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Application of high expansion nitrogen foam to control mine fire – a case study

High expansion nitrogen foam technology has been found an effective technique world over for controlling underground mine fire. In this paper the conventional methods adopted in coal mines for dealing a fire have been briefly discussed. Attempts have been made to highlight the advantages and merits of high expansion foam technology over the other techniques. A success story of application of high expansion nitrogen for controlling underground fire in record time in MCL mines has been presented and reference of other places in Indian coal mines where the technique were applied successfully, has been made in brief.

Introduction

The problem of fire in coal mines particularly those mining bituminous and sub-bituminous coal is well known phenomenon. The magnitude and losses due to fire in Indian coal mines have been discussed by a number of researchers. In a combustion process fuels, oxygen and heat are essential. Removal of any of the three completely will stop the progress of the fire. However, in case of coal mines, removal of fuel is difficult. Therefore stress is laid mainly on restricting/cutting supply of oxygen and removal of heat. The commonly adopted methodologies for control of fire in coal mines may be described as below:

- Loading out the fire – removal of fuel bodies
- Sealing off the fire – cutting off the oxygen supply
- Application of water – operating mainly from cooling effect
- Infusion of slurry/solid inert and Gel – cooling cum smothering
- Inert gas infusion – oxygen remover cum cooling
- Halons and powder chemicals – inhibition to combustion cum oxygen remover
- Pressure balancing
- Foam type-acting from smothering and inertization action
- Application of protective coatings (sealant) after sealing off the fire

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All the abovementioned techniques have their merits and demerits and thus for optimum benefits, the technology should be adopted considering the specific fire conditions.

Use of inert gases to fight mine fires was introduced in the middle of the last century. The inert gases in addition to inertization of the affected area for quenching the fire also helps in minimizing risk of explosion during or after sealing of fire [1-5].

Some significant advantages of inert gas application may be summarized as under:

(a) Reduction in oxygen concentration in the air around the seat of fire.

(b) Reduces risk of explosions during direct fire fighting or after sealing.

(c) Minimizes the intensity and spread of secondary combustion.

The notable drawbacks of the inert gas application are

- Limited availability of large quantities of inert gas at site at short notice during emergency.
- Loss of gas due to leakage and hence methods are costly.
- Rate of inert gas injection plays important role in determining efficacy of the application under different condition.

In commonly adopted practices there are three types of inert gases which have been used to fight mine fires. These are Carbon dioxide (CO_2), combustion gases and nitrogen (N_2).

In view of the above for improvement in inertization techniques, incorporation of high expansion high stability nitrogen foam has been made. It brings many advantages over the conventional use of inert gases alone.

In this paper, introduction to application of high expansion nitrogen foam in controlling fire and reopening of fire affected sealed off area safely in underground coal mines have been discussed. A few success stories have also been discussed to illustrate the efficacy of the techniques.

The foam

Foam is a system of laminae which encloses gas bubbles in the interetstics of solution or suspensoids containing highly capillary active substances. It is a homogeneous mass of tiny air or gas filled in bobbles of low specific gravity which, when applied in the correct manner and in sufficient quantity, form a compact fluid and stable blanket which is capable of blanketing completely the burning mass and thus preventing atmospheric air to reach the burning source. It is produced by mechanically mixing a gas or air to a solution of a foam compound (concentrate) in water (Fig.1).

Fig.1 High expansion foam being produced

High expansion high stability nitrogen foam

Development of high expansion nitrogen foam technique in recent past has opened new ways for quick displacement of oxygen from fire affected areas along with removal of heat. Use of foam has been found significantly effective in dealing with fires due to its smothering action, by cutting off air feed to the burning fuel as well as acting as coolant. Additionally, the technique also guaranties inertization of the area for a protracted period. Amalgamation of the above properties in one has made the technique an extremely useful tool for quick control of fire even in working mines. Accordingly, application of a number of foaming compounds have been used in coal mines in coal producing countries for various purposes viz. dealing fire, construction of mine seals, filling of voids and rib support [6-10].

General properties of foam suitable for coal mines

The foam selected for application in coal mines for dealing with fire/heating problems should have the following properties:

- Good expansion ratio
- More life/high stability of foam
- Inhibiting properties
- Should not have any health hazard during or after the application
- Cost and availability

The foam system

Use of foam in dealing fire both in coal and non-coal industry is practiced since long back. The system employed for generation of foam basically consists of two units:

- Foam generator
- Foaming agent

Foam generator

There are different types of foam generators. Selection of foam generator is to be made depending upon the foaming agent and application requirement. The following three types of foaming system are generally used:

- Hand held portable foam generator – Used for small scale fires.
- High pressure foam generators – Used to produce rather stabler and large-scale foam.
- Solid foam generator – Used to generate solid foam for filling up of voids etc. rather than fire prevention or quenching.

For large-scale application of foam, a specially designed foam generator (Fig.2) is used. The generator comprises a pump and a foaming chamber. Pump feeds the foaming solution into the foaming chamber which is connected with a nitrogen gas supply at about 2.5 bar pressure. Foaming solution and nitrogen gas passes through a fine net provided into the chamber. Thus foam is generated. The generated foam is moved through flexible hose pipe up to the desired location.

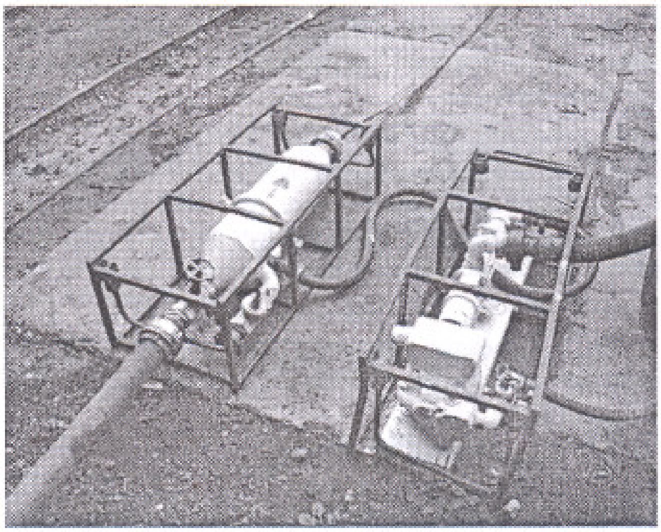

Fig.2 High expansion foam generator

Foaming agent

In the beginning it was believed that formation of foam is facilitated in solutions, where surface tension is lowered, e.g. in lypophilic solutions. However, now it is known that any substance producing change in surface tension, increase or decrease, will facilitate foam formation. Presently two types of foaming agents are used.

- Organic resin based: Used for isolation, filling of voids etc.
- Aqueous high expansion foam concentrates: Used for inertization, direct fighting of fire.

In Indian coal mines protein foam concentrate is mostly used for inertization and dealing with fire.

Protein foam compound

Protein foaming agent/compound is prepared by hydrolyzing animal protein with suitable additives for preservation and to protect against microbiological organism. A few chemical inhibitors are also mixed to it to make the foam a spontaneous heating retardant. Some of the physical and chemical properties of the protein foaming agent studied in the laboratory are given in Table 1.

TABLE 1: PHYSICAL AND CHEMICAL PROPERTIES OF PROTEIN FOAM COMPOUND

	Parameter	Observation/result
1	Colour	Blackish brown
2	Odor	Rotten protein odour
3	pH	6.2
4	Specific gravity, g/cc	1.12
5.	Expansion	21.74
6	Viscosity, cps	38.2
7	Skin irritation if any	Nil
8	Surface tension, dyn/cm	20.5
9	Miscibility with water	Easily miscible in water

PREPARATION OF FOAM

Three to five per cent of the aqueous solutions of the protein foam compound are prepared for making the high expansion foam.

Foam generating machine for small applications

A suitable powerless foam-generating machine has been designed for making high-pressure high stability foam. The uniqueness of the machine is that it does not require electrical power. The layout of the machine is shown in Fig.3.

WORKING PRINCIPLE

This is a pneumatic powerless foam-generating machine of variable capacity. The generation of foam may be controlled on the basis of demand in the drill holes in coal pillars. In the machine, nitrogen at 1.5 - 2.5 kg/cm^2 pressure is fed to mixing chamber [1] through connecting pipe [6] and foam chemical solution is fed from foam solution tanker [3] and foam is discharged through outlet [7]. The foaming solution from chamber [3] is pressurized, by adjusting the control valve, fitted with inlet side of foaming chamber.

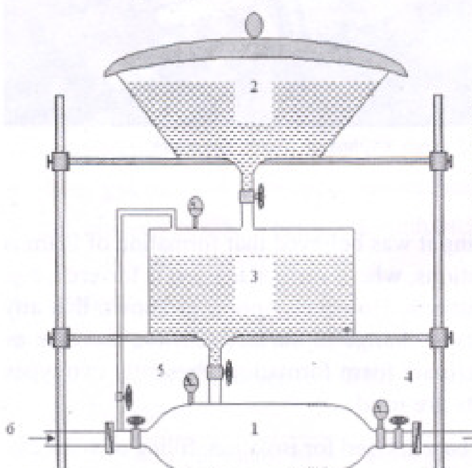

Fig.3 Schematic layout of HPHS foam generator

Case studies

DEALING FIRE AT ORIENT COLLIERY, MINE NO 3, MCL

Orient Mine No.3, MCL, situated west of Ib River is one of the best U/G mines of MCL producing more than 1600 tonnes of coal per day. The mine had to be sealed off from mouth top due to a intense fire, broke out in Lajkura seam (34 LS district, bottom section) of the mine on 24.12.2005.

The mine management after initial efforts to control the fire observed that the situation is deteriorating and subsequently sought assistance from concerned departments. CIMFR (erstwhile CMRI) was requested to assist in dealing the fire.

After about a months hard work by the mine management, DGMS Bhubneshwar, CIMFR and invited experts, the fire was brought under control and ultimately on 6th February 2006 the mine was successfully reopened in record time.

The chronology of events, important observations and results are presented below (Table 2):

Investigations

A CIMFR Camp laboratory was established for onsite analysis of air samples, measurement of pressure at selected locations and interpretation of results.

ASSESSMENT OF STATUS OF FIRE BY ANALYSIS OF MINE AIR SAMPLE

Since collection of air samples from underground was difficult hence it was decided to monitor the status of fire by collecting the air samples from fan drift. The results of analysis are graphically represented in Figs.4 to 8. Subsequently 4 boreholes namely 1, 2, 3 and 4 were drilled from surface. These boreholes were used for drawing of air samples, measurement of pressure and injection of nitrogen gas/high expansion foam.

STUDY OF VARIATION OF PRESSURE WITH TIME IN THE MINE

To find the efficacy of sealing off the mine, it was decided to carry out pressure variation measurement through boreholes and selected isolation stoppings. The results are graphically represented in Figs.9 and 10.

DISCUSSION OF RESULTS

The results of air sample results are represented in Figs. 4, 5, 6, 7 and 8. It can be seen from Fig.4 that the fire was very active in the mine as indicated by the air sample results of 1st Jan.06, (O_2 4.7%, CO_2 10.3%, CH_4 5.86% and CO 1.5%). In view of this the mine was sealed off from mouth top on 3.1.06.

TABLE 2

Date	Event	Action taken	Remarks
24.12.2005 7 p.m.	CO at 29L/3D jn of Lajkura seam (top sec.) return was noted. It was confirmed that CO was coming from discontinued 34 LS panel of bottom section.	At 9:00 PM workings beyond 55 D, 34LS Distt (bottom sec.) was filled with smoke. Air flow in the district was increased to clear the smoke.	
25.12.2005 to 30.12.2005	The site of the fire/heating was located at 60 Dip off 48 LS.	It was decided to quench the fire by adopting available means by conventional techniques.	
31.12.2005	The BH sample results revealed no perceptible change in CO and CO_2%. However O_2 and CH_4 increased to 4.0 and 2.7% respectively. N_2 flushing through surface borehole was started at 8.25 PM @ rate of 98 m^3/min.	To stop ingress of fresh air into the T&B section. One temp. stopping was erected at 4 companion Dip by rescue team to isolate northern flank of bottom section.	
1.1.2006	4 temp. stoppings were constructed between 8 and 9 L to isolate top section. First liquid nitrogen tanker arrived at 1:30AM. Second borehole was drilled from surface to connect UG workings at 60R/44L.	Injection started at 4:00PM BH-1.Air samples from BH was drawn before liquid N_2 flushing, which showed O_2, 4.7%, CO_2 10.3%, CH_4 5,86% and CO 1.5%.	
2.1.2006	N_2 flushing continued up to 2:20PM. DMS opined that atmospheric conditions of UG workings do not permit sectionalizing the workings from main intakes. Instead, all efforts should be made to first quench the fire through surface borehole by flushing liquid N_2. The mine condition can be assessed by drawing samples from boreholes already drilled and another two holes that need to be drilled over 34LS and 59LS panel workings. Re-opening of the mine can be thought of at a later date.	Air samples were collected from the BH-2, which revealed O_2 4.8%, CO 1.03%, CO_2 10.4% and CH_4 1.8%. The rescue team reported that influx of smoke laden air was continuing from 27LS. Leakages were also observed at 3L and 11L, indicating that return still had positive pressure to contaminate the intake air current. The sample collected by rescue team from 27LS revealed O_2 5.6%, CO 0.924%, CO_2 10.4% and CH_4 1.6%.	Details of gas analysis results are shown in Fig.5.
3.1.2006	Second liquid N_2 tanker arrived.	Injection started at 3:00 PM. Monitoring of atmospheric condition from BH-3 continued.	The mine was sealed from surface closing all entries.
4.1.2006	The mine was sealed off from all inclines (No. 4, 5 and travelling incl.) and fan drift (PV-200 and 300)	LN_2 injection from BH-2 and high expansion Foam (HEP) through BH-1 at a rate of 300 m^3/hrs.	The monitoring and advice was entrusted to CMRI.
6.1.2006	LN_2 injection was shifted from BH-1 to BH-2 on 6/1 at 11.15 PM. HEF injection from BH-1 started at 10.15 PM	Injection continued. Repairing of air leakage points were taken up.	Sign of regular improvement were observed.
12.1.2006	The injection of LN2 (from 12.1.06, 7.15PM) and HEF (13.1.06, 9:55 PM) stopped.		Improvement continued.
28.1.2006	Meeting of Expert Committee held at MCL HQ	CMRI presented the results and suggested reopening of the mine. The scheme for reopening was also proposed.	The committee agreed to the proposal.
6.2.2006	The mine re-opening started		Reopening completed on 8/2/06 Fig.6.

Subsequently since 4.1.06, injection of high expansion high stability nitrogen foam in conjunction with nitrogen gas was taken up.

From the results of monitoring shown in Fig.7, it is evident that even after about 15 days of stoppage of nitrogen and high expansion foam, CO came down below 50 ppm or less, O_2, below, 0.5%, CH_4, less than 1.0%, CO/CO_2 ratio is below 0.05%. All the above parameters are indicative of the fact that fire has died down.

The mine has been re-opened successfully on 6th February 2006 and production is resumed.

Strategy adopted during re-opening

1. The breaching of stopping by rescue team in incline no.4 (haulage incline) and PV-200 fan drift stopping was started at 11:00 AM. The breaching of stoppings was completed by 2:00 PM.

CENTRAL INSTITUTE OF MINING & FUEL RESEARCH, DHANBAD CAMP LABORATORY ORIENT MINE NO. 3, MCL

VARIATION OF CO2, O2 AND CO WITH TIME IN FAN DRIFT

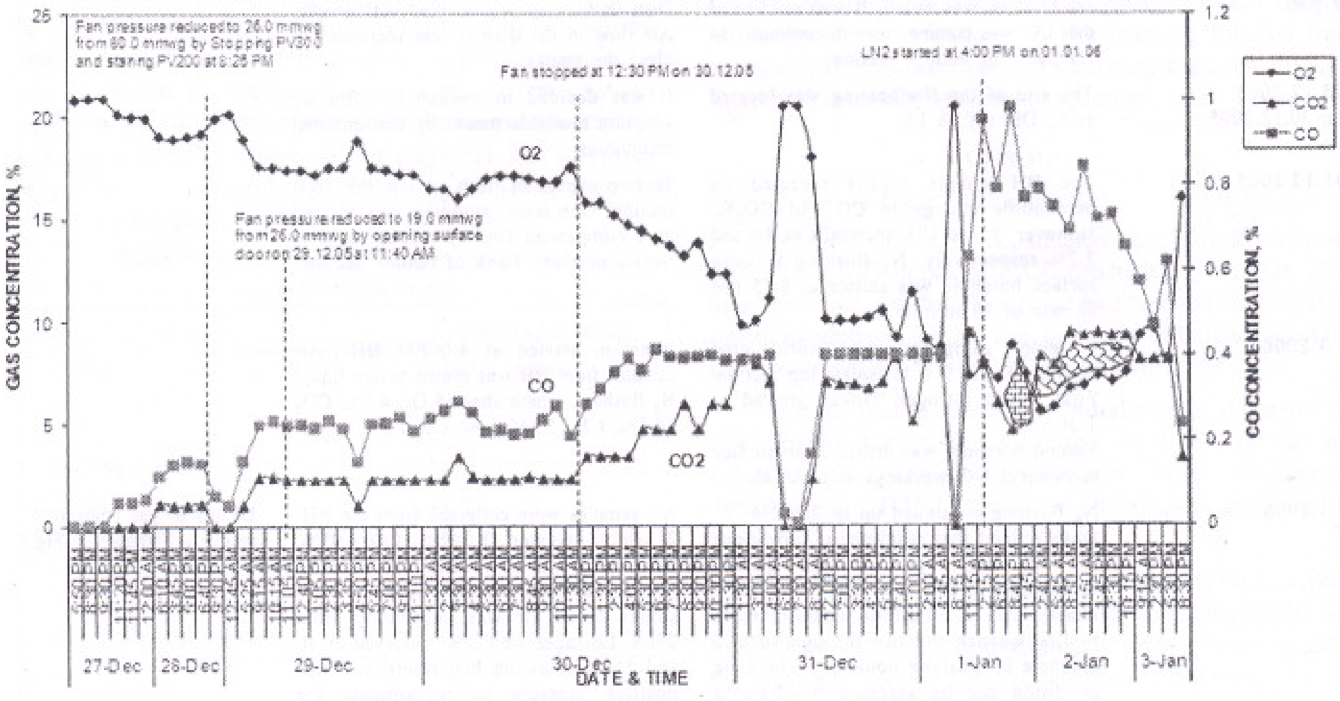

Fig.4

CENTRAL INSTITUTE OF MINING & FUEL RESEARCH, DHANBAD CAMP LABORATORY ORIENT MINE NO. 3, MCL

VARIATION OF CH4 IN FAN DRIFT

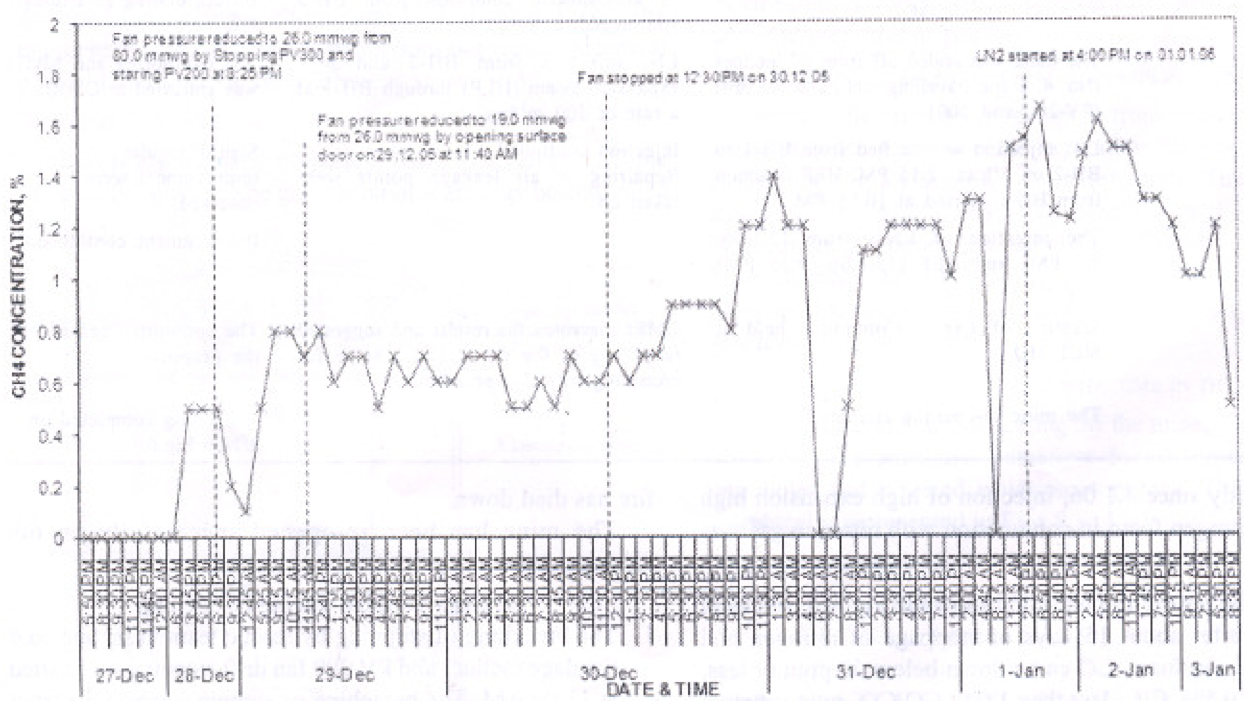

Fig.5

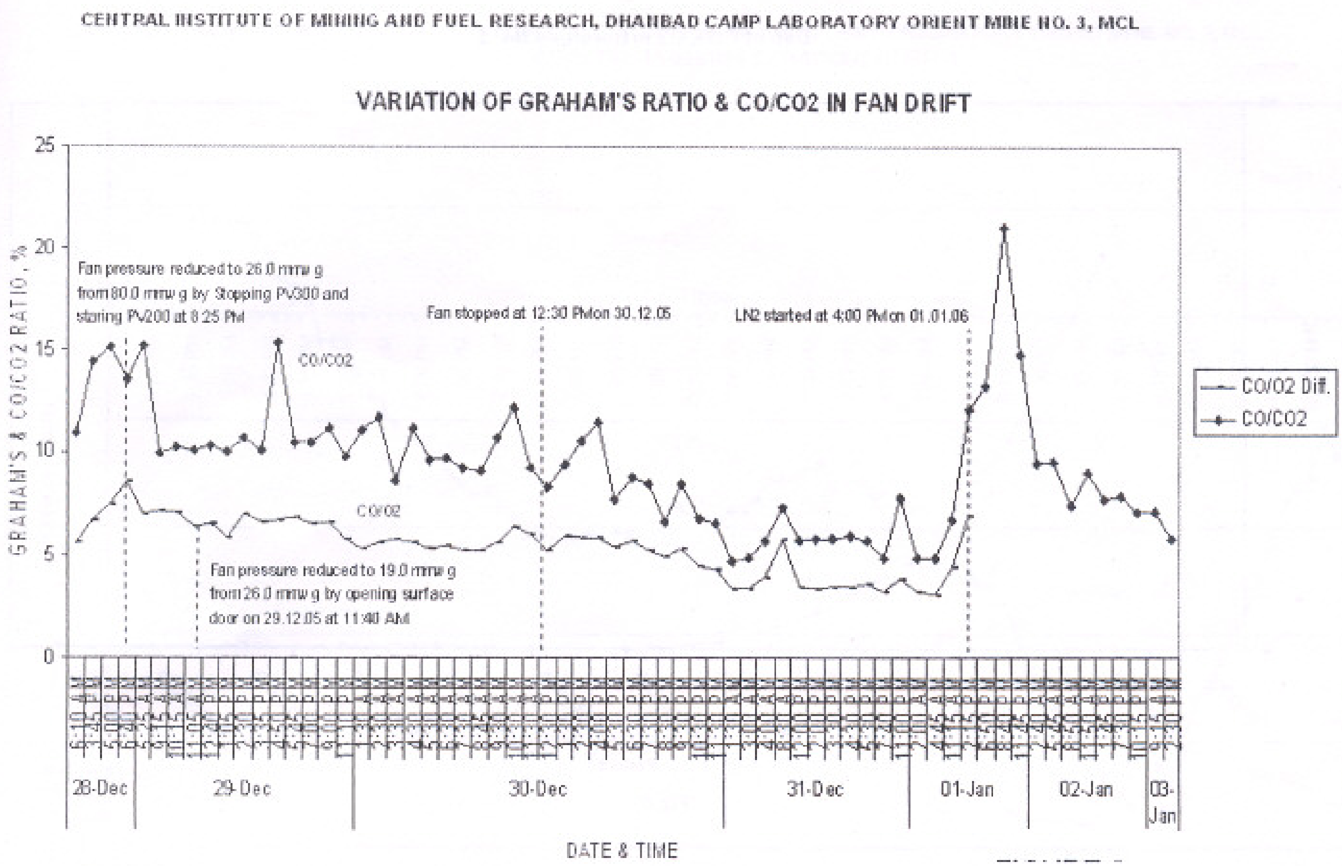
CENTRAL INSTITUTE OF MINING AND FUEL RESEARCH, DHANBAD CAMP LABORATORY ORIENT MINE NO. 3, MCL
VARIATION OF GRAHAM'S RATIO & CO/CO2 IN FAN DRIFT
GRAHAM'S & CO/CO2 RATIO, %
Fan pressure reduced to 26.0 mmw g from 80.0 mmw g by Stopping PV300 and staring PV200 at 8.25 PM
Fan stopped at 12:30 PM on 30.12.05
LN2 started at 4:00 PM on 01.01.06
CO/CO2
CO/O2
Fan pressure reduced to 19.0 mmw g from 26.0 mmw g by opening surface door on 29.12.05 at 11:40 AM
CO/O2 Diff.
CO/CO2
28-Dec
29-Dec
30-Dec
31-Dec
01-Jan
02-Jan
03-Jan
DATE & TIME

Fig.6

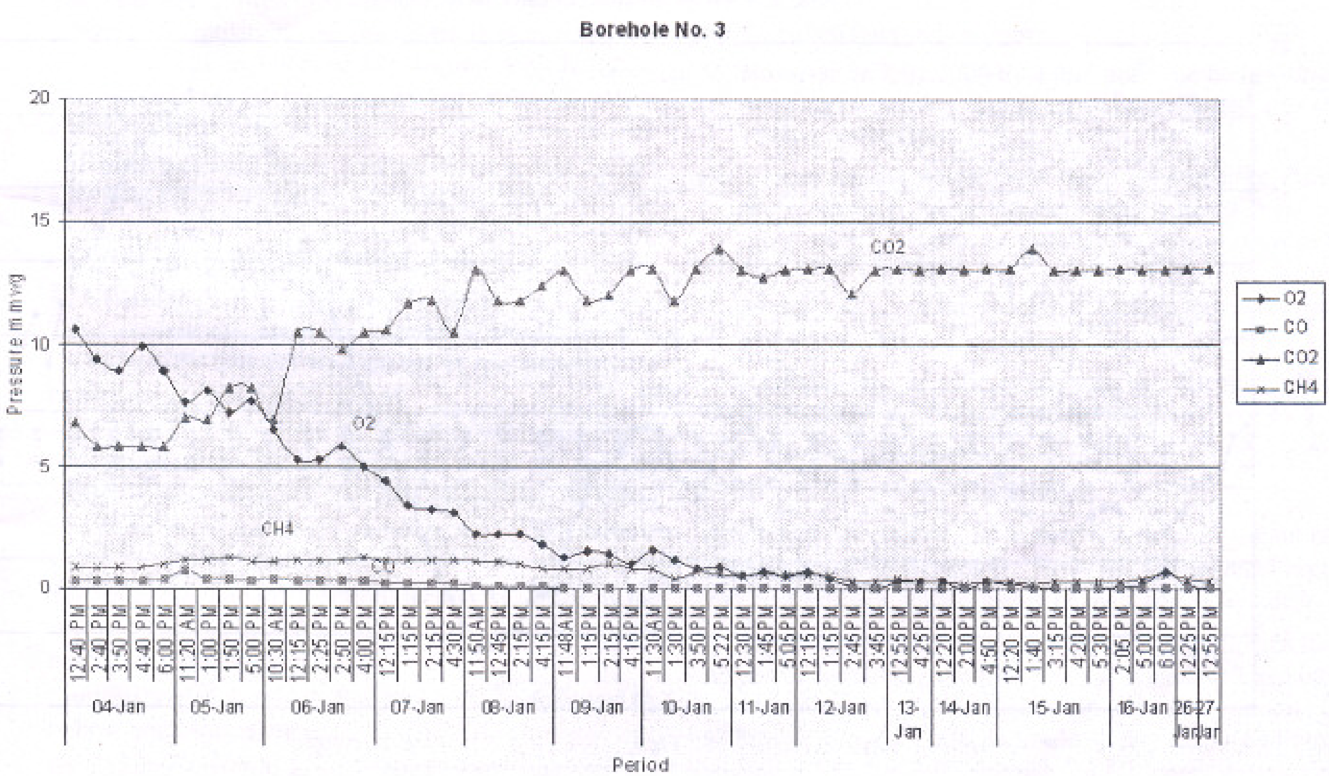
Borehole No. 3
Pressure m mwg
CO2
O2
CH4
CO
O2
CO
CO2
CH4
04-Jan
05-Jan
06-Jan
07-Jan
08-Jan
09-Jan
10-Jan
11-Jan
12-Jan
13-Jan
14-Jan
15-Jan
16-Jan
26-Jan
27-Jan
Period

Fig.7

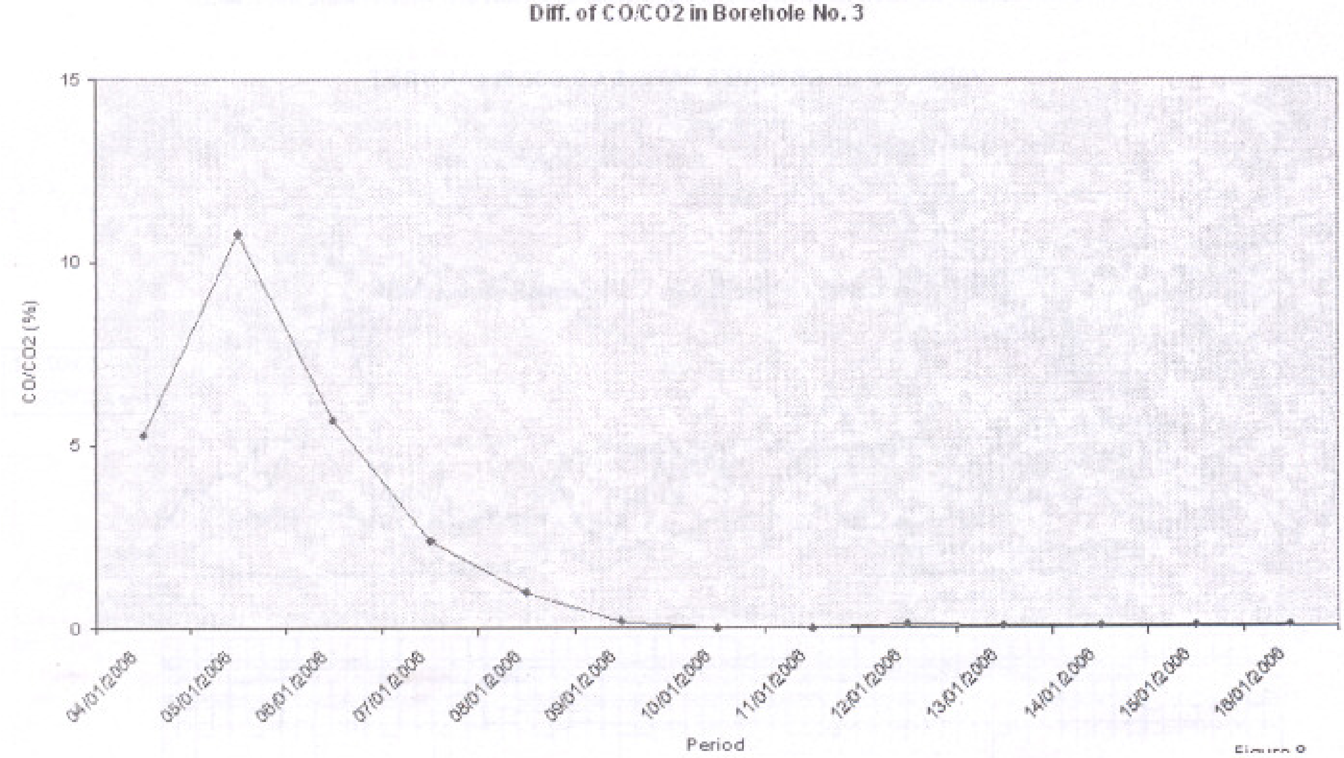
Diff. of CO/CO2 in Borehole No. 3
CO/CO2 (%)
15
10
5
0
04/01/2006
05/01/2006
06/01/2006
07/01/2006
08/01/2006
09/01/2006
10/01/2006
11/01/2006
12/01/2006
13/01/2006
14/01/2006
15/01/2006
16/01/2006
Period

Fig.8

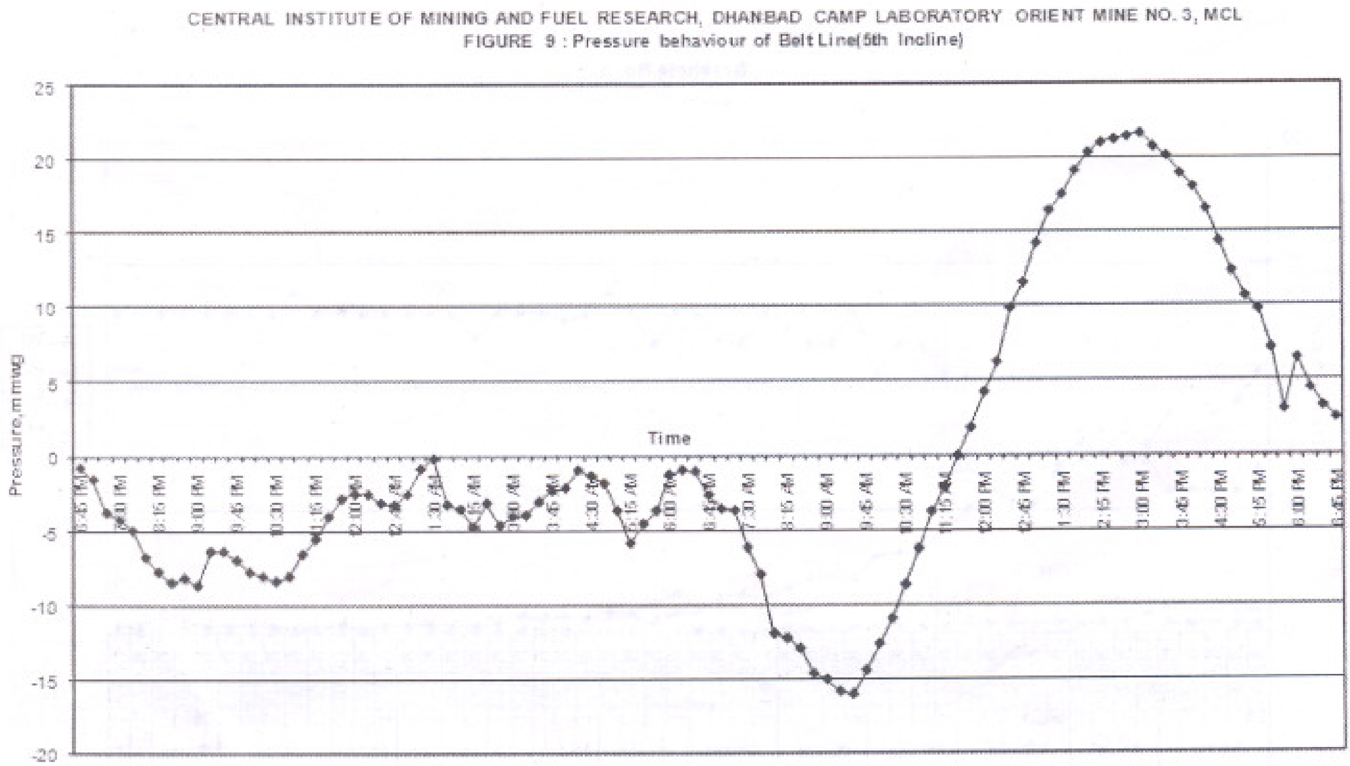
CENTRAL INSTITUTE OF MINING AND FUEL RESEARCH, DHANBAD CAMP LABORATORY ORIENT MINE NO. 3, MCL
FIGURE 9 : Pressure behaviour of Belt Line(5th Incline)
Pressure, mmwg
25
20
15
10
5
0
-5
-10
-15
-20
Time

Fig.9

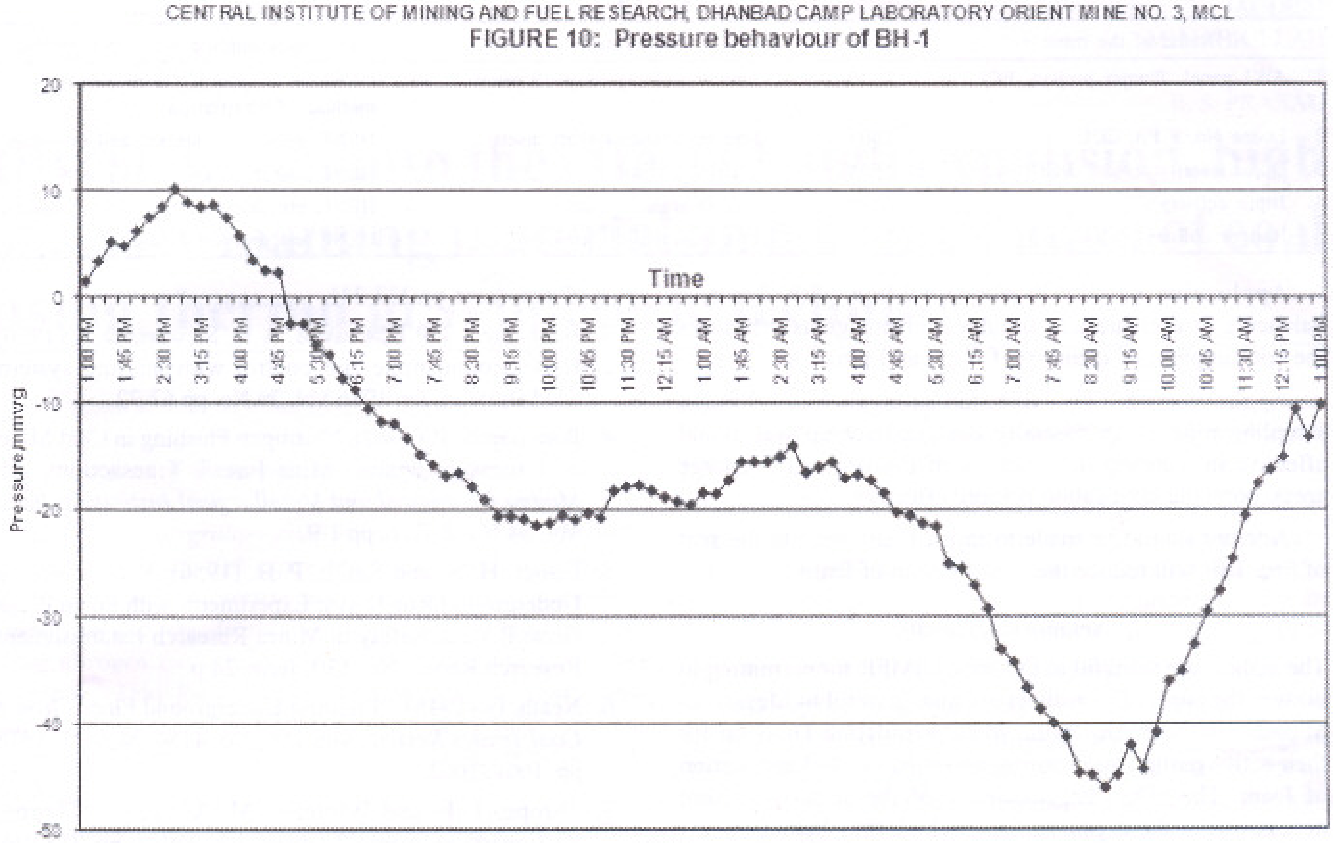

Fig.10

2. The mine was allowed to ventilate at NVP. After about 2-3 hours of ventilation, the rescue team went down the mine up to 12L and opened 12L section door. It was as per our prediction that the area maximum up to 12L can be cleared by NVP.
3. The mine was kept under NVP however, within 5-6 hrs after opening of door at 12L the NVP became almost in-effective. In fact on 7.02.2006 by 10:00 AM the air started exhausting from both the openings (incline no.4 and PV-200 fan drift).
4. To overcome the problem as per our prediction and suggestion PV-200 fan was started at low pressure (15 mmwg) on 7.02.2006 at 11:00 AM.
5. After 1 hour of ventilation the 12L door was again closed by rescue team. Also in top section the return was partially opened (initially closed at the time of sealing). By doing so the air was allowed to ventilate up to 38L bottom section.
6. The inspection up to 27L bottom section was made by the rescue team and it was found that the environment is normal and safe for working.
7. Construction of stoppings first by GI sheets followed by hollow brick was taken up.
8. By 8.02.2006 9:00 AM 12 GI stoppings were completed and the area was partially isolated. In the mean-time there was indication of rise in CO concentration at BH-2 on 8.02.2006 from early morning.
9. However on 8.02.2006 by a mid night the hollow bricks stoppings were also completed and the affected area was isolated successfully.
10. To keep a close watch on the condition of the fire, during the reopening operation w.e.f from 6.02.2006 regular monitoring in respect of gas and pressure was taken up by CIMFR at BH-2, BH-3 and BH-4. Also on the spot advice was given for ventilation in the mine particularly at work places.

Application of high expantion nitrogen foam (HENF) in other mines is shown in Table 3.

Conclusions

Application of inert gas in dealing fire in underground coal mines is a proven technology. However, for optimum results and cost efficacy, undue losses of inert gas be avoided.

Application of high expansion high stability nitrogen foam helped in controlling the fire in orient Mine No. 3 and other mines mentioned above. Application of high expansion high stability nitrogen foam technology has many additional advantages viz. cooling, inertization for longer duration etc. compared to inert gas alone.

TABLE 3

	Name of the mine	Year	Problem	Technique applied to control the fire
1.	AWI panel, Jhanjra project, ECL	2000	Fire in working longwall panel	HENF in conjunction with chamber method of ventilation
2.	Lodna No. 8 Pit, CCL	2004	Fire in downcast shaft insets	HENF, pressure balancing and inhibitors
3.	Gopal Gareria project, BCCL	2005	Trench cutting	HENF and inhibitors
4.	Jitpur colliery	2008	Fire in sealed-off area	HENF, pressure balancing and inhibitors
5.	Haripur colliery, ECL	2009	Fire in sealed-off area	HENF and pressure balancing

Application of HENF in conjunction with dynamic balancing of pressure has an added advantage as it reduces the consumption of quantity of foam and nitrogen.

Application of high expansion nitrogen foam through sampling pipe using specially designed set up was found effective in reducing the intensity of fire/heating. For large areas, borehole application is more effective.

Attempt should be made to inject foam close to the seat of fire. This will reduce the consumption of foam.

Acknowledgements

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COMBATING COAL MINE FIRE – APPLICATION OF HIGH PRESSURE WATER JET TECHNOLOGY ADOPTED BY GOMA ENGINEERING PVT. LTD.

(Continued from page 418)

In underground mines area affected by fire can be removed by cutting off the burning chunks.

Thus it will be seen that application of high pressure water jet systems can bring down the worries from authorities by reducing loss due to spontaneous burning or otherwise.

The equipment needed will be basically triplex plunges pumps driven by diesel engines or electric motor. Looking into the physical conditions of coal dump as well as the coal extraction areas the technical specifications of pumps and other accessories are to be determined. Range of pump sizes from the smallest to large ones will find place depending on physical conditions and logistics of operations.

The requirements for operations of pumps are supply of clean filtered water, electrical connection/diesel and required quantity of hose pipes.

This proposal has not yet been tested but is a low cost highly effective in nature if applied in all sincerity. Payback period for the investments will be relatively low.

It is sincerely expected that coal mining community will give fair chance to high pressure water jet technology to fight coal fire. Goma Engineering is geared to work together with Coal India towards saving millions of hard cash that would have been lost into ashes.