Hazard and Risk in Mining Industry: A Case Study Based on Senghenydd Colliery Disaster

Aayush Kumar, Shravan Nair, Bikarama Prasad Yadav, and P. A. Arun

1 Introduction

The Occupational Safety and Health Administration (OSHA) in the USA defines combustible dust as a solid material which is made up of prominent particles or pieces, despite its size, shape, or chemical composition, which exhibits a fire or deflagration hazard when suspended in air over a range of concentrations. Dust explosion may occur frequently in many industrial environments where there is a presence of fine particles in air, like flour, coal, starch, sawdust etc. Mining and flour mills are the most susceptible to such dust explosions.

The National Institute for Occupational Safety and Health has given the following statistics of 623 coal mining disasters (with five or more fatalities):

Date	Mine name	Type	Product	Fatality
30–12–1970	Finley Coal No. 15 and 16	Explosion	Coal	38
26–02–1972	Buffalo Mining	Dam failure	Coal	114
22–07–1972	Blacksville No. 1	Fire	Coal	9
16–12–1972	Itmann No. 3	Explosion	Coal	5
09–03–1976	Scotia	Explosion	Coal	15
11–03–1976	Scotia (second)	Explosion	Coal	11
01–03–1977	Porter Tunnel	Flood	Coal	9
04–04–1978	Moss No. 3	Suffocation	Coal	5
07–11–1980	Ferrell No. 17	Explosion	Coal	5
15–04–1981	Mid-Continent CO	Explosion	Coal	15
07–12–1981	Adkins Coal Mine	Explosion	Coal	8

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A. Kumar · S. Nair · B. P. Yadav (✉) · P. A. Arun
University of Petroleum and Energy Studies, Dehradun, India
e-mail: bikarama@gmail.com

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Date	Mine name	Type	Product	Fatality
08–12–1981	Grundy Mining	Explosion	Coal	13
20–01–1982	RHF No. 1	Explosion	Coal	7
21–06–1983	McClure #1 Mine	Explosion	Coal	7
19–12–1984	Wilberg Mine	Fire	Coal	27
06–02–1986	Loveridge Mine	Collapsed coal pile	Coal	5
13–09–1989	William Station No. 9 Mine	Explosion	Coal	10
07–12–1992	No. 3 Mine	Explosion	Coal	8
03–09–2001	No. 5 Mine	Explosion	Coal	13
02–01–2006	Sago Mine	Explosion	Coal	12
20–05–2006	Darby Mine No. 1	Explosion	Coal	5
06–08–2007	Crandall Canyon Mine	Fall of face or rib	Coal	6
05–04–2010	Upper Big Mine	Explosion	Coal	29

Note Owing to the extensive nature of the table, only the data of last 40 years are taken into consideration

As it can be seen from the above table, almost 73% of all the accidents which occurred in the last four decades had explosion as their type which indicates the presence of dust particles and the harm that it may cause in the mining industry.

Complimentary to the well-known fire triangle which needs fuel, oxygen and an ignition source for fire to occur, dust combustion has two additional components, namely dispersion of dust particles and confinement of the dust cloud. This dust pentagon when completed gives rise to dust explosions whose intensity may vary from time to time according to certain parameters. Combustible dust explosions are further classified as primary explosion and secondary explosion. In any typical dust explosion, due to the dust present in the confined space getting ignited (due to some ignition source) will cause a fire relatively small in nature. This is known as primary explosion. But the most destructive explosion type happens after this, which is the major problem. The primary explosion will cause the accumulation of dust forming a dense cloud in the confined area, which on getting airborne will get ignited resulting in a much more dangerous uncontrolled explosion. More often than not it is this secondary explosion which is the cause of a number of fatalities in any factory/industry it takes place.

Coal dust in this case is one of the major causes of dust explosions to take place in any industry, specially mining. Historically, majority of the fatalities and casualties have occurred due to coal dust explosions, namely Courrieres mine explosion in France (1907), Benxihu Colliery disaster in China (1942), Farmington coal mine disaster in USA (1968) and the one used for this study, i.e. Senghenydd colliery disaster. There is a certain range of concentration of dust and air mixture which will determine whether the explosion will occur or not occur. Upper explosive limit is the range above which the explosion will not take place whatsoever, whereas lower explosion limit is the lowest concentration of dust capable of causing an explosion.

It also has to be noted that the most unmanageable explosions are produced when there is enough oxygen content present in the dust cloud which results in complete combustion.

When a solid or liquid particle is finely divided and dispersed in air, it forms a higher degree of risk to explosions as compared to any other matter. When dispersed, its surface area increases by manifold as well as the space occupied by the dispersed material is expanded over many times. These conditions cause the material to burn more rapidly, and the energy which is liberated gets released suddenly along with the production of high quantity of heat energy. This heat energy produced exerts large amount of pressure on the walls of the area confining the dust cloud. All this along with some fuel leads to fire and explosions of high magnitude which further entraps the people working in these areas leading to their death.

2 Literature Review

Ben Harvey examined the Oaks Colliery Disaster which occurred in 1806 to understand the safety concerns related to coal industry in much more context. He explored different safety legislations that were enacted by the industry and how well it was followed by different hierarchies of management from management level to the workers. Although the disaster occurred following series of explosions which was caused by firedamp that ripped through the entire framework, he determined the root cause of this incident in terms of the behavioural management of the workers and staff that led to this mishap. It helped him to quantify safety duties and state regulations that need to be undertaken by the industrial workers and other parties (Harvey 2016).

C. Chu, R. Jain, et al., statistically analysed coal mining safety in accordance with the increasing advent of technologies in China. Different parameters used for this analysis were fatalities per million tons, labour productivity and fatalities per 10 000 exposure hours. Statistics Package for Social Science (SPSS) was used for this correlational analysis between the mining accidents and technology advancement. Direct connection was observed between the monetary investment, new technology with the coal mine safety from the year 2001–2010 in China (Chu et al. 2016).

Kenneth L. Cashdollar studied the explosibility of coal dust in order to determine improvement factors in mining and other industries with respect to safety where coal is used or is being processed. Minimum explosible concentrations, minimum oxygen concentrations, highest pressure rise rate, maximum explosion pressures and total required quantity of rock dust for inheriting the coals which are the few parameters were measured. Laboratory explosibility chamber (USBM 20 litre) was used for this purpose. The relation between coal explosibility and particle size was assessed, and it was observed that particles with fine size are more hazardous than particles of relatively larger diameter (Cashdollar 1900).

Robert G. Neville reviewed the second-largest colliery disaster known as The Courrieres Colliery Disaster, 1906, which happened in France. Although the exact initial cause of this explosion is unknown because all the witnesses of this catastrophe are gone, still he examined the two causes of the accident which were known after the investigation which were ignition of methane by the naked flame of a miner's lamp and handling of mining explosives (Neville 1978).

Irving Hartmann has conducted extensive research on industrial dust explosions, mine fire control unit, dust allaying in mines, alternate and healthy use of mining explosives, strength and compressibility of coal pillars, variations in humidity, temperature impact and development and control of coal mine explosions and other mine safety problems. He came into conclusion that dissemination of dust, adequate ventilation, use of flame safety lamps, large exhaust dust collectors on mining machine and rock dusting of all mine workings are few of the preventive measures that could be taken to prevent such explosion (Hartmann 1954).

Zhao Dai-ying, Nie Bai-sheng statistically evaluated the serious accidents in coal and mining industry in China. For this study, they took accident data of 30 years, i.e. from 1981 to 2010. Relative indexes according to time, employee and output were calculated by statistical method. They came into conclusion that in coal mines, the death of hundred thousand employees has reduced over a course of time by relative indexes analysis. According to type analysis, it was identified that not only gas but also flooding accidents are one of the dangerous kinds, whereas month-based analysis reveals that larger PSCA incidents occur from March till May and from November till December (Dai-Ying and Bai-Sheng 2011).

Michael J. Brnich, Kathleen M. Kowalski-Trakofker examined the changing trends in colliery disasters by capturing the past data of underground coal mine disasters in USA of almost 110 years. Different parameters of this study were frequency of fatalities, increase in behavioural-based safety concern, general types and the responses to those disasters. They emphasized on the fact that human behaviour plays a vital role with respect to the coal mining accidents. This research includes the leadership quality of a person in this situation, decision-making capability, communication, incident command centre issues, expectations training and issues related with the introduction of refuge chambers. They divide the coal disasters into three different time periods such as 1900–1909, 1910–1969 and 1970 to present. It was observed that as the period goes on, there was a notable downfall in the underground colliery explosions. Also, the main reason for this achievement was advancement in psychosocial and human behaviour factor and their recognition by the industries. Hence, it was concluded that behavioural science and psychology have a huge impact on mine safety and health.

E A Khamidullina, S. S Timofeeva, et al. took into account the safety quality parameter, i.e. risk indicators to identify the extent of accidents in the coal and mining industries. The purpose of this study was to analyse the social risks associated with the coal mining and represent it in the terms of F/N curve. For preparing this curve, he took past data of 70 years, i.e. from 1943 to 2012, and the nominal values for risks were evaluated. It was observed that cumulatively, all the accidents resulting in deaths were comparatively more than number of deaths in the worst conditions. Also, from the F/N diagram, it was visible that normative level was attained by the frequency of accidents with higher number of fatality, thus indicating larger risk values (Khamidullina et al. 2017).

Timothy hynes with the help of past researches has tried to examine different events that lead to the mining and explosion disasters in an organization. He related mock bureaucracy with the accidents and examined different factors leading to the violation of safety rules at a workplace. He came into conclusion that growth of mock bureaucracy is due to macro-environmental factors, managerial non-compliance, workers non-compliance, cultural factors and delegitimization of safety rules by external agencies (Hynes and Prasad 1997).

Metin Akgun studied different coal accidents and compared its impacts with the explosion in Soma Eynez mining quarry to determine the causes of these accidents and to evaluate various preventive measures for it. He realized that the main reasons for this disaster were spontaneous combustion of coal and the presence of methane gas. He further examined the respiratory emergencies in coal mines. Different aspects for this evaluation were the history of coal accidents, procedures undertaken while rescue operation, management of the emergencies encountered while the accident, precaution that should be undertaken prior the process and respiratory emergencies (Akgün 2015).

James C. Cawley conducted a study focusing on various electrical hazards in a mining industry. He studied 1926 electrical accidents which occurred between 1990 and 1999, where all these data were MSHA closeout data and few preliminary data. It was seen that electrical hazards contributed to fourth highest cause of mine disaster also 14th most cause of injuries. He analysed different factors such as circuit voltage, cables, grounding, circuit breakers, batteries, meter usage and working on energized circuits and came with some preventive measures to reduce such electrical hazards which were mitigation of likelihood and consequence of flash burn injuries, electrical injuries in maintenance work activities and of electrical shock injuries (Cawley 2003).

Letícia Couto Garcia, Danilo Bandini Ribeiro, et al. reviewed Brazil's worst mining accident of Samarco Corporation owned mine which was demolished. This disaster resulted in death of 20 people and affected biodiversity by degrading the local indigenous land, pollution of water and death of marine life. He further studied the steps undertaken by the organization to prevent reoccurrence of such accidents, compensation given, improvement brought in the monitoring system and the environmental bond (Garcia et al. 2017).

3 Causes of the Accident

Investigations into the incident were first opened on 2 January 1914 which ran for about three days before getting adjourned. Reopening again on the 27th of January of the same year, it continued for a period of 13 days. The report titled "Causes of and circumstances attending the Explosion which occurred at the Senghenydd Colliery on Tuesday, 14th October, 1913" was submitted by Richard Redmayne who was the commissioner of chief controller of mines and the assessors included Evan Williams, Chairman of South Wales and Monmouthshire Coal owners' Association along with Robert Smillie, President of miners' association of Great Britain to the Secretary of State for the Home Department, Great Britain on 3 March1914.[1] Various theories and their acceptance put forward by the committee were:

1. The only obvious way by which the start of the explosion could have happened was found to be spark from electric signal wire or sparks from the rocks brought down by the fall. This was supported by the experiments conducted with electrical signals having same voltage of the batteries which were present at the site where accident occurred.
2. There were very large falls on the road, exposing seams of coal and beds of hard rocks which may have caused the outburst of gases responsible for getting ignited and causing the explosion.
3. The theory of the falls being responsible was supported by Mr Watts Morgan who took a prominent part in the exploration work and also a member of the committee of control which was established after the explosion had occurred.
4. The mining engineers also put forward their theory that the ignition could have taken place due to the lamp present at the lamp cabin which was supported by the Manager, Mr Shaw.
5. Another probable theory which came up by Mr J. Winstone was that the gas existing in a cavity in the main West Level at the arch end and friction caused by a haulage rope rubbing against timbers near the roof resulting in the induction of spark. Though this theory was opposed by timberman Edwards, the most experienced man amongst the miners said that he had never seen a rope running in the timbers or the places mentioned by Mr Winstone.
6. There were also several features which opposed the lamp station as being the point of ignition. The cabin in which the lamp was present was whitewashed only two months previous to the explosion and showed no signs of discolouration, which should have occurred had the explosion originated in the cabin. Also an underground lamp was found lying on the table of the lamp cabin with unburnt paper inside it.
7. The primary cause being the ignition caused by sparks was further strengthened by the evidence of Mr Shaw who had frequently seen the sparks from falls of ground. An account of this incident was further supported by the overman (R.W. Evans) and a Fireman (J.Loyd), who had witnessed it.

Along with this, Dr Wheeler's report on experiment with signalling apparatus was also submitted in which a number of tests were carried out using one of the Sengenydd bells in the laboratory. The experiments were conducted in such a manner that either the bell or the signal wires were enclosed in a chamber containing an explosive mixture of methane and air. It was found that the ignition at the bell due to the maintained spark at the spring contact could be obtained with a battery of five cells, the current when the circuit was closed being at 0.70 amperes and voltage across the bell terminals being 7.5.

[1] Senghenydd-Explosion-Report-opt.pdf.

It has to be noted that as is the case with every inquiry report, this inquiry also failed to identify a definite cause for the explosion to occur, though the spark from the signalling gear igniting the coal dust–air mixture was considered as the most likely cause of the accident. Also, one of major reasons for the explosion to occur was the breach of the mining regulations which was considered as a failure on the behalf of the management. Additionally, disapproval was aimed towards the course of action in place in case of any emergency such as shortage of respirators and the shortage of ample water supply for firefighting.

4 Conclusion

After the careful study of the authentic investigation reports on this particular accident, it is now known that there were multiple underlying causes for this catastrophic accident, in which the main and preceded event is liberation of substantial quantity of gas by the falls. These hefty falls revealed the deposits of coal and hard rock beds, and a rush of gas attacked one of them. In there, the sole method of fire was a spark caused by the electrical signalling gadgetry. The possibilities of match and lamps as a means of ignition were remote, and no sufficient evidence was there to start discussion. Use of electric wires into the West Mafeking District were the existence of gas was reported previously to an accident and it has also revealed that the particular area of mine where inflammable gas was present already in appropriate amount had a suitable environment for fire aided by the presence of electrical signalling equipment in that area.

Making this electrical signalling apparatus as a primary means of ignition in the scene, investigators carried the experiments on type of electrical signalling apparatus which was used at the mine.

Dr. Wheeler's report on experiments with signalling Apparatus
His experiments showed that there were three Dania cells giving a current (on closed circuit) of 0.45A under a pressure (on open circuit) of 4.5 volts making conditions possible to produce a spark, by short circuiting the current, which exploded a mixture of air and methane when methane was present at 8.2%.

Underlying cause/Root Cause
Non-compliance with the statutory requirements of Sect. 62(3) of the Coal Mines Act, 1911. It was argued that according to the sub-sections, the cleaning of dust from the floor, roof and sides should be carried out "as far as practicable", which was lacking in the mine.

Non-compliance with the code of electricity Regulations 1905 which states that no bare wires shall be used for signalling circuits except in haulage roads and also no apparatus was permitted as per the code of 1905 to produce external sparks in places where gas might occur in amount which is adequate enough to be suggestive of the hazard which it possesses.

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