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Application of nitrogen as preventive and controlling subsurface fire – Indian context

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The application of liquid/gaseous nitrogen, which inhibits combustion for preventing, controlling and extinguishing mine fires, is now universally accepted for last 50 y. This paper presents the scientific relevance and selective criteria for use of N_2 in subsurface fire and reviews experiences of N_2 use in Indian coalmines for more than 20 y. The different techniques of N_2 production, its advantages and disadvantages are described briefly. A case study of using N_2 as a preventive material, in goaf area of working panels of blasting gallery (BG) method of mining is also highlighted.

Keywords: Spontaneous heating, Liquid nitrogen, Inertisation, Blasting gallery
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Introduction

Mine fire is one of the major problems to coal mining industry world wide due to spontaneous heating of coal. Fire in coalmines is a threat to mine safety, losing huge quantity of natural resources, making mining difficult or impossible, endanger human lives and evolution of toxic gases and fumes that damage the environment. India is currently the world's third largest producer of coal from opencast and underground mines. Indian coalmines have a historical record of extensive fire activity for over 140 y (Raniganj coal field, 1865)[1,2]. It gives to a serious safety hazard to mine personnel as well as fire can take a heavy toll in terms of loss of production, machineries and fire fighting material; often requiring sealing a large section of mine or the entire mine. This essentially contributes to global problems such as loss of coal reserves and environmental pollution, which adversely affect mining economics.

Inert gases were used to fight mine fires during latter half of the 19th century. Subsequently, flue gases, carbon dioxide and nitrogen were used for combating mine fire with varied degree of success. Probably, the earliest report to extinguish mine fires using inert gases was in 1850, at the Clackmannan Mine, Scotland[3-5]. Among all these inert gases, nitrogen emerged supreme for smothering and combating fires in sealed off areas by inertisation of the environment without endangering the persons engaged in such operations. The liquid nitrogen was used first time[3,6] in 1949, to smother an underground fire at Doubrave Mine in the Ostrava – Karniva Coal Basin, Czech Republic. Since then, many countries had used nitrogen for fighting, suppression and prevention of underground fires. A well-organized system for combating mine fire using nitrogen had been developed after 1960. In India, the first trial of nitrogen was done to control an old fire in Laikdih Deep Colliery, BCCL in March 1981[7].

Why Nitrogen

Among inert gases, the efficacies of nitrogen gas to prevent and control the underground fires are as follows: (i) It is lighter (sp gr 0.967 at 1.013 bar & 21°C) than air and can fill the whole space in vicinity of the goaf areas; (ii) It has low temperature (-210.1°C, thermal conductivity 24 mW/mK at NTP) which will takeout heat from surrounding strata in underground as well as from seat of fire to help dissipation of heat in the sealed off area and working panels, thereby enabling its use for prevention and control of spontaneous heating/fire in sealed off areas and working panels; (iii) Nitrogen is a non-toxic gas available from atmosphere very economically; (iv) It reduces the possibility of atmosphere becoming explosive in sealed off areas or goaf areas of working panels; (v)

Transportation of liquid and gaseous nitrogen from surface to underground is easy; (vi) It is non-corrosive than CO_2, which forms carbonic acid; (vii) Liquid nitrogen (1 m^3) converts to gaseous nitrogen (691 m^3 at 1.013 bar & 15 °C, density 4.614 kg/m^3), which is sufficient to create an inertisation umbrella over the sealed off/goaf area of the panels; viii) The latent heat of vaporisation is 198.38 kJ/kg (1.013 bar at b p –195.9 °C), which is very good to act as coolant; ix) It reduces the oxygen content in the sealed off area/ goaf area by inertisation; x) It reduces the intensity and spread of secondary combustion in fire area; and xi) It seals off fire zones with pressure chamber in case of negative pressure difference.

Techniques of Nitrogen Production

Nitrogen is produced commercially from air using cryogenic distillation, combustion of natural gas or propane and air, and pressure swing absorption. The choice of methods depends primarily on the desired production capacity, nitrogen purity requirements and cost effectiveness (Table 1).

Application of Nitrogen in Indian Context

Indian coalmines have a long history of extensive fire in Raniganj and Jharia coal field[1,2]. French nitrogen flushing equipment[7] was proposed as the means of preventing heating in mining of the Samala Seam in ECL. The first trials at Laikadih colliery in March 1981 used one inert gas generator of 500 m^3/h capacity based on combustion technology (Table 2). Spontaneous heating started on 1983 in S4 panel of Jambad seam J K unit of Madhujore Colliery and liquid nitrogen tanker (4000 l capacity) was used. In 1985-86, Indian Oxygen Company installed a plant at Lodna Colliery and delivered a total quantity of 94,000 m^3 spread over a period of about 8 months, an average of less than 400 m^3/d. In July 1986, portable nitrogen generator (PSA) type plants were installed at the same mine and this type of nitrogen plant was first application in a mine safety context. In April 1986, large scale of liquid nitrogen (462 m^3) was used by a mobile tanker (8.4 m^3 capacity) at the GDK No-9 Incline Mine, SCCL to combat a blazing underground waste fire[8]. Liquid nitrogen flushing and a PSA were used during the Jhanjra project for suppression of spontaneous heating in a goaf of longwall face AW1 in the R-VIIA seam of Jhanjra Mine, ECL. Fire in XIII and XIV seams sealed off areas of Sijua Colliery, TISCO, which continued for several years. PSA type generator (500 m^3/h) was installed in 1994 and 70 lakhs m^3 nitrogen has been injected so far in a total void area of 8 million m^3. In October 1993, fire was taking place at the junction of travelling and conveyor roadways in 51 level of Seam–V of Churcha Colliery, SECL. In August 1993, heating was observed in F1 longwall caving panel of Seam - XVI combined of Monididh Colliery, BCCL. In New-Kenda Colliery, ECL fire occurred in main intake in Dobrana Seam near 2 pits on January 1994. Liquid and gaseous nitrogen was flushed into the affected zone through boreholes. In April 1997, powered support and other equipments of more than 1000 million rupees were trapped in P-3 longwall face at Kottadih Colliery of ECL due to sudden loading and collapse of the part of strata, which caused spontaneous heating in the goaf of the panel[9]. Liquid nitrogen was flushed in the goaf of the panel through borehole from surface at the rate of 800 m^3/h. The infusion of liquid and gaseous nitrogen (trolley mounted PSA type) were used in AW1 longwall panel of Jhanjra 1 & 2 incline in 2000 to control the fire of sealed off area[10,11]. Some global nitrogen applications are given in Table 3.

Case Study

The problem of spontaneous heating in Blasting Gallery (BG) panels during extraction is a major threat to safety and productivity in GDK-10 Incline Mine Ramgundam, SCCL. Most of the BG panels of Seam-3 have been sealed due to the occurrences of spontaneous heating during extraction of the panel. The thickness of the seam-3 (10.5-11.0 m) is developed along bottom section leaving 1.5 m coals in the floor. So, an experimental work was started on December 2001, at Seam-3 of BG-2A Block–C panel (area, 17200 m^2) GDK-10 incline mine, Ramagundam (Fig. 1) to prevent spontaneous heating/fire in goaf area of working panel[12-14].

During extraction of the panel, regular thermo-compositional monitoring and application of preventive measures i.e. continuous nitrogen flushing inside the goaf, sealant application on loose coal left inside the goaf as well as on barrier pillars has been carried out. A probe gallery has been developed first time in BG-2A, block C panel along the barrier for taking gas samples as well as for application of fire fighting measures. Gaseous nitrogen was infused from February to June 2002, through probe gallery to goaf area of the panel to inertise the goaf for prevention of spontaneous heating/fire from PSA based nitrogen plant, which has capacity to generate nitrogen (purity, 94-95%) at flow rate of 210 m^3/h. A total of 5.80 lakh m^3 gaseous nitrogen was infused in the goaf to

Table 1 — Different nitrogen production techniques, its merits and demerits

Methods	Principle	Advantages	Disadvantages
Cryogenic air separation	The cryogenic air separation plant separates N_2 from compressed air. The air, compressed to ca 700 KPa (ca 100 psi), is supplied to a thermally insulated cold box containing reversing heat exchangers, a gel trap, a distillation column and a super heater. The compressed air is cooled in the reversing heat exchangers against outgoing N_2 product and waste gas. All the water, most of the CO_2 and hydrocarbons entering with the air are removed by freezing in the reversing heat exchangers and are reversed at regular intervals. The clean air is cooled further in the super heater and is fed into the distillation column where it is liquefied and separated into high purity N_2 and waste gas.	It is cold and dry and poses no problem with cooling or compressor. It is economically beneficial for large-scale production and high purity requirements. It can be distributed by pipeline or liquefied for storage and shipment in vacuum insulated vessels.	The production cost is high compared to PSA type generator. The availability of base material is limited.
Inert gas generator	Natural gas or propane is burned with air and the products of combustion are removed leaving purified nitrogen. The typical inert gas generator includes an air pump, air and natural gas flow controls, a burner and combustion chamber, a refrigerant dryer and molecular sieve adsorbent bed. Filtered air is drawn through pump. Air and natural gas are controlled to provide specific air gas ratio to the burner. The gas burns in the combustion chamber in an exothermic reaction and essentially a complete combustion achieved. The burned gas contains N_2, CO_2, water vapour, H_2 and small amount of CO. Gases leaving the combustion chamber are cooled in a surface condenser and passed through a vapour separator to remove condensed water. The gases than flow to a refrigerant dryer where the dew point is reduced to 4 ^oC. CO_2 and more water vapour are removed in a molecular sieve bed; two beds are used alternatively one for gas to purify and other to reactivated by pumping.	It is economically beneficial for small-scale production and high purity requirements. It can be distributed by pipeline or liquefied for storage and shipment in vacuum insulated vessels.	
Pressure swing adsorption (PSA)	Bergbau-Forschung, Essen of FRG developed pressure swing adsorption (PSA) technology in eighties to separate N_2 from ambient air by use of carbon molecular sieves (CMS). The plant is having two separated vessels charged with CMS coke, which is produced from hard coal. A compressor loads one bed with air, from which O_2, water vapour and CO_2 are adsorbed while rich N_2 passes through to the product pipeline. At the same time, the other bed is depressurised and O_2, water vapour and CO_2 are desorbed from the molecular sieve coke. The pressurisation and depressurisation of the beds are alternatively reversed using control valves. The cycle time approx. for both operations is 2 min. Optimum loading and desertion periods are selected according to N_2 purity desired.	It is economically beneficial for large-scale production and high purity (99.9%), which can serve the purposes for inerting the mine atmosphere. Production cost of gaseous nitrogen is less as compared to cryogenic plant and it can be distributed by pipeline easily for applications in mine.	The initial capital cost is high. The replacement of CMS, required after certain interval for getting pure N_2, is an expensive exercise. The frequent breakdown gives high running for maintenance and replacement of parts. The purity of N_2 decreases progressively.

— *Contd….*

Table 1 — Different nitrogen production techniques, its merits and demerits — (*Contd.*)

Methods	Principle	Advantages	Disadvantages
Membrane Based Nitrogen gas generator	The membrane based nitrogen gas generator consists of millions of hollow fibres, each about size of human hair, through which compressed air is passed. The components of air- O_2, CO_2 and moisture diffuse through the semi permeable membrane surface, leaving behind high purity nitrogen.	This system offers highest recovery of N_2 from air and can generate N_2 up to 99.9% purity. It operates at a constant pressure (11 kg/cm^3) with no change – over cycle results in consistent in gas purity and eliminates the need of a gas booster resulting in capital, spares, maintenance and downtime. The system is unaffected with change in ambient temperature and is more compact.	The initial cost is high.

Table 2 — Status of nitrogen application in Indian coal mines

Name of the colliery	Year	Methods	Quantity m^3	Rate of injection m^3/h	Remarks
Laikadih colliery	1981	Gaseous N_2	10,00,000	500	Within two months time the O_2 percentage was brought down to 0.57% and CO in traces. However, operation was partially successful due to heavy leakage round the fire-affected area.
Madhujore colliery S4 panel	1983	Liquid N_2	4000		The fire was controlled to some extent.
Lodna colliery	1985	Liquid N_2 flushing PSA type N_2 generator	94,000	500	Fire was dealt by feeding evaporated liquid nitrogen through boreholes followed by installation of PSA type nitrogen generator.
GDK-9 Incline mine	1986	Liquid N_2	3,23,645	1470	The mine was reopened after 55 d and the production restored within 125 d.
Churcha colliery, SECL	1993	Gaseous N_2 PSA type N_2 generator	Not available	Not available	Fire was controlled within a month.
Moonidih Colliery, BCCL	1993	Gaseous N_2	Not available	Not available	N_2 flushing proved successful in controlling the fire and helped in salvaging of longwall equipment
New Kenda Colliery, ECL	1994	Liquid and gaseous N_2	Not available	Not available	Fire was brought under control. The mine was reopened and resumed normal production.
Kottadih colliery, ECL	1997	Liquid N_2	106400	680	The panel was reopened successfully after 19 d of sealing and it was possible to keep the temp. below 40 °C. This paved way for safe recovery of all the healthy supports and other equipments worth over Rs 400/million.
Sijua colliery, TISCO	1997	Gaseous N_2 PSA type N_2 generator	7000000	500	Fire was brought under control in most parts except a few places in sealed off areas where O_2 content could not show the desired level.
Jhanjra 1&2 incline AW1 LW Panel	2000	Gaseous N_2	Not available	Not available	Fire was brought under control after a long struggle extending over 8 m.
GDK-10 Incline mine SCCL	2002	PSA based Gaseous N_2	5800000	180	For prevention of spontaneous heating in goaf of BG-2A panel of this mine through probe gallery.

Table 3 — Status of nitrogen application in World coal mines (except India)

Name of the colliery	Year	Methods	Quantity m^3	Rate of injection m^3/h	Remarks
Doubrava Mine, Hubert Seam Czech Republic	1949	Liquid N_2 Cryogenic N_2 generator	5057000	600-650	The fire was controlled and afterwards the mine was reopened.
Roslin Colliery UK	1953		16697	Not available	Area was reopened and combustion fell from 3.85 % to 2.92 %.
Fernhill Colliery UK	1962	Liquid N_2	2400000	850	It was possible to control the atmosphere in the sealed roadway to safe limits, so that work could be carried out near the seat of fire without an explosion hazard.
No-29 Mine, Vorkutaugol Coal Produce Siberia	1968	Liquid N_2	179400	660-1900	The fire area was sealed for 8 months and than reopened.
Osterfeld Colliery, Germany	1974	Liquid N_2	154000	3600	It gives guard against the danger of an explosion during salvage operations in a section of the mine in which a heating had developed.
Schlagel Colliery Germany	1975	Gaseous N_2	700000		The fire was controlled.
Rozley Colliery, Blanzy Coalfield France	1976	Gaseous N_2	Not available	40-150	It enabled recovery of the face equipment.
Spring field Colliery, SA	1977	800	65180	Not available	Fire subsided after some time.
Daw Mill Colliery, Warwickshire	1979-90	Gaseous N_2 PSA N_2 generator	38100000	1200	N_2 is used to make atmosphere inert in drought off, thus avoiding the problems of spontaneous heating and atmospheric explosive conditions during or after sealing.
Sainte Fontaine Colliery France	1982	N_2	Not available	3000-17500	It was used to avoid risk of explosion during sealing. The use of N_2 enabled the face to be reopened after one week without damage to equipment.
Fryston Colliery, North Yorkshire	1983	Liquid N_2	765180	150-3000	The spontaneous combustion was extinguished.
Sosnica Mine in the Zabre Mine Union, Poland	1983		3700000	Not available	The fire was subsided and economically successful.
Babino Mine Bulgaria	1986-96	Liquid N_2	43807000	2000-3000	Earlier the N_2 gas was used for fighting of underground sealed off fires i.e. 46 percent of total and rest is used for the control of heating in wastes of producing faces.
President Gottwald Mine, Hardina	1986-87	Liquid N_2	14246	1800	The fire was prevented and controlled without any occurrences of explosion.

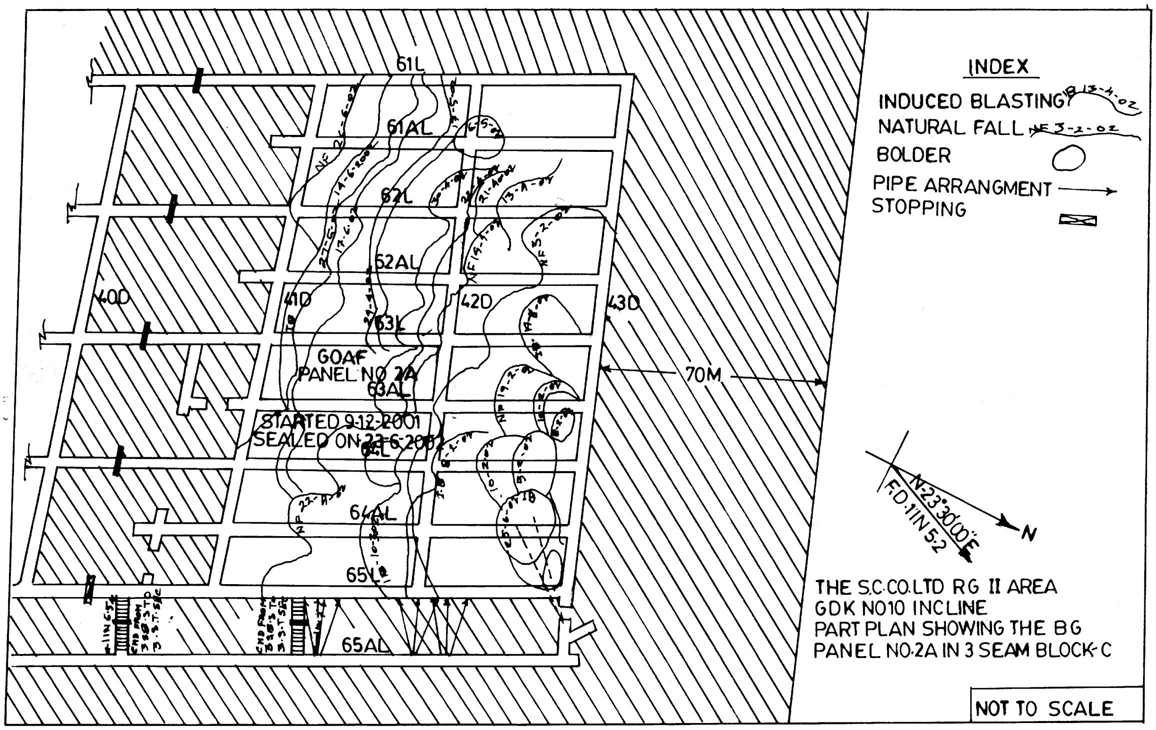

Fig. 1 — Blasting gallery panel 2A of Block –C of GDK-10, Incline mine

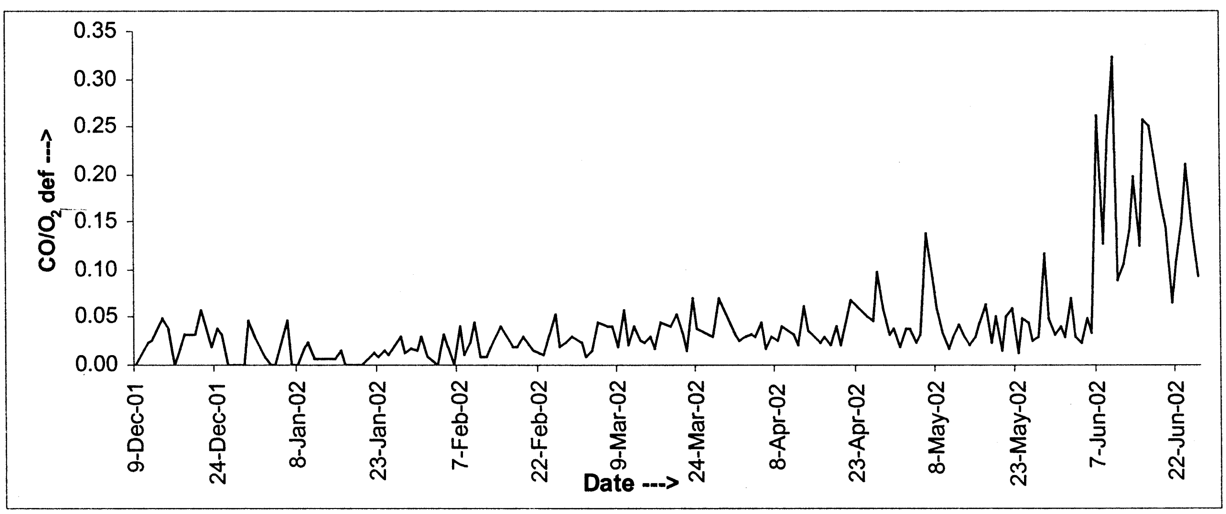

Fig. 2 — CO/O_2 Deficiency ratio (District return) of BG-2A, Block-C panel

dissipate accumulated heat and to maintain inert atmosphere for prevention of spontaneous heating in panel. In May 2002, CO was found in the probe gallery sample pipe and temperature was also increasing. At that moment, high pressure foaming material and CO was injected in this panel. As an experimental trial basis, CO_2 has been tried in this panel and found effective to decrease the temperature inside the goaf. After regular thermo compositional monitoring of the goaf from probe gallery, CO was not found regularly. So the CO found from probe gallery may be due to blasting fumes or major roof fall may generate a superficial heating in goaf.

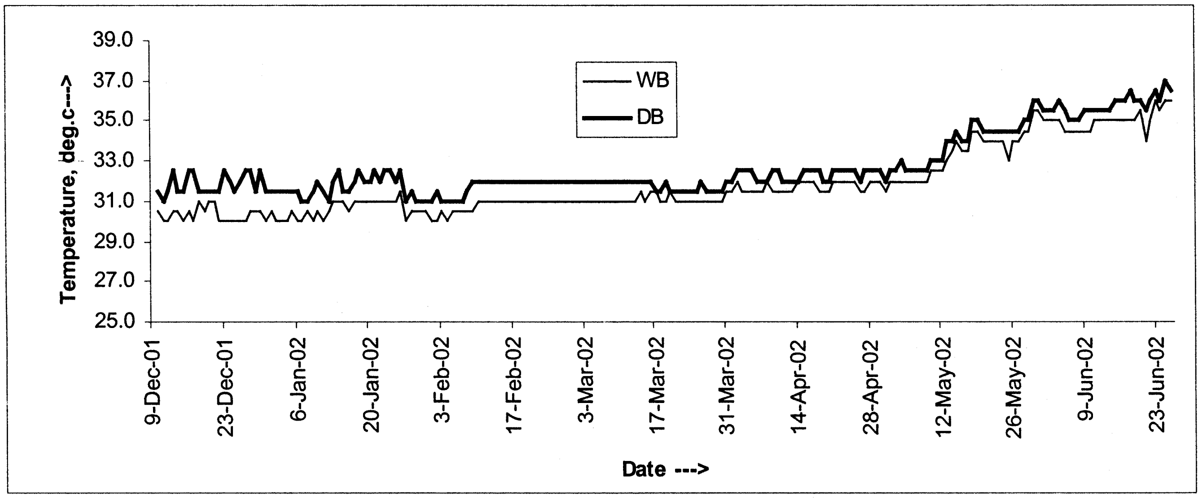

Fig. 3 — Temperature variation (Goaf return) of BG-2A, Block-C Panel

Discussion

The regular thermo compositional monitoring of the panel plays a very important role for safe extraction of the panel. CO/O_2 deficiency varied (0.05-0.37) in the goaf return and district return (Fig. 2) during running period of the panel, which signifies no occurrences of spontaneous heating in the panel. The temperature increased from 31 to 36.5 °C (Fig. 3).

Ambient temperature reached after application of suitable preventive and control measures. Thus, due to regular infusion of gaseous nitrogen through probe gallery, proper inertisation takes place in the goaf. This panel was successfully sealed on 29^{th} June 2002 with 85 per cent (1.85 lakh tonne) extraction of coal without any occurrences of spontaneous heating and lasted up to 6 months 20 days.

Conclusions

The use of nitrogen for prevention, control and extinguishing underground fires was exclusively from 1960, worldwide due to its physical and chemical properties. For the last 20 years, significant progress has been made largely due to its availability and also cost effectiveness as compared to other inert gases in India. It helps to protect rescuers from fire and explosions, creates the opportunity to open sealed off fire area and to control spontaneous combustion in goaf of working panels. 1980-90 is called the 'Golden Age' of the use of nitrogen to inertise the sealed off fire areas. Extensive experiences of the use of nitrogen in mines for last two decade in India has shown that it is useful to combine this technology with other measures in the prevention and control of subsurface fires. The following factors should be considered before its use in underground fires: i) Leakage factor should be taken into account for application of nitrogen in sealed off fire areas; ii) Dissipation of accumulated heat should take place in goaf areas of working panels to avoid spontaneous heating; and iii) Regular thermo compositional monitoring should be carried out during and after application of nitrogen in goaf area to know the explosive behaviour of gas mixture.

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