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Indian coals vis-a-vis spontaneous heating problems

The paper highlights the alarming problem of spontaneous heating in mines so that immediate remedies can be identified and implemented. The status of spontaneous heating in the last four decades has been summarized showing the changing trend of spontaneous heating occurrences in India. The paper also deals with some new methods of dealing mine fires which so far have not been implemented in India but have great potential.

Introduction

The problem of spontaneous heating has been associated with coal mining from the day mining started. Earlier, it was considered that much heating were associated with only certain types of coal but now it has engulfed the whole coal mining sector. Much research work has been carried out on this very important subject and more is going on but aspects of the mechanism of underground coal mine fire are yet to be thoroughly understood and the status of our knowledge on spontaneous heating is far from complete.

Spontaneous heating is considered as a main cause of mine fires and it constitutes more than 50% of such fires. Some of these fires are continuing for a long time and resulted in the loss of huge amount of coal. Besides waste of valuable coal, such fires also pose danger to life. In the recent past, two disasters due to fire at Jagannath opencast project (1981) and New Kenda colliery (1994) have taken heavy toll of lives. From economic point of view, even a small incident of spontaneous heating can take a heavy toll in terms of loss of production, loss of machinery and expenses incurred in fighting it out. Spontaneous heating requires three main ingredients for its occurrence : (a) fuel—coal having specific chemical-physical properties, mass and geometrical shape, (b) supply of oxygen at specific concentration and flow (c) adequate conditions for heat accumulation (Banerjee, 1985). Spontaneous heating prevention calls for removal of any one of these conditions, but practically it is not possible to eliminate any one of them completely.

The main factors which make coal susceptible to spontaneous heating are low rank coals with high oxygen content, coal containing more vitrain and clarian, high moisture coal, pressure of pyrites, fribility of coal etc. Apart from these, there are geological, mining and seam factors which also contribute towards spontaneous heating. However, these factors vary from mine to mine. It is generally the low rank coal which pose the problem of heating at every stage of mining the rate of oxidation being lower in high rank coals. For low rank coals, the incubation period usually varies between 3 to 6 months and for high rank coals the period is found to vary between 6 to 9 months (Mukherjee et al., 1988). Thus the heating should be dealt with from the incipient stage. If not dealt effectively and efficiently in this stage, even a small incident can cause devastating results.

Coal presents hazards between the time it is mined and its eventual consumption. Some of the characteristics of spontaneous fires in coal are given below. These characteristics can be used to evaluate the potential of coal fires and as guidelines for minimizing the probability of a fire (CMPDIL, 1995; Ramlu, 1975)

- The higher the inherent moisture, the higher the heating tendency.
- The lower the ash free Btn, the higher the heating tendency. Btu
- 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, greater 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 high surface area fines at another location. Coals with a large top size [e.g., 100 mm], will segregate more in handling than those of smaller size [50 mm].
- 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 increase in temperature.

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- 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 an insufficient airflow to dissipate the heat generated, the reaction rate increases and the temperatures may eventually exceed desirable limits.
- 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 dissipates less heat thus causing self heating.

In India, fires due to spontaneous heating are known to occur in almost all coal fields of which Raniganj and Jharia fields lead the league table.

Status of dangerous occurrences of spontaneous heating

The status of spontaneous heating in Indian collieries during 1965 to 1997 is shown in Fig. 1 and Fig. 2. During this period, spontaneous heating occurrences constituted about 45% of the total dangerous occurrences (Cases in which neither any life is lost nor any person is seriously injured, but

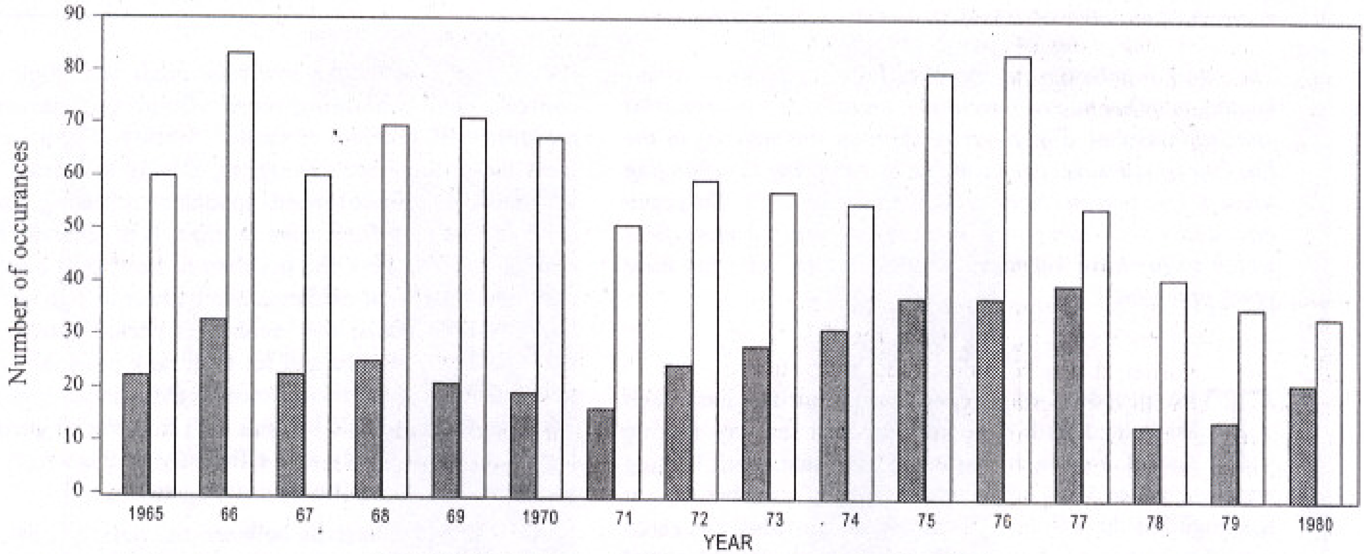

Fig.1 Status of spontaneous heating occurances year-wise (1965-1980)

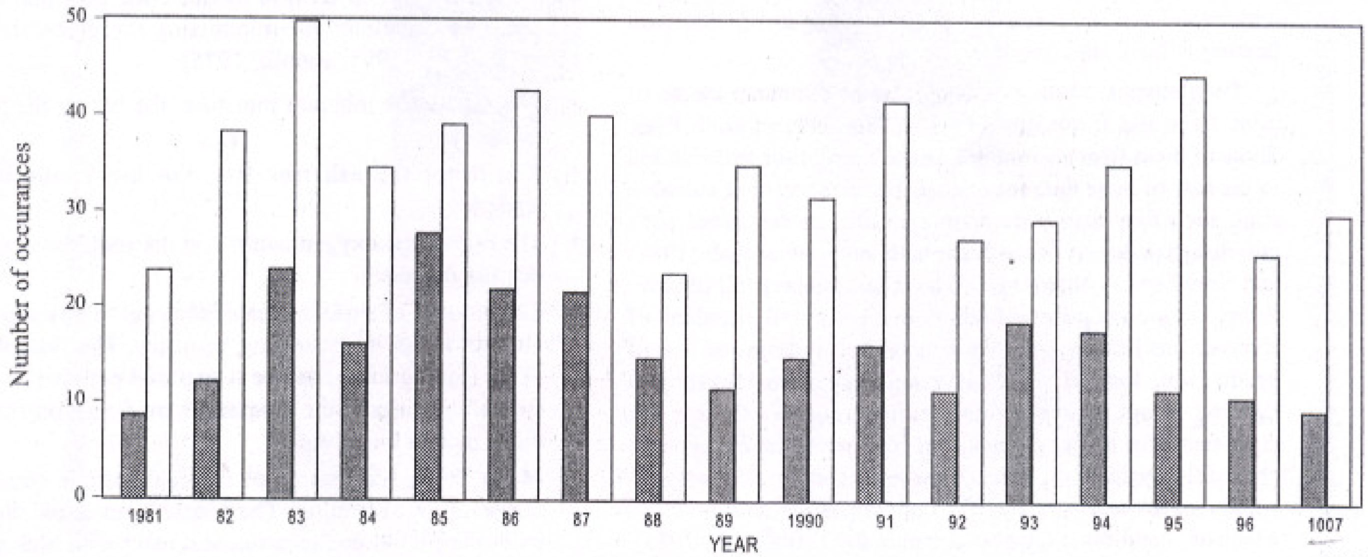

Fig.1 Status of spontaneous heating occurances year-wise (1981-1997)

1997

Total dangerous occurrences   Spontaneous heating occurrence

* Source – DGMS, Dhanbad

could have been had persons been present at the spot of occurrence, are covered under the category "Dangerous occurrences"). This represents an average of 21 occurrences per year.

From the figures it is evident that the total dangerous occurrences have considerably reduced from 84 occurrences in 1966 to 30 occurrences in 1997. But spontaneous heating occurrences still constitute the major chunk of the dangerous occurrences. Thus, it can be inferred that it is mainly the other dangerous occurrences that have been brought under control. Though spontaneous heating occurrences have decreased, yet they have not decreased in proportion to that of total occurrences. In the last 2 to 3 years, the spontaneous heating occurrences have shown a decreasing trend. But the same cannot be predicted for the coming years due to the changing trend of previous years. However, decreasing trend can be continued by dealing spontaneous heating effectively in early stage. Thus the development of new and innovative techniques of early detection and control is immediately required and this calls for lot of research and experimental work.

Methods of prevention/control of spontaneous heating in Indian coal mines

Various methods used for control of spontaneous heating as applied in India mines are :

1. Cooling by water or water in the form of fog or mist.
2. Using extinguishers
3. Digging and loading out the fire.
4. Remote sealing of mine gallery.
5. Surface seals.
6. Protective coating of fire retardant chemicals.
7. Impregnation of coal with Gel solution.
8. Pressure balancing of goaf.
9. Inertisation.
10. Mud flushing

However, 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). Table 1 gives brief details of various methods applied so far in some of the Indian mines.

New methods of fire prevention and control

Early detection

The delay in spontaneous heating control can be serious in terms of the risk to human life. The situation becomes more difficult due to the confined nature of mine workings. The belated action may sustain the fire due to spontaneous heating which many a time spread to adjacent properties and it requires much skill and resources to control such fires. Thus, early and reliable detection is necessary. In present day practice, goaf stink, appearance of haze and increasing value of CO/O_2 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 (Bhowmick et al. 1995) :

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

Environmental telemonitoring systems suitable for underground coal mines have also proved advantageous in the 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 (Kiyoshi et al., 1997 and Hambleton et al., 1997). 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 the UK and Japan (Kiyoshi et al., 1997).

In Japan, experiments are being conducted with a robot equipped with number of sensors for early detection of heating. The robot will traverse a mine segment once every hour or so and transmit the data to a central computer. Analysis of the data will reveal the condition of the mine (Mitsumasu et al., 1997).

High pressure foam

Use of foam plugs has been successful in fighting mine fires in roadways where direct attack with water is not possible (Ramlu, 1991). Studies by the United States Bureau of Mines (USBM) reveal that the water content of the foam should not be less than 0.20 Kg/m^3 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 (Nagy, Murphy and Mitchell, 1960). Foam does not appear to be effective against deep seated, rapidly advancing, buried or dead end fires (Ramlu, 1991)

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 foam produced is transported by pipelines or fire hoses to the fire

* Ventilation pressure [illegible] may be used

Table I Method applied to control fire in Indian mines

Name of the colliery	Year	Method applied	Remarks
Underground			
Laikdih deep colliery, BCCL	1981	Installation of nitrogen plant. Occasional water infusion	Within 2 months time the percentage of O_2 was brought down to 0.57% and CO in traces. However, operation was partially successful due to heavy leakage round the fire affected area.
Lodna colliery	1985	Liquid nitrogen flushing. Installation of PSA type nitrogen generator.	Fire problem was tackled by feeding evaporated liquid nitrogen through boreholes followed by installation of PSA type nitrogen generator.
Madhujore colliery, 5 & 6 pit, ECL	1986	Dynamic pressure balancing thermo-compositional monitoring	Dynamic balancing of pressure was applied for the first time and the fire bought under control within three weeks time.
GDK-9 Incline, Singareni Collieries	1986	Surface blanketing. Building of concrete plugs around fire affected area. Liquid nitrogen flushing.	The mine was reopened after 55 days and the production restored within 125 days.
Sripur colliery, ECL	1989	Dynamic pressure balancing thermo-compositional monitoring	Fire in Koithee seam goaf was kept under control for two years till the districts on the dip side were fully extracted.
Sayal'D colliery	1990	Pressure balancing. Gel infusion. Surface blanketing. Bitmen coating.	Implementation of pressure balancing and other methods help in controlling the fire as well as improving the ventilation condition of the mine.
Real Kajora unit of Naba Kajora colliery, ECL	1991	Dynamic pressure balancing thermo-compositional monitoring	In lower Kajora seam of the mine, dynamic balancing of pressure along with improvement in fan drift and surface airlock system paved the way to safely win 1.6 million tonnes coal at a faster rate.
Churcha colliery, SECL	1993	Liquid nitrogen flushing.	Fire was controlled within a month
Moonidih colliery, BCCL	1993	Nitrogen flushing	Nitrogen flushing proved successful in controlling the fire and helped in salvaging of longwall equipment.
North Searsole colliery, ECL	1993	Dynamic pressure balancing Infusion of Hydrajel and sealant	Nagging problem of fire in coal pillars in Kenda bottom seam of the mine, close to upcast shaft was brought under control. The mine operating safely.
Sijua colliery, TISCO	1994	Pressure balancing bitmen coating cement injection of pillars. Nitrogen infusion by PSA type nitrogen generator.	Fire was brought under control in most parts of the mine except a few places in the sealed off area where O_2 content could not show the desired level. This was attributed to existence of air leakage path extending beyond pressure balancing zones. Dynamic balancing of pressure along with nitrogen infusion by PSA type nitrogen generator as recommended by CMRI is showing encouraging results.
New Kenda Colliery, ECL	1994	Liquid and gaseous nitrogen flushing. Application of foam (mixture of Mariflex resin and Mariflex catalyser) to construct and strengthen stoppings to prevent air leakage. Pressure balancing	Fire was brought under control, the mine reopened and resumed normal production. The disaster however cost 55 lives.

Ningha colliery, ECL	1995	Dynamic pressure balancing thremo-compositional monitoring	Fire in Poniati seal was brought under control by application of dynamic balancing of pressure simultaneously in Poniati and Dishergarh seam.
Kottadih, ECL	1997	Dynamic pressure balancing. Nitrogen flushing.	The panel was reopened successfully after 19 days of sealing and it was possible to keep the temperature of the face below 40^{0}C. This paved the way for safe recovery of all the healthy supports and other equipment worth over Rs.400 million.
Jhanjra 1 & 2 incline, AW1 LW Panel	2000	Dynamic Pressure Balancing Infusion of liquid & gaseous nitrogen. Infusion of high pressure, high stability nitrogen foam	Fire was brought under control after a long struggle extending over 8 months. Panel was reopened and sealed three times. Finally use of high pressure nitrogen foam and trolley mounted PSA type nitrogen generator proved very effective in controlling the fire.
Opencast			
Jagannath project, MCL	1995	Coating material developed by CMRI	No temperature rise was detected in the coated loose coal for a period of six months. Temperature remained near about ambient.
Karkatta project, CCL	1995	Coating material developed by CMRI	No indication of heating was detected even after two months of coating the loose coal.

area. Inert gases (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 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 shelf 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 stopping. 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 semiplastic 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 (Kajdasz et al., 1997). Mariflex are other compounds available for this purpose. Mariflex has been successfully used in New Kenda Colliery in 1994 for building isolation stoppings. The man disadvantage of solid foam is high cost and restricted shelf life.

Development of 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 compounds like magnesium chloride, cadmium chloride and trisodium phosphate in pilot phase of testing. The tests have been effected in the presence of phosphate ions resulting from phosphoric acid introduced in the sample. The tests pointed out an inhibiting efficiency in the range of 34.21-89.47% for the inorganic salts tested (Toth et al., 1997)

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 'PLUS' package enables deals with a mine monitoring system which collects data form 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 for Australian coals which clearly indicates the 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 combination 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 and 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 control and extrinsic factors can be controlled.

Various methods are available to calculate risk indices (Singh et al, 1984). These are :

- Olpinski method
- Feng, Chakravarty and Cochrane technique
- Adiabatic oxidation method
- Modified Bystron and Urbanski method

In 1982, Banerjee developed risk index utilising spontaneous combustion potential of coal and 22 different mining parameters. These parameters were assigned high, medium or low value. In 1990, Singh et al worked on assessment of spontaneous combustion risk in longwall mining and developed an index using an expert system.

Conclusion

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 the 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.

Though a large number of methods have been tried for categorize the spontaneous combustion susceptibility of coals from various perspectives, none can take into account all the parameters responsible for heating. In India, the general practice is to combat spontaneous heating after it has completely taken the form of a fire. No technology is applied in order to arrest the spontaneous heating in its early stage. Thus there is an urgent need to start systematic research work on this front.

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(Continued on page 135)

Conclusion

The conventional approaches (LEM, FEM, DEM, etc.) for analysis and design of waste dumps are highly idealised and can consider only a few features (such as, height, slope and shape of dump, specific weight and frictional parameters of dump material, water condition in the dump, etc.) out of many factors effecting the dump stability. Establishment of correct mathematical relationships between the factors is required taken into account is required in the calculation for assessment of factor of safety (for existing dumps) or for estimation of stable slope angle (for a new situation) as the case may be. On the other hand, the models based on neural networks do not require any prior knowledge of the functional relationships between the input and output variables, but only require data for input and output parameters for training purpose and these models are capable of modelling multiobjective phenomenon. These models can take into account qualitative parameters in addition to quantitative parameters affecting the dump stability in analysis and design of waste dumps provided that sufficient data are available and also can be used effectively in the situations where the data are noisy or some of the data are missing. Moreover, the method of partitioning connection weights facilitates the study of the sensitivity of the variables and to estimate the percentage influences of each of the input parameters on the end results.

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INDIAN COALS VIS-A-VIS SPONTANEOUS HEATING PROBLEMS

(Continued from page 128)

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