MINE FIRES AND VENTILATION

By
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ABSTRACT

An underground mine fire will influence the ventilation equilibrium in several ways which results in a redistribution of the ventilating quantities and pressures throughout the whole mine. The ventilation carries the combustion products which constitute the greatest danger of mine fires through the mine and provides the oxygen on which the intensity of the fire depends. However, as a result of the ventilation disturbances created by the fire, changes in airflow patterns can take place which are not always obvious, especially when the mine is being served by several fans. The use of computer simulation techniques allow for the likely effects to be tested and the different ventilation options to be evaluated as an integral part of the overall emergency/rescue planning and control procedures.

INTRODUCTION

Little has been published about the actual ventilation changes which have taken place during an underground mine fire emergency and only a few ventilation reversals have been recorded such as the Davidson shaft fire in 1952 at Mount Isa and the Sunshine mine fire in U.S.A. (1).

As the use of digital computers is gaining general acceptance for conventional ventilation planning within the Mining Industry, their suitability as a simulation tool in areas outside those normally considered, such as sudden gas emissions, prolonged fan stoppages and underground fires is increasingly being recognised.

The complexity of multiple main fan ventilation systems and the high probability of reversed air flows was investigated in some detail by Kingery and Kapsch (1959) (2) using analog computers. The introduction of digital computers in the sixties has made the calculation of airflow and pressure distributions (commonly called network calculations), almost a routine matter for ordinary ventilation planning purposes. These techniques currently find wide application in ventilation stability determinations for the West German coal mines (3).

VENTILATION MODELS

Hardy Cross (4) developed the mathematics which enabled ventilation networks to be calculated on digital computers using a reiterative procedure. Most simulation programmes currently available use the above technique and treat the air as an incompressible medium, which means that the change in density due to temperature, elevation, humidity and mixtures of other gases is being ignored. For routine ventilation planning purposes this incompressible assumption does not give rise to unsatisfactory results as the errors are usually within the limits of those encountered during the pressure-quantity surveys.

When considering Natural Ventilating Pressures (N.V.P.) during fan stoppages (5) (6), air velocities in excess of 100 m/s and

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differences in elevation greater than 500 metres (7) the incompressible model no longer gives results within an acceptable error range. Under these conditions the air must be treated as a compressible medium which uses the laws of thermodynamics to define the mathematical relationships between the variables.

It does not require much imagination to realise that when considering the interaction between mine fires and the mine ventilation system that the thermodynamic approach must also be used.

EFFECTS OF MINE FIRES

Fires have basically two effects on the ventilation equilibrium :-

(a) Throttling effect, which is mainly caused by the volume increase of air passing through the fire zone and being heated.

(b) Buoyancy effect, which is caused by the conversion of heat into mechanical energy which is then available to propel the air.

Both effects can have a pronounced effect on the distribution of the main fan pressure throughout the mine workings and can lead to instability in part or as a whole of the mine network. This is particularly the case for extended workings over significant elevation differences and/or multi fan situations. The instability can result in reduced or reversed quantity flows which in turn could result in explosive mixtures being drawn over the fire, increases of CH_4 concentrations to unacceptable high levels and severely endanger those engaged in the fire fighting/rescue operation. A secondary concern would be the total disorientation in relation to escape routes of mining personnel as a consequence of a ventilation reversal.

THROTTLING EFFECT

As a result of the temperature increase of the air as it passes through the fire zone, an increase in volume takes place which in turn results in an increased pressure drop over that section. This pressure drop would be :

$$p = R\ T2/T1\ Q^2$$

where p = pressure drop change (pa)

R = resistance of section of roadway ($Ns^2/m8$)

T_2 = absolute fire temperature (K)

T_1 = absolute intake temperature (K)

Q = quantity before the fire (m^3/s)

In addition, the products of combustion give rise to an increased volume flow which results in the following pressure drop :-

$$p = RQ^2\ (\Delta Q)^2$$

where ΔQ = increase in volume due to the products of combustion.

This means that for a fire source temperature of 800°C giving off 10% by volume or products of combustion, the pressure drop over the fire zone would change by a factor of 3.8.

BUOYANCY EFFECT

As the temperature of the air increases the density decreases, which means that if an air column is available through a difference in elevation a buoyancy effect takes place. This buoyancy does therefore not only depend on the temperature of the fire itself, but also on the height of the air column available on the intake and outbye side of the fire. If there is no difference in elevation on the intake side of the fire, no permanent reversal of the airflow can take place. This means that if the fire source is located at the top of a downcasting staple shaft the effect would be a pulsating throttling down to zero flow, but no reversal will take place unless the network is short circuited.

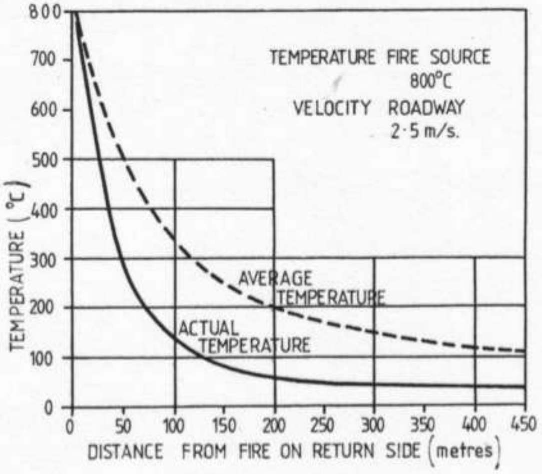

FIGURE 1

ACTUAL AND AVERAGE AIR TEMPERATURES BEHIND AN U.GROUND FIRE (AFTER SCHUBERT AND BOTH)

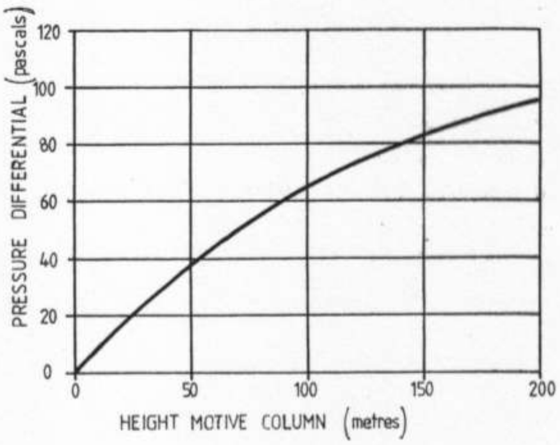

FIGURE 2

PRESSURE DIFFERENTIAL OF MOTIVE COLUMN DUE TO AN U.GROUND FIRE (AFTER SCHUBERT AND BOTH)

Figure 1 shows the temperature distribution along a single roadway for a 800oC heat source fire as reported by Schubert and Both (1974)(8). Figure 2 illustrates the buoyancy effect of the same fire source related to air column height available using the following relationship :

$$p = (b \times h \times (tm - ti)) \div (r(ti + 273) \times (tm + 273))$$

where b = absolute air pressure (K)

h = effective difference in elevation (m)

tm = average temperature in oC on return side of the fire

ti = intake air temperature in oC

r = universal gas constant

From this relationship the significance of an accurate knowledge of the fire source temperature and the temperature gradient along the roadway becomes readily apparent.

VENTILATION INSTABILITY

Ascentional Ventilation

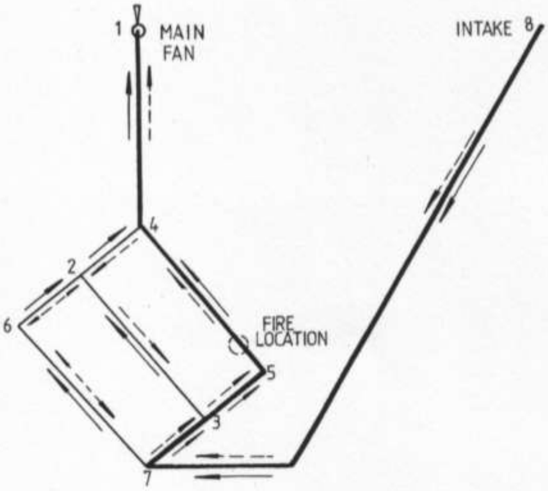

FIGURE 3

STABILITY OF AIRFLOW WITH AN UNDERGROUND FIRE ASCENSIONAL VENTILATION

5 — NODE LOCATION

——→ — FLOW DIRECTION BEFORE FIRE

– – → — FLOW DIRECTION BECAUSE OF FIRE

━━━ — STABLE AIRWAYS

Figure 3 shows a simplified network with ascensional ventilation, i.e. node 7 is the lowest point. By having a fire at a location between nodes 5 and 4, we note that the quantity flowing to the fire is increased because the buoyancy effect is usually greater than the throttling effect. The overall effect on the network would be :-

Increased flow:	3-5, 5-4
Reversal of flow:	2-3
Instability:	6-2, 7-6, the

direction of flow depending on the relative resistances within the network. This means that of the network only airways 8-7, 7-3, 3-5, 5-4 and 4-1 are stable.

Descensional Ventilation

In this situation the ventilaing quantity is reduced both by the throttling effect and the buoyancy effect which both act against the normal ventilating direction.

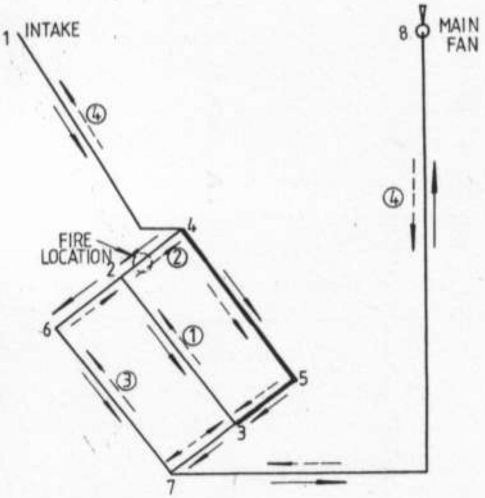

FIGURE 4

STABILITY OF AIRFLOW WITH AN UNDERGROUND FIRE

DESCENTIONAL VENTILATION

5 — NODE LOCATION
1 — REVERSAL SEQUENCE
——— — FLOW DIRECTION BEFORE FIRE
– – — — FLOW DIRECTION BECAUSE OF FIRE
━━━ — STABLE AIRWAYS

Figure 4 shows a simplified network with a fire between nodes 2 and 4. The following sequence of events is likely to occur :

Reversal of ventilation between nodes 3-2 which, in turn, causes the airflow to be reversed across the fire, 2-4. Reversal between nodes 3-7, 7-6 and 6-2 will depend on the relative resistances of the network. If the fire is large enough, reversal of the ventilation of the whole mine network is possible, which would be the case at the bottom of a downcast drift for instance.

The stability of the ventilation is dependant on the size of the fire and location of the fire itself. It is important to note that only the column of air above the fire source is of influence for the reversal due to the buoyancy effect.

The size of any fire will ultimately be limited by the supply of oxygen available in the airstream flowing along the roadway and that a decreasing flow of air to the fire source will, in turn, result in a diminishing intensity of the fire. When maximum development is reached the fire tends to behave as a heat source of constant temperature (9).

FIRE SIMULATION MODELS

For the purposes of the simulations the ventilation programme as available from A.C.I.R.L. was used. The buoyancy effect of the fire was represented by a booster fan which either aided or negated the ventilation of the roadway. The throttling effect was achieved by increasing the resistance of the fire section of the roadway. The network was purposely kept very simple so that the order of magnitude of the effects could be more readily appreciated, likewise the values used were chosen accordingly.

Figure 5 shows the basic network as used for the fire simulations.

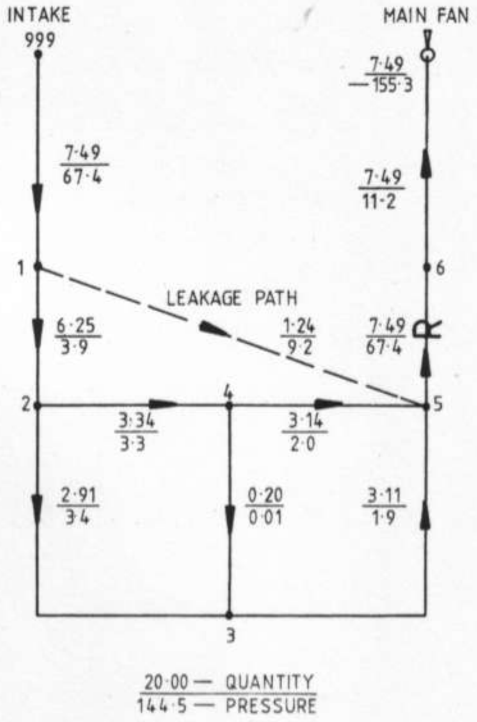

FIGURE 5

BASE CASE NETWORK — NORMAL CONDITIONS

Table 1 lists the input data and the results of the simulation run.

Nodes	Resistance NS^2/m8	Pressure Pa	Volume m^3/s
xxx Airways ***			
999-1	1.2	67.4	7.49
1-2	.1	3.9	6.25
2-3	.4	3.4	2.91
3-5	.2	1.9	3.11
6-Main Fan	.2	11.2	7.49
2-4	.3	3.3	3.34
4-5	.2	2.0	3.14
4-3	.9	.01	.20
xxx Leakage Path xxx			
1-5	6.0	9.2	1.24
xxx Regulator xxx (Fixed Resistance Roadway)			
5-6	1.2	67.4	7.49
xxx Fan xxx			
Main Fan - 999		-155.3	7.49

TABLE 1

BASE CASE NETWORK SIMULATION

Figure 6 shows the basic network with the fire working against the main ventilation. As can be seen, the relative resistance of path 4-3 was high enough to induce reversal of the airflow along 5-3. As a result of the increased leakage quantity the flow along 1-2 has decreased significantly. The fire was simulated by a booster fan delivering 4.16m^3/s at a pressure of 44.1 pascals which is quivalent to an airpower of 0.18 kilowatts. The total combustion of 52 kg of Bulli Seam coal in one hour or alternatively, approximately 156 kg of pit timber (untreated) would be sufficient to liberate 0.18 kilowatts in that hour. In addition, an available air column of 63 metres would be sufficient to create a pressure differential of 44 pascals. Table 2 gives the listing of the simulation run. The options of tackling the fire, by either increasing the main fan pressure and/or restricting the flow along airway 2-4 is readily evaluated by changing the appropriate variables of the input data. The flow characteristics of leakage path 1-5 will have a significant bearing on the options available.

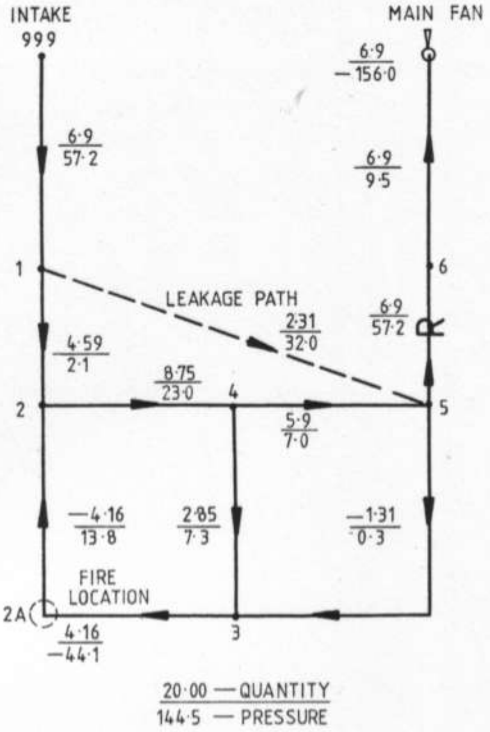

FIGURE 6

FIRE WORKING AGAINST MAIN VENTILATION

Nodes	Resistance NS^{2}/m8	Pressure Pa	Volume m^{3}/s
*** Airways ***			
999-1	1.2	57.2	6.9
1-2	.1	2.1	4.59
2-2A	.8	13.8	-4.16
3-5	.2	.3	-1.31
6-Main Fan	.2	9.5	6.9
2-4	.3	23.0	8.75
4-5	.2	7.0	5.9
4-3	.9	7.3	2.85
*** Leakage Path ***			
1-5	6.0	32.0	2.3
*** Regulator *** (Fixed Resistance Roadway)			
5-6	1.2	57.2	6.9
*** Fans ***			
Main Fan -999		-156.0	6.9
Fire + 3-2A		-44.1	4.16

TABLE 2

NETWORK SIMULATION WITH FIRE WORKING AGAINST
MAIN VENTILATION

Figure 7 illustrates the effect of a fire with the ventilation. The reversal along airways 4-2 and 3-4 was expected and the relative resistances of airways 3-4 and 5-3 influence the air flow of 4-5. Table 3 gives the listing of the simulation run. The fan used represents an airpower of 0.28 kilowatts of which 0.1 kilowatts was supplied by the main fan. The degree of throttling influenced the stability of flow along the leakage path significantly as without throttling the flow was from node 5 to node 1, which means that the air inbye node 1 could become contaminated with products of combustion. The fresh air base for the initial firefighting/rescue operations should therefore be at node 1. The effect of restricting the airway 2-3 as part of the firefighting operation may readily be evaluated by changing the resistance of that roadway.

The change of the main fan requirements in both examples should be noted. The reason that the operating point of the main fan is not significantly influenced by the fire is because both are separated by relatively high resistance air paths, considerable fan interaction is to be expected if this were not the case or if the fire fan power input were large enough.

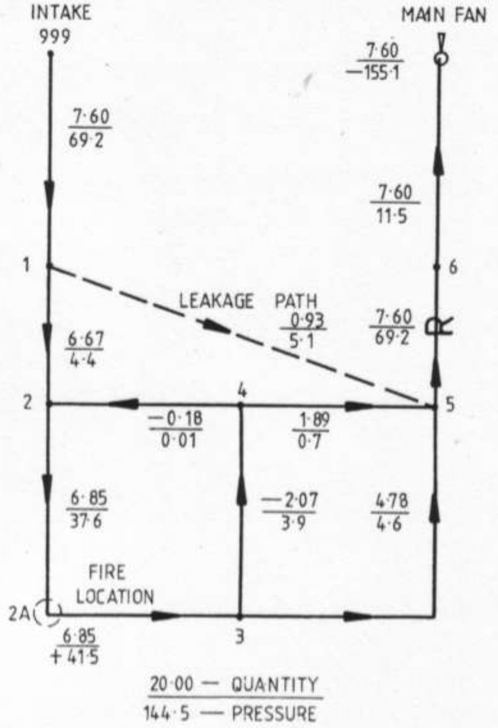

FIGURE 7

FIRE WORKING WITH MAIN VENTILATION

Nodes	Resistance NS^2/m8	Pressure Pa	Volume m^3/s
*** Airways ***			
999-1	1.2	69.2	7.6
1-2	.1	4.4	6.67
2-2A	.8	37.6	6.85
3-5	.2	4.6	4.78
6-Main Fan	.2	11.5	7.6
2-4	.3	0.01	- .18
4-5	.2	.7	1.89
4-3	.9	3.9	-2.07
*** Leakage Path ***			
1-5	6.0	5.1	.93
*** Regulator *** (Fixed Resistance Roadway)			
5-6	1.2	69.2	7.60
*** Fans ***			
Main Fan -999		-155.1	7.60
Fire + 2A-3		+ 41.5	6.85

TABLE 3
NETWORK SIMULATION WITH FIRE WORKING WITH MAIN VENTILATION

CONCLUSIONS

It is clear that changes of the mine ventilation can take place as a result of an underground fire. The theory of airflow reversal is generally well appreciated by most mining engineers, but the actual interaction between variables such as the relative quantities, resistances and the energy input of the heat source cannot be overseen for complex ventilation networks and the use of computer simulation techniques is required.

Although this approach still needs considerable refinement it is thought that even in its present form it may confidently be applied as an emergency contingency planning tool.

Several basic unknowns still have to be quantified for Australian conditions such as :

.. The temperature of the fire source. Is the figure of 800°C as mentioned by Schubert and Both (8) realistic or is 400°C closer to reality? It would appear that the type of fire would greatly influence the source temperature.

.. The temperature gradient along "standard Australian type" roadways is also an important factor.

.. The importance of the various assumptions requires clearer definition and their influence on the reliability of the results tested. The interaction of the Natural Ventilating Pressures, degree of compressibility of the air and density changes of the air as a result of the fire source are thought to have a significant influence on the stability of a rapidly changing airflow pattern. In addition, the importance of the throttling effect on the fire behaviour in general should be considered.

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DISCUSSION

R.D. LAMA (C.S.I.R.O.): Both last papers hit at the top of the question which has been raised by Mr. Martin: that in cases where the lives of people are in danger no decision except the right decision is acceptable. The use of computer techniques in solving complex network flow problems is a great help in making the right decision. It is alright when it is a non-gassy mine; the change in temperature and change in volume can be taken into consideration and it can cause constriction or the reverse of it. But what factors would be taken into consideration when there is a gassy mine, and when there would be a definite inflow of gas from coal surrounding the roadway which is undergoing change in temperature and where the temperature is increasing. The problem is certainly a complex one and has it been taken into consideration in the theory presented?

A. RALPH (A.C.I.R.L.): The use of digital computers to simulate a mine fire has only certain applications. It can't be used in all instances, if there are any sort of flammable or explosive gases flowing back over a fire because of a reversal then an explosion is going to occur. If those gases come from the front of the fire then an explosion will occur. What actually happens in individual situations or a situation like that is not too sure in terms of the explosion. The technique has got a use if there has been a fire in a place or if a fire is to be simulated in a particular place to know what is going to happen to the ventilation system.

M. VELZEBOER (The Shell Company of Australia): Further on that, there are programmes available, in Germany the W.B.K. for instance, has a programme where streams of methane can be put in and the effect of that can be analysed. This problem has not been considered at this stage.

D. ROWLANDS (University of Queensland): This particular paper and the problem that Mr. Martin posed in the previous paper brought to mind the Box Flat disaster where there were parallel roadways dipping towards the face, 2 intakes at least and the fire was in the return on the one side. One of the effects that occurred of course was that the pressure built up behind the fire was sufficient to bring a null point across at least one cross cut. The air started to re-circulate and fumes then came down the intake and products of combustion went back over the fire. So the kind of problem discussed is very real in Australia and the Box Flat example is a good one. That also brings up the problem that Mr. Martin posed: "Is the fire controlled or isn't it"? That is a very very important thing when a decision of this kind is being made in order to keep the fire controlled. It is a very easy one and it is easier to say that lives are being discussed, not money. That is the first one that must be made and then the other one in this theory is the problem that perhaps Dr. Lama indicated is a major one. This is where talk about fires commences and the other point is that there are these gases, the distillation gases behind the fire and any analysis obviously has to take into account the pressures and volumes associated with the distillation gases. It isn't quite as simple as it looks.

M. VELZEBOER: It was not the intention to present it as simple. When there is reversal it is accepted that the combustion gases will be coming across the fire again. By injecting gas into the air stream, was rather meant in a return situation if all of a sudden a lot of gas comes from a goaf area, then the consideration of how this gas goes through the system before it comes up the upcast shaft was not made. Certainly it is a point needing consideration. The stability of the ventilation network was given concentrated attention rather than local instabilities which are often very difficult to simulate accurately. Common sense will usually suffice in predicting what will probably occur.

R. LAMA: A very important point is that two solutions take into consideration two separate times. First is the initial stage and the second is what happens after the fire has taken place and the whole thing is stabilised. But there is an in-between phase which is related to the inertia of the movement of the air - a mass of air in the whole network. That period could be substantial, without guessing how much. Really it depends upon the total length of the roadways and total mass of air which is flowing and the number of fans and the pressure differences. This time could be extremely critical. It is doubtful whether the solutions are available which take into consideration the inertia of the moving air, so as to decide when the reversal will take place. It may give sometimes enough lead time for the management to take a decision and sometimes that lead time may be extremely small. Are there any more thoughts on that?

A. RALPH: There was some work by the U.S.B.M. on propagation of timber fires in a confined area and they have got lead times going from for instance an oxygen rich stage to a fuel rich stage. There is very little information on coal fires as such in terms of any lead or lag time.

A.J. HARGRAVES (B.H.P. Steel Division Collieries): This is going on from Dr. Lama's first question in regard to the effect downstream of the fire of the gas emitting from ribsides etc. In the normal course the normal ventilation is cooler than the strata and there is a temperature gradient from warmer in the virgin condition to cooler in the exposed condition and this has the effect of allowing the coal to shrink and at the same time to partially relieve itself of the load which is on it and the net result of this appears to be an increase in permeability. There is a corollorary to this to consider on the downstream side of the fire where the temperature gradient is reversed and I imagine that the coal, having tried to expand, comes under higher stress with the corresponding reduction in porosity and the corresponding reduction in permeability. It would appear that less gas should come out, depending on the temperature, and if there was any coking of the coal downstream of the fire this would result in a medium even less permeable than the coal itself, not only because of the coking, but because of the healing of bedding planes and cleats in the coke. The result should be for the time being at least a reduction in the gas emission from the ribsides. Pillar ribs might not be emitting significant gas anyway.

M. VELZEBOER: This is seen basically as an emergency planning tool. A mine manager in the middle of a crisis centre would not be very worried about the shrinkage or expansion but would be very concerned about other details.

A. RALPH: Most of the combustion products are volatile matter that would be produced in the combustion zone, downstream from the fire which would be an area of preheating as the fire progresses further.

D. MOWBRAY (B.H.P. Collieries, Newcastle): How quickly can this tool help a practising mine manager? If somebody rings and tells a manager that there is a fire underground, how soon can he expect help from this tool or should he do what Mr. Martin has suggested?

M. VELZEBOER: Assuming it is only dealing with a large mine, if there is just a single fan, a single intake it is very easy. No computer is required just the back of envelope should do. In a large multi fan situation normally the ventilation network would be up to date. That is updated maybe once a year which requires maybe a two-man-week exercise. Assuming that the base data is available probably it would not be unrealistic to expect to have it in an hour or two hours. To illustrate this at a mine which has about 4 upcast fans and 2 blowers possibly one of the main fans could fail all of a sudden. The Manager asked the question what is going to happen to the ventilation, which units can I have on the air etc.? It was possible to give him that answer within two hours and to tell him "This is where you possibly get reversal, your options are these units or those units but this is your air production". This is where the computer application wins hands down as a practicing tool rather than research.

D. ASHBRIDGE (B.H.P. Collieries): This is somewhat confusing to a practising mine manager. A previous paper has suggested that he should consider going down the mine and quickly assessing the situation at the scene of the fire. On the other hand it is now suggested that he should act only after taking advice from people with appropriate expertise with the added aid of a computer. The appropriate decision would take one to two hours to work out assuming all information was available. In addition there is the required travelling time for the experts to arrive at the mine. To obtain all the information would require spotters underground to indicate whether, in fact, there has been a recirculation and to what extent. Under these circumstances such people don't exist and very often a quick decision is difficult.

The 'incident' mining plan where the appropriate decision under those circumstances was indicated was interesting. But were not those decisions made in hindsight after probably weeks of gathering information after the incident. Guessing, only roughly 20% of all required information would be available when a decision has to be made very quickly.

A. RALPH: This technique is not the technique that should be relied upon to solve any on the spot decisions. It would take a considerable amount of time to put any one network of any one colliery up on a computer to start with. To do that all of the resistance values for the various roadways would need to be known as well as what there was in the pit prior to the fire starting. The time involved would just be too great in the situation of the fire. It is perhaps a tool that could be used, perhaps, a precautionary tool where there is a very complex network and it is not really sure what might happen it a fire should break out in a particular location.