

Parameters Affecting Mine Gas Drainage And Outburst Control Research

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ABSTRACT: Removing gases from mine environment represents the most important challenge that any mine operator is faced with. The ease with which the challenge is met and addressed depends on better understanding of the various parameters. Coal permeability and porosity is one of the key factors affecting the drainability of the coal. Coal matrix structure and coal mineralization provide a key to various issues related to effective drainage. Abnormal geological intrusions such as faults and dykes are likely to adversely affect the drainability of the coal seam. A combination of coal permeability, volumetric matrix change and petrography studies has been found to provide a new methodology in determining the ease with which a coal seam can be drained particularly with respect to geologically difficult sites. Various methodologies and techniques are described to provide the latest of research currently being pursued at the University of Wollongong, NSW, Australia, which is now providing a clear direction to predicting the drain ability of gassy coal seams.

1. INTRODUCTION

The capture and utilisation of methane gas is receiving increasing attention in recent years as mines are gearing up for high output in order to remain economically viable, particularly in export oriented countries like Australia. Methane, as the major component of natural gas, is drained from the coal seam prior to mining and the most common method of high rate of gas drainage is by borehole drainage. Figure 1 shows a typical patterns of gas drainage systems currently being implemented in various Australian Mines. A lead time around six months is generally allowed prior to the commencement of mining the predarined coal panel.

The success of a coal drainage programme by borehole drilling is influenced by the geological conditions and also by the gas environment. Accordingly, there has been a continuous programme of research at the School of Civil, Mining and Environmental Engineering, University of Wollongong for the past two decades to provide essential research needs of the Australian coal industry. Initially the main study was related to sorption technique for determining

gravimetrically the gas content of coal, and the extended later to the volumetric method. Other studies undertaken include the modelling of gas sorption in

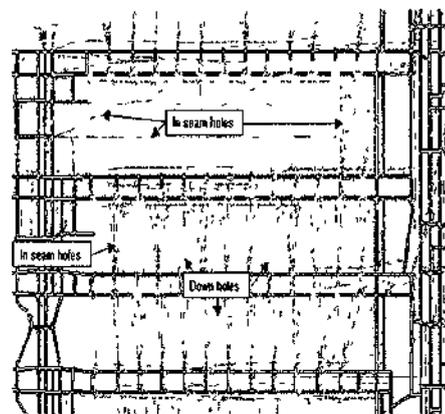


Figure 1 Typical pattern of gas drainage drilling

coal. The next phase of the research involved the development of a multi function outburst rig

(MFORR) for outburst research. The MFORR was initially used to study the effect of gas environment on the strength properties of coal including:

- i) The effect of gas pressure on coal tensile strength, using the well known Brazilian method of indirect tensile testing of cylindrical core samples in different gas pressure confinements,
- ii) The effect of gas pressure gradient on coal load bearing capacity, and
- iii) Study of the strength of coal by examining the particle size distribution of drill cuttings under different gas environments. A high precision drill of controlled speed up to 10 different levels was used to study the changes in particle size distribution with respect to increased gas type, gas pressure. The changes in coal strength properties were also compared with drilling of coal in air (Aziz Hutton, and Indraratan, 1996)

Concurrent with the above, an extensive study of various coal seams gas content was conducted using an in-house built adsorption and desorption apparatus. Research emphasis has since been shifted towards the establishment of a long-term database for coal properties including coal permeability, coal shrinkage and coal petrology. The later aspect of the study is the establishment of indices for coal drainage characterisation.

2. EQUIPMENT DESCRIPTION

2.1 Adsorption and desorption apparatus

This equipment has been the focus of outburst programme research for the past two decades. Initially it was constructed to determine indirectly, and gravimetrically the gas content of coal at different gas pressures, nowadays it is also used for coal sample preconditioning, prior to permeability, coal shrinkage and coal strength tests. The apparatus (Figure 2) consists of number cylindrical pressure vessels, known as pressure 'bombs'. Coal samples are sealed in gas bombs and pressurised to a saturation level at various predetermined pressures up to 5 MPa. The sample containers are immersed in a water bath, but are isolated from the water bath by copper sleeves to keep them dry. A thermostatically controlled water bath (with a stirrer) allows the coal samples to be kept at the desired temperatures. Further details of equipment construction, operation and gas content calculations at various pressure levels are

described elsewhere (Aziz, and Ming-Lee, 1999).

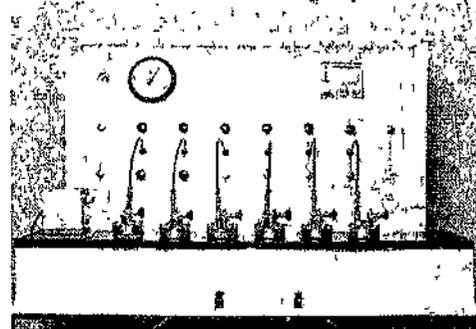


Figure 2 High pressure sorption /desorption apparatus

2.2 Coal Shrinkage test

Figure 3 is basically the pressure vessel (bomb) component of adsorption and desorption equipment used previously for indirect method of determining the gas content of coal. The only modification introduces to the bomb is the addition of pressure transducer on the lid of each bomb to monitor the bombs inlet gas pressures. Coal samples are sealed in gas bombs and pressurized to a saturation level at 3 MPa. It is then immersed in a water bath to maintain it at a constant temperature of around 25°.

Before, the coal samples are placed in the bombs; four strain gauges are mounted on each sample surface to monitor axial and radial strains on coal size due to gas sorption. The mounting of the strain gauges is carried out in accordance to International Society of Rock Mechanics (ISRM) standard. A data taker 'model DT50' is used to retrieve information from the bomb which is then connected to a PC for data analysis.

2.3 Multi Function Outburst Research Rig (MFORR)

MFORR comprises a number of components, which can be utilised on a variety of research studies, initially built for the study of the evaluation of changing coal strength properties with respect to changing gas environment of the coal sample tested. At present the rig is used mainly for coal permeability studies. The integrated components

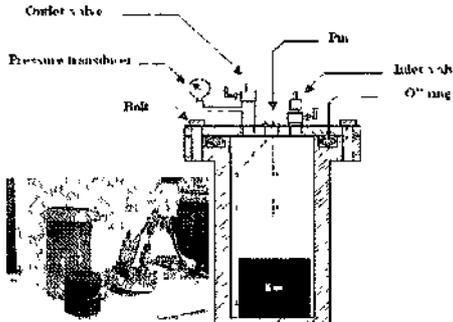


Figure 3 Coal shrinkage test vessel (Bomb) of the MFORR include

1. Main frame
2. Gas pressure chamber - also used for coal permeability studies
3. Drilling system
4. Drill support frame
5. Drill cutting collection system
6. Universal Socket for vertical load application,
7. Flow meters (see in Figure 4)
8. Data Acquisition System
9. Various components for coal strength properties tests

Figure 4 shows a general view of the MFORR. The components of the MFORR are interchangeable with respect to the type of tests undertaken. The main frame comprised a sturdy steel structure, which houses the gas chamber, a drilling frame which carried the drill, the universal thrust connector and the drill motor speed controller. The gas pressure chamber is a rectangular prism of cast iron with removable front and back viewing plates. The dimensions are 110 mm x 110 mm x 140 mm.

2.3.1 MFORR for Precision drilling and coal strength analysis

When used as a precision drill, the pressure drill rig (PDR) consists of drill frame, drill motor with drill bit, drilling thrust system and drilling cutting collection device. A multi-pulley system enabled constant thrust to be applied on the drill bit. The thrust is generated by a suspended steel cylindrical bucket filled with lead shot. The drill-cuttings are collected in a specially designed catcher, fitted with a disc of filter, and connected to a suction pump. The collected drill cuttings are subsequently

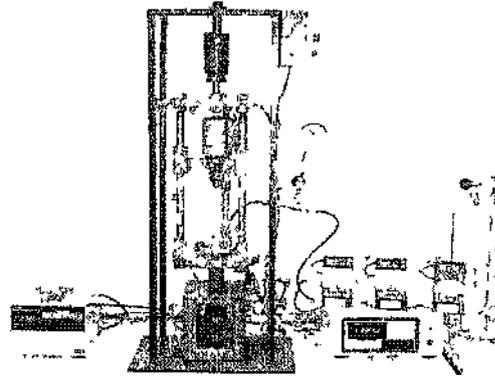


Figure 4 A general view of MFORR

weighed and analysed for particle size characterisation. A Malvern particle size analyser is used to conduct particle size analysis of drill cuttings. The particle size analyser is capable to classifying particle sizes between 1 mm and 0.5 microns (urn).

2.3.2 MFORR for permeability test

When MFORR is used for coal permeability, the precision drill section and drill cutting collection system are disengaged and the gas pressure chamber is reassembled to cater for the needs of the permeability tests. Figure 5 shows the schematic diagram of the test rig (Sereshki, Aziz and Porter, 2004). The high-pressure gas chamber is connected to a set of flowmeters for monitoring gas flow rates. To conduct the test, the samples are cut into 50 mm lengths, and the ends polished. In the centre of each sample, a 6 mm hole was drilled through each sample. The sample ends are then sealed with a lock-tite seal. The core sample is then placed between loading plates of the chamber. Axial strain is then applied to the core sample via a universal torque. Changes in the sample axial and lateral load dimensions due to gas sorption are monitored by two sets of strain gauges. Parameters that are monitored include:

- a. Application of stress
- b. Measurement of strain on the sample
- c. Measurement of gas flow rate
- d. Application of constant circumferential gas pressure
- e. Application of constant suction.

Gas is charged into the sealed pressure chamber at a pressure of 3 MPa and maintained constant for a period of one week to allow the coal to be sufficiently saturated. The strain is recorded for

this period. In the tests reported here little change in strain was observed over the time period. Once the sample was fully saturated, the release valve was opened and released gas passed through various flow meters of differing flow rates consisting of:

- Low flow range 0 - 100 ml / minute
- Medium flow range 0 - 2 L/ minute
- High flow rate 0 - 15 L/ minute

Information from the load cells, strain gauges and flow meters were monitored in a data logger connected to a PC.

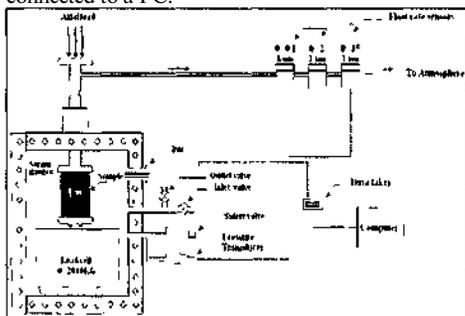


Figure 5 Schematic diagram of permeability test rig

3. RESULTS AND DISCUSSION

3.1 Gas Type And Pressure and Coal Strength Relationship

Figure 6 shows the bar charts of three different gas sorption quantities in Bulli coal seam, Sydney Basin. The gases used were CH₄, CO₂, and CH₄ / CO₂ /

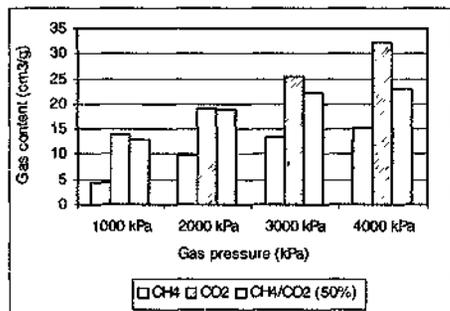


Figure 6 Sorption levels of CH₄, CO₂, and CH₄/CO₂ at various pressures of Bulli coal seam

CO₂ (50%) mixture. There is a clear trend of different gas sorption quantities in coal, with the higher sorption being of CO₂ gas.

Figure 7 shows the average values of drill speed record of coal specimens tested under both in air (i.e., normal atmospheric condition) and under increased gas pressures of 1 500 and 3 000 kPa. Ten tests were made for each sample environment. The rate of drilling of coal samples in air was relatively slower than that drilled in higher confined gas pressures. The highest values were obtained in CO₂ confinement. The increase in gas pressure to 3000 kPa also resulted in an increase in the rate of drilling.

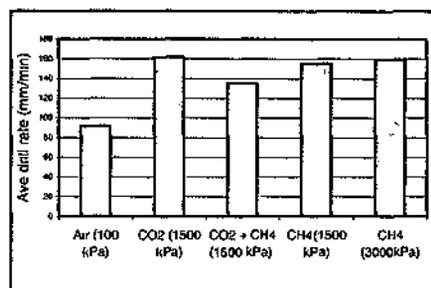


Figure 7 Drilling rates in coal under different gas types and confining pressures.

Figure 8 shows particle size distribution of drilling cuttings in various gas pressures. The graphs represent the mean line for 10 samples tested under each gas type and pressure. The particle size distribution ranged between 0.5 um and 878.67 um. Drilling in air produced finer particle sizes than drilling under gas pressure confinement. Additional observations made include:

- Drilling in CO₂ environment produced coarser particle sizes than in CH₄ and CH₄ /CO₂ environment at 1500 kPa pressures.
- The coarse particle size were lower in CH₄/CO₂, and even lower in CH₄ alone environment
- Increasing CH₄ gas pressure confinement to 3000 kPa produced coarser drill cuttings. In fact the particle size distribution for CH₄ at 3000 kPa was similar to that produced from drilling in coal saturated with CO₂ gas at a confinement pressure of 1500 kPa. This is to be expected, as the increased gas pressure to 3000 kPa may have forced more gas into coal micropores leading to a reduction in surface energy of the coal.

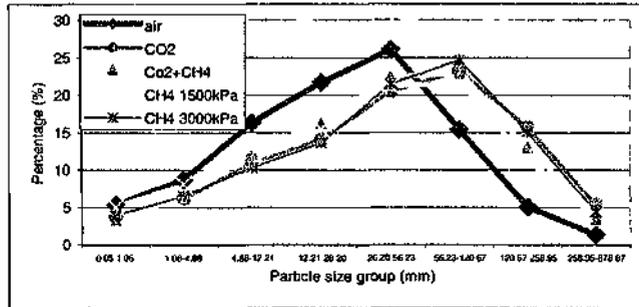


Figure 8 Particle size distribution of drill cuttings in various gas pressures

All this indicates that the presence of confining pressure has a detrimental effect on the strength of coal. It is possible that the presence of sorbed gases in coal at higher pressures may weaken the coal tensile strength by introducing micro-fractures into the coal structure. According to established facts and reported by Gray (1995), heavily fractured and soft rocks usually produce coarse drill cuttings with high rate of drill penetration.

Coal Shrinkage Test Results

Changes in the volume of coal matrix were calculated using the average of the two strains in the axial and radial directions. The shrinkage coefficient (C_m), is defined as the rate of change of coal matrix volume to the change in gas pressure and is given by (Harpalani and Chen, 1997):

$$C_m = \frac{1}{V_m} \left(\frac{dV_m}{dP} \right)$$

- Where
- V_m = Matrix volume (m^3)
- dV_m = Change in volume (m^3)
- dP = Change in applied pressure (MPa)
- C_m = Shrinkage coefficient (MPa^{-1})

Figure 9 shows the relationship between applied gas pressure and volumetric change in coal. The coal sample was initially charged to a maximum pressure of 3 MPa. The changes in coal volume were monitored in increments of 0.5 MPa. As can be seen, the reduction in coal volume is different for different gas medium.

A minimal change in coal volume was measured with nitrogen while a CO2 environment produced the highest volume change. Obviously, the influence of

CO2 reflects a strong affinity of the gas for coal. As coal adsorbs CO2 more strongly than methane, it is thus likely the high rate of gas storage in coal is accommodated with the increase in coal volume. Clearly the change in coal volume in this case is more than five fold in CO₂ in comparison with the methane environment.

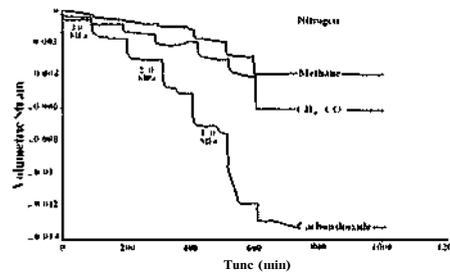


Figure 9 Volumetric strain for different gases and pressure reductions at increments of 0.5 MPa

The relative change in coal volume in mixed CO2/CH4 environment is between pure CH4 and CO2, but the mixture proportions influenced the degree of volume change.

3.3. Coal permeability test

Figures 10 and 11 are permeability graphs of coal samples tested in both methane and carbon dioxide gases under different gas pressures. The axial applied load was maintained constant at 2000 kg. The Bulli seam coal samples tested were collected from two geologically different locations in a local mine working Bulli seam in the Illawarra Coalfield of Sydney basin, NSW. Samples collected came from 800 panel (Sample #800051) and 900 panel (Sample # 900114 and #900104).

The geology of these two areas at hand specimen scale is significantly different and can be described 800 Panel - 'normal' coal in terms of cleat spacing and orientation, orthogonal, regular spacing, normal ordered horizontal bright and dull layers, does not display visible deformation

900 Panel - 'structured' coal with broken structure, cleats often not sub vertical, cleat spacing irregular, occasional small scale dislocation amongst bright and dull layers Calcite mineralization often found towards the top of the seam, usually oblique to bedding plane but tends towards bedding plane in lower parts of each vein

From a practical perspective, gas drainage has been exceedingly difficult in the 900-panel area when compared to the 800-panel area. Management has resorted to the 'grunching' method of

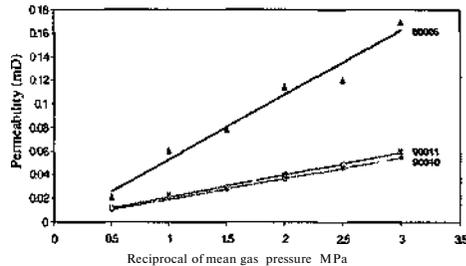


Figure 10 Coal permeability in carbon dioxide at different gas pressures and at 2000 kg axial load

heading development using explosives, particularly where gas content levels have been greater

than the allowable gas threshold limits. The coal structure has been disturbed to a point where the contained gas does not freely move from high in-seam fluid pressures to the drainage lines. The permeability of each sample was calculated using the following Darcy flow equation (Lama 1995)

$$K = \frac{mQ \ln(r_0 / r_i)}{\pi h (P_0^2 - P_u^2)} \quad (2)$$

Where

- K = Permeability (Darcy)
- l = Height of sample (cm)
- Q = Rate of flow of gas (cc/sec)
- P₀ = Absolute pressure in chamber (bars)
- r₀ = External radius of sample (cm)
- r_i = Internal radius of sample (cm)
- P_u = Absolute pressure in outlet (bars)
- H = Viscosity of CH₄ (Ns/m²)

The results showed a marked difference in the resultant permeability between the 800 and 900 panel coals. The difference in permeability (mildarcy) between 800 panel and the 900 panel coal for each of carbon dioxide and methane is quite different. 800 panel had approximately three times greater permeability when compared to the 900 panel coals (Figures 10 and 11)

Permeability tests for both carbon dioxide and methane show that the 900 panel coals have much lower permeability's than the 800 panel coals. Since permeability is a function of a number of

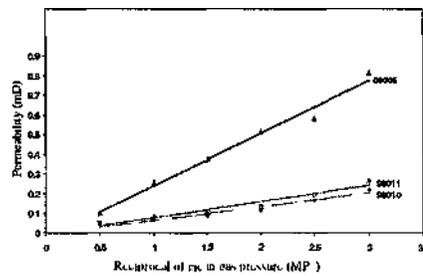


Figure 11 Coal permeability in methane at different gas pressures and at 2000 kg axial load

parameters including size, distribution and frequency of cleats, any phenomenon that reduces cleat porosity will decrease permeability. Given that 900 panel coals contain much higher carbonate contents than the 800 panel coals, and also have the lowest permeability, it is suggested that the reduced porosity of the 900 panel coals is due to the infilling of the cleats with carbonate. The reduced permeability value explains why the 900 panel area is much harder to degas. The carbonate in-filled cleats restrict the movement of gases from the surrounding coal to the gas drainage holes.

4 COAL PETROLOGY

The maceral analysis for the samples is given in Table 1. As can be seen there is a marked difference in the mineral matter and carbonate content for the samples originating from 900 panel compared to panel 800. Figures 12 and 13 show the petrological composition of coal from both 800 and 900 panels.

Petrographically, the three samples have similar organic components. They have similar vitrinite, haptinite and inertinite contents. However, the mineral contents of the samples are quite different.

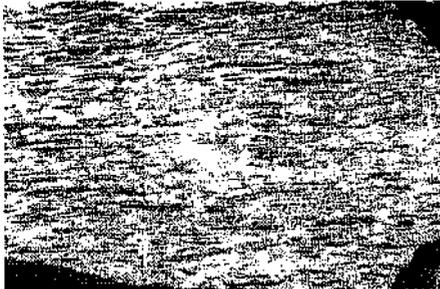


Figure 12 Sample from Panel 900 showing vitrinite with clay-filled cell lumen. Clay filled lumen would reduce permeability and reduce degassing. (Field width = 0.5 mm)



Figure 13 Sample from Panel 800 showing typical composition of the Tahmoor coal characterized by inertinite layers and mixed vitrinite-inertinite layers. (Field width = 0.5 mm).

Table 1 Coal composition for different coals

Panel / Sample	VIT%	INT%	LIP%	MMO%	CAR%	CAV%	FRA%	TOTAL%
800 - S1	70.4	21.8	1.8	2.0	0	3.8	0	99.8
900 - S2	68.4	19.0	1.0	2.8	2.7	5.3	1	100.2
900 - S2	67.8	19.8	1.8	6.6	1.2	2.6	0	99.8

One of the 900 panel coals contains a much higher mineral content including much higher carbonate (calcite). Although not in sufficient quantities to show in the point count, the second 900 panel coal also showed some carbonate. In both samples the carbonate infilled cleats and also some of the pores in inertinite macerals. If the mineral content and spe

cialities is common for the coal as a whole in 900 panel, the permeabilities and degassing problems associated within the panel can be explained in terms of petrography.

The permeability tests for both carbon dioxide and methane show that the 900 panel coals have much lower permeabilities than the 800 panel coals. Since permeability is a function of a number of parameters including size, distribution and frequency of cleats, any phenomenon that reduces cleat porosity will decrease permeability. Given that 900 panel coals contain much higher carbonate contents than the 800 panel coals, and also have the lowest permeability, it is suggested that the reduced porosity of the 900 panel coals is due to the infilling of the cleats with carbonate. When viewed on a micro scale, the reduced permeability also explains why the 900 panel area is much harder to degas. The carbonate infilled cleats restrict the movement of gases from the surrounding coal to the gas drainage holes.

5. CONCLUSIONS

The programme of research activities reported in this paper is a clear demonstration of our commitment in maintaining research on coal and gas outburst as a priority research for the benefit of the coal industry. It has been demonstrated that:

1. The study of the effect of gas pressure on coal strength through the analysis of particle sizes is a valid approach,
2. Permeability and shrinkage studies can serve as an effective approach in understanding the drainage characteristics of coal seam with intrusions and other geological disturbances. The effectiveness of these methods can be better enhanced through assessment of coal composition and mineralization.
3. The status of current research programme pursued at the University of Wollongong, is a continuation of the research work dating back to more than two decades. We are looking ahead to better utilise the latest know-how and technologies for the establishment of a predictive indices for safe mining and improved production and productivity.

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