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

School of Civil, Mining and Environmental Engineering

2011
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:


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° to the face cleat and between 0 and 40° to the maximum horizontal stress. Boreholes drilled up-dip, with an apparent dip between 0.0 and +3.0° 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):

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

- 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
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

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<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACIRL</td>
<td>Australian Coal Industry Research Laboratories</td>
</tr>
<tr>
<td>BHPBIC</td>
<td>BHP Billiton Illawarra Coal</td>
</tr>
<tr>
<td>$\Phi$</td>
<td>porosity (%)</td>
</tr>
<tr>
<td>CBM</td>
<td>coalbed methane</td>
</tr>
<tr>
<td>cc/g</td>
<td>cubic centimetres per gram</td>
</tr>
<tr>
<td>cm</td>
<td>centimetre</td>
</tr>
<tr>
<td>$\mathrm{CO}_2$-e</td>
<td>carbon dioxide equivalent</td>
</tr>
<tr>
<td>D50</td>
<td>initial 50 days of gas production from UIS drainage boreholes</td>
</tr>
<tr>
<td>daf</td>
<td>dry and ash free</td>
</tr>
<tr>
<td>DRI</td>
<td>desorption rate index (ml)</td>
</tr>
<tr>
<td>DTV</td>
<td>defined threshold value</td>
</tr>
<tr>
<td>ECBM</td>
<td>enhanced coalbed methane</td>
</tr>
<tr>
<td>g</td>
<td>gram</td>
</tr>
<tr>
<td>GHG</td>
<td>greenhouse gas</td>
</tr>
<tr>
<td>Gt</td>
<td>gigatonnes (1x10^9 tonnes)</td>
</tr>
<tr>
<td>IDR</td>
<td>initial gas desorption rate ($\frac{ml}{\sqrt{\text{min}}}/kg$)</td>
</tr>
<tr>
<td>IDR30</td>
<td>gas desorbed from sample in initial 30 secs of testing ($\text{m}^3/\text{t}$)</td>
</tr>
<tr>
<td>kPa</td>
<td>kilopascal</td>
</tr>
<tr>
<td>L/s</td>
<td>litres per second</td>
</tr>
<tr>
<td>L/min</td>
<td>litres per minute</td>
</tr>
<tr>
<td>LWD</td>
<td>logging-while-drilling</td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
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<tr>
<td>mm</td>
<td>millimetre</td>
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<td>m/s</td>
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<td>milli Darcy</td>
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<td>megapascal</td>
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<tr>
<td>MRD</td>
<td>medium radius drilling</td>
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<tr>
<td>Mt</td>
<td>megatonne (1x10^6 tonnes)</td>
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<tr>
<td>Mtpa</td>
<td>million tonnes per annum</td>
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<tr>
<td>MWD</td>
<td>measure-while-drilling</td>
</tr>
<tr>
<td>nm</td>
<td>nanometre (1x10^-9 m)</td>
</tr>
<tr>
<td>NCM</td>
<td>non-coal matter</td>
</tr>
<tr>
<td>NTP</td>
<td>normal temperature and pressure (20°C and 101.325 kPa)</td>
</tr>
<tr>
<td>P</td>
<td>absolute gas pressure</td>
</tr>
<tr>
<td>Pa</td>
<td>Pascal</td>
</tr>
<tr>
<td>P_{\text{CDP}}</td>
<td>critical desorption pressure</td>
</tr>
<tr>
<td>$P_i$</td>
<td>initial reservoir pressure</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>$P_L$</td>
<td>Langmuir pressure constant</td>
</tr>
<tr>
<td>$P_0$</td>
<td>atmospheric pressure (101.325 kPa)</td>
</tr>
<tr>
<td>$Q_1$</td>
<td>gas lost during coal core sample recovery (m$^3$/t)</td>
</tr>
<tr>
<td>$Q_2$</td>
<td>gas released from coal core sample during desorption testing (m$^3$/t)</td>
</tr>
<tr>
<td>$Q_3$</td>
<td>gas released from coal sample after crushing (m$^3$/t)</td>
</tr>
<tr>
<td>$Q_M$</td>
<td>total measured gas content; sum of $Q_1$, $Q_2$ and $Q_3$ (m$^3$/t)</td>
</tr>
<tr>
<td>STIS</td>
<td>surface to inseam</td>
</tr>
<tr>
<td>$T$</td>
<td>absolute strata temperature (°K)</td>
</tr>
<tr>
<td>TLV</td>
<td>outburst threshold limit value</td>
</tr>
<tr>
<td>$\rho$</td>
<td>rho - density (t/m$^3$)</td>
</tr>
<tr>
<td>ROM</td>
<td>run-of-mine</td>
</tr>
<tr>
<td>rpm</td>
<td>revolutions per minute</td>
</tr>
<tr>
<td>$\mu$m</td>
<td>micrometre, or micron (1x10$^{-6}$ m)</td>
</tr>
<tr>
<td>UIS</td>
<td>underground to inseam</td>
</tr>
<tr>
<td>$V_i$</td>
<td>in situ gas content</td>
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<td>$V_L$</td>
<td>Langmuir volume constant</td>
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<tr>
<td>$V_{sat}$</td>
<td>saturated gas content</td>
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<tr>
<td>WCC</td>
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