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FACTORS AFFECTING THE DRAINAGE OF GAS FROM COAL AND METHODS TO IMPROVE DRAINAGE EFFECTIVENESS

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by

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AFFIRMATION

I, Dennis John Black, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Department of Civil, Mining and Environmental Engineering, University of Wollongong, is wholly my own work unless otherwise referenced or acknowledged. The document has not been submitted for qualifications at any other academic institution.

Dennis J. Black

The following publications are the result of this thesis project:

Black, D J, 2007. Gas management challenges at West Cliff Colliery, *ACARP Gas and Outburst Seminar* (ed: J Hanes), Mackay, Queensland, 29 June, pp 98-106.

Black, D J and Aziz, N I, 2008. Improving UIS gas drainage in underground coal mines, in *Proceedings of the 8th Underground Coal Operator's Conference COAL2008*, University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 14-15 February, pp 186-196.

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Black, D J and Aziz, N I, 2008. Improving UIS gas drainage in underground coal mines, in *Proceedings of the 16th Coal Congress of Turkey*, Chamber of Mining Engineers of Turkey, Zonguldak, Turkey, 26-28 May, pp 157-170.

Black, D J and Aziz, N I, 2008. Development of hydraulic fracturing in high stress conditions in Australian underground coal mines, in *Proceedings of the 16th Coal Congress of Turkey*, Chamber of Mining Engineers of Turkey, Zonguldak, Turkey, 26-28 May, pp 171-184.

Black, D J and Aziz, N I, 2008. Gas drainage improvement in underground coal mines, in *Proceedings of the 1st ASIA Pacific Coalbed Methane Symposium*, University of Queensland, Brisbane, 22-24 September, Paper No. 043.

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University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 11-12 February, pp 203-209.

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The following presentations are the result of this thesis project:

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ABSTRACT

The relationship between gas production from underground-to-inseam (UIS) drainage boreholes and various coal seam properties and operational factors were examined. Gas production from 279 UIS gas drainage boreholes was collated and assessed relative to a variety of coal geological properties and operational factors. The reasons for poor coal seam gas drainage performance from particular zones were investigated and actions to improve gas drainage performance have been recommended. Investigation were focussed on gas drainage performance from the Bulli seam of the Sydney Basin, focussing on West Cliff Colliery, where gas production was highly variable and many zones found to be difficult to drain.

The degree of saturation (DoS) was found to have a significant impact on coal seam gas drainage, with decreased gas production from highly undersaturated zones with low permeability. Within West Cliff Colliery, in the areas where gas drainage was found to be particularly difficult, conventional UIS drainage was shown to be incapable of reducing the reservoir pressure below the critical desorption point prior to roadway development.

From analysis of operational factors, drainage time was found to have a significant impact on gas production and appeared to be closely related to DoS indicating that coal with lower DoS required increased drainage time. Borehole length and orientation were found to have some impact on gas production with maximum gas production achieved from boreholes between 500 and 1 000 m long oriented between 5 and 60^{O} to the face cleat and between 0 and 40^{O} to the maximum horizontal stress. Boreholes drilled up-dip, with an apparent dip between 0.0 and $+3.0^{O}$ achieved increased gas production and the relationship was strongest in highly undersaturated coal. In saturated coal the initial gas flow rate tends to be high and the increased gas flow velocity supports the borehole to self-clear water and fines. With increasing age, gas flow velocity reduces which appears to affect the ability of the borehole to self-clear, particularly in boreholes oriented down-dip. Undulations such as troughs existing along the length of the boreholes also allow water and fines to accumulate which impedes gas drainage. No evidence was found to support a relationship between applied suction pressure and gas production. However where high suction pressure is applied to boreholes increased

leakage may occur. A new method for enhancing coal seam gas production using cyclic injection of inert gas is proposed.

The nature of coal seam gas emission from both fast and slow desorption gas testing methods was investigated using results from 4 185 gas tests collected from eight Australian underground coal mines, four located in Queensland and four in New South Wales.

The following equations were found to best represent the average relationship between each gas content component and the total measured gas content (Q_M):

- $Q_1 = 0.0064 \times Q_M{}^{2.0227}$
- $Q_2 = 0.0257 \times Q_M{}^{1.9692}$
- $Q_3 = 1.1631 \times Q_M{}^{0.7529}$

The following equations were proposed for use in estimating average and maximum Q_M based on Q_1 and initial desorption rate (IDR):

- $Q_{M(ave)} = 9.3729 \times Q_1{}^{0.3328}$
- $Q_{M(max)} = 2.5665 \times \ln(IDR) + 2.1686$
- $Q_{M(ave)} = 0.7413 \times \sqrt{IDR}$

- The relationship between Q_M and desorption rate index (DRI) was investigated and found to be different from the relationship presented in 1995, which is the basis for the DRI900 methodology used to determine outburst threshold limit values (TLV) applicable to non-Bulli seam mines. The impact of recent increases to outburst TLV at several Bulli seam mines and the relationship between Q_M and DRI identified during this study suggests that a TLV applicable to the Bulli seam may be directly transferrable to non-Bulli seam mines.
- From analysis of 3 355 fast desorption test results the relationship between Q_M and DRI was found to be independent of gas composition and represented by the following equation:
  - $Q_M = 0.008 \times DRI$

The following relationships were identified from analysis of slow desorption data.

- A linear relationship exists between Q_2 and Q_M that is independent of changes in seam gas composition. The rate of gas desorption was shown to be faster from samples with increased Q_M. Extending total desorption time beyond 200 days was shown to have little impact on Q_2 or the Q_2:Q_M ratio.

- From analysis of Q_2 and the Q_2:Q_M ratio, no relationship was found between vitrinite content, porosity and mineral matter content of each sample, suggesting the nature of desorbed gas emission was independent of coal petrography.
- Q_3 did not vary significantly in response to increasing Q_M whereas the Q_3:Q_M ratio reduced. The results indicate coal samples with high Q_M, having increased DoS, desorb gas at a faster rate resulting in the Q_3:Q_M ratio being less than from samples with low Q_M that desorb gas at a slower rate. The relationship between Q_3 and Q_M appeared to be independent of changes in seam gas composition. Extending the total desorption time beyond 200 days had little effect on residual gas content.
- From analysis of Q_3 and the Q_3:Q_M ratio relative to the measured vitrinite content, porosity and mineral matter content of the coal samples, it was found that residual gas content was independent of coal petrography.

To reduce the risk of gas loss into solution from prolonged contact with the current conventional slow desorption testing apparatus; consideration should be given to the use of electronic gas testing apparatus for continual analysis of the desorbed gas from coal.

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ACIRL	Australian Coal Industry Research Laboratories
BHPBIC	BHP Billiton Illawarra Coal
Φ	porosity (%)
CBM	coalbed methane
cc/g	cubic centimetres per gram
cm	centimetre
CO_{2-e}	carbon dioxide equivalent
D50	initial 50 days of gas production from UIS drainage boreholes
daf	dry and ash free
DRI	desorption rate index (ml)
DTV	defined threshold value
ECBM	enhanced coalbed methane
g	gram
GHG	greenhouse gas
Gt	gigatonnes ($1x10^9$ tonnes)
IDR	initial gas desorption rate ($\sqrt{ml \div \sqrt{min} \div kg}$)
IDR30	gas desorbed from sample in initial 30 secs of testing (m^3/t)
kPa	kilopascal
L/s	litres per second
L/min	litres per minute
LWD	logging-while-drilling
m	metre
mm	millimetre
m/day	metres per day
m^3	cubic metre
m^3/m	cubic metre per metre
m^3/t	cubic metre per tonne
m/s	metres per second
mD	milli Darcy
MPa	megapascal
MRD	medium radius drilling
Mt	megatonne ($1x10^6$ tonnes)
Mtpa	million tonnes per annum
MWD	measure-while-drilling
nm	nanometre ($1x10^{-9}$ m)
NCM	non-coal matter
NTP	normal temperature and pressure ($20^{O}C$ and 101.325 kPa)
P	absolute gas pressure
Pa	Pascal
P_{CDP}	critical desorption pressure
P_i	initial reservoir pressure

P_L	Langmuir pressure constant
P_O	atmospheric pressure (101.325 kPa)
Q_1	gas lost during coal core sample recovery (m^3/t)
Q_2	gas released from coal core sample during desorption testing (m^3/t)
Q_3	gas released from coal sample after crushing (m^3/t)
Q_M	total measured gas content; sum of Q_1, Q_2 and Q_3 (m^3/t)
STIS	surface to inseam
T	absolute strata temperature (^OK)
TLV	outburst threshold limit value
ρ	rho - density (t/m^3)
ROM	run-of-mine
rpm	revolutions per minute
μm	micrometre, or micron ($1x10^{-6}$ m)
UIS	underground to inseam
V_i	*in situ* gas content
V_L	Langmuir volume constant
V_{sat}	saturated gas content
WCC	West Cliff Colliery