Review of current method to determine outburst threshold limits in Australian underground coal mines

Dennis J. Black

University of Wollongong, dennisb@uow.edu.au

Follow this and additional works at: https://ro.uow.edu.au/eispapers1

Part of the Engineering Commons, and the Science and Technology Studies Commons

Recommended Citation


Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au
Review of current method to determine outburst threshold limits in Australian underground coal mines

Abstract
Desorption rate index (DRI) was presented to the Australian underground coal industry in 1995 as a means for determining outburst threshold limits for Australian coal seams. DRI is a measure of the gas volume released from a coal sample in the first 30 s of crushing during the Q3 stage of gas content testing, multiplied by the ratio between measured Q3 and QM. Relationships were identified between QM and DRI for both CO2 and CH4 rich coal samples collected from the Bulli Seam at West Cliff Colliery and that identified relationship was referred to as the Bulli Seam Benchmark. The outburst mining gas content threshold limit values specified for the Bulli Seam at that time, when applied to the QM-DRI Bulli Seam benchmark, was shown to closely align with a DRI value of 900 (DRI900), for both CO2 and CH4 rich seam gas conditions. The Australian coal industry adopted the DRI900 as the basis for determining outburst gas content TLV for Australian coal seams. Outburst mining experience in Australia has shown that gas content is not the only significant factor that impacts outburst risk, as all significant outburst events have been associated with abnormal geological conditions, such as faults and dykes. Therefore, assessing the potential application of additional outburst risk factors, to accurately define outburst risk zones, set safe mining threshold levels, and determine appropriate mining controls, warrants further investigation. Several Australian coal mines have implemented mining procedures enabling mining to continue in areas with gas content greater than the TLV determined using the DRI900 approach, without inducing an outburst. There is a broad lack of understanding among Australian coal mine operators as to the procedure and calculations used to determine DRI. Also, there has been growing concern regarding the accuracy and validity of the DRI900 method for determining outburst TLV. A comprehensive set of gas data has been collected from Australian coal seams, including the Bulli Seam, and this data has been used to investigate the DRI, Bulli Seam Benchmark, and the applicability of using DRI900 as the basis for assessing outburst risk and determining gas content TLV. The results are presented and discussed.

Disciplines
Engineering | Science and Technology Studies

Publication Details
Review of current method to determine outburst threshold limits in Australian underground coal mines

Dennis J. Black *

CoalGAS, Bulli 2516, Australia
Department of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong 2500, Australia

A B S T R A C T
Desorption rate index (DRI) was presented to the Australian underground coal industry in 1995 as a means for determining outburst threshold limits for Australian coal seams. DRI is a measure of the gas volume released from a coal sample in the first 30 s of crushing during the Q3 stage of gas content testing, multiplied by the ratio between measured Q3 and QM. Relationships were identified between QM and DRI for both CO2 and CH4 rich coal samples collected from the Bulli Seam at West Cliff Colliery and that identified relationship was referred to as the Bulli Seam Benchmark. The outburst mining gas content threshold limit values specified for the Bulli Seam at that time, when applied to the QM-DRI Bulli Seam benchmark, was shown to closely align with a DRI value of 900 (DRI900), for both CO2 and CH4 rich seam gas conditions. The Australian coal industry adopted the DRI900 as the basis for determining outburst gas content TLV for Australian coal seams. Outburst mining experience in Australia has shown that gas content is not the only significant factor that impacts outburst risk, as all significant outburst events have been associated with abnormal geological conditions, such as faults and dykes. Therefore, assessing the potential application of additional outburst risk factors, to accurately define outburst risk zones, set safe mining threshold levels, and determine appropriate mining controls, warrants further investigation. Several Australian coal mines have implemented mining procedures enabling mining to continue in areas with gas content greater than the TLV determined using the DRI900 approach, without inducing an outburst. There is a broad lack of understanding among Australian coal mine operators as to the procedure and calculations used to determine DRI. Also, there has been growing concern regarding the accuracy and validity of the DRI900 method for determining outburst TLV. A comprehensive set of gas data has been collected from Australian coal seams, including the Bulli Seam, and this data has been used to investigate the DRI, Bulli Seam Benchmark, and the applicability of using DRI900 as the basis for assessing outburst risk and determining gas content TLV. The results are presented and discussed.

1. Introduction
Following the fatal outburst that occurred at West Cliff Colliery on 25 January 1994, the NSW Department of Mineral Resources issued a directive to operators of Bulli seam mines, which included a requirement to improve the control and management of outburst risk, in addition to specifying gas content threshold limit values (TLV) for normal and outburst mining [1]. As shown in Fig. 1, the prescribed TLV for ‘normal’ mining was 9.0 m3/t in 100% CH4 conditions and 5.0 m3/t in 100% CO2 conditions and the TLV for ‘outburst’ mining was 12.0 m3/t in 100% CH4 conditions and 10.0 m3/t in 100% CO2 conditions.

A relationship between total measured gas content (QM) and a new term, referred to as desorption rate index (DRI), was presented in 1995 [2]. The relationship between QM and DRI, identified from analysis of gas emission data during gas content testing of core samples sourced from West Cliff Colliery containing high concentrations of CH4 and CO2, is presented in Fig. 2. The data indicates a linear relationship between QM and DRI, represented by the equation, QM = a × DRI where the variable gradient of the trendline, a, representing the average of the data points, equals 0.01 for >90% CH4 and 0.0067 for >90% CO2. This relationship between QM and DRI, identified from testing Bulli Seam coal samples sourced from West Cliff Colliery, was referred to as the Bulli Seam Benchmark. The relationship was assumed to be representative of all Bulli Seam conditions [2].

* Address: PO Box 2019, Woonona East NSW 2517, Australia.
E-mail address: db@coalgas.com.au
Testing to determine DRI involves measuring the volume of gas emitted from a 200 g sub-sample of coal material after crushing for 30 s and extrapolating the result to the total gas content (QM) of the full core sample to determine the DRI of the full coal sample [3]. The process to determine DRI is presented graphically in Fig. 3 [3].

Using the Bulli Seam Benchmark, Williams and Weissman reported that gas content values of 9.0 m³/t for CH₄ rich coal and 6.0 m³/t for CO₂ rich coal, both corresponded to a common DRI value equal to 900 (Fig. 4) [2]. They further proposed that, subject to determining the average gradient (\(a\)) of the QM-DRI relationship for a given coal seam, the QM value corresponding to a DRI of 900 represents the applicable outburst TLV for that coal seam. Fig. 5 illustrates the method used to determine the equivalent outburst gas content TLV using the equation \(QM = a/QM\) where (\(a\)) is determined for each coal seam. Mining in areas where the gas content level has been reduced below this threshold is intended to result in zero gas dynamic incidents and outbursts, regardless of the severity of any other condition (e.g. stress, degree of faulting, rate of mining).

Recent investigation and analysis of gas test data sourced from Australian coal seams, including the Bulli Seam, has confirmed the two input variables required to calculate DRI are (a) the volume of gas released from a sub-sample of core in the initial 30 s after crushing during the Q3 phase of gas testing, adjusted to a standard sample mass of 200 g (Q3 (30 s)), and (b) the relative percentage of QM reported as Q3 (Q3/QM). As DRI is effectively a measure of the rate of gas release during mechanical crushing of coal, which occurs at the final stage of the gas test process, it is suggested that DRI is not a valid measure of gas desorption rate.

There has been increasing concerns raised by Australian mine operators that DRI is overly simplistic and not a valid measure to fully assess and quantify outburst risk. Australia is the only country using DRI to establish outburst threshold limits for seam gas content. China, Russia and other European countries use a variety of alternate indices to assess outburst risk that involve measurement of gas pressure or gas volume release from fresh coal samples collected in advance of working faces. Examples of these indices, which aim to measure and compare gas emissions in the early stages of gas desorption from coal samples include: ΔP, ΔP-60, ΔP Express, KT Index, V30 and V index [4].

With reference to current Australian standards and practice, initial desorption rate (IDR30) is a measure of the volume of gas desorbed from coal in the initial 30 min following collection of the core. IDR30 is routinely reported as part of gas content testing in accordance with Australian Standard AS3980:2016 [5]. Limited work has been undertaken to date to investigate the use of IDR30 as a potential indicator of outburst risk.

Another critical factor that impacts outburst risk is coal strength/coal toughness, and the ability of the coal to remain intact and avoid sudden brittle tensile failure due to mining induced fracturing and applied gas pressure. As the majority of outburst events in Australian underground coal mines have been associated with geological structures, the impact and increased risk of outburst associated with structures must be considered.

The current ACARP funded research project (C26055) is investigating the relevance and applicability of the Bulli Seam Benchmark and DRI for use in assessing outburst risk and determining appropriate outburst threshold gas content values for Australian underground coal mines.
2. Bulli Seam Benchmark

Raw gas emission data collected during gas testing on coal samples collected from areas of the Bulli Seam rich in both CH$_4$ and CO$_2$ seam gas has been analysed to investigate the current Bulli Seam Benchmark to determine whether the nature of gas emission from current mining areas has shifted from the original data presented in 1995. Fig. 6 shows the relationship determined from the Bulli Seam data collected to date. The results show a shift in the QM-DRI relationship for both CH$_4$ and CO$_2$, compared to the 1995 relationship, with increased DRI values relative to gas content.

Using records of gas emission during Q3 testing, the DRI calculation was repeated using the gas volume liberated from coal samples after the initial 60 s of crushing during Q3 testing, DRI(60 s). The QM-DRI(60 s) relationship for CH$_4$ and CO$_2$, presented in Fig. 7, highlights the effect of increased gas volume release in the initial 60 s compared to the initial 30 s of Q3 crushing. Considering the extreme case of 100% of recorded Q3 gas emission being released from the coal samples within the initial 30 s of Q3 crushing, for both CH$_4$ and CO$_2$ rich coal samples, the resulting QM-DRI relationship is shown in Fig. 8. This analysis confirms the significant impact and sensitivity that the measurement of gas volume released from coal samples during crushing has on the DRI.

The investigation of gas data collected during 2017 indicated a change in Bulli Seam Benchmark relationship for both CH$_4$ and CO$_2$ rich coal samples, presented in Fig. 6, compared to the 1995 relationship presented in Fig. 2. Given the impact that crushing efficiency and rate of gas release during Q3 has on DRI, a direct comparison of Q3 gas emission from two similar coal samples tested at different laboratories confirmed a difference in crushing efficiency and rate of gas release, shown in Fig. 9. Further investigation also confirmed differences in crushing equipment used at two separate gas test laboratories. As shown in Figs. 10 and 11 respectively, Lab 1 uses twin puck and Lab 2 uses a single puck arrangement in the bowls of their ring mill crushers.

Analysis of the recorded gas emission from CH$_4$ and CO$_2$ rich coal subsamples weighing approximately 200 g, after crushing in the Lab 1 ring mill for 30 s, confirmed initial gas release from CO$_2$ rich coal was consistently greater than from CH$_4$ rich coal. Figs. 12 and 13 show the impact of seam gas composition on the percentage of Q3 gas content released from crushed coal samples in the initial 30 s (Q3(30 s)/Q3) and the initial 60 s (Q3(60 s)/Q3) of flow measurement. For CH$_4$ rich coal samples, QM ranging from 4.0 to 11.0 m$^3$/t, Q3(30 s)/Q3(total) varied between 64% and 74% whereas for CO$_2$ rich coal samples, QM ranging between 2.0 and 17.0 m$^3$/t, except for one sample, Q3(30 s)/Q3(total) varied between 83% and 95%.

Figs. 14 and 15 provide a comparison of the relevant gas emission data for both CH$_4$ and CO$_2$ rich coal that impact the DRI calculation, which include (a) volume of gas released from crushed coal in the initial 30 s of Q3 gas content testing (Q3(30 s)), and (b) percentage of total gas content recorded as Q3 (Q3/QM). The data shows that, for a given gas content (QM), (a) the volume of gas released in the initial 30 s of Q3 crushing from CH$_4$ rich coal is less than from CO$_2$ rich coal, and (b) the volume of gas measured during Q3 (Q3/QM) tends to be greater in CH$_4$ rich coal, indicating a larger
component of QM is released during the Q1 and Q2 stages of gas content testing from CO2 rich coal.

3. Desorption rate index-DRI

Using the DRI approach to assess outburst proneness was regarded by Williams as being directly related to the desorption rate of the coal [6]. However, this investigation of Bulli Seam Benchmark has shown that DRI is extremely sensitive to small changes in gas testing procedures, in particular (a) the time when the Q2 phase of gas testing is concluded, (b) time to break core and prepare subsamples of core material for use in Q3 testing, and (c) the equipment and energy applied to crush the coal during Q3 testing. Other potential limitations in the use of DRI to assess outburst risk and the use of DRI900 to determine outburst threshold levels has been investigated.

Fig. 16 presents results from gas content testing on coal core samples collected from a CH4 rich non-Bulli Seam Mine, which includes the reported gas content component values, Q1, Q2 and Q3, IDR30 and DRI for core samples ranging in gas content from 3.0 to 14.1 m3/t. The graph shows DRI closely aligns with QM, whereas variability in Q1 and IDR30 does not have any impact on DRI.

Fig. 17 presents a comparative analysis of 21 core samples with gas content QM = 10 m3/t, to show the impact that (a) change in the relative percentage of QM reported as Q1, Q2 and Q3, and (b) volume of gas recorded at Q3(30 s), has on the calculated DRI value for each coal sample. Comparing the results of sample 3 and 21, both samples having QM = 10.0 m3/t and DRI = 1700; the Q3 of sample 3 is 4.0 m3/t (Q3/QM = 40%) and Q3(30) = 510 mL, and the Q3 of sample 21 is 7.0 m3/t (Q3/QM = 70%) and Q3(30) = 893 mL. This example highlights how two coal samples with significantly different gas emission characteristics can produce equal DRI values.

Fig. 18 compares reported gas test results from six Australian coal mines, each sample having QM = 10 m3/t and DRI = 1200. The results highlight the variability that can occur in the reported gas content component values, IDR30 and Q3(30 s), without impacting the DRI value.

Lama and Bodziony discuss a number of outburst prediction indices that have been used in different countries [4]. Whilst the method used to determine each index varies with respect to (a) sample particle size or sample mass, (b) measured volume or pressure of desorbed gas, or (c) duration of measurement period, all methods test fresh coal and focus on initial desorption rate. In
the current Australian Standard for gas content testing, AS3980:2016, the only measure of initial gas desorption rate is the IDR30, which is a measure of the volume of gas released from a coal sample in the initial 30 min immediately following sample collection, measured in m$^3$/t [5]. The relationship between DRI and IDR30 relative to gas content (QM) for both CH$_4$ and CO$_2$ rich coal samples has been considered. Gas data from testing CO$_2$ rich coal sourced from reference mines M1 and M15 is presented in Fig. 19, and gas data from testing CH$_4$ rich coal from reference mines M8 and M12 is presented in Fig. 20. The gas data from the mines presented in Figs. 19 and 20 shows that while the average relationship between DRI and QM is linear, there is a non-linear and notable increase in IDR30 from samples with higher QM.

4. Other factors than impact outburst threshold limits

Many theories have been presented regarding the type and significance of factors that contribute to the occurrence of coal and gas outbursts [7]. Lama listed the following five factors considered to have the potential to contribute to an outburst: tensile strength of coal; gas emission rate; gas pressure gradient; moisture level; and depth or stress level [8].

Lama also reported that the presence of seam gas was considered the major contributing factor to outburst occurrence in the Bulli Seam [8]. Gas content has therefore been used as the primary indicator of outburst risk in all Australian underground coal mines and, where gas content is found to be at levels above the threshold limit, gas drainage is used to reduce gas content to a safe level prior to mining [9]. There are however many other factors that are relevant, and should be considered, in an assessment of outburst risk [4,7,10]. The factors considered to have the most significant impact on outburst risk presented in the outburst risk matrix shown in Fig. 21.

Black and Aziz reported several Bulli seam mines that had introduced increased outburst threshold levels and discussed concerns that the Bulli Seam Benchmark and use of DRI900 as the basis for determining outburst threshold limits may not be appropriate [11]. Recent investigations into Australian outburst history and mining experience in areas where gas content was above the 1994 Bulli seam outburst threshold limits have provided no evidence that outburst had occurred at gas content levels below approximately 9.5 m$^3$/t, independent of gas composition. Most outburst events are associated with abnormal geological conditions. Walsh reported that of the approximately 250 outbursts that had been recorded at West Cliff Colliery at that time, 70% occurred on strike-slip faults, 4% on dykes and faults, 1% on thrusts, 3% on normal faults; and 19% on bedding slips [12].

Fig. 22 provides a summary of core sample gas test results from areas where gas content was above the ‘normal mining’ outburst threshold limit, that were mined using non-standard mining methods. Subject to the mine and their respective outburst risk management process, non-standard mining methods may include fully remote mining, grunching (shotfiring) and mining at reduced advance rate (limited rate mining). Tahmoor Colliery has utilised limited rate mining for more than 15 years without an outburst, through both structured and non-structured coal, with gas content up to 12.0 m$^3$/t (CH$_4$) and 10.0 m$^3$/t (CO$_2$) [13].

The experience at Tahmoor Colliery demonstrates the ability to successfully manage outburst risk, to enable mining to be carried out, without outburst, in areas where gas content is greater than the 1994 threshold limit for ‘normal mining’.

Further work is required to determine safe threshold limits, considering the key factors that impact outburst risk. Research is continuing, in conjunction with the University of Wollongong, to develop an outburst risk index that considers other factors in addition to gas content/pressure, such as coal toughness, that may be used to assess outburst risk in Australian underground mines.
5. Conclusions

Investigations into the characteristics of the Bulli Seam Benchmark, using gas data collected from areas recently mined in the Bulli Seam, has identified changes in the average QM-DRI relationship compared to data presented in 1995. Further investigation of the method used to calculate DRI has highlighted that (a) the performance of the crushing equipment, and (b) the crushing and gas emission measurement procedure used to determine Q3, have a significant impact on the DRI value, which also affects the Bulli Seam Benchmark.

Investigations into DRI and the factors that affect the QM-DRI relationship demonstrated that the average QM-DRI relationship for each coal seam varies in accordance with the relative percentage of total gas emission recorded during Q3 testing that is released in the initial 30 s of crushing, i.e., \( Q_3(30 \text{ s})/Q_3(\text{total}) \). Moreover, the use of DRI incorrectly assumes that the rate of gas release from a combined mass of 150 or 200 g of mechanically crushed coal, during Q3 residual gas content testing, is a measure of gas desorption rate. DRI is the only measure used to assess outburst risk and define outburst thresholds limits that is based on measurement of the gas emission rate from crushed coal in the later stages of gas content testing.

Gas content is considered to have the most significant impact on outburst risk. Gas drainage to reduce gas content to a safe level plays a significant role in control and reduction of outburst risk in Australian underground coal mines. There are other significant factors that affect outburst risk and mining experience has demonstrated that where outburst risk factors, such as abnormal geological conditions are not present, mining can be conducted without outburst at gas content levels greater than current normal mining threshold limits, and greater than those presently determined using the DRI900 method.

Further work will continue in association with the University of Wollongong to (a) investigate and determine threshold limits appropriate for other outburst risk indicators, such as coal toughness and gas pressure, and (b) develop a multi-factor outburst risk index appropriate for assessing outburst risk in Australian mining conditions.

Acknowledgments

The author acknowledges and thanks ACARP and the Australian underground coal mine operators who have supported this research project. The author also acknowledges and thanks the staff of the South 32 gas lab for the support provided to this project. The author would also like to thank the University of Wollongong for its continued support of gas and outburst related research.

References


