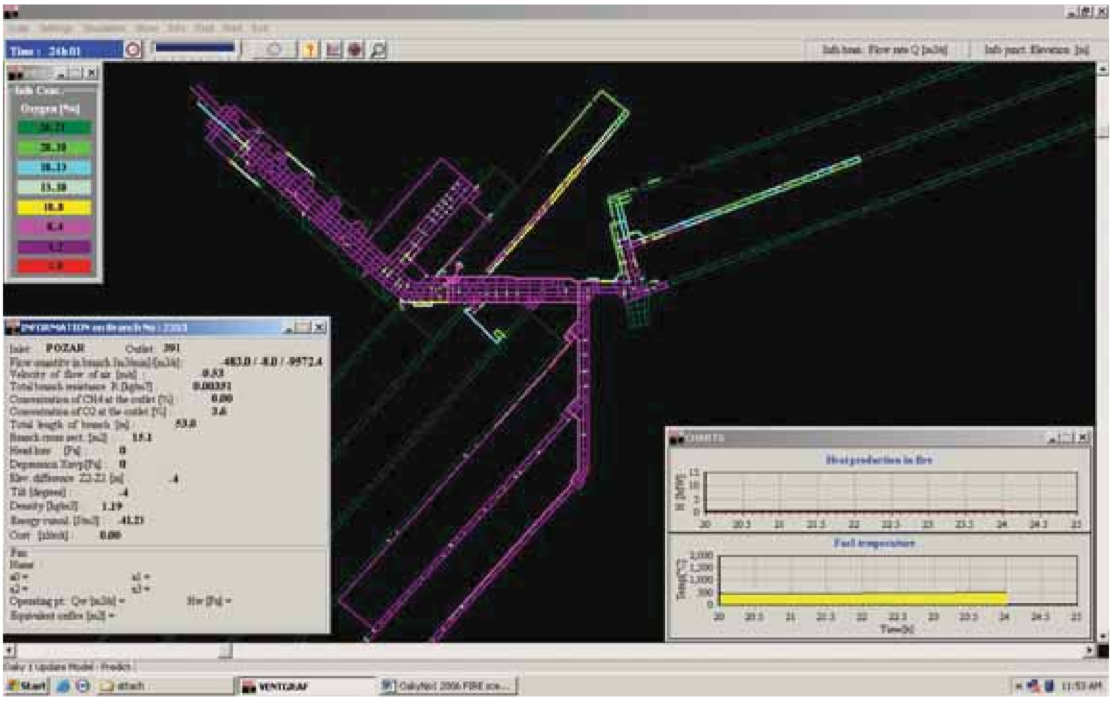
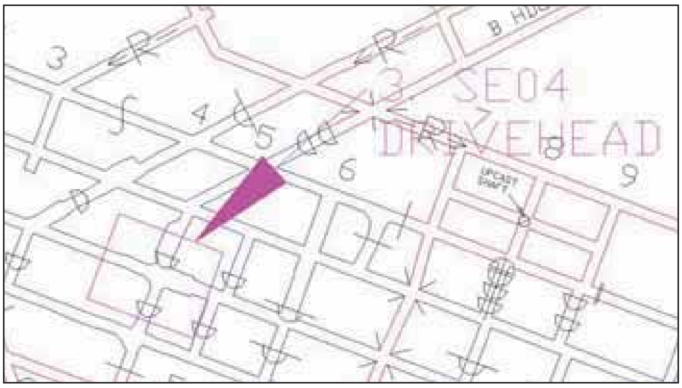


Figure 8.5 Oxygen distribution after 1440 minutes.

Summary *With GAG running Fire intensity insignificant at 24 hours and oxygen level outbye fire at less than 3.5 percent. However ventilation air reversal occurred across the fire after all fans stopped but no methane reversed across the fire.*

8.3. Oaky Creek No 1 Fire Scenario 3

Scenario *In the "C" main dips at bottom of main dips at the C5-C6 (belt drive head area), hydraulic oil has caught on fire. SE04 Drivehead - Main Dips C5-C6 - Belt Drivehead area which is segregated.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

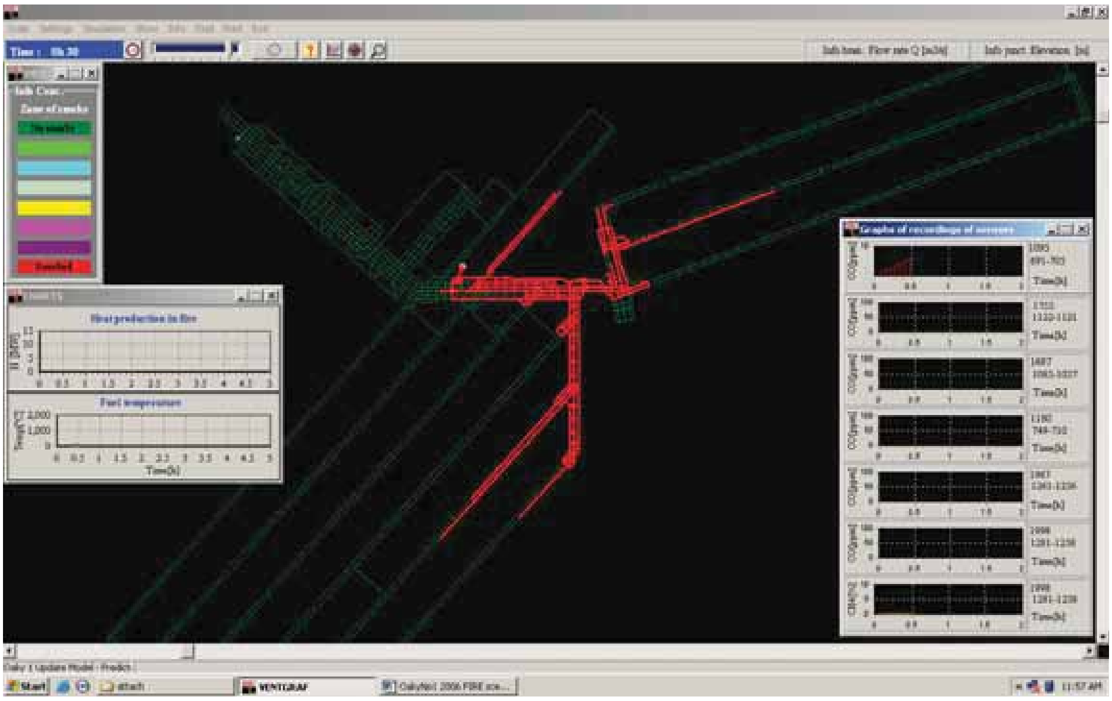


Figure 8.6 Smoke distribution after 30 minutes.

Smoke reaches surface at 5 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator.
Simulate 7m length fire over entry width; time constant 120s, intensity 10.
Smoke reaches Longwall face at 37 minutes
Smoke reaches MG26 face at 37 minutes
Smoke reaches MG25 face at 45 minutes

Control Fire fighting control is suppressing oil fire

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

East Main CO concentration is less than 50ppm throughout, except C heading

Control Fire fighting ineffective within 120 minutes.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Control Assess effectiveness of GAG
Examine fan curve operating point; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 After 330 minutes Shut down No 1 fan; fan louvre doors closed R=10.

Close Portal Dip A Heading Emergency Door R=10.

Step 7 After 360 minutes Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip B Heading Emergency Door R=10

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 8 Shut down No 3 fan; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1

Localised reversal occurs

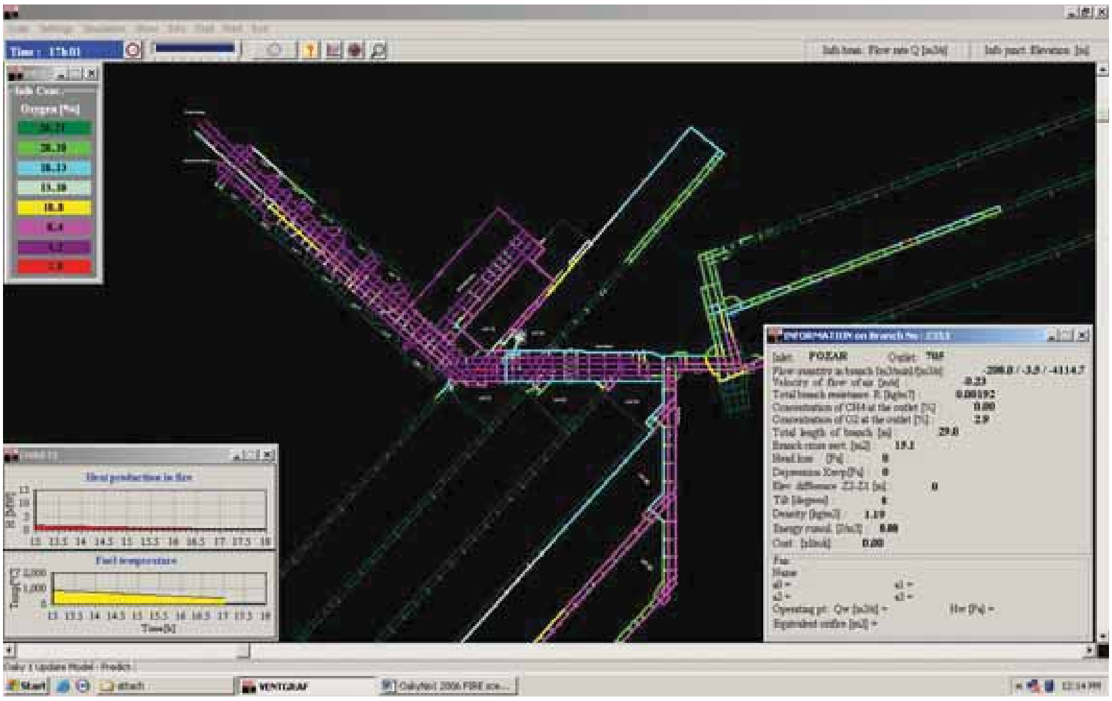
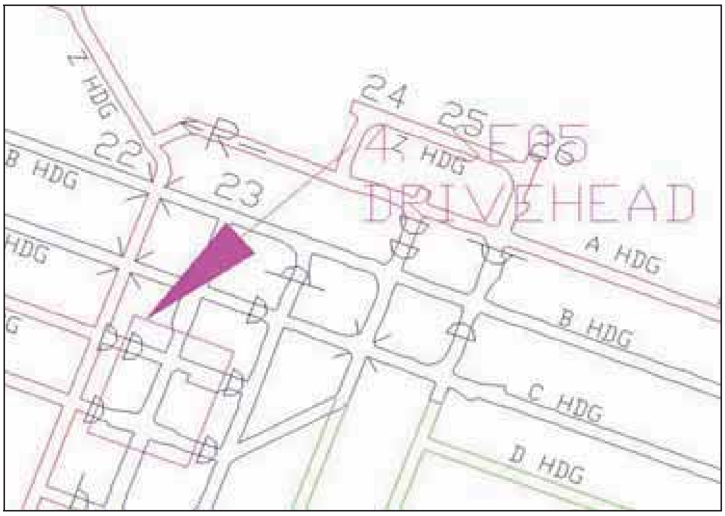


Figure 8.7 Oxygen distribution after 1020 minutes.

Summary *With GAG running Fire intensity insignificant at 17 hours and oxygen level outbye fire at less than 2.9 percent.*

8.4. Oaky Creek No 1 Fire Scenario 4

Scenario *In the East mains dips at bottom of main dips at the 23ct D-E (belt drive head area), hydraulic oil has caught on fire. SE05 Drivehead – East mains Dips 23ct D-E Belt Drivehead area which is segregated.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 15 minutes
Smoke reaches Longwall face at 26 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Smoke reaches MG25 face at 33 minutes

Control Fire fighting control is suppressing oil fire

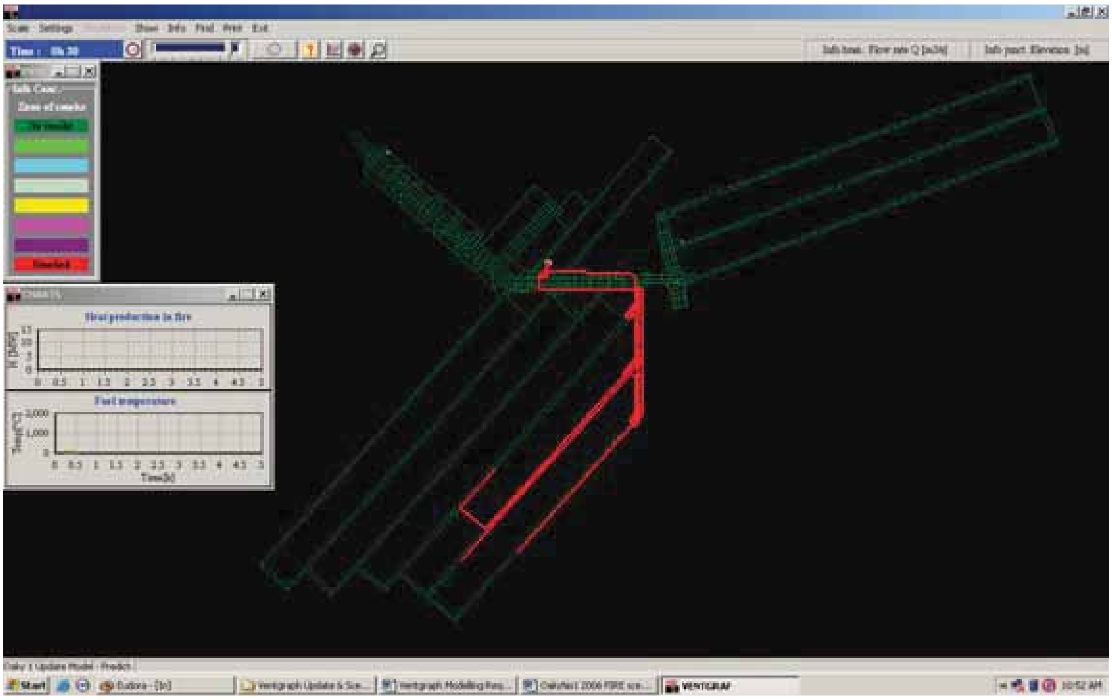


Figure 8.8 Smoke distribution after 30 minutes.

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

Control Fire fighting ineffective within 120 minutes.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts. Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Control Assess effectiveness of GAG

Examine fan curve operating point

NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 After 360 minutes Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Control Assess effectiveness of GAG

Step 7 After 390 minutes Shut down No 2 fan; fan louvre doors closed R=10.
Close Portal Dip B Heading Emergency Door R=10.

Control Assess effectiveness of GAG

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 8 After 420 minutes Shut down No 3 fan; fan louvre doors open.
Close Portal Dip C Heading Emergency Door R=1.

Control Assess effectiveness of GAG

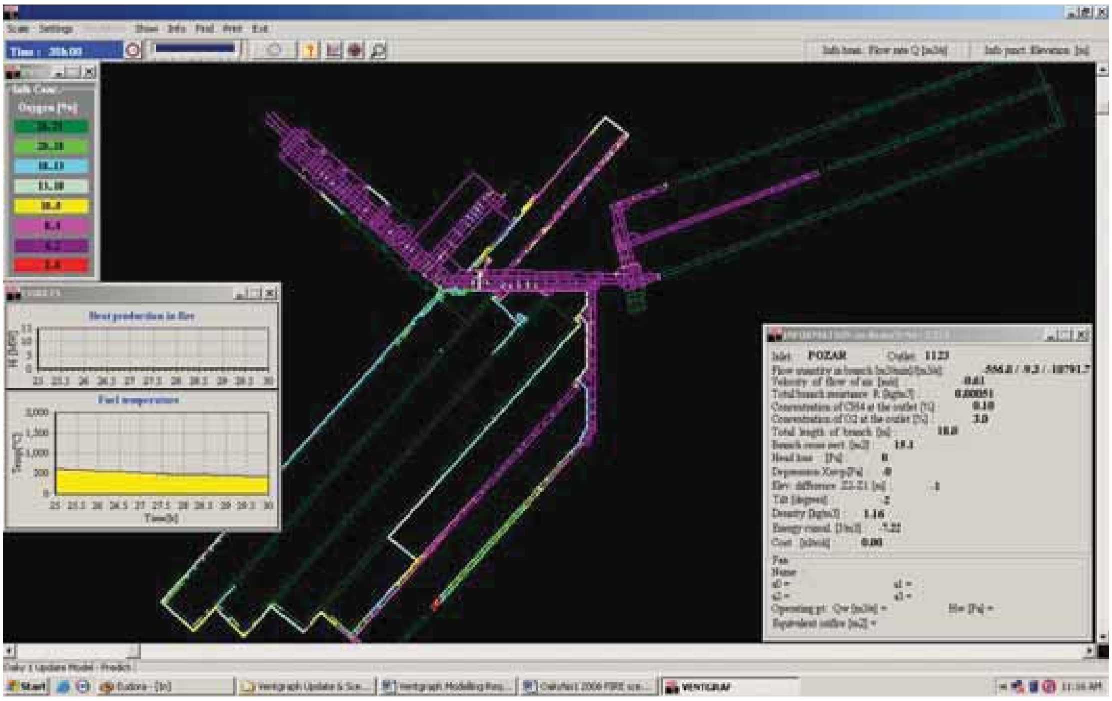


Figure 8.9 Oxygen distribution after 1800 minutes.

Summary *With GAG running Fire intensity insignificant at 30 hours and oxygen level outbye fire at less 3.0 percent.*

8.5. Oaky Creek No 1 Fire Scenario 5

Scenario *In the South Mains D8 to MG24 C2 (belt drive head area), hydraulic oil has caught on fire. LW Drivehead - South Mains D8 to MG24 C2 - Belt Drivehead area which is segregated.*

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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 27 minutes
Smoke reaches Longwall face at 30 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Control Fire fighting control is suppressing oil fire

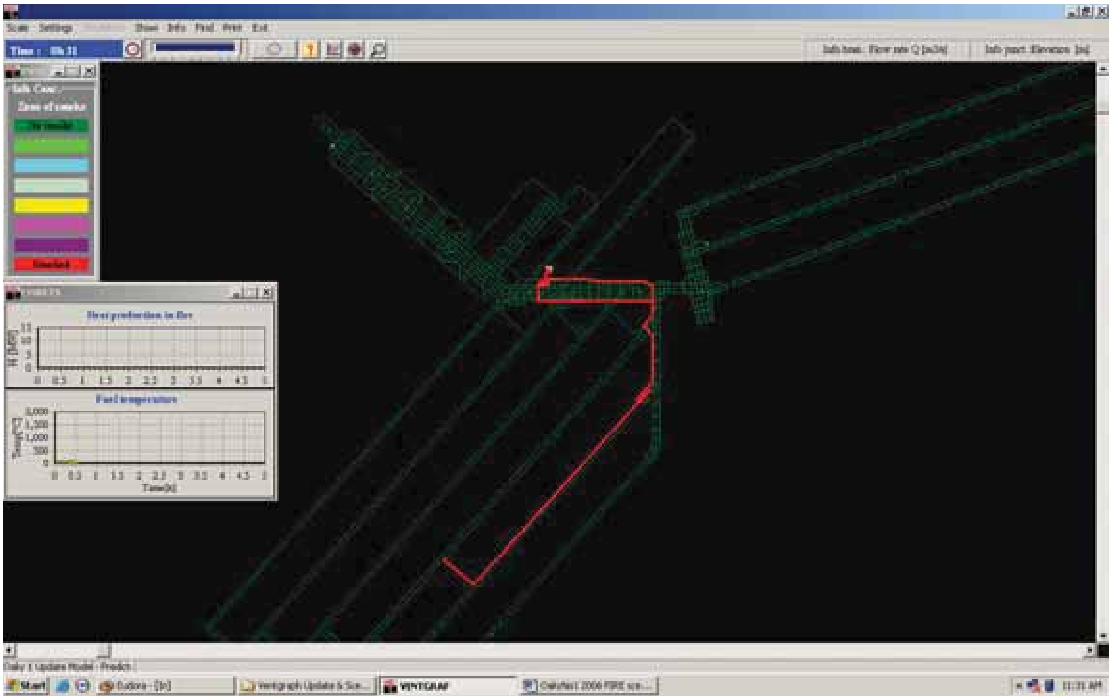


Figure 8.10 Smoke distribution after 30 minutes.

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

Control Fire fighting ineffective within 120 minutes.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 350 minutes: continue 50 m entry length coal burning.

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Control Assess effectiveness of GAG

Examine fan curve operating point

NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 After 390 minutes Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Control Assess effectiveness of GAG

Step 7 After 420 minutes Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip B Heading Emergency Door R=10

Control Assess effectiveness of GAG

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 8 After 450 minutes Shut down No 3 fan; fan louvre doors open.
Close Portal Dip C Heading Emergency Door R=1.

Control Assess effectiveness of GAG

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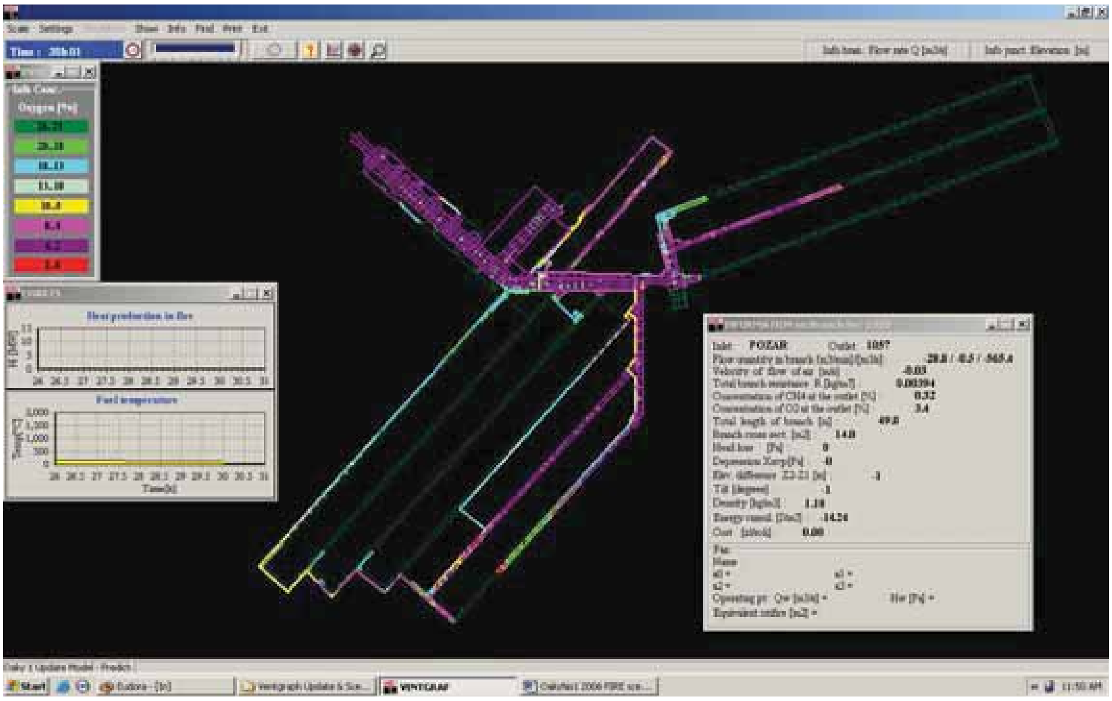
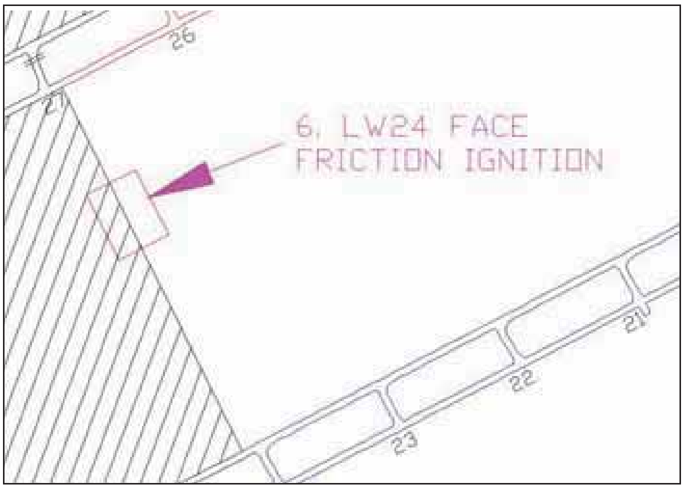


Figure 8.11 Oxygen distribution after 1800 minutes.

Summary *With GAG running Fire intensity insignificant at 36 hours and oxygen level outbye fire at less than 3.2 percent.*

8.6. Oaky Creek No 1 Fire Scenario 6

Scenario *Fire on LW 24 face at mid point caused by friction ignition of methane igniting coal.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.
- O_2 sensor on LW face 100m from MG and O_2 sensor on LW face 200m from MG; O_2 sensors do not occur in the mine.

Simulation

Step 1 Time 0 – 30 minutes: Methane blower burning. Simulate as 30 litres oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 2 Time 30 – 60 minutes: 5 m coal length at mid-longwall, time constant 14,400s, intensity 5, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 32 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 3 Time 60 – 90 minutes: 20 m entry length coal develops, time constant 14,400s, intensity 5.

Control Fire fighting ineffective within 90 minutes; management decision to change to ventilation control strategies; 30-45 minutes to implement.

Step 4 Time 90 – 240 minutes: 50 m entry length coal develops, time constant 14,400s, intensity 5.

Time 120 minutes: Brattice placed at BSL R=0.2

Control Fire fighting ineffective within 120 minutes; management decision to further change ventilation control strategies; 45 minutes to implement.

Time 165 minutes: Brattice placed Outbye LW equipment, belt dropped R=5

Control Fire fighting ineffective within 165 minutes; management decision to further change ventilation control strategies; 45 minutes to implement.

Time 210 minutes: Brattice placed at first and second CT Outbye LW face R=5

Fire out of control

Control Fire fighting ineffective within 210 minutes; management decision to introduce high flow inertisation – GAG; 120 minutes to implement.

Step 5 Time 240 - 360 minutes: 125 m entry length coal develops, source time constant 14,400s, intensity 5.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 6 Time 360 minutes: Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Control Assess effectiveness of GAG

Examine fan curve operating point. NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 Time 420 minutes: Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Control Assess effectiveness of GAG

Step 8 Time 480 minutes: Shut down No 2 fan; fan louvre doors closed R=10.
Close Portal Dip B Heading Emergency Door R=10.

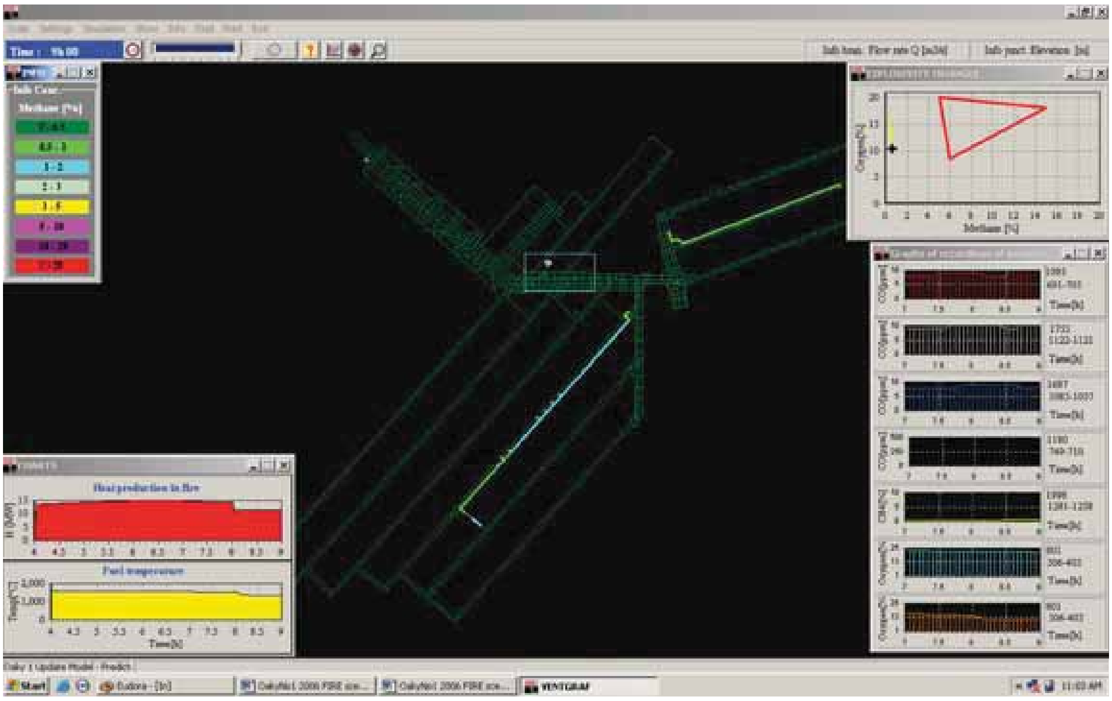


Figure 8.12 Methane distribution after 540 minutes.

Control Assess effectiveness of GAG

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

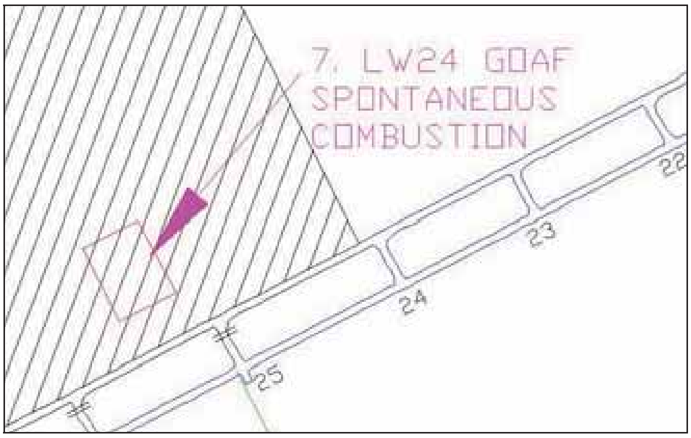
Step 9 Time 540 Shut down No 3 fan; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1

Reversal occurs bringing methane over the fire source causing an explosion.

***Summary** Reversal occurs bringing methane over the fire source. Explosion occurred*

8.7. Oaky Creek No 1 Fire Scenario 7

Scenario *LW Goaf Spontaneous Combustion - Longwall 24 Goaf heating. Longwall 24 face currently at 26 ct. Fire located at 27 ct on MG side 40m into goaf.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW12A at 80 l/s, MG25 at 55 l/s and MG26 at 80 l/s.
  LW24 seven sources total 230 l/s, 110 l/s on face, four sources of 30 l/s each spaced 20m in from MG Hdg.
- *O_2 sensor on LW face 100m from MG and O_2 sensor on LW face 200m from MG; O_2 sensors currently do not occur in the mine at these points.*

Simulation

Step 1 Time 0 – 360 minutes: 1 m entry length coal fuel in 18 c/t MG edge of goaf burning; time constant 14400s, intensity 1 $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control.

Smoke reaches surface at 39 mins.
CO at TG exceeds 5ppm at 70 mins.

Step 2 Time 360– 720 minutes: 5 m entry length coal burning with gas continuing to burn; time constant 14400s, intensity 2.

Step 3 Time 720 – 1080 minutes: Continue coal fire 25 m entry length coal burning; time constant 14400s, intensity 4.

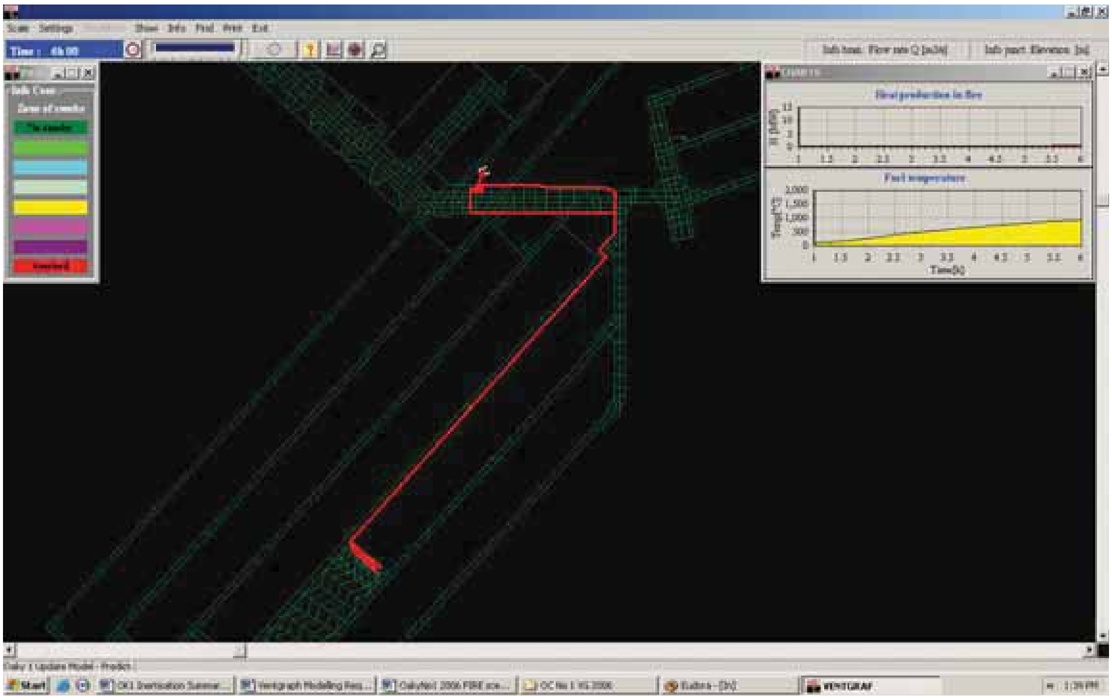


Figure 8.13 Smoke distribution after 360 minutes.

Step 4 Time 1080 - 1440 minutes: Continue coal fire 100 m entry length coal burning; time constant 14400s, intensity 8. Fire very unstable and not under control

CO concentration at 19 hours sets off alarm at bottom of vent shaft.

Step 5 Time 1440 - 1800 minutes: Continue coal fire 200 m entry length coal burning; time constant 14400s, intensity 10.

Step 6 Time 1450 minutes: Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Examine all three main fan curve operating points; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 1500 minutes: Shut down No 1 fan; fan louvre doors closed R=10
Examine No 2 and No3 fan curve operating points

Step 8 1560 minutes: Close Portal Dip A Heading Emergency Door R=10.

Step 9 1590 minutes: Shut down No 2 fan; fan louvre doors closed R=10

Step 10 1620 minutes: Close Portal Dip B Heading Emergency Door R=10

Step11 1680 minutes: Shut down No 3 fan; fan louvre doors open

Close Portal Dip C Heading Emergency Door R=1; at about 28 hours local reversal occurred to produce a minor methane burn off.

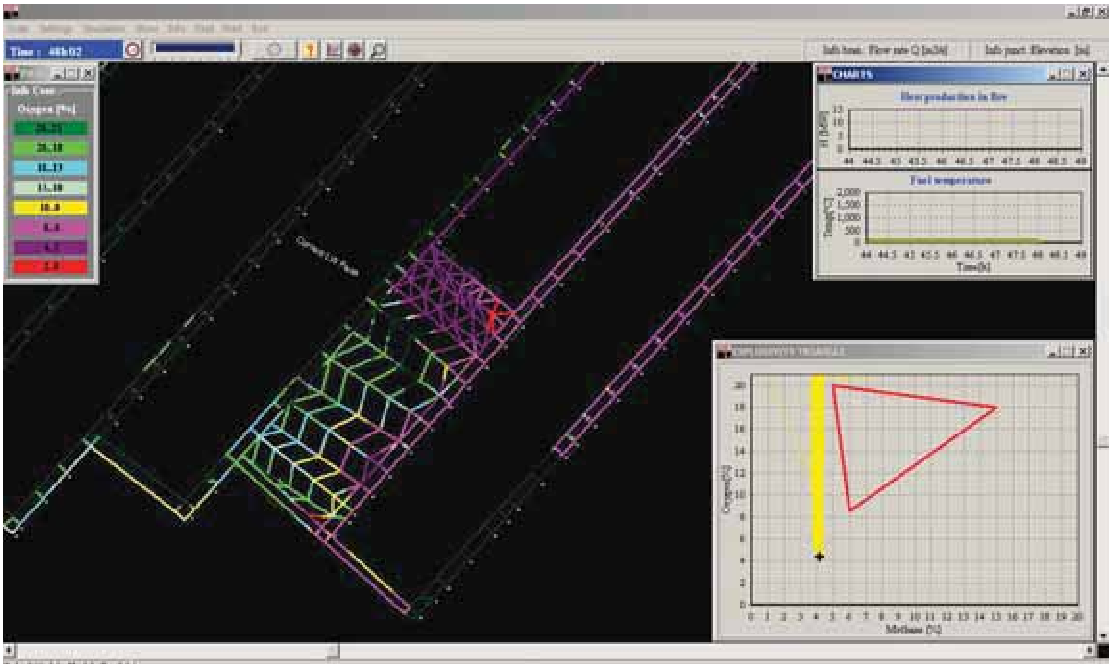


Figure 8.14 Oxygen distribution after 2880 minutes.

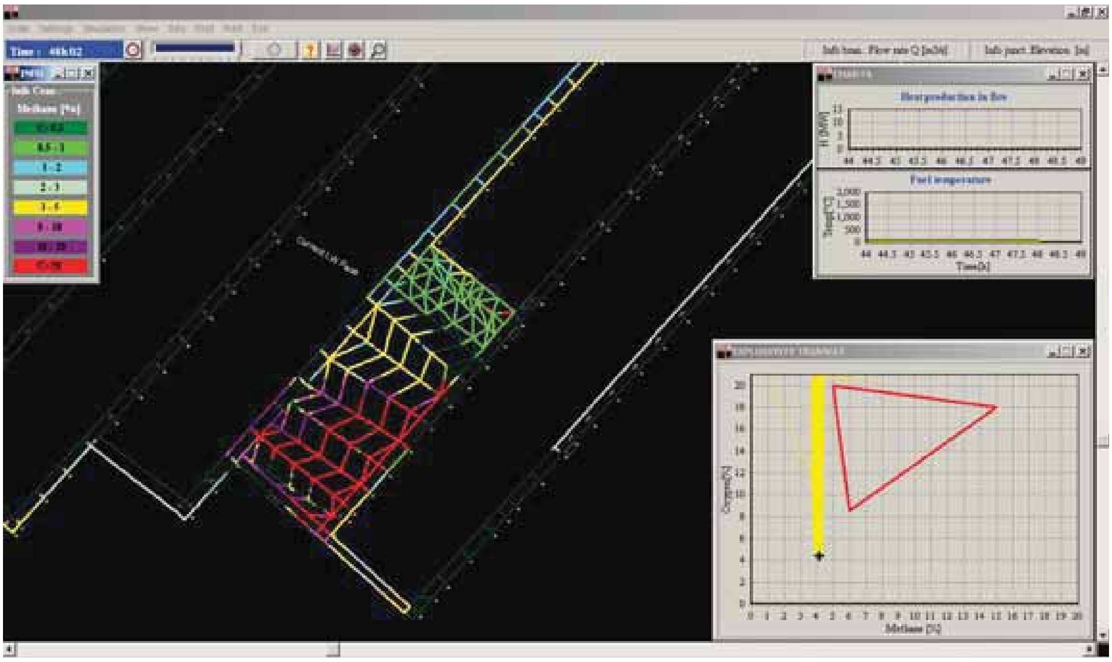


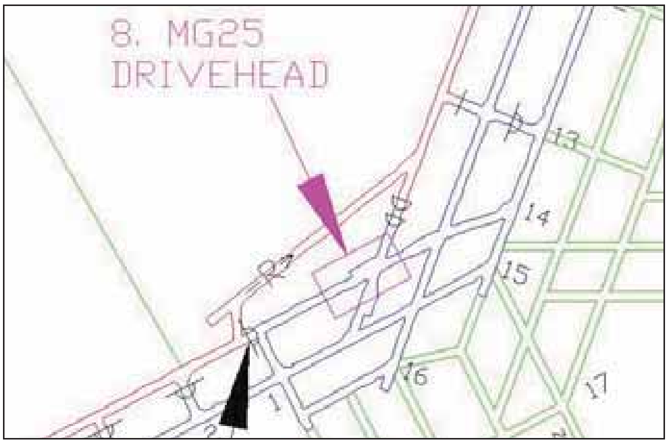
Figure 8.15 Methane distribution after 2880 minutes.

Fire substantially reduced without GAG exhaust reaching fire but GAG ensures full extinguishment.

Summary *With GAG running fire intensity insignificant at 48 hours and oxygen level outbye fire at less than 2.5 percent.*

8.8. Oaky Creek No 1 Fire Scenario 8

Scenario *In the South Mains D14 to MG25 C2 (belt drive head area), hydraulic oil has caught on fire. MG25 Drivehead - South Mains D14 to MG25 C2 - Belt Drivehead area which is segregated.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

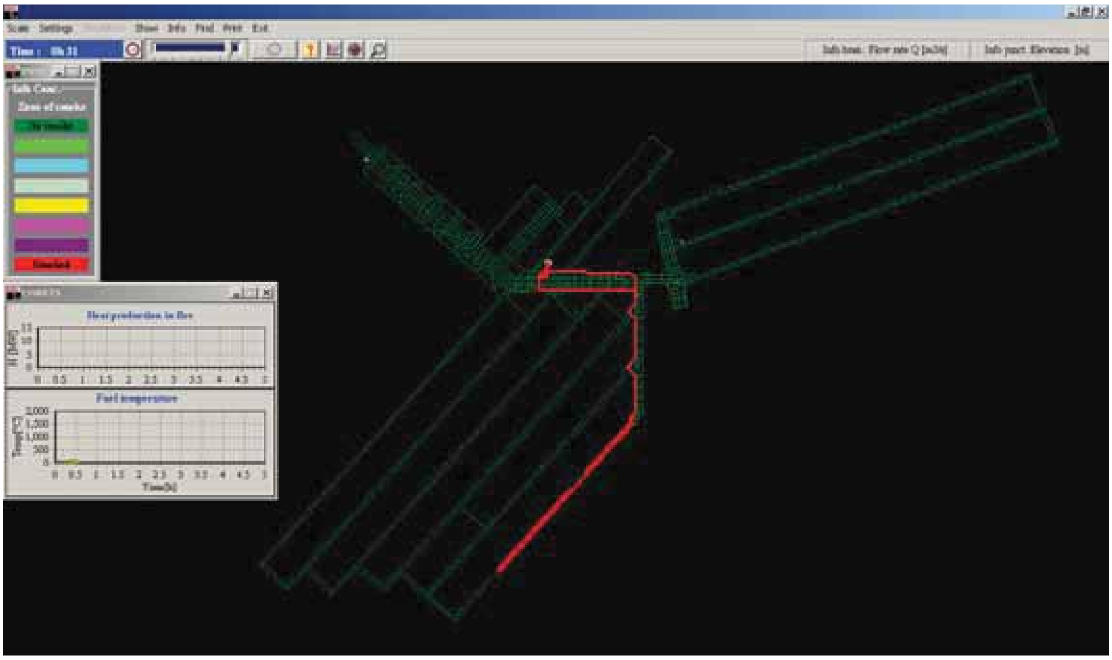


Figure 8.16 Smoke distribution after 30 minutes.

Smoke reaches surface at 27 minutes; Smoke reaches Longwall face at 25 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Control Fire fighting control is suppressing oil fire

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

Control Fire fighting ineffective within 120 minutes.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts. Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: Continue 50 m entry length coal burning.

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Examine fan curve operating point; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 After 360 minutes Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Step 7 After 390 minutes Shut down No 2 fan; fan louvre doors closed R=10.
Close Portal Dip B Heading Emergency Door R=10.

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation.

Step 8 After 450 minutes shut down No 3 fan; fan louvre doors open.
Close Portal Dip C Heading Emergency Door R=1.

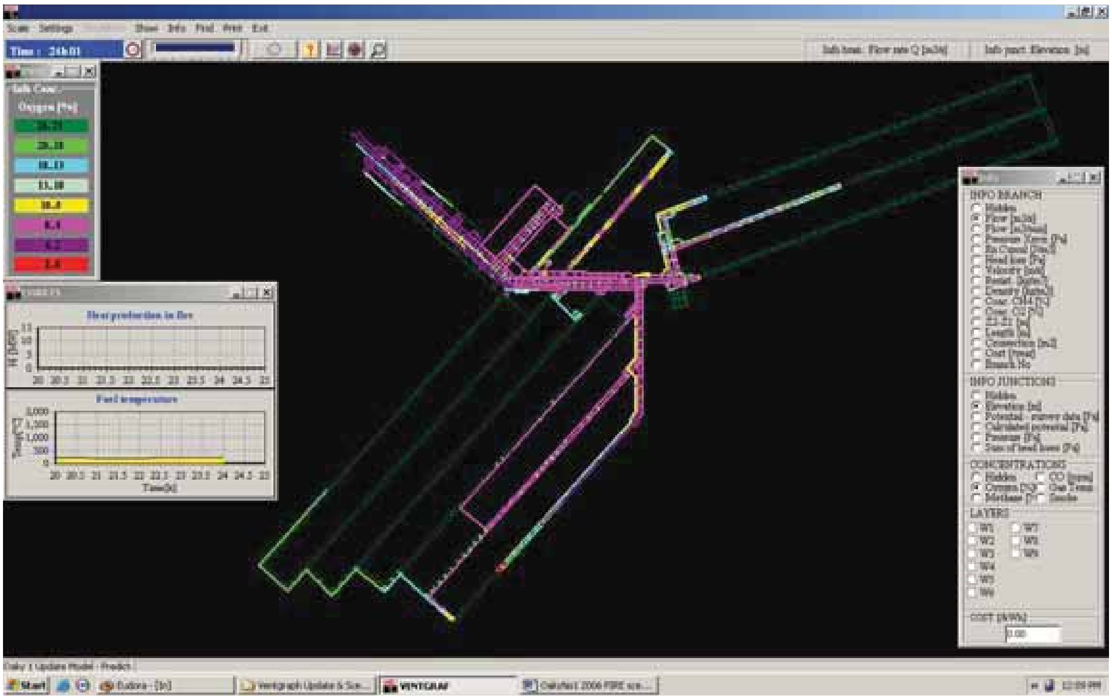


Figure 8.17 Oxygen distribution after 1440 minutes.

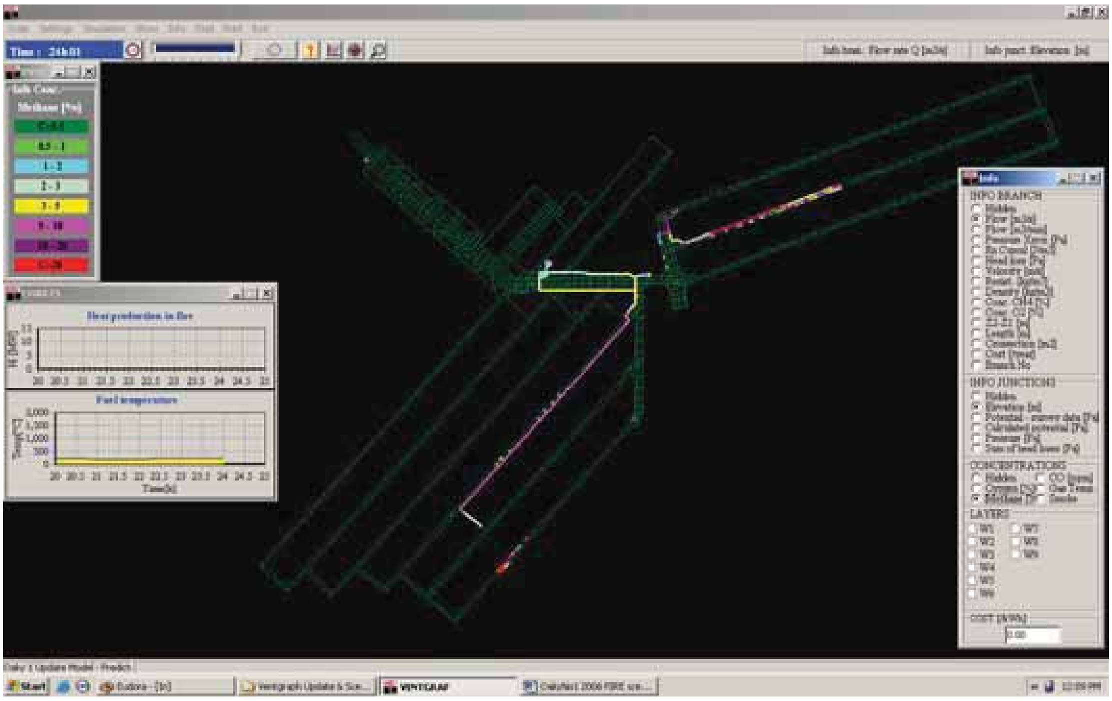
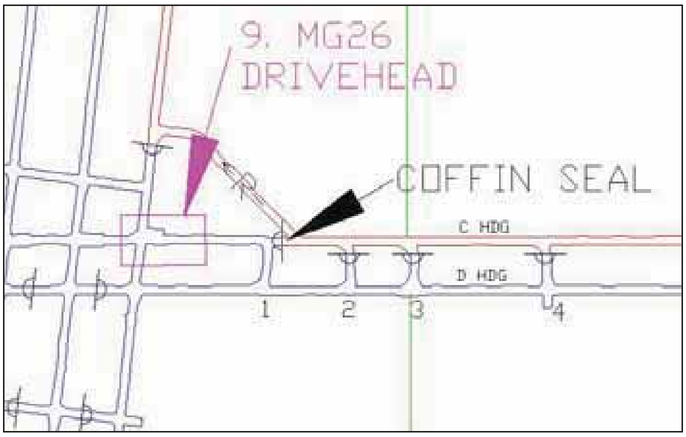


Figure 8.18 Methane distribution after 1440 minutes.

Summary *With GAG running Fire intensity insignificant at 24 hours and oxygen level outbye fire at less 2.9 percent.*

8.9. Oaky Creek No 1 Fire Scenario 9

Scenario *In the Sandy Creek East Mains D6 to MG26 C1 (belt drive head area), hydraulic oil has caught on fire. MG26 Drivehead - Sandy Creek East Mains D6 to MG26 C1- Belt Drivehead area which is segregated.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 25 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

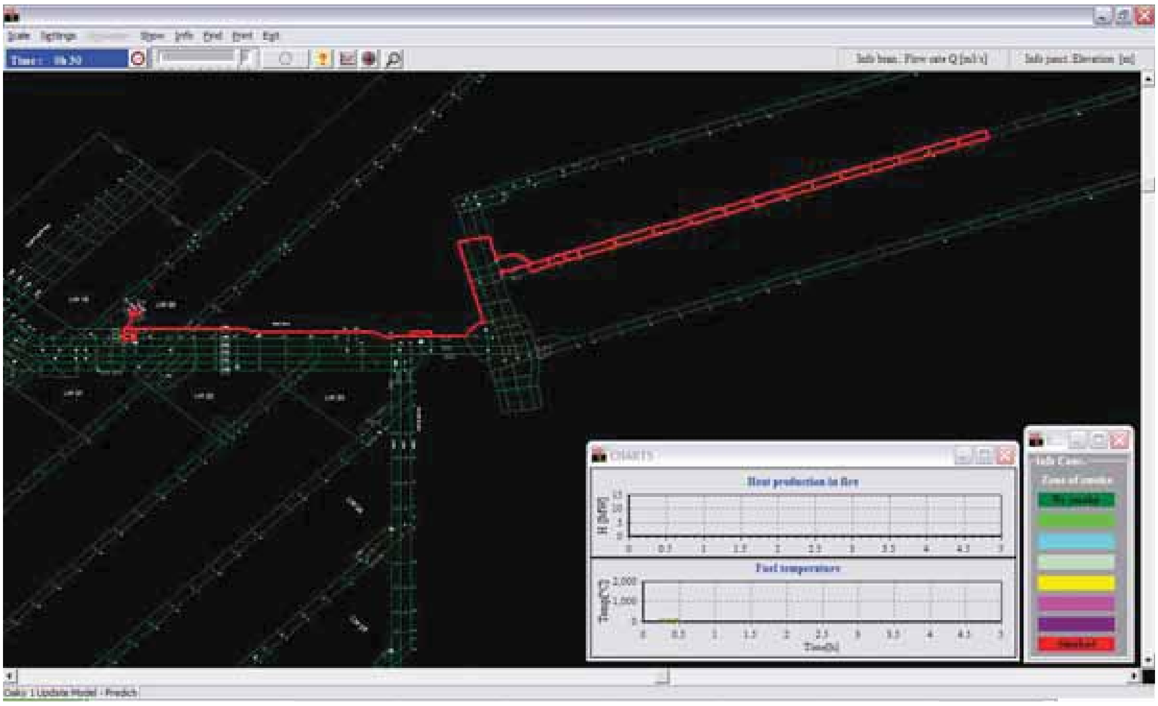


Figure 8.19 Smoke distribution after 30 minutes.

Control Fire fighting ineffective within 120 minutes.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2$ = 0.1 (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

At 300 minutes GAG has been set up at C Heading Portal Dips and C Heading Emergency Doors closed, R=10

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.
Examine fan curve operating point; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 After 330 minutes Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Step 8 After 360 minutes Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip B Heading Emergency Door R=10

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 9 After 390 minutes Shut down No 3 fan; fan louvre doors open.
Close Portal Dip C Heading Emergency Door R=1.

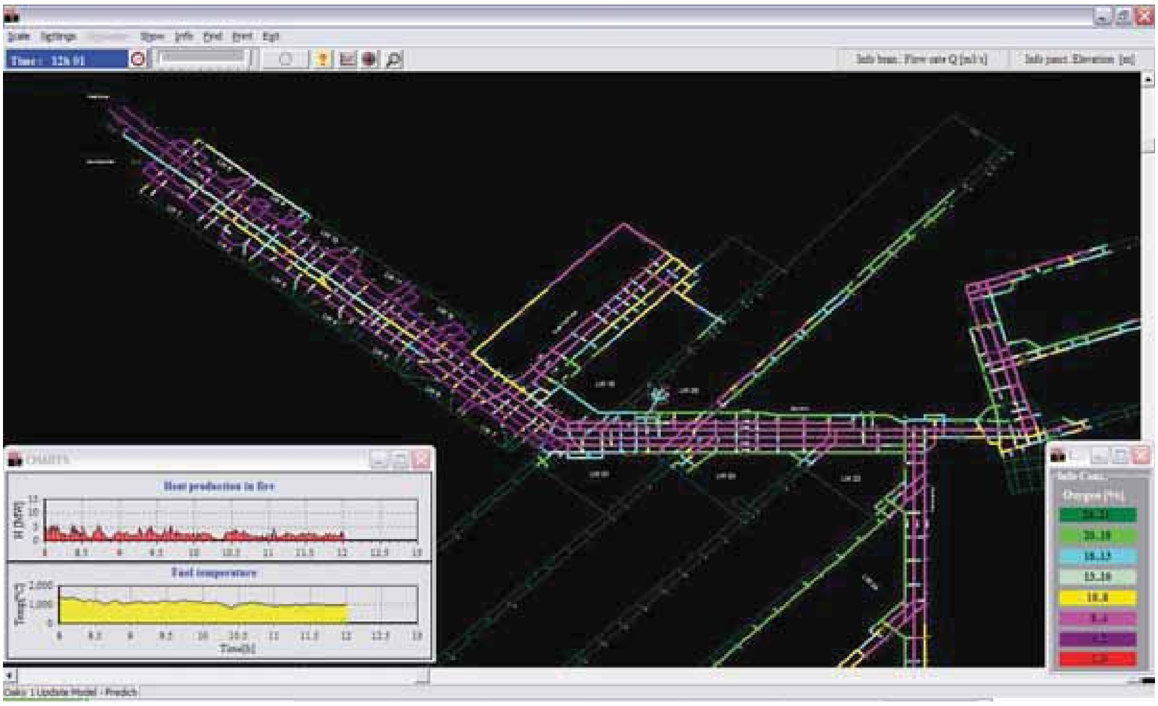
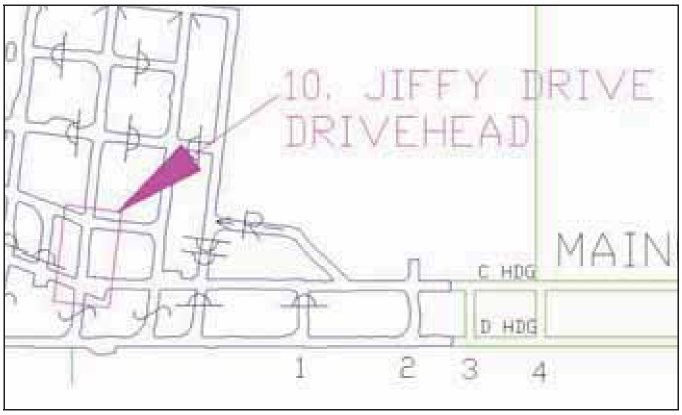


Figure 8.20 Oxygen distribution after 720 minutes.

Summary: *Fire fluctuating and not reducing in intensity after 720 minutes with GAG in operation.*

8.10. Oaky Creek No 1 Fire Scenario 10

Scenario *In the Sandy Creek East Mains C13 to C12 (belt drive head area), hydraulic oil has caught on fire. Jiffy Drive 1 Drivehead - Sandy Creek East Mains C13 to C12-Belt Drivehead area which is segregated.*



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

- Initiation of GAG at Downcast Shaft entry connected to 3 CT D Heading on Main dips
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 30 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

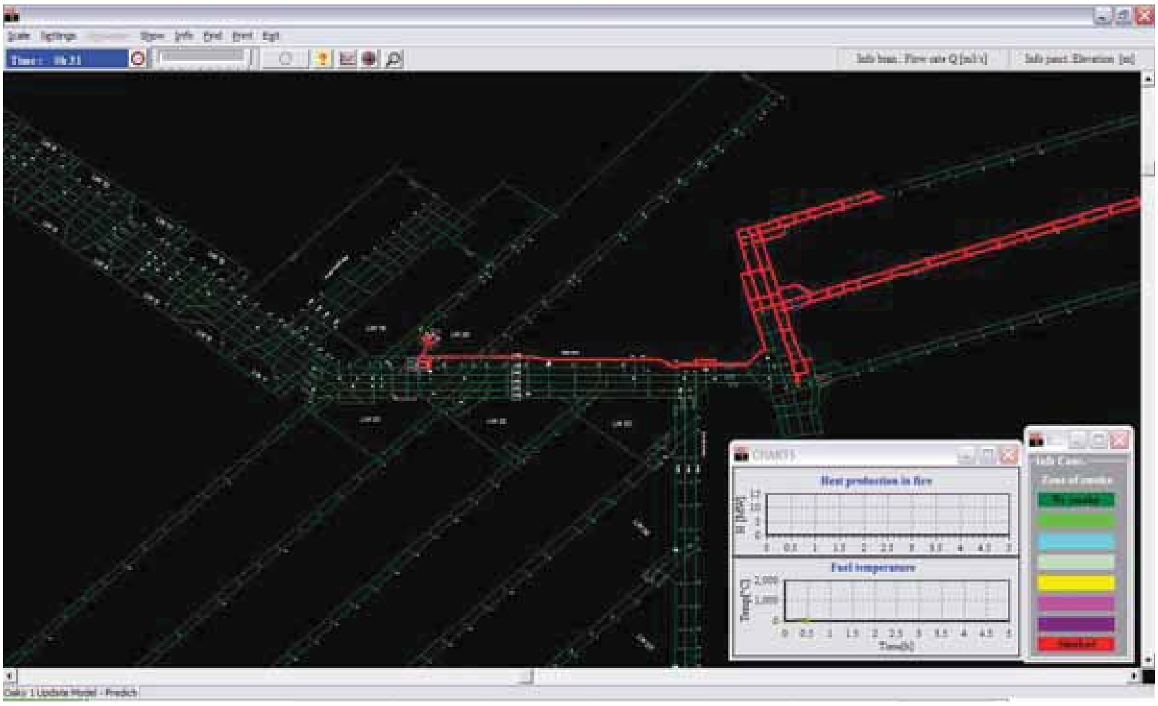


Figure 8.21 Smoke distribution after 30 minutes.

Control Fire fighting ineffective within 120 minutes

Step 4 Time 120 – 300 minutes: Coal is fuel source as all liquid fuel has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

At 300 minutes GAG has been set up at C Heading Portal Dips and C Heading Emergency Doors closed, R=10

Commence GAG control action; GAG has been set up at Downcast Shaft entry connected to 3 CT D Heading on Main dips. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Control Assess effectiveness of GAG

Examine fan curve operating point; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 After 330 minutes Shut down No 1 fan; fan louvre doors closed R=10.
Close Portal Dip A Heading Emergency Door R=10.

Step 7 After 360 minutes Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip B Heading Emergency Door R=10

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 8 After 390 minutes Shut down No 3 fan; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1

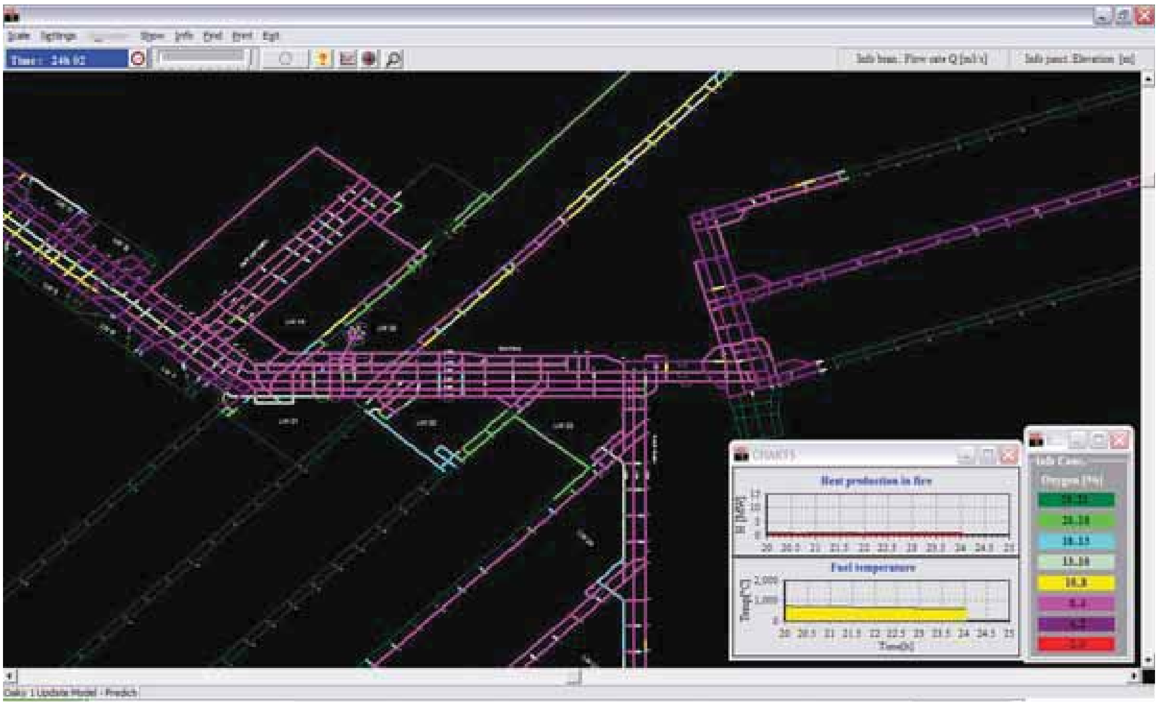


Figure 8.22 Oxygen distribution after 1440 minutes.

Summary *With GAG running, fire intensity insignificant at 24 hours and oxygen level outbye fire at less than 2.9 percent.*

9. REVIEW OF OPTIONS FOR IMPROVING ABILITY TO INERTISE PRIORITY FIRES AT OAKY NO 1 MINE

As mentioned in Section 3.3, location position of the inertisation unit's point of coupling to the mine, or the docking point, is a major determinant of potential success for most efficient suppression of a specific underground fire. Traditionally in Queensland docking points have been placed on intake ventilation access openings (such as travel or conveyor belt roads or adjacent vertical shafts). Some mines have prepared docking points on boreholes of about 1.0 to 2.0m diameter placed at the back of longwall panels.

Scenarios developed for Oaky Creek No 1 Colliery have been examined as to the ability of a GAG inertisation unit placed at the current docking point on the intake shaft adjacent to the Highwall Declines to inert a fire in the mine recovery stage following a fire. Table 9.1 shows results of the outcome of the ten scenarios investigated in Chapter 8.

The ten scenario outcomes have been categorised as follows.

- Category A covers fire in which the inertisation product is directed fully over the fire without significant dilution of the GAG exhaust. None of the ten mine priority fires examined achieved the situation in which the simulated fire is directly stabilised to aid recovery in a timely manner.
- Category B covers situations in which the inertisation product goes straight to the fire but there is significant dilution from other ventilation air or leakage through stoppings. Because of dilution stabilisation of a fire through inertisation can only be achieved with some main surface fan changes. Four Oaky Creek No 1 scenarios are in this category. Under these situations the fire should, over time, be abated or stabilised to a point where conventional recovery approaches can be initiated.
- Category C covers priority fires in which the GAG output will never reach the fire location without stopping of one or more main surface fans to rebalance ventilation within the pit. In many of these cases requiring fan changes to put GAG output across the fire location effective ventilation air velocity has been reduced to the extent that local reversal across the fire occurs and fire fumes are pulled across the fire. This is an unsatisfactory situation as fire smoke and fumes can carry combustible products. This situation broadly prevails for five scenarios of the cases examined.
- Category D covers priority fires in which the GAG output will never reach the fire location even if surface main fans are altered. These are fire locations within panel sections in which either the fire behaviour stops normal intake ventilation flow into the section headings or the GAG docking point is in an airway that is isolated from the section. There is no such case in the ten scenarios examined.
- Category E covers priority fires in gassy mines in which section production gas make has been included in the simulation modelling. GAG exhaust will never reach the fire location

without stopping of one or more main surface fans to rebalance ventilation within the pit. However this change in ventilation causes working section methane and ventilation air (incl. fire fumes) to reverse across the fire. This is clearly a potentially dangerous situation. This situation was found in one scenario of the cases examined.

Alternative approaches to improve the efficiency of GAG inertisation in the event of a major fire can be considered from the following.

1. Maintain use of existing docking station but with additional underground segregation to control the delivery of inert.
2. Try new Portal docking station.
3. Try new Portal docking station possibly with additional underground segregation.
4. Drill new borehole to deliver inert gas directly to the fire site.
5. MG regulator should be opened further to dump belt coffin seal air to return.
6. Coffin seal regulator should be opened further to dump all belt air to return.

The following sections describe how some of the scenarios where improvement was considered possible have been re-simulated based on consideration of these alternative actions as described in this section of the report.

Scenarios which had been assessed at Category B were not re-examined. This is the situation with Scenarios 4, 5, 8 and 10. It was considered that Category B was the best rating they could achieve.

Table 9.1 Summary of Original Scenario Outcomes on the Effects of Inertisation using current GAG Portal.

No	Fire Location	Fire Type	GAG Position	Segregation Actions	Fan Actions	Outcomes	GAG Inertisation	Comments
1	SE02 Drivehead Main Dips C9-C10	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category C***	Exhaust cannot reach fire until all fans off and air reversal occurs. Fire insignificant after 20 hrs.	No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off.
2	SE03 Drivehead Main Dips C21-C22	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category C***	Exhaust cannot reach fire until all fans off and air reversal occurs. Fire insignificant after 24 hrs.	No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off.
3	SE04 Drivehead East Mains C5-C6	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category C***	Exhaust reaches fire but with dilution. Fire insignificant after 17 hrs.	No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off.
4	SE05 Drivehead East Mains C23-D23	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category B***	Exhaust reaches fire but with dilution. With all fans off air reversal occurs. Fire insignificant after 30 hrs.	Methane had potential to reversal across the fire. Ventilation air reversal occurred over the fire after all fans turned off.
5	LW Drivehead South Mains D8 to	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B	Fans turned off one by	***Category B***	Exhaust reaches fire but with dilution. Fire	Air unstable after #2 fan shut down but reversal not

	MG24 C			after #2 Fan off; Close Drift C after #3 Fan off	one		insignificant after 36 hrs.	evident.
6	LW Friction Ignition Longwall 24 face	Gas → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category E***	Exhaust reaches fire but with dilution.	Ventilation air reversal occurred over the fire after all fans turned off. Methane had reversal across the fire and explosion occurred.
7	LW Goaf Spon Comb LW 24 Goaf heating	Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off		***Category C***	Exhaust reaches fire but with dilution. Fire insignificant with all fans off after 48 hrs.	Ventilation air reversal occurred over the fire after all fans turned off. Methane had reversal across the fire.
8	MG25 Drivehead South Mains D14 - MG25 C	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category B***	Exhaust reaches fire but with dilution. Fire insignificant after 24 hrs.	Fire unstable throughout. No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off.
9	MG26 Drivehead Sandy Creek East Mains D6 to MG26	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category C***	Exhaust reaches fire but with dilution. Fire fluctuating and not reducing in intensity after 12 hrs.	Fire unstable throughout. No methane reversal across the fire.
10	Jiffy Drive 1 Drivehead Sandy Creek East Mains C13 to C1	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	***Category B***	Exhaust reaches fire but with dilution. Fire insignificant after 24 hrs.	No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off.

9.1. Oaky Creek No 1 Fire Scenario 1A

Scenario *In the "C" main dips at bottom of main dips at the C9-C10 (belt drive head area), hydraulic oil has caught on fire. SE02 Drivehead - Main Dips C9-C10 - Belt Drivehead area which is segregated.*

Changed Inertisation Strategy**:** *GAG docked on Portal Dip C heading.*

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

- Initiation of GAG at Portal Dip C Heading.
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW12A 80 l/s, LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 22 minutes

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Smoke reaches Longwall face at 50 minutes

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

Control Fire fighting ineffective within 120 minutes

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

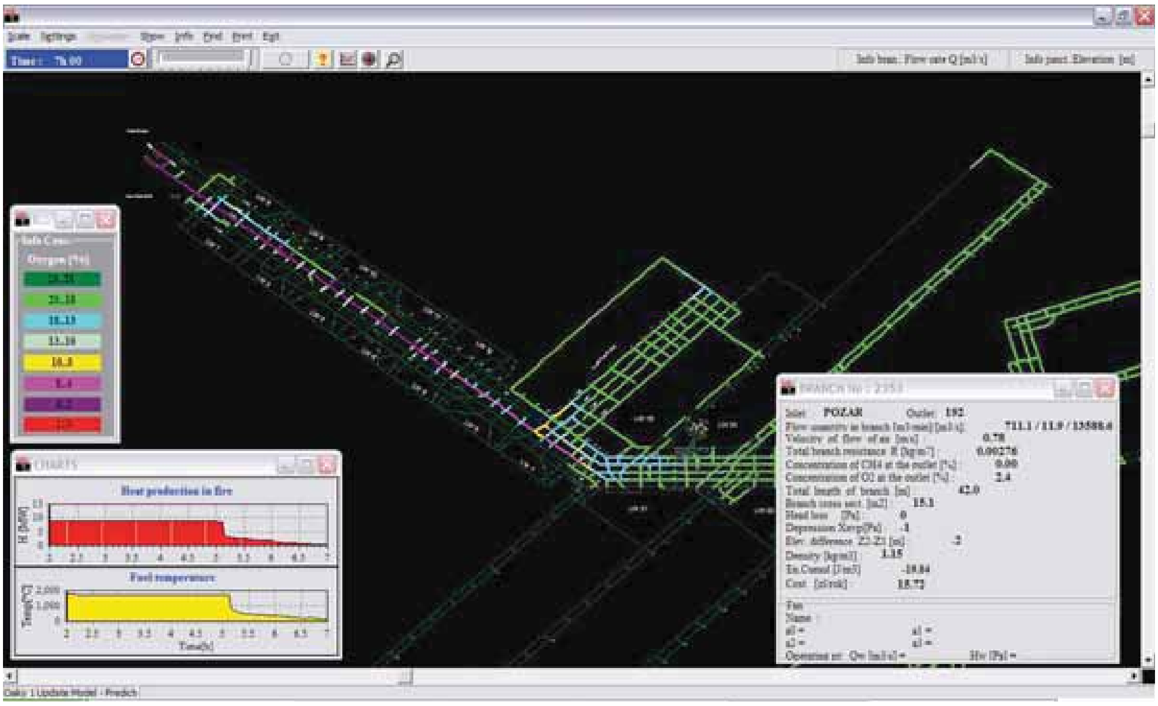
Commence GAG control action; GAG has been set up at Portal Dip C Heading.
Emergency Door at Portal Dip C Heading closed, R=10; Set GAG to 11,000rpm, efficiency 10%.
Examine fan curve operating point; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 6 At 330 minutes: Shut down No 1 fan; fan louvre doors closed R=10.

Step 7 At 360 minutes: Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip A Heading Emergency Door R=10

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 8 At 390 minutes: Shut down No 3 fan; fan louvre doors open
Close Portal Dip B Heading Emergency Door R=10



Inlet: POZAR Outlet: 192
Flow quantity in branch [m3/min][m3/s]: 711.1 / 11.9 / 13588.6
Velocity of flow of air [m/s] 0.78
Total branch resistance R [kg/m7] 0.00276
Concentration of CH4 at the outlet [%]: 0.00
Concentration of O2 at the outlet [%]: 2.4
Total length of branch [m] 42.0
Branch cross sect. [m2] 15.1
Head loss [Pa]: 0
Depression Xerp[Pa] -1
Elev. difference Z2-Z1 [m] -2
Density [kg/m3] 1.15
En.Consd [J/m3] -19.84
Cost [zl/rok] 15.73
Fan
Name :
a0 = a1 =
a2 = a3 =
Operating at: Qw [m3/s] = Hw [Pa] =

Figure 9.1 Oxygen distribution after 420 minutes.

Control Assess effectiveness of GAG

Summary *With GAG running, fire intensity insignificant at 7 hours and oxygen level outbye fire at less than 2.5 percent. No ventilation air reversal occurred across the fire.*

9.2. Oaky Creek No 1 Fire Scenario 2A

Scenario *In the "C" main dips at bottom of main dips at the C21-C22 (belt drive head area), hydraulic oil has caught on fire. SE03 Drivehead - Main Dips C21-C22 - Belt Drivehead area which is segregated.*

Changed Inertisation Strategy**:** *GAG docked on Portal Dip C heading.*

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

- Initiation of GAG at Portal Dip C Heading.
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW12A 80 l/s, LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 16 minutes

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Smoke reaches MG26 face at 45 minutes; Smoke reaches Longwall face at 47 minutes; Smoke reaches MG25 face at 54 minutes

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$.

East Mains CO concentration is less than 50ppm throughout.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.
Commence GAG control action; GAG has been set up at Portal Dip C Heading.
Emergency Door at Portal Dip C Heading closed, R=10; Set GAG to 11,000rpm, efficiency 10%.
Examine fan curve operating point; NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 At 330 minutes: Shut down No 1 fan; fan louvre doors closed R=10.

Step 8 At 360 minutes: Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip A Heading Emergency Door R=10
Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 9 Shut down No 3 fan; fan louvre doors open
Close Portal Dip B Heading Emergency Door R=10

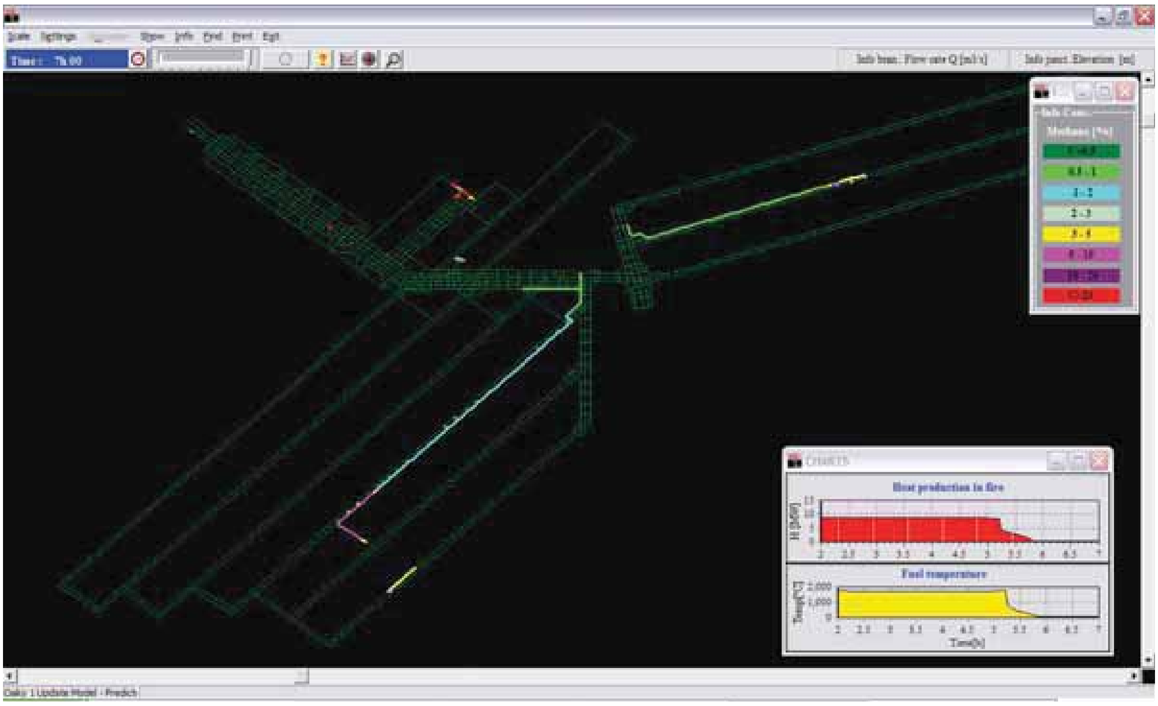


Figure 9.2 Methane distribution after 420 minutes.

Summary *With GAG running Fire intensity insignificant at 7 hours and oxygen level outbye fire at less than 2.6 percent. No ventilation air reversal occurred across the fire.*

9.3. Oaky Creek No 1 Fire Scenario 3A

Scenario *In the "C" main dips at bottom of main dips at the C5-C6 (belt drive head area), hydraulic oil has caught on fire. SE04 Drivehead - Main Dips C5-C6 - Belt Drivehead area which is segregated.*

Changed Inertisation Strategy**:** *GAG docked on Portal Dip C heading.*

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

- Initiation of GAG at Portal Dip C Heading.
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 5 minutes

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.
Smoke reaches Longwall face at 37 minutes; Smoke reaches MG26 face at 37 minutes
Smoke reaches MG25 face at 45 minutes

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$.

East Main CO concentration is less than 50ppm throughout, except C heading

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning.

Commence GAG control action; GAG has been set up at portal C entry. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.
Examine fan curve operating point NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 After 330 minutes Shut down No 1 fan; fan louvre doors closed R=10.

Step 8 After 360 minutes Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip A Heading Emergency Door R=10

Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 9 After 390 Shut down No 3 fan; fan louvre doors open
Close Portal Dip B Heading Emergency Door R=1

Localised reversal occurs

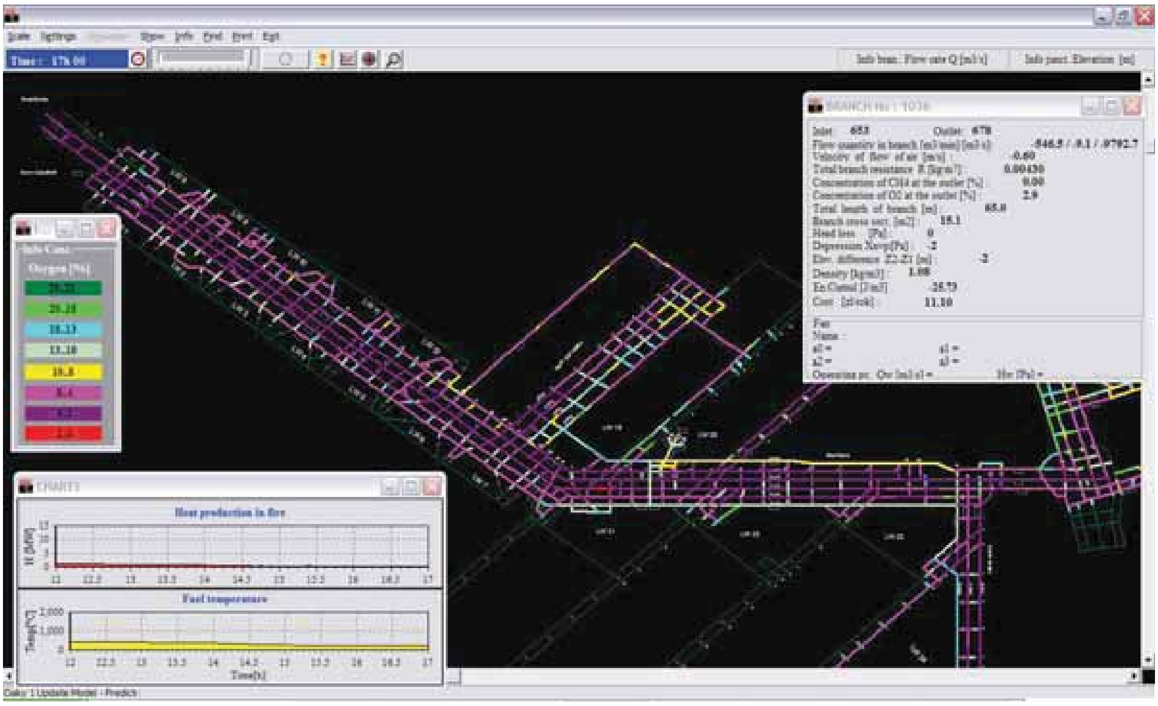


Figure 9.3 Oxygen distribution after 1020 minutes.

Summary *With GAG running Fire intensity insignificant at 17 hours and oxygen level outbye fire at less than 2.9 percent.*

9.4. Oaky Creek No 1 Fire Scenario 6A

Scenario *Fire on LW 24 face at mid point caused by friction ignition of methane igniting coal.*

Changed Inertisation Strategy**:** *GAG docked on Portal Dip B heading.*

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

- Initiation of GAG at Portal Dip B Heading.
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.
- O_2 sensor on LW face 100m from MG and O_2 sensor on LW face 200m from MG; O_2 sensors do not occur in the mine.

Simulation

Step 1 Time 0 – 30 minutes: Methane blower burning. Simulate as 30 litres oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Step 2 Time 30 – 60 minutes: 5 m coal length at mid-longwall, time constant 14,400s, intensity 5, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 32 minutes

Control Fire fighting control commences with water jet, fog and low expansion foam suppressing oil fire.

Step 3 Time 60 – 90 minutes: 20 m entry length coal develops, time constant 14,400s, intensity 5.

Control Fire fighting ineffective within 90 minutes; management decision to change to ventilation control strategies; 30-45 minutes to implement.

Step 4 Time 90 – 240 minutes: 50 m entry length coal develops, time constant 14,400s, intensity 5.

Time 120 minutes: Brattice placed at BSL R=0.2

Control Fire fighting ineffective within 120 minutes; management decision to further change ventilation control strategies; 45 minutes to implement.

Time 165 minutes: Brattice placed Outbye LW equipment, belt dropped R=5

Control Fire fighting ineffective within 165 minutes; management decision to further change ventilation control strategies; 45 minutes to implement.

Time 210 minutes: Brattice placed at first and second CT Outbye LW face R=5

Fire out of control

Control Fire fighting ineffective within 210 minutes; management decision to introduce high flow inertisation – GAG; 120 minutes to implement.

Step 5 Time 240 - 360 minutes: 125 m entry length coal develops, source time constant 14,400s, intensity 5.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 6 Time 360 minutes: Commence GAG control action; GAG has been set up at B Heading Portal Dips and B Heading Emergency Doors closed, R=10

Commence GAG control action; Set GAG to 11,000rpm, efficiency 10%.
Examine fan curve operating point. NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 Time 420 minutes: Shut down No 1 fan; fan louvre doors closed R=10
Close Portal Dip A Heading Emergency Door R=10

Step 8 Time 480 minutes: Shut down No 2 fan; fan louvre doors closed R=10

Concern that too much restriction of air to mine will put face into Coward Triangle.
Check LW face methane situation

Step 9 Time 540 minutes: Turn down No 3 fan to $P_{fan} = 0.25$; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1

Step 10 Time 630 minutes: Shut down No 3 fan; fan louvre doors open

Reversal occurs bringing methane over the fire source however, oxygen level is very low at 3.3% outbye the fire.

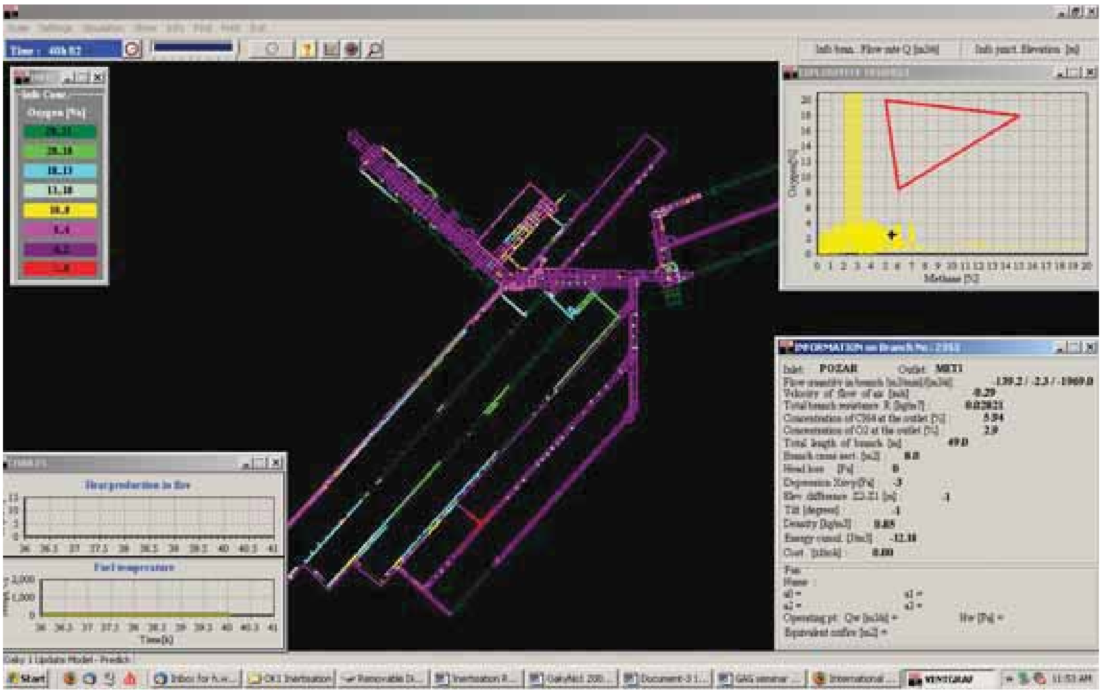


Figure 9.4 Oxygen distribution after 2400 minutes.

Summary *Fire insignificant after 11.5 hrs. New GAG docking position prevents methane explosion. However, reversal of methane at LW face still occurred immediately after the No 3 fan is turned off. Methane laden air had reversed across the fire but with very low levels of oxygen no explosion occurred.*

9.5. Oaky Creek No 1 Fire Scenario 7A

Scenario *LW Goaf Spontaneous Combustion - Longwall 24 Goaf heating. Longwall 24 face currently at 26 ct. Fire located at 27 ct on MG side 40m into goaf.*

Changed Inertisation Strategy**:** *GAG docked on Portal Dip B heading***.**

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

- Initiation of GAG at Portal B Heading.
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW12A at 80 l/s, MG25 at 55 l/s and MG26 at 80 l/s. LW24 seven sources total 230 l/s, 110 l/s on face, four sources of 30 l/s each spaced 20m in from MG Hdg.
- *O_2 sensor on LW face 100m from MG and O_2 sensor on LW face 200m from MG; O_2 sensors do not occur in the mine.*

Simulation

Step 1 Time 0 – 360 minutes: 1 m entry length coal fuel in 18 c/t MG edge of goaf burning; time constant 14400s, intensity 1 $CO:CO_2 = 0.1$. (assume H_2 = CO level); fire very unstable and not under control.

Smoke reaches surface at 39 mins.
CO at TG exceeds 5ppm at 70 mins.

Step 2 Time 360– 720 minutes: 5 m entry length coal burning with gas continuing to burn; time constant 14400s, intensity 2.

Step 3 Time 720 – 1080 minutes: Continue coal fire 25 m entry length coal burning; time constant 14400s, intensity 4.

Step 4 Time 1080 - 1440 minutes: Continue coal fire 100 m entry length coal burning; time constant 14400s, intensity 8. Fire very unstable and not under control

CO concentration at 19 hours sets off alarm at bottom of vent shaft.

Step 5 Time 1440 - 1800 minutes: Continue coal fire 200 m entry length coal burning; time constant 14400s, intensity 10.

Step 6 Time 1450 minutes: Commence GAG control action; GAG has been set up at Portal B entry. Emergency Door closed, R=10; Set GAG to 11,000rpm, efficiency 10%.

Examine all three main fan curve operating points. NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 1510 minutes: Shut down No 1 fan; fan louvre doors closed R=10
Examine No 2 and No3 fan curve operating points

Step 8 1560 minutes: Close Portal Dip A Heading Emergency Door R=10.

Step 9 1620 minutes: Shut down No 2 fan; fan louvre doors closed R=10

*Step 10*1680 minutes: Shut down No 3 fan; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1

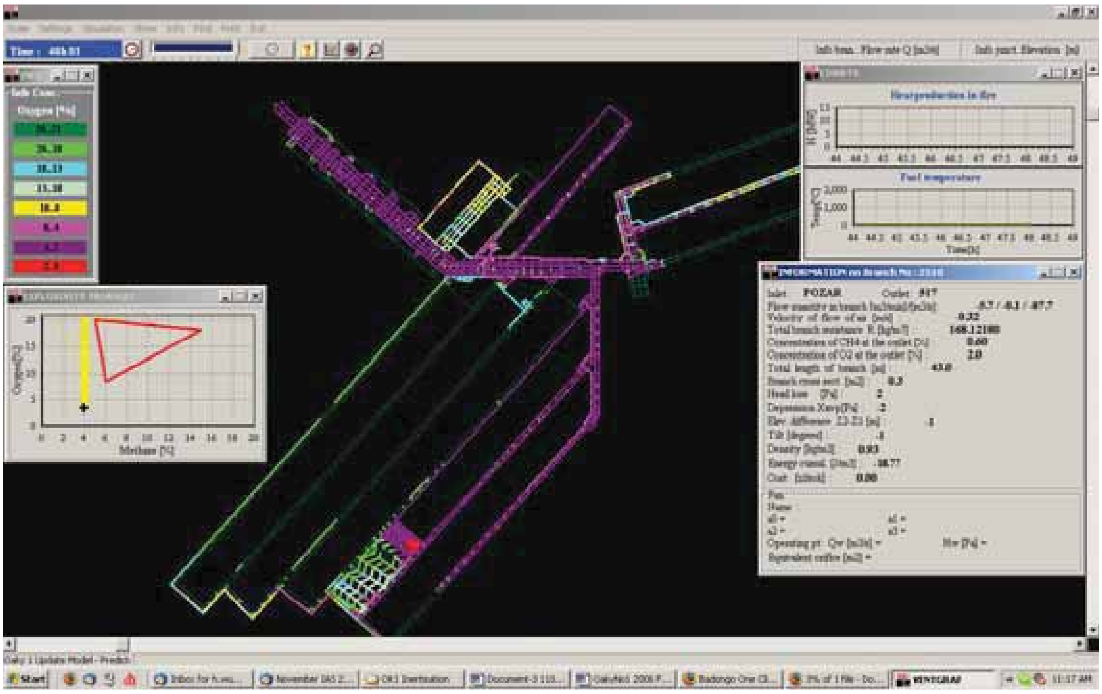


Figure 9.5 Oxygen distribution after 2880 minutes.

Fire substantially reduced without GAG exhaust reaching fire but GAG ensures full extinguishment.

Summary *With GAG running fire intensity insignificant at 48 hours and oxygen level outbye fire at about 0.6 percent. No methane reversal over the fire with new GAG docking position.*

9.6. Oaky Creek No 1 Fire Scenario 9A

Scenario *In the Sandy Creek East Mains D6 to MG26 C1 (belt drive head area), hydraulic oil has caught on fire. MG26 Drivehead - Sandy Creek East Mains D6 to MG26 C1- Belt Drivehead area which is segregated.*

***Inertisation Strategy*:** *GAG on Portal Dip B heading.*

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

- Initiation of GAG at portal B Heading.
- CO gas monitors set at Mains C 9-10ct, C 22-23ct, East Mains C 5a-6ct, South Mains 1-2ct, MG24 Belt 0-1ct, MG24 Belt 16-17ct and MG26 DL. They occur here in the mine.
- CH_4 gas monitor set at MG26 DL.
- Face methane outputs: LW24 at 230 l/s, MG25 at 55 l/s and MG26 at 80 l/s.

Simulation

Step 1 Time 0 – 30 minutes: 30 litres hydraulic oil burning. Simulate 1m length fire over entry width; time constant 120s, intensity 10, $CO:CO_2 = 0.1$. (assume H_2 = CO level).

Smoke reaches surface at 25 minutes

Step 2 Time 30 – 60 minutes: 230 litres cooling oil burning from heat exchanger radiator. Simulate 7m length fire over entry width; time constant 120s, intensity 10.

Smoke reaches Longwall face at 50 minutes

Control Fire fighting control is suppressing oil fire

Step 3 Time 60 – 120 minutes: 230 litres fuel is still burning and 20m length of coal pillar equivalent of 20m additional burning; Simulate 27m length fire over entry width; time constant 120s, intensity 7, $CO:CO_2 = 0.1$. (assume H_2= CO level); fire very unstable and not under control.

Step 4 Time 120 – 300 minutes: all liquid fuel as fire source has been fully consumed. Simulate 50m length coal pillar fire over entry width; time constant 1200s, intensity 6. $CO:CO_2 = 0.1$ (assume H_2 = CO level). Fire very unstable and not under control despite fire fighting attempts.

Fire out of control, withdraw all personnel from mine.

Control Decision made to introduce high flow inertisation – GAG

Step 5 Time 300 – 330 minutes: continue 50 m entry length coal burning. At 300 minutes GAG has been set up at B Heading Portal Dips and B Heading Emergency Doors closed, R=10
Commence GAG control action; Set GAG to 11,000rpm, efficiency 10%.
Examine fan curve operating point. NB Check approach to stall point (Do not allow to stall as program exceeds limitations)

Step 7 After 330 minutes Shut down No 1 fan; fan louvre doors closed R=10.

Step 8 After 360 minutes Shut down No 2 fan; fan louvre doors closed R=10
Close Portal Dip A Heading Emergency Door R=10
Concern that too much restriction of air to mine will put face methane into Coward Triangle. Check LW face methane situation

Step 9 After 390 minutes Shut down No 3 fan; fan louvre doors open
Close Portal Dip C Heading Emergency Door R=1

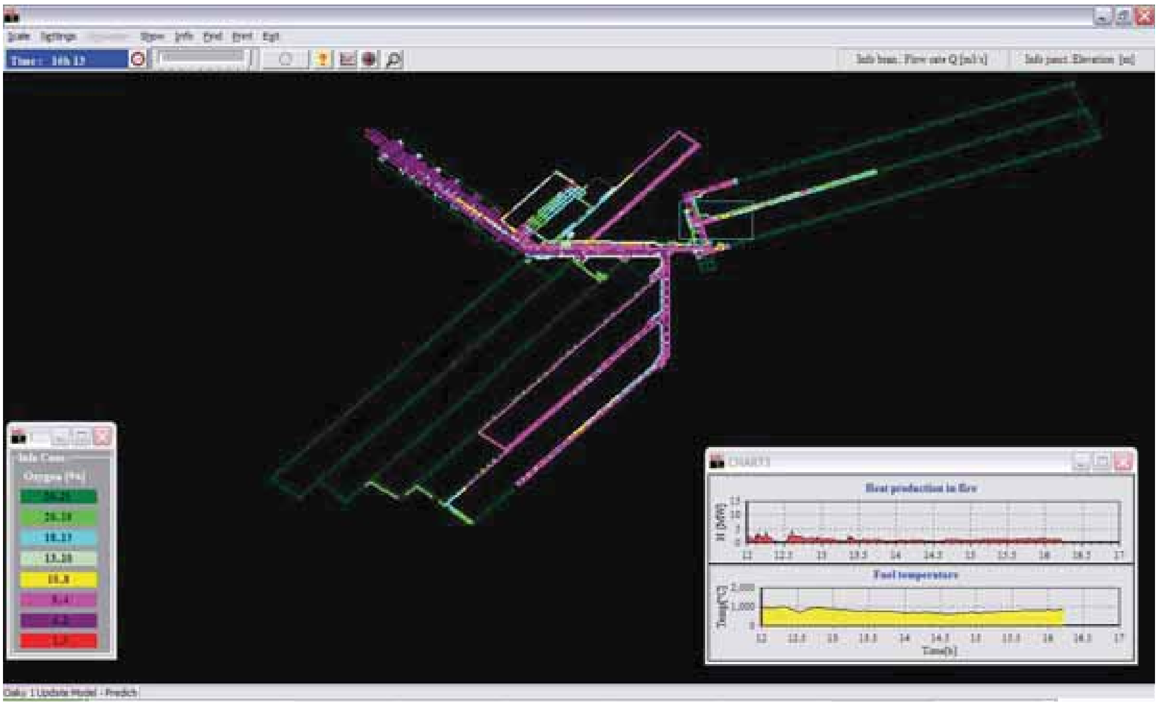


Figure 9.6 Oxygen distribution after 960 minutes.

Summary *Oxygen levels outbye the fire less than 2.9% after 960 minutes, however methane passing across fire with potential to cause explosions. Exhaust reaches fire but with dilution. Fire fluctuating and not reducing in intensity after 16 hrs.*

9.7. Summary of Scenarios Examined and Alternative Inertisation Strategies

A study has examined the potential for simulation of the effects of inertisation on fires within a mine ventilation network. The project involved applying the VENTGRAPH mine fire simulation software to preplan for situations created by mine fires. As an introduction some general conclusions from relevant work undertaken to date at a range of Australian coal mines is discussed.

Priority fire locations at mines with VENTGRAPH simulation models developed in an ACARP research project entitled "Mine Fire Simulation in Australian Mines using Computer Software" have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage. In the study it was assumed that the GAG would be docked at a prepared position designated by the mine (most commonly the current fabricated docking installation). A review of 35 scenarios showed that there was no fire examined that achieved the situation in which GAG docking inerted the simulated fire to aid recovery in a timely manner. Further, only 20 percent of scenarios showed a situation in which the inertisation product went straight to the fire site even though it arrived with significant dilution from other ventilation air or leakage through stoppings.

Other introductory sections examined issues with borehole location and sizing for delivery of GAG output and the influence of stopping leakage on GAG exhaust dilution in parallel intake airways

The principal purpose of this study is examination of Oaky Creek No 1 case study priority fires selected from across the pit layout with five in the mains, two in development panel gateroad, two in a longwall panel and one in the newly formed longwall goaf. GAG inertisation strategies were examined for the ten cases and details of the development of the individual scenarios are set down in chapter 4. Following this in chapter 5 six case scenario studies were re-examined to evaluate whether a better inertisation strategy was possible through GAG relocation to an alternative portal docking station locations to deliver inert gas more directly to the fire site.

Table 9.2 Comparison of inertisation effects between original GAG operation and new segregation and/or GAG Docking Positions

No	Fire Location	Fire Type	GAG Position	Segregation Actions	Fan Actions	Outcomes
1	SE02 Drivehead Main Dips C9-C10	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	Exhaust cannot reach fire until all fans off and air reversal occurs. Fire insignificant after 20 hrs. No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off ***(Category C)***.
1A	SE02 Drivehead Main Dips C9-C10	Oil → Coal	Portal C entry	Intake shaft closed; Close Drift A after #1 and #2 Fans off; Close Drift B after #3 Fan off	Fans turned off one by one	Exhaust reaches fire but with dilution. Fire insignificant at 7 hours. No ventilation air reversal occurred across the fire ***(Category B)***.
2	SE03 Drivehead Main Dips C21-C22	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	Exhaust cannot reach fire until all fans off and air reversal occurs. Fire insignificant after 24 hrs. No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off ***(Category C)***.
2A	SE03 Drivehead Main Dips C21-C22	Oil → Coal	Portal C entry	Intake shaft closed; Close Drift A after #1 and #2 Fans off; Close Drift B after #3 Fan off	Fans turned off one by one	Exhaust reaches fire but with dilution. Fire insignificant at 7 hours. No ventilation air reversal occurred across the fire ***(Category B)***.
3	SE04 Drivehead East Mains C5-C6	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	Exhaust reaches fire but with dilution. Fire insignificant after 17 hrs. No methane reversal across the fire but ventilation air reversal occurred over the fire after all fans turned off ***(Category C)***.
3A	SE04 Drivehead East Mains C5-C6	Oil → Coal	Portal C entry	Intake shaft closed; Close Drift A after #1 and #2 Fans	Fans turned off one by	Exhaust reaches fire but with dilution. Fire insignificant after 17 hrs. No methane reversal across the fire but ventilation air

				off; Close Drift B after #3 Fan off	one	reversal occurred over the fire after all fans turned off ***(Category C)***.
6	LW Friction Ignition Longwall 24 face	Gas → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	Exhaust reaches fire but with dilution. Ventilation air reversal occurred over the fire after all fans turned off. Methane had reversal across the fire and explosion occurred ***(Category E)***.
6A	LW Friction Ignition Longwall 24 face	Gas → Coal	Portal B entry	Close Drift A after# 1 and #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	Fire insignificant after 11.5 hrs. Exhaust reaches fire but with dilution. Ventilation air reversal occurred over the fire after all fans turned off. Methane had reversal across the fire but with very low oxygen level – no explosion occurs ***(Category C)***.
7	LW Goaf Spon Comb LW 24 Goaf heating	Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	Exhaust reaches fire but with dilution. Fire insignificant with all fans off after 48 hrs. Ventilation air reversal occurred over the fire after all fans turned off. Methane had reversal across the fire ***(Category C)***.
7A	LW Goaf Spon Comb LW 24 Goaf heating	Coal	Portal B entry	Close Drift A after# 1 and #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	Exhaust reaches fire but with dilution. Fire insignificant with all fans off after 48 hrs. No ventilation air reversal occurred across the fire ***(Category B)***.
9	MG26 Drivehead Sandy Creek East Mains D6 to MG26	Oil → Coal	Intake Shaft	Close Drift A after #1 Fan off; Close Drift B after #2 Fan off; Close Drift C after #3 Fan off	Fans turned off one by one	With GAG running fire intensity insignificant at 48 hours and oxygen level outbye fire at about 0.6 percent. No methane reversal over the fire with new GAG docking position. ***(Category C)***.
9A	MG26 Drivehead Sandy Creek East Mains D6 to MG26	Oil → Coal	Portal B entry	Intake shaft closed; Close Drift A after #1 and #2 Fans off; Close Drift C after #3 Fan off	Fans turned off one by one	Exhaust reaches fire but with dilution. Fire fluctuating and not reducing in intensity after 16 hrs. Ventilation air reversal occurred over the fire after all fans turned off. Methane had reversal across the fire ***(Category E)***.

9.7.1. Scenario 1

Scenario 1 examined a Mains belt fire at SE02 Drivehead Main Dips C9-C10. It was considered as a situation where inertisation by itself would not help extinguish the fire in the belt heading (Category C) as the GAG was docked at the Downcast Shaft entry connected to D Heading 3 ct on Main dips. The inert gases in this case were travelling alone Main Dips A and E headings and were unable to get into C Heading. Progressive turning off of the three main surface fans did after much time cause the fire to be extinguished through combustion caused reduction of oxygen aided by the addition of inert gases which reach the fire after alteration of the pit ventilation. With fans off seam methane emissions caused gas levels to build up in the panels and although the VENTGRAPH simulation did not show these recirculating across the fire this could be a dangerous situation.

The Scenario 1A reassessment of approaches to improve the inertisation strategy led to the decision to dock the GAG unit at the Portal C Heading entry. This position forced inert gas directly into C Heading and onto the fire and led to a satisfactory outcome (Category B). To avoid dilution portal doors in A and B were progressively closed and to avoid stalling Main surface fans were progressively turning off. As the inert gas pressurised the C Heading directly no ventilation air reversal occurred across the fire after the main surface fans were turned off.

9.7.2. Scenario 2

Scenario 2 examined a Mains belt fire further inbye than Scenario 1 at SE03 Drivehead Main Dips C21-C22. It was considered as a situation where inertisation by itself would not help extinguish the fire in the belt heading (Category C). The GAG was docked at the Downcast Shaft entry connected to D Heading 3 ct on Main dips. As a result the inert gases were travelling inbye along Main Dips A and E headings and couldn't get into C heading where the fire was. Progressive turning off of the three main surface fans did after much time cause the fire to be extinguished through combustion caused reduction of oxygen aided by the addition of inert gases which reach the fire after alteration of the pit ventilation. With fans off seam methane emissions caused gas levels to build up in the panels and although the VENTGRAPH simulation did not show these recirculating across the fire this could be a dangerous situation.

The Scenario 2A was a reassessment of approaches to improve the inertisation strategy by docking the GAG unit at the Portal C Heading entry. This position could introduce inert gas directly into C Heading and onto the fire and led to a more satisfactory outcome (Category B). To avoid dilution portal doors in A and B were progressively closed and to avoid stalling Main surface fans were progressively turning off. As the inert gas pressurised the C Heading directly, no ventilation air reversal occurred across the fire after the main surface fans were turned off.

9.7.3. Scenario 3

Scenario 3 examined a Mains belt fire at SE04 Drivehead in East Mains C5-C6. It was considered as a situation where inertisation by itself would not help extinguish the fire in the belt heading (Category C) as the GAG was docked at the Downcast Shaft entry connected to D Heading 3 ct on Main dips. Under this situation the inert gases were unable to get into C Heading but travelled inbye along Main Dips A and E headings. Progressive turning off of the three main surface fans did after much time cause the fire to be extinguished through combustion caused reduction of oxygen aided by the addition of inert gases which reach the fire after alteration of the pit ventilation. With fans off seam methane emissions caused gas levels to build up in the panels and although the VENTGRAPH simulation did not show these recirculating across the fire this could be a dangerous situation.

The Scenario 3A reassessment of approaches to improve the inertisation strategy led to the decision to dock the GAG unit at the Portal C Heading entry. It was hoped that this position could inject inert gas directly into C Headings and onto the fire. However, as segregations along C Heading was not completed at the last cut-through of Mains and the first cut through of East Mains, the inert gas was diluted and not able to deliver to a satisfactory outcome. To avoid dilution portal doors in A and B were progressively closed and to avoid stalling Main surface fans were progressively turning off. No improvement in the outcome (Category C) resulted from the new docking position.

9.7.4. Scenario 6

Scenario 6 examined a fire on LW 24 face at mid point caused by friction ignition of methane igniting coal. It was considered as an inertisation failure (Category E) in that use of the GAG did not cause stabilisation of the fire. Dilution of inert exhaust at pit bottom means little low oxygen air will effectively reach the fire. Progressive turning off the three main surface fans led, after 9 hours, to reversal of face air carrying explosible concentrations of methane over the fire which caused a large explosion.

Scenario 6A reassessment of approaches to improve the inertisation strategy led to the decision to dock the GAG unit at the Portal B Heading entry. This position could introduce inert gas through a more direct route into LW panel and onto the fire. To avoid dilution portal doors in A and C were progressively closed and to avoid stalling Main surface fans were progressively turning off.

Ventilation air reversal occurred over the fire after all fans were turned off. Methane had reversed across the fire but with very low oxygen levels no explosion occurs. The new GAG docking position prevented a potential methane explosion with a slight improvement in the outcome (Category E).

9.7.5. Scenario 7

Scenario 7 examined a spontaneous combustion fire in the longwall panel goaf on the MG side about 40m back from the face. It was considered as a situation where inertisation by itself would not help extinguish the fire in the goaf (Category C). Progressive turning off of the three main surface fans did after much time cause the fire to be extinguished through combustion caused reduction of oxygen aided by the addition of inert gases which reach the fire after alteration of the pit ventilation. With fans off seam methane emissions caused gas levels to build up in the panels to produce a minor methane burnoff and although the VENTGRAPH simulation did not show these recirculating across the fire this could be a dangerous situation.

Scenario 7A reassessment of approaches to improve the inertisation strategy led to the decision to dock the GAG unit at the Portal B Heading entry. This position could introduce inert gas through a more direct route into the LW panel and led to a more satisfactory outcome (Category B). To avoid dilution portal doors in A and C were progressively closed and to avoid stalling Main surface fans were progressively turning off.

Fire substantially reduced without GAG exhaust reaching the fire in the goaf but use of the GAG ensures full extinguishment.

9.7.6. Scenario 9

Scenario 9 examined a panel belt fire at MG26 Drivehead Sandy Creek East Mains D6 to MG26. It was considered as an inertisation failure (Category C) with the GAG was docked at Downcast Shaft entry connected to D Heading 3 ct on Main dips as the fire was not stabilised. The use of the GAG did eventually cause stabilisation of the fire. Progressive turning off of the three main surface fans did in time cause the fire to be reduced in intensity but not extinguished through combustion caused reduction of oxygen aided by the addition of inert gases. Seam methane emissions caused gas levels to build up in the panels however these did not recirculate across this Mains located fire.

The Scenario 9A reassessment of approaches to improve the inertisation strategy led to the decision to dock the GAG unit at the Portal B Heading entry. It was hoped that this position could inject inert gas more directly onto the fire. To avoid dilution portal doors in A and C were progressively closed and to avoid stalling Main surface fans were progressively turning off.

Ventilation air reversal still occurred over the fire after all fans were turned off. Methane had reversed across the fire but with very low oxygen levels no explosion occurs. No improvement in the outcome (Category E) resulted from the new docking position as the inert gas was mixed and diluted in the same way as Scenario 9 with the GAG docking at the Downcast shaft.

9.8. Conclusion and Recommendations

The principal focus of this study of inertisation strategies has been to examine priority fire locations and best approaches to stabilising of fires with availability of GAG inertisation. It was determined that Oaky Creek No 1 Mine has a mine layout under which some improvements could be made to inertisation strategies in the event of a major fire

Based on the results from the simulation actions described in Chapter 8 some scenarios under which an improved strategy was considered possible have been re-simulated with new approaches to inertisation. Outcomes for these re-simulated alternative scenarios were compared with the original simulation results as described in previous sections. A summary of the comparisons is shown in Table 9.3.

The approach taken to improve the effectiveness of the existing mine inertisation situation in the underground ventilation network was to try alternative Portal docking station locations through use of existing ventilation structures. It was assumed that men would be out of the mine and it would not be possible to change underground ventilation structures to alter or improve inertisation. It was also assumed that it would not be possible to drill new boreholes to intersect workings in event of a fire or to use the upcast shaft. The best inertisation strategy as determined from alternative simulation exercises for the six priority fire locations are summarised in Table 9.3.

Fire Number 1 gave an outcome in which this Mains fire was stabilised by docking the GAG to the Drift C Portal. Adjacent intake airways namely the Intake shaft and Drift A and B were progressively sealed as main fans were shut down. This approach allowed inertisation exhaust to move directly to the fire source although there was some dilution. Turning off all fans poses high risk issues in a gassy mine; however in this scenario the fire is in the Mains and so panel flow reversals of methane laden air was not presented as an issue. With GAG running, fire intensity was insignificant at 7 hours (2 hours after starting the GAG) and oxygen level outbye fire at less than 2.5 percent. No ventilation air reversal occurred across the fire.

Fire Number 2 gave a very similar outcome to Fire Number 1. This Mains fire was stabilised by docking the GAG to the Drift C Portal. With GAG running, fire intensity was insignificant at 7 hours (2 hours after starting the GAG).

Table 9.3 Summary of optimum outcomes for the six fire simulation revised exercises

No	Fire Location	Fire Type	GAG Location	Fan Action	Outcome	Category
1	SE02 Drivehead Main Dips C9-C10	Oil → Coal	Intake Shaft	All shut down	Fire stable at 20 hours, fire fumes over fire possibility.	C
1A	SE02 Drivehead Main Dips C9-C10	Oil → Coal	Portal C entry	All shut down	Fire stable at 7 hours.	B
2	SE03 Drivehead Main Dips C21-C22	Oil → Coal	Intake Shaft	All shut down	Fire stable at 24 hours, fire fumes over fire possibility.	C
2A	SE03 Drivehead Main Dips C21-C22	Oil → Coal	Portal C entry	All shut down	Fire stable at 7 hours.	B
3	SE04 Drivehead East Mains C5-C6	Oil → Coal	Intake Shaft	All shut down	Fire stable at 17 hours, fire fumes over fire possibility.	C
3A	SE04 Drivehead East Mains C5-C6	Oil → Coal	Portal C entry	All shut down	Fire stable at 17 hours, fire fumes over fire possibility.	C
6	LW Friction Ignition Longwall 24 face	Gas → Coal	Intake Shaft	All shut down	Reversal, gas explosion	E
6A	LW Friction Ignition Longwall 24 face	Gas → Coal	Portal B entry	All shut down	Fire stable at 11.5 hours, methane over fire possibility.	E
7	LW Goaf Spon Comb LW 24 Goaf heating	Coal	Intake Shaft	All shut down	Fire stable at 48 hours, fire fumes over fire possibility.	C
7A	LW Goaf Spon Comb LW 24 Goaf heating	Coal	Portal B entry	All shut down	Fire stable at 48 hours.	B
9	MG26 Drivehead Sandy Creek East Mains D6 to MG26	Oil → Coal	Intake Shaft	All shut down	Fire unstable at 12 hours and not extinguishing.	C
9A	MG26 Drivehead Sandy Creek East Mains D6 to MG26	Oil → Coal	Portal B entry	All shut down	Fire unstable at 16 hours and not extinguishing. Methane over fire possibility.	E

Fire Number 3 on first appearance gave a similar outcome to Fires Number 1 and 2. Again this Mains fire was stabilised by docking the GAG to the Drift C Portal. With GAG running, fire intensity was insignificant at 17 hours (12 hours after starting the GAG). The difference was substantial air came in the belt heading and caused dilution which slowed the inertisation exercise. Also ventilation air reversed across the fire after all fans were off which is potentially dangerous. Further segregation of the belt heading progressively down dip should overcome these dilution and belt air reversal issues.

Scenario 6 examined a fire on LW 24 face at mid point caused by friction ignition of methane igniting coal which with progressive turning off of the three main surface fans led to reversal of face and a large explosion. The new inertisation strategy of docking the GAG unit at the Portal B Heading entry introduced inert gas through a more direct route into the LW panel and onto the fire but still led to a not fully satisfactory outcome. Again progressive improvements in sealing Mains belt headings will allow less dilution of inert carrying air.

This fire is a long way from the GAG docking point and so inertisation under this scenario will be difficult. The new GAG docking position was an improvement and reduced chance of a potential methane explosion.

Fire Number 7 examined how a longwall spontaneous combustion goaf fire could be stabilised. With the original inerting docking point and fans off gas levels built up in the panel and atmospheric recirculation across the fire could have led to a dangerous situation. Docking the GAG unit at the Portal B Heading entry introduced inert gas through a more direct route into the LW panel and led to a more satisfactory outcome with the GAG ensuring full extinguishment.

Scenario 9 examined a panel belt fire at a considerable distance from the mine Portals. This was deemed an inertisation failure, as the fire was not stabilised. The reassessment led to the decision to dock the GAG unit at the Portal B Heading entry. It was hoped that this position could inject inert gas more directly onto the fire. No improvement in the outcome resulted from the new docking position with an unstable situation persisting.

In conclusion these ten fire simulation exercises have produced scenario results in three categories:

1. Those in which satisfactory inertisation can be achieved from use of the mine’s current single docking point at the Main Intake Shaft. This applies to Scenarios 4, 5, 8 and 10.
2. Those in which a better and satisfactory inertisation strategy can be achieved from use of a docking point other than the Main Intake Shaft. This applies to Scenarios 1, 2 and 7. The other alternatives for docking were the Main Drift Headings B or C. It is recommended that GAG docking stations should in future be fabricated for all ventilation intake openings to the mine and currently for Drift Headings B and C.
3. Those in which an unsatisfactory inertisation outcome is achieved from use of the Main Intake Shaft and where the alternative reappraisal led to an unsatisfactory outcome. This applies to Scenarios 3, 6 and 9. Investigations which were outside the scope of this report could be undertaken for these three Scenarios to determine whether use of another access point to the mine, namely a specially excavated borehole would provide a satisfactory inertisation outcome.

Oaky No 1 mine has all current intake air portals close together. This means that some parts of the mine with active workings are at considerable distance from inertisation docking points on access intake airways. Strategically placed boreholes near active workings where priority fires may occur can be placed to advantageously allow inertisation when required.

It is recommended that Oaky No 1 mine examine how use of boreholes or other approaches could effectively allow satisfactory inertisation of priority fires locations used in Scenarios 3, 6 and 9.

General recommendations arising from the analyses are as follows:

1. GAG docking stations should be fabricated for all ventilation intake openings to the mine. The existing apparatus at the Main Intake Shaft should be supplemented by docking points at the Drift Headings and any future pit boreholes of appropriate diameter and future main shafts. In effect each docking point can deliver to a restricted geographic zone within the pit; multiple points allow the appropriate point to be utilised.
2. Segregation strategies simulated at points along the various Mains have shown that distribution of inert gases to separate Mains headings can be improved. Current segregation is less effective for fires located a long way inbye the mine and in the longwall production and development panels (due to increasing dilution through stoppings).
3. It is recommended that a borehole with a diameter of at least 1 m should be considered at the beginning of each panel for potential delivery of inert gases to each longwall production or development face. These boreholes can also be used for other purposes such as delivery of ballast or emergency extrication of people out of the mine. They may be used for other services. Incorporation of remote controlled doors should be considered to give control over which gateroad should be used to carry the inert gases into the panel.
4. Scenarios in which no satisfactory inertisation strategy was apparent should be further examined to determine the merits of locating a borehole or shat in the vicinity to enable satisfactory outcomes.

These fire simulation exercises have demonstrated that it is possible to efficiently evaluate possible inertisation strategies appropriate to a complex mine layout extracting a gassy seam and determine which approach strategy (if any) can be used to stabilise a mine in a timely fashion.

To support the report's main findings some discussions on borehole delivery of inert gases and aspects of Mains segregation have been included. Some considerations for selecting the best surface portal location placement for the inertisation unit for most efficient suppression of a fire have been examined. There is a brief examination of the possibility of a wider and proactive application of GAG in Australian mines responding to or recovering from mine fires or spontaneous combustion heatings or elimination of the potential explosibility of newly sealed goafs is examined. The primary focus here is on systems involving delivery of GAG exhaust through docking to surface boreholes connecting into underground workings. Attainable designs for panel boreholes and how GAG docking to boreholes can improve delivery of GAG exhaust are discussed. Introduction of inert gases can present difficult emergency management decision making. 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?

Mine fires and heatings are recognised across the world as a major hazard issue. New approaches allowing improvement in understanding their use of inertisation techniques have been examined. The outcome of the project is that the mining industry is in an improved position in their understanding of mine fires, use of inertisation and the use of modern advances to preplan for the handling of possible emergency incidents.

10. PROACTIVE USE OF THE GAG INERTISATION UNIT USING MINE BOREHOLES

10.1. INTRODUCTION

The potential use of appropriately sized boreholes to deliver inertisation output directly to a fire or heating has advantages. An analysis has been undertaken of design considerations for varying diameter and depth boreholes taking into account backpressure considerations inherent in fluid flow through relatively small diameter borehole airways. This exercise examines the relevant theoretical thermodynamic theory required to understand flow behaviour in systems involving borehole delivery of GAG exhaust through docking to pre-drilled surface boreholes into underground workings. The study examines attainable designs for panel boreholes and how GAG docking to boreholes can improve delivery of GAG exhaust through a mine ventilation network.

10.2. Inertisation Through Boreholes

Economic installation of well placed boreholes could allow the proactive use of larger inertisation units such as the GAG in a wider application in Australian mines responding to or recovering from mine fires or spontaneous combustion heatings, the elimination of the potential explosibility of newly sealed goafs or in the making safe of old mine workings prior to final sealing.

Australian coal mines have experienced significant goaf heatings or goaf fires in recent years. Incidents at mines such as Dartbrook in 2002 and 2005/06, Austar in 2003/04, Moranbah North in 2004, North Goonyella in 2004/05 and Newstan in 2005/06 have caused significant loss of production time and in some cases mine reserves. Mine inertisation approaches relying on use of the Mineshield, Nitrogen Pressure Swing Adsorption (Floxal) and Tomlinson Boiler units have been used in these Australian recent mine incidents involving goaf heating. The low output of 2 m^3/s or less of these units has limited their success. The GAG has the ability to supply a much higher output at an operating cost advantage but has not been considered to date for these applications due to inability to deliver the inert exhaust to the affected area.

There is potential for an increased role for the GAG built on experience gained in the use of the GAG and other inertisation units in recent years. This can encompasses

- How GAG docking to boreholes can improve delivery of GAG inert gases to high priority potential fire locations particularly in working panels.
- How GAG docking to boreholes can be used to economically inert goaf spontaneous combustion incidents. More than five Australian collieries has experienced major goaf

heatings in recent years and the small inert gas units have not been of sufficient capacity.

- How GAG docking to boreholes can be used to inert goafs on sealing to avoid explosible atmospheres and movement of atmospheres into the "Coward Triangle".

Boreholes placed within panels or more remote areas of mine workings have the capability of being used to deliver inert gases to nearby fires and so aid in mine recovery. Since the early 1990s drilling of boreholes through the overburden overlying worked underground seams has come a long way. Some major challenges with unstable strata have been overcome and a number of drilling companies service the market. Many collieries currently utilise one or more boreholes for ventilation or road base delivery purposes. Boreholes can also be used for man escape or delivery of GAG inert flow if necessary.

The challenge faced is how to effectively design these holes cost efficiently. The GAG has capability of delivering an exhaust stream of about 20 m^3/s although some of this is water vapour that quickly drops out of the air stream. There are limits to delivery of GAG output through different diameter holes at varying depths. Deeper holes naturally require larger diameter openings to overcome back pressure. Some require very large diameter boreholes of greater that 1.5 m that are prohibitively expensive.

Inertisation exhaust flow in deeper or smaller diameter holes faces significant back pressure. What is needed is a variable pressure fan that can be placed in line with the GAG flow and overcome substantial back pressure to allow holes of economical dimensions to be utilised.

A primary requirement is to examine attainable designs for panel boreholes under Australian conditions with current drilling technology. Part of this is to calculate design considerations for a variable pressure fan that can assist flow against back pressure. There is a limit to the contribution a variable pressure fan can make to assist flow. An objective will be to define the

- Hole designs (diameters and depths) that can deliver directly without assistance of any fan,
- Hole designs that can deliver with assistance of a fan and the pressure required for this delivery to be attained, and
- Specifications of boreholes design parameters that cannot achieve delivery even with fan assistance.

Inertisation users in Australia and in particular GAG operators such as Mines Rescue organisations need the answers to these questions for future planning. In particular detailed designs are needed by operating mines. Borehole drilling into operating mines has become common place in recent years and designs that allow multiple use for ventilation requirements, delivery of road base, potential man escape and delivery of inert gases provide a step forward for the industry. A systems involving borehole delivery of GAG exhaust is set out in Figure 10.1.

Development of such a system needs enhanced engineering understanding in a number of areas.

- Borehole design parameters need to be established applicable to Australian conditions based on the complex fluid flow theory that describes the dynamic, hot, pressurised exhaust carrying a superheated vapour. To investigate the possibility of using GAG in small diameter boreholes for either production inertisation or fire fighting purposes, it is necessary to understand GAG exhaust fluid behaviour. Steady flow energy equation based on Bernoulli's equation made applicable to compressible flow can be put in a form to describe the behaviour of GAG exhaust fluid being pushed down the borehole. Work needed to overcome resistance to flow exiting the GAG outlet can be evaluated as *Work to handle any issues of energy loss due to compression, work to overcome frictional rubbing drag on outlet walls, work to overcome shock losses, work to overcome elevational buoyancy effects and finally work to overcome water vapour super heating issues.* In the system of passing GAG exhaust down mine boreholes all components will be additive. These can be put in the form of an equation

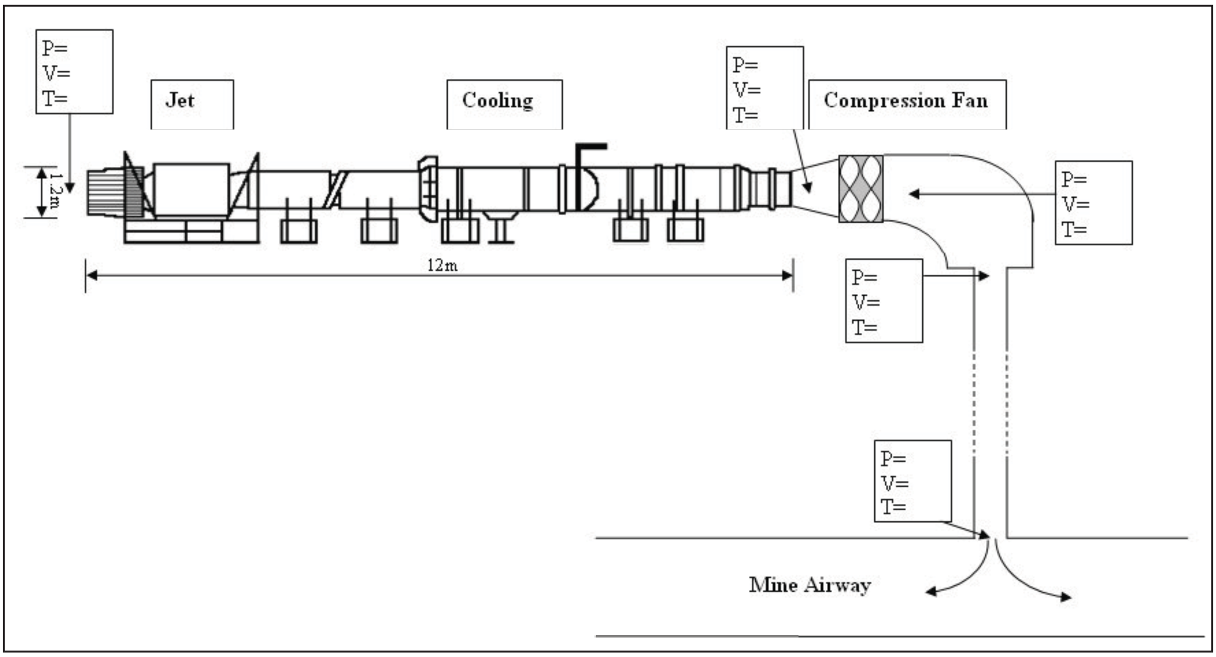


Figure 10.1 Schematic of system comprising GAG unit and compressor fan for borehole delivery

$$W_{12} = \int_1^2 VdP + F_{12} + \left(\frac{u_1^2 - u_2^2}{2} \right) + (z_1 - z_2)g + \text{superheat effects}$$

Where W = Work to achieve flow, VdP = Compression Work, F_{12} = Friction Impedance to fluid passing through pipe, u_1, u_2 = Fluid velocity terms, z_1, z_2 =

Elevation terms. Each component in the equation can be established separately by knowing various fluid flow conditions or parameters.

A discussion on some of the fundamentals of the thermodynamic theory pertinent to the operation of this system of a GAG engine, borehole delivery and assisting compressor fan is briefly set out in the following section.

- Determinations need to be made of the relationships between borehole back pressure and GAG thrust relationships.
- Determinations of the best variable pressure fan design that can be coupled to the system to overcome bask pressure need to be made.
- Determinations of how a variable pressure fan can be powered either through external sources or by direct coupling to the jet engine and utilisation of its potential power need to be made.
- Designs for automation of GAG operations need to be made. The GAG-3 gas turbine is a thrust engine and as such can be used against pressure for inertisation through a reduced diameter borehole. To accomplish this aim the GAG-3 has to be electronically controlled with spare I/O capacity for butterfly valve and proportional control on a tee piece in the exhaust delivery duct. The control system needs to react to duct pressure measurement input and output PID control of the engine rpm and afterburner fuel flow with dynamic measurement of backpressure against the turbine section.
- Mine layout and application of inert gases to fire or heating or to keep sealed area atmospheres out of the explosive range need to be considered. Any use of the GAG must examine its interaction with the complex ventilation behaviour underground during a substantial fire. VENTGRAPH simulation can be used to examine critical issues which include location of the GAG and boreholes for high priority fires or other issues, design dimensions of borehole or other passages required to deliver inert gases and back pressure issues, time required for inertisation output to interact with fire or other issues, effects of seam gas on fire behaviour with inertisation present, changes that can be safely made to the ventilation system during inertisation including switching off of some or all fan, and spontaneous combustion time frame issues.

10.3. Understanding GAG Exhaust Fluid Behaviour Down A Borehole

To investigate the possibility of using GAG in small diameter boreholes for either production inertisation or fire fighting purposes, it is necessary to understand GAG exhaust fluid behaviour.

The GAG-3A jet engine has ability to deliver a thrust of approximately 10 kN. This is effectively a pressure delivery of about 2 MPa. The GAG jet is set up to operate safely with effectively no thrust This is achieved by allowing exhaust to exit the unit across the full crow section of the outlet and there is no contraction to build up pressure. This works well when the GAG is delivering into a large cross section mine airway which creates little backpressure. This can be considered as free flow from the isolated GAG engine.

The discussion that follows has been developed to illustrate in a simplified form the major aspects that need to be considered in delivering jet exhaust down a borehole or through any passageway that creates significant back pressure. The analysis has introduced a compressor fan to assist motivation of the flow through the borehole. However this could as effectively be achieved by harnessing some of the potential thrust that the jet is capable of delivering in its normal mode of doing “real work” in powering an aircraft. The effects of the super heating on the system will vary with a number of conditions and need to be investigated further.

Steady flow energy equation based on Bernoulli’s equation made applicable to compressible flow can be put in a form to describe the behaviour of GAG exhaust fluid being pushed down a borehole. Work needed to overcome resistance to flow exiting the GAG outlet can be evaluated as Work to handle any issues of energy loss due to compression In the example this is simplifies as work associated with passage through a compressor fan), work to overcome frictional rubbing drag on outlet walls, work to overcome shock losses, work to overcome elevational buoyancy effects and finally work to overcome water vapour super heating issues. Depending on the configuration of the outlet conduit these components may not all be additive. However in the system of passing GAG exhaust down mine boreholes all components will be additive. These can be put in the form of an equation. A systems involving borehole delivery of GAG exhaust is set out in Figure 10.2.

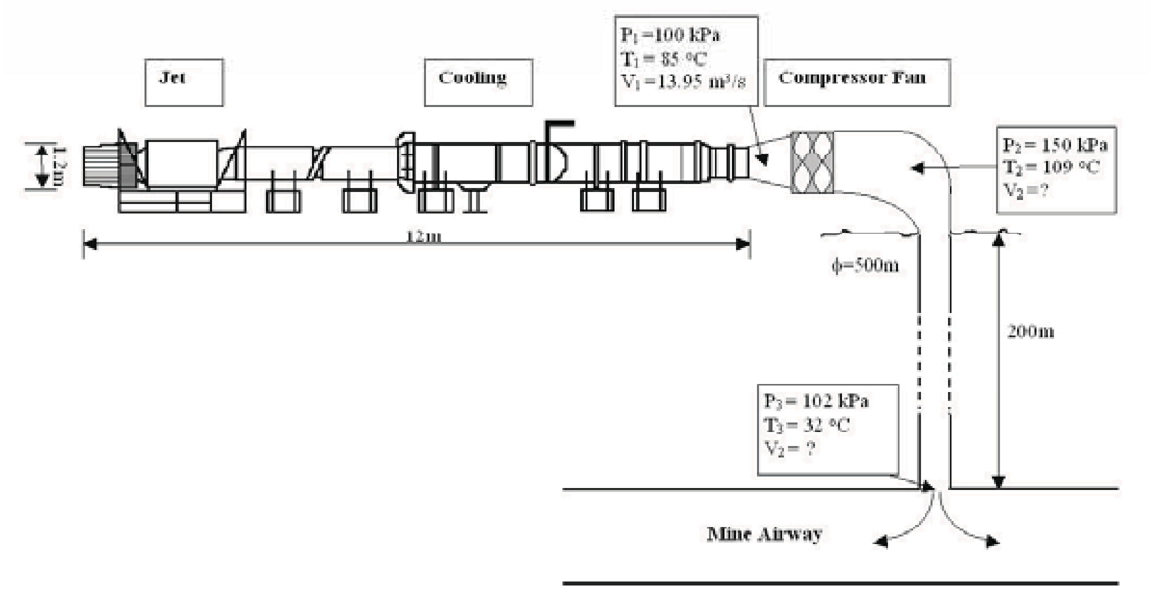


Figure 10.2 Schematic of GAG unit and compressor fan for borehole delivery.

$$W_{23} = \int_{2}^{3} VdP + F_{23} + \left(\frac{u_2^2 - u_3^2}{2} \right) + (z_2 - z_3)g + \text{superheat}$$

(A derivative of McPherson, 1993 Equation 3.25, page 60)

where W_{23} = Work to achieve flow down the borehole, J/kg

VdP = Compression Work by compressor fan

F_{23} = Friction Impedance to fluid passing through pipe
u_2, u_3 = Fluid velocity terms, Shock loss
z_2, z_3 = Elevation terms
plus Superheated moisture energy.

(Superheated moisture energy may be important. This accounts for latent heat energy changes when steam is formed at the water boiling point (boiling point varies with the exhaust flow atmospheric pressure at the specific point). Superheated steam energy will be of greater importance under conditions when the exhaust mixture is forced through small diameter openings due to compression effects. This analysis has not gone into a detailed analysis of the mathematics of this energy transformation process).

10.3.1. The Fluid under Analysis - GAG output behaviour

Assume the GAG is operated at 7,200 rpm. From GAG operating information (Urosek, et al, 2004) as set down in Chapter 2, the GAG jet engine under free flow operating conditions will generate 13.95 m^3/s exhaust gas (0.5-2% O_2, 80-85% N_2, 13-19% CO_2) at 85°C and atmospheric pressure of 100 kPa. Under this situation there is a requirement for 5.48 kg/s inhaled air, a consumption of 17 litres per minute of Jet A1 fuel (sg. 0.80 kg/m^3) and a mixing with the cooling water at a rate of 7.5 l/s (or 7.5 kg/s). A mass balance of the GAG system is as follows. Inputs to the GAG are

- Air - 5.48 kg/s
- Jet A1 fuel - 0.017 $m^3/min \div 60s \times 0.8\ kg/m^3 = 0.23\ kg/s$
- Mixed cooling water - 7.50 kg/s

Thus the total inputs mass is 13.21 kg/s.

Output from the GAG is 13.95 m^3/s at 85°C saturated conditions and atmospheric pressure of 100 kPa. Total output mass can be calculated by examination of psychometric properties as follows.

At outlet measurement point:

Saturated Vapour Pressure, P_{WS} $= 0.6105\ \mathrm{Exp}\ (17.23 \times T_{WB}/(237.3 + T_{WB})$
$= 0.6105\ \mathrm{Exp}\ (17.23 \times 85/(237.3 + 85)$
$= 58.04$ kPa

Apparent Specific volume, ASV $= 287.23 \times (T_{DB} + 273.15)/(P - P_{WS})$
$= 287.23 \times (85 + 273.15)/(100{,}000 - 58{,}040)$
$= 2.45\ m^3/kg$

Mass flow of dry air, m_a $= 13.95/2.45$
$= 5.69$ kg/s

True Density, ρ $= (P - 0.378\ P_W)/(287.23 \times (T_{DB} + 273.15))$
$= (100{,}000 - 0.378 \times 58{,}040)/(287.33 \times (85 + 273.15))$
$= 0.759\ kg/m^3$

Moisture content, r = 0.622 × $P_{WS}/(P - P_{WS})$
= 0.622 × 58.04/(100,000 – 58,040)
= 0.860 kg/kg
Mass flow rate, m = 13.95 × 0.759
= 10.58 kg/s

This mass flow includes approximately 5.69 kg/s of dry air and 4.89 kg/s of water vapour which is added by the direct contact of water for cooling of the exhaust gas. There is an imbalance of (13.21 - 10.58 = 2.63) kg/s in the system. This imbalance is caused by the excess liquid) water droplets carried over in the exhaust (and into the mine) from the mixing cooling water. Therefore, a breakdown of the GAG exhaust gas can be arrived at as follows.

- Exhaust gas - 5.69 kg/s
- Water vapour - 4.89 kg/s
- Excess water droplets carried over - 2.63 kg/s

The excess water droplets in the exhaust would in part be super heated under compression conditions during the GAG exhaust down a borehole The following sections attempt to establish some understanding of the different components in the system delivering GAG exhaust down a borehole.

1. To Establish Work under Compression

$$W = \int_1^2 VdP = R(T_2 - T_1)\frac{\ln\left(P_2/P_1\right)}{\ln\left(T_2/T_1\right)} \qquad \text{J/kg, (McPherson, 1993 Equation 3.73)}$$

Now from Figure 1 GAG Diagram, to establish Work change from Points 2 to 3 and assuming the use of a Compressor Fan of output = 50 kPa

If P_2 = 100 kPa (Atm) + 50 kPa (Comp Fan ΔP)
P_3 = 100 kPa (Atm) + (Pressure at depth)
R = Universal gas constant (From McPherson, 1993 table, Page 62) = 368.7

From General Gas Equation: $\frac{V_1}{V_2} = \frac{P_2}{P_1}\frac{T_1}{T_2}$ thus $\frac{T_3}{T_2} = \left(\frac{P_3}{P_2}\right)^{1-\frac{1}{n}}$

$\therefore T_3 = (273 + 85)\left(\frac{150}{100}\right)^{1-\frac{1}{1.2}}$ and Assuming Polytropic Conditions n = 1.2

$\therefore T_3 = 109°C$

$$\int_2^3 VdP = 368(109-85)\frac{\ln\left(150/100\right)}{\ln\left(109/85\right)}$$

$$= 368\times(24\times 6.15)$$

$$= 54.31 \text{ kJ/kg}$$

Work required is 54.31 kJ/kg × 10.62 kg/s = 576.77 kW

2. Friction Impedance in Descending Borehole

Assume Lines borehole $\phi = 500$mm with a depth = 200m
Now pressure loss for compressed air in a pipe (or borehole) can be calculated by the following equation (from Borrows et al, 1982, Ch 9 Page 256).

$$\Delta P = \frac{R_f \times m^2 \times L}{\rho} \times 10^{-3}$$

where R_f = resistance factor, m^{-5}
m = mass flow rate, kg/s
L = pipe length, m
ρ = air density, kg/m^3

ρ is calculated from average at top of shaft T_2 = 109°C, P_2 = 150 kPa and at bottom, T_3 = 32°C and P_3 = 100 kPa using the following equation.

$$\rho = \frac{P\times 10^3}{RT}$$

$$\rho = \frac{(150+102)/2\times 10^3}{368.7\times(382+313)/2}$$

$$= 0.987 \text{ kg/m}^3$$

R_f for 500 mm pipe diameter is 0.36.\

$$\therefore\ \Delta P = 0.36\times(10.62)^2\times 200\times 10^{-3}\times\frac{1}{0.987} = 8.23 \text{ kPa}$$

$$\therefore F_{23} = m\times\Delta P = 10.62\times 8.23 = 87.4 \text{ kW}$$

3. Elevation component - work to overcome elevational buoyancy effects

Elevational buoyancy effects can be calculated by the following equation

$\rho g(Z_2 - Z_3) = 0.987 \times 9.81 \times (200) = 1{,}936.5$ Pa or 1.94 kPa

Work to overcome Elevational buoyancy effects is

$10.62 \times 1.94 = 20.6$ kW

4. Shock losses for exit into mine

Shock Losses $= x\dfrac{v^2}{2g}(Pa)$ Assume hole (entry and exit) $x \approx 1.0$

Q = 5.2 m^3/s at exit (at 32°C, density of 1.143 kg/m^3 and with majority of moisture already having dropped out)

$$Vel = \frac{5.2}{\pi r^2} = \frac{5.2}{\pi \times 0.25^2} = 26.3\,m/s$$

Assume $x = 1.0$

$$\therefore Shock = 1.0 \times \frac{26.3^2}{2 \times 9.81} = 35.3 Pa$$

$$\therefore Work = \frac{1}{\rho} \times 10.62 \times 0.035$$

$$\therefore Work = \frac{1}{1.143} \times 10.62 \times 0.035$$

$= 0.33$kW

Therefore, compressor fan would be required to input the follow work

$$W_{23} = \int_2^3 VdP + F_{12} + \left(\frac{u_2^2 - u_3^2}{2}\right) + (z_2 - z_3)g + \text{superheat}$$

The first four terms in the equation as worked out above are

$W_{23} = 576.8 + 87.4 + 20.6 + 0.33 = 685.13$ kW

Thus delivery of 13.95 m^3/s GAG exhaust down a 200 m borehole of 500mm in diameter would require at least 700 kW of energy without consideration of the super heating component.

10.3.2. Flow through various borehole designs

Inertisation exhaust flow through deeper or smaller diameter holes faces significant backpressure. A variable pressure fan placed in line with the GAG flow could overcome substantial backpressure to allow holes of economical dimensions to be utilised.

A primary requirement is to examine attainable designs for panel boreholes under Australian conditions with current drilling technology. Part of this is to calculate design considerations for a variable pressure fan that can assist flow against backpressure. There is a limit (assumed up to 50 kPa) to the contribution a variable pressure fan can make to assist flow. The following tables show attainable borehole sizes for free (up to 2 kPa and compressor fan assisted delivery with various amount of exhaust delivered. Three categories are shown in the table with different shadow colours. Dziurzyński, (2004) stated that the GAG could operate continuously against a backpressure of 2 kPa.

- Hole designs (size and depth) that can deliver directly without assistance of any fan,
- Hole designs that can deliver with assistance of a fan and the pressure required for this delivery to be attained, and
- Specifications of boreholes design parameters that cannot achieve delivery even with fan assistance.

Table 10.1 Attainable borehole sizes for free and compressor fan assisted delivery with various amount of exhaust delivered (Pressure shown in kPa)

Exhaust Q (m^3/s)	Borehole Depth(m)	Diameter (mm)															
		100	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2400
10.0	100	19453.7	607.93	80.06	19.00	6.23	2.50	1.16	0.59	0.329	0.195	0.08	0.04	0.02	0.01	0.01	0.00
	150	29180.6	911.89	120.08	28.50	9.34	3.75	1.74	0.89	0.494	0.292	0.12	0.05	0.03	0.02	0.01	0.00
	200	38907.4	1215.86	160.11	38.00	12.45	5.00	2.31	1.19	0.659	0.389	0.16	0.07	0.04	0.02	0.01	0.00
	250	48634.3	1519.82	200.14	47.49	15.56	6.25	2.89	1.48	0.824	0.486	0.20	0.09	0.05	0.03	0.02	0.01
	300	58361.1	1823.78	240.17	56.99	18.68	7.51	3.47	1.78	0.988	0.584	0.23	0.11	0.06	0.03	0.02	0.01
	350	68088.0	2127.75	280.20	66.49	21.79	8.76	4.05	2.08	1.153	0.681	0.27	0.13	0.06	0.04	0.02	0.01
	400	77814.8	2431.71	320.23	75.99	24.90	10.01	4.63	2.37	1.318	0.778	0.31	0.14	0.07	0.04	0.02	0.01
	450	87541.7	2735.68	360.25	85.49	28.01	11.26	5.21	2.67	1.483	0.875	0.35	0.16	0.08	0.05	0.03	0.01
	500	97268.5	3039.64	400.28	94.99	31.13	12.51	5.79	2.97	1.647	0.973	0.39	0.18	0.09	0.05	0.03	0.01
	550	106995.4	3343.60	440.31	104.49	34.24	13.76	6.37	3.27	1.812	1.070	0.43	0.20	0.10	0.06	0.03	0.01
	600	116722.2	3647.57	480.34	113.99	37.35	15.01	6.94	3.56	1.977	1.167	0.47	0.22	0.11	0.06	0.04	0.01

Exhaust Q (m^3/s)	Borehole Depth(m)	Diameter (mm)															
		100	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2400
15.0	100	43770.8	1367.84	180.13	42.74	14.01	5.63	2.60	1.34	0.74	0.44	0.18	0.08	0.04	0.02	0.01	0.01
	150	65656.2	2051.76	270.19	64.12	21.01	8.44	3.91	2.00	1.11	0.66	0.26	0.12	0.06	0.03	0.02	0.01
	200	87541.7	2735.68	360.25	85.49	28.01	11.26	5.21	2.67	1.48	0.88	0.35	0.16	0.08	0.05	0.03	0.01
	250	109427.1	3419.60	450.32	106.86	35.02	14.07	6.51	3.34	1.85	1.09	0.44	0.20	0.10	0.06	0.03	0.01
	300	131312.5	4103.51	540.38	128.23	42.02	16.89	7.81	4.01	2.22	1.31	0.53	0.24	0.13	0.07	0.04	0.02
	350	153197.9	4787.43	630.44	149.61	49.02	19.70	9.12	4.68	2.59	1.53	0.62	0.28	0.15	0.08	0.05	0.02
	400	175083.3	5471.35	720.51	170.98	56.03	22.52	10.42	5.34	2.97	1.75	0.70	0.33	0.17	0.09	0.05	0.02
	450	196968.7	6155.27	810.57	192.35	63.03	25.33	11.72	6.01	3.34	1.97	0.79	0.37	0.19	0.10	0.06	0.02
	500	218854.1	6839.19	900.63	213.72	70.03	28.14	13.02	6.68	3.71	2.19	0.88	0.41	0.21	0.12	0.07	0.03
	550	240739.5	7523.11	990.70	235.10	77.04	30.96	14.32	7.35	4.08	2.41	0.97	0.45	0.23	0.13	0.08	0.03
	600	262625.0	8207.03	1080.76	256.47	84.04	33.77	15.63	8.01	4.45	2.63	1.06	0.49	0.25	0.14	0.08	0.03

Exhaust Q (m^3/s)	Borehole Depth(m)	Diameter (mm)															
		100	200	300	400	500	600	700	800	900	1000	1200	1400	1600	1800	2000	2400
20.0	100	77814.8	2431.71	320.23	75.99	24.90	10.01	4.63	2.37	1.32	0.78	0.31	0.14	0.07	0.04	0.02	0.01
	150	116722.2	3647.57	480.34	113.99	37.35	15.01	6.94	3.56	1.98	1.17	0.47	0.22	0.11	0.06	0.04	0.01
	200	155629.6	4863.43	640.45	151.98	49.80	20.01	9.26	4.75	2.64	1.56	0.63	0.29	0.15	0.08	0.05	0.02
	250	194537.0	6079.28	800.56	189.98	62.25	25.02	11.57	5.94	3.29	1.95	0.78	0.36	0.19	0.10	0.06	0.02
	300	233444.4	7295.14	960.68	227.97	74.70	30.02	13.89	7.12	3.95	2.33	0.94	0.43	0.22	0.12	0.07	0.03
	350	272351.8	8510.99	1120.79	265.97	87.15	35.02	16.20	8.31	4.61	2.72	1.09	0.51	0.26	0.14	0.09	0.03
	400	311259.2	9726.85	1280.90	303.96	99.60	40.03	18.52	9.50	5.27	3.11	1.25	0.58	0.30	0.16	0.10	0.04
	450	350166.6	10942.71	1441.01	341.96	112.05	45.03	20.83	10.69	5.93	3.50	1.41	0.65	0.33	0.19	0.11	0.04
	500	389074.0	12158.56	1601.13	379.96	124.50	50.04	23.15	11.87	6.59	3.89	1.56	0.72	0.37	0.21	0.12	0.05
	550	427981.4	13374.42	1761.24	417.95	136.95	55.04	25.46	13.06	7.25	4.28	1.72	0.80	0.41	0.23	0.13	0.05
	600	466888.8	14590.28	1921.35	455.95	149.40	60.04	27.78	14.25	7.91	4.67	1.88	0.87	0.45	0.25	0.15	0.06

In Table 10.1 it shows that if the borehole diameter is 800mm, the GAG can deliver 15 m^3/s of exhaust without assistance of a compressor fan to overcome the backpressure from the borehole for up to 100 m in borehole depth. However some fan assistance is required for the borehole depths in excess of 100 m.

For 500 mm borehole, it could deliver 15 m^3/s of exhaust for borehole depth up to 350 m with compressor fan assistance. When the borehole depth is more than 350m, it is not able to deliver 15 m^3/s of exhaust even with fan assistance but it is possible to deliver a lesser amount of exhaust of 10 m^3/s.

The following figures show various borehole designs (diameter/depth) for free delivery of various GAG exhaust quantities with a borehole frictional (back) pressure of less than 2 kPa and for fan assisted delivery with a borehole frictional (back) pressure of less than 50 kPa.

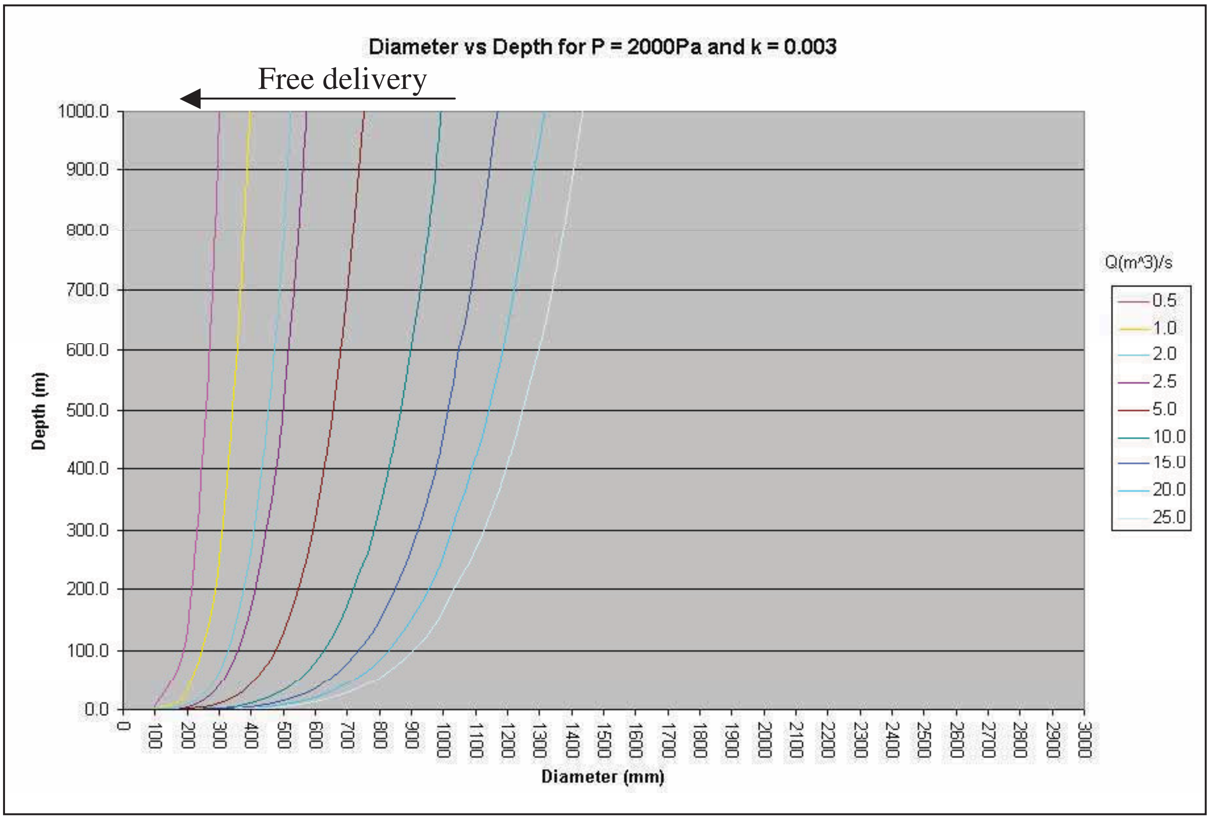
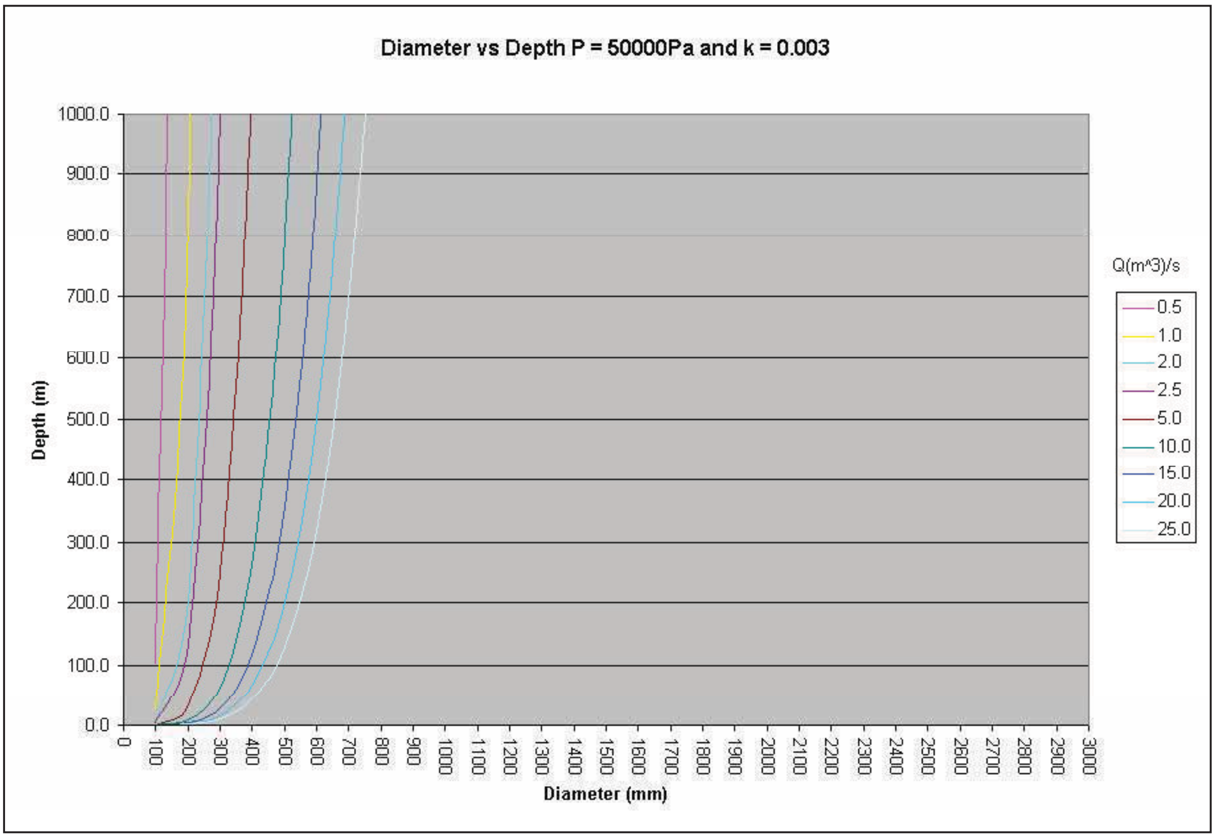


Figure 10.3 Borehole design for free delivery of GAG exhaust.



10.4. CONCLUSIONS

Borehole design parameters have been established applicable to Australian conditions based on the complex fluid flow theory that describes the dynamic, hot, pressurised exhaust carrying a superheated vapour. Determinations have been made of the relationships between borehole back pressure and GAG thrust relationships and the best approach to vary the jet engine thrust to overcome this bask pressure. These mathematical relationships can now be applied to investigate the possibility of using GAG in small diameter boreholes for either production inertisation or fire fighting purposes. This would be a verification exercise taking the equations describing GAG exhaust fluid behaviour based on the steady flow energy equation and comparing the theoretical predictions of GAG exhaust fluid behaviour with actual measurements of pressure, quantity and temperature at various locations downstream from GAG exhaust trials proposed.

11. CONCLUSION AND RECOMMENDATIONS

The primary objective of the project was to use mine fire simulation software to gain better understanding of how inertisation (GAG, Mineshield, Pressure Swing Adsorption and Tomlinson Boiler) units can interact with the complex ventilation behaviour underground during a substantial fire. Inertisation systems for handling underground fires, sealing of mine or mine sections, spontaneous combustion heatings and elimination of the potential explosibility of newly sealed goafs have been accepted as important safety approaches within the Australian industry.

Computer simulation of mine fires and effects on ventilation networks has been introduced to the industry with considerable interest and success. This has already put a significant number of mines in an improved position in their understanding of mine fires and the use of modern advances to preplan for mine fires and the handling of possible emergency incidents. The project has relied on substantial mine site and mines rescue support.

The project endeavoured to increase understanding of behaviour of mine fires in modern mine ventilation networks with the addition of inert gas streams. It also aimed to develop inertisation related modifications to the fire simulation software.

Inertisation has been accepted to have an important place in Australian mining emergency preparedness. The two jet engine exhaust GAG units purchased from Poland by the Queensland government in the late 1990s for the Queensland Mines Rescue Service have been tested and developed and mines made ready for their use in emergency and training exercises. Their use in real and trial mine fire incidents has underlined the need for more information on their application.

The NSW Mineshield (liquefied nitrogen) apparatus dates to the 1980s and has been actively used a number of times particular in goaf heating incidents. The Tomlinson (diesel exhaust) 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” and for goaf spontaneous combustion heatings. Nitrogen Pressure Swing Adsorption (Floxal) units are available and in use both for reducing time in which goafs are “within the explosive range” and for goaf spontaneous combustion heatings. Each of these facilities puts out very different flow rates of inert gases. Each is broadly designed for a different application although there is some overlap in potential usages.

Various types of inertisation systems currently available and in use in Australian coal mines for elimination of the potential explosibility of newly sealed goafs, for combating goaf spontaneous combustion heatings, for sealing of old mine workings or for stabilising fires in high priority locations have been examined. Systems have been compared to aid decision making in selection.

The potential for simulation of the effects of inertisation on fires within a mine ventilation network was examined. The project involved applying the VENTGRAPH mine fire simulation software to preplan for mine fires. Work undertaken to date at some Australian coal mines is discussed as examples. The effort has been built around the modelling of fire scenarios in selected different mine layouts.

Case studies have been developed to examine usage of the GAG inertisation unit. One section examined seam gas emissions in the face area; 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?

Another section has focused on selection of the surface portal location for placement of the GAG for effective fire suppression. The difficulties that some current approaches present are highlighted. The advantages that can be gained from use of various inertisation docking positions depends on a number of considerations including the location of the fire, the relative distance from the inertisation docking 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, fuel, water and other operating requirements.

Priority fire locations at a wide selection of mines with a developed and current Ventgraph simulation model have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage. In the study it was assumed that the GAG would be docked at a prepared position designated by the mine (most commonly the current fabricated docking installation). Many mine layouts were reviewed and from these 35 scenarios were considered appropriate for use of the GAG. These fires were categorised A to E in terms of ability of the GAG exhaust to effectively stabilise and extinguish the fire. As examples of results no fires met the category A description, 14 percent met category D and 20 percent met category E. The conclusion is that the current situation is not well placed to effectively inert most colliery priority fires.

These simulation exercises undertaken with a wide range of Australian mines focused attention to the situation that many potential underground mine fire sources cannot be successfully inertised with the GAG docked at the current specified point. This inability to deliver GAG output is particularly so for fires in extended areas of workings or in panels. Two important conclusions are

- Successful delivery of GAG output from units on the surface must consider other (that is alternative to Mains Travel or Conveyor Heading portals) delivery conduits directly into workings near the fire through existing or purpose drilled boreholes.

- During a fire the stopping of the main surface fan or fans will lead to rebalancing of pit ventilation and in some cases potential explosions through air reversals bringing poorly diluted explosible seam gases or fire products across the fire site.

Another section has looked at inertisation and dilution issues in Mains headings. These present a complex ventilation network and with additional interference from a fire, maintaining control of the movement of inert gas is more difficult than elsewhere in the mine. Even good quality segregation stoppings allow significant dilution of inertisation flows over relatively short distances. There is a section that has examined considerations presented by “punch” mines layouts. A number of recent punch longwall mines are accessed off highwalls. These mines have some provision for GAG docking from within the highwall pit but all have put down boreholes to workings which enable the GAG team to operate the engine from the surface.

The calibration exercise was in two parts. The back analysis of the gas monitoring data during a fire at the US Pattiki Mine showed that a VENTGRAPH model could be established to simulate satisfactorily this incident. The inertisation exercise during part sealing of the Newlands South workings (without a fire present) highlighted a number of findings.

- The GAG quantity measured exhausting from the mine area being sealed was at first considered to be unrealistically low. However further analysis, as detailed in Chapter 10 of this report, indicates that accounting for temperature and moisture mass changes explains any differences.
- The hypothesis that some of the GAG exhaust, with diurnal pressure changes, will flow into and out of goafs is of interest and needs to be accounted for.

Further monitoring of mine site GAG exercises are warranted to give greater understanding to this complex system.

A chapter has given a brief overview of the VENTGRAPH simulation software. It has highlighted the new features that have been added to the software as a consequence of this inertisation project and in particular the ability to use up to four different types of inertisation gases (at varying flow rates) across a mine layout simultaneously and the ability to include carbon dioxide and nitrogen seam gases as well as methane.

Exercises based on Oaky North and Oaky No 1 mines have involved “evaluation or auditing” of ability to deliver inert gases generated from GAG units to high priority underground fire locations. These exercises have been built around the use of the fire simulation computer program VENTGRAPH and modelling of fire scenarios across the mine layouts. A coding system, A to E, has been developed to assist interpretation within the audit exercises.

The primary objective of the exercises was to use mine fire simulation software to gain a better understanding of how inertisation approaches using the GAG jet engine exhaust can interact with the complex ventilation behaviour underground during a substantial fire.

The principal sections examining Oaky North Colliery focus on the development of scenarios for examining priority fire locations and firstly their effect on the mine ventilation system and secondly the influence of introducing inertisation gases to stabilise the fire. Inertisation outcomes in all case scenarios have been examined through introduction through the mine's present docking point at the Transport Drift. Each scenario has then been re-examined one or more times to establish if a different docking point, altered underground ventilation segregation or other approach would be more effective in stabilising the simulated fire.

Five major case study scenarios based on the modelling of fires with introduced inertisation in a number of high priority different points geographically spread within the Oaky North longwall mine layout have been discussed. Possible alternative strategies for successfully inerting the fires have been examined and conclusions drawn to the success or otherwise of these approaches. Approaches focus on use of alternative portal docking points, increased underground segregation and possible use of boreholes to delivery GAG exhaust directly to the fire seat.

These fire simulation exercises have shown that some priority Oaky North fires can be stabilised through GAG inertisation strategies. One scenario goaf fire strategy developed is a case in point where use of a panel borehole with careful segregation allowed a relatively fast outcome to be achieved. Another scenario development heading fire was similar in that a borehole GAG delivery gave the best outcome. Both these were achieved with one surface fan operating and maintaining minimum pit ventilation and seam methane dilution. A third scenario fire, a Mains belt fire, utilised the GAG positively through use of an alternative Portal for docking. These examples showed that the audit was a success in that it highlighted successful approaches to use of inertisation where the previous approach was inadequate.

On the other hand Mains belt and Development heading belt) scenario fires were placed such that alternative approaches to inertisation were ineffective because pit layout means excess dilution affects the GAG exhaust quality which can be brought to the fire.

Recommendations arising from the Oaky North analyses were as follows:

1. GAG docking stations should be fabricated for all ventilation intake openings to the mine. The existing apparatus at the Travel Decline should be supplemented by docking points at the Highwall portals, any pit boreholes of appropriate diameter and future main shafts. In effect each docking point can deliver to a restricted geographic zone within the pit; multiple points allow the appropriate point to be utilised.
2. Segregation strategies simulated at pit bottom areas have shown that distribution of inert gases to separate Mains headings can be improved. They were useful for fires

located inbye from the pit bottom in the Mains but were less effective for the fires located a long way further inbye and in the longwall production and development panels (due to increasing dilution through stoppings).

3. It was recommended that a borehole with a diameter of at least 1 m should be considered at the beginning of each panel for delivering inert gases to each longwall production or development face. These boreholes can also be used for other purposes such as delivery of ballast or emergency extraction of people out of the mine. They may be used for other services. Incorporation of remote controlled doors should be considered to give control over which gateroad should be used to carry the inert gases into the panel.

In the inertisation evaluation of Oaky No 1 Mine, ten major case study scenarios based on the modelling of fires with introduced inertisation in a number of high priority different points geographically spread within the longwall mine layout are discussed. Possible alternative strategies for successfully inerting the fires have been examined and conclusions drawn to the success or otherwise of these approaches. Approaches focus on use of alternative portal docking points, increased underground segregation and possible use of boreholes to delivery GAG exhaust directly to the fire seat.

These ten fire simulation exercises have produced scenario results in three categories:

1. Those in which satisfactory inertisation can be achieved from use of the mine's current single docking point at the Main Intake Shaft. This applies to four of the fire scenarios examined.
2. Those in which a better and satisfactory inertisation strategy can be achieved from use of a docking point other than the Main Intake Shaft. This applies to three scenarios examines. The other alternatives for docking were the Main Drift Headings B or C. It was recommended that GAG docking stations should in future be fabricated for all ventilation intake openings to the mine and currently for Drift Headings B and C.
3. Those in which an unsatisfactory inertisation outcome was achieved from use of the Main Intake Shaft and where the alternative reappraisal led to an unsatisfactory outcome. This applied to three scenarios examined. Investigations which were outside the scope of this report could be undertaken for these three scenarios to determine whether use of another access point to the mine, particularly a specially excavated borehole would provide a satisfactory inertisation outcome.

Oaky No 1 mine has all current intake air portals close together. This means that some parts of the mine with active workings are at considerable distance from inertisation docking points on access intake airways. Strategically placed boreholes near active workings where priority fires may occur could be placed advantageously to allow inertisation when required.

It was recommended that Oaky No 1 mine examine how use of boreholes or other approaches could effectively allow satisfactory inertisation of priority fires locations and particularly the three specific scenarios highlighted.

General recommendations arising from the Oaky No 1 Colliery analyses are as follows:

1. GAG docking stations should be fabricated for all ventilation intake openings to the mine. The existing apparatus at the Main Intake Shaft should be supplemented by docking points at the Drift Headings and any future pit boreholes of appropriate diameter and future main shafts. In effect each docking point can deliver to a restricted geographic zone within the pit; multiple points allow the appropriate point to be utilised.
2. Segregation strategies simulated at points along the various Mains have shown that distribution of inert gases to separate Mains headings can be improved. Current segregation is less effective for fires located a long way inbye the mine and in the longwall production and development panels (due to increasing dilution through stoppings).
3. It was recommended that a borehole with a diameter of at least 1 m should be considered at the beginning of each panel for potential delivery of inert gases to each longwall production or development face. These boreholes can also be used for other purposes such as delivery of ballast or emergency extrication of people out of the mine. They may be used for other services. Incorporation of remote controlled doors should be considered to give control over which gateroad should be used to carry the inert gases into the panel.
4. Scenarios in which no satisfactory inertisation strategy was apparent should be further examined to determine the merits of locating a borehole or shaft in the vicinity of the fire to enable satisfactory outcomes.

The fire simulation exercises at Oaky North and Oaky No 1 mines demonstrated that it is possible to efficiently evaluate possible inertisation strategies appropriate to a complex mine layout extracting a gassy seam and determine which approach strategy (if any) can be used to stabilise a mine in a timely fashion.

A final chapter has focused on borehole design parameters. Analyses have been established applicable to Australian conditions based on the complex fluid flow theory that describes the dynamic, hot, pressurised exhaust carrying a superheated vapour. Determinations have been made of the relationships between borehole back pressure and GAG thrust relationships and the best approach to vary the jet engine thrust to overcome this bask pressure. These mathematical relationships can now be applied to investigate the possibility of using GAG in small diameter boreholes for either production inertisation or fire fighting purposes. This would be a verification exercise taking the equations describing GAG exhaust fluid behaviour based on the steady flow energy equation and comparing the theoretical predictions of GAG exhaust fluid behaviour with actual measurements of pressure, quantity and temperature at various locations downstream from GAG exhaust trials proposed.

Mine fires and heatings are recognised across the world as a major hazard issue. New approaches allowing improvement in understanding their use of inertisation techniques have been examined. The outcome of the project is that the mining industry is in an improved position in their understanding of mine fires, use of inertisation and the use of modern advances to preplan for the handling of possible emergency incidents.

11.1. Additional Work

Based on the findings from this project, it is proposed that a study on production or proactive use of inertisation and particularly the GAG inertisation unit should be undertaken. The study should aim to examine the possibility of a wider and proactive application of GAG in Australian mines responding to or recovering from mine fires or inertisation of sealed mine workings or spontaneous combustion heatings or elimination of the potential explosibility of newly sealed goafs.

This project should take many of the findings from the current project report. Three of the main conclusions from this project are the objectives of this proposed project

- Positioning of the GAG inertisation units is a major determinant of potential success for most efficient suppression of a specific fire. Studies undertaken with most Australian underground collieries have concluded that the current situation is not well placed to effectively inert most colliery priority fires.
- There is a need to examine attainable designs for GAG inerting using panel boreholes under Australian conditions with current drilling technology. Part of this is to calculate design considerations to overcome backpressure. There is a limit to the ability of the GAG jet engine to deliver exhaust down smaller dimension borehole. The objective will be to define the
  - Hole designs (diameters and depths) that can deliver directly without assistance of any fan,
  - Hole designs that can deliver with modifications to the jet engine to improve thrust to overcome back pressure required for this delivery to be attained, and
  - Specifications of boreholes design parameters that cannot achieve delivery even with full GAG jet thrust.
- There is a need to examine the use of the GAG for production or proactive uses in a wider application in Australian mines responding to recovering from mine fires, spontaneous combustion heatings, elimination of the potential explosibility of newly sealed goafs or inert mines or mine sections on closure. Some of the current uses of low flow inertisation facilities could be more effectively undertaken with the GAG unit.

Any use of the GAG must examine its interaction with the complex ventilation behaviour underground during a substantial fire and fire simulation exercises will be undertaken using

Ventgraph software. Inertisation users in Australia and in particular GAG operators such as Mines Rescue organisations need the answers to these questions for future planning. In particular detailed designs are needed by operating mines. Borehole drilling into operating mines has become commonplace in recent years and designs that allow multiple use for ventilation requirements, delivery of road base, potential man escape and delivery of inert gases provide a step forward for the industry.

The current project has been examining the aspect of positioning of the inertisation units which is a major determinant of potential success for most efficient suppression of a specific fire. Priority fire locations at mines with a developed and current Ventgraph simulation model have been examined as to the ability of a GAG inertisation unit to inert a fire in the mine recovery stage. In the study it was assumed that the GAG would be docked at a prepared position designated by the mine (most commonly the current fabricated docking installation). The conclusion is that the current situation is not well placed to effectively inert most colliery priority fires.

These simulation exercises undertaken with a wide range of Australian mines focused attention to the situation that many potential underground mine fire sources cannot be successfully inertised with the GAG docked at the current specified point. This inability to deliver GAG output is particularly so for fires in extended areas of workings or in panels. Two important conclusions are

- Successful delivery of GAG output from units on the surface must consider other (that is alternative to Mains Travel or Conveyor Heading portals) delivery conduits directly into workings near the fire through existing or purpose drilled boreholes.
- During a fire the stopping of the main surface fan or fans will lead to rebalancing of pit ventilation and in some cases potential explosions through air reversals bringing poorly diluted explosible seam gases or fire products across the fire site.

A major project outcome will be that the GAG unit moves from a specialise facility only using in training or emergencies to one which is part of the production process. In this way the unit will be used frequently and will by necessity evolve in its applications and usage. More of the industry workforce will be trained in its usage, as it will be frequently brought to mine sites. This will reduce the real cost of training and it can be written off against the production particular use.

Some of the current uses of low flow inertisation facilities could be more effectively undertaken with the higher flow GAG unit. Sponsoring mines will have both a detailed design developed for specific borehole locations appropriate to their mine plan and simulation scenarios developed on how GAG exhaust could be utilised in elimination of the potential explosibility of newly sealed goafs or in combating goaf spontaneous combustion heatings.
The work program for project will be undertaken in two stages with second grant application to ACARP following successful completion of stage 1.

Stage 1

- Design for automation of GAG operation should be finalised and implemented. The automated GAG unit should be tested over a 10 day surface trial to establish back pressure versus thrust relationships and other operating parameters. A series of test are required to configure the control system for backpressure and can be combined with training sessions.
- To investigate the possibility of using GAG in small diameter boreholes, a verification exercise should be undertaken comparing the theoretical predictions with actual measurements of pressure, quantity and temperature at various locations downstream from GAG exhaust trials proposed.
- Determinations should be made of the relationships between borehole backpressure and GAG thrust relationships and the best approach to vary the jet engine thrust to overcome this bask pressure.
- Ventgraph simulation on mines of supporting companies should be used to examine critical issues such as location of the GAG and boreholes for high priority fires or related issues. Evaluations should be undertaken against real mine situations with the support of mine operators.

Stage 2

- A second phase should be proposed as a follow on to undertake a physical trial with a GAG coupled to a mine borehole to do the job as pre-tested initially in surface trials. This is very likely to be supported by a mine undertaking final closure and sealing of a mine section.

11.2. Completion of the Project

The ACARP Grant that has funded this study set down a list of activity stages that would be undertaken by the project to place the Australian mining industry in an improved position in understanding of use of inertisation in response to and recovery from mine fires.

- The status of the industry in its use of mine inertisation has been established. The technical specifications of units currently in use have been givens and various application described as set down inn chapter 2. Frequent liaison has occurred with mines rescue personnel in NSW and Queensland. A review of other inertisation sources that may be available to the mining industry has not occurred, as there is no documented evidence of any mine application of other sources in recent years.
- A review of international use of inertisation in modern mining practice particularly in the US and Europe has occurred as set down inn chapter 2.
- General mine simulations have been undertaken to assess how inertisation sources can be utilised in a fire emergency. A number of different situations have been examined as laid down in Chapter 3.
- Undertake simulations of the effects of common fire causes and fire progress rates with inertisation units simulated at more than one mine "docking" surface point to help mines

decide on optimal placement. Detailed aspects that were targeted for examination in a focused section of the report included:

  - Location of the unit for high priority fire positions; e.g. portal docking position, special boreholes.
  - Time required for inertisation output to interact with and extinguish a fire.
  - Effects of seam gas on fire behaviour with inertisation present.
  - Changes that can be safely made to the ventilation system during inertisation including switching off of some or all fans.

  Simulations require a detailed study of a number of mine layouts to identify optimum portal placement for inertisation units for various underground fire locations. Comprehensive exercises have been undertaken over 15 different scenarios at Oaky North and Oaky No 1 Mines as described in chapters 6 to 9.

- Liaison has occurred throughout the project with the Polish program authors (by frequent email contact and visits by the Polish authors to Australia and visits by Australian researchers to Poland) to enhance the findings of the project and make inertisation related modification to the VENTGRAPH program from the project findings. Specific issues that were addressed included:
  - Variation in inertisation units outputs by quantity.
  - Approaches for including other inertisation devices apart from the GAG in simulations.
  - Discussions on GAG jet engine “fan” characteristic curves to allow calculation of ability of GAG to deliver through small diameter boreholes.
  - Ability to model additional seam gases.

  Changes that have occurred are set down in chapter 5.
- Preparation of teaching material on theory of fires, mine simulation and development of emergency management plans has occurred. It has been made use of in various areas of technology transfer as set down in chapter 12.
- Technology transfer from the project was considered vital and the various means by which this has occurred are comprehensively described in chapter 12. Significant presentations have occurred at mine sites in addition to industry seminars and conference deliveries. A bank of teaching material is available from these various efforts.

In addition to the specified outcomes significant and relevant development have occurred.

- The calibration exercises on VENTGRAPH for fire simulation and inertisation usage that have occurred are described in chapter 4.
- A rigorous mathematical thermodynamically based analysis has been developed to give understanding to the issue of delivery of GAG exhaust down small diameter boreholes as set down in chapter 10.
- The conclusion section in chapter 11 includes some recommendations on additional work that could follow from the project to answer a number of issues current in the industry. This additional work is related to the issues of borehole delivery and greater production usage of the GAG unit.

12. TECHNOLOGY TRANSFER

Technology Transfer has encompassed both presentations of papers at conferences, publication of papers in refereed Conference Proceedings and publication of papers in refereed Journals. It has included attendance at specialised Workshops. Furthermore discussions and presentations were made at various mine sites within Queensland and NSW to all levels of management, engineers, safety personnel and crewmembers.

12.1 Papers and Presentations

The following papers and presentations were given on the topic of fire simulation and inertisation during the grant's currency or in the immediate period before.

1. DEMONSTRATION OF VENTGRAPH MINE FIRE SIMULATOR
   ADS Gillies
   Queensland Department of Natural Resources and Mines Chief Inspector's Chief Executives' Meeting, Brisbane, December 2003

2. CASE STUDIES FROM SIMULATING MINE FIRES IN COAL MINES AND THEIR EFFECTS ON MINE VENTILATION SYSTEMS
   ADS Gillies and HW Wu
   Proceedings Fifth Australasian Coal Operators Conference, Ed. N. Aziz and B. Kininmonth, Aus. Inst. Min. Metall., Melbourne, pp. 111-125 February 2004.

3. LESSONS FROM TWO UNDERGROUND COAL FIRES IN AUSTRALIA USING RETROSPECTIVE NUMERICAL SIMULATION STUDY
   A.M. Wala, A.D.S. Gillies and H.W. Wu
   SME Annual Conference, Denver, February 2004

4. EFFECTS OF MINE FIRES ON MINE VENTILATION, GASES AND INERTISATION
   ADS Gillies and HW Wu
   Queensland Department of Natural Resources and Mines Inspectors' Meeting, Mackay, May 2004

5. EFFECTS OF MINE FIRES ON MINE VENTILATION PARTICULARLY IN GASSY MINES
   ADS Gillies and HW Wu
   Mine Managers' Association of Australia Seminar, Belmont NSW, May 2004

6. CASE STUDIES FROM APPLICATION OF NUMERICAL SIMULATION SOFTWARE TO EXAMINING THE EFFECTS OF FIRES ON MINE VENTILATION SYSTEMS
   H.W. Wu, A.D.S. Gillies & A.M. Wala
   Tenth US Mine Ventilation Symposium, Anchorage, Balkema, The Netherlands, pp. 445-455, May 2004.

7. SIMULATION OF MINE FIRES AND GAG USAGE
   ADS Gillies, HW Wu and R.S. Hosking
   Queensland Mines Rescue Service Inertisation Seminar, Mackay, May 2004

8. USE OF MINE FIRE SIMULATION FOR EMERGENCY PREPAREDNESS
   A.D.S. Gillies, H. Wu, D. Reece and R.S. Hosking
   Queensland Mining Industry Health and Safety Conference, Townsville, Queensland Resources Council, pp. 13-22, August 2004

9. AUSTRALIAN MINE EMERGENCY EXERCISES AIDED BY FIRE SIMULATION
   A.D.S. Gillies
   Third School of Mine Ventilation, Zakopane, Poland, 283-308, October 2004.

10. SPONTANEOUS COMBUSTION AND SIMULATION OF MINE FIRES AND THEIR EFFECTS ON MINE VENTILATION SYSTEMS
    ADS Gillies and HW Wu
    Coal Operators' Conference, Aus. Inst. Min. Metall., Melbourne, 225-236, April 2005.

11. INTRODUCTION OF SIMULATION SOFTWARE EXAMINING THE EFFECTS OF FIRES ON MINE VENTILATION SYSTEMS IN AUSTRALIA
    ADS Gillies, HW Wu and A Wala
    Eighth International mine Ventilation Congress, Brisbane, AusIMM, July 2005, pp 317-324.

12. AUSTRALIAN MINE EMERGENCY EXERCISES AIDED BY FIRE SIMULATION
    A.D.S. Gillies, H.W. Wu and A.M. Wala
    Archives of Mining Sciences, Polish Academy of Sciences, Krakow, Poland vol 50, issue 1 2005 pp 17-47.

13. FIRE SIMULATION ASSISTS MINE EMERGENCY TRAINING EXERCISES
    A.D.S Gillies and H.W. Wu
    31st Safety in Mines Research Institutes Conference, Safety in Mines Testing and Research Station, Brisbane, 254-260 October 2005.

14. QUEENSLAND MINE EMERGENCY LEVEL EXERCISES ASSISTED BY FIRE SIMULATION
    A.D.S Gillies and H.W. Wu
    Eleventh US Mine Ventilation Symposium, State College, Pennsylvania, Balkema, The Netherlands, 351-358, June 2006.

15. ISSUES IN USE OF INERTISATION OF FIRES IN AUSTRALIAN MINES.
    A.D.S Gillies and H.W. Wu
    Queensland Mining Industry Health and Safety Conference, Townsville, vol 1, 53-66 August 2006.

16. INERTISATION OF FIRES AND HEATINGS IN AUSTRALIAN MINES,
    A.D.S Gillies and H.W. Wu
    Proceedings, Fourth School of Mine Ventilation, Polish Acad. of Sci. Mine Ventilation Section of the Mining Committee, Cracow, October 2006 139-149.

17. GAG INERTISATION OF FIRES AND USE OF BOREHOLES,
    A.D.S Gillies and H.W. Wu
    Queensland Mine Rescue Service GAG Seminar, Mackay, 6 – 7 December 2006.

18. INERTISATION OF FIRES AND HEATINGS IN AUSTRALIAN MINES,
    A.D.S Gillies and H.W. Wu
    Archives of Mining Sciences, Polish Academy of Sciences, Krakow, Poland vol 52 issue 1 2007

12.2 Workshops

Workshops have included the following.

Two day Workshops to engineers from mines using fire simulation and inertisation software. These were held in Brisbane as follows

- December 2004
- December 2005
- March 2007

QMRS Workshops

The Queensland Mine Rescue Service organised Workshops in May 2004 and December 2006 at Mackay. Presentations of different aspects of inertisation were given at both of these.

Furthermore four days of Training on fire simulation and inertisation were given to QMRS Managers in 2005

NSW Workshop

Bruce Dowsett of Centennial kindly organised a NSW workshop at the beginning of the grant activities in April 2005. The purpose of the Workshop was to explain its aim and purpose and elucidate comments from participants.

Attendance at Inertisation Workshop, 4 April 2005, Newcastle

PERSON	COMPANY	POSITION	COMMENTS
Proud John	Mines Rescue	Training Coordinator	
Healey Paul	DPI	Inspector	Integrated into mine preparedness systems; establish responses.
Anderson Ian	DPI	Inspector	
Cowan Graham	DPI	Inspector	
Porteous Richard	Xstrata	Tech Support Manager	Rep Glenn Lewis. Establish contract interest within Xstrata.
Linde Gerard	United Colliery	Mining Engineer	Keen to apply; re-contact
Leggett Ray	DPI	Inspector	
Stoddard Ron	CFMEU	Check Inspector	
Davis Roger	Centennial-Mannery/Munmorah	Tech Services Manager	Showed interest
Shields Greg	Centennial-Mandalong	Ventilation Officer	Methods comparison, identify gas dangers. Showed interest
Cornford Peter	Centennial-Myuna	Ventilation Officer	Multi seam applications, other inertisation
Dowsett Bruce	Centennial	Group OHS Coord	Will continue to monitor interest in the Xstrata Group
Beikoff Steve	Xstrata-West Wallsend	Tech Services Manager	Inert limitations, mine factors required. Showed interest
Hempellstall John	Centennial	Group Manager OHS	
MacPherson David	Excel, Chain Valley	Manager	Showed interest
Justen Marc	Xstrata, Beltana	Ventilation Officer	Minimum standards, preparedness difficult to achieve
Bird Murray	Mines Rescue	Superintendent	Good training tool; program cannot do everything.
Glashoff Tony	Centennial-New Stan	Ventilation Officer	Unable to attend but interested
Bergin Peter	Centennial		Unable to attend but interested
Bracken Steve	Centennial		Unable to attend but interested
Mcalary Neville	Xstrata Head Office		Unable to attend but interested. In South Africa
Lewis Glenn	Xstrata Head Office		Unable to attend but interested, Rep by Richard Porteous
Myors Andrew	Centennial		Unable to attend but interested
McCreadie Lindsay	Mines Rescue Singleton		Unable to attend but interested
Enright Ken	Mines Rescue Singleton		Unable to attend but interested

Participants at the April 2005 workshop were give a Questionnaire.

The Questionnaire sheet and a summary of responses are produces below.

INERTISATION AND MINE FIRE SIMULATION QUESTIONNAIRE

Name:	Company:
Email:	Phone:

ACARP Grant: INERTISATION AND MINE FIRE SIMULATION USING COMPUTER SOFTWARE

Duration: 1 April 2005 – 31 March 2006

Purpose: The primary objective of the study is to use the Polish mine fire simulation software VENTGRAPH to gain better understanding of how inertisation (GAG, Mineshield, Nitrogen Pressure Swing Adsorption (Floxal) and Tomlinson Boiler and other) units interact with the complex ventilation behaviour underground during a substantial fire. Critical aspects targeted for examination under the project grant include location of the unit for high priority fire positions, size of borehole or pipe range required, underground segregation requirements, time required for inertisation output to interact with and extinguish a fire, effects of seam gas on fire behaviour with inertisation present and main fan management. A second major aim of the project is to take findings from the exercises tied to the above objectives to develop inertisation related modifications to the program in conjunction with the Polish program authors.

From an operating mine's point of view, what would you like to see the grant achieve?

- Technical evaluation of available inertisation facilities
- Development of approaches for simulation of effects of inertisation on mine ventilation systems under emergencies
- Appraisal of how mines should pre-prepare for use of inertisation e.g.. docking point, segregation, prioritising fire points etc
- Assistance to mine site for pre-preparedness for use of inertisation

INERTISATION AND MINE FIRE SIMULATION QUESTIONNAIRE RESULT SUMMARY

Of the 17 people attending the seminar, 7 participants responded in detail to the questionnaire. A summary of some comments and suggestions from the responses is as follows.

From an operating mine's point of view, what would you like to see the grant achieve? (comments or suggestions made in participants in ***italics and bold***).

- Technical evaluation of available inertisation facilities

    - ***Yes***
    - ***Limitations and applicability***
    - ***Multi seam applications***
    - ***Comparison between methods of inertisation***

- Development of approaches for simulation of effects of inertisation on mine ventilation systems under emergencies.

    - ***Yes***
    - ***More features required***
    - ***Other types of inertisation/combinations***
    - ***Simulation software capable of identifying dangerous gas mixtures/scenarios i.e. Recirculation.***

- Appraisal of how mines should pre-prepare for use of inertisation e.g.. docking point, segregation, prioritising fire points etc.

    - ***Yes, minimum standard recommendations not necessarily those of QLD but what will work for GAG, Mineshield, and PSA etc.***
    - ***Software able to save and compare results***
    - ***Ability to reverse changes made***

- Assistance to mine site for pre-preparedness for use of inertisation.

    - ***Integrated into other mine safety systems, e.g.. Emergency preparedness, mine fires, spontaneous combustion management***
    - ***Establish "standard" scenarios with prepared responses***
    - ***No, too many mine sites, life-of-mine plans extensive and not enough time and money.***

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