GAS EMISSION AND OUTBURST ASSESSMENT IN MIXED CO_2 AND CH_4 ENVIRONMENTS

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ABSTRACT

This paper is primarily concerned with the emission characteristics of CH_4 and CO_2. The scope covers:

- Slow gas emission from gas drainage boreholes.
- Rapid gas emission associated with instantaneous outbursts of coal and gas.
- The effect of statutory differences in maximum allowable concentrations.

An aim of the paper is to present a new approach for setting gas content threshold values for outburst proneness assessment.

On the basis of GeoGAS laboratory testing, CO_2 exhibits up to an 85% higher desorption rate compared to equivalent gas content, CH_4 coals. This occurs by analogy, in circumstances where the confining pressure is suddenly released - cutting coal at the face, desorption from bore cores and during an outburst.

The gas desorption rate linearly changes for intermediate gas compositions.

Where the confining pressure is slowly released, the higher desorption pressure for CH_4 results in preferential release of CH_4 ahead of CO_2. Such circumstances occur during slow drainage from in-situ conditions such as in-seam predrainage and rib emission.

In defining gas content threshold limits for outburst assessment, it is suggested that gas content thresholds be tied to a constant gas desorption rate. The gas desorption rate as routinely measured by GeoGAS's "Quick Crush" method of gas content determination, provides a simple and readily quantifiable approach to the setting of gas content thresholds. Gas desorption rate is believed to be an integral part of the process of outburst initiation.

Consideration should be given to using the desorption rate of coal from selected South Coast collieries as the bench mark for comparison with other coals.

In conjunction with this, the broad range of permeabilities applying to an area need to be quantified and compared to the "bench mark" area. This is to identify the potential for high gas content gradients to develop ahead of the mining face.

INTRODUCTION

CO_2 forms a significant proportion of the seam gas over wide areas of the Sydney and Bowen Basins. Districts with areas containing high proportions of CO_2 are the northern Bowen Basin at Collinsville, the western Bowen Basin near Emerald, the upper Hunter Valley near Muswellbrook, the lower Hunter Valley near Cessnock, and the Southern Coalfield near Wollongong.

CH_4 and CO_2 are physically and chemically very different. Their affect on mining reflects these differences in terms of statutory maximum allowable concentrations, imposed gas content threshold limits as used in South Coast mines in outburst management plans, and in the nature of the gas emission.

The basic physical, chemical and physiological properties of CO_2 and CH_4 are well documented. The reader is referred to publications such as Strang and Mackenzie-Wood (1990) for a listing of these properties.

This paper is primarily concerned with the emission characteristics of the two gases. The scope covers:

- Slow gas emission from gas drainage boreholes
- Rapid gas emission associated with instantaneous outbursts of coal and gas.
- The effect of statutory differences in maximum allowable concentrations.

An aim of the paper is to present a new approach for setting gas content threshold values for outburst proneness assessment.

Unless otherwise stated, gas content values refer to total desorbable gas content (Q1+Q2+Q3) calculated to 20°C and 101.3 kPa absolute.

ACKNOWLEDGMENTS

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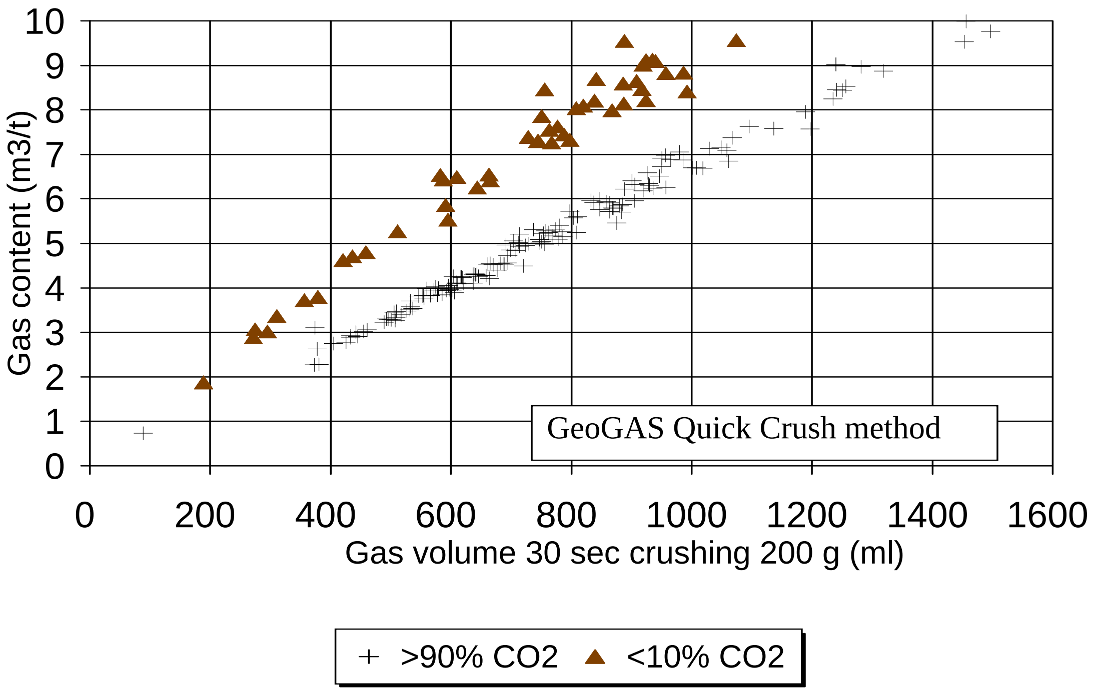
MIXED CO_2/CH_4 EMISSION - SOME BASIC ASPECTS

Movement of gas through coal is widely believed to occur under two processes, starting with diffusion in which gas is desorbed from the coal matrix into the fracture network (Fick’s diffusion law), and then movement within the fracture network according to pressure difference as described by Darcy’s law. The essential difference between the two processes is that with the diffusion, there is a time delay between when the pressure is reduced and when the resulting reduction in gas content reaches equilibrium with the ambient pressure conditions. This delay is quite sensitive to the gas composition, with CH_4 being slower to reach equilibrium than CO_2.

While this delay is well known during bore core desorption for Q2 gas content determinations, its effect is most accurately quantified during crushing of coal to measure the remaining gas. In GeoGAS's "Quick Crush" gas content test, measurement of the desorption rate during crushing is an integral part of the method. A comparison of >90% CO_2 coal with >90% CH_4 coal at West Cliff Colliery shows that CO_2 desorbs from finely crushed (around 212 microns to < 45 microns) coal from 35% to 85% more quickly than CH_4 for the same gas content (figure 1). Alternatively, for the same gas desorption rate, the gas content for the >90% CH_4 coal can vary from 35% to 85% more than for the >90% CO_2 coal. eg a 9.5 m3/t CH_4 coal has an equivalent gas desorption rate to a 6.8 m3/t CO_2 coal.

Fig.1 Gas Content and Desorption Rate During Crushing



While CO_2 desorbs more quickly than CH_4 from laboratory samples, in the field, another process related to the differences in the gas desorption pressures of CO_2 and CH_4 dominates. The gas desorption pressures are indicated by the Langmuir gas sorption isotherms (figure 2). CO_2 has a much lower desorption pressure than CH_4. Consequently, even though it desorbs more rapidly than CH_4, it requires a lower pressure to initiate desorption. The result is that for mixtures of CO_2 and CH_4, the CH_4 can begin to desorb at higher pressures than CO_2, causing the composition of the drained gas to be significantly richer in CH_4 than would be expected from the gas content composition.

This effect is readily seen in the field (Williams 1991) and closely duplicated using the SIMED II gas reservoir simulator. In SIMED II, the inputs are the initial free gas composition and the corresponding gas desorption pressure. An iterative calculation is used to define the virgin gas content and gas composition that, in accordance with the isotherms, produces the initial gas composition and desorption pressure. This results in CH_4 emissions being higher than CO_2 emissions at least in the early stages of gas emission, with gas compositions being up to 20% richer in CH_4 than expected from the results of gas content tests (figure 3).

Fig.2 Example Gas Sorption Isotherms

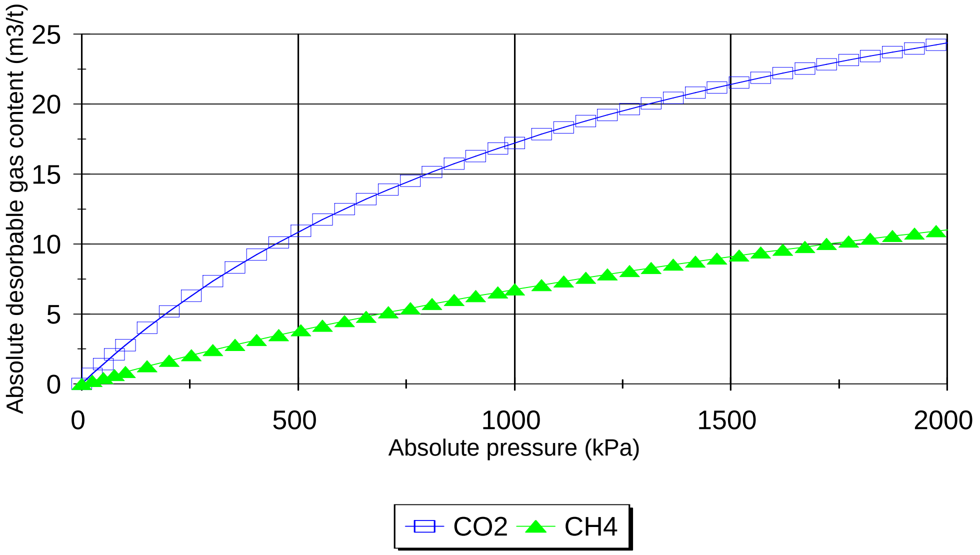
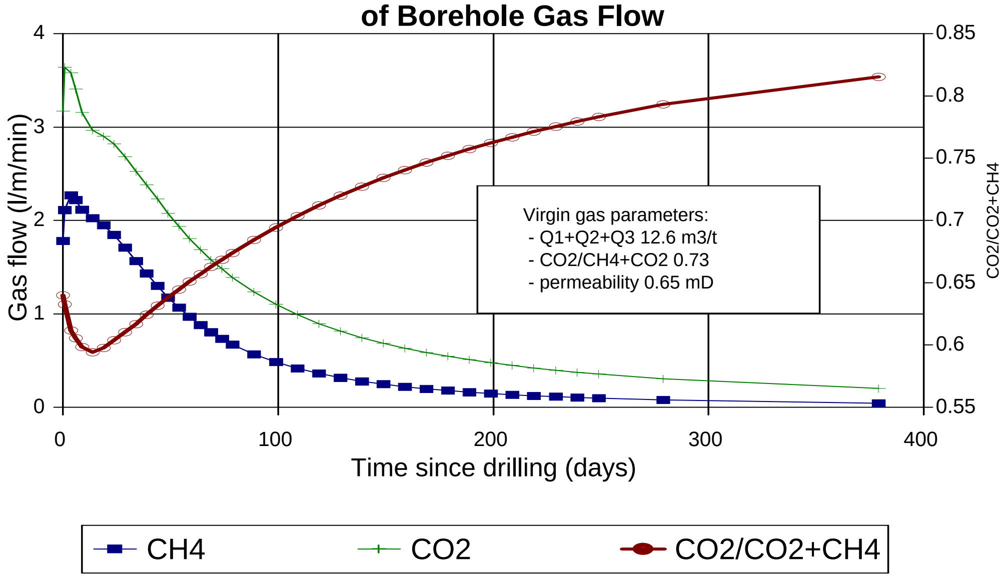


Fig.3 Example SIMED II Simulation of Borehole Gas Flow



The complex set of factors that together define the rate of gas emission can be reduced to the following independent parameters:

- The rate of coal desorption (affected by pressure difference, gas content magnitude, gas composition and physical coal characteristics).

- The “gross” permeability (affected by insitu stresses and fracture development).
- The gas reservoir size.

MAXIMUM ALLOWABLE CONCENTRATIONS

Because of the pressures to reduce development time, a minimum number of roadways are driven. This means that mines operate closer to the line dividing a purely ventilation solution from a ventilation/gas drainage solution. There is a diminishing return on the improvement in gas concentration for the amount of air supplied, with the added negative of increased ventilation air pressures and reduced ventilation efficiency. It then becomes a choice between gas drainage/gas capture or driving additional roadways. The boundaries depend upon a variety of factors, but differences in the maximum allowable concentrations of CO_2 and CH_4 have a significant effect.

In NSW, the maximum allowable concentration of CO_2 any where in the ventilated areas is 1.25%. For CH_4, the maximum allowable concentration is 0.25% for intake roadways to the start of the “hazardous zone”, 1.25% in the face area and 2% in the return roadways (remote from non intrinsically safe, power sources).

Because of these limits, gas problems present themselves differently. CH_4 is often a problem in the intake, especially with longwall blocks in excess of 2000 m. It takes a relatively low level of gas emission to exceed 0.25% CH_4. CO_2 is only likely to be an intake problem under quite abnormal conditions such as contamination from outbye in-seam boreholes with inadequate or faulty gas handling systems.

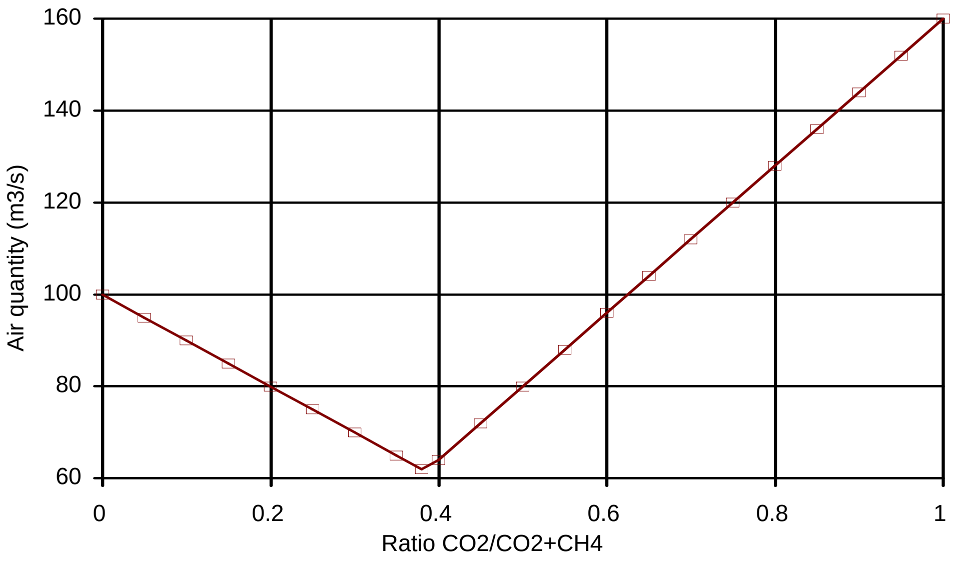
Inadequate or no gas drainage can cause development mining gas emissions for either CO_2 or CH_4 to rise above 1.25% in the face area. This is exacerbated by full face continuous miners such as the ABM20, that monitor the gas concentration in the discharge shute behind the cutting heads. The faster rate of desorption of CO_2 causes CO_2 to more easily exceed the 1.25% limit.

On the longwall face, gas concentrations can similarly rise to in excess of 1.25% at the tail gate end. This particularly applies to U ventilation and even Z ventilation, where caving on the tailgate end creates too great a restriction for air to be pulled back along the goaf edge.

Experiencing trip outs in the face area often leads to a gas drainage solution. Having implemented gas drainage, gas control for both CO_2 and CH_4 is normally easily achieved. Sudden gas in-rushes are a separate phenomenon.

It is in the return roadways where CO_2 becomes much more difficult to control, where the CO_2 is still limited to 1.25% but the CH_4 limit has increased to 2.00%. As indicated by Nicholls (1989) an advantage of having a mixed CO_2/CH_4 gas concentration is the ability to dilute more gas with the same quantity or air. The optimum gas mixture is 38% CO_2 and 62% CH_4. In the example shown in figure 4, just over 60 m3/s of air are needed to dilute 2000 l/s of this gas mixture. With increasing quantities of CO_2, the required air quantity rapidly increases at a rate of around 15 m3/s of air for every 10% increase in the proportion of CO_2. For example, at a mixture of 40% CO_2 and 60% CH_4, the air required is 64 m3/s. At a mixture of 50% CO_2 and 50% CH_4, the air required is 80 m3/s.

Fig.4 Air Required to Dilute 2000 l/s Total Gas of CO2 and CH4



The advantage of having a mixed gas ceases at 63% CO_2 and 27% CH_4, where the air quantity is the same as that required to dilute 100% CH_4 (figure 4). CO_2 proportions in excess of 63% attract an increasing penalty, such that with 100% CO_2, the quantity of air required for dilution is 160 m3/s, a full 60 m3/s more than that required to dilute the same quantity of CH_4 (figure 4).

Because control of gas emission during development (excluding sudden gas in-rushes) is readily achievable, it is not covered further in this paper. Difficulties persist in terms of acceptable rates of productivity for a given standard of safety, in control of CO_2 during longwall mining and control of rapid gas emissions and outbursts. For coverage of mixed gas emission during longwall mining, the reader is referred to Williams (1991).

INSTANTANEOUS OUTBURSTS OF COAL AND GAS

Mechanism

While a wide array of factors can be listed as contributors to outbursting, in Australia, these can be reduced to two basic factors:

- **Rapid gas desorption rate** (particle size, gas content, gas composition, gas pressure)
- **Low permeability** (stress conditions, coal strength/modulus, gas pressure gradient, fluid saturation)

The consequences of an outburst are additionally determined by the **size of the gas reservoir**.

The author believes the most important parameter is gas desorption rate, in conjunction with the gas content gradient ahead of the face. The process is described with the aid of figure 5, which shows what should be a generally accepted sequence of events leading up to the point of outburst initiation.

Normal mining conditions are characterised by a relatively low gas content gradient ahead of the face (figure 5a). The steepness of the gradient will increase according to the permeability and the speed of face advance. The distance from the face to the virgin gas content region would be in the vicinity of 10 m to 20 m for an actively advancing face. While mining is proceeding, gas is continuously being bleed from the coal in the face area.

In outburst prone conditions, the coal hardens in response to increased stresses, and the permeability rapidly declines as the stress increases. High stressed, low permeability zones are often associated with the load concentration that occurs as the coal “barrier” between the face and the outburst structure is progressively diminished (figure 5b). A characteristic of this tightening is a reduction in gas emission, and the coal being harder than normal to cut. Such an effect has been widely associated with outburst occurrences in Australia. The gas content gradient is very steep, with near virgin gas pressures occurring within metres of the face.

With continued mining, this highly stressed “pillar” reaches the point of rapid or sudden failure (figure 5c). At this time, the stress on the coal is suddenly reduced and the ambient pressure on the coal changes from being mostly above the desorption pressure to suddenly being well below the desorption pressure for the gas content of the coal.

It is useful to make the distinction between the process of slow gas emission during gas drainage and the sudden gas emission during an outburst. In the former there is time for a near state of equilibrium to be achieved between gas pressure and gas content (eg according to the sorption isotherms in figure 2). In the latter, the pressure is reduced so quickly, that no such equilibrium can be achieved. *(Remember there is a considerable time delay between when the gas pressure is reduced and when the gas content decreases to be in equilibrium with that gas pressure).* None-the-less, gas pressure is generated (not necessarily very high) in the newly created fractures according to the rate at which the gas can desorb. Because for similar gas contents, CH_4 desorbs its gas more slowly than CO_2, it is CO_2 that is more prone to outbursting.

The actual gas content of the coal is in itself inconsequential. It is only when the gas leaves the coal that it comes into play. The important factor is how quickly this is achieved**.** The desorbing gas exerts a pressure that promotes outward projection of the coal. With small particle sizes, the desorption rate can be increased to the point where the coal becomes entrained in the desorbing gas.

Central to the argument is the notion that:

- The gas pressure in the fracture network is a combination of how fast the gas desorbs and how fast the gas can escape along the fractures - ie the permeability of the fracture network.

- Until the gas desorbs, there is no gas pressure generated in the fracture network.

Gas Content Threshold Values

Gas content threshold values used on the South Coast, reflect the greater outburst proneness of CO_2 by according CO_2 a lower gas content level for safe mining (typically 6 m3/t for 100% CO_2 and 9 m3/t for 100% CH_4). These values have been determined on largely empirical grounds from starting points of 9 m3/t being the CH_4 threshold limit in (West) German mines, to 5 m3/t (Q1+Q2) being an empirically defined limit for CO_2 at Collinsville.

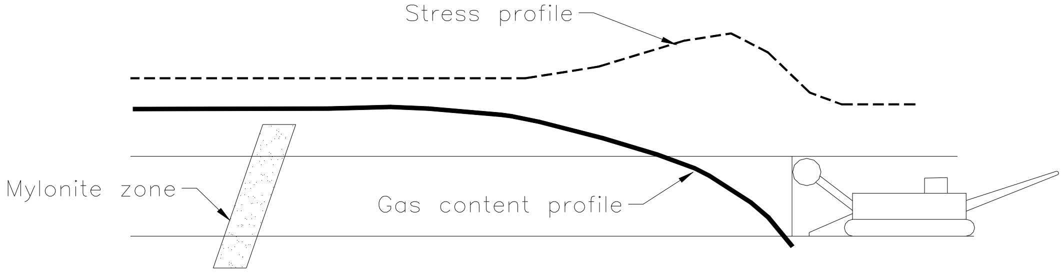
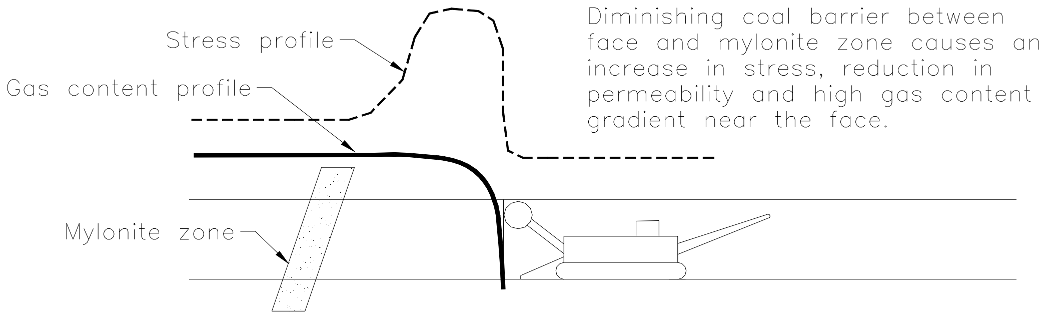


Fig.5a Normal Stress Distribution and Gas Content Gradient



Diminishing coal barrier between face and mylonite zone causes an increase in stress, reduction in permeability and high gas content gradient near the face.

Fig.5b Peak Stress Concentration and Gas Content Gradient

Sudden/rapid collapse of the coal barrier causes destressing of this coal and a reduction of ambient pressure conditions from above the desorption pressure limit to suddenly below it. Gas pressure in the fractured coal is dependent totally upon desorption rate.

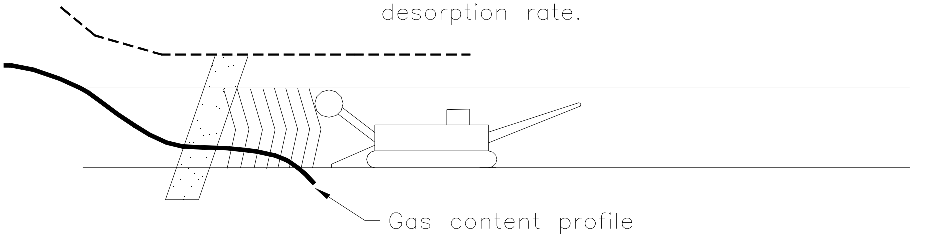
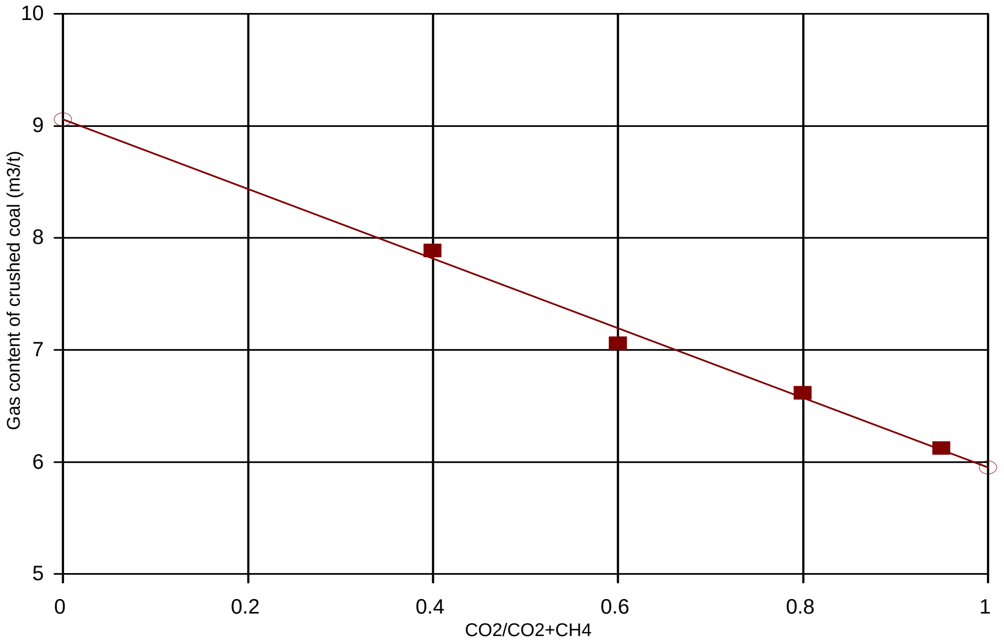


Fig.5c Conditions at the Time of Outburst Initiation

The limits of 9 m3/t for CH_4 and 6 m3/t for CO_2 (with some variations between mines) have to date proved to be reasonable, with no surprises occurring, to the authors knowledge, in coal that has been drained to the required level.

On the basis that gas desorption rate is the critical differentiating parameter, the relative gas content thresholds for 100% CO_2 and 100% CH_4 do reflect the similar gas desorption rates at these values. Linear regressions of the data contained in figure 1, show that for CH_4 of 9 m3/t, the corresponding gas content for CO_2 for an equivalent desorption rate is 6.4 m3/t. These relativities in desorption rate are similar for both borecore (initial desorption for Q1) and coal during crushing (GeoGAS Quick Crush method). The latter provides a much clearer distinction and is used in figure 1.

Fig.6 Effect of Gas Composition on Gas Content for Constant Desorption Rate



How does the gas desorption rate vary for intermediate gas compositions? Using Metropolitan Colliery data, regressions were calculated from plots similar to figure 1, but for gas composition ranges 35%-45% CO_2, 55%-65% CO_2, 75%-85% CO_2 and >90% CO_2. (There are few samples with <35% CO_2 at Metropolitan Colliery). The gas content for each range of gas composition was defined for a constant desorption rate tied to that producing a gas content of 6 m3/t for 100% CO_2 (943 ml in 30 secs from 200 g sample - GeoGAS Quick Crush method). A linear trend for intermediate gas compositions is indicated (figure 6), with the extrapolation to 100% CH_4 being close to 9 m3/t. These results are consistent with the threshold limits used by Metropolitan Colliery.

Work on other coals has shown that for similar gas contents and gas compositions, the desorption rates on crushing the coal can be different to the West Cliff Colliery, Metropolitan Colliery coals. This is due to the different structural make up of the coals.

It is suggested that as a guide to the setting of gas content threshold limits for coals from new areas, desorption rate be used as the fundamental parameter, and that the bench mark desorption rate be coal from selected South Coast Collieries with an established history of outburst management. Consideration needs to be given to setting threshold values based upon the difference in the measured desorption rates of the coal in question, to the desorption rates of these “bench mark” coals. Such comparisons would need to be accompanied by sieve analyses of the crushed coal.

Permeability

In assessing the outburst proneness for different areas, consideration also needs to be given to the likely range of insitu coal permeability. While this is a more difficult parameter to quantify, it is suggested that significance be attached to only large differences in permeability. For example, on the South Coast, the permeability ranges from say 0.01 to 5 mD. It is pointless trying to differentiate a mine yielding a permeability measurement of 4 mD compared to one with a measurement of 0.5 mD. Permeability can change over this range very quickly, especially in response to stress concentrations associated with outbursting.

On the other hand, it is probably being unnecessarily too cautious to assign a South Coast style gas content threshold limit to a colliery whose permeability regime is no where near that of the South Coast. For example, for the relatively shallow underground mines in the Hunter Valley and Bowen Basin, let us assume that they exhibit high gas desorption rates. At depths from 100 m to 200 m, permeabilities may range from say 20 mD to 100 mD. In this range, high gas content gradients are unlikely to develop even when mining up to geological structures that would otherwise be outburst prone.

There are four possible categories as follows:

1. Low permeability/high gas desorption rate - Outburst prone, (South Coast, areas of the Bowen Basin >250 m depth)

2. High permeability/high gas desorption rate - Non outburst prone

3. Low permeability/low gas desorption rate - Non outburst prone

4. High permeability/low gas desorption rate - Non outburst prone

Points 3 and 4 are of no consequence from an outburst view point. The main requirement is to identify the transition from 2 (high permeability) to 1 (low permeability) for high gas desorption rates. This gradation is most likely to occur in the Bowen Basin, where with increasing depth, permeability decreases and gas desorption rate increases.

It is suggested that the quickest way of assessing these broad permeability trends is curve matching of borehole flow, rib emission, gas content profile or gas pressure profile data using a gas reservoir simulator such as SIMED II. Real time gas emission monitoring should be considered as a means of establishing the pattern of normal gas emission and identify (permeability) changes toward abnormal emission (Williams and Slater, 1995).

A formal system for tying together gas desorption rates and permeability with geology and mining practices is part of a mines outburst management plan. Such treatment is outside the scope of this paper.

Gas Reservoir Size

The discussion so far has centred upon initiation of an outburst. Consideration also needs to be given to the consequences of an outburst. Gas desorption rate is again important, but the extent to which the rate is sustained will be influenced by the size of the gas reservoir - primarily the thickness of the coal seam. With thicker seams, the quantity of mylonite would normally be greater, producing larger outbursts - all other parameters being equal.

Assessment of gas reservoir size is straight forward in seams of consistent quality, but is considerably more difficult in thick, highly banded seams such as the Wongawilli seam. A method for such an evaluation is given in Williams and Maddocks (1993).

CONCLUSIONS

On the basis of GeoGAS laboratory testing, CO_2 exhibits up to an 85% higher desorption rate compared to equivalent gas content, CH_4 coals. This occurs by analogy, in circumstances where the confining pressure is suddenly released - cutting coal at the face, desorption from bore cores and during an outburst.

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Where the confining pressure is slowly released, the higher desorption pressure for CH_4 results in preferential release of CH_4 ahead of CO_2. Such circumstances occur during slow drainage from in-situ conditions such as in-seam predrainage and rib emission.

In defining gas content threshold limits for outburst assessment, it is suggested that gas content thresholds be tied to a constant gas desorption rate. The gas desorption rate as routinely measured by GeoGAS's “Quick Crush” method of gas content determination, provides a simple and readily quantifiable approach to the setting of gas content thresholds. Gas desorption rate is believed to be an integral part of the process of outburst initiation.

Consideration should be given to using the desorption rate of coal from selected South Coast collieries as the bench mark for comparison with other coals.

In conjunction with this, the broad range of permeabilities applying to an area need to be quantified and compared to the “bench mark” area. This is to identify the potential for high gas content gradients to develop ahead of the mining face. While higher gas content thresholds may not be applicable in areas of high permeability, it is likely that gas drainage for gas emission control would need to be practiced anyway, with gas content targets probably no higher than those applying to the thresholds for outburst control. This particularly applies to the newer, relatively shallow underground mines of the Hunter Valley and Bowen Basin.

It may be argued that his approach is too simple. The authors believe that one of the main potential weaknesses is not in the setting of threshold values per se, but in the systems mines employ, to know to a very high level of certainty that such a state of gas drainage has been achieved (Williams, 1994).

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