SAFE ESCAPE FROM

LONGWALL DEVELOPMENT SECTION IN CASE OF A BELT FIRE

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Abstract

When a fire occurs outby a working area, the immediate safe evacuation of miners from the mine should always be the first action during the rescue operation.

However, many times, the dedicated escape ways for the evacuation of the miners become contaminated by the by-products of fire from adjacent entries.

The purpose of this paper is to present the ventilation-control process that would keep escape way free from contaminants and, thus, available for travel. A few scenarios of mine belt fires in longwall development entries are analysed, and discussed.

To perform these studies, a mine-fire simulator (MFS) named 'VANTGRAPH' was used. This software provides a dynamic representation of the fire's progress (in real-time) and gives a colour-graphic visualisation, of the spread of combustion products, oxygen, and temperature of the gases throughout the ventilation system.

This presentation, for the Queensland Mining Industry Health and Safety Conference, based on paper published by Wala (1996), however, this time the new mine-fire simulator 'VENTGRAPH', with modified fire's parameters was used.

Also presented and discussed are ways in which the MFS can be used as a training and teaching tool for miners and, particularly, for ventilation and safety specialists.

Introduction

Despite remarkable improvements in mine-safety procedures, coal-mine fires remain among the most serious hazards in underground mining. How much of a threat that a fire presents depends upon the nature and amount of material ignited, the ventilation system arrangement, the duration of the fire, the extent of the spread of combustion products, the ignition location and, very importantly, the time of occurrence. The response to the fire by mining personnel will depend upon all of these factors.

Then a fire occurs outby the working section, the immediate safe evacuation of miners from these areas should always be the first action during the rescue operation.

Usually, the intake entries are dedicated as the primary escape ways from the working section. In many cases, the dedicated escape ways are contaminated with fire by-products from abutting entries, (eg a belt entry) due to leakage through stoppings. Therefore, it is important to keep these escape ways unobstructed and free from contamination.

As suggested by Mitchell (1990), miners escaping from a mine fire should erect a check curtain in the intake escape way. The check curtain should be close to the face to reduce smoke infiltration from an abutting entry that is on fire.

In 1991, Kissell and Timko investigated the use of a parachute stopping which could be rapidly activated to prevent spreading of contaminated air. The data collected during their study indicated that the pressure of the intake escape way increased after installation of the parachute, thus preventing smoke infiltration from the adjacent entry and making the escape ways available for travel.

In their conclusions, Kissell and Timko said, 'It is not possible to reliably forecast the degree of pressure unbalance and leakage created by mine fire. However, during the early stages of a fire when miners should be making their escape, checking off the intake escape way will serve as a viable way to improve safety.'

They also noted that, 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 effect), and constriction (throttling effect) caused by the fire.

This reversal jeopardises the functioning of the ventilation system, whose stability is critical for maintaining the escape ways free from contamination and therefore available for travel.

The major goal of this paper is to analyse and visualise underground mine fire scenarios that control fire contaminants and maintain safe escape ways. To perform these studies, the authors used a mine-fire simulator (MFS). It utilised a colour-graphic visualisation of the spread of combustion products, oxygen, and temperature throughout the ventilation system and provided a dynamic representation of fire progress.

During the simulation session the user can interact with the ventilation system (eg implement check curtains, breach stoppings, and change fan characteristics) to study different ways of controlling the system.

In studies conducted by Goodman and Kissell (1990), who used risk analysis on reducing the dangers associated with escape from an underground mine emergency, it was shown that one of the most important factors in saving lives during a mine fire is miners' training.

Therefore, this paper also presents and discusses ways in which the MFS could be used as a teaching and training tool for Mining Engineering students and ventilation and safety specialists (Wala, 1992). In particular, training that concerns the probable behaviour of mine ventilation systems during a fire is of utmost importance.

Capability of the mine-fire simulator (MFS)

The MFS used to perform these studies was developed by Trutwin, Dziurzynski, and Tracz (1992). The program, coded in Pascal, combines three distinct modules:

- a conventional program for mine ventilation network calculations
- a program to simulate the fire development (real-time heat and product-of-combustion simulator)
- a program to calculate the air temperature changes due to a fire.

The purpose of this simulator is to predict the behaviour of the ventilation system in the case of a fire.

For clear and convenient display of the calculations results, the MFS provides a dynamic (animated) representation of the fire's progress, including a colour-graphic visualisation of the spread of combustion products, the temperature, the flow and other parameters throughout the ventilation system in real-time.

This program also enables the simulation of other fire-controlling actions, such as changing an emergency check curtain, opening or closing a regulator (door), breaching a stopping, and changing the fan characteristics.

All of these changes can be simulated at an arbitrary instant, which allows for the testing of various fire-control and suppression strategies.

These capabilities of the MFS, take advantage of the full power of the computer to design the safest ventilation system, to serve as an advisor during a real emergency action, and for instruction and training of mining personnel.

Validation studies of the MFS were performed using data gathered from a real mine fire (Wala et al (1995).

The MFS program is fully interactive. All data are entered from the keyboard during program execution. Input is simplified to such an extent that basic computer skills are sufficient. The user is precisely menu guided throughout the simulation session.

The usefulness of the MFS to analyse, diagnose, and explain certain situations when controlling ventilation for determining miners' safe escape route(s) from the section in case of fire will be presented later.

Description of the studied ventilation systems

Two different scenarios for a longwall development entries are investigated. Both represent the three-entry system with a standard single-split ventilation. The difference between the two scenarios is the incline of the entries.

Figure 1 depicts a typical three-entry, single-split ventilation arrangement. The intake air reaches the faces through the belt entry, which is adjacent to a solid barrier pillar (requires approved 101-C Petition for Modification of Section 75.326 of Title 30, CFR), and through the middle intake entry dedicated as a primary escap eway.

This primary escape way is isolated from the belt/track and return entries by rows of permanent stoppings. A man-door is installed in every fifth stopping.

The belt/track entries are assumed to be 7.3m (24 ft) wide, while all other entries are assumed to be 6.4m (21 ft) wide. A mining height of 1.5m (5 ft) is used in all calculations. Friction factors used to calculate airway resistance were determined from data collected during ventilation surveys performed by the author and are as follows:

· intake entries: 0.00835 kg/m^3 **(45 x 10E-10 lb min^2/ft^4)**

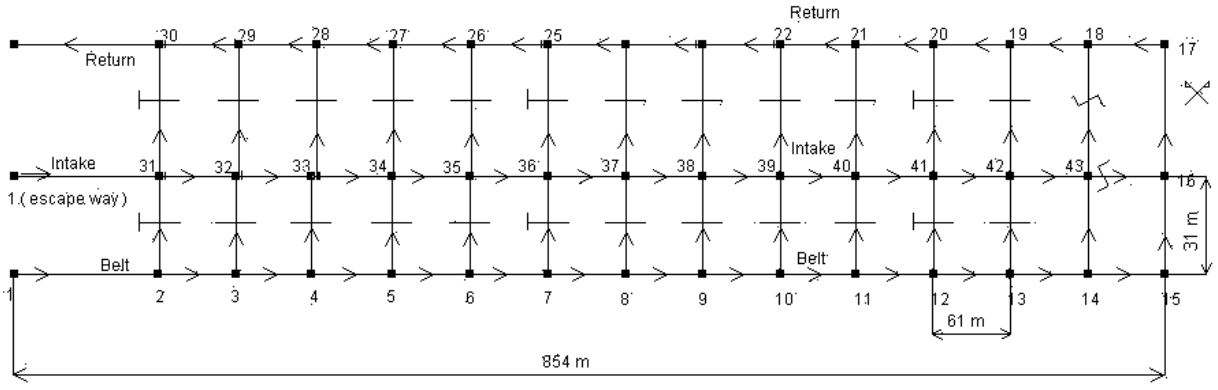
- return entries: 0.0167 kg/m^3 (90 x 10E-10 lb min^2/ft^4)
- belt entries: 0.0426 kg/m^3 (230 x 10E-10 lb min^2/ft^4).

The pillar centres were assumed to be 61m (200 ft) by 30.5m (100 ft).

To present how the buoyancy, throttling, and stoppings' leakage affect the availability of escape ways for travel in case of fire, this system is tested as horizontal and incline (rise 10 percent toward the face) with medium air-tight stoppings.

The resistance assumed for such a stopping is 500 N s^2/m^8 (4480 x 10E-10 in. min^2/ft^6), which means that if differential pressure across the stopping is 25 Pa (0.1 in. WG), the leakage is 0.22 m^3/s (465 cfm). The resistance assumed for the stoppings with the man-

Figure 1 Schematic of the three-entry, single-split ventilation arrangement for longwall development panel



doors is 100 N s^2/m^8.

For the purpose of exaggerating the problem the resistances for two stoppings in the system were assumed lower. Lower resistance indicates stopping damage. The resistance of the damaged stopping between notes 3-32 (see Figure 1) is 30 N s^2/m8 (269 x 10E-10 in. min^2/ft^6) and for stopping between the notes 34-27 is 50 N s^2/m^8 (448 x 10E-10 in. min^2/ft^6).

The total length of the tested longwall development section is 854m (2800 ft), as shown in Figures 1.

To generate a proper amount of an airflow through the system, a differential pressure equal to 250 Pa (1.0 in. WG) across the intake and return, at the mouth of the development section, was introduced.

Simulation exercises

The purpose of performing these exercises is to visualise how the ventilation controls could be used to maintain the escape ways free from contaminants and available for travel in case of fire. These simulation exercises were carried out for the three-entry, single-split ventilation system for the longwall development panel with horizontal and incline (rising, ascentional) entries.

Hands-on experience with the simulator has potential for improving mine workers' understanding of mine fires and ventilation interactions. For example, the placing of a check curtain (parachute stopping) in an intake near the face, and the resulting changes in mine ventilation and the fire's behaviour, can immediately be viewed in real but accelerated time. Also, the buoyancy and throttling effects on the ventilation system can be directly observed.

- The fires simulated for all exercises have the similar characteristics:
- they are located in the belt entry, 800m (2700 ft) outby the face
- coal, of heating value equal 29,000 kJ/kg (12,500 Btu/lb), is on fire
- fire is spreading (building-up) with a given time constant to reach the visible fire area of 65m^2 (see Figure 2 graph $A_f(t)$), according to a study carried out by Dziurzynski and Tracz (1994), the relationships between the fire area and the visible fire area can be described by a proportionality factor

· time constant of the fire development is 1200 second (fire growth rapidly in purpose to accelerate time of the whole rescue action)

· intensity of fire, ie, the amount of coal burning during the fire, is shown in Figure 2 as a graph I(t)

· during the oxygen-rich stage of fire, the combustion gases CO and CO_2 are produced in a $CO:CO_2$ ratio of 1:10 are produced.

Exercise 1

Single split, horizontal entries. The objective of this exercise is to demonstrate how to prevent infiltration of the fire's contaminants into the primary escape way in the longwall development panel with horizontal entries. For this arrangement, this goal can be achieved in the following two ways:

- by pressurising the intake entry by erecting a check curtain (parachute) close to the face (eg branch 42-43), as shown in Fig 3
- by lowering the pressure inby the fire by checking off the belt entry outby the fire (eg branch 1-2), again as shown Fig 3.

Besides lowering the pressure inby the fire, the second action also reduces the oxygen provided to the fire. This oxygen reduction could lead to a fuel-rich type of fire, requiring special attention.

With concern for the time required for implementation of these two approaches for making the escape way available for travel, the first alternative is more favourable. However, sometimes the second solution is recommended, especially when entries are inclined. This case will be discussed during the next exercise.

Figure 3 depicts the tested three-entry, single-split ventilation system with horizontal entries, with the fire located in the belt entry. In particular, this figure shows the flow and carbon monoxide distribution in the

Figure 2The growth of the fire area and intensity of the fire

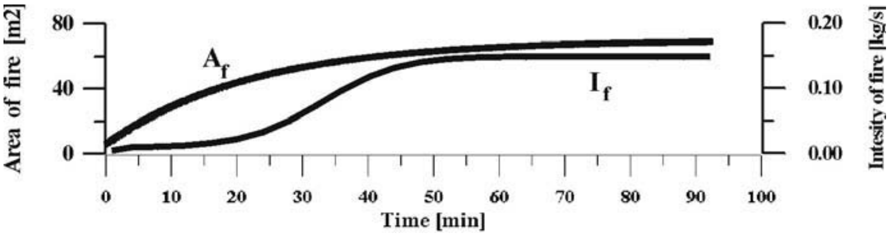
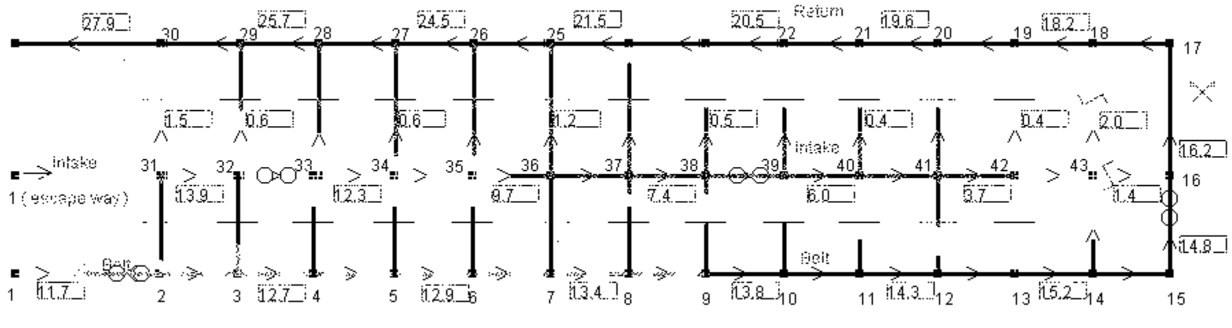


Figure 3 The flow of gases in m^3/sec and carbon monoxide concentration (thick lines) 45 min after fire's ignition



system 45 minutes after the fire's ignition.

The numbers in the small boxes display the flow of gases in m^3/s. The thick lines depict branches containing carbon monoxide. These lines, displayed in colours on the computer screen (or produced on printer), could indicate concentrations of oxygen, combustion products or the temperature of the gases.

Figure 4 shows transients of carbon monoxide in the ventilation system caused by the fire and by implementation of the check curtain (parachute) outby the face area.

This check-off curtain was erected 40 minutes after the fire started and 15 minutes after concentration of carbon monoxide in the face area reached 15ppm. Carbon monoxide concentrations were measured by sensors located at points A, B, C, and D, as shown in Fig 3.

Figure 5 depicts transients in the same ventilation system as details above, with one exception: the check curtain was erected outby the fire in the belt entry. In this scenario, it was shown that by lowering the pressure inby the fire, the escapeway could also be kept free of combustion gases.

Exercise 2

Single split, incline entries. The objective of this exercise was to demonstrate the interrelationships between the mine ventilation system and mine fires in a mine with incline (rise) entries.

It is well known that heat generated by the mine fire, especially a severe open fire in a mine with incline entries, can affect the stability of a ventilation system by buoyancy (natural ventilation pressure) and throttling.

These effects can range from flow-constriction, smoke rollback to a complete reversal of flow. The consequences can be disastrous, because entries designated as escape way (and presumed to be free of contamination) can fill quickly with toxic fumes, gases, and thick smoke.

To effectively use ventilation control to assist miners to escape, mine operators, mining engineers, miners, and safety and ventilation personnel must have a thorough understanding of relationships between the ventilation system and a mine fire. And they must be capable of applying this knowledge to the particular mine and location where they work.

Figure 6 depicts the same layout for the longwall development panel used in Exercise 1, except

Figure 4 The transients in the system with horizontal entries and check curtain being erected in the intake close to the face. The graphs in Figure 4 show that by checking off the intake entry close to the face area, the infiltration of the fire by-products into the escape way could be prevented. Similar results were observed during the study carried out by Kissell and Timko (1990).

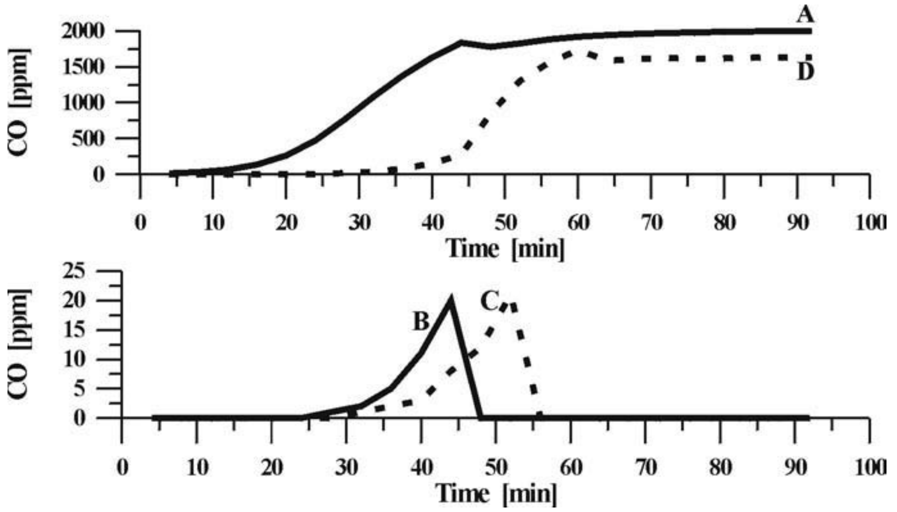
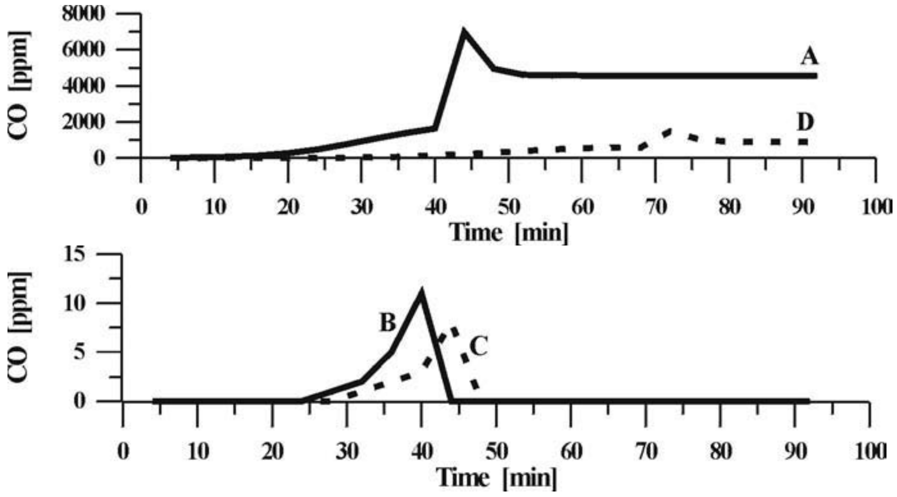


Figure 5 The transients in the system with horizontal entries and check curtain being erected outby the fire in the belt entry



that the entries rise 10 percent toward the face.

As in Exercise 1, to exclude fire by-products from the primary escape way, the check curtain (parachute) was installed in the intake entry outby the face area 40 min after the fire's ignition and 15 min after the concentration of carbon monoxide reached 15ppm in the face area.

The carbon monoxide (the thick lines) and the flow distribution 45 minutes after the fire's ignition, are also displayed in Fig. 6. The transients in this ventilation system caused by the fire and placement of the check curtain are shown in Fig. 7.

A comparison of Figs. 4 and 7 indicates that the same control procedure affects these two systems differently. This is because of the buoyancy in the mine with the inclined entries.

These two figures depict the mechanics of the buoyancy and its interaction with ventilation controls for horizontal and inclined system.

In the case of the incline system, where the natural ventilation pressure builds up mostly in the incline belt entry, implementation of the check curtain in the intake entry close to the face dose not help to keep the escape way free of combustion gases.

As shown by graphs B and C in Fig. 7b, the concentration of carbon monoxide in the intake entry (primary escape way) reached 200ppm.

The objective for the next simulation study was to display the behaviour of he ventilation system as a responses to the following control scenario:

- 25 min after fire ignition, the CO concentration in the face area reaches 15ppm;
- 15 minutes later (40 min after fire's ignition), a check curtain is installed outby the face in intake entry (primary escape way)
- utilising a Self-Contains Safe Rescuers, miners escaped from the section through the intake escape way on battery-powered portal bus
- 60 minutes after fire's ignition, the miners (after they were outby the fire) erect the check curtain to make the fire area accessible to fire fighters.

Figure 8 depicts the flow distribution and carbon monoxide concentration in the system, 70 min after fire's ignition.

Figure 9 depict the transients of the carbon monoxide. Figure 10 depicts the flow rate changes (due to the fire and control process) measured by sensors A, B, C, and D in branches 1-2, 32-33, 38-39, and 15-16, respectively.

It was found that, during these simulation exercises that placement of the check curtain outby the face in the intake entry, during the early stage of the fire, does not keep the escape way free of combustion gases.

Implementation of the check curtain outby the fire in the belt entry could only keep the escape way free of

Figure 6 The flow of gases in m^3/s and carbon monoxide concentration (thick lines), 60 minutes after fire's ignition

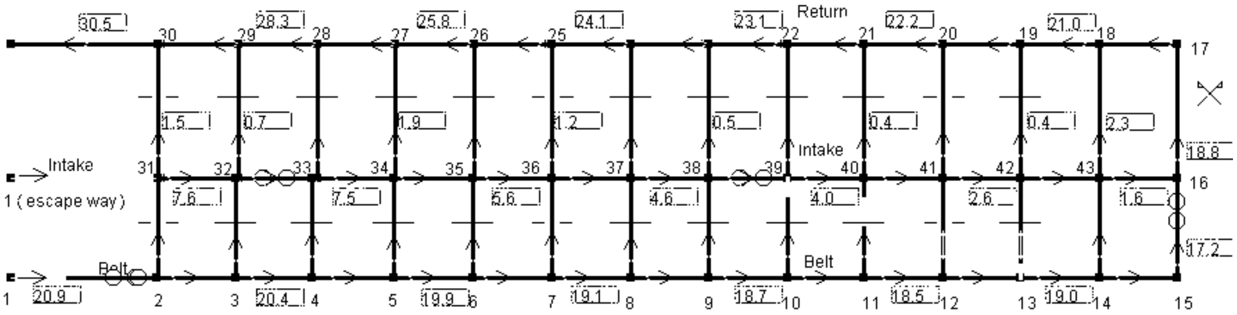
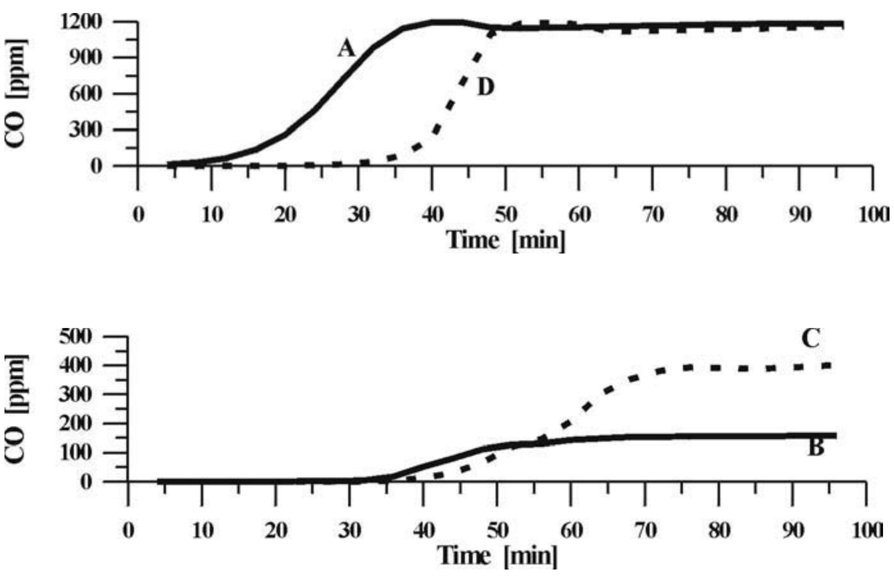


Figure 7 The transients of carbon monoxide in the system shown in Figure 6



combustion products.

Conclusions

Mine emergencies and disasters are rare events in the experience of individual miners, and this is as it should be.

However, a consequence fact is that the majority of underground coal miners in the United States have little or no chance to practice their decision-making skills in actual mine fires.

Thus, well-designed computer simulation exercises, based on actual mine fires and the actions of miners during these emergencies, may be useful for teaching, maintaining, and assessing miners' proficiency in critical self-rescue and escape skills.

Training mine personnel in the wise and proper use of mine-ventilation controls to aid the escape from fires remains a largely undeveloped area.

Little systematic instruction is available for this complex area. The mine fire simulator implemented in Computer Assisted Instruction (CAI), (Wala 1992), shows much promise as a means to provide such training.

When fully developed, the CAI system might be used for teaching and training mining engineers and safety and ventilation personnel who are responsible for ventilation arrangements during fire fighting, mine rescue, and recovery.

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Figure 8 The flow of gases in m^3/s and carbon monoxide concentration (thick lines), 90 minutes after fire's ignition

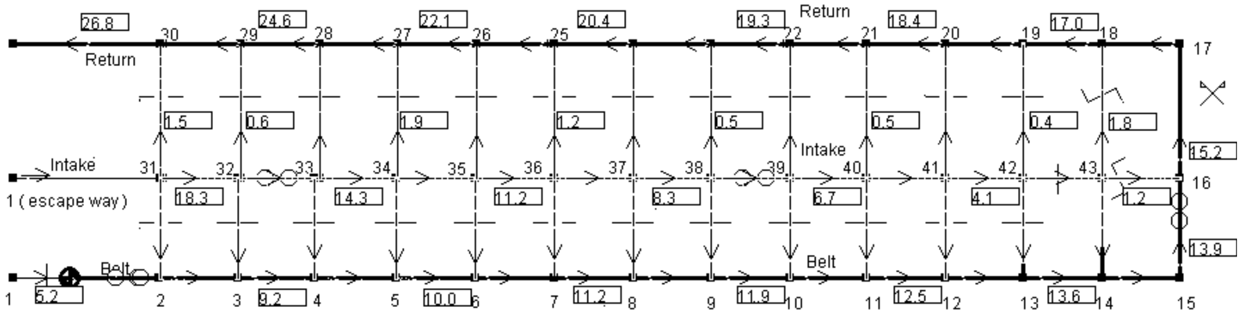

Figure 9 **The transients of carbon monoxide in the system shown in Figure 8**

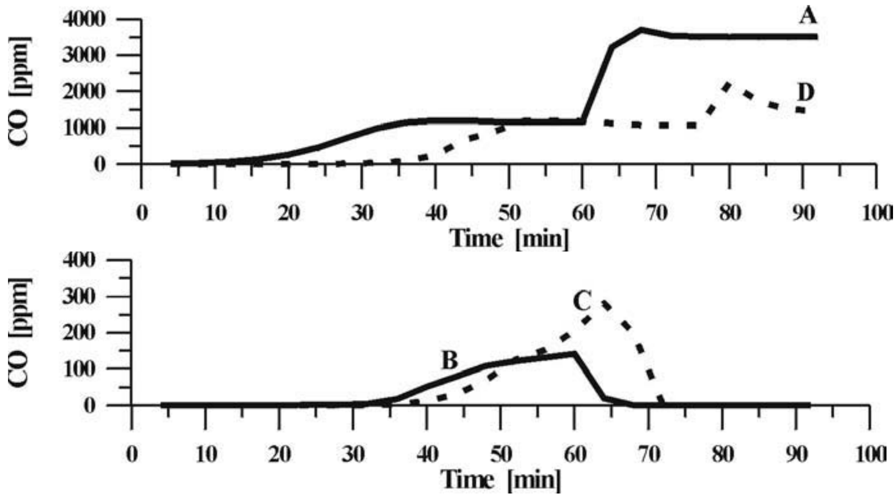

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Figure 10 The flow changes in the system due to the fire and control process