# ADVANCEMENT IN COAL MINE DISASTER MANAGEMENT

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Mankind has faced many disasters from **natural causes** throughout the history of civilization. Earth quakes, floods, typhoons and volcanic eruption, events with potential to kill large number of peoples to cause substantial damage to the property and environment - have been on record since time immemorial. Government of India has already initiated steps and a High Power Committee at national level constituted to workout comprehensive plan for prevention and mitigation of disaster in our country.

As civilisation has advanced, ironicaly the potential for major disaster has also increased whose origin lies in **human activities**. In India escape of methyle isocynate from chemical plant at Bhopal caused loss of over 2000 lives, injury to over two lakh persons living near by. It is not the only example of disaster in our country. We quite often read about disasters caused due to rail, road and air or industrial accident. Disaster may thus broadly be classified into the following two categories;

1. **NATURAL DASASTER**
2. **MAN MADE DISASTER**

Man Made Disaster includes industrial disaster. We will discuss here Coal Mine disaster in some detail which comes under the category MAN MADE DISASTER.

Coal mining is probably one of the most disaster prone sectors among the various other industrial sectors. In fact the history of mining through the world has been marred by many disasters killing and maiming large number of workers.

According to studies made earlier in Jharia and Raniganj coalfield there are about 70 active fires in 34 mines of the coalfield covering an area of approximately 70.5 Sq. Km. Which is gradually expanding. It has been estimated that if fire in this coalfields is brought under control 1864 millions of prime cocking coal worth about Rs 3, 72,800 Crores can be recovered. Further, some of the fire area is in close proximity to Trunk railway routes, highways and township particularly Jharia town. Unchecked advancement of fire in near future will jeopardize the safety of these township and disrupt rail and road connections passing through the coalfield.

In addition to risk of fire, inundation, explosion and roof fall are other major causes of disaster in coalmines. Cause wise analysis of the fatalities during 1993-96 are tabulated below:

| CAUSE | 1993 | 1994 | 1995 | 1996 |
|---|---|---|---|---|
| Ground movement | 42 | 51 | 52 | 43 |
| Haulage & Winding | 21 | 20 | 11 | 11 |
| Wheeled trackless transport | 18 | 23 | 13 | 20 |
| Conveyors | 03 | 02 | 04 | 01 |
| Non-transport rn/c | 08 | 11 | 11 | 08 |
| Explosives | 05 | 06 | 05 | 00 |
| Electricity | 05 | 01 | 01 | 04 |
| Gas, dust etc. | 11 | 02 | 05 | 02 |
| Inundation | 00 | 00 | 77 | 00 |
| Fire | 00 | 00 | 55 | 00 |
| Others | 19 | 15 | 09 | 19 |
| **Total** | **132** | **131** | **243** | **108** |

The major causes of disaster and their details are discussed as under

**CAUSES OF DISASTER IN COAL MINES:**

1. Inundation,
2. Explosion,
3. Roof fall, and
4. Fire

## 1.0 INUNDATION :

Underground coal mines are associated with the problem of water inflow which may fill up the workings. The inflow may be gradual or sudden, either from surface sources or from underground sources of water. Gradual inundation do not cause any casualty to men but make the working districts inoperative and drown the machines. However, sudden inrush of water into the mines have resulted in heavy loss of life in addition to causing stoppage of work and drowning of equipment. List of the coal mines where inundation has taken place are given below;

| Name Of Mine | Date Of Occurrence | Number Of fatalities |
|---|---|---|
| Phularitand Colliery | 11.01.1912 | 23 |
| Jotejanki Colliery | 28.06.1913 | 13 |
| Makerwal Colliery | 16.1.1935 | 14 |
| Majri Colliery | 6.7.1942 | 11 |
| Newton Chikli Colliery | 10.12.1954 | 63 |
| Burra Dhemo Colliery | 26.9.1956 | 28 |
| Central Bhowrah Colliery | 20.2.1958 | 23 |
| Damua Colliery | 5.1.1960 | 16 |
| Silwara Colliery | 18.11.1975 | 10 |
| Chasnalla Colliery | 27.12.1975 | 375 |
| Central Saunda Colliery | 16.9.1976 | 10 |
| Hurriladih Colliery | 14.9.1983 | 19 |
| Mahabir Colliery | 13.11.1989 | 06 |
| Gaslitand Colliery | 26.9. 1995 | 55 |
| Bagdighi Colliery | 02.02.2001 | 31 |

Sources of surface water: River and nallahs, tanks and reservoirs and accumulated water in old opencast workings or low – lying areas.

Sources of underground water: Old water-logged workings, a sump either in the same seam or another seam, water-logged workings in the adjoining mine and highly water-bearing strata overlying the working seam.

Water from the above sources may inundate the active workings because of

- Accidental connection
- Development of cracks, fissures and fractures
- Failure of barrier or parting
- Failure of dams

## 2.0 EXPLOSION:

An explosion is an intensely rapid combustion of a substance or a mixture of substances ( gas, liquid or solid) forming largely or entirely gaseous substances with the development of high pressure and heat. The main explosive substances are methane and coal dust in coal mines and sulphide dust in metal mines. Two factors viz. the presence of an explosive mixture and a suitable source of ignition are essential to cause an explosion. The explosions are caused due to the following reasons in the mines –

- Firedamp alone
- Coal dust alone
- both firedamp and coal dust

| Name Of Mine | Date Of Occurrence | Number Of fatalities |
|---|---|---|
| Khost Colliery | 16.6.1908 | 20 |
| Disergarh Colliery | 7.2.1910 | 11 |
| Namdang Colliery | 26.11.1910 | 14 |
| Kendwadih Colliery | 9.11.1911 | 14 |
| Chowrasi Colliery | 22.10.1913 | 27 |
| Disergarh Colliery | 20.7.1916 | 14 |
| Disergarh Colliery | 18.11.1918 | 10 |
| Amlabad Colliery | 28.2.1921 | 11 |
| Khost Colliery | 9.3.1932 | 13 |
| Parbalia Colliery | 4.1.1923 | 74 |
| Bagdigi Colliery | 20.6.1935 | 19 |
| Kurharbaree Colliery | 24.7.1935 | 62 |
| Poidih Colliery | 18.12.1936 | 200 |
| Begunia Colliery | 19.3.1946 | 13 |
| Darma Colliery | 14.3.1954 | 10 |
| Amlabad Colliery | 5.2.1955 | 52 |
| Chinakuri Colliery | 19.2.1958 | 176 |
| Dhori Colliery | 28.5.1965 | 268 |
| Jeetpur Colliery | 18.3.1973 | 48 |
| Sudamdih Colliery | 4.10.1976 | 43 |
| Baragolai Colliery | 22.1.1979 | 16 |

## 3.0 ROOF FALL:

Fall of roof and sides is the common phenomenon in underground coal mines. About 20% of the serious accidents ( 4-9 deaths) are caused due to roof or side fall. Though the accident due to roof fall is frequent but disaster due to it ( more than 10 death) are not more. The list dasaster that have occurred in past are tabulated below:

| Sl. No | Name of mine | Date of occurance | No. of persons killed |
|---|---|---|---|
| 1 | Sitalpur colliery | 15.10.1910 | 12 |
| 2 | Kessurgarh Colliery | 9.8.1975 | 11 |
| 3 | Topa Colliery | 16.7.1982 | 16 |

## 4.0 FIRE :

Fire is one of the most serious hazards in underground mines because an underground fire can fill a mine with deadly carbon monoxide gas, smoke and heat in minutes. This rapid rate of contamination coupled with the long period of time needed to evacuate workers can make even a small fire a potential source of disaster. Fire in the coalfield both below ground and on surface, have caused loss of large quantities of valuable coal reserves. Mine fire may classified into two categories (I) Accidental fire (ii) Spontaneous heating.

### Accidental Fire:

Accidental fire in mines are caused due to any of the following causes

- Belt conveyors
- Cutting machines
- Electricity
- Explosive and blasting

Fire initiated due to any of the above reasons may further aggravate if coal catches fire.

### Spontaneous Heating:

Coal undergoes slow oxidation on exposure to air at ambient temperatures with the evolution of heat, gases and moisture. The heat generated, if not dissipated, gives rise to an increase in the temperature of the coal which in turn increases the rate of oxidation. This oxidation process is known as spontaneous combustion / self heating. Spontaneous heating is considered as a main cause of mine fires. Some of these fires are continuing for a long time and has resulted in loss of huge amount of coal.

Some of the characteristics of spontaneous fires in coal are as under. These characteristics can be used to evaluate the potential for coal fires and as guidelines for minimizing the probability of a fire (Underground mine fire and explosions, CMPDIL, 1995 & Ramlu, 1975)

- The higher the inherent moisture, the higher the heating tendency.
- The lower the ash content, the higher the heating tendency.
- The higher the oxygen content in the coal, the higher the heating tendency.
- The amount of surface area of the coal that is exposed is a direct factor in its heating tendency. The finer the size of the coal, the more surface is exposed per unit of weight (specific area) and the greater the oxidizing potential, all other factors being equal.
- Many times, segregation of the coal particle sizes is the major cause of heating. The coarse sizes allow the air to enter the pile at one location and react with the high surface area fines at another location. Coals with a large top size [e.g., 100 mm ({> =}4 in.)], will segregate more in handling than those of smaller size [50 mm ({> =}2 in.)].
- Coal absorbs oxygen at all temperatures with slight rise in temperature. It is generally believed that the rate of reaction doubles for every 8 to 11 degrees C (15 to 20 degrees F) increase in temperature.
- Freshly mined coal has the greatest oxidizing characteristic, but a hot spot in a pile may not appear before one or two months.
- There is a critical amount of airflow through a portion of a coal pile that maximizes the oxidation or heating tendencies of coal i.e. when there is just sufficient airflow for the coal to absorb most of the oxygen from the air and an insufficient airflow to dissipate the heat generated, the reaction rate increases and the temperatures may eventually exceed desirable limits. Critical velocity of air is considered as less than 0.9m/sec.
- Flow rate of 0.1 to 0.9 m$^3$/min. with $O_2$ percentage more than 17 is considered risky.
- Coal with low thermal conductivity dissipate less heat thus causing quicker self heating.
- Presence of faults in coal seams / zone of weakness often contributes to the development of heating by allowing air and water to migrate into the coal seams.
- Thick seam mining, longwall caving are often considered to have more potential for spontaneous combustion because these methods usually involved high losses of coal in goaf areas.
- Coal seam under shallow overburden (below 50m) are prone to self heating because the goaf areas are generally connected to the surface by cracks and fissures which provides easy access of air and water from surface to the coal seam.
- Deeper seams are more vulnerable to spontaneous heating. The temperature of the strata increases with depth. Therefore the oxidation rate increases with depth. At greater depth pressure also increases therefore crushing takes place.

## DETECTION OF SPONTANEOUS COMBUSTION

### Physical Indication

First sign that a heating has developed is the characteristic smell fire stink in the air. The smell of fire stink is the distillation product from coal. In the initial stages of the heating the smell resembles that of petrol but as the heating progresses it changes to a kerosine and later to a tarry odour.

Haze is formed when air heated by an incipient fire meets colder air. In mines which are naturally dry, a heating may be detected by the presence of patches of droplets of water on cooler surfaces in its vicinity.

## Chemical Indication / Fire Ratios

Since the beginning of the twentieth century a number of ratios and composites of gas concentration have been suggested to assist in the interpretation of fire gases. Some of these are as follows:

Graham's ratio - $[CO]/\Delta O_2$
Young's ratio - $[CO]/\Delta O_2$
Wilett's ratio - $CO_2/[\text{excess } N_2 + CO_2 + \text{combustibles}]$
Oxides of carbon ratio - $[CO]/[CO_2]$
Jones and Trickett ratio - $\{[CO_2] + 0.75[CO] - 0.25[H_2]\}/\Delta O_2$

Among the above ratio, Graham's ratio is most widely used in mines.This ratio now-a-days used as a criterion of the state of heating and fires in their early as well as later development stages. As a thumb rule it can be taken that

- 0.4% or less indicates normal value
- 0.5% indicates necessity for a thorough a check-up
- 1% indicates existence of heating
- 2% indicates serious heating approaches active fire
- 3% and above indicates action fire with certainty.

## Crossing Point (CP)Temperature and Moisture content

Crossing point temperature is the temperature when coal temperature becomes equal to or exceeds bath temperature. DGMS circular technical 3/1994 has defined the procedure to determine CP temperature of coal. The following scale is usually employed in our country to determine the proneness.

| Crossing point temperature, $^{0}C$ | Moisture content, % | Proneness towards spontaneous heating |
|---|---|---|
| = 160 | < 2 | Poorly susceptible |
| 140 - 160 | 2 – 5 | Moderately susceptible |
| 120 - 140 | > 5 | Highly susceptible |

From the study of constitution of coal and the proneness to oxidation it has been found that the functional oxygen groups like hydroxyl, carboxyl and carbonyl group and fuel ratio has a definite relation with proneness to oxidation. The more the number of hydroxyl and carboxyl group in coal, more number of sites will be available for attack by oxygen. Hence the rapid oxidation takes place resulting in lowering the crossing point temperature. Fuel ratio (ratio of fixed carbon to volatile matter) again is a important parameter because proneness to oxidation decreases with increase in fuel ratio.

## PREVENTION OF SPONTANEOUS COMBUSTION

Two basic factors are to be kept in mine while preventing spontaneous combustion of coal. They are

- Elimination of coal from the area

- Control of ventilation so as to exclude oxygen entirely from the area or to maintain air flow rate such that it can dissipate the heat efficiently as it is generated and before a critical temperature reached.

**Mining Parameters**

- Coal surfaces not being directly worked must be protected against adsorption of oxygen by stone dusting or by coating.
- The panel system is an appropriate one for mining seams liable to spontaneous combustion. Panels must be of a size which would permit complete extraction within the incubation period.

**Air Leakage**

Leakage of air caused trouble to a mine in two ways

⇒ It reduces the quantity of air in ventilation district
⇒ It provides oxygen to fire prone area

The formation of leakage path should be minimised by providing adequate support i..e. adequately sized pillars and good gate side packs. Sometimes leakage paths should be sealed off by sealant coating or injection of cement, hydrogel etc.

Surface cracks are generally extended cracks from sealed off area. They become source of air leakage path. Artificial sealing from the surface, usually by sand can prevent such leakage.

Regulators, Doors & stoppings should be correctly placed. The ventilation pressure difference should be balanced across the old panel. Every roadway in coal should be ventilated and unused roadways sealed off.

**Early Detection**

In present day practice, goaf stink, appearance of haze and increasing value of CO/O2 deficiency ratio are normally used for detection of onset of incipient or active heating which is confirmed by appearance of smoke. The system needs immediate attention for its improvement in the following direction

- Use of infrared sensors for detection of hot spots in pillar/stopping.
- Continuous monitoring of CO in return and other segments of mine airway.

Environmental telimonitoring system suitable for underground coal mines have also proved advantageous in early detection of heating.

As there are some detectable odours which are generated before CO, $CO_2$ and other gases in the spontaneous heating of coal, detection system using various smell sensors can be employed. The detection depends upon two factors:

- right detection equipment.

- placing the equipment in the right place.

Since early detection of incipient fires provides for easier fire fighting and evacuation of personnel, it is important to ensure that fire detection equipment is placed closed to the potential fire sources for maximum effect. Early detection shall give sufficient time to take appropriate action. Though, this system is still in development stage, yet lot of experimental work has been carried out in UK and Japan .

In Japan, experimentation are being conducted with a robot equipped with number of sensors for early detection of heating. The robot will traverse a mine segment once in every hour or so and transmit the data to a central computer. Analysis of the data will reveal the condition of the mine .

**Thermo-decompsitional analysis of coal**

This analysis is meant for early detection of spontaneous combustion and also to assess the status of fire. Recently this facility has been developed by CMRI. Sample of coal of 40 mesh size, 60 gm in weight is placed in a reaction vessel designed for thermal oxidation. The reaction vessel is kept in a air oven/furnace, temperature of which can be maintained at a desired level. Air is introduced into the furnace with a flow rate of 90 cc/min. The gases emitted during heating of coal is collected in a sample tube and analysed in a Chromatograph. Carrier gases used for the chromatographic analysis are nitrogen, zero air and hydrogen. Different gases viz., $O_2$, $CO_2$, CO, $H_2$, $CH_4$ and other hydrocarbons are emitted at different temperature starting from $40^{O}C$ to $300^{O}C$. This gives a clear cut idea of spontaneous combustion characteristics of a particular coal seam for which experiments are carried out.

## CONTROL OF SPONTANEOUS COMBUSTION

Selection of appropriate method for combating spontaneous heating is site specific. It also depends upon the seat of fire, magnitude of the fire, approachability, gassiness of the mine, ventilation situation and availability of resources (Banerjee, 1985).

**Injection of Inert gases**

Inert gases can be used in fighting mine fires in the following ways :

a) reducing the oxygen concentration in the air around the seat of fire to such a percentage that fire dies down.
b) the prevention of gas explosions when they are fought directly or when seals are constructed or closed.
c) reducing the intensity and spread of secondary combustion and cool the area surrounding the fire zone.
d) the sealing fire zones with pressure chambers.

The main drawbacks of inert gas methods have been the limited availability of large quantities of gas at site at short notice. Moreover, the methods are costly.

There are three types of inert gases which have already been used to fight mine fires.
They are: a) Carbon dioxide b) Combustion gases c) Nitrogen

Among these nitrogen is widely used in our mines.

### Nitrogen

Nitrogen can be delivered into fire area in liquid form through a tanker or in gaseous form through air separation unit / evaporation unit via piping arrangements.

There are several advantages of liquid nitrogen.

1. The nitrogen is cold and dry and thus poses no problem with cooling and in compression as is the case with other processes where the gas is produced by chemical reaction or catalytically.
2. It is simple to deliver liquid nitrogen on-site and the safety aspects are good.
3. It can be gasified in vaporisers with a rated output of up to 300 $m^3$/min. and this can be raised even further by operating vaporisers in parallel.

However, the system also has some disadvantages

1. It is unsuitable for storage over long periods. Therefore, sometimes it is very difficult to obtain sufficient quantity if large amounts (i.e. more than 300 $m^3$/min. for several days) are needed. This may arise when there are several fires at the same time or if there is really a big fire.
2. It can only be introduced into the pit by piping it from the surface which calls for a great deal of preparatory work in surfaces as well as underground.
3. Nitrogen is less expensive than Carbon dioxide but costlier than Combustion gases.
4. Liquid nitrogen as the base material is not available in unlimited quantities.

To avoid storage problems of liquid nitrogen, skid mounted on-site storage vessels are used. They are transportable and they can be filled up regularly by cryogenic tankers. Thus liquid nitrogen can be stored and be used directly on the fire from the vessel through boreholes so as to have an uninterrupted and continuous flushing of nitrogen. Nitrogen flushing is always accompanied with air sample analysis of the fire affected area. Quantity of nitrogen flushing or its rate depends upon $O_2$ percentage in that area. As $O_2$ percentage get reduced, CO percentage decreases and requirement of nitrogen become less.

### Inorganic Inhibitors

National Institute of Safety in Mine and Explosion Protection (INSEMEX) Petrosani, Romania has developed inorganic inhibitors to diminish self-heating / self-combustion of coal. They have selected inorganic compound like magnesium chloride, cadmium chloride & trisodium phosphate in pilot phase of testing. The test have been effected in the presence of phosphate ions resulting from phosphoric acid introduced in the sample. The test pointed out an inhibiting efficiency in the range of 34.21-89.47% for the inorganic salts tested.

### Sealant

CMRI has developed three type of sealants for use in isolation stoppings, coal pillar and open cast benches to control spontaneous combustion of coal. One is Mica based, the other one is rubber based and the third one is bitumen based. The basic purpose of sealant is to maintain minimum leakage through stoppings as well as coal pillars so that possibility of heating in coal pillar is minimum. The effectiveness of sealants have been convincingly demonstrated by their application in number of coal mines. Madhuband colliery of BCCL; Madhujore colliery, Khaskajora colliery and Jaipuria kajora colliery of ECL ; GDK 1 incline of SCCL and Karkatta OCP & Jagannath OCP are to name a few.

### High Pressure Foam

Use of foam plugs has been successful in fighting mine fires in roadways where direct attack with water is not possible. USBM studies reveals that the water content of the foam should not be less than 0.20 Kg/m3 otherwise the foam is not capable of controlling the fire (Nagy, Murphy and Mitchell, 1960). With sufficient ventilating forces a properly generated foam may be transported over 300 m. Foam does not appear to be effective against deep seated, rapidly advancing, buried or dead end fires.

Suppression of spontaneous heating by high pressure high stability foam is a new and effective method. This method has been widely used in Czech mines in controlling spontaneous heating of the mined out areas of longwall panels.

The foam is produced by high pressure foam generator under the pressure of foaming gas. The produced foam is transported by pipelines or fire hoses to the fire area. Inert gas ($N_2$, $CO_2$), compressed air or a combination of both are used as foaming gas. The foam generator consists of two independent units namely pumping unit and foam generating unit. The foam is produced from a mixture consisting of water and 5% foaming agent. This mixture is pumped by pumping unit into foam generating unit where the foam is produced (Voracek, 1997).

The foam helps in controlling the spontaneous heating in following manner.

- Reducing air leakage through mined out area
- Reducing temperature
- Reducing the rate of sorption of oxygen by the coal as the foam forms a thin protective film over the coal.

High pressure nitrogen foam has recently been used in AW1 longwall panel of Jhanjra colliery, ECL with very encouraging results. In this mine foam was injected in the longwall goaf through boreholes. A trolley mounted PSA type nitrogen generator having a capacity of 300 $Nm^3$/hr. was used. High pressure high stability nitrogen foam is cheap (one kg of foaming agent capable of producing 2 $m^3$ of foam costing about 2.1 $) and has long self life.

### Seal Construction of Light Foams

Sealing off fire becomes necessary in case of fires due to spontaneous heating or large scale underground fires. It is a method of cutting off oxygen feed to the fire by construction of stoppings. But construction of stoppings usually takes a long time. A new method of seal construction is being used in polish mines using light foams. This method is considered to be reliable and quick for sealing the fire. Carbamide (commercial name 'Krylamina') is used as the foam which on exposure to flame forms a layer of carbonized foam protecting further layer of foam against burning. The foam is produced from Krylmin resin and catalyser with a special pump (4 part of resin and 3 part of catalyser). The foam comes out in the form of semi-plastic mass filling the desired space. This foam could be used to insulate the walls and roof of the working, to fill the cracks in the rock and coal seams due to its plastic properties. Mariflex, Wilflex are other compound available for this purpose. Mariflex has been successfully used in New Kenda Colliery in 1994 for building isolation stoppings. The main disadvantage of solid foam is high cost and restricted shelf life.

**Dynamic Balancing of Pressure:**

When an area is isolated/ sealed by two or more stoppings, the pressure on the outer faces of each stopping should, as far as is practicable, be balanced to prevent circulation of air through the sealed area to prevent initiation or existence of heating.

Conventional techniques developed abroad could not be adopted successfully in our country due to difficult geo-mining conditions. To over come the problem, CMRI, Dhanbad developed a technique named DYNAMIC BALANCING OF PRESSURE. The technique has successfully been applied in a number of coal mines in our country.

The technique is simple. It utilizes available mine ventilation pressure to neutrlise the pressure differential across stoppings.

**Software Development**

Safety in Mines Testing and Research Station (SIMTARS), Queensland, Australia has developed many software packages to improve mine environment monitoring system to identify and track incipient heating and mine fires.

The 'SPLUS' package enables the gas analysis data to be interpreted with respect to a potential mine heating. 'SAFEGAS' package deals with a mine monitoring system which collects data from sampling points within the underground mine and acts as a guard with respect to the presence of equipment failure, mine fires or spontaneous combustion (Dent, 1997)

SIMTARS has also developed a Fire ladder based on Australian coals which clearly indicates hierarchy of gas with respect to temperature for a particular type of coal (Dent, 1997)

SPONCOM expert system was developed by the USBM to assess the spontaneous combustion risk of an underground mining operation (Smith et al. 1995). The program determines the coal's spontaneous combustion potential and what effect the coal properties, geologic & mining conditions and mining practices have on the spontaneous combustion risk of the mining operation.

**Risk indices for spontaneous combustion**

Feng et al (1973) developed a risk index considering the mine environment as well as the coal's spontaneous combustion potential. Factors like coal properties and geological features are called intrinsic factors and factors related to mining practices are called extrinsic factors. Intrinsic factors are beyond controlled and extrinsic factors can be controlled. Various methods are available to calculate risk indices.

CONCLUSION

1. Spontaneous heating has always been a problem in coal mines. Much work has been done on this subject particularly in understanding the mechanism of the process and to evolve effective counter measures but a satisfactory solution to the problem remains to be achieved. This may be attributed to the fact that all kinds of coal do not have same spontaneous heating characteristics. Also onset of spontaneous heating depends not only on the properties of coal but also on the external condition caused due to mining operations. Thus even if indexing of spontaneous combustion susceptibility of coal is made, it is apparent that the results would only compare the behaviour of different coals under different heat transfer conditions.

2. the present safety practices if reinforced by the following measures have a potential of avoiding major disasters in mines due to fire and / or minimum loss of property and life even if a major fire breaks out in the mine.

- Pressure monitoriang of sealed area and pressure balancing across all sealed goaves to be established and maintained.
- Use of low pressure fan preferably below 40 mm wg pressure to reduce the chances of heating. For extensively developed mines, multi-zonal system of ventilation may be adopted which will help in reducing spontaneous heating.
- Inertisation and cooling of sealed goaf in a seam susceptible to heating by infusion of liquid nitrogen so that oxygen concentration remains below 2% and temperature of the goaf maintained below the strata temperature.
- Installation of a number of doors in a mine at strategic locations which can even be closed remotely for isolation of any segment of the mine that gets affected by fire.
- Prevention of two totally independent intakes in a working so that when any one of them gets polluted by toxic gases of fire the other remains safe for withdrawal of personnel. For this **purpose multi-zonal ventilation system using large diameter borehole** may prove advantageous.
- Thorough training of every personnel working underground regarding the use of safety wares viz., self rescuer and other breathing apparatus, alternate escape route, ventilation circuits, effect of fire on ventilation etc. is necessary, rather it should be made compulsory.
- For the purpose of early warning throughout the mine recently developed ultra low frequency radio signaling system may be adopted after giving it a trial.
- Suitably designed safety chambers to accommodate all personnel of an active working for about a week may be constructed close to a working.