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Investigations into the identification and control of outburst risk in Australian underground coal mines

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ABSTRACT

Australian coal mines currently use gas content to assess outburst risk. The gas content threshold values for each mine are indirectly determined from measurement of gas volume liberated from 150 g coal samples during Q3 residual gas content testing. It has been more than twenty (20) years since this method, known as DRI900, was presented to the Australian coal industry, and in that time there have been significant changes in mining conditions and the outburst threshold limits used at the benchmark Bulli seam mines.

Current coal mining legislation in both Queensland [7] and New South Wales [6] provide little guidance in determining appropriate outburst threshold limits. NSW Regulations list matters to be considered in developing control measures to manage the risk of gas outburst, and specifies that (a) gas content, or (b) GeoGAS Desorption Rate Index (DRI) method, is used as the basis for determining outburst control zone. Whilst Queensland Regulations state that a coal or rock outburst is a high potential incident there is no guidance provided to assist mine operators to define outburst prone conditions.

A research project is planned at UOW to investigate the application of the DRI900 method and other potentially significant factors, such as gas pressure, coal toughness and permeability, which can be utilised by mine operators to assess outburst risk and determine appropriate outburst threshold limits and controls.

Key words:

Outburst, Desorption rate, DRI, Threshold limit.

1. Introduction

Following the introduction of outburst threshold limits in Bulli seam mines in 1994, there was a significant decrease in the number of unexpected coal and gas outburst incidents. With the reduction in incidents the attention of the mining industry has shifted away from outburst. There has been a reduction in support to conduct research to investigate the factors that define outburst prone coal and to develop new methods to identify and manage such areas to minimise the risk to mine safety and productivity.

Various theories have been presented regarding the factors that contribute to the occurrence of coal and gas outbursts and in 1995 Ripu Lama [5] listed the following factors as having the potential to contribute to an outburst:

1. Tensile strength of coal;
2. Gas emission rate;
3. Gas pressure gradient;
4. Moisture level; and
5. Depth or stress level.

From studies conducted in the Bulli seam, Lama concluded that stress does not play a significant role and it is gas which is the major contributing factor to outburst occurrence. The use of gas drainage to reduce the gas content of the coal seam to a value considered safe for mining has been uncritically accepted by the mining industry. In the 20 years following the Bulli seam studies conducted by Lama, an increasing number of Australian coal mines have moved into areas with increased gas content and reduced permeability. The combination of these two factors tend to reduce the efficiency and effectiveness of gas drainage at reducing the gas content of the coal seam below previously defined outburst threshold levels.

Given that underground coal mining operations are carried out in coal seams that present a broad range of potential outburst factors, it is reasonable to question the validity of relying solely on the Desorption Rate Index (DRI) to be transferable between all Australian coal seams and not consider other factors that may impact outburst risk [2].

2. Background

In 1995, Lama presented details of gas content and gas composition determined at nine (9) separate locations in the Bulli seam where outburst incidents had occurred [5]. Lama also proposed outburst threshold limits, shown in Fig.1, that he considered appropriate to control outburst risk in the Bulli seam. In this example, provided the gas content has been reduced below 9.5 m^3/t in 100% CH4 rich coal and 6.4 m^3/t in 100% CO2 rich coal, Lama considered there to be negligible risk of outburst regardless of mining rate and presence of geological structures. Lama also proposed two additional threshold levels that allowed mining to continue at a limited advance rate, capped at a maximum of 50 metres per day, in areas with and without geological structures.

A number of outburst events have occurred in Australian coal seams in the years following the work completed by Lama. Details of those outburst events will be collated by the author to produce an outburst event database and reassess the threshold limits proposed by Lama, shown in Fig. 1.

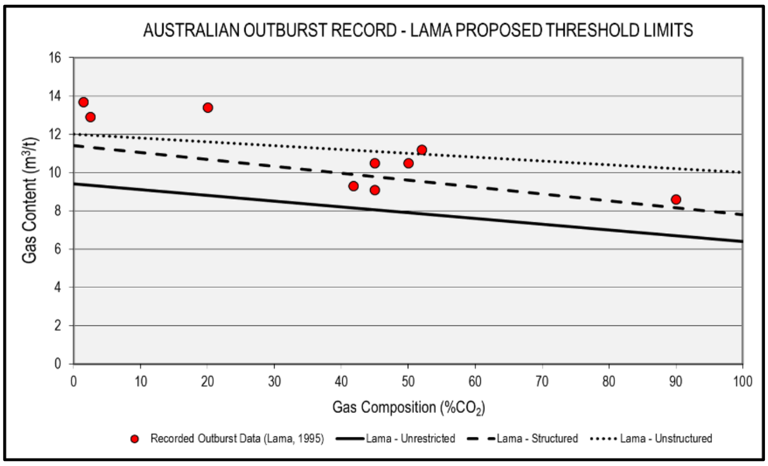

Fig. 1. Bulli seam outburst event details and proposed outburst threshold limits.

Following the last fatal outburst that occurred in Australia, at Westcliff Colliery on 25th January 1994, a directive was issued to all Bulli seam mine managers detailing actions to be implemented to control the outburst risk [4]. The directive, issued by the Coal Mining Inspectorate and Engineering Branch of the New South Wales Department of Mineral Resources, included the prescribed outburst threshold limits shown in Fig. 2, and these threshold limit values were lower than the values recommended by Lama.

The introduction of the threshold limits resulted in a significant increase in the intensity of drilling and gas drainage in these mines for the purpose of structure identification and gas content reduction. Operators developed comprehensive outburst management plans which included standard drilling patterns and routine management controls to deal with the issue of gas content reduction.

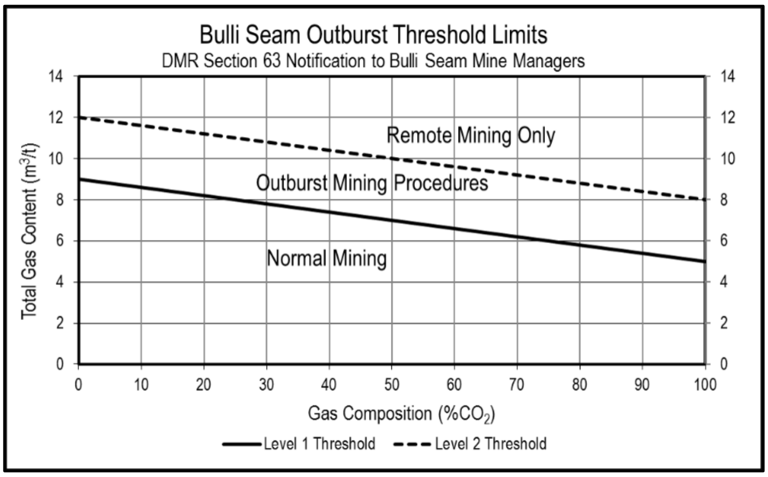

Fig. 2. Bulli seam outburst threshold limits.

3. Desorption Rate Index

Williams and Weissman presented data from gas testing CH4 and CO2 rich coal samples from the Bulli seam that showed the relationship between gas content and a newly defined desorption rate index (DRI) value [9]. The data presented in Fig. 3 suggests an approximately linear relationship exists between total measured gas content (QM m^3/t) and DRI and that the gas emission rate from CO2 rich coal is greater than from CH4 rich coal.

The relationship between QM and DRI for CH4 and CO2 rich Bulli seam coal samples, which was referred to as the Bulli seam benchmark, is represented by the following equations:

QM = 0.01 x DRI (CH4 rich coal samples; and

QM = 0.0067 x DRI (CO2 rich coal samples)

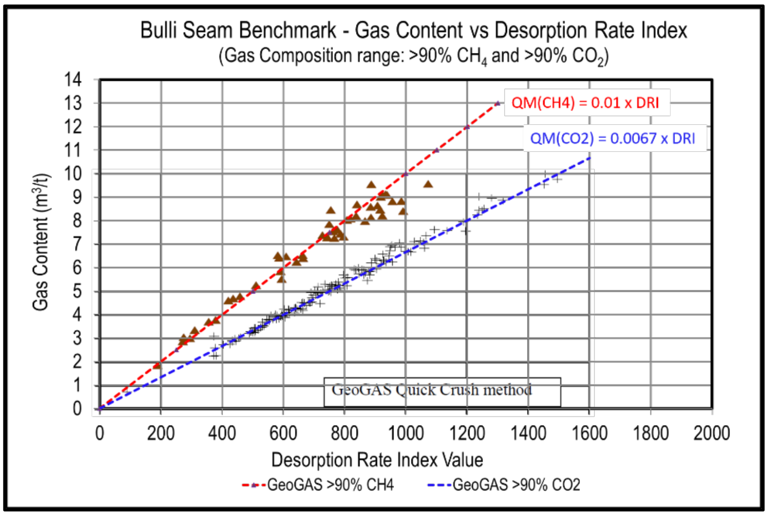

Fig. 3. Gas content and DRI relationship for CH4 and CO2 rich Bulli seam coal.

Williams and Weismann recommended that the Bulli seam benchmark and the desorption rate index DRI provide a means of determining outburst threshold limit values given the Bulli seam outburst threshold limit values of 9.0 m^3/t for CH4 rich coal and 6.0 m^3/t for CO2 rich, when applied to the Bulli seam benchmark, both corresponded to a DRI value of 900, as shown in Fig. 4. Given the relationship indicated in the Bulli seam, Williams and Weismann proposed that it would also be appropriate to use DRI900 to determine outburst threshold limits for other Australian coal seams.

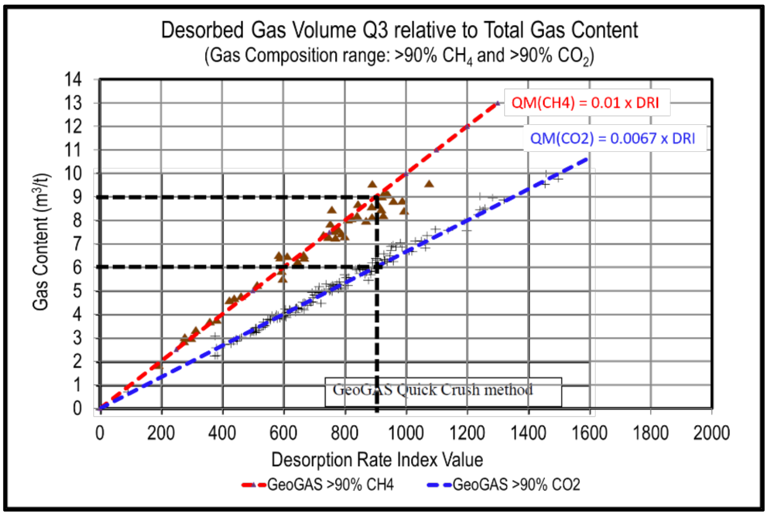

Fig. 4. Bulli seam benchmark and outburst threshold limits corresponding to DRI900.

It is now generally accepted that outburst threshold limits applicable to Australian coal mines are determined through a process of preparing a dataset of gas test results from the coal seam and plotting the reported gas content (QM) and desorption rate index (DRI) values, as shown in Fig. 5. Statistical analysis of the dataset is used to calculate the standard deviation (SD) of the QM values from the average of the dataset and a value of two (2) standard deviations is subtracted from the average. The outburst threshold limit value for this dataset is the gas content value at the point where the DRI value of 900 meets the (average minus 2 x SD) line. Determining the outburst threshold in this way means that at DRI900 there is only a 5% chance that the gas content value, based on statistical analysis, could be less than defined outburst threshold gas content value.

Whilst statistical analysis has merit, and using a conservative approach to determine outburst threshold limits may be appropriate, it is concerning that the process is completely centred on DRI900. It could be argued that the data used to establish the Bulli seam benchmark was not subjected to statistical analysis and it may be coincidence that the Bulli seam outburst threshold limit values for CH4 and CO2 rich coal seam gas conditions happened to align closely with the average of the two datasets. Would it be more appropriate to use the gas content value that corresponds to the average of the non-Bulli seam QM-DRI dataset? It could also be argued that further investigation is required to determine whether DRI is actually an appropriate tool to rank outburst risk and if so, whether the DRI900 is an appropriate basis for determining outburst threshold gas content values.

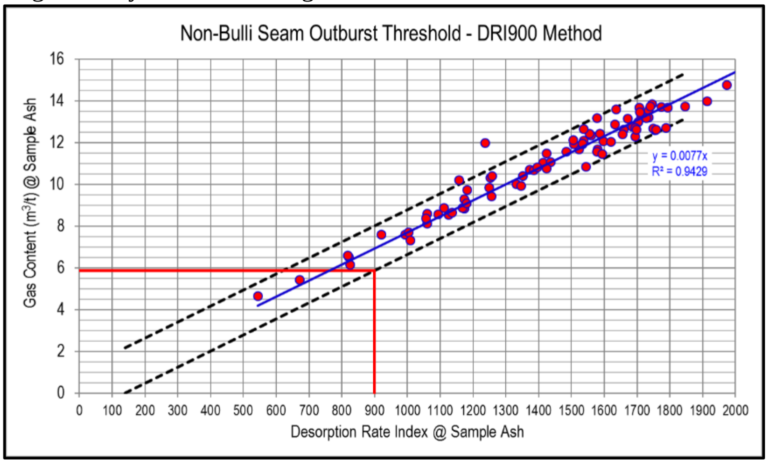

Fig. 5. Process of using DRI900 to determine the outburst threshold gas content value.

While specific details of the procedure and calculations used to determine the DRI value reported in gas test reports is not disclosed by GeoGAS, Williams [8] did report that DRI is determined by measuring the volume of gas emitted from a 200 g sample of coal after crushing for 30 seconds and relating the result to the total gas content of the sample. Williams presented the gas content – desorption rate graph (Fig. 6) to describe the method used to determine DRI. Following the initial work to develop a procedure to determine DRI, the mass of the coal sample used in the Q3 crush test has been reduced from 200 g to 150 g and it is understood that an additional correction factor was applied to the DRI calculation.

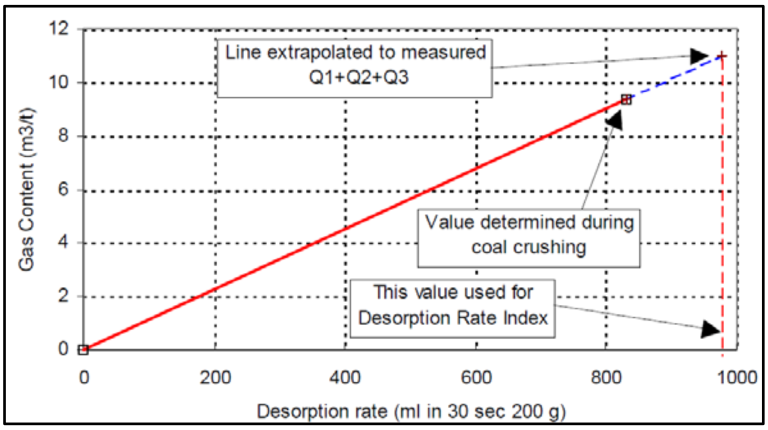

Fig. 6. Approach to determining DRI from gas emission measurement during coal crushing [8].

Analysis of gas emission data collected during gas content testing of a number of coal samples, using the quick crush method described in AS3980 [1], has found that the DRI value for a coal samples is governed by two (2) variables:

A. volume of gas emitted from a coal sample after crushing for 30 seconds during the Q3 crushing stage of gas content testing (*Q3(30s) volume mL*); and
B. the proportion of total gas content released during the Q3 crushing stage of gas content testing (Q3/QM).

A standard correction factor is also applied to account for the fact that the standard sample mass used during Q3 crush testing has been reduced to 150 g, which is less that the 200 g sample mass that was the standard when the

Bulli seam benchmark was determined.

Fig. 7 shows the results of DRI values calculated using raw gas emission data compared to the DRI values reported in gas content test reports for 34 separate coal samples. Whilst the results are similar, the calculated DRI values are consistently less than the reported values, which suggests additional adjustment factors are applied to the gas emission data to produce the reported DRI values.

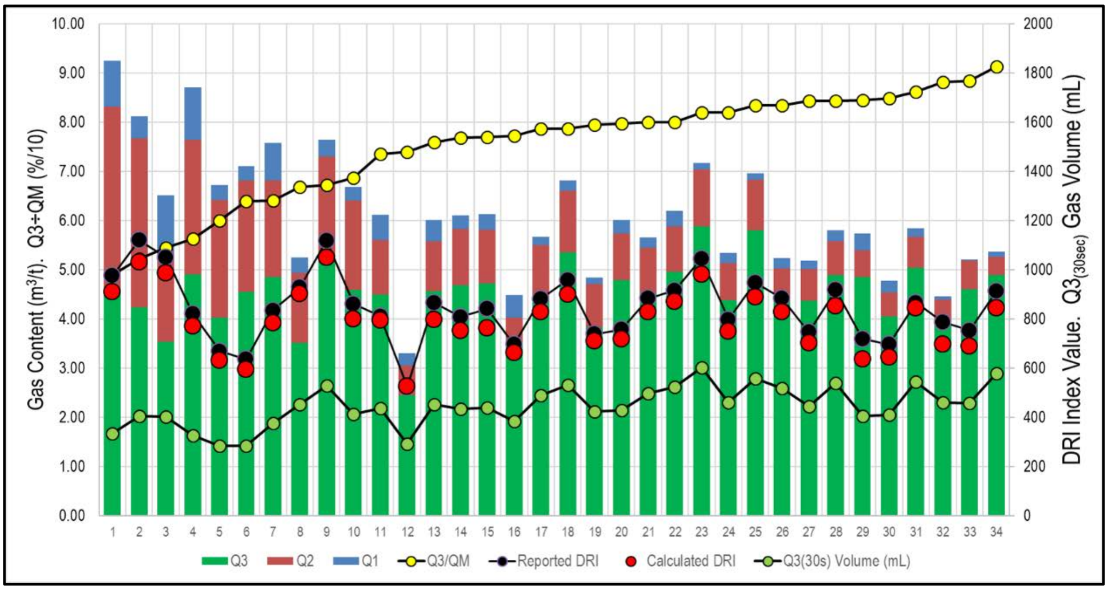

Fig. 7. Summary of gas content test results comparing Calculated and Reported DRI values.

Figs. 8 and 9 each compare gas emission data from two (2) coal samples and highlights the impact of (a) the Q3(30s) volume, and (b) Q3/QM, on the reported DRI value.

Fig. 8 shows the first coal sample, with QM = 8.7 m^3/t, has a reported DRI of 822 and the second coal sample, with QM = 8.1 m^3/t, has a reported DRI of 1119. The reason for the second sample having the higher DRI value is due to the fact that the second sample recorded (a) a higher gas volume released during the first 30 seconds of crushing (404 mL compared to 325 mL), and (b) the proportion of gas released during Q3 stage of the gas content test was less (0.52 compared to 0.56).

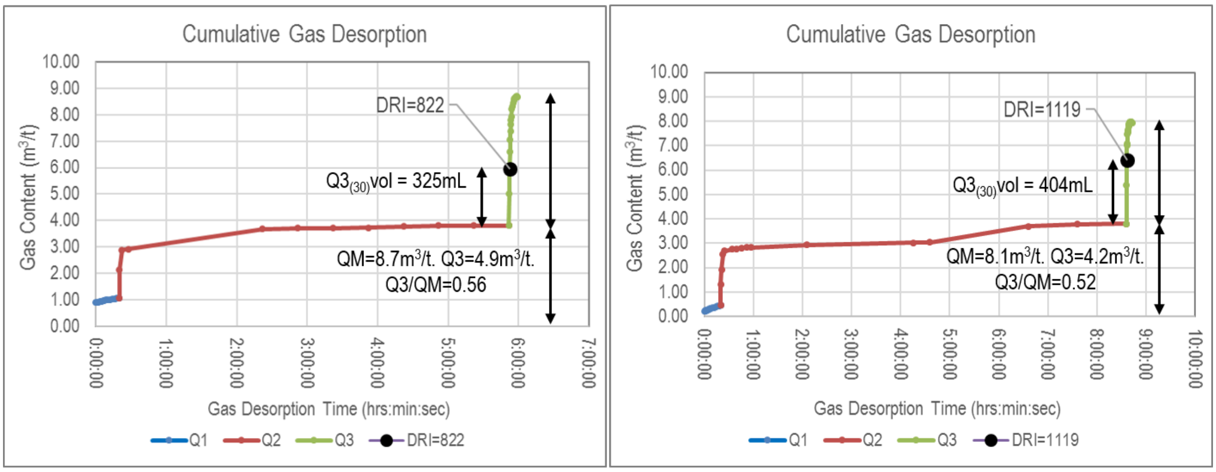

Fig. 8. Comparison of gas emission data used to determine DRI values for coal samples with similar QM gas content.

Fig. 9 shows the first coal sample, with QM = 6.7 m^3/t, has a reported DRI of 669 and the second coal sample, with QM = 6.8 m^3/t, has a reported DRI of 958. The reason for the second sample having the higher DRI value is due to the fact that the second sample recorded (a) a significantly higher gas volume released during the first 30 seconds of crushing (531 mL compared to 284 mL), and (b) the proportion of gas released during Q3 stage of the gas content test, whilst higher than the first sample (0.79 compared to 0.60), does not significantly reduce the impact that a high Q3(30s) volume has on producing a high DRI value.

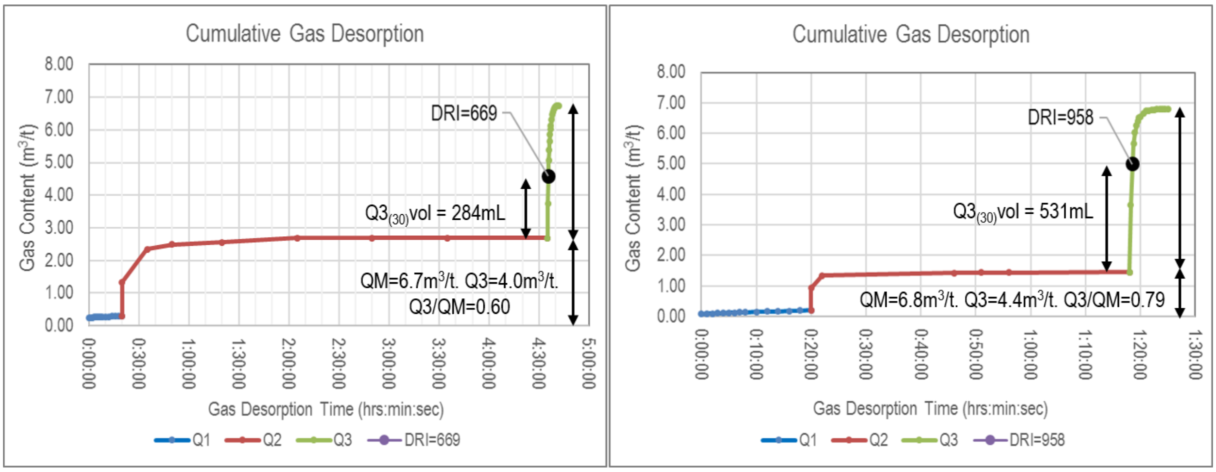

Fig. 9. Comparison of gas emission data used to determine DRI values for coal samples with similar QM gas content.

Analysis of reported QM and DRI data from several Australian coal seams has indicated the relationship between QM and DRI may not be linear, as shown by the difference between the linear and non-linear trend lines presented in Fig. 10. It is reasonable to accept that the relationship may be non-linear as the Q3/QM ratio tends to decrease in response to increasing QM as the Q1, and particularly the Q2, gas content components increase.

Given the significance that is placed on DRI, it is extremely important that the testing and data collection procedures are consistent and accurate. Inconsistency in the gas testing procedure, in particular the point during gas emission testing when the Q2 gas desorption testing is stopped and the coal sample is prepared for Q3 crush testing may have a significant impact on the DRI value determined during the test.

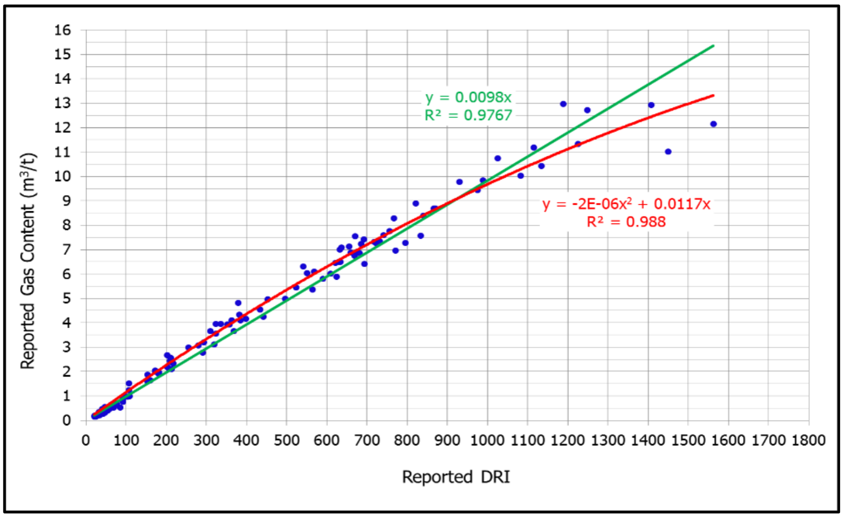

Fig. 10. QM and DRI data indicating the difference between linear and non-linear trend lines.

4. Bulli seam outburst threshold limits

In addition to investigating the Bulli seam benchmark and DRI to confirm whether they are in fact a valid basis for determining outburst thresholds in Australian coal seams, the impact of changes made to the Bulli seam outburst threshold limit values must also be investigated.

Tahmoor and Westcliff were the first mines to review outburst threshold limits and introduce additional control to support raising their respective outburst threshold limits. Fig. 11 shows the range of the increase in outburst threshold limits at both Tahmoor and Westcliff [3]. In areas where the gas content falls within the shaded zone in Fig. 11, mining may continue provided additional control actions are in place, which may include (a) increased drilling to identify geological structure that may represent an increased outburst risk, (b) increased core sample collection and gas content testing to identify any rapid change in gas content or gas composition that may indicate an increased outburst risk, and (c) restricted mining rate to provide more time to allow gas content and gas pressure contained within the coal seam in close proximity to the working face to dissipate. It is very interesting to note that the three outburst threshold limits used at Tahmoor are the same as the threshold limits originally proposed by Lama, as presented in Fig. 1.

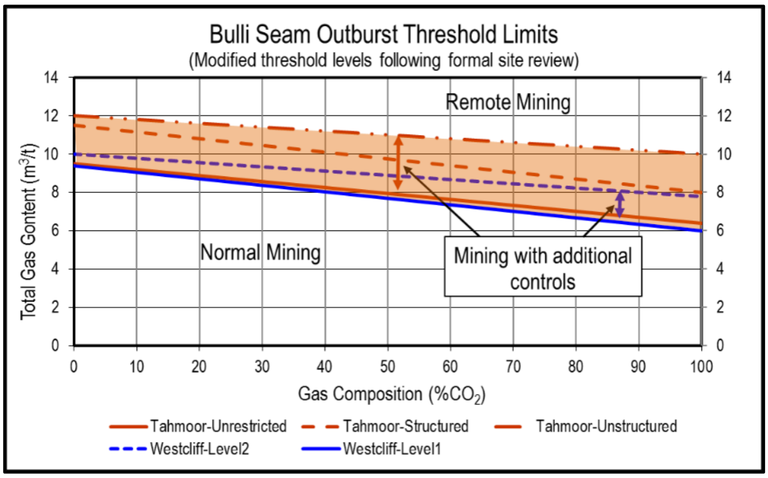

Fig. 11. Increased outburst threshold limits introduced at the Tahmoor and Westcliff mines.

If the proposed investigations into the Bulli seam benchmark and the use of DRI confirm this to be a valid and appropriate method for determining outburst threshold limits for all Australian coal seams, then the impact of introducing increased outburst thresholds in Bulli seam mines must also be considered. Applying the Level 2 outburst threshold values of 12.0 m^3/t for CH4 rich conditions and 8.0 m^3/t for CO2 rich conditions that were specified by the DMR in 1994, both correspond to a common DRI value of 1200 when projected onto the Bulli seam benchmark, as shown in Fig. 12.

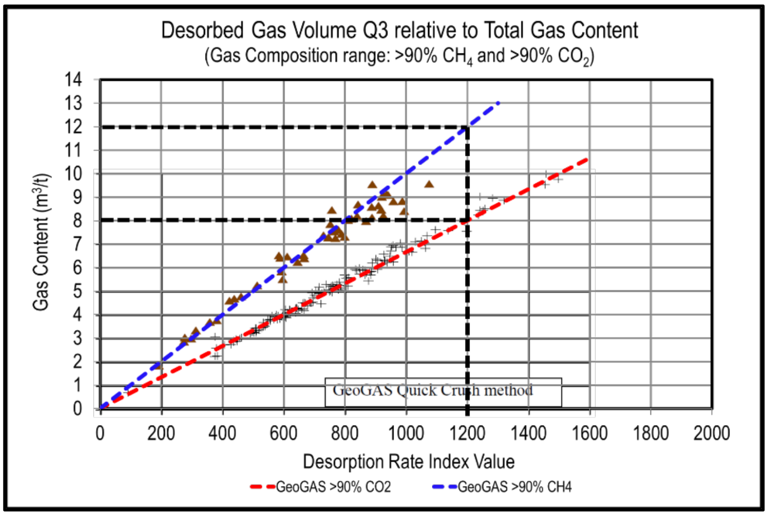

Fig. 12. Increased outburst threshold limits applied to the Bulli seam benchmark correspond to DRI1200.

Given the broad range of conditions encountered in Australian underground coal mines, the impact that other factors may have on outburst risk, in addition to gas content and composition, should be considered. Additional factors that may affect outburst risk include gas pressure, coal strength and toughness, horizontal and vertical stress, permeability, and moisture content.

5. Conclusions

The background and use of DRI900 as a method to define outburst threshold gas content values for Australian coal seams has been presented and discussed. Significant developments have occurred in the years following the introduction of the DRI900 approach, the most significant being the introduction if increased outburst threshold limits in Bulli seam mines. The conditions in many active coal seam sections has changed over the past 20 years, with many experiencing increased gas content, increased stress and reduced permeability.

Given the changes that have occurred in mining conditions it is considered appropriate to review the methods and procedures used to determine outburst thresholds to confirm whether they remain appropriate and valid for continued use in current conditions. The proposed investigation will consider the following:

- Calculation of the desorption rate index and its application to assessing outburst risk and propensity;
- Potential changes to the Bulli seam benchmark relationships for CH4 and CO2 rich coal and the potential change to the DRI value used in determining the outburst threshold limits in non-Bulli seam mines;
- Potential for the QM-DRI relationship to be non-linear and the effect that such a change would have on determining outburst threshold limit values;
- Transferability of increased Bulli seam outburst threshold limits to non-Bulli seam mines; and
- Consideration of the significance and relevance of other factors in assessing outburst risk, establishing threshold limits, implementing controls to reduce risk, and monitoring to confirm an area is safe to mine with negligible outburst risk.

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