Spontaneous Combustion and Simulation of Mine Fires and Their Effects on Mine Ventilation Systems

A D S Gillies[1], H W Wu[2] and D Humphreys[3]

ABSTRACT

The structure of a comprehensive research project into mine fires study applying the Ventgraph mine fire simulation software, preplanning of escape scenarios and general interaction with rescue responses is outlined. The project has Australian Coal Association Research Program (ACARP) funding and also relies on substantial mining company site support. This practical input from mine operators is essential and allows the approach to be introduced in the most creditable way. The effort is built around the introduction of fire simulation computer software to the Australian mining industry and the consequent modelling of fire scenarios in selected different mine layouts.

Application of the simulation software package to the changing mine layouts requires experience to achieve realistic outcomes. Most Australian mines of size currently use a ventilation network simulation program. Under the project a small subroutine has been written to transfer the input data from the existing mine ventilation network simulation program to 'Ventgraph'. This has been tested successfully. To understand fire simulation behaviour on the mine ventilation system, it is necessary to understood the possible effects of mine fires on various mine ventilation systems correctly first. Case studies demonstrating the possible effects of fires on some typical Australian coal mine ventilation circuits have been examined. The situation in which there is some gas make at the face and effects with fire have also been developed to emphasise how unstable and dangerous situations may arise.

The primary objective of the part of the study described in this paper is to use mine fire simulation software to gain better understanding of how spontaneous combustion initiated fires can interact with the complex ventilation behaviour underground during a substantial fire. It focuses on the simulation of spontaneous combustion sourced heatings that develop into open fires. Further, it examines ventilation behaviour effects of spontaneous combustion initiated pillar fires and examines the difficulties these can be present if a ventilation reversal occurs. It also briefly examines simulation of use of the inertisation to assist in mine recovery.

Mine fires are recognised across the world as a major hazard issue. New approaches allowing improvement in understanding their consequences have been developed as an aid in handling this complex area.

INTRODUCTION

Many people consider that mine fires remain among the most serious hazards in underground mining. The threat fire presents depends on aspects such as the nature and amount of flammable material, the ventilation system arrangement, the duration of the fire, the extent of the spread of combustion products, the ignition location and the reaction of personnel present.

An Australian Coal Association Research Program supported project incorporating a number of mine site exercises, as described by Gillies, Wala and Wu, 2004 and Wu, Gillies and Wala, 2004 has been undertaken focused on the application of mine fire and ventilation software packages for contaminate tracing and fire modelling in coal mines. This paper in particular examines aspects of spontaneous combustion initiated open fires in underground workings.

The study into this complex area has utilised the recently upgraded Polish mine fire simulation software, 'Ventgraph'. There is a need to understand the theory behind the simulation program and to allow mine site use by those already familiar with the main existing mine ventilation analysis computer programs currently popular within the Australian, United States and South African industries such as 'Ventsim', 'VnetPC' and 'Vuma'. 'Ventsim', 'VnetPC' and 'Vuma' were not designed to handle fire effects on mine networks. Under the project a small subroutine has been written to transfer the input data from the existing mine ventilation network simulation programs to 'Ventgraph'.

It is difficult to predict the pressure imbalance and leakage created by a mine fire due to the complex interrelationships between the mine ventilation system and a mine fire situation. Depending on the rate and direction of dip of the entries (dip or rise), reversal or recirculation of the airflow could occur because of convection currents (buoyancy effect) and constrictions (throttling effect) caused by the fire. This reversal jeopardises the functioning of the ventilation system. Stability of the ventilation system is critical for maintaining escapeways free from contamination and therefore available for travel. Reversal of air following fires can have a tragic outcome (Wala, 1999).

Simulation software has the great advantage that underground mine fire scenarios can be analysed and visualised. A number of fire simulation packages have been developed to allow numerical modelling of mine fires (such as Greuer, 1984; Stefanov *et al*, 1984; Deliac, Chorosz and D'Albrand, 1985, Greuer, 1988; Dziurzyñski, Tracz and Trutwin, 1988). The Ventgraph fire simulation program has been described in detail by Trutwin, Dziurzyñski and Tracz, 1992. 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 (eg 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. Validation studies on Ventgraph have been performed using data gathered from a real mine fire as undertaken by Wala *et al*, 1995.

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EFFECTS OF FIRES ON MINE VENTILATION

The effects of fire on a mine ventilation network are complex. An open fire causes a sharp increase in the temperature of the air. The resulting expansion of the air produces a number of distinct effects. First the expansion attempts to take place in both

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directions along the airway. The tendency to expand against the prevailing direction produces a reduction in the airflow. Secondly, the expansion in volume increases air velocity downwind from the fire causing additional pressure loss. This is known as the choke or throttling effect. Finally, the decreased density results in the heated air becoming more buoyant and causes local effects as well as changes in the magnitudes of natural ventilating energy.

The choke or throttling effect

This effect results from an increase in volume of air as it passes through the fire. The effect has been described by Litton *et al*, 1987. This increase in volume is due to gas expansion as well as the addition of combustion products such as fire gases and evaporated water. As a result the velocity of air downwind from the fire is increasing and additional pressure loss following the square law results.

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

$$R_t \propto T^2$$

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

Buoyancy (natural draft) effects

Local or roll back effect

The most immediate effect of heat on the ventilating air stream is a very local one. The reduced density causes the mixture of hot air and products of combustion to rise and flow preferentially along the roof of the airway. The pronounced buoyancy effect causes smoke and hot gases to form a layer along the roof and, under low air velocity in a level or descentional airway, may back up against the direction of airflow. This has been discussed by Mitchell, 1990.

Whole mine natural ventilation pressure effects

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

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

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

ANATOMY OF A HEATING

The development of a spontaneous heating in coal is a complex phenomenon and is poorly understood. This is at least in part because it is so difficult to observe real heatings and particularly those in underground coal mines which have the greatest potential to cause damage. Much of what is known about spontaneous heatings is derived from laboratory studies of very small scale tests. These tests provide valuable data on the many parameters that affect the oxidation process and the production of off-gases that might be used for detection purposes. It is, however, virtually impossible to comprehensively examine a real heating, to measure its temperature distribution, to measure the airflow involved, or to measure almost any aspect of its behaviour. It is impossible to conduct an 'autopsy' on a heating to see what has happened. Considerable insight can, however, be gained into the nature of real heatings by examining in detail the results obtained from a simulated heating.

All spontaneous heatings require that certain conditions are satisfied for the coal temperature to continue to rise. Primary amongst these conditions is that, at some point within the pile or solid mass of coal, the rate of heat generation from oxidation exceeds the rate of heat loss due to conduction and convection. If ever this condition is not fulfilled, the heating will have reached a maximum temperature and there will be no further increase. The temperature in the pile or mass of coal will henceforth begin to decrease. Whilst the requirement for this condition is well known, it is difficult to predict the characteristics of coal mass or size, coal reactivity, airflow flux and other parameters that will allow the development of a high temperature heating.

Model used to examine the development of a spontaneous heating

Humphreys, 2004 has developed a numerical model to examine the development of a heating within a coal mass, pillar or pile. For the purposes of modelling, it has been assumed that the starting conditions in the coal pile are homogenous; that is with all coal at the same particle size, reactivity and initial temperature. An underground coal pillar or solid mass will have a permeability that allows passage of air as controlled by the mine ventilation air pressure across the pillar. This permeability is likely to be lower than that exhibited by loose coal in a pile although the spontaneous combustion development characteristics will follow the same trend. In Humphreys' analysis the airflow flux is constant across the model although obviously there is consumption of oxygen as air passes through the model. For the purposes of examining the nature of a spontaneous heating as it occurs in a pile of coal, a quasi three-dimensional model has been run for a representative coal.

Humphreys, 2004 summarises the base case modelling parameters in Table 1.

The output from the model was selected to give the distribution of coal temperature and oxygen content in the pile during the development of the heating. This data has been used to show the development of a heating to the point that would represent a significant hazard if present in a coal mine or stockpile.

Development of a spontaneous heating

At the commencement of the simulated heating, the temperature throughout the pile was set at 35°C and it was noted that there was linear gradation in oxygen content across the pile from the upwind surface at 21 per cent toward the downwind surface where it had fallen to 17 per cent. Some aspects of this development are illustrated in Figure 1. During the very early stages of the heating development, the oxygen concentration in the pile tends to rise as the initial high rate of oxidation diminishes, due to the effect of accumulated oxidation. The

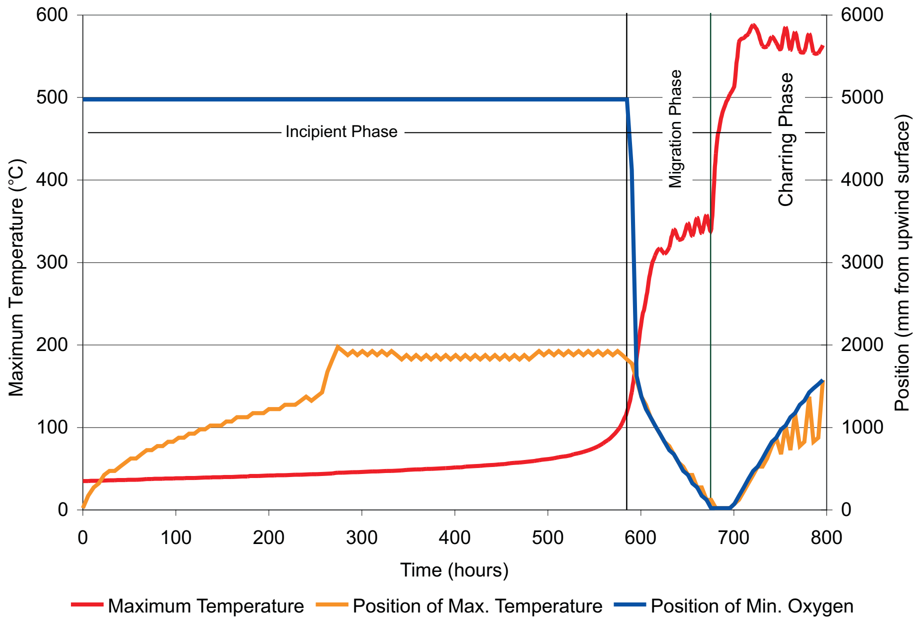


FIG 1 - Base case heating development – temperature and oxygen.

TABLE 1

Base case modelling parameters.

Property	Value
R_{70}	0.9°C/hour
RIT	162°C
Ko	6500 g O_2/min/kg
Ho(40°C)	4500 J/g O_2
Relative oxidation reactivity	25%
Particle top size 95% passing (mm)	91 - 400 mm
Airflow flux	20 litres/min/m^2
Diameter	5 m
Length	5 m
Mass	128 tonnes
Initial coal and ambient temperature	35°C

oxygen concentration is quickly dominated by the effect of increased temperature in the centre of the pile. A temperature gradient is also rapidly established around in the pile as the interior begins to heat but the temperature at the edges remains low due to heat losses to the surroundings.

The simulation model shows that at about 444 hours the peak pile temperature has reached 55°C about 1875 mm from the upwind surface and the temperature distribution already shows a steeper gradient at the front of the pile than at the back. The oxygen concentration is everywhere more than 17.8 per cent, although there is a gradient from the front to the back of the pile. The rate of oxidation is therefore not significantly affected by the oxygen content at any point in the pile, but will be slightly higher at the front of the pile. The minimum oxygen concentration occurs at the back surface on the centreline of the pile. The rate of self-heating is only about 0.1°C/hour.

The situation is only slightly different at 549 hours when the peak temperature has reached 75°C. The peak temperature is still located about 1875 mm from the upwind surface. The major difference is that the minimum oxygen concentration in the pile has now fallen to about 14.6 per cent still at the downwind surface on the pile centreline. The rate of self-heating in the pile rises to about 0.4°C/hour.

By 574 hours, the peak temperature has reached 95°C still at about 1875 mm from the upwind surface of the pile and the minimum oxygen content has fallen to nine per cent at the downwind surface of the pile. At the position of the highest temperature, the oxygen concentration is still in excess of 15 per cent. This will not significantly limit the rate of self-heating which has reached about 1.25°C/hour. This is a considerable increase over the rate at 75°C and it can be expected to continue to increase. There appears to be a distinct 'hotspot' forming with only about six per cent of the coal hotter than 75°C.

The hotspot becomes more significant as the heating continues to develop. By 585 hours, it has reached 119°C and has moved slightly forward in the pile to about 1825 mm. The rate of self-heating in the pile continues to rise and has reached about 2.6°C/hour. There is a significant gradient in the oxygen concentration from the front to the back of the pile, where the minimum oxygen concentration has fallen to less than three per cent. The most significant reduction in the oxygen content is on the centreline of the pile in the region of the hotspot. This gives rise to a complicated mass/temperature/oxygen distribution in the pile whereby, in some parts of the pile, the rate of oxidation is now significantly reduced due to the low oxygen concentration irrespective of the coal temperature. The oxygen concentration at the hotspot however, remains above 12 per cent and therefore the oxidation rate and self-heating rate are not significantly affected by any oxygen reduction. At the hotspot, the rate of self-heating is about 75 per cent of that in air. The areas most affected by oxygen reductions at this stage are those downwind of the hotspot.

Over the next few hours, there is a significant change in the nature of the heating. The temperature of the hotspot continues to rise and the temperature profile upwind of the hotspot becomes such that all the oxygen entering the pile on the centreline is consumed before reaching the hotspot. Because the rate of oxidation at the hotspot must also have fallen to zero due to the low oxygen concentration, the temperature at that point can no longer rise through oxidation, but only by heat transfer to it from other 'hotter' parts of the pile. The only points in the pile that can become hotter than the current hotspot are those upwind on the centreline, where oxygen is still available. All points downwind are receiving no oxygen. All other points off the centreline will have higher heat losses through conduction to 'cooler' parts of the pile. This causes the hotspot to migrate forward in the pile.

By 610 hours, the peak temperature has reached 277°C and the hotspot has migrated forwarded to be 1075 mm from the upwind surface of the pile. This coincides with the position of the minimum oxygen concentration in the pile which has fallen to zero per cent.

The rate of self-heating in the pile tends to decrease for a period between 620 and 680 hours. The peak temperature in the pile remains fairly constant at about 340°C but the position of the hotspot migrates forward from 675 mm to 275 mm leaving behind substantial quantities of hot coal which can no longer oxidise due to the low oxygen levels. This is evident in changes in the mass/temperature distributions and there is a significant increase in the coal mass above 300°C over this period.

There is an obvious limit to the forward movement of the hotspot when it encounters the upwind surface of the pile at about 675 hours. This triggers another change in the behaviour of the heating and there is another rapid rise in the peak coal temperature. At 685 hours, the peak temperature has reached 467°C and is located at the upwind surface of the pile. At this point, it could be expected that the heating will cause the outbreak of open fire, if the coal is loose enough or falls away from the side of the pile, and excess oxygen becomes available to the hot coal. This transition is likely to be very rapid as the temperature gradients ahead of the hotspot are very high, exceeding 2000°C/metre during this phase of the heating.

Alternately, it is possible that the heating continues without fire at the upwind surface and the peak temperature continues to climb and eventually leads to the formation of a charline, when the heating consumes all the reactive portion of the coal. For this heating, this occurs after 705 hours and the coal has reached a peak temperature of about 570°C. The cumulative loss of reactive material is such that the coal can be regarded as being coked and a charline is formed in the pile. The position of the charline is superimposed upon the oxygen distribution at 710 hours in Figure 2.

Upwind of the charred zone, oxidation and pyrolysis has consumed the entire reactive portion of the coal leaving an unreactive coke or char material. In the mass-temperature distribution, the mass of coal at a particular temperature range is spilt between oxidising and unoxidising. Unoxidising coal represents that part of the original coal lost to oxidation and pyrolysis. Much of this is in the form of solid char, although some is lost as gaseous products of oxidation and pyrolysis. There is a very significant increase in the unoxidising coal once the temperature exceeds about 550°C and char is formed in the pile as shown.

The heating has now entered its final phase of charring and, unless halted by some other process, continues to char the whole pile as illustrated in Figures 1 and 2 between 700 and 800 hours. The charline expands laterally and migrates downwind leaving behind hot unreactive coke.

In summary the development of this heating can be summarised in the two fairly simple Figures 1 and 2 showing the important features discussed above. The peak temperature in the pile, the position of the peak temperature (the hotspot) and the position of the minimum oxygen concentration in the pile are shown in Figure 1. The development of the charline is shown in Figure 2. The main features that have been discussed above are readily visible. At the very start of the heating, there is a moderately rapid increase in temperature, with the 'hotspot' located at the upwind surface of the pile and the minimum oxygen concentration at the back surface. The rate of temperature rise moderates (not visible on the figure but occurs nevertheless) and the position of the peak temperature moves gradually downwind. The position of the minimum oxygen remains at the back surface of the pile, although the minimum oxygen concentration is decreasing. After 275 hours, the peak temperature has moved to the furthest downwind position at about 1900 mm. The hotspot remains in this position until its temperature exceeds 125°C.

This triggers a change in the behaviour of the heating and the hotspot begins to migrate forward. Shortly afterwards, the minimum oxygen concentration in the pile falls to zero, as does the oxygen concentration at the hotspot. Despite this, the peak pile temperature is increasing rapidly, at approximately 8°C/hour.

Once the positions of the peak temperature and minimum oxygen concentration coincide, they begin to migrate together toward the upwind surface. This can only begin when the temperature profile in the coal ahead of the hotspot is sufficient to consume all the oxygen entering that part of the pile. The forward migration of the heating is limited by the upwind surface which triggers another increase in the coal temperature. A short while after this, the temperature of the coal is sufficient to cause charring and a charline is formed in the pile. The final phase of the heating is the lateral expansion and downwind migration of the charline, as all the reactive elements in the coal are consumed by oxidation.

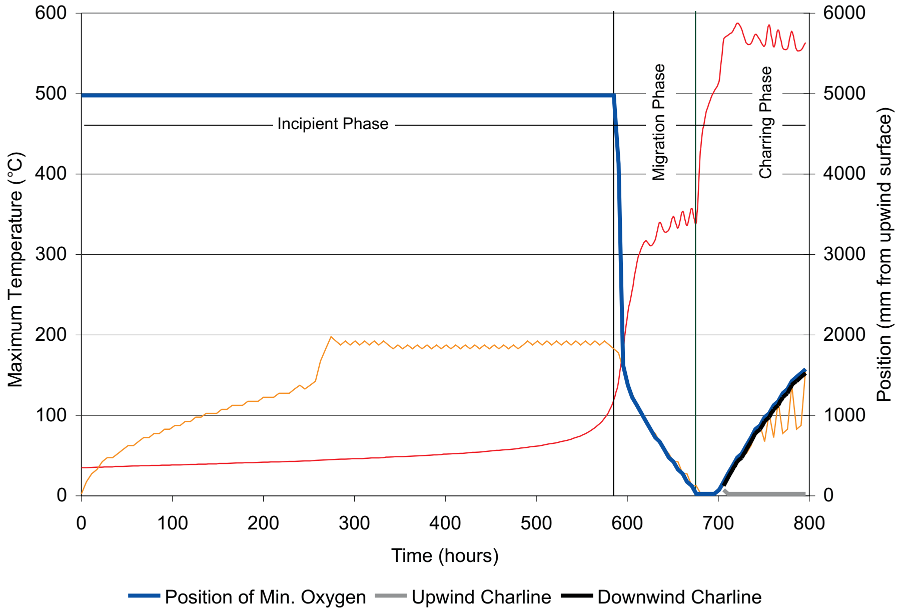


FIG 2 - Base case heating development – charline development.

From this analysis, it is possible to divide the development of this heating into three distinct phases:

1. The incipient phase characterised by peak temperatures up to about 125°C. During this phase a hotspot develops from the upwind surface, migrates downwind to a maximum depth and remains static in that position.
2. The migration phase characterised by the forward migration of the hotspot. During this phase the oxygen concentration falls to zero per cent and there is a very rapid increase in the peak coal temperature. Without remedial action, the heating continues to develop and could lead to the outbreak of fire at the upwind surface of the pile.
3. The charring phase, when the temperature in the pile is sufficient to cause the formation of unreactive char. Without remedial action the heating will continue to develop until the hotspot and charline encounter the downwind surface when an open fire could break out.

These phases have been shown in Figures 1 and 2. The most significant phase in any heating is the initial incipient phase to about 125°C. Any spontaneous heating which is sufficiently large as to pose a threat to safety will have to pass through the incipient phase. Most of the time required for a dangerous heating to develop will be in reaching 125°C. There may be circumstances in which a coal can be exposed to airflow and such a heating will not develop. For example, if the mass or thickness of the coal pile is insufficient, heat losses will predominate at some temperature and a spontaneous heating will not occur. However, for heatings of significance, the incipient phase time period will be significant and there are a number of important factors in determining whether spontaneous combustion will occur in a particular coal.

SIMULATION OF A SPONTANEOUS COMBUSTION INDUCED MINE FIRE

Ventgraph fire simulation software has been used to examine and illustrate the effects on the mine ventilation network of an open fire on a pillar sidewall rib induced by a spontaneous combustion heating developed from within the pillar. The simulation illustrates the effects of the fire on the whole mine ventilation network after an incubation period of about 700 hours following the outbreak of the pillar fire following a long incipient period and a migration phase upwind. The pillar under examination is positioned separating a mains intake heading from a return heading and so the heating has initially migrated toward the intake air. A fire development is examined in two stages within the case study mine.

1. an open fire that has broken out on the intake side of the pillar; and
2. a subsequent stage when an open fire has broken out on the return side of the pillar (the charring phase, when the heating has continued to develop until the hotspot and charline encounter the pillar rib on the return side).

This hypothetical spontaneous combustion incident is reported as a simulation scenario that focuses on effects across the whole mine network. It is written up as a series of developments against time from the outbreak of the open fire in the pillar rib.

FIRE SCENARIO DEVELOPMENT

Spontaneous combustion fire in fractured pillar coal in the rib of F Heading inbye 27 c/t. There is a very high pressure of about 1200 Pa across the F to G (intake/return) pillar. Heating started as deep-seated oxidation. In the initial stages of heating, moisture transfer and coal oxidation predominate. Mains entry nomenclature is as follows:

- Headings C and D are intake transport roads,
- Heading E is the intake belt road,
- Heading F is another intake road (second means of egress), and
- Headings B, G, H and I are returns.

Intake side fire following the migratory phase

As the coal dries out, a substantial local hot spot develops near the air inlet and begins to migrate upwind. Heating front has moved upstream in search of oxygen to the F Heading pillar rib. It has just developed to the point of an open fire. Prior to running the Ventgraph simulation mine ventilation and gas characteristics and monitoring controls that may be required are pre-entered.

- CO and CH_4 electronic sensors inbye the fire at 4 N LW and 5N development TG Dog Legs;
- CO sensors in E Heading 10 - 11 c/t and 38 - 30 c/t; and
- CH_4 sources of 0.4 m^3/s from 4N LW face and 5N development face.

Assume CO sensors in control room have alarm set at 8 ppm.

Simulation

- **Step 1** – Time 0 - 30 minutes: simulate 1 m length open fire over entry width.

  Smoke first reaches 5N development face at 22 minutes.

  Control: Hypothetical action of development face crew. Crew see smoke and phone outbye deputy at 30 minutes. Crew contact control room operator (CRO) and CRO ask LW crew to evacuate mine. Crews drive out in smoke. Crews reach surface at time since fire outbreak of 45 minutes.
- **Step 2** – Time 30 - 60 minutes: coal fire grows. 5 m entry length coal burning.

  Control: Hypothetical action of deputy:
  - deputy finds fire source at 45 minutes after fire start, and
  - deputy has hose ready to fight by 60 minutes.
- **Step 3** – Time 60 - 90 minutes: coal fire grows. 25 m entry length coal burning.

  Control: Deputy cannot extinguish fire at 90 minutes and drives out of mine. Reaches surface at 105 minutes. Fire out of control. Decision reached that underground ventilation control will be ineffective. Decision made to shut down the two underground booster fans and one main fan.
- **Step 4** – Time 90 - 120 minutes: continue coal fire. 25 m entry length coal burning.

  No CO sensors in mine have alarmed yet.
- **Step 5** – Time 120 - 180 minutes: coal fire grows. 50 m entry length coal burning.

  CO sensors on 5N development Dog Leg first alarms at 130 minutes.

  Air carrying significant CH_4 never reaches the fire zone during the simulation. CO sensor 4N LW Dog Leg has not alarmed after 180 minutes.
- **Step 6** – Time 180 - 240 minutes: coal fire grows. 100 m entry length coal burning.

  CO sensor 5N Dog Leg is alarming at 240 minutes.
- **Step 7** – Time 240 - 420 minutes: continue coal fire, 100 m entry length coal burning.

  CO sensor in E Heading 32 c/t alarming and smoke has reached LW face.

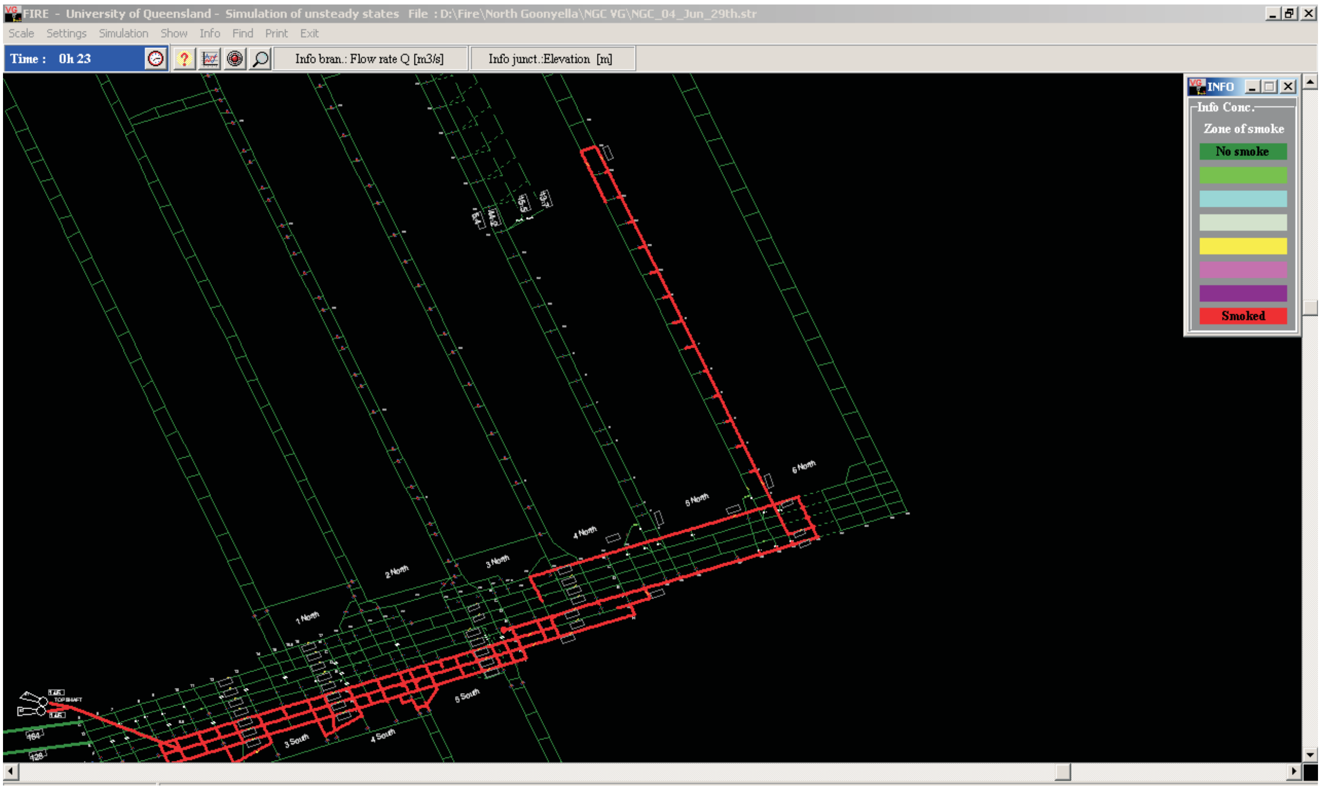


FIG 3 - Smoke distribution after 22 minutes. Some smoke is reaching surface exhausting main fans outlets.

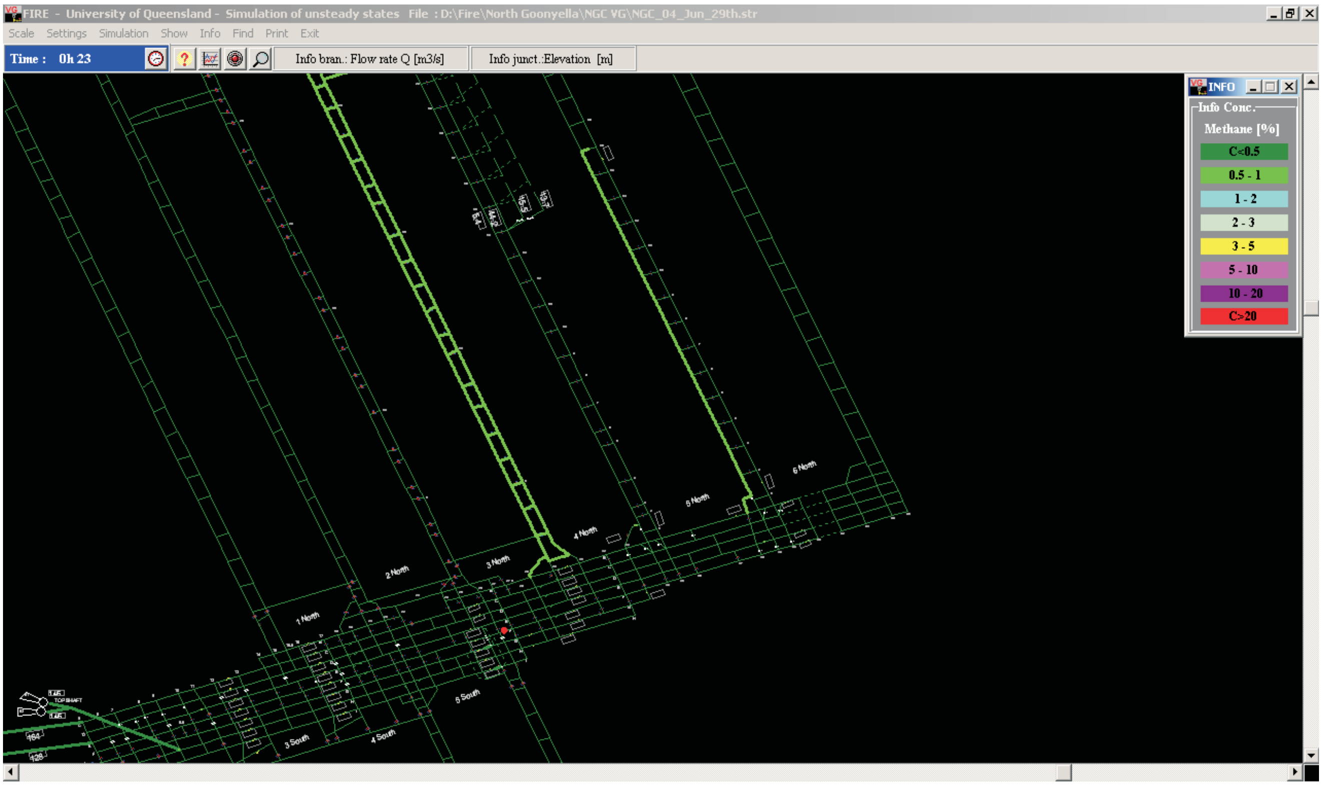


FIG 4 - CH_4 distribution from mine seam gas after 22 minutes.

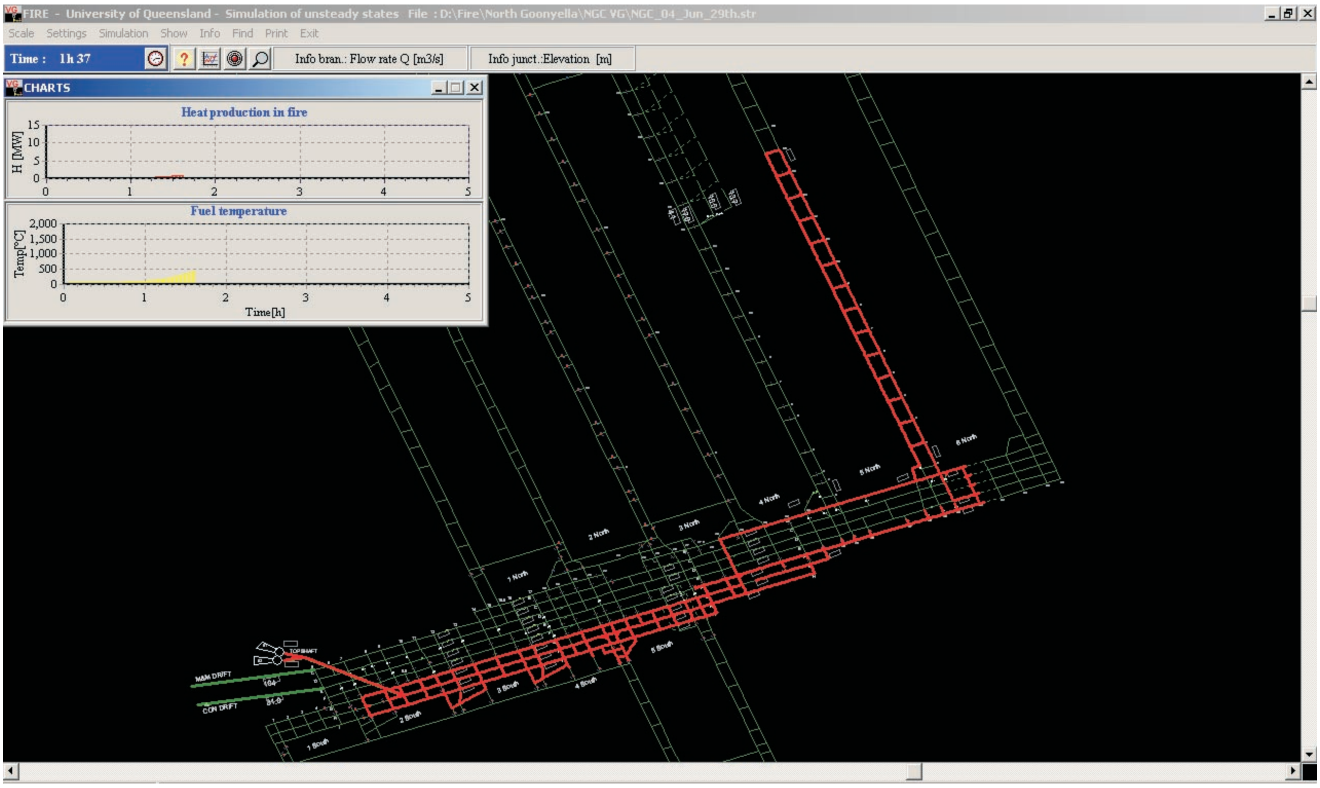


FIG 5 - Smoke distribution, heat production and fire temperature after booster and mine fans turned off 97 minutes after fire started.

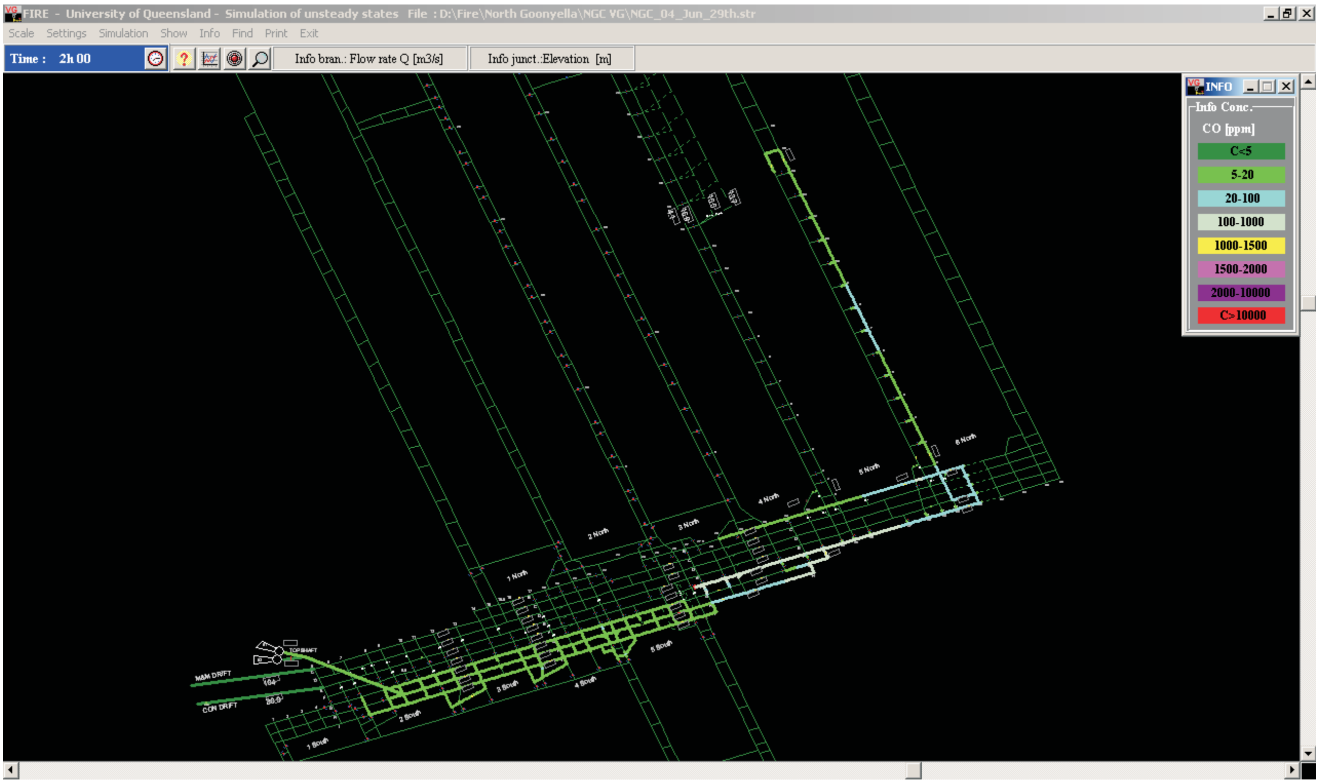


FIG 6 - CO distribution after 120 minutes.

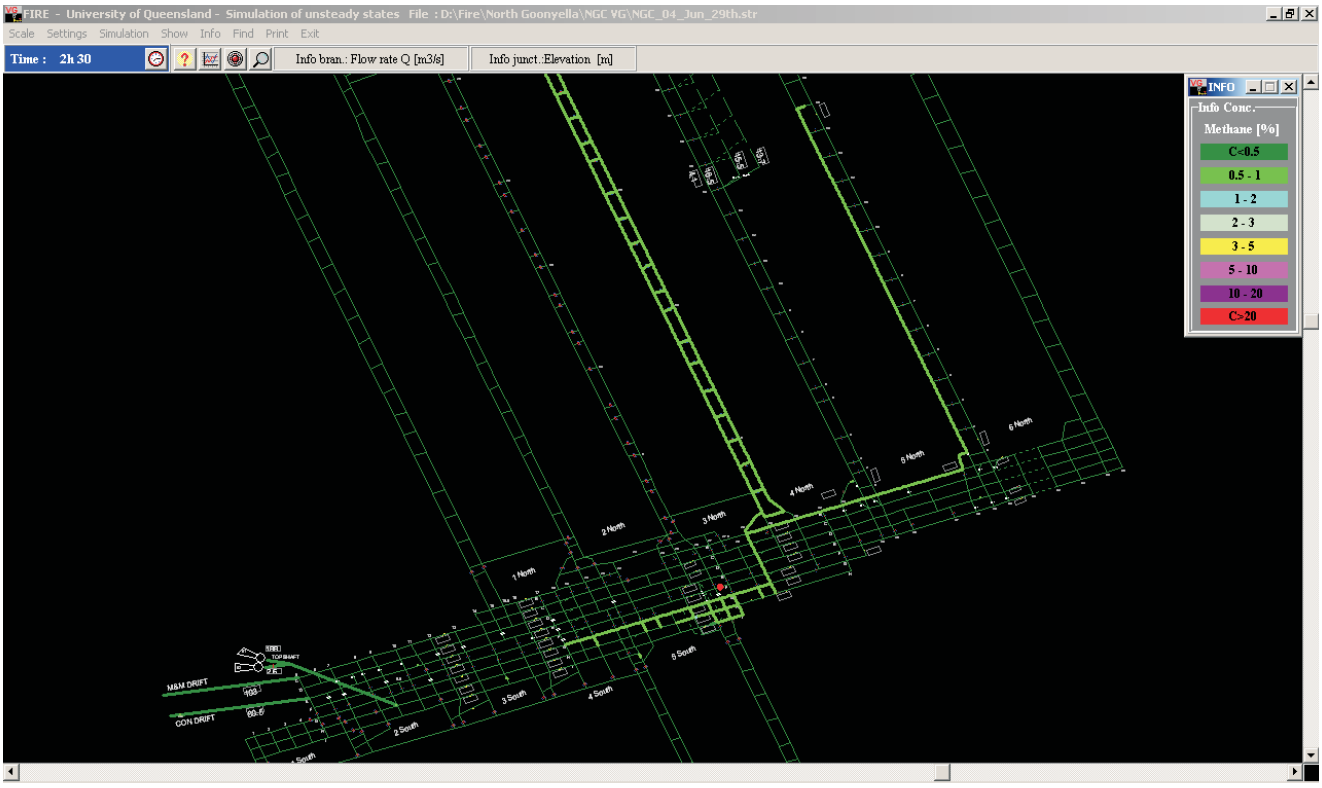


FIG 7 - CH_4 distribution after 150 minutes.

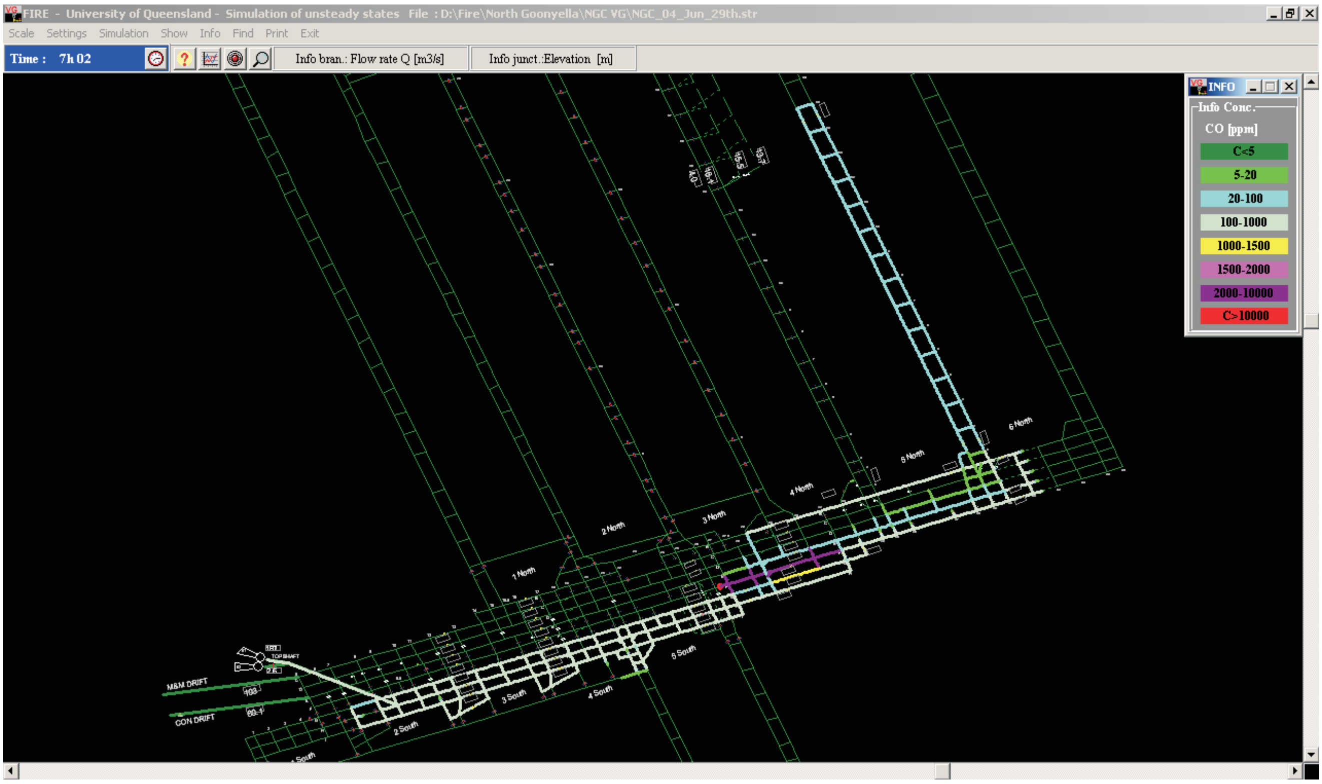
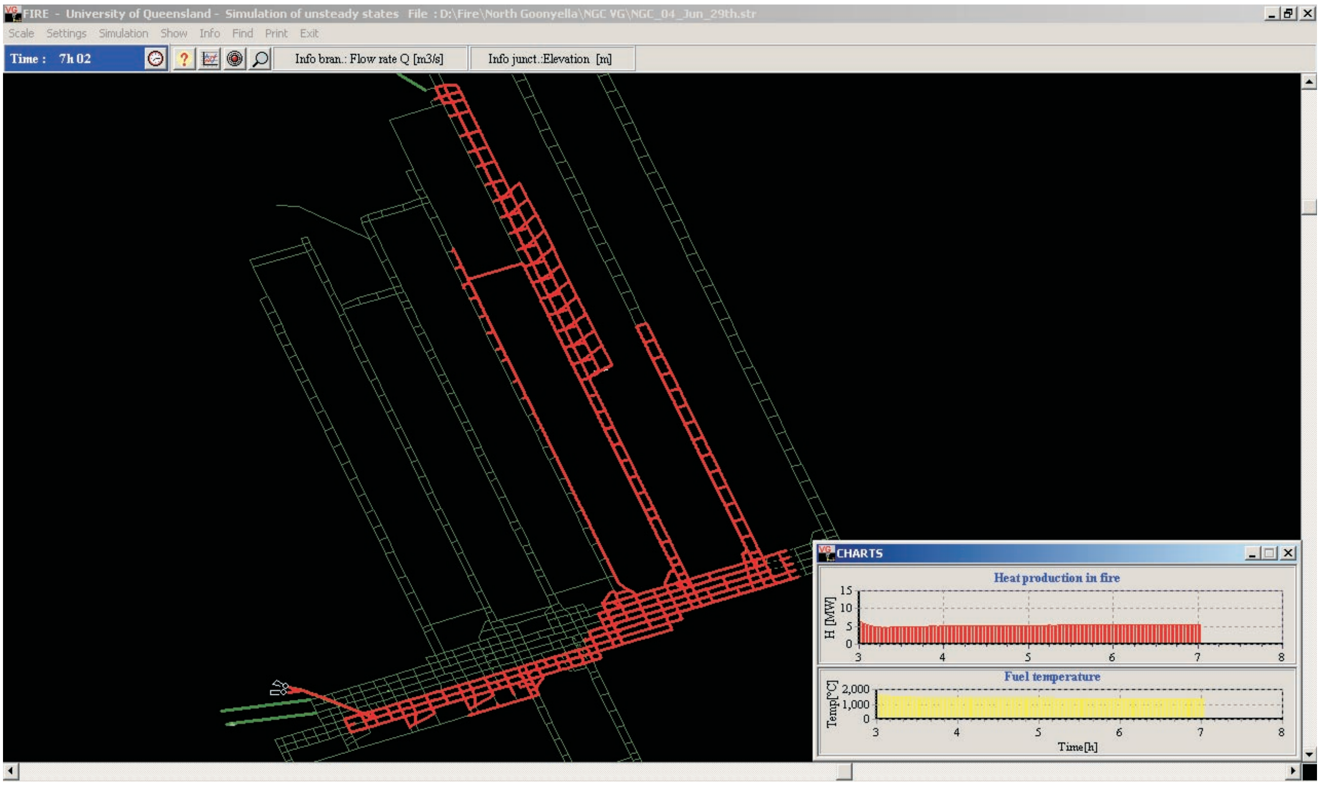


FIG 8 - CO distribution after 420 minutes.



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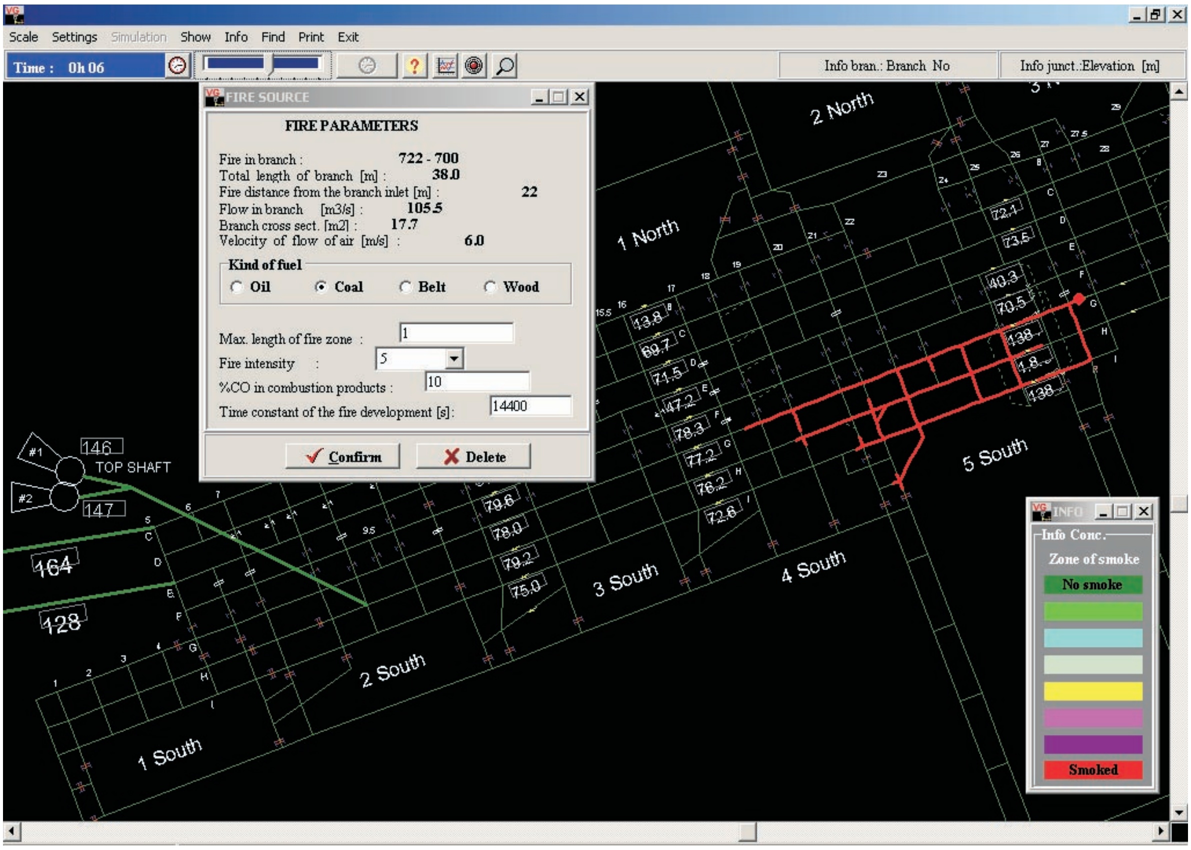
Time : 7h 02

Info bran.: Flow rate Q [m3/s]

Info junct.:Elevation [m]

FIG 9 - Smoke distribution, heat production and fire temperature after 420 minutes.



Time : 0h 06

Info bran.: Branch No

Info junct.:Elevation [m]

FIRE SOURCE

FIRE PARAMETERS

Fire in branch : 722 - 700
Total length of branch [m] : 38.0
Fire distance from the branch inlet [m] : 22
Flow in branch [m3/s] : 105.5
Branch cross sect. [m2] : 17.7
Velocity of flow of air [m/s] : 6.0

Kind of fuel
○ Oil ● Coal ○ Belt ○ Wood

Max. length of fire zone : 1
Fire intensity : 5
%CO in combustion products : 10
Time constant of the fire development [s]: 14400

FIG 10 - Smoke distribution after five minutes.

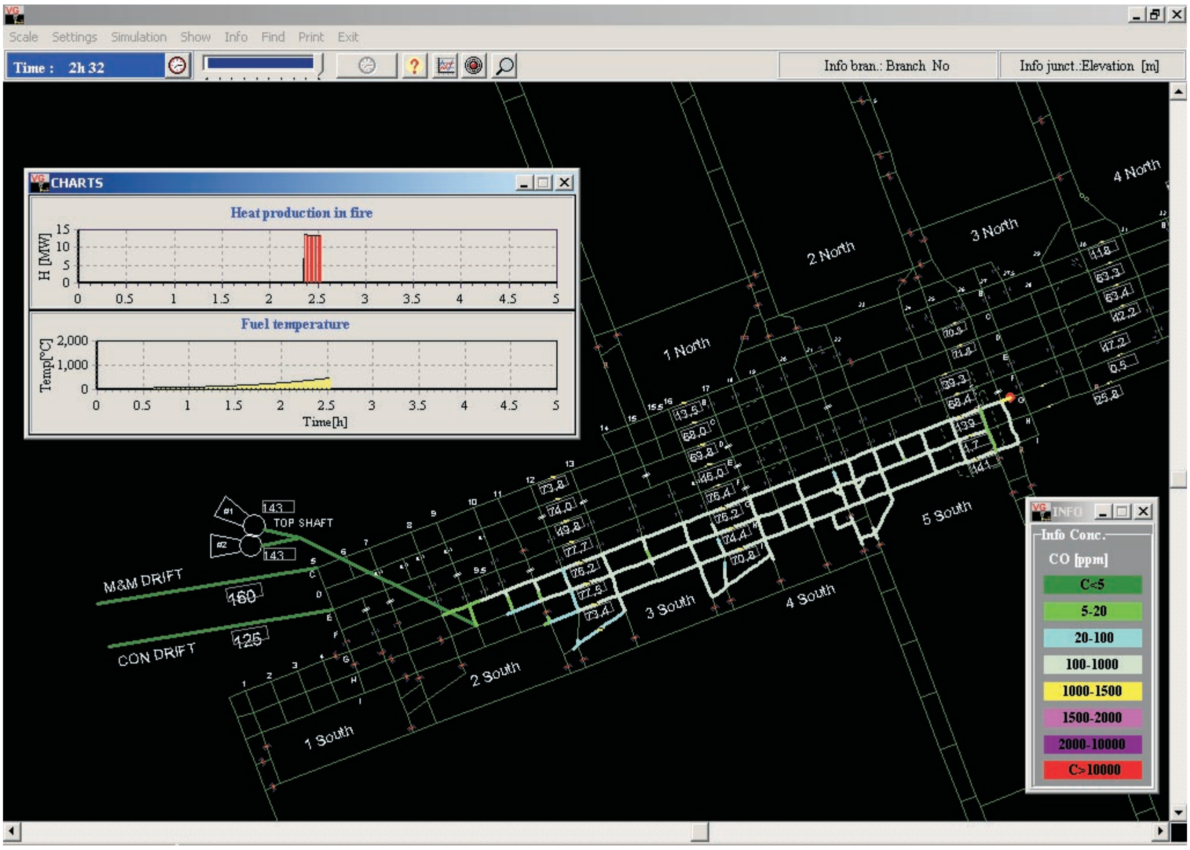


FIG 11 - CO distribution levels after 150 minutes.

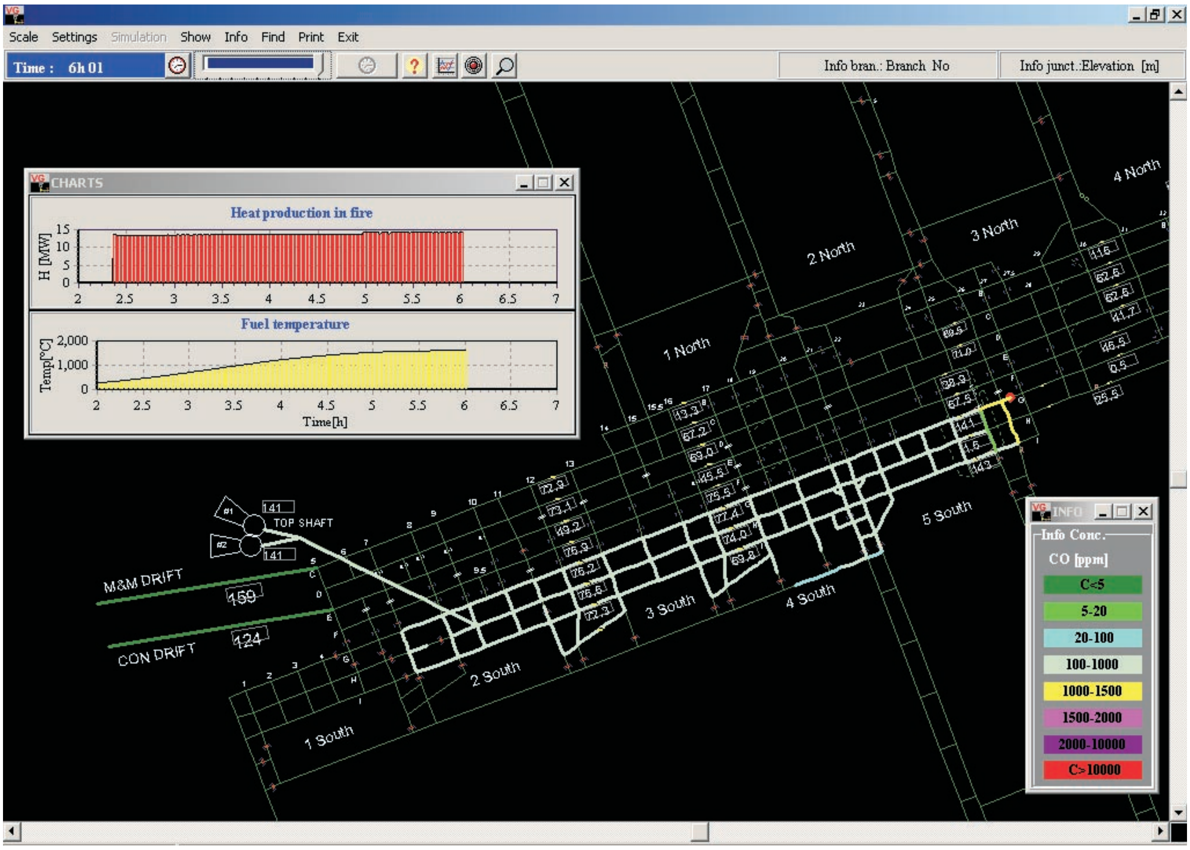


FIG 12 - CO distribution levels, heat production and fire temperature after 360 minutes.

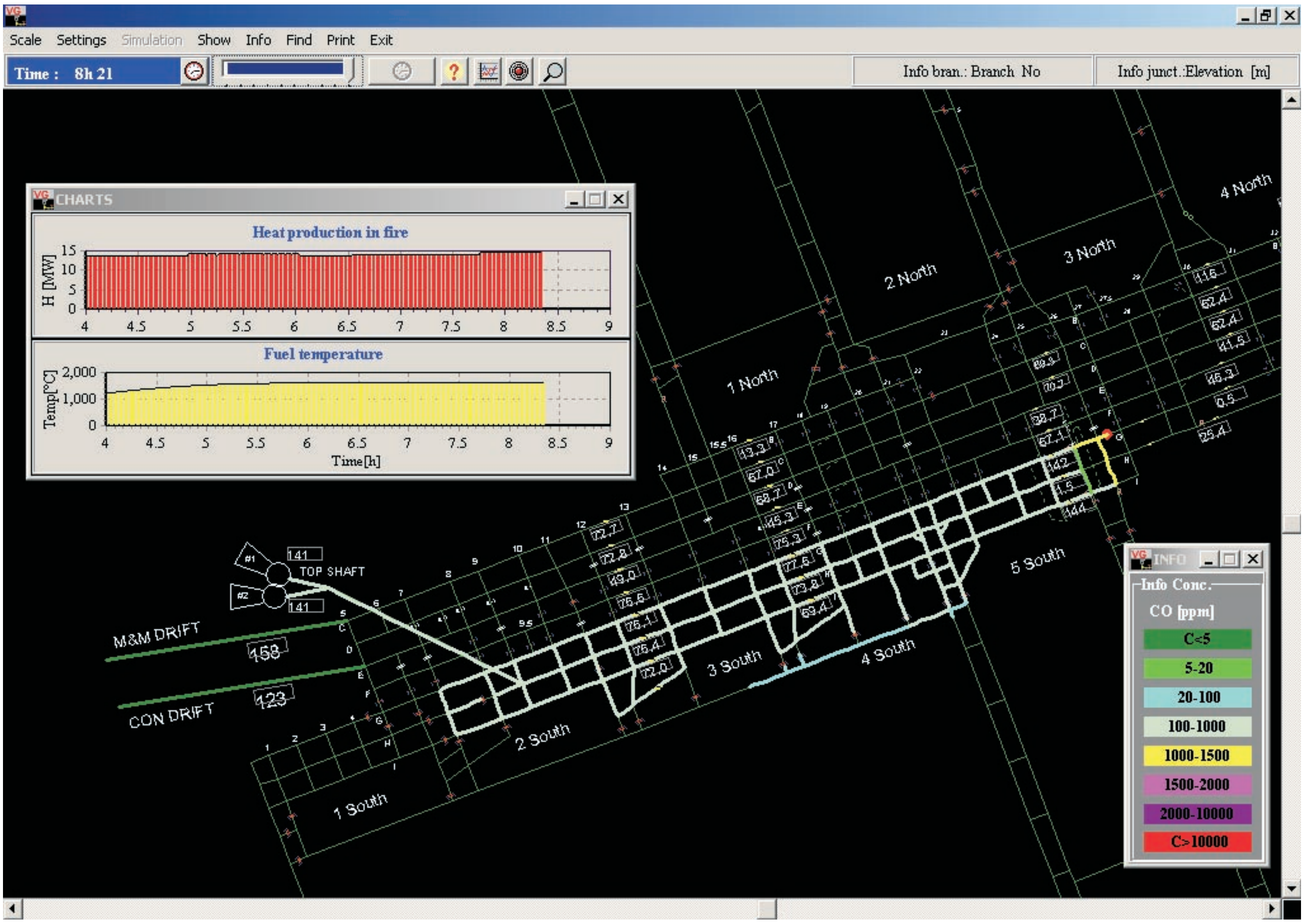


FIG 13 - CO distribution levels, heat production and fire temperature after 500 minutes.

Return side fire following the charring phase

Following the charring phase, when the heating has continued to develop until the hotspot and charline encounter the pillar rib on the return side an open fire has broken out on the downwind side of the pillar.

A spontaneous combustion initiated fire in fractured rib pillar coal in G Heading (return) outbye 27 cut through and near the No 2 booster fan. There are no electronic sensors inbye the fire.

Simulation

- **Step 1** – Time 0 - 360 minutes: simulate 1 m length fire over entry width.
- **Step 2** – Time 360 - 720 minutes: continues coal fire 5 m entry length coal burning.

Both these intake and return side scenario simulation could be undertaken for much longer on the assumption that coal within the mine continues to burn and no remedial action such as flooding or introduction of gas inertisation occurs. It has shown how a relatively common form of mine fire, a spontaneous combustion initiated coal pillar fire (with the pillar separating intake and return air and with substantial pressure differences) can affect the mine workings. It has shown how CO levels in mine airways increase over time for a specific fire build up scenario.

In the intake side fire significant CO levels reach the mains and 5N development faces early but also eventually reach the 4N LW face if the fire is not stabilised and extinguished. The fumes from the fire have only limited effect on the LW face as it receives most of its intake air from mains C and D transport roads.

In the return side fire significant CO levels build up. However, these pollutants are restricted to the return airways and so do not directly imperil miners who are evacuating the mine.

CONCLUSIONS

A study has examined the potential for simulation of the effects of a relatively common form of mine fire, a spontaneous combustion initiated coal pillar fire on a mine ventilation network. The project involved applying the 'Ventgraph' mine fire simulation software to preplan for mine fires and possible emergency evacuations.

The background to this approach to simulating the effects of mine fires on the mine ventilation network has been examined. The anatomy of a spontaneous combustion heating has been analysed. The three stages in the development of a mine pillar or pile heating, namely the incipient phase, the migration phase characterised by the forward migration of the hotspot and possible open fire on the forward surface and the charring phase, when without remedial action the heating will continue to develop until the charline encounters the downwind surface when an open fire could break out.

A case study of the simulated effects of fumes from a fire on the ventilation of a modern Australian mine has been examined. Mine fires are recognised across the world as a major hazard issue. New approaches allowing improvement in understanding their consequences have been developed as an aid in handling this complex area.

The mine fire simulator Ventgraph has been shown to be an important tool in planning for mine fires developed from spontaneous combustion heatings. The capability to visually display the spread of effects of a fire quickly and reliably provides a strong aid to those involved in developing emergency plans or contributing to emergency management. The active use of mine fire simulation in emergency planning should continue to be encouraged.

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