

Outbursts in Underground Coal Mines

A Coherent Approach for Improved Management 2013

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Abstract

This paper is written to indicate how a coherent quantitative strategy towards outbursts can be achieved, taking into account all of the factors that contribute to an outburst. While the paper is written for an Australian coal mining audience it draws on worldwide experience. It is written to lead to a better way by which mines may determine the risk of outbursts and how to deal with them. The need for a better approach is brought about by the simplistic and indeed incorrect nature of what is being used in Australia at present. This generally, but not invariably, leads to overly conservative gas drainage practice.

Definition of an Outburst

Outbursts are violent expulsions of gas and coal from the working face. They are energy release phenomena that can have catastrophic consequences. They may cause injury or kill by mechanical force or through asphyxiation. Uncontrolled gas release may reverse ventilation and in the event of there being an ignition source, lead to an explosion.

Most outbursts that are severe occur on geological structures in the coal seam that contain gouge (ground up) material. Some however occur from solid coal which fragments during the outburst. Examples of two kinds of outburst can be seen below.

Figure 1 shows a sketch of an outburst that occurred at Westcliff Colliery, NSW which moved the continuous miner backwards. The energy source of this outburst was a sheared zone of coal behind the face.

Figure 2 shows a sketch of a typical outburst that occurred from solid coal at Leichhardt Colliery, Queensland. Here the outbursts always occurred across the cleat, often preceded by an onion ring appearance in the face before buckling occurred outwards leaving a cone in the ribside. The size of these outbursts varied from 1 to 350 tonnes.

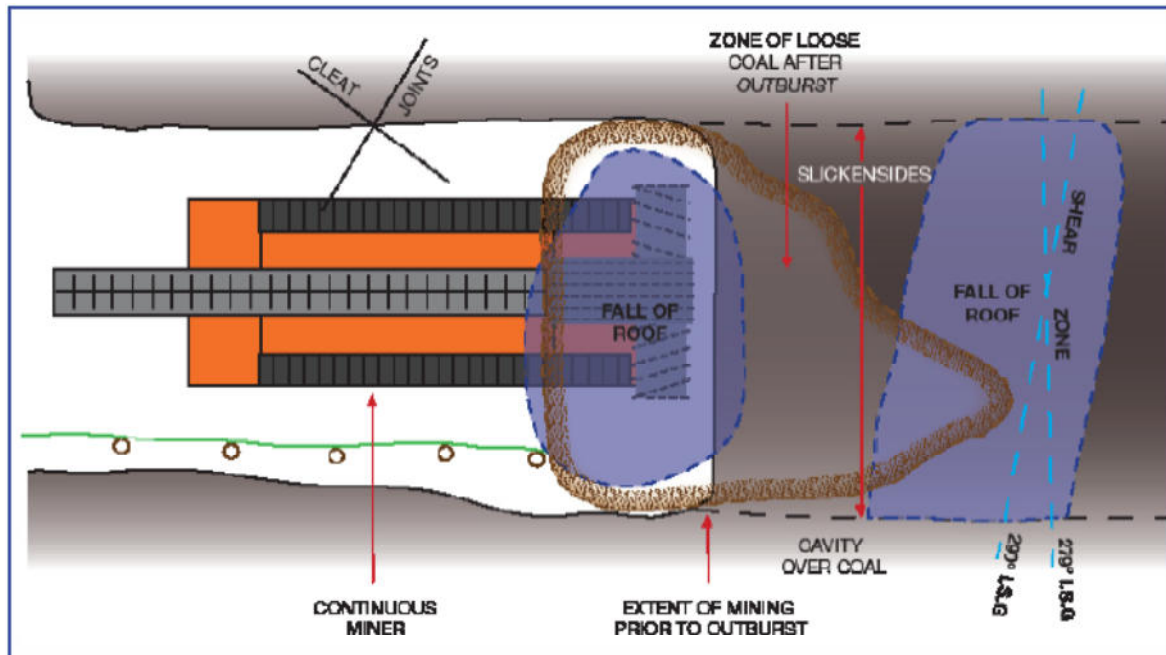


Figure 1. A plan of an outburst that occurred at Westcliff Colliery (Adapted from Marshall et al, 1980).

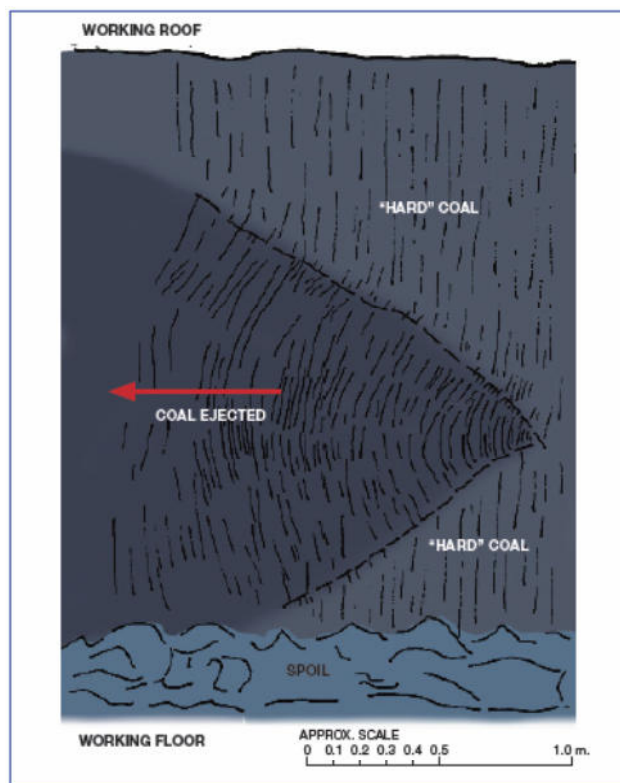


Figure 2. An typical view of the ribside after mining through small outburst cone at Leichhardt Colliery (Adapted from Moore and Hanes, 1980).

For an outburst to occur, failure of the coal must first take place. Failure is commonplace in mining and is due to the effective stress exceeding the material (in this case coal) strength. In an outburst the failure is accompanied with the release of energy and gas. The key to

understanding outbursts is determining the likely sources of energy release while the key to controlling them is in minimising the potential for energy release.

Care should be taken to not describe a slump from a face or ribside which is accompanied by gas release as being an outburst. The energy release in a slump is primarily derived from gravity, though the failure itself may be assisted by the effects of gas on the effective stresses.

Current and Past Approaches to Assessing Outburst Propensity

Because of the apparently complex nature of outbursting and the presence of gas, there has been a tendency to focus efforts on the gas properties of the coal in determining whether an outburst will occur. This work all began with index tests which focused on measuring the following:

- Gas released from cuttings in a certain period after drilling
- The adsorption or desorption speed of a cuttings size range in the laboratory
- The pressure rise rate in a packed off hole directly after drilling
- The flow rate from a hole packed off after drilling
- The measurement of the volume of cuttings produced from a hole drilled at known dimensions (diameter x length).

Some of these index tests are discussed in much more detail by Lama & Bodziony (ACARP project C 4034, chapter 9, 1994) and they are summarised in Appendix 1.

In the Australian context, the focus switched entirely to examining the gas content as determined by core desorption with a later addition called the DRI 900 test of GeoGAS which will be discussed further in this paper.

The problem with virtually all index tests is that they focus on a snapshot of behaviour rather than the bigger picture. They are also dependent on more than one fundamental parameter. Take for example one of the tests of field desorption whether it be the Polish Desorbometer, the Hargraves Emission Value Meter or the current device used by the Chinese. All of these take a volume of a sieved size interval of cuttings which are placed in a chamber that is then sealed and the volume of gas produced from those cuttings is measured either against a small manometric head, or against the negligible back pressure of a soap bubble in a tube or by a small pressure rise in a chamber which is sealed. In each case what is measured is some parameter that includes the:

- gas content of the sample, which is the gas content of the coal minus the gas loss in getting the sample to the device
- the diffusion coefficient of the coal
- the size of the coal (somewhat variable despite sieving to say 1.5 to 3 mm as per the Chinese)
- the actual mass of coal packed into the sample chamber

This derived index may be described by

Index of desorption= function (gas content (concentration) x the diffusion coefficient)

It is also dependent on the timing of the measurement from drilling time as well as the length of the sampling interval.



Figure 3. Polish Desorbometer to measure gas release from sieved sample (between sizes) of known volume versus a manometer.



Figure 4. Chinese Desorbometer with sieve, internal container to hold cuttings and external part to provide dead volume and electronics to measure change in pressure within the container over a period.

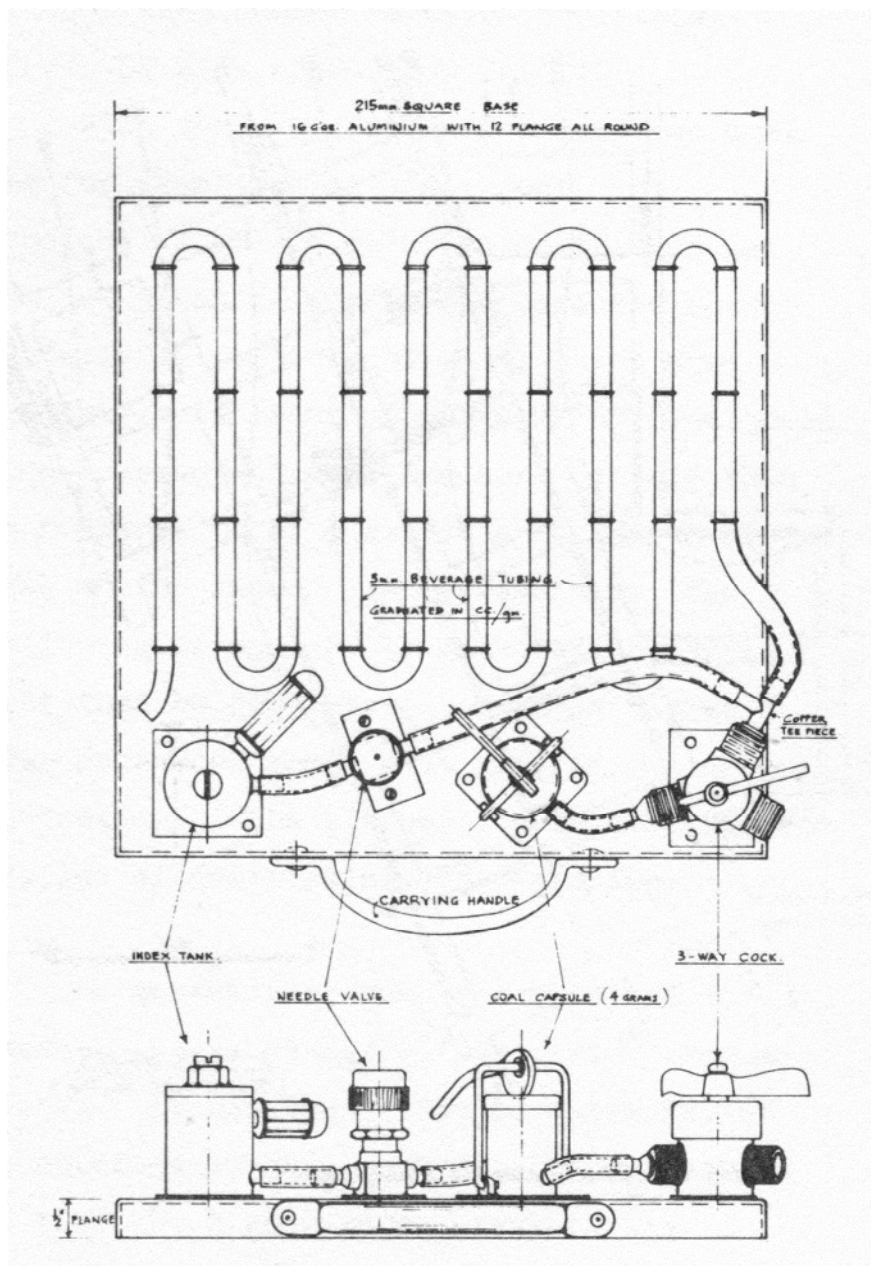


Figure 5. Hargraves' emission value meter with chamber to hold cuttings and system to inject soap bubble into tubing as a marker prior to directing gas from the desorbing cuttings behind the tubing.

The in hole methods have their own limitations too. The process of drilling a hole and then packing it off to measure flow from the interval of borehole provides a measurement which is:

- In the case of an impermeable coal a function of the gas content and the diffusion coefficient
- In the case of a permeable coal more dependent on the permeability and gas pressure and the state of water saturation in the coal cleating.

Where the hole is drilled and packed off to get a pressure measurement the pressure build up is dependent on:

- The time the hole is open
- The volume of the hole
- The permeability of the coal both surrounding and far from the hole
- The fluids in the coal seam (gas and water)
- Any leakage that occurs around the seal

This is not therefore a simple procedure but one which requires experience to both conduct and to interpret.

The measurement of cuttings volume following drilling a section of known length and diameter is in fact a very sensible process as it simulates the creation of a mine roadway in the coal with all the in situ conditions except that the size of the hole is much smaller than the roadway. Therefore pre-existing fractures will not interact with it in the same way.

If, as is usually the case in Europe, Eurasia and China, the hole is air flushed it bears an even greater resemblance to a mined roadway than if it were water flushed. It is a well-known phenomenon that the volume of coal produced in an outburst appears significantly greater than the volume of the cavity whence it came due to bulking as was the case at Cynheidre Colliery in Wales (Davies, 1980) and in the mines of the Karaganda Coalfields in Kazakhstan (the Author, 2008). Therefore, if the volume of cuttings is compared with the volume of hole drilled on a stage by stage basis then this becomes a direct indicator of outburst conditions.

The more enlightened mining countries have looked at more than simply the gas related phenomena. The Chinese for example have a system that takes into account:

- Coal structure (by description)
- Diffusion Coefficient (via a laboratory based index test)
- Toughness (via a drop hammer index test)
- The seam gas pressure (a gauge pressure measurement of 0.74 MPa is considered to be an indicator of outburst risk in its own right).

These parameters are used individually or together to arrive at outburst risk. This is better, but not fully, described in Appendix 2.

Current Australian Practice

The current Australian practice in determining the outburst risk is centred around the use of gas content measurement.

The gas content thresholds in use in the Bulli seam in New South Wales were originally specified by the then NSW Department of Mineral Resources and are dependent on the gas type with those areas with a higher fraction of carbon dioxide being seen as having a higher risk of outbursts. This is graphically shown in Figure 6 taken from Black et al (2009).

Outburst management is described in a publication MGD No 1004 'Outburst Mining Guideline' by the then NSW Department of Mineral Resources.

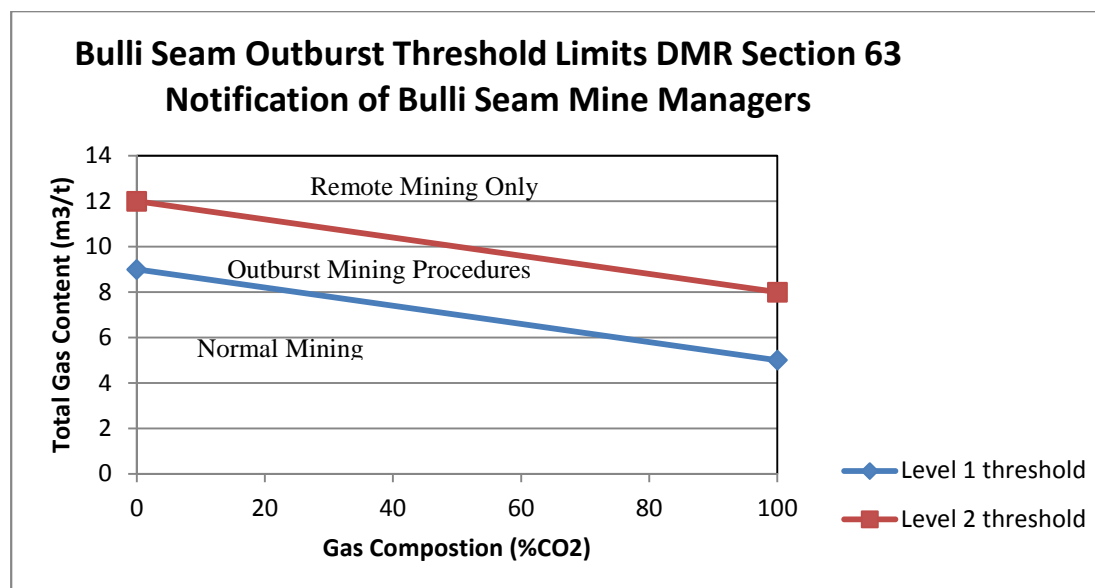


Figure 6. DMR Section 63 notification to Bulli seam Mine Managers as regards mining within the Bulli Seam with respect to gas content and outburst risk.

In the same paper Black et al (2009) show some relaxation to the gas contents shown in Figure 6 for Tahmoor and Westcliff Collieries. In the case of Tahmoor some note is taken of coal structure.

To complicate matters further GeoGAS introduced the Desorption Rate Index as an indication of outburst proneness. This test involves the taking of a core for gas content measurement as per AS3980-1999 quick crush measurement. There is some initial but variable gas loss before the core is placed in the canister. This is followed by additional gas loss while the initial rate of gas desorption is determined. The canister is then sealed and the gas content of the core approaches some state of equilibrium with the partial pressure of the gas in the canister. This is dependent on the amount of coal in the canister, its gas content prior to being placed in the canister, the dead volume of the canister and in addition the temperature of the canister. At the laboratory the canister is drained of gas and the core removed. A 200 g sample is then taken and crushed (in a specific crusher) for 30 seconds and the gas volume that is released is measured. The gas release during this process will depend on the gas content of the coal taken from the canister, the degree to which the core breaks up on crushing and the diffusion coefficient of the coal fragments.

Despite all of these variables GeoGAS has determined that this volume of gas released has a direct relationship with the virgin gas content of the seam and this may then be related to Lama's estimates of gas content that lead to outbursts. Specifically they have proposed that if 900 ml (hence DRI900 threshold term) of gas are desorbed then this corresponds exactly with an initial gas content of 9 m³/t of methane or 6 m³/t of carbon dioxide in Bulli seam coal.

An example plot relating the DRI900 index and gas content is shown in Figure 7.

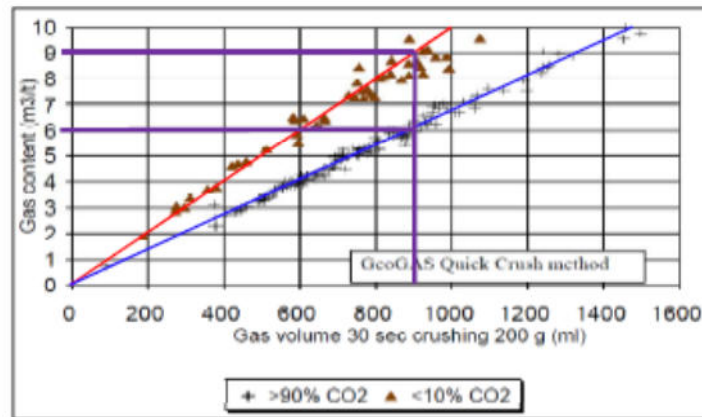


Figure 7. Presentation of GeoGAS desorption rate (DRI900) relative to Lama’s outburst threshold limit values. Taken from Black et al 2009.

The errors contained in the process of arriving at a DRI value are described further below with reference to the isotherms shown in Figure 8. The steps shown are:

1. The initial gas content and pressure
2. The gas content following some loss on coring
3. The gas content following further loss due to Q1 sampling
4. The drop in gas content and pressure as an equilibrium is approached between coal gas content and the canister pressure.
5. The gas content at 1 atmosphere partial pressure of gas

Note the 30 second quick crush of the DRI900 approach obtains some of the gas between points 4 and 5.

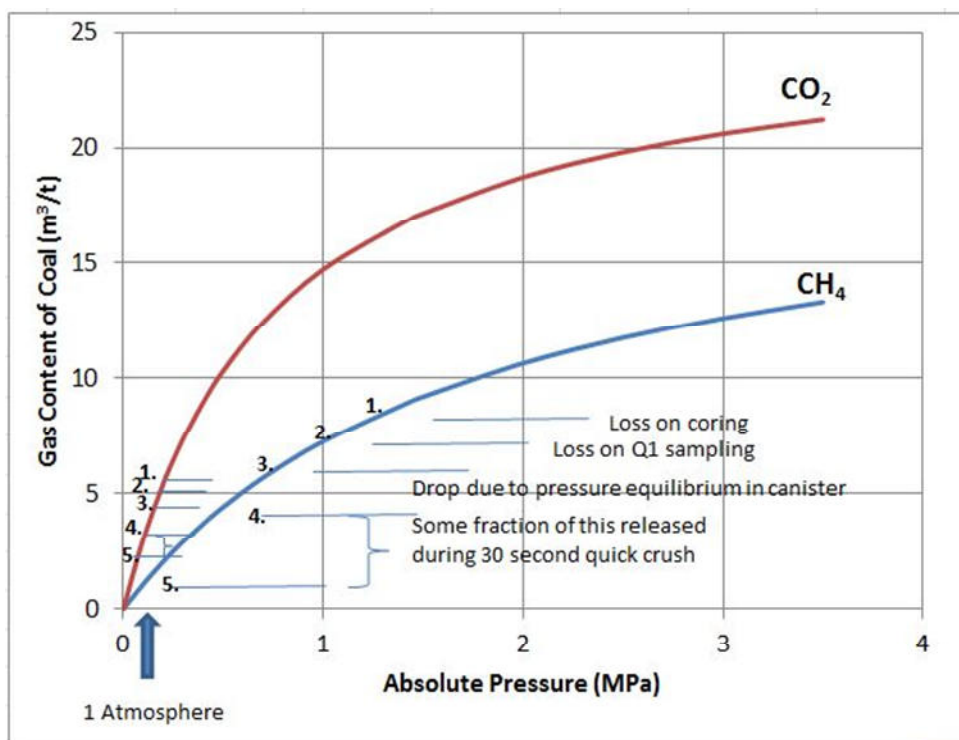


Figure 8. Methane and carbon dioxide isotherms showing the stages of pressure/volume drop through the process of gas content determination.

More worryingly there has been a trend to use the DRI900 value to determine whether non Bulli seam coals are outburst prone. This compounds the problems of measurement error with inconsistencies between coal seams. We are therefore of the opinion that the DRI 900 measurement is an unreliable indicator of outbursting conditions that is founded on pseudo-science fitting a straight line to some group of data without having thought through the measurement process and the errors it contains.

One Measurement Does Not Fit All

The concept of a single measurement being an indicator of whether a coal seam is outburst prone is might be convenient but is not valid. The clearest illustration of this is some of the Chinese semi-anthracite coals which are regularly mined with gas contents of the order of 15 m³/t but do not suffer outbursts. This is achievable because the gas pressure is low as the sorption isotherms for these coals show a very high capacity to hold gas at a low pressure. The seams are also supposed to be subject to detailed scrutiny for adverse structure as part of the outburst assessment.

The attempt by the Australian mining industry to shoehorn all of our outburst risk assessment on to a single gas content measurement is a gross simplification. For it to be successful in weak outburst prone coals it must be set at a very conservative level and one that is not appropriate for tough, more slowly desorbing coals.

It is time for the industry to become somewhat more discerning in how it determines the risk of outburst.

Work By Sigra Since 2006

Sigra has been actively involved in dealing with outbursts since its inception in 1994. Gray (2006) prepared report C14032 for ACARP which covered the mechanism of outbursts and in particular the energy release associated with them. The work on quantitatively describing energy release was particularly important and developed on the work started by Gray in 1980 and 1983. In addition to this work which will be discussed further in this paper Sigra became involved in consulting work to deal with outbursts in Russia, China and Kazakhstan. The exposure to the Chinese approach to dealing with outbursts was particularly interesting as it was far broader than that adopted in other countries. It is described more fully in Appendix 2.

The Kazakh experience was immediate as one of the authors was exposed to an outburst at fairly close quarters. It also led to the development of some measurement techniques from drilled particles that can be considered to be particularly useful. The Russian experience served as a warning to the limitations of shot firing as a safe way of mining through outburst prone conditions. Outbursts can and do occur sometime after a shot and sometimes from the ribside.

In addition to the overseas work and theoretical aspects, Sigra has in Australia, developed some techniques for dealing with gassy coals. These relate to the measurement of gas content and the determination of the diffusion coefficient of coals in a more sophisticated manner than has hitherto been undertaken. It has also developed a Gas Content Without Coring

(GCWC) system which permits the gas content of all strata to be determined as part of a drilling operation in an overbalanced open hole from surface.

The Energy Release Approach

In the work by Gray (2006) for ACARP the total energy available for release was considered to be fundamental in determining the severity of an outburst. The sources of energy for an outburst are considered to be:

Strain Energy from Rock and Coal – This is dependent on the state of stress in the coal and its elastic properties. Very often the state of maximum stress is limited by failure at the face. In the case of outbursts that progressively erode from the face into solid coal, the state of stress varies from that at the face, which is limited by the unconfined coal strength, to that in the virgin condition. Strain energy may also be supplied to an outburst by the inward movement of the surrounding strata.

The Expansion of Gas from Free Void Space – This comes from the adiabatic expansion of gas from the free void space (cleats). It is a virtually linear function of void space and gas pressure. If the coal is water saturated then there is no gas in the cleats to expand.

The Diffusion of Gas from Coal Particles – Gas may diffuse from the coal particles to an intermediate pressure within the failing coal mass in an outburst. This gas may then expand adiabatically to provide energy. The key to the energy release is the gas content which is linked to the gas pressure through the sorption isotherm, the coal particle size distribution and the diffusion coefficient. These factors determine the rate of gas release.

There is also significant energy absorbed during the failure process which reduces the total outburst energy. It is related to the toughness of the coal. Toughness is by definition a measure of energy absorbed in causing failure.

The approach of examining the energy release components is valuable in determining which are the important energy contributions to an outburst or slump. In a slump the principal energy contributor comes from gravity alone.

Table 1 describes the important parameters that contribute to an outburst. The coal solid parameters combined with gas pressure lead to failure. How much energy is released on that failure depends on what strain energy was contained before the outburst took place and how much is used up causing failure. Any excess energy will be converted into kinetic energy that will move the gas and coal.

GAS RELATED PARAMETERS	COAL SOLID RELATED PARAMETERS
Gas stored in void space	Void space
Gas Content linked via isotherm To	
Gas Pressure (scalar) >	{Effective stress (tensor) = stress - gas pressure
Particle Size Produced in Outburst	< {Pre-existing structure (anisotropic)
	{Strength and toughness (anisotropic)
Diffusion Coefficient	

Table 1. The important and fundamental factors in outbursting.

The process of determining the level of risk from an outburst is one of estimating the energy release per unit volume of the outburst and the likely volume of coal that may be involved. The latter may in some circumstances be defined by the extent of gouge material that may be affected.

The energy absorbed by coal failure per unit volume is difficult to measure but indications of the coal toughness may come from grindability testing, drop hammer tests or by gassing up solid stressed coal and suddenly releasing the pressure to determine the level of fracturing that may occur. More work certainly needs to be done to quantify the energy consumed in breaking up coal.

Potential Energy release calculations have been undertaken for the outburst situation that might have existed at Leichhardt Colliery. These are summarised in Table 2. As a reference, the kinetic energy that 1 m³ of coal would have if it fell 1 m (0.014 MJ/m³) is marked at the bottom of the table. It is similar to the potential energy release from gas stored in pore space. These values are however dwarfed by the potential elastic energy stored in the coal and the surrounding rock and by the amount of energy that might be released from desorbing coal. The latter is very dependent on the particle size that is created and the diffusion coefficient of these particles.

The model from which these latter energy values are derived is one of a desorbing sphere that desorbs gas into a pressurised void space between particles and which then expands adiabatically. This model is shown in Figure 9. The importance of the diffusion coefficient and the size of fragments of coal which form is obvious from the values.

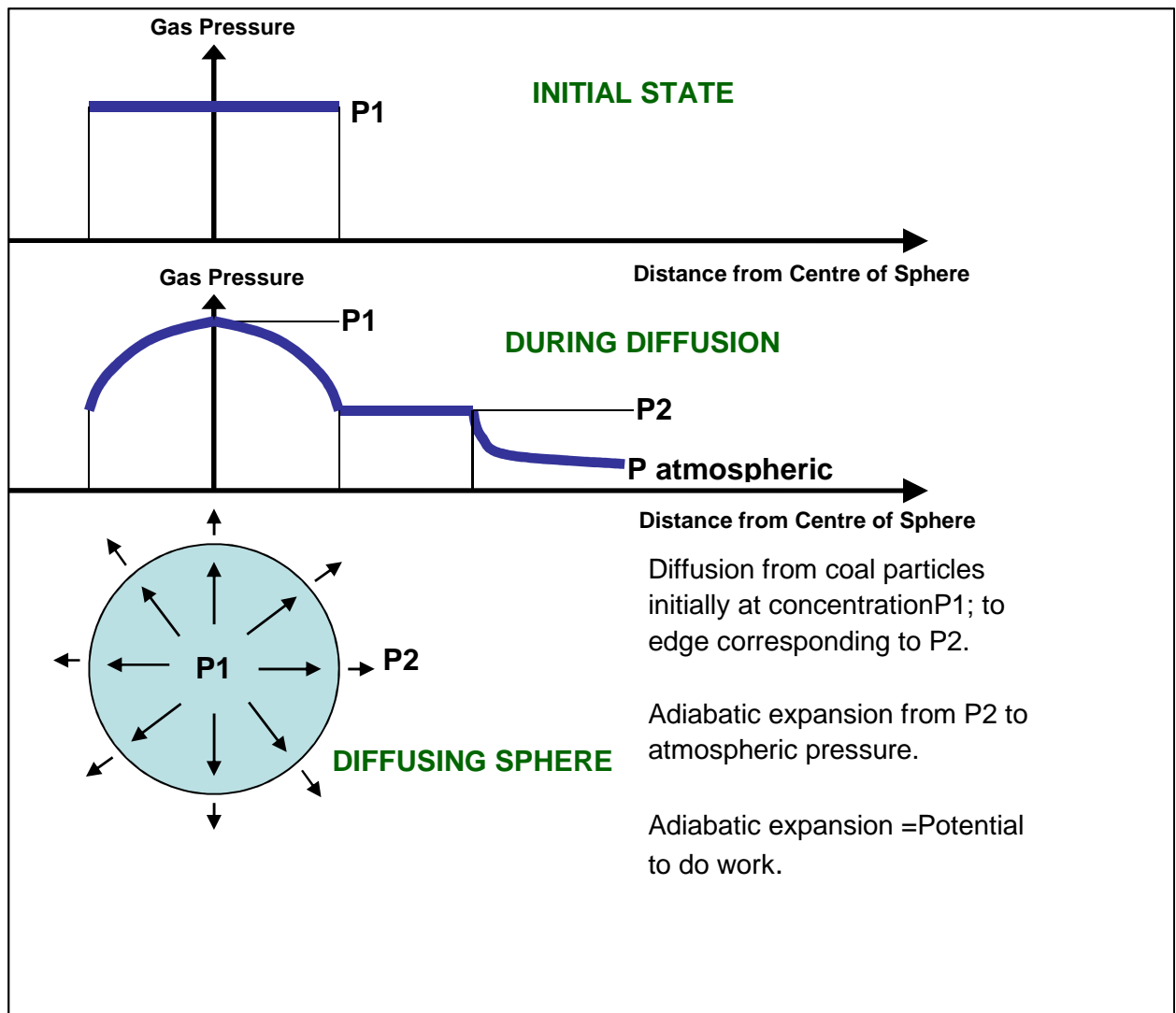


Figure 9. The concept of the diffusing sphere from Gray 2006.

PROPERTIES	UNITS	VALUE
Young's Modulus	GPa	2
Poisson's Ratio		0.3
UCS	MPa	12
Mean stress	MPa	12
Sorption Pressure	MPa	4
Gas content	m ³ /t	14.8
Void ratio		0.005

Strain Energy	MJ/m ³	0.16
Pore gas expansion	MJ/m ³	0.03

Diffusion Coefficient	m ² /s	1x10 ⁻⁸	1x10 ⁻¹⁰	Particle Size mm
Diffusional Energy	MJ/m ³	0.94	0.47	0.1
Diffusional Energy	MJ/m ³	0.47	0.009	1
Diffusional Energy	MJ/m ³	0.009	0.001	10

Energy in Falling 1 m	MJ/m ³	0.014
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Properties
Units
Energy Terms
Energy Values



Table 2. Potential Energy Releases for 1 m³ of stressed, gassy coal. Note no account is taken of energy consumed in the failure process.

Cuttings Desorption From Air Drilling

The European and Asian coal mining world engages in drilling open holes using air flushing to determine conditions ahead of mining. This is regularly done without any problems of ignition in the hole. The process for doing this in the underground mine context is shown in Figure 10 and was set up by Sigra as a result of a need to find gas content whilst using normal local drilling methods used in Kazakhstan-

Here drilling takes place using air flushing with the cuttings being collected by a cyclonic separator and bag filter arrangement. The cuttings collected are transferred to a canister and the gas release with time is measured, much as in the case of core desorption, except that the process happens more quickly (approximately 2 hours) because the coal is in small pieces. As desorption slows, the canister can be opened, the sample weighed and a sub sample taken for crushing to obtain a value of the residual gas content. Thus the measured gas release includes

both the values from normal desorption (Q2) and from crushing (Q3).

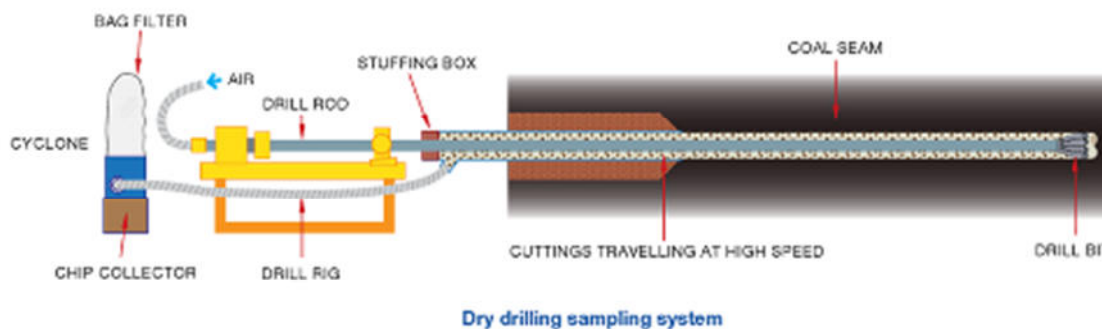


Figure 10. Underground drilling setup to collect cuttings with air flush drilling.

There is a need to then determine the lost gas volume (Q1). This is in some ways easier to do than for the case of core desorption because the time at which gas loss starts is known with precision (within 30 seconds) as the time at which drilling takes place. The key to determining the lost gas is to measure the particle size distribution of the remaining cuttings. Using this size distribution, and the gas release versus time information, combined with the residual gas content it is possible to use a model of diffusion to determine the lost gas using a best fit history match. Equation (3) from Crank (1975) has been found to model the situation quite adequately. It describes Fickian diffusion from spherical particles.

$$\frac{M_t}{M_\infty} = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} e^{\left(\frac{-Dn^2\pi^2t}{a^2} \right)} \quad (1)$$

where $\frac{M_t}{M_\infty}$ is the ratio of desorbed gas over the total gas that may be released

D is the diffusion coefficient (length²/time)

t is time

a is the radius of the nominally spherical particles.

The total gas content is thus determined from the estimate of lost gas and the measured gas released, providing a very accurate estimate of the gas content of coals and a value of the diffusion coefficient of the coal particles. Figure 11 shows an example of a real gas content determination from this process. The example is from work by the author in the D6 seam at Lenina mine in the Karaganda Basin, Kazakhstan. This was a dry coal seam which made the operation easier.

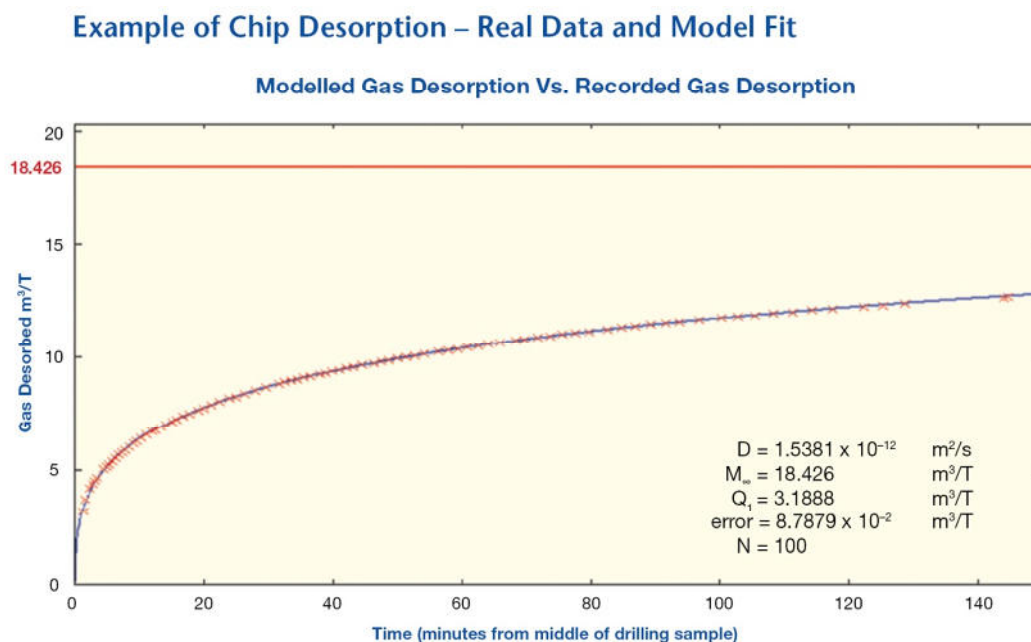


Figure 11. An example of gas content measurement from air drilled cuttings desorption.

The results taken from the case described in Figure 11:

- The diffusion coefficient is calculated at $1.54 \times 10^{-12} \text{ m}^2/\text{s}$;
- The total gas content is calculated at $18.4 \text{ m}^3/\text{tonne}$;
- The lost gas estimate is $3.19 \text{ m}^3/\text{tonne}$; and
- The residual gas measured is identical to that predicted – $4.6 \text{ m}^3/\text{tonne}$.

These results could be available four hours from drilling in a well set up mine.

The system also permits the ratio of cuttings volume to hole drilled to be determined which is in itself a very important indicator of outburst prone conditions. The system has potential to be modified to operate under wet drilling conditions.

The Use of Core Drilling in Determining Outburst Conditions

Core desorption is the standard process for determining the gas content of cores. This process is described by McCulloch and Diamond (1976), and more recently Standards Australia (1999). The process generally involves using wireline coring to cut a core so that the core may be retrieved quickly. Once the core is retrieved to surface the core is placed in a canister and the released gas is monitored with respect to time. This should be undertaken at reservoir temperature. An example of gas release versus time is shown in Figure 12.

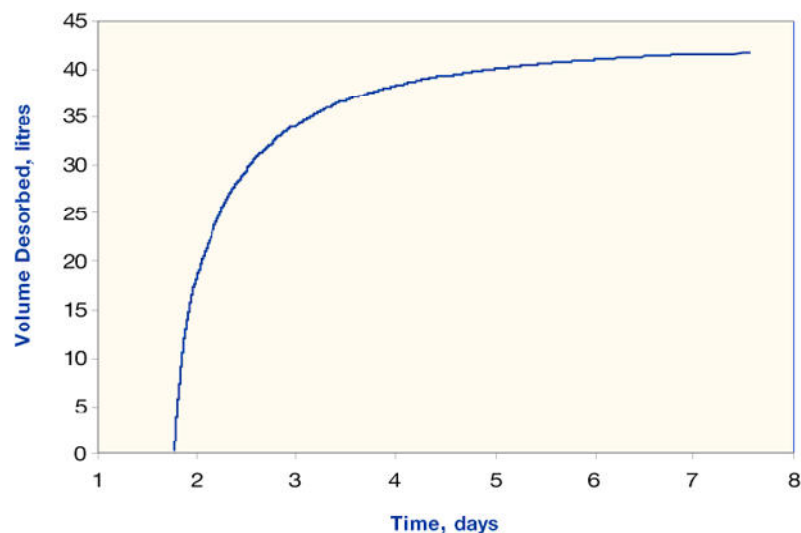


Figure 12. Example of desorbed gas measurement (Q2). Note the time here refers to time of day.

Once the core has been further desorbed the canister is opened and the core is logged and weighed with density determination. Weighed sub sections of the core are then crushed to enable the remaining gas to diffuse out more quickly than from the core.

This process is relatively straightforward but the determination of the gas lost before the core is placed in the canister is not. The usual process adopted is to assume a time when the core begins to release gas and to plot the gas release with respect to the square root of time. An example of such a plot is shown in Figure 13.

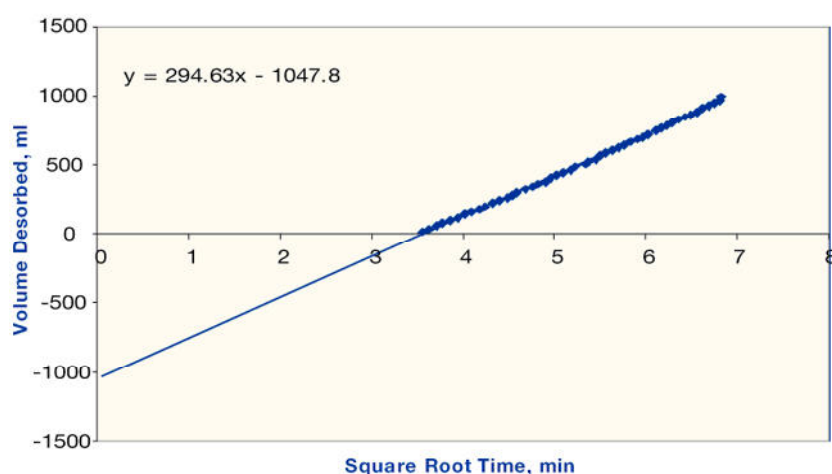


Figure 13. Example of lost gas determination plot (Q1).

Figure 13 shows a very good straight line plot. Equation (1) for Fickian diffusion from a homogeneous cylinder is as published by Crank (1975).

$$\frac{M_t}{M_\infty} = 1 - \sum_{n=1}^{\infty} \frac{4}{JOR_i} e^{\left(-D\left(\frac{JOR_i}{a}\right)^2 t\right)} \quad (2)$$

where $\frac{M_t}{M_\infty}$ is the ratio of desorbed gas over the total gas that may be released

$$J_o(a\alpha_n) = 0$$

JOR_i are the roots of a Bessell function of the first kind for the equation

D is the diffusion coefficient (length²/time)

t is time

a is the radius of the cylinder

For small values of Dt/a^2 equation the general equation may be approximated to that of equation 3 below, also taken from Crank (1975):

$$\frac{M_t}{M_\infty} = \frac{4}{\sqrt{\pi}} \left(\frac{Dt}{a^2}\right)^{\frac{1}{2}} - \frac{Dt}{a^2} - \frac{1}{3\sqrt{\pi}} \left(\frac{Dt}{a^2}\right)^{\frac{3}{2}} + \dots \quad (3)$$

The straight line approximation with the square root of time comes from the first term of the above equation and shows a 10% error at a value of $Dt/a^2 = 0.05$. For values of Dt/a^2 greater than 0.05 the value from the first term approximation of equation 2 diverges rapidly from the theoretically correct solution.

Care must be exercised in the use of the straight line approximation for gas loss. A prime source of error is the incorrect determination of the time when initial gas loss occurs. Standards Australia (1999) arbitrarily sets this at the mean time between when the core starts being pulled and reaches the surface. In some cases determining the onset of gas release in the hole needs to be looked at more carefully. Another source of error occurs if the core is retrieved too slowly and substantial gas loss occurs. In this case the value of Dt/a^2 may mean that the linear approximation is quite simply incorrect. This can be checked quite readily from a calculation of the slope of the lost gas plot and the total gas content.

It must be remembered that the coal core is not a uniform cylinder. It is inhomogeneous and fractured and contains various macerals and ash. The more highly fractured components of the core and those with higher diffusion coefficient will release their gas more quickly than the less fractured ones with a slower diffusion coefficient. A basic method of checking the validity of the initial gas loss estimation is to examine the ratio of the lost gas (Q1) to total measured gas content (Q2+Q3). If this value is too high then a question will remain over the total gas content value.

It is possible to derive an estimate of the diffusion coefficient from the slope of the lost gas plot and the total gas content. This estimate is what we call the Apparent Diffusion Coefficient (D_A). The term apparent applies because it is actually affected by the fracturing within the core as well as the diffusion coefficient. It is however a useful number to have in determining how a coal will behave from both the outburst and the gas emission viewpoint.

$$D_A = 3.273 \times 10^{-3} \cdot \left(\frac{Sl \cdot a}{M_{ml}^{\infty}} \right)^2 \quad (4)$$

Where

Sl – slope of the initial desorption curve

plot of M_t vs. $t^{1/2}$, $\frac{ml}{\sqrt{min}}$

M_{ml}^{∞} = total gas content of core in ml

a = core radius in m

Sigra has more recently adopted the practice of determining the actual diffusion coefficient from core desorption combined with a fracture size distribution in a far more accurate way so as to assess the initial gas loss. This process involves pulling core using what is usually a wireline system from a vertical hole. The core is then placed in a canister held at constant temperature in a water bath and connected to an automated positive displacement electronic flowmeter which records the gas release with time. Such a system is shown in Figure 14.

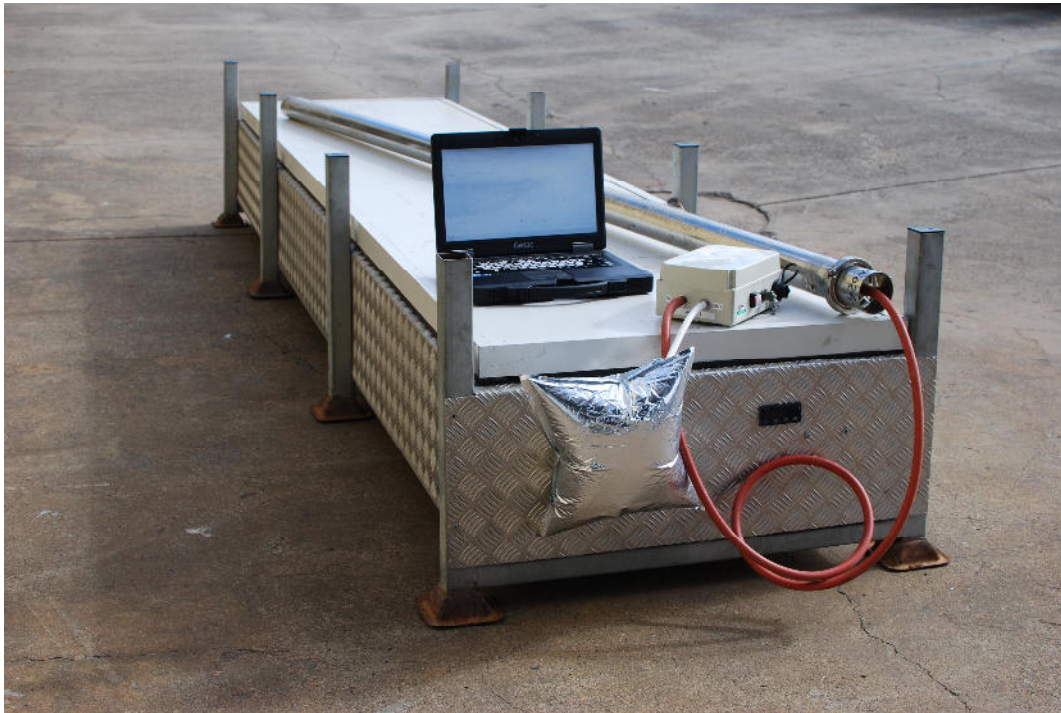


Figure 14. Canister, automatic desorption monitor and controlled temperature bath.

The long term desorption curve is then acquired until about 80% of gas is desorbed. Using the shape of the desorption curve which is fundamentally different from that of a uniform cylinder it is possible to arrive at a fracture spacing distribution within the core, the diffusion coefficient and an estimate of the gas content. The gas content estimate is then refined by measurement of the residual gas by crushing and the lost gas is recalculated on the basis of the diffusive behaviour of the fractured core taking into account the sorption isotherm of the coal. This process is significantly more accurate, particularly where there is a high initial gas loss. It also yields important information on the degree of coal fractures and diffusion coefficient.

One of the most important measurements that can be obtained from coring gassy coals is in the failure to recover core. This is frequently an indicator of broken coal.

The Importance of Coal Permeability

The permeability of the coal has no direct bearing on the severity of an outburst at a given gas content and level of stress. However coals with low permeabilities are far more prone to outbursting because they are much harder to drain.

Conclusion - The Next Stage in Outburst Management

The approach to outburst management may be to drain gas to a universal low level so that even if gouge zones are mined they will not produce an outburst of any severity. This may however be completely impractical in coals of low permeability where the solid coal could be safely mined at a higher gas level.

What Sigra advocates is an approach that takes into account all the important factors that contribute to outbursting. These include:

- Geological Structure
- Coal Strength – Toughness
- Stress
- Gas Pressure / Content
- Diffusion Rate

The use of the energy release approach will show fairly rapidly which of the factors are important and therefore not every parameter will need to be measured in precise detail. Those that are measured should however be measured properly to deliver an absolute measurement rather than an index which is a function of multiple properties. This approach enables the properties to be used in the energy release models.

The use of an open hole to gather cuttings is seen as a particularly useful technique as it is a scale model of roadway development so that failure can be detected in the form of excessive cuttings make compared to hole volume. As Sigra has in addition devised means to determine the very important parameters of gas content, diffusion coefficient and particle sizing from the open hole it becomes a very attractive and fundamentally simple exploration tool for use in determining outburst proneness.

Probably the greatest weaknesses in the approach advocated and those requiring the most development are those related to determining the energy consumed in breaking coal and in remotely determining the structure of the coal. Faulted zones need to be detected and therefore the confidence in the exploration procedure needs to be very high. This can only be achieved with a combination of approaches using in-seam drilling with detailed geological measurement, extrapolation and geophysical techniques.

References

AS 3980, *Australian Standard™ Guide to the determination of gas content of coal – Direct desorption method*, second edition. 1999.

Black D, Ajiz, Naj, Jurak, Matt and Florentin, Raul (2009). Outburst Threshold Limits – Are they Appropriate? 2009 Coal Operators Conference.

Crank, J. 1975. *The Mathematics of Diffusion*, 2nd Edition. Oxford: Clarendon Press.

Gray, Ian (1980). The Mechanism of, and Energy Release Associated with Outbursts. Proceedings of The Occurrence, Prediction and Control of Outbursts in Coal Mines Symposium, September 1980. The AusIMM Southern Queensland Branch.

Gray, Ian (1983). Factors Influencing Outbursting and Gas Drainage in Underground Coal Mines. Thesis in partial fulfilment of the degree of PhD, UNSW.

Gray, Ian (2006). Coal Mine Outburst Mechanism, Thresholds and Prediction Techniques. Australian Coal Association Research Program Report C14032. August 2006.

Lama, Ripu D & Bodzioni J (1996). Final Report, Project No C4034, Sudden Outbursts of Gas and Coal in Underground Coal Mines.

Marshall P, Griffiths L and Lama R D (1980). Occurrence of Outbursts at West Cliff Colliery. Papers Presented at the Symposium on The Occurrence, Prediction and Control of Outbursts in Coal Mines. AusIMM Southern Queensland Branch, September 1980.

McCulloch, C.M. and Diamond, W.P. 1976. Inexpensive Method Helps Predict Methane Content of Coalbeds. *Coal Age* 81 (6): 102-106.

Moore R D and Hanes J (1980). Bursts at Leichhardt Colliery, Central Queensland and the Apparent Benefits of Mining by Shotfiring. Papers Presented at the Symposium on The Occurrence, Prediction and Control of Outbursts in Coal Mines. AusIMM Southern Queensland Branch, September 1980.

APPENDIX 1 – OUTBURST INDICIES USED IN VARYING COUNTRIES TO PREDICT OUTBURSTS – TAKEN FROM LAMA AND BODZIONY, 1996.

Ettinger's Sorption/ Desorption index : This index was developed initially by Ettinger (1953) as the means of classifying coal in terms of proneness to outburst. The gas emission index was based on the gas pressure build-up (P) in millimeters of Mercury (Hg) of coal enclosed in a pressure chamber of known dimensions. This was also reported by outburst scoping study.

P 0-60 index: This index was developed as a follow up to P 0-30 index based on the work of Ettinger et al (1953). This method was mainly used in Belgian coal mines (Vandeloise, 1964).

P 0-60 Index is used to estimate the liability of outburst in an advancing face. The value has been found to depend upon the depth of the borehole and the structure of coal (ACARP C 4034 Chapter 9 Section 9.2.2).

Polish Desorbometer: This instrument was mainly used in Poland for defining outburst conditions in Anthracite mines with CO₂ in the lower Silesian coal field basin (Kozlowski and Polak, 1978 a, b). Its application in Australian mines was also reported by Lama (ACARP project no C3079, chapter 13, page 573).

KT index: This index is a measure of the change in desorption rate of coal sample (ACARP C 4034 Chapter 9 Section 9.2.4). The index KT was determined by Janas and Winter (1977) for Leichhardt Colliery, Gemini seam (Australia) as reported in ACARP C 4034.

Delta P Express index: Developed by Paul,(1977), this method was used to determine KT index when the automatic equipment for KT determination was not developed (ACARP C 4034 Chapter 9 Section 9.2.5).

Gas emission V index: The V index is the measure of the volume of gas in the early stages of desorption of coal sample under atmospheric pressure. This index was used in France Somnier (1960) (ACARP C 4034 Chapter 9 Section 9.2.6).

Hargraves emission rate: Hargraves emission meter, measures gas emitted from the samples with virtually no back pressure (± 25 mm H₂O) in a tube coiled flat on a plate. This index has been widely used in several Australian coal mines, particularly at Metropolitan and other mines in the southern coal fields of NSW, and in some mines of Queensland (ACARP C 4034 Chapter 9 Section 9.2.7).

Gas flow index G: This index has been used mainly in Russia, Ukraine, Czech Republic and other Eastern European countries. The method is based upon measurement of gas flow from bore holes drilled in the face (ACARP C 4034 Chapter 9 Section 9.3).

Seam thickness variation index Mm: Seam thickness variation index is a measure of the tectonic stress which can cause local compression of the coal seam. Seam thickness variation index (Mm) was used in Bulgaria and Russia (ACARP C 4034 Chapter 9 Section 9.6).

V30 index : This is an index of the initial desorption rate which defines the amount of gas liberated in the first 30 seconds after the coal face has been blasted. It is a measure of the gas content of coal and the rate of gas emission based on the assumption that the firing pattern and the amount of explosive used remain the same. The underlying assumption is that the

outbursts manifest themselves when the gas content exceeds 9 m³/t (Noak et al, 1983) (ACARP C 4034 Chapter 9 Section 9.7).

APPENDIX 2 – CHINESE OUTBURST ASSESSMENT STANDARDS

The system in use in Chinese mines to determine outburst risk involves examining four parameters. These are:

1)

A consideration as to how broken the coal is in the ground. This is a measure of the degree of faulting, gouge material etc. The categories considered are:

- I. Unbroken Coal
- II. Broken Coal
- III. Seriously Broken Coal
- IV. Comminuted Coal

2) The initial rate of gas emission ΔP

This is a laboratory based test that involves placing a 3.5 gm sample of ground coal sieved in the size range 0.2 to 0.25 mm into a special vessel. This vessel is then evacuated for 1 ½ hours. The sample is then gassed to 0.1 MPa for 1 ½ hours. A mercury U tube manometer is then balanced and the valve from the sample chamber to the manometer is opened for 10 seconds and closed. The manometer pressure is then read. The valve is re-opened 45 seconds later for 15 seconds and then closed. The manometer is read again. The difference in the two manometer readings is ΔP . The process is repeated for a second sample. If there is more than 1 mm of Hg pressure difference between the two samples the process is repeated. The outburst threshold is considered to be 10 mm Hg.

The experiment must be dependent on sample chamber size and on the diameter of the U tube manometer. These measurements were however not determined.

3) The coal hardness coefficient (f)

This is a drop hammer test on lump coal with measurement of the coal size reduction.

The process involves five weighed sets of coal of size range 20 to 30 mm. These are placed in an apparatus comprising a drop hammer of 2.4 kg weight with a 600 mm travel.

The first sample has the hammer dropped on it 3 times and the sample is sieved. If the fines of less than 0.5 mm diameter exceed a certain value 30 (described as length l) the remaining samples are tested.

If the sample has a length value of less than 30 the sample is hammered an additional 5 times.

The hardness value is described by equation 19.

$$f_{new} = 20 n / l \quad (19)$$

Where

f_{new} is the new hardness value

n is the number of blows

l is the length of fines

If the coal is too fine to obtain 20 to 30 mm lumps from then a sieved sample in the 1 to 3 mm range is used and hammered 3 times.

In this case if $f_{1-3 \text{ mm}} > 0.25$ then $f_{new} = 1.57$ if $f_{1-3 \text{ mm}} < 0.14$

otherwise $f_{new} = f_{1-3 \text{ mm}}$

A hardness number f_{new} of less than 0.5 is considered to be outburst prone.

4) Pressure P

This is simply a pressure measurement of gas in the coal. It may be direct or indirect via gas content and sorption isotherms. If the seam pressure exceeds a value of 0.74 MPa the coal is considered to be outburst prone.

Supposedly if any of the above parameters are exceeded the coal is considered outburst prone. This does not however make sense as if the coal has no gas then its degree of breakage or softness are irrelevant.

There are also combined measurements of outburst proneness. One is a K value.

$$K = \Delta P / f_{new} \quad (20)$$

Another is the D value

$$D = (0.0075 h/f-3)(P-0.74) \quad (21)$$

Where

h is the depth (m)

f is the hardness coefficient

P is pressure

The threshold values of K and D for outburst prediction are unknown.