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Prevention of frictional ignition in coal mines using chilled water sprays

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PREVENTION OF FRICTIONAL IGNITION IN COAL MINES USING CHILLED WATER SPRAYS

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ABSTRACT: A key objective of this paper is to share application of chilled water sprays for prevention of frictional ignitions in coal mines to provide a safe occupational environment. Frictional ignitions in underground mines if not managed adequately may lead to major explosions. Historic statistics have indicated that the greatest explosion risk originates from frictional ignitions. Methane and dust related to explosions have resulted in over 7500 lives lost in the last ten years worldwide. The experiences of chilled water sprays used for managing heat in deep metal mines in South Africa is highly relevant to frictional incendive/face heat management in Australian coal mines.

Mine ventilation and water sprays (used for dust suppression and dilution ventilation) are established technologies that are widely used in coal mines for the prevention of frictional ignitions. However, greater benefits of cooling or the sharp reduction in incendive heat from cutting picks by the use of chilled water sprays outweighs cooling using the current practice of using warm service water. Chilled water spray droplets have the potential to become 'improved last line of defense' against gas ignitions. For example, introduction of chilled water sprays with millions of fine chilled water droplets around picks and face area would provide a simple, reliable and rapid cooling power of 210 kW and 1 005 kW for continuous miners faces and Longwall shearer face respectively. A US study has noted that 90% of all frictional ignitions occurred in coal mines that liberated at least 0.39% of CH_4 through their mine ventilation air methane system. However, analyses of South African statistics indicate that frictional ignition have occurred in coal and gold mines that liberated even with lower emissions between 0.02% to 0.05% of CH_4 through their mine ventilation air methane system. Therefore, it is important to raise awareness that frictional ignition risks are ever present in coal mines regardless of gas contents or gas emissions. The application of wet head systems, proactive ventilation and methane monitoring, active suppression systems, and frequent safety interactions for preventing frictional ignitions are discussed.

INTRODUCTION

Frictional ignitions (FI) in mines are an operational safety threat that may lead to major explosions. A FI is an ignition of flammable gases initiated by a heat energy source resulting from frictional means. It may involve friction between different media, but commonly involves steel cutting elements rubbing against rocks with incendive (heat generating) properties such as high quartz or pyritic content. It is believed that the semi-molten trail of rock and pick metal left behind the tool (not the shower of orange sparks usually associated with rock cutting) is the primary source of heat that is igniting methane.

Knowledge of FI has been known for at least past 330 years. A FI review by Phillips (1997) noted that in July 1675, a Mr. Jessop of Broomhall, Yorkshire communicated the problem of FI with the Royal Society. In South Africa, the first FI was recorded in 1968. In addition, during the 1970's seven FIs were recorded and 31 were recorded in 1980's. In the last ten years, 10 FIs were recorded. A valuable FI research was conducted in Australia through ACARP project C7029 (2000). In the last two years, there have been reported incidents of FIs in Australian mines.

FIs are mostly associated as a pre-cursor to the deadly methane and coal dust explosions. Statistics have indicated that the greatest explosion risk comes from FIs, and that the most likely site for an ignition to become a major incident is in a development drivage (Browning and Warwick, 1993). However, recent statistics have highlighted that longwall faces are not immune to FI risks.

Possible energy sources for gas ignitions are lightning strike, spontaneous combustion, electrical ignition, mechanical heat sources, contraband, and frictional heat. FI controls exist in the form of mine safety systems and procedures and in particular environmental monitoring, ventilation systems, trigger action response plans.

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A study on changing pattern of ignition source (Figure 1) due to changes from conventional drill and blast to mechanized mining have been carried out (Phillips, 1996). There was a recorded case of gas ignition leading to flames that may have been caused by short circuiting or incomplete detonation in a blasting face in Ermelo mines in South Africa (Stone, 1990). As seen from the statistics, other than the lightning as the key contributor in gas ignition, all other major factors are not contradictory or debatable. It was noted that an increased mechanisation has also increased FI incidents. There is known evidences of lightning in the explosion of methane gases. However, the debate surrounding the role played by lightning in the gas ignition may not subside soon, but adequate lightning protection control procedures will aid in reducing the FI related incidents.

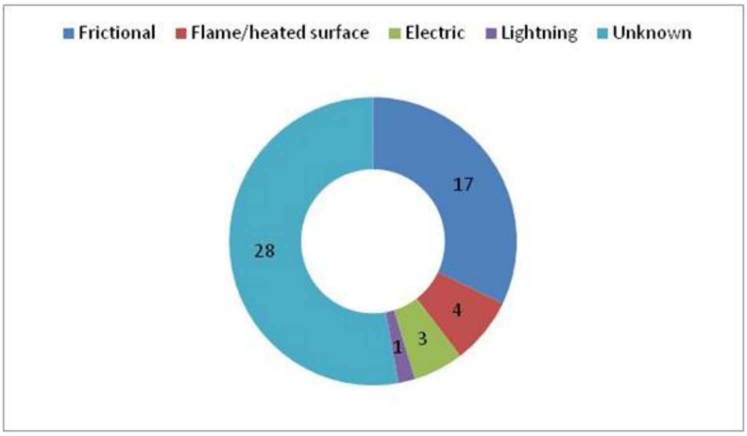

Figure 1 - Sources of FI in South African Collieries for the period between 1984 and 1993 (Phillips, 1996)

Another interesting statistics that is essential in understanding the ignition risks and control status is the impact of seasonal variation such as winter months (Figure 2). Unfortunately, no statistics could be found on Y-axis.

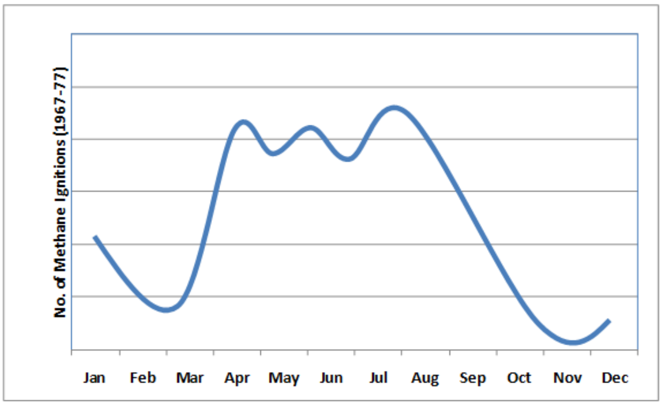

Figure 2 - Number of methane ignitions and season of the year (South African Experience)

FI's are of regular nature and not unique to developed or developing countries, low or high inherent methane coal seams, low or high Ventilation Air Methane (VAM) from shafts. The seriousness of the methane ignition and the resulting methane and coal dust explosions are witnessed by the series of explosions in the coal mines worldwide (China, South Africa, Ukraine, USA, and New Zealand). Figure 3 shows the explosion statistics collated from the public domain. In South Africa, there are known cases of ignition of flammable gases from gold, platinum and coal mines leading to 78 accidents in the past seventeen years (1988 to 2005) with loss of multiple lives and injuries.

Some of the recognisable pattern of factors contributing to such events can be summarized as follows:

- Inadequate understanding of the inherent ignition and explosion risks;
- Inadequate and at risk installation, quality assurance and maintenance practices of monitoring hazardous environment using early warning devices;

- Inadequate management of ignition controls;
- Inadequate management and control of ignition sources;
- Inadequate integration of explosion risks into the overall mine design, control and systems;
- At-risk behavior, poor or non-implementation of risk management standards and procedures.

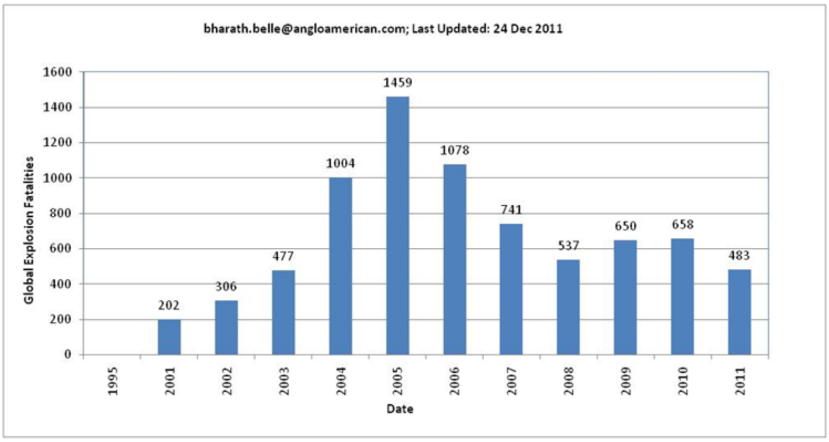

Figure 3 - Statistics on global mine explosions

CONDITIONS FOR FRICTIONAL IGNITION

Prediction of transient methane explosive mixtures present in a mine atmosphere in and around coal cutting environment or face area is complex and thus prevention of its possible contact with frictional/incendive heat energy sources is a means of management to prevent FI in mines. Presence of methane or scenarios leading to FI or explosions is often termed as 'abnormal' situations. It is the adequate management of these 'abnormal' situations that will aid the mining industry in prevention of ignitions and loss of lives.

The literature review on FI highlights a number of pertinent facts (Robertson, 2010):

- Whilst the explosive range of methane in air is approximately 5-15%, the maximum sensitivity exists for 6.5-7.5% mixtures. The minimum ignition temperature is thought to be around 650 to 750 ºC, but this increases to over 1 000 ºC as the size of igniter reduces. The time to initiate an explosion is around 0.3 sec for 9.6% methane composition, increasing to 8 seconds at 12 to14% mixtures. These facts suggest that for an incendive spark to ignite a gas mixture, the concentration would need to be optimal, the temperature quite elevated (approaching 2 000 ºC) and the contact time of several seconds.
- Above dynamics support the concept of "hot spots" as the source of ignition. The area of 'hot spots' as the source of ignition, is a function of the nature of the streak developed behind the tool; wide streaks result from blunt tools and hot streaks develop when fused quartz from the rock adheres to steel on the tool and then rubs on the rock surface. Rocks with greater than 50% quartz content are highly incendive, especially where the quartz grain size is greater than 70 micron. Tests have indicated that even under these conditions, temperatures in excess of 1 000 ºC are needed to cause an ignition.
- Rocks can be categorised by allocating a so-called Ignition Potential Categorisation (IGCAT) rating in accordance with physical and mineralogical properties. This solution is impractical considering the wide and complex geological conditions.
- Pyritic inclusions in the rock exacerbate incendivity due to raised temperatures during oxidation of pyrite when cut.
- Worn picks dissipate more energy in friction than sharp picks increasing the chances of an ignition occurring.
- Pick back clearance angles of greater than 12^o are necessary to avoid the likelihood of steel shank material contacting rock.

- Steel rubbing on such rocks creates the necessary frictional heat whereas hard tool coatings such as tungsten carbide, ceramics or diamonds produce less heat. A frozen (non-rotating) conical pick can cause an ignition with tungsten carbide contact if a large enough flat is worn.
- There is variable evidence as to the importance of force and cutting speed but current thinking indicates that pick speeds below 1.5 m/s are less likely to create FI conditions, with lower forces also less conducive.

The probability of the appropriate juxtaposition of both methane condition and cutting condition to cause a FI is enhanced by the myriad of pick strikes developed from rotation of a laced drum in different face configurations.

Common FI causes

Globally, known causes of FI are not new and include the following absent and failed defenses:

- Blunt and worn out picks on coal cutting machine head;
- Missing Pick blocks;
- Cutting a large quantity of roof rock;
- Hard pyritic stone in the roof;
- Failure to identify abnormal geological conditions;
- Failure of picks to rotate and design of pick angle on cutting drums;
- Current pick speed may be too fast for mining conditions;
- Missing, blocked and ineffective water sprays;
- Ventilation/gas drainage ineffective in dissipating local gas make;
- Missing rubbers on ventilation duct reducing face ventilation;
- Not aware that in-seam or exploratory horizontal or vertical boreholes had been cut through;
- Current gas drainage methodologies do not eliminate residual gas make from borehole stubs;
- Not all crew members have current awareness of frictional ignition procedures in detail;
- Inaccessible and complex Safety and Health management systems;
- Latest wet head technology or active suppression systems not fitted (currently not available).

The occurrence of recent Australian FIs indicates that there are opportunities to improve on existing controls (to eliminate human interventions), and for improving the risk profile the following are suggested:

- Review and upgrade of the current FI SOPs and Safe Work procedures;
- Ensure adequate stone dusting for prevention of coal dust explosions;
- Adequately maintain coal cutting machine;
- Regularly change worn out picks and keep all sprays in designed condition;
- Create greater awareness of FIs for all workers;
- Investigate the viability of introducing "wet head" technologies;
- Review the configuration of existing underground UIS drainage hole monitoring;
- Investigate the viability of sealing boreholes;
- Investigate options of roadway geometry including cutting less roof and more floor;
- Research other mines recent experience with FIs.

FRICTIONAL IGNITION LEADING PRACTICES

Energy needed from literature states that as little as 0.3 milli-joules of electrical energy is required to ignite a methane air mixture. This is equivalent to 1/120 000 000 of the energy used in 1 second by a 37 kW motor or about one-fiftieth of the static electricity accumulated by an average size man walking on a carpeted floor on a dry day (Du, 1994). Therefore, any improvements in eliminating or further reducing the heat energy source (Figure 4) would help in succeeding the challenges over FIs. The section hereafter discusses the cross-pollination of technology and in particular use of chilled water sprays for prevention of FI commonly used in South African gold and metal mines.

Managing human behaviour including lack of discipline is difficult but key contributing factors in failure of series of controls leading to FIs. In the case of frictional ignitions, failure of an individual could have significant multiple consequences. Therefore, where possible, introduction of new technologies that would overcome such breaches due to human factors would be helpful to the mining industry.

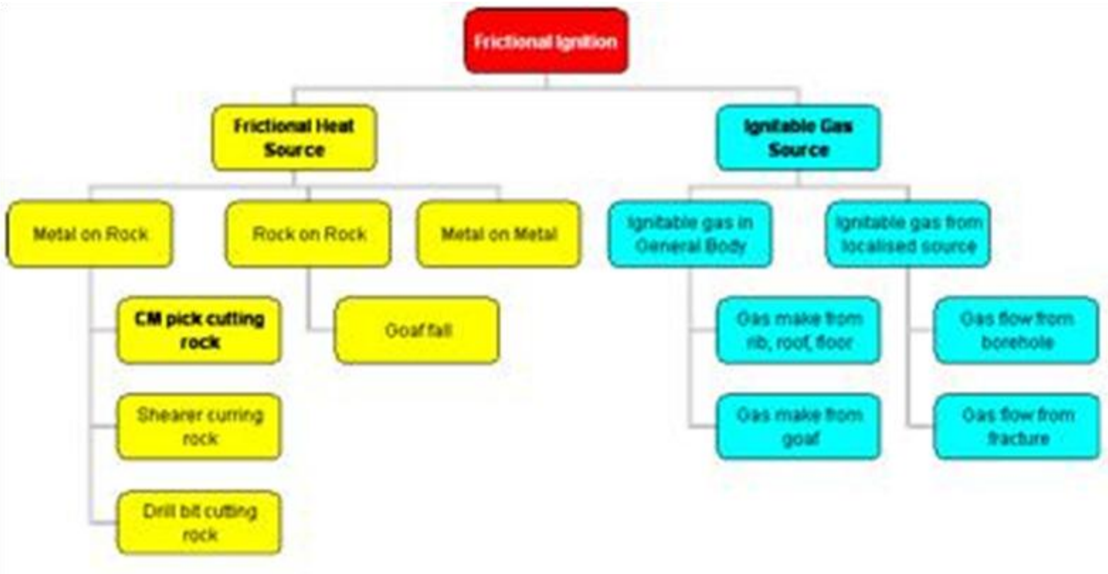

Figure 4 - FI fault tree analyses (Robertson, 2010)

The general principles of the frictional ignition control, viz., ventilation, water sprays has been researched and documented (BCC, 1990) and practiced in the mining industry globally. The generic mitigation strategy based on reducing the friction, cooling the cut surface and/or reducing local methane concentrations can be summarised as follows:

- Ensure that adequate ventilation is always in place in development headings such that any ignition is contained to a small a methane source as possible. Explosion cannot occur in the presence of adequate ventilation;
- Reduce and dilute methane make from the face area to minimise the development of pockets of explosive methane;
- Design, maintain and operate cutting systems that minimise friction when cutting rock so as not to create ignition conditions;
- Maintain and operate effective back pick flushing sprays that cool rock surfaces behind the pick.

Cutting pick condition management

Globally, according to various reports, cutter pick condition is the most important factor because nearly 70% of all FIs initiated by this means. All coal cutting heads are equipped with picks (Figure 5) featuring hard cutting tips for wear resistance and these picks wear quickly when cutting hard rock. Picks are fitted to pick blocks welded to the cutting drum, often via a removable adaptor piece or pick sleeve. The lacing of the drum determines the spacing and sequence of pick contact on the rock surface and the set-up of the tool determines the angle of attack, pick body clearance etc. On a positive note, recent technologies have created high temperature stable diamond composite materials that offer encouraging life.


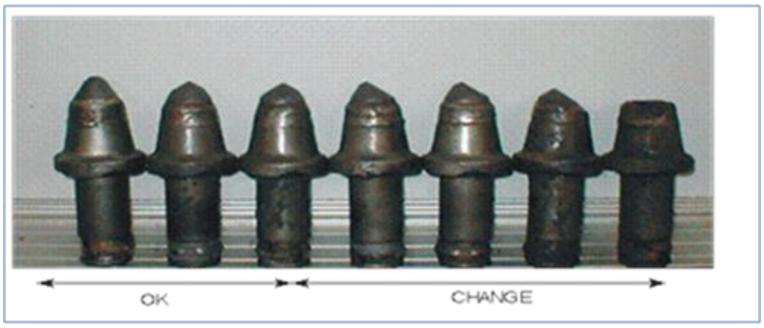

Figure 5 - Cutter head with picks (left) and Pick condition reference guide (right)

Face environmental monitoring

Other key feature of early prevention practices in prevention of FI is detection of hazard. In the prevention of FI, critical monitoring parameters of interest are methane, section or face air velocity, alarm settings of these monitors. Studies (Kissell, *et al.*, 1986) have suggested that the methane monitor on the mining machine is an essential control for early detection of gas which would shut off the machine sooner. Depending on the machine type and data communication systems, it would useful to understand the trends of gas emissions from face area. This is one of the FI control barriers. In all or most of FI incident investigation reports it is reported that there was a failure to analyse the pre-ignition gas trend due to limited manual gas records or unconnected real-time recording and data collection system. Improvement in collection of this crucial information is worth the effort for improved understanding and management of FI risks in the face area.

Application of chilled water sprays

It is noted that frictional energy and thus the thermal environment near the picks is an important contributing factor in initiating an FI. It is recognised that FI is not caused by the orange sparks which are observed as particles which are torn off during mechanical process and ejected glowing visibly. The cause of FI is the hot spot left behind the trailing edge of the pick on the rock. The hot spot is formed by a thin layer of metal wiped on to the rock, or rock adhering to the metal and then smeared. Depending on its lifetime, size of smear and temperature, this smear ignites methane if present. The temperature at which both Tungsten carbide and quartz liquefies is about 1 710 ºC whilst the melting point of carbon steel is 1500 ºC. Therefore, chilled water sprays with arrival temperature of 8 ºC to 10 ºC may present as a simple, rapid, reliable, and proven technology for FI prevention.

Effects of hot thermal environment have been studied and effectively managed in coal mines elsewhere in South Africa, USA, Europe and Australia. The first use of cooling plant was in Brazilian gold mines in the late 1800s. In the mid 1930's, first surface bulk air cooling was first started in South African mines. Improvement in cooling technology has resulted in current use of slurry ice and chilled water on a daily basis in those hot underground mines. Chilled water technology has become mature and its application in Australia is just a matter of acceptance and time.

In Moranbah region coal mines at a depth of 300 m, the thermal environment at a coal face is the same as met by those gold mines of South Africa at a depth of 4 000 m and Platinum mines at a depth of 1500 m. Currently, bulk air cooling is the strategy that is being implemented in Australian coal mines. Current BAC discharge air temperatures vary from 10 ºC to 13 ºC with mixed air with temperature at the shaft bottom of 18 ºC. As known from Australian experiences, ventilation air alone will not contribute a significant cooling impact. The challenge is the arrival temperature of cooled air at coal face which has to travel long lengths of roadways with positional efficiency of cooled air at its lowest at coal face. Therefore, alternative cooling strategy such as chilled water is a practical opportunity and would aid in cooling and avoiding FI environment.

Traditionally, mine cooling is commonly achieved in the following order in the mining industry:

- Ventilation;

- Surface bulk air coolers (direct spray heat exchangers);
- Underground bulk air coolers;
- Spot cooling coils;
- In-stope coolers;
- Chilled water;
- Surface ice plant for slurry ice cooling.

The experiences of chilled water sprays used for cooling deep hot mines in South Africa is highly relevant to FI prevention and incendive/face heat management in Australian coal mines. From a FI prevention perspective, ventilation and water sprays (used for dust suppression and methane dilution through ventilation) are established technologies that are widely used in coal mines. However, greater benefits of cooling or sharp reduction in incendive heat from cutting picks by the use of chilled water sprays outweighs the current practice of service water. For example, introduction of chilled water sprays and millions of fine chilled water droplets at temperatures of 8 ºC to 10 ºC would provide a rapid heat removal rate of 210 kW and 1 005 kW Continuous Miner faces and Longwall (LW) shearer faces respectively (Figure 6). On the other hand, CM and LW face ventilation alone may provide a heat removal range between 70 kW and 350 kW. Thus, chilled water spray droplets have the potential to become 'improved last line of defense' against gas ignitions.

Figure 6 - Use of chilled water sprays behind the picks

It is simple operational practice in mines with Virgin Rock Temperature (VRT) of 55 ºC to use jet sprays using 4 to 5 L/s of chilled water to rapidly fix and improve hot face environment conditions. Typical daily chilled water consumption in those metal mines is approximately 200 L/s against the Australian coal mine conditions that may require up to 50 L/s of chilled water. Unlike laboratory environment, due to complexity of mining conditions, stand alone benefits of chilled water sprays have been difficult to quantify other than operational qualifications.

In the case of FI, concepts such as cyclical cooling and ventilation on demand must be considered by coal mines with extreme caution as they may lead to 'delayed cooling' or creation of unplanned explosive atmospheres.

Application of wet head systems

The original concept of the wet head system on CMs was centred on water sprays being emitted from nozzles mounted on the rotating drum head and close to each bit. This differs from conventional external sprays as water is sprayed continuously to the bit and its vicinity as it cuts the coal. The water is strategically placed in the Pick Back Flushing Mode (PBF) position to reduce the probability of FIs. The wet head concept was developed in the 1970s by the former United States Bureau of Mines (USBM), the Bituminous Coal Re-search National Laboratory (BCRL) and various manufacturers (Merritt, 1987). The spray system on the wet head are integral with the tool holder and spray in the PBF mode known to be essential to reduce the incidence of incendive ignitions (Browning and Warwick, 1993; Courtney, 1987; Powell and Billinge, 1981).

It has been clearly established that FIs are caused by hot material that is ejected from behind the cutting tool and that water can be effective in preventing an ignition. It has also been established that less water is required when applied behind the cutting tool instead of in front (Powell and Billings, 1981). A laboratory study at Pittsburgh Research Centre using cutter-drum-mounted water sprays indicated that FI during dry cutting of sandstone with a carefully designed water spray nozzle located behind the bit (PBF mode) substantially reduced the likelihood of FI (Courtney, 1987).

Sprays directed at the cutting area near picks ("wet heads") have been the subject of much development work, both for dust suppression as well as for FI mitigation. Several companies (Hydra Tools, Joy, Eimco, Sandvik (excluding ABM machines), and Kennametal) have conducted wet head development programs. Successful designs are commercially available for shearers and road headers but are still in the prototype stage for CMs. This is largely due to difficulties in plumbing water (sealing related problems) to the rotating head and in maintaining clear pick jets.

Despite the interest in both the 1970s and the 1987 trials of the wet head on CMs, there is a lack of further literature indicating progress. This state-of-affairs is, in fact, explained by comments from the machinery manufacturers who have indicated that the high cost of producing and maintaining wet heads (including the cost of sophisticated seals), and, despite enquiries during the early 1990's, no wet heads were ordered until late in 1994 (Phillips, 1997). Further to this, first series of wet head tests using new seals were carried out in South Africa (Belle and Clapham, 2001) have indicated the benefits of wet heads in terms of dust and bit consumption. Furthermore, the CM operators indicated that improved visibility in the cutting zone.

Active On-board explosion suppression system

Active on-board explosion suppression systems are mounted on coal cutting machines and detect the presence of a methane ignition by means of light sensors. The electronic signals from the sensors trigger the suppression system which creates a barrier of flame-suppressing material, thus containing the flame in the immediate vicinity of the ignition and so preventing further development and propagation of an explosion.

Active suppression systems can therefore be used in conjunction with 'traditional' methods of explosion prevention. Several active suppression systems have been tested in the 20 m rectangular Kloppersbos explosion tunnel to determine whether a system or configuration is able to fulfil the acceptable criteria for various cutter head positions, methane concentrations and roadway heights (Belle and Du Plessis, 2000).

In the year 2000, in response to an approach from the French research institute INERIS, which required further precautionary measures for their collieries, an on-board active suppression system, "Explo-Stop®", was trialed in South Africa (Figure 7). This project involved four different companies - Centrocen, the CSIR, INERIS and HBCM - the French mine in which the system was to be installed subsequent to the success of the tests.

The results of the tests showed that the system managed to suppress a methane mixture volume of 180 m^3 of a 9% methane concentration. This was achieved with a temperature rise of less than 100 ºC at the operator's cab and no flame was detected at the operator's cab.

A South African thermal colliery further installed an active suppression system (in early 2000's) and its performance could not be verified (as there were no triggers) and further installation was not pursued. Similarly, due to closure of all mines in France, experiences on active suppression system are not available.

Figure 7 - The Explo-Stop® on-board active suppression system on a Dosco 1300H

Frictional ignition limit awareness

Awareness of FI is quintessential in the management of it as it drives the consistent application of the prevention methodologies and adherence to procedures and standards.

Any ignition in an underground coal mine is an issue of great concern to all parties. There exist in some Queensland mines, rules relating to maximum *in situ* methane gas content of 5.75 m^3/t to reduce FI risk. This was based on past experiences of FI incidents in seams with gas levels above 6.5 m^3/t in the 1990's. FI risk is ever present in a coal mine, where a recent case of FI occurred in Queensland in a similar mining seam after 12 years despite complying with the 5.75 m^3/t gas limit. For example, a study by Krog and Schatzel (2009) noted that 90 % of all FIs occurred in u/g coal mines that liberated at least 0.39% of CH_4 through their mine ventilation system. Interestingly, US production data suggested that there is no relationship between FI and productivity.

Figure 8 shows the FI statistics between 1990 and 2010 in metallurgical coal (Australia) and thermal coal mines (South Africa). As can be seen, there is no relationship between gas content and number of FI incidents. A study by Krog and Schatzel (2009) noted that 90% of all FIs occurred in underground coal mines that liberated at least 0.39% of CH_4 through their mine ventilation system. However, South African statistics indicated that FI have occurred in coal and gold mines that liberated even with lower methane emissions between 0.02% and 0.05% through their mine VAM system (Belle, 2009). Therefore, it is important to communicate that FI risks are ever present in coal mines regardless of gas contents or gas emissions.

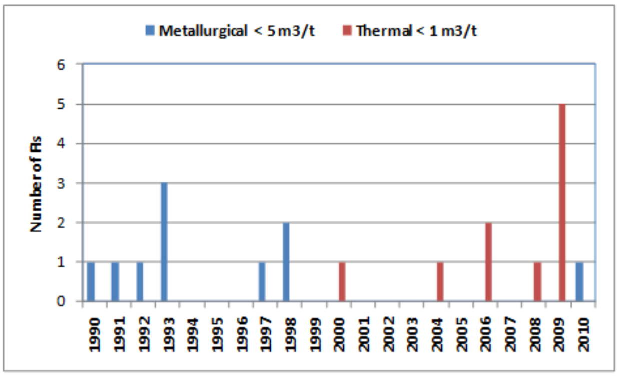

Figure 8 - FI incidents in metallurgical (Australia) and thermal coal mines (South Africa)

Ignition of methane is applicable to metal mines with known fatalities in gold and platinum mines of Witwatersrand with extremely low gas contents. As recent as previous decade, several lives have been lost due to ignition of methane related explosive gases. On a positive note, there are suitable standards and procedures and PHMPs related to FI. However, misunderstanding of FI limit such as 5.75 m^3/t be eliminated during early training and mine induction period.

CONCLUSIONS

The preceding discussions on causes of FI are not new. The FI and explosion statistic definitely provide valuable information to drive and guide proper safety strategies at the time of risk assessment, determining likelihood and consequences. However, some of the identified new technologies such as chilled water sprays on CMs and LW shearers, use of wet head systems, active suppression systems and improved air velocity and gas monitoring systems will further aid in alleviating FI risks. Chilled water use in coal face area will have the added benefit of reducing thermal stress hazards. Although there is no empirical evidence of a relationship between chilled water and FI incidents, the progressive and safety conscious nature of mining industry would witness the benefits of cooling picks and face area using chilled water sprays, if adopted in years to come. This paper was written in the hope that it will enhance cross-pollination of experiences and aid in the prevention of FIs in mines through transfer of established technologies (in gold and platinum mines in South Africa) such as chilled water on face cutting machines.

In conclusion, this paper has presented ideas for prevention of FIs in the mining industry. It is noted that benefits of chilled water sprays for prevention of FIs will only be reflected through future FI statistics.

Lastly, the slogan (Phillips, 2007), "the price of safety is eternal vigilance," applies to FI and any tools to improve such vigilance must be embraced sooner rather than later.

ACKNOWLEDGEMENTS

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