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Coal mine fires – hazards and modern control techniques

Fires have long been recognized as hazards associated with coal mining. Coal mine fire causes economic losses by virtue of loss of coal and coal winning machinery. Environmental problems at surface and underground due to coal mine fire are discussed in terms of production of noxious, toxic gases, global warming and fire damp explosion. Social and health problems due to mine fire are dealt with. An account of modern techniques like water mist technology, remote sensing and infusion of carbon dioxide are also given.

Introduction

Coal fire is a kind of natural disaster in an area of coalfield. It can occur either within the coal seam itself or in stock piles and overburden dumps on the surface. Coal fires are reported from coalfields in China, India, Indonesia, Venezuela, South Africa, USA, Australia, Germany etc. They have not only been a problem since the start of coal mining. There are geological evidences that some fires were burning several hundred thousand years ago. The burning mountain in New South Wales, Australia is a well known coal fire. Ellyett and Fleming (1974) estimated the age of the fire to be at least 6000 years.

In this paper an attempt has been made to discuss on hazards associated with coal mine fires, be it from surface or underground and some modern techniques to deal with the fire.

Factors causing coal fires

Coal as a fossil fuel can catch fire by both natural and man-made causes. Spontaneous combustion of coal, one of the main causative factors for coal fires, is a natural phenomenon that has occurred repeatedly during the recent geological past. It can occur at any site where deformation, uplift and dissection have exposed coal to the air. It is likely to occur during interglacial dissection of river valleys at moderate uplift rates (Zhang et al. 2004).

Several geological processes, such as faulting, folding and erosion by river action, can bring the coal to the surface thus lead to coal fires.

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Other causes responsible for coal fires are listed below:

- Forest fires close to coal seams
- Traveling fire from one seam to the other or surface fires communicated to underground workings
- Natural hazards (e.g. thunderstorms)
- Electricity, lighting systems that causes sparks
- Cutting and welding
- Friction
- Ignition of gas
- Explosives
- External heat sources i.e. illegal distillation of alcohol

Hazards encountered from fires

Coal fire causes considerable economic and environmental problems. It is directly associated with the health of the miners. Many a times it becomes a social problem to rehabilitate and resettle the project affected persons (PAPs) to a safer place. Details of these problems are discussed below.

Economic

A huge amount of coal reserve, the nonrenewable fossil fuel, is being lost due to coal fire. It is estimated that in China between 100 and 200 million tonnes of high quality coal is consumed by spontaneous combustion every year. It is not only the burned coal that becomes useless for economic purpose but the access to remaining reserves is often made difficult or impossible by fires and many a times sealing the underground fire area becomes the only option left out. In multi-seam workings like Jharia coalfield (JCF), fire restricts the working to lower seams. Some scholars estimate that mine fires of JCF have made about 1864 million tonnes of coking coal inaccessible and unmineable (Tripathy and Pal, 2001).

Environmental

Surface

Environmental problems associated with coal fire may be noticed at local and global level. Release of heat and noxious gases like SO_2, NO, CO, CO_2, CH_4, and particulate matter affect the immediate surroundings of active coal fire. Coal fire endangers the surface civil structures and damage to surface vegetation. The degradation in surface vegetation results in change in the status of hydrological condition too. The effects also include an increase in water overflow and decrease in evapo-transpiration.

Subsidence occurs due to mining operations both in new or old workings. Both bord & pillar and longwall mining with caving are responsible for subsidence. The depth of cover of the deposit also plays an important role in this aspect. Fires belowground turn coal to ash, thereby reducing the support to overburden rock and this causes subsidence. Subsidence caused from fire not only threatens surface structures like overhead railway lines, roads, bridges, streams etc., but also aggravates the fire itself establishing air leakage path to the underground fire area from the surface.

Coming to its effect on global environment it produces vast quantity of carbon dioxide, the main 'green house' gas. It has been estimated that the contributions of CO_2 in atmosphere have increased 15% during this century and is rising at 0.3% per annum (Banerjee, 2000). With this rate of rise of CO_2, it is projected that its content in the atmosphere would rise from 330 ppm to 600 ppm within 50-70 years - if fuel consumption rates get doubled. Thus the global annual temperature may rise by 2° to 3° K with maximum warming up to 10°K in the polar regions disturbing eco-balance with possibility of rise in sea level. Corresponding rainfall is also likely to increase by 5-7%. The Chinese fires also make a big, hidden contribution to global warming through the green house effect, scientists said. Each year they release 360 million tonnes of carbon dioxide into the atmosphere, as much as all the cars and light trucks in the United States. Presently, Chinese coal fires produce 2-3% of the world's total annual output of CO_2 caused by fossil fuels (Zhang et al. 2004).

Underground

Underground fires destroy the static geologic structure as the burning process reduces the coal volume to a small amount of ash. Therefore, cavities arise and due to falling material crevices and holes appear on the surface. These collapsing materials cause a noticeable change of surface shape and in case of hilly regions, land slides occur.

There is always a risk of explosion from the emission of CH_4 that comes out as POC from underground fire. When fighting mine fire in a gassy mine by introducing inert gases directly or by construction of seal, care should be taken to maintain mine air in such proportions of gases that it does not form an explosive mixture. Further, toxicity of carbon monoxide, which starts coming from the early stages of heating, endangers life even in remote areas from the seat of fire. CO has acute harmful effect by displacement of O_2 in blood forming a stable complex called carboxy-hemoglobin. Death arises due to fire is many a times not by burning effect but by the toxicity of CO gas.

Social

Mine fire not only causes environmental pollution to the surroundings but also creates stability problem of the area. In Jharia coalfield in seam fire damages the geologic features of the strata and becomes unstable. Social and environmental status of an area highlights its quality of life (QOL). While mining directly employs about 100,000 people, who comprise around 10% of the total population of the Jharia coalfield, more than 85% of the working population of the whole of Dhanbad district depends on mining and related activities (Pan, 2003). Mining in the last 110 years has made major changes in the overall social and environmental scenario in the coalfield. Today, the environmental status in JCF is far below the desired level and the overall QOL is poor (Chakraborty and Ghosh, 2005). There is no proper solid waste management system in the region for treating solid waste from mines and other mining related industries. Proper sanitation facilities are not provided to majority of the people in the coalfield.

Health

Noxious gases coming out from the fissures in the fire-affected areas make life miserable for the local inhabitants by its suffocating odour. The local people around the fiery coal mines area is not only plagued by the unpleasant environment but also suffered from diseases like cancer, coal mine pneumoconiosis and gastrointestinal diseases. Soot from the fires in China, India and other Asian countries are a source of the "Asian brown haze". It is a 2-mile thick cloud of soot. This soot causes various lung diseases causing deaths of thousands of people around the world.

Some researcher (Banerjee, 1990) made a survey of health of workers in Jharia coalfields. He found suspended particulate matter – including benzene soluble particulates were much higher than permissible limits. People in coal mines and surrounding area are suffering from high dust level, higher temperature causing poor visibility and health problems like irritation of eyes, tuberculosis, indigestion etc.

Fire fighting techniques

Depending on size of fire, location, depth of the mine or age of the coal fire there are different techniques existing to extinguish the fire. Methods that are employed in case of a fire are listed below. They can be operated alone or used in combination.

- Direct attack with water, chemicals, rock dust or sand
- Flooding affected area or the mine
- Digging and loading out the burning coal by bulldozing or blasting
- Inertisation with liquid nitrogen or CO_2 or high pressure high stability nitrogen foam
- Cutting off air supply by means of surface seals/remote sealing of mine gallery
- Filling cracks with soil or slurry/mud flushing/ impregnation of coal with gel solution for leakage

prevention

- Protective coating with fire retardant chemicals
- Dynamic balancing of pressure technique
- Reversal of underground mine ventilation
- Inertisation of goaf in operating panels

Inertisation with liquid nitrogen, nitrogen generated from nitrogen generator, carbon dioxide or high pressure high stability nitrogen foam has been very popular technique to control or extinguish the underground fire. Dynamic balancing of pressure in conjunction with inertisation technique has been very much successful in controlling underground fire in recent times. Fire protective coating material has been used to control opencast bench fire. Trench cutting to isolate an open fire to save the surface structure is also in vogue. Inertising goaf by injection of carbon dioxide in blasting gallery (BG) panel has yielded excellent result by enhancing incubation period of the panel. Still there is lot of scope to adopt new techniques to control fire. Some of the techniques are discussed below.

Modern techniques to deal fire

Carbon dioxide (CO_2)

The density of carbon dioxide is higher than air and it is good for controlling fire located in depressions and downgrade workings. The solid form of carbon dioxide is known as 'dry ice'. There are instances where 'dry ice' has been transported to the fire site for its control (Bacharach et. al., 1986). Coal fires contribute a lot for production of CO_2 whereas thermal plants still remains to be the major contributor. The consequences of this CO_2 in the atmosphere will be global warming which is responsible for climate change and melting of polar ice etc. (Ray, 2006).

For battling the CO_2 menace it is suggested to capture of CO_2 emissions from power plants and subsequent injection into geological underground formations for long term use.

The fire can be controlled with CO_2 in the following manner:

- Using the exhaust from the stack of a conventional thermal power plant which could be piped underground and quench the fire.
- Pumping lot of CO_2 as a part of carbon sequestration, in order to extinguish fires. Some kind of thermal imaging should be done in order to map out how the burn is occurring underground. Accordingly, boreholes are to be made to pump in the CO_2 at right places for maximum quenching effect.

Remote Sensing Approach

Remote sensing technology has made it possible to detect coal fires and study their effects. Thermal and optical images along with field-based measurements are used to determine the location, size, and depth, propagation direction, burning intensity, temperature and coal consumption of a fire (Vekerdy et. al., 1999). In China, to monitor coal fire and fighting it out, Beijing Remote Sensing Corporation has been established in 1992. Recently remote sensing geographic information system (GIS) based investigations are in progress to monitor coal fires in northern China to support fire fighting activities and reduction of CO_2 emission. A dedicated GIS system specifically tailored for the coal fire problem will use different information layers to depict coal fire location maps; risk/ hazard scenarios; priority maps for coal fire fighting along with suggestions for the best fire fighting techniques considering local conditions and other information relevant for the fire fighting and environmental monitoring teams (Prakash & Vekerdy, 2004). They would utilize space borne and airborne remote sensing data.

In India, CMPDI, Ranchi (1982) in collaboration with NRSA, Department of Space, developed methodology for thermal studies of coal seam fires using airborne thermal infrared scanning supplemented by geophysical methods. On a pilot scale the integrated study used ground thermometric and surface magnetic surveys over a part of JCF covering about 30 km^2 around Mukunda opencast project area. Prakash et al (1995) laid down procedure for determining the depth of buried hot features, using thermal remote sensing data for a homogeneous medium of constant diffusivity. Gangopadhyay et al (2005) made an attempt to identify temperature anomalies of the Raniganj coalfield to locate the spatial distributions of coal fires using Landsat TM thermal band data along with normalised vegetation index (NDVI).

Space-borne remote sensing offers important information such as digital elevation models (DEMs) as basic data for geologic formations and routes for access to burning area, hot spot detection for fire assessment, and estimation of environmentally harmful gases. Airborne remote sensing method is often affected by climatic changes and may not be easy to carry out in nighttime. The space-borne systems are cheaper. With rapid advance in computer facilities and space research in the recent years, the degree of accuracy of capturing and interpretation of satellite images has gone up largely making the system more reliable and applicable for regular detection and monitoring of surface fire.

Detection of coal fire relies on picking up one, either, reflectance, temperature anomalies, surface cracks or subsidence associated with fire. Among these remote sensing detection indicators, burnt rocks are the most important, and these can be easily recognized from remote sensing acquired in the optical wave length (Zhang et al. 2003).

If sufficiently reliable information on fire is available through space borne based satellite remote sensing technique, it would be workable to plan mining and/or mitigation measures at and around any given fire at any point of time, including the evaluation of loss of coal and appraisal of damage due to fire.

Water Mist

"Water mist" refers to fine water sprays in which 99% of the volume of the spray is in droplets with diameter less than 1000 μm. The evaporation of the water displaces oxygen reducing the effective concentration of the oxidizer and removes heat from the burning material. Thus it helps to eliminate two of the three sides of the fire triangle. In addition, radiation attenuation provided by water mist stops the fire from spreading to un-ignited fuel surface and reduces the pyrolysis rate at the fuel surface. Water mist when applied in fire areas, it cleans the air by dissolving soluble toxic gases produced during combustion, washing down smoke and suppressing dust, and thus improves visibility as well. It can safely be used in manned areas and found to be effective in open condition. Water mist fire suppression systems have demonstrated a number of advantages such as good fire suppression capability, no environmental impact and no toxicity. However, water mist does not behave like a total flooding agent, thus the effectiveness of water mist depends on potential size of fire, properties of the combustibles, and the degree of obstruction.

A survey carried out in 1996 indicated that nearly 50 agencies around the world were involved in the research and development of water mist fire suppression systems, ranging from theoretical investigations into extinguishing mechanisms and computer modeling to the development, patenting and manufacturing of water mist generating equipment (Mawhinney & Richardson, 1997).

Experiments have been conducted in USA, India in their experimental tunnel or model gallery with a view to develop water mist technology for fighting mine fire. Water mist has shown a positive impact to control a fuel-rich duct fire (Loomis & McPherson, 1995) when a series of experiments on water mist was carried out in a 30 cm square, 9 m long wind tunnel constructed in the Department of Mining & Minerals Engineering, Virginia Polytechnic Institute & State University. A fire is called fuel-rich when the oxygen concentration falls to below 15% in products of combustion (Roberts & Blackwell, 1969).

To determine the efficacy of water mist as a fire-fighting agent to control open fire in coal mine a set of experiment was conducted in Central Mining Research Institute (CMRI) mine fire model gallery (Ray & Singh, 2005). The model gallery is 65.5 m long, arch in section with a base of 2.4 m and crown height of 2.7 m. The cross section of the gallery is 5.86 m^2. The gallery is equipped with an axial flow fan. Water mist infusion has been proved to be safe and very effective technique for not only controlling open fire in underground mines but also reducing toxic gases, minimizing rollback and improving visibility in the fire affected areas.

Conclusions

Coal mine fire not only causes threat to the property but also responsible for loss of lives. It creates environmental pollution in the surrounding area. Subsidence problems many a times caused due to fire only affect stability of the area. Further, socio-economic status of the miners is thereby deteriorated. Many fire suppression techniques are nowadays available to control fire. Either a single technique or a combination of technique are utilised to extinguish or control fire. Depending upon the fire size, depth of its existence these techniques are used. Modern techniques like water mist, remote sensing technology or carbon dioxide infusion may be employed to deal with the fire. Water mist technology should be made compatible with the Indian geomining condition before applying it to real scenario. Remote sensing technology should be utilised to detect and monitor coal fires and thereby different mitigation measures may be planned. There is lot of scope of R&D in these areas. Carbon dioxide obtained from exhaust of thermal power plants should be utilised in mass scale to control fire whenever the situation permits.

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