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# Factors affecting the drainage of gas from coal and methods to improve drainage effectiveness

Dennis John Black  
*University of Wollongong*

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

A thesis submitted in fulfilment of the requirements for the award of the degree

**DOCTOR OF PHILOSOPHY**

from

**UNIVERSITY OF WOLLONGONG**

by

**DENNIS JOHN BLACK**

**B. Eng. (Hons) (Mining), Assoc. Dip. Mine Ventilation, Grad. Cert. Mgt**

**School of Civil, Mining and Environmental Engineering**

**2011**

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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

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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 8<sup>th</sup> 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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University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 11-12 February, pp 203-209.

**Black, D J** and Aziz, N I, 2010. Impact of coal properties and operational factors on mine gas drainage, in *Proceedings of the 10<sup>th</sup> Underground Coal Operator's Conference COAL2010*, University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 11-12 February, pp 229-240.

**Black, D J** and Aziz, N I, 2010. Coal properties and mine operational factors that impact gas drainage, in *Proceedings of the 13<sup>th</sup> U.S. / North American Mine Ventilation Symposium* (eds: S Hardcastle and D L McKinnon), Sudbury, Ontario, 13-16 June, pp 251-258.

**Black, D J** and Aziz, N I, 2011. Actions to improve coal seam gas drainage performance, in *Proceedings of the 11<sup>th</sup> Underground Coal Operator's Conference COAL2011*. University of Wollongong, (eds: N I Aziz, R J Kininmonth, J A Nemcik and T X Ren), Wollongong, 10-11 February, pp 309-316.

**Black, D J**, Aziz, N I and Florentin, R M, 2010. Assessment of factors impacting coal seam gas production, in *Proceedings of the 2010 International Coalbed & Shale Gas Symposium*, University of Alabama, Tuscaloosa, 17-21 May, Paper No. 1004.

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**Black, D J**, Aziz, N I, Jurak, M J and Florentin, R M, 2009. Gas content estimation using initial desorption rate, in *Proceedings of the 9<sup>th</sup> Underground Coal Operator's Conference COAL2009*, University of Wollongong, (eds: N I Aziz and J A Nemcik), Wollongong, 12-13 February, pp 193-198.

**Black, D J**, Aziz, N I and Ren, T X, 2011. Enhanced gas drainage from undersaturated coalbed methane reservoirs, in *Proceedings of the 3<sup>rd</sup> Asia Pacific Coalbed Methane Symposium*, University of Queensland, Brisbane, 3-6 May, Paper No. 50.

The following presentations are the result of this thesis project:

**Black, D J**, 2007. Gas management challenges at West Cliff Colliery, paper presented to the Gas and Outburst Committee Seminar, Wollongong, New South Wales, 27 June, pp 13-21.

**Black D J**, 2010. Appropriate risk control and drainage to avoid gas outbursts, paper presented to Mining Ventilation 2010, Brisbane, 01 September.

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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<sup>0</sup> to the face cleat and between 0 and 40<sup>0</sup> to the maximum horizontal stress. Boreholes drilled up-dip, with an apparent dip between 0.0 and +3.0<sup>0</sup> 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

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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):

- $Q_{M(\text{ave})} = 9.3729 \times Q_1^{0.3328}$
- $Q_{M(\text{max})} = 2.5665 \times \ln(\text{IDR}) + 2.1686$
- $Q_{M(\text{ave})} = 0.7413 \times \sqrt{\text{IDR}}$
- 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:
  - $Q_M = 0.008 \times \text{DRI}$

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

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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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## LIST OF SYMBOLS AND ABBREVIATIONS

ACIRL	Australian Coal Industry Research Laboratories
BHPBIC	BHP Billiton Illawarra Coal
$\Phi$	porosity (%)
CBM	coalbed methane
cc/g	cubic centimetres per gram
cm	centimetre
CO <sub>2-e</sub>	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 <sup>9</sup> 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 <sup>3</sup> /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 <sup>3</sup>	cubic metre
m <sup>3</sup> /m	cubic metre per metre
m <sup>3</sup> /t	cubic metre per tonne
m/s	metres per second
mD	milli Darcy
MPa	megapascal
MRD	medium radius drilling
Mt	megatonne (1x10 <sup>6</sup> tonnes)
Mtpa	million tonnes per annum
MWD	measure-while-drilling
nm	nanometre (1x10 <sup>-9</sup> m)
NCM	non-coal matter
NTP	normal temperature and pressure (20 <sup>o</sup> C and 101.325 kPa)
P	absolute gas pressure
Pa	Pascal
P <sub>CDP</sub>	critical desorption pressure
P <sub>i</sub>	initial reservoir pressure

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$P_L$	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 in-seam
T	absolute strata temperature ( $^{\circ}K$ )
TLV	outburst threshold limit value
$\rho$	rho - density ( $t/m^3$ )
ROM	run-of-mine
rpm	revolutions per minute
$\mu m$	micrometre, or micron ( $1 \times 10^{-6}$ m)
UIS	underground to in-seam
$V_i$	<i>in situ</i> gas content
$V_L$	Langmuir volume constant
$V_{sat}$	saturated gas content
WCC	West Cliff Colliery