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Mine gas drainage and outburst control in Australian underground coal mines

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Abstract

Australia produces both black and brown coal and is the world's fourth largest producer of black coal, after China, USA and India. Australian underground coal mines operate under controlled safety codes. The establishment of the mine safety management system, including the 1994 outburst management plan, contributed to a significant improvement in mine safety leading to non-fatality in outburst related incidences since 1994. The management of outburst risk, as a part of the overall safety and health management system is described. Also discussed are the introduction of outburst threshold limit values and the desorption rate index which forms the basis for determining safe mining conditions along with the "Authority to Mine" process The measures taken and lessons learned from safe mining of Australia's outburst prone mines represent an opportunity for improved mining safety in other countries, such as China. . The role of the Australian Coal Association Research Program, which supports research in critical areas such as outburst risk control and management, is also discussed.

Keywords: Mine, Gas, Outburst, Mine safety management, Threshold limit values, Risk management;

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1. Introduction

Australia produces both black and brown coal and is the world's fourth largest producer of black coal, after China, USA and India, and the fifth largest producer of brown coal, after Germany, Russia, Turkey and USA. In 2009, Australia produced approximately 346 Mt of saleable black coal from 451 Mt of total raw coal production, and approximately 68 Mt of brown coal [1][2]. Almost 98% of Australian black coal production is sourced from the two eastern states of New South Wales (NSW) and Queensland (QLD) while brown coal is produced mainly in Victoria, with 98% coming from the Latrobe Valley. All of the brown coal production is utilised within Victoria for power generation.

In 2009, Australia supplied 29% of global black coal export market, and has been the leading exporter of black coal since 1984. Black coal is Australia's principal export commodity, generating A$55 billion in revenue for the nation last year. Australia produces and exports both metallurgical and thermal coal in approximately equal proportions. The majority of Australia's metallurgical (coking) coal is produced in Queensland, while New South Wales produces predominantly thermal (steaming) coal. The Australian coal mining industry directly employs approximately 30 000 people and indirectly supports the employment of a further 100 000 people who provide services to the coal industry.

Coal seam gas represents a potentially significant risk to the safety and productivity of underground mines. Ineffective control and management of coal seam gas increases the risk of creating conditions that may result in either a coal and gas outburst or a methane and coal dust explosion. Poor gas management may also lead to general body gas concentrations exceeding statutory limits necessitating the cessation of production activities within the affected area. Over 730 outbursts have occurred in Australian mines since 1895. Table 1 lists both fatal and other incidents related to coal seam gas explosions and gas outbursts. Such incidents have shaped coal mine legislation and operating practices and provide the motivation to develop and maintain safe working conditions and operating practices. Many of the leading Australian coal mining companies now strive for "Zero Harm" and significant resources are dedicated to achieving this goal.

Australian mining now relies on the use of Safety and Health Management Systems (SHMS) that identify hazards and other potential risks present at individual mines and requires the development of management plans and operating procedures that detail the process to identify and assess hazards and implement appropriate controls to reduce risks to as low as reasonably achievable.

The management of the Mine/Colliery is required to reduce and minimise the risks associated with outbursts in development panels and on longwall faces. This aim is achieved by the drainage of inseam gas to reduce *in situ* content to below defined Threshold Limit Values (TLV) and implementing a system of measurement and assessment of outburst risk prior to authorising mining activities to take place in any part of the mine.

2. Outburst Risk Management

The Outburst Management Plan (OMP) [6] is an integral part of a mine's SHMS and is developed and maintained to effectively control the risks associated with the outburst hazard. An example of a typical relationship between the OMP and other components of the mine SHMS is illustrated in Fig. 1.

The prime objective of the Mine/Colliery OMP is to facilitate exploratory inseam drilling and gas drainage with the aim of reducing *in situ* coal seam gas contents, in all areas of the mine where development and longwall operations (and subsequent longwall extraction) are to be carried out. Reducing the pressure and content of gas within the coal seam through focussed gas drainage has been proven in Australia to be the most effective control to ensure that the risk of an outburst (or other release of dangerous quantities of noxious or flammable gas) is minimised and allows normal mining operations to be carried out. In exceptional circumstances, where conditions within the coal seam prevent effective gas drainage, the OMP makes allowance for alternate mining procedures to be used, under strictly controlled and considered circumstances. In all circumstances the intent of the OMP is to maintain the protection provided to employees and the operation. The OMP applies to all employees of the Colliery who are engaged in development mining, longwall mining, gas drainage or associated tasks and any other parties associated with the application of the OMP. It covers the strategies associated with prediction and prevention techniques as well as methodologies associated with the protection of personnel and the operation from the effects of an outburst.

Table 1: Gas explosions and outburst incidents in Australia * (updated from [3] [4] and [5])

Colliery	Date	Seam	Basin	Depth (m)	No of O/B	No. Killed	Gas	Ejected coal size (t)	Work Place
Metropolitan*	1895-pres.	Bulli	Sydney	425	154 (tot)	-	CO_2 Mainly with CH_4	200	Pick
Metropolitan	1896	Bulli	Sydney	425		3	Firedamp		Single shot
Metropolitan	1926	Bulli	Sydney	400		2	Black damp	140	undercutting
Metropolitan	1954	Bulli	Sydney	425		2	CO_2	90	Undercutting
Metropolitan	1961	Bulli	Sydney	425			CO_2 +CH_4	300	Induced shotfiring
North Bulli	1911	Bulli	Sydney	370			CH_4	1	Pick-delayed
Coal Cliff	1961	Bulli	Sydney	450			CO_2+CH_4	2	Cont Miner
Corrimal	1967	Bulli	Sydney	400	4		CO_2 +CH_4	50	Cont Miner
Appin	1966	Bulli	Sydney	520			CH_4	60	Cont Miner
Bulli	1972	Bulli	Sydney	380			CH_4	100	Cont Miner
West Cliff	1977-93	Bulli	Sydney	460	253		CH_4	4-300	Cont Miner
Collinsville	1954-1978		Bowen	220	19		CO_2	400	
C.C.C.P	1978		Bowen	280				25	Cont Miner
Leichardt	1975		Bowen	370			CH_4	500	Cont Miner
Tahmoor	1985	Bulli	Sydney		90*	1	CO_2		Cont Miner *Since 1981
South Bulli	1991	Bulli	Sydney			3	CO_2	300	Development
West Cliff	1994	Bulli	Sydney			1	CH_4		Development
Central	2001	German Ck	Bowen	400	1		CH_4	60-80	Development
Brimestone /Oakdale	1992-1995	Bulli	Sydney		2		CH_4 +CO_2	10	Development
Kemira	1980-1	Bulli	Sydney		2		CH_4	6-100	Development
Tower	1981 - 2000	Bulli	Sydney		19		CH_4	1-80	Development *Since 1981
Appin	2010	Bulli	Sydney		3		CH_4 +CO_2		Development

* Total Number of outbursts > 730

If a coal seam is identified to be outburst prone, it is a requirement for the Mine/Colliery operating in such coal seam to develop and operate in accordance with an outburst management plan (OMP). This plan has been developed to address the risk of a gas induced outburst. The OMP's prime operational objective is to carry out effective in-seam drilling and gas drainage, sufficiently in advance of development mining, in order to reduce *in situ* seam gas contents to below the normal mining thresholds and allow mining to be carried out under normal conditions. The main elements of the plan include Prediction, Prevention and Protection (Control).

2.1 Prediction

There are several factors that are accepted as the key parameters associated with outburst prediction. The geological structures of coal, excessive gas content and ground tectonic stresses are the key factors. In general, geological structures are likely to be the location of any outbursts. Geological structures are considered to present an increased risk of outburst as such structures may create stress concentrations and create a barrier that results in a high gas pressure differential. The detection of geological structural anomalies ahead of mining is achieved by in-seam drilling and the nature of the anomalies are subsequently elaborated through the use of various geophysical logging methods such as 2D and 3D seismic surveys, and the use of other technologies such as radio imaging and radar.

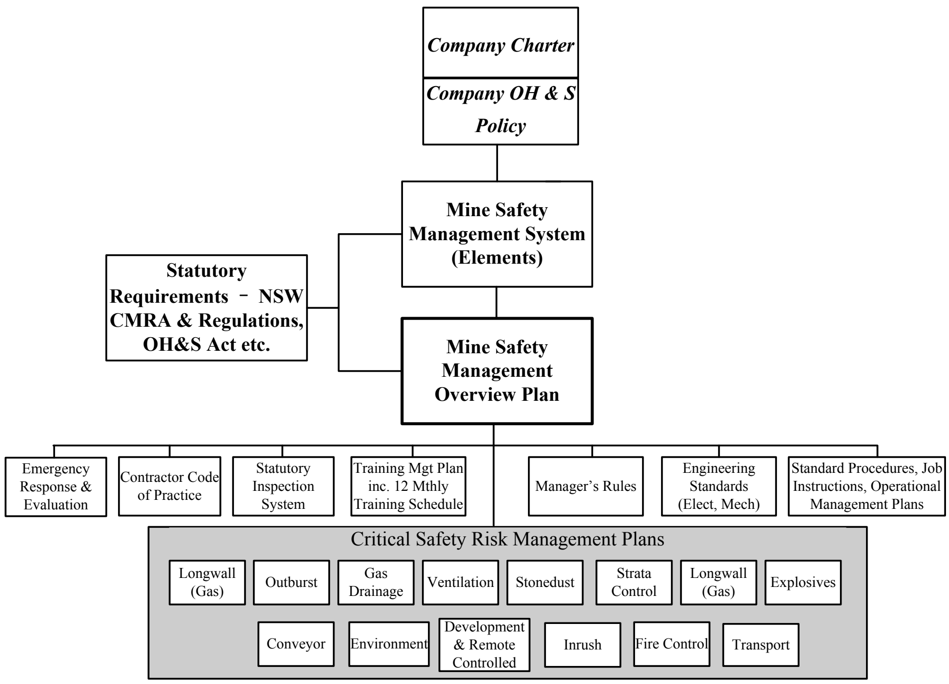

Fig. 1 Mine safety management system

Other methods of gas outburst prediction tools include the prediction indices [7] and using tube bundle and/or real time gas monitoring systems to detect the gas concentrations throughout the mine.

In each mine the mine geologist will be responsible for the collection, analysis (with regard to outburst potential) and maintenance of the data; the mine surveyor [8] will be responsible for a drill log summary sheet for each in-seam borehole drilled within the Colliery for the purpose of exploration, structure prediction core sampling or gas drainage and plot any anomalies recorded by drillers onto the Surveyors plan, independent of the geological interpretation of that data. The gas drainage engineer will establish documented standards and assessments for drilling of in-seam boreholes, connecting the drainage holes to the gas drainage system in the mine, and the monitoring of gas flows from boreholes, and maintenance of the gas drainage system to maximise effectiveness and the safe means of clearing a borehole suspected of being blocked. Other responsibilities of the mine geologist, the surveyor and the gas drainage engineer are described in the New South Wales Department of Mineral Resources OMP [6].

2.2 Prevention

This is related to the effectiveness of gas drainage coupled with gas flow monitoring, and regular core sampling, so that the mine manager is always aware of the seam gas and structural environment into which the mine is about to develop or extract. Prevention of outburst during mining of development roadways is achieved by the deployment of gas drainage in reducing seam gas contents to below the appropriate threshold value for the composition of the prevailing seam gas.

Both prediction and prevention form the input into the Authority to Mine (ATM) process which, upon completion, will determine the mining methodology to be used to develop each roadway or sequence of roadways and extract longwall panels.

2.3 Protection or Control

This is offered to development operators by way of routine training in outburst awareness, the identification of outburst warning signs and use of first response rescue and escape equipment, the provision of that equipment in the development panel at all times and the ability to suspend mining and initiate an inspection at any time should outburst warning signs be observed.

Various systems and measures, which contribute to control/or protection from outbursts to include:

- Ground destressing, which includes stress relief drilling, stress relief mining, inducer shot firing and gas drainage,
- The use of OMPs[6],
- Hydraulic fracturing; a method that has increasing application both for UIS and SIS operations,
- Pulse infusion shot firing, and
- Water infusion.

Pulsed infusion shot firing and water infuse are not generally used in Australia.

3. Authority to Mine (ATM)

The prediction and prevention provisions are designed to develop a clear picture of the conditions prevailing ahead of development panels and to reduce the seam gas content to below the threshold value corresponding to the seam gas composition prevailing in that area. The data generated as a result of the prediction and prevention provisions provide the input into the Authority to Mine process. The method of working will be decided for each set of circumstances by using the available and recognized outburst decision making flowchart" [6]. The Outburst Risk Review Team (ORRT) will be responsible for and manage the ATM process. The ATM will be co-authorised by the mine manager, undermanager-in-charge and the gas drainage engineer. ORRT is a group responsible under the OMP to review data relevant to outburst risk at the mine and to manage mining activities through the ATM process. The group normally consists of mine manager, gas drainage engineer or ventilation coordinator, undermanager-in-charge, gas drainage engineer, mine geologist, workforce representative and development coordinator. The mine manager, undermanager-in-charge and gas drainage engineer are responsible for approving an ATM.

4. Threshold Limit Values (TLV)

Following the last outburst related fatality in Australia, which occurred at West Cliff Colliery, Illawarra Coalfield, Sydney Basin, on 25th January 1994, the NSW Department of Mineral Resources (DMR) issued a directive to all mines operating in the Bulli seam detailing actions to be implemented to prevent further outburst related fatalities. Arguably the most significant of these actions was the stipulation of limits on seam gas content prior to mining, known as outburst Threshold Limit Values (TLV). Fig shows the Bulli seam TLV prescribed by the DMR [9]. The TLV varied linearly based on gas composition, decreasing from a maximum in CH_4 rich conditions to a minimum in CO_2 rich conditions. The Level 1 TLV indicates the maximum gas content limit for normal mining above which outburst mining procedures must be followed. The Level 2 TLV indicates the maximum gas content limit for outburst mining above which mining must only be undertaken using remote operated equipment, with all personnel remaining clear of the outburst risk zone.

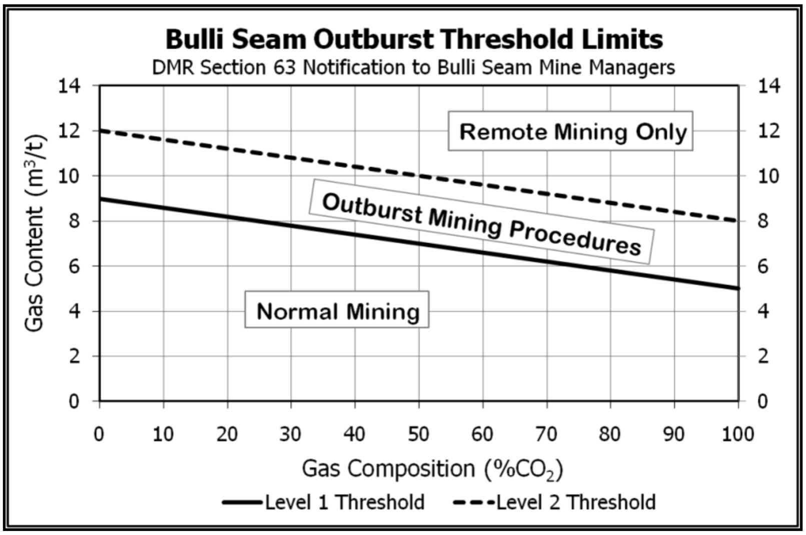

Fig. 2 Prescribed Bulli seam Outburst Threshold Limits [9]

Lama [10] described the process that led to his recommendation of TLV for safe mining of the Bulli seam, based on total gas content. The Level 1 TLV of 6.4 m^3/t for CO_2 and 9.4 m^3/t for CH_4 are considered safe under all circumstances, i.e. when mining in close proximity to geological structures with a development advance rate up to 50 m/d. Lama [10] suggested that if the rate of development advance was reduced to 10-12 m/d the Level 1 TLV could be safely increased by 20%. Lama also proposed a Level 2 TLV of 10.0 m^3/t and 12.0 m^3/t for CO_2 and CH_4 when it was known that no geological structures were present within 5.0 m of the excavation during roadway development in virgin areas. In presenting the TLV, Lama [8] stated the proposed TLV would include a safety factor of 19% (1.1 m^3/t), considered higher than the error in gas content measurement.

In recent times a few mines are operating at varied TLV values with approval from the DMR inspectorate. At Tahmoor Colliery for example, in addition to the Level 1 TLV, below which no restrictions are placed on mining, two additional TLV levels were introduced. The Level 2 TLV applies to structured coal. Where the measured gas content is greater than Level 1 and less than Level 2, in addition to more intensive drilling and coring, the rate of development advance is restricted to 12 m/d. The Level 3 TLV applies to coal free of geological structures. Where the measured gas content is greater than Level 1 and less than Level 3, in addition to increased drilling and gas content testing, the rate of development advance is restricted to 25 m/d in each heading and cut-through to a maximum of 75 m in any 24 hour period. In areas where gas content remains above the defined TLV, normal mining is prohibited and grunching is the only approved development mining method.

At West Cliff Colliery, in addition to the Level 1 TLV, one additional TLV was introduced. While no restrictions are placed on the rate of development advance, where the measured gas content is between the Level 1 and Level 2 TLV increased drilling, structure identification and gas content testing is required. Where the gas content remains above the Level 2 TLV normal mining is prohibited and an alternative mining method, such as remote control or grunching, shall be used.

Williams and Weissman [11] introduced the concept of using the rate of gas desorption from crushed coal, during Q_3 testing, known as Desorption Rate Index (DRI), to determine TLV applicable to coal mines operating in coal seams other than the Bulli seam. The test involved measuring the volume of gas emitted from a 200 g sub-sample of coal material after crushing for 30 seconds and extrapolating the result to the total gas content (Q_M) of the full core sample to determine the DRI of the full coal sample (Williams, 1996 [12] and Williams, 1997 [13]). The data presented in Fig, which represents data collected from the 386 panel at West Cliff Colliery [14] demonstrate a strong correlation between Q_M and DRI for both CO_2 rich and CH_4 rich coal samples. The relationship was assumed by Williams and Weissman [10] to be representative of all Bulli seam conditions. As shown in Fig.3, the Bulli seam TLV of 9 m^3/t (100% CH_4) and 6 m^3/t (100% CO_2) correspond to a common desorbed gas volume of 900 mL. From this assessment, Williams and Weissman concluded that the Q_M value corresponding to a DRI of 900, based on a unique Q_M-DRI relationship determined specifically for each mine and coal seam, represent the TLV applicable to that coal mine.

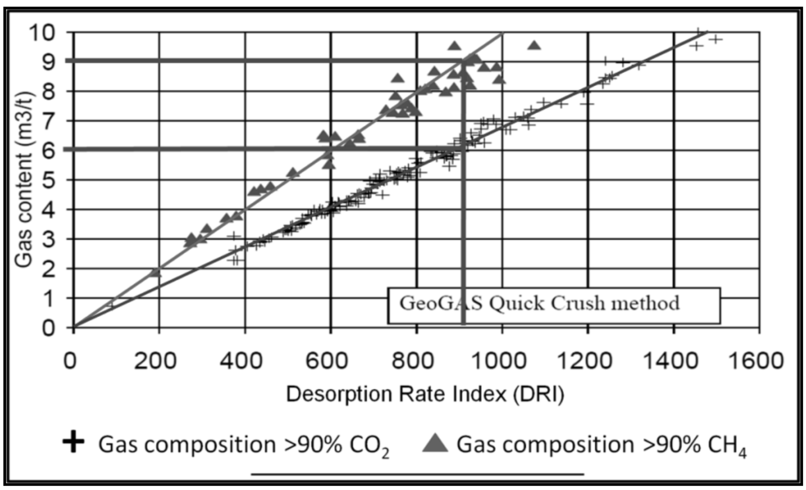

Fig. 3 Q_M relative to DRI for CO_2 and CH_4 rich coal from 386 panel [13]

5. The Role of Research

Research on coal and gas outburst goes back some fifty years and the pioneering work of Hargraves [15]. Hence the Australian coal mining industry is served by a number of research activities and research organisations such as Commonwealth Scientific and Industrial Research Organisation (CSIRO), university research, consultants and individual mining companies. Funds can be obtained from the Australian Coal Association Research Program (ACARP) research and development (R&D) investment program. This program is funded by a A$0.05 per saleable tonne levy that is managed by representatives of the coal industry.

ACARP has been in operation since 1992 and currently supports research activities into the safe and sustainable production and marketing of coal [16]. With an expenditure of about A$15 million per year, the program supports a critical mass of R&D activities covering issues determined by the ACARP committee members to be of interest to coal producers and other key stakeholders.

Fig. 2 shows the distribution of direct ACARP funds [17], which amounts to around A$50 million over the last five years. Underground projects have attracted some 36% of the pool, which has been expanded by the wind down of funding for the low emissions coal use committee since 2008. In 2011, around 10-15% of the total A$15 million was allocated to coal mine gas and outburst and gas drainage projects. The outburst funds also include the money spent on postgraduate scholarships for doctorial studies. Since 2005 ACARP has contributed to the establishment of various websites relating to mine gas and outburst, including http://www.uow.edu.au/eng/outburst/.

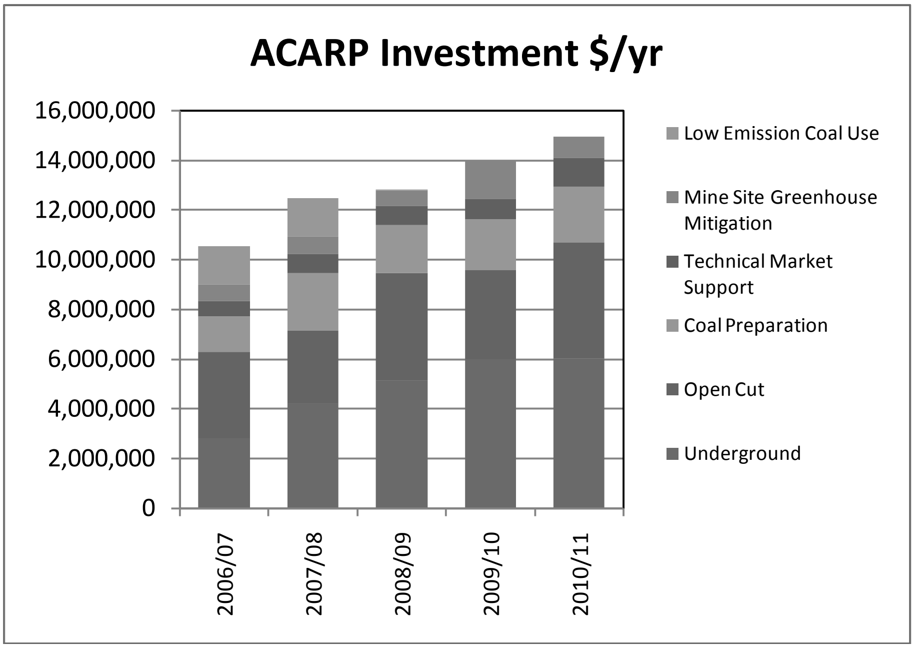

Fig. 2 ACARP annual funding allocation [17]

6. Conclusions

The stringent guidelines under which the Australian underground coal mines operate demonstrate that coal mining can be achieved safely. China and other high coal producing countries with abundance of coal reserves may consider the use of SHMS's and OMP's similar to those being used in Australia. In the present era of advanced knowhow and technology there is no reason why underground coal mining cannot operate totally free from injuries and fatalities. This is a great challenge that must not be ignored.

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