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Studies on fire behaviour at CIMFR experimental fire tunnel

A small-scale experimental fire tunnel has been designed and constructed at CIMFR, Dhanbad, India to understand the different aspects of fire dynamics. The tunnel is arch shape 65.5 m long and 5.86m² in cross section provided with two cross cuts, sliding doors, fan and chimney etc. It is equipped with state-of-the–art computer aided on-line tele-monitoring system having 130 sensors to monitor the parameters like temperature, gas concentration, velocity of air, pressure drop across fire zone and fan pressure, heat flux, smoke density all along the tunnel length. A data acquisition system comprising data-loggers, software and computer etc. have also been provided. Experiments for coal fire studies under varied airflow rate were carried out in the tunnel to understand the dynamic phenomenon of open fires and to evolve a suitable fire suppression technique. If such monitoring system will be installed in any road or rail tunnel, can enhance the safety of the tunnels with regards to fire. Further if any fire breaks out in road or rail tunnels, fire suppression techniques like HPHS nitrogen foam and water mist technology can be used to suppress the fires.

Introduction

Fires have long been recognized as a hazard associated with the coal mining as they pose an immediate life threat to the underground personnel. It represents one of the two most probable causes of major disaster in underground coal mine involving loss of precious lives, hindrance in coal production and sealing of entire mine or working section for a long period. The majority of deaths arising from mine fires are however caused not by burning or blast effects, but by inhalation of toxic gases.

The outbreak of open fire in main intake of mine gallery may cause disaster if it was not taken care properly in the beginning. A systematic in-depth study on different aspects of open fires may help in formulating the strategies for its prevention and control. A lot of research work has been done in different parts of the world on small, intermediate and large- scale tunnels to study the dynamics of open fire. Till recent past no experimental facility was available in India to carry out systematic in-depth study on different aspects of fires. CIMFR, Dhanbad took initiative and designed and constructed a small-scale experimental fire tunnel for the study.

Experiments were carried out in the tunnel under varied airflow rate to evolve a suitable fire suppression technique which can effectively control the dynamic open fires with great success. The same system with little modifications can be tried to solve the road and rail tunnel fires also.

The paper highlights the important design feature of the tunnel, instrumentation system and data acquisition system, experimental highlights and operating principle of fire suppression techniques applied to suppress the fire.

Description of the tunnel

The fire tunnel is arch shape 65.5 m long, and 5.86 m² in cross section. The tunnel is basically divided into two zones. First 10.5 m long segment is non-firing zone, the second 22 m long segment is firing zone and the third 33 m long segment is again a non-firing zone. One cross cut of 3m long with two stoppings have been provided at the center of the firing zone and second cross cut of 13.75m length has been provided at the dip end of the tunnel. One exhaust type axial flow fan capable of handling 25 m³/sec of air quantity at a pressure of 50 mm.wg has been installed at the end of second cross of the tunnel. To avoid air pollution in the surroundings due to burning of coal in the gallery a 10m height and 1m dia. has been provided with the fan. Two sliding doors, one at 5m from the tunnel entry and the other, at end of the tunnel, have been provided for sealing the fire whenever required. One rolling shutter is fitted at the end of the second cross cut of tunnel opposite to the fan end to regulate and dilute the incoming hot and toxic gases from the firing zone. A monitoring room for installation of sensors, data logger, computer, printer, plotter etc. adjacent to the gallery has been constructed [1]. An isometric view of CIMFR fire tunnel is shown in Fig.1.

Instrumentation system

The fire tunnel is equipped with state-of-the-art computer aided on-line tele-monitoring system. The system consists of 130 sensors with data logger, computer peripheral etc. for continuous monitoring of various parameters like gas concentration, air velocity, and pressure drop across fire zone,

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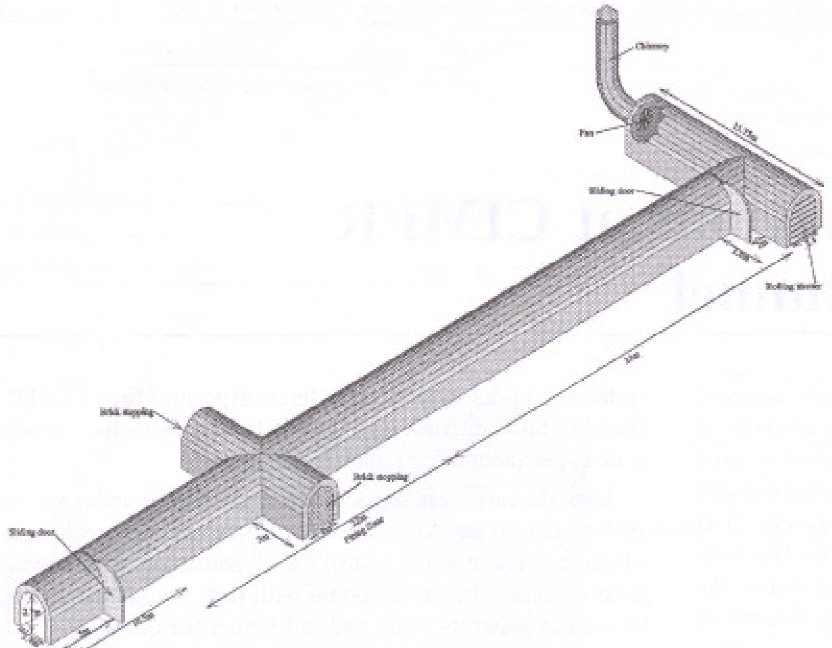


Fig.1 Isometric view of fire tunnel

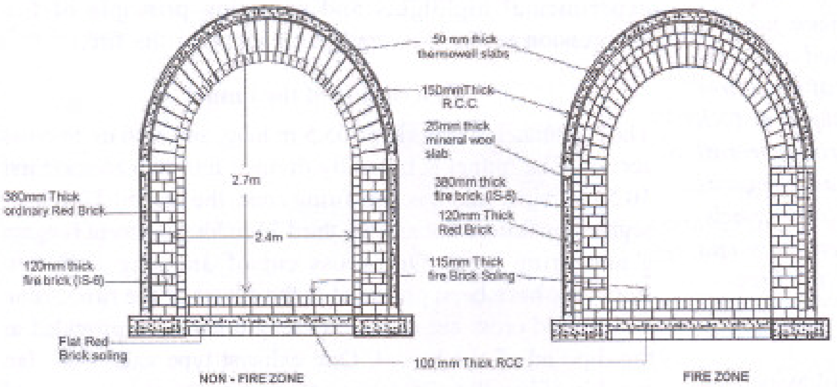


Fig.2 Sectional view of firing and non-firing zones

temperature, heat flux and suspended particulate matter (SPM) concentration. It was expected that during experimentation the temperature inside the tunnel might rise up to 1200°C. Under such condition only temperature sensors can be placed inside the gallery and other sensors have been placed either in the monitoring room or outer side of the gallery wall with proper cooling arrangements.

For better understanding the entire monitoring system may be described in two heads viz. instrumentation in the gallery for data generation and data acquisition system for collection, storage and analysis of data

Instrumentation in the gallery for data generation

The computer aided on-line tele-monitoring system comprises 130 sensors installed in the gallery as well as in the monitoring room. It may be noted that temperature, pressure, velocity, heat flux, smoke density meter sensors are installed at the tunnel site with proper cooling arrangements and gas sensors are mounted on a panel in the monitoring room, adjacent to the tunnel for continuous monitoring of CO, CO_2, CH_4, O_2 and H_2 gases. Gas samples from inside the tunnel will be continuously drawn out by membrane pumps. The gases so drawn would pass through the stack of gas sensors after being cooled and filtered. Altogether five sampling systems are provided at five gas sampling points. Details of sampling and data acquisition system of the instrumentation scheme are shown in Fig.3.

Data acquisition system for collection, storage and analysis of data

Data acquisition system consists of two data loggers, computer peripheral, printer, plotter and software for collection, storage and analysis of data obtained during experimentation.

SCADA software on Window-98 operating system provided has the following features:

1. It can store data on daily basis, which can be retrieved in future also.
2. It gives digital and graphical representation of individual channel daily and for entire period of the experiment.

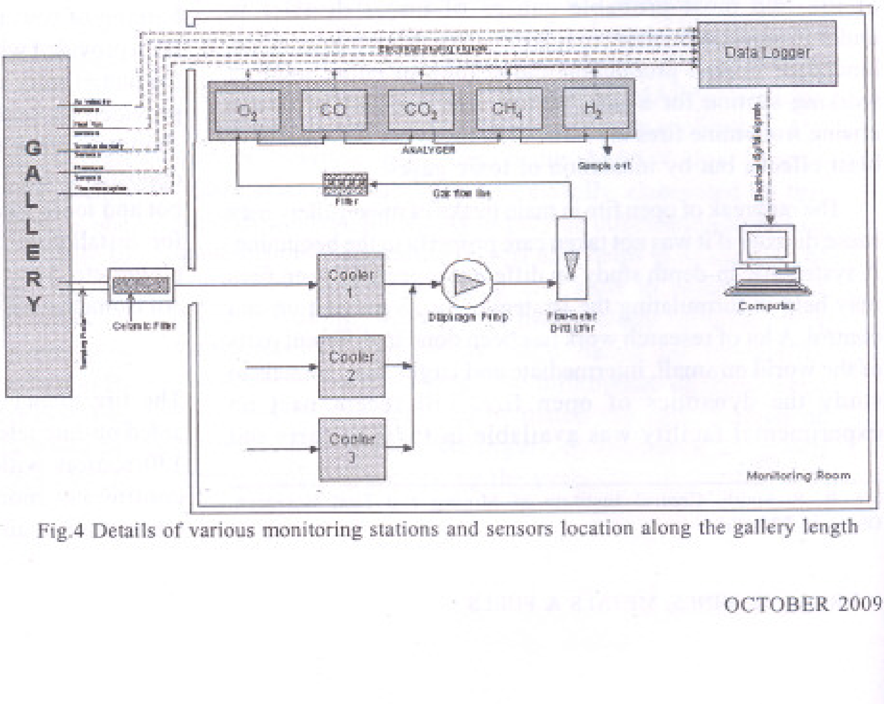
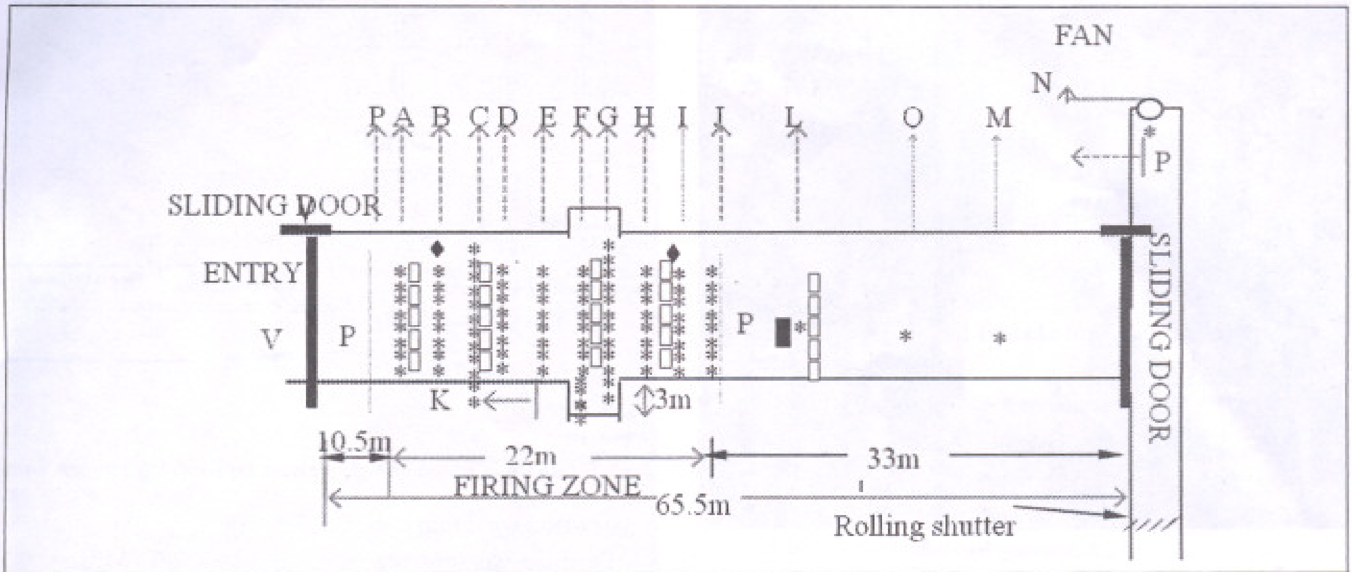


Fig.4 Details of various monitoring stations and sensors location along the gallery length



Location	Entry	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Distance from opening (m)	4.8	12.7	14.9	17.1	19.3	21.5	23.7	25.9	28.1	30.3	32.5	Side gallery	42.5	52.5	62.5	Near fan	10.2	48.5

Type of sensor	Temperature	Gas	Velocity	Pressure	Heat flux	Smoke density meter	Total
Symbol	*	□	V	P	◆	■	
No. of sensors	98	25	01	03	02	01	130

Fig.4 Details of various monitoring stations and sensors location along the gallery length

3. It can identify each sensor and have alarm generation facility for critical values of different parameters.
4. Outline diagram of tunnel along with location of sensor can be displayed on the monitor along with current reading as and when required (user configurable mimic display).
5. Facility for incorporation of EXPLO program developed by CIMFR in the main software to determine the explosibility of gases during experimentation.
6. It can detect the errors like sensor failure, cable fault and any other fault in the system.

Experimental highlights

Coal slabs of 8-10 cm thick were pasted in all the inner sides of 22m long firing zone of the tunnel using a mixture of air setting cement and liquid binder. Coal samples were also provided in the floor of the tunnel.

Predetermined air velocity was established through the tunnel with AF-50 exhaust type axial flow fan and adjustment of rolling shutter provided in the opening at the end of the dip side cross cut of the gallery. Both the sliding doors were completely opened.

The fire was initiated in the beginning of fire zone by artificial means (jute, kerosene, wood etc.). After about one and half-hour of fire initiation, coal on all sides and floor started burning at the beginning of the fire zone. Full-fledged fire was developed after two and half-hours of fire initiation. The entire instrumentation system was switched on at the time of initiation of fire so that all the important fire parameters like temperature, pressure, gas concentration, heat flux, air velocity and smoke density are continuously monitored. Data thus generated were recorded and stored in the computer memory.

When the intensity of fire was very high, heavy backlash with dark smoke and fumes started coming out towards the entry of the gallery. Fig.5 shows the backlash with flame. It was also observed that duration of backlash was about 5 minutes recurring at an interval of 15-20 minutes. During the period of backlash intensity of fire was very high; airflow in the tunnel section was divided into two distinct zones. Up to 1.4 m height from the floor of the tunnel airflow was normal but in the rest upper portion of the airflow was reverse. At that time the quantity of airflow in the gallery was reduced by 28-50 per cent.

The fire parameters were continuously monitored for about 4-5 hours in open fire condition to study the dynamics of open fire. Thereafter fire suppression techniques like liquid nitrogen (LN_2), HPHS nitrogen foam and water mist were applied to see its effectiveness on open as well as sealed

Fig.5 Showing backlash

condition of fire. The important features of the technique have been discussed in the following.

Application of high pressure high stability (HPHS) nitrogen foam for suppression of fire

High pressure high stability nitrogen foam has been used in Czech Republic for control of fire in a number of coal mines [2-4]. The foam generating machine and foaming agent were brought from Czech Republic to test its efficacy in the tunnel for application in Indian coal mines. The machine consists of two units viz. foaming unit and pumping unit. The high-pressure nitrogen foam is produced in the foaming unit from a mixture of water and foaming agent (foam concentrate) prepared in 95: 5 ratio in a mixing reservoir and it was pumped by a pumping unit into foam generating unit. At the same time compressed gas (N_2) is also supplied into foam generating unit at a minimum pressure of 0.2 MPa, mixed with foaming mixture sprayed from nozzles and then passes through a fine mesh installed inside the foam generation unit. At the outlet of the foaming unit a fire resistant hose pipe of 50–75 mm diameter is attached by which the foam is transported to the place of injection. The schematic diagram of the setup is shown in Fig.6.

The detail specification of the pumping and foam-generating units is as follows:

PUMPING UNIT

Flow rate	0.73 lit/sec.
Delivery pressure	0.6 MPa
Revolving speed	940 min^{-1}
Rated input	0.78 kW
Motor	1.2 kW
Dimensions	150×180×778 mm
Weight	24 kg

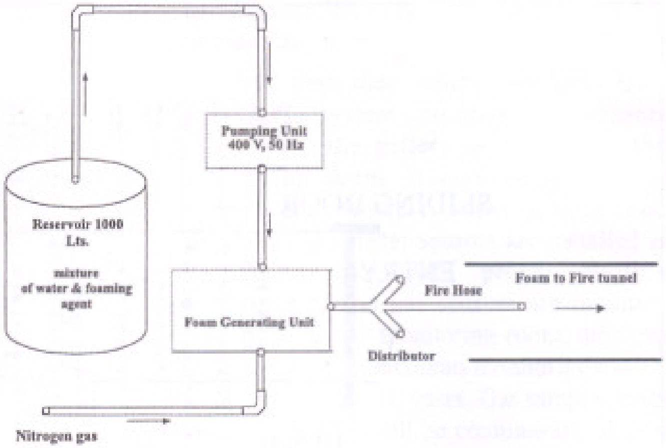


Fig.6 Set-up for injection of high-pressure high stability nitrogen foam

FOAM GENERATING UNIT

Foaming gas pressure	0.2-0.6 MPa (nominal 0.4 MPa)
Foaming gas consumption	0.06-0.12 m^3/sec.
Foaming mixture pressure on the nozzle	0.6 MPa
Foaming expansion factor	80-160
Dimension	560×450×1340 mm
Weight	62 kg

With the above system foam was injected in the tunnel, from the entry of the tunnel in the beginning of fire-zone. Thereafter the injection point was shifted towards downstream of fire through GI pipe provided in the side of the tunnel. The injection rate was 200 m^3/hour. The duration of foam injection in open fire condition was two and half-hours.

Figs.7 and 8 show the foam injection machine, from the entry of the tunnel respectively. After that the fire was sealed through two sliding doors installed at both ends of the gallery and foam injection continued for another four hours.

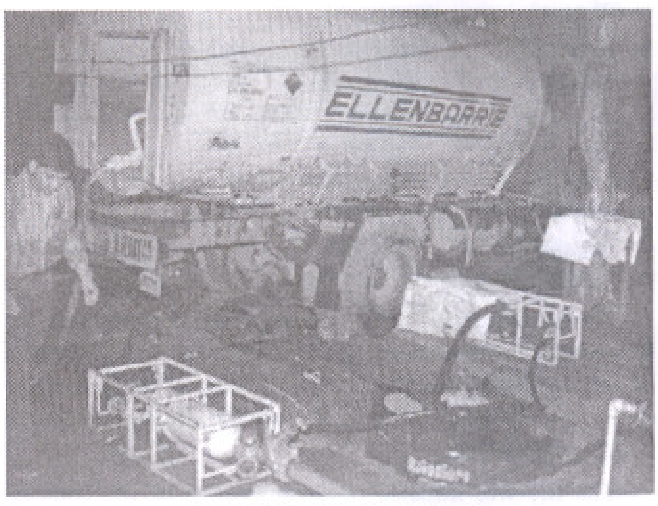


Fig.7 Foam injection machine

Fig.8 Infusion of foam

Application of water mist for suppression of fire

The concept of water mist to suppress the fire is a unique one and for the first time in India it has been tried in the fire tunnel to work out the strategy to control fire with the water mist in actual mine condition. For the purpose an indigenous system for generation of water mist has been developed.

The system essentially consists of a high-pressure pump, motor and two sets of Fog-jet nozzles. The Fog-jet nozzle is capable of producing a shower-like full cone spray pattern of very fine drops. The nozzle assembly consists of a nozzle body and seven removable atomizing spray caps (1" NPT or BSPT). Each cap has an internal core, which is easily removed for cleaning or replacements. The nozzles are mounted on a GI pipe of 4.87cm diameter, placed on a height adjustable stand of maximum height 1.4m. In the GI pipe two sets of nozzles are fitted at 45° angle with the length of the pipe. The distance between two sets of nozzles is 2.65m. A water pressure gauge and a water flow meter are also attached to the system. Water is supplied to the GI pipe by a 4.03-cm diameter flexible hose from a high-pressure pump. Coupling arrangements are provided to join the flexible hose with the GI pipe. The system can withstand a pressure of 10 kg/cm^2. To release the excess pressure, if any, a safety valve is provided at the end of the pipe where nozzles are fitted [5]. The schematic diagram of the system has been shown in Fig.9.

Discussion

1. The experimental fire tunnel and its instrumentation system designed at CIMFR can be utilized to study the fire behaviour in different fire scenario.
2. Strategies for prevention and control of road and rail fires can be formulated by enlarging the instrumentation system along the road or rail tunnels for monitoring of different fire parameters.
3. The fire suppression system can also be utilized in larger dimension to suppress the road and rail tunnel fires.
4. Fire suppression technique was quite effective to control the coal fires hopefully it will certainly be effective to control road and rail fires.

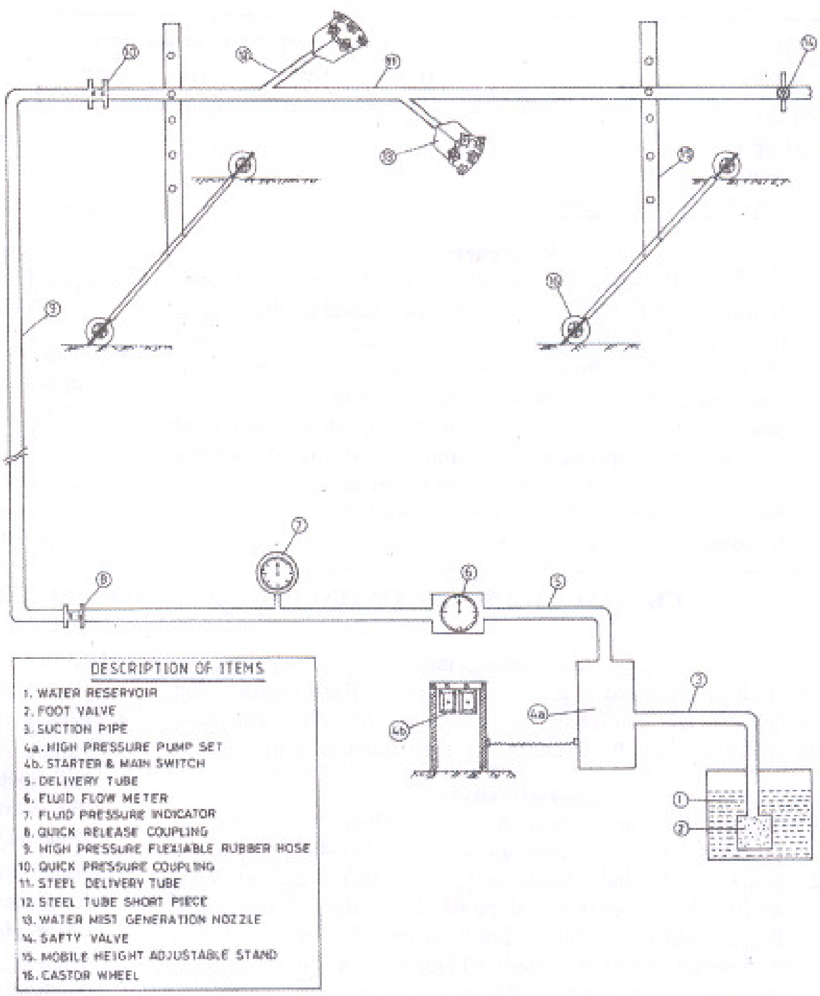


Fig.9 Water mist generation system

Fig.10 Generation of water mist

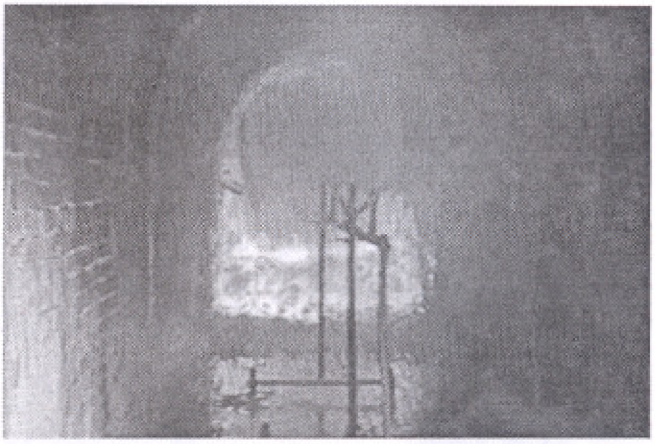


Fig.11 Application of water mist in the tunnel

TABLE 1: EFFECT OF INFUSION OF HPHS NITROGEN FOAM ON TEMPERATURE

	Temperature, °C at various locations in the tunnel										
Condition	A	B	C	D	E	F	G	H	I	J	L
Normal	847	653	783	761	925	1100	854	827	971	854	809
Open	315	291	342	110	317	438	603	880	372	341	262

TABLE 2: EFFECT OF WATER MIST INFUSION ON TEMPERATURE

	Temperature, °C at various locations in the tunnel									
Condition	A	B	C	D	E	G	H	I	J	L
Normal	497	695	752	976	872	1050	975	992	952	972
Rate of reduction in. temperature after infusion, °C/min	-	4.95	3.3	1.72	0.5	7.23	5.3	5.5	-	10.7

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CONTINUUM AND DISCONTINUUM ANALYSIS ON FAILURE BEHAVIOUR OF DUMP SLOPE

(Continued from page 312)

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