Investigations of Hard (difficult) to drain Seam

Dr Ting Ren, Professor Naj Aziz and Dr Jan Nemcik
Mining Research Group
School of Civil, Mining and Environmental Engineering
University of Wollongong
Industry Drives

- **Safety of Coal Mining**
  - Outburst hazards
  - Frictional ignition for development drivage

- **Mine Production**
  - Reduced drainage lead time
  - Less delay in roadway development
  - Reduced gas-outs due to gas emission

- **Management of fugitive emissions**
  - Carbon pricing

- **CBM/CMM/Coal Seam Gas**
  - Gas recovery from tight seams for energy use
Industry Drives – Coal Mines around Wollongong

Future Areas?

Hard to drain areas with High CO2 content
Research Objective

- Identifying the main reasons contributing to “hard-to-drain” in coal seams;
- Establishing the ‘fingerprints’ of hard-to-drain coals to give early warning signs for future drainage process;
- Investigating a new method based on nitrogen flushing to enhance gas drainage in these ‘tight’ areas.
Adsorption Capacity Study - Isotherms

- Indirect gravimetric method to calculate the volume of gas adsorbed.
- Coal samples from hard-to-drain area and easy-to-drain areas tested for comparative isotherms.
Adsorption Capacity Study – Isotherms for Hard-to-drain and Easy-to-drain

Adsorption Isotherm at 25°C (GME 2126)
- CO2
- CH4

Hard-to-drain

Adsorption Isotherm at 25°C (GME 2128)
- CO2
- CH4

Hard-to-drain

Adsorption Isotherm at 25°C (GME 2233)
- CO2
- CH4

Easy-to-drain

Adsorption Isotherm at 25°C (GME 2238)
- CO2
- CH4

Easy-to-drain
### Langmuir parameters for the tested samples in terms of CO₂ and CH₄

#### Samples from hard-to-drain area

<table>
<thead>
<tr>
<th>Langmuir parameters</th>
<th>GME 2126</th>
<th>GME 2127</th>
<th>GME 2128</th>
<th>GME 2130</th>
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<tbody>
<tr>
<td>Drainage area</td>
<td>Hard-to-drain</td>
<td>Hard-to-drain</td>
<td>Hard-to-drain</td>
<td>Hard-to-drain</td>
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<tr>
<td>Langmuir volume for CO₂ (cc/g)</td>
<td>29.2</td>
<td>35.2</td>
<td>33.1</td>
<td>31.4</td>
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<tr>
<td>Average Langmuir volume for CO₂ (cc/g)</td>
<td>32.2</td>
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<td></td>
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<tr>
<td>Langmuir pressure for CO₂ (kPa)</td>
<td>653.4</td>
<td>992.1</td>
<td>845.0</td>
<td>704.4</td>
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<tr>
<td>Langmuir volume for CH₄ (cc/g)</td>
<td>18.6</td>
<td>23.4</td>
<td>18.2</td>
<td>15.3</td>
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<tr>
<td>Average Langmuir volume for CH₄ (cc/g)</td>
<td>18.9</td>
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<td></td>
<td></td>
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<tr>
<td>Langmuir pressure for CH₄ (kPa)</td>
<td>774.4</td>
<td>1213.5</td>
<td>812.8</td>
<td>1457.5</td>
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</table>

#### Samples from easy-to-drain area

<table>
<thead>
<tr>
<th>Langmuir parameters</th>
<th>GME 2192</th>
<th>GME 2233</th>
<th>GME 2238</th>
<th>GME 2198</th>
<th>GME 2203</th>
<th>GME 2213</th>
<th>GME 2218</th>
<th>GME 2225</th>
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<td>Easy-to-drain A</td>
<td>Easy-to-drain A</td>
<td>Easy-to-drain B</td>
<td>Easy-to-drain B</td>
<td>Easy-to-drain B</td>
<td>Easy-to-drain B</td>
<td>Easy-to-drain B</td>
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<tr>
<td>Langmuir volume for CO₂ (cc/g)</td>
<td>36.5</td>
<td>28.4</td>
<td>30.9</td>
<td>32.0</td>
<td>31.5</td>
<td>31.5</td>
<td>33.0</td>
<td>29.7</td>
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<td>Average Langmuir volume for CO₂ (cc/g)</td>
<td>31.9</td>
<td>31.54</td>
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<tr>
<td>Langmuir pressure for CO₂ (kPa)</td>
<td>776.9</td>
<td>626.1</td>
<td>827.3</td>
<td>878.9</td>
<td>636.4</td>
<td>582.7</td>
<td>741.0</td>
<td>635.7</td>
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<tr>
<td>Langmuir volume for CH₄ (cc/g)</td>
<td>20.2</td>
<td>18.1</td>
<td>22.1</td>
<td>19.8</td>
<td>18.4</td>
<td>17.2</td>
<td>19.5</td>
<td>17.4</td>
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<tr>
<td>Average Langmuir volume for CH₄ (cc/g)</td>
<td>20.1</td>
<td>18.5</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Langmuir pressure for CH₄ (kPa)</td>
<td>1415.8</td>
<td>667.5</td>
<td>1120.7</td>
<td>971.4</td>
<td>1288.3</td>
<td>1194.8</td>
<td>1508.5</td>
<td>1396.9</td>
</tr>
</tbody>
</table>

- Isotherms- no significant difference
- Average Langmuir volume of CO₂ for the hard-to-drain area is slightly higher than the easy-to-drain areas
- Higher adsorption capacity for CO₂
- Hard to drain samples are highly under-saturated – maximum in-situ total gas content around 10m³/t
Gas Saturation Degree and gas drainability

Considering the same initial *in-situ* gas condition, gas content (10.5 m³/t) and pressure (3.5 MPa), it can be seen that a CO₂ rich coal requires far larger reservoir pressure reduction to reach the critical desorption point than that for an equivalent CH₄ rich coal.

(Black and Aziz, 2010)
Scanning Electron Microscope (SEM) technology to analyse the coal matrix system and the microstructures difference between the hard-to-drain area and easy-to-drain coal samples.
The microstructures of the hard-to-drain coal samples appear solid surface was the dominating feature compared with the easy-to-drain samples. This reason for the difficulty of draining gas from coal sections of Bulli seam in hard-to-drain area, where the coal microstructure is tight.
Coal Microscopy Study – Easy-to-drain

Image showing the coal fracture and open porous structure (easy-to-drain area)

Generally fracture and open pore structure were easily captured in the SEM scan from both perpendicular and parallel directions of easy-to-drain samples. These porous structures will act as the main gas flow and transportation media when the gas drainage process is carried out.
Permeability Study

Multi Function Outburst Research Rig (MFORR) and tested coal samples

\[ K = \frac{\mu Q \ln \left( \frac{r_o}{r_i} \right)}{\pi L \left( P_1^2 - P_2^2 \right)} \]
Permeability Study

Triaxial Compression Apparatus and tested coal samples

\[ K = \frac{2Q\mu LP_2}{A(P_1^2 - P_2^2)} \]
The permeability converges to a steady level **below 1 mD** under high triaxial stress conditions portraying the near in situ conditions of the Bulli seam.
Out of the total 519 samples of whole database, 325 are “Pass” samples (62.6%) , and 194 are “Fail” samples (37.4 %);

The area with gas composition CH4/ (CH4+CO2) less than 0.2 (20%) includes 171 “Fail” samples, accounting for 88.1 % of total “Fail” samples.
A close look of the gas data from typical hard-to-drain area:

- All in the CO2 rich area, the largest ratio of CH4/ (CH4+CO2) is 0.21.
- The zone of CH4/ (CH4+CO2) less than 0.2 includes 60 “Fail” samples, accounting for 93.8 % of total “Fail” samples.
A special high pressure triaxial cell was used to carry the CO2 and CH4 recovery by N2 injection process. The tests aim to

- understand the mechanism of injecting N2 gas to enhance the recovery of CO2 and CH4 as in the hard-to-drain area.
- establish relationship between N2 injection/flushing time and CO2 and CH4 recovery.
During the N2 flushing process, CO2 composition of the chamber gas gradually decreases and N2 composition increases during the N2 flushing test, which indicates that CO2 gas continues to be flushed out by N2.

The total gases consumed from N2 flushing test was estimated to be 100.9 L of N2 in the flushing test, liberating 33.1 L of CO2 out of the system.
N2 Gas Flushing Test to Enhance CO2 Recovery

In the desorption process, CO2 composition starts to increase from 3.4% to 9.4%, while N2 composition decreases from 96.6% to 90.6% over a period of around 3 hrs (200 min) time. At the end of test a total 37.7 L of N2 and 2.3 L of CO2 is collected.
Enhanced seam gas recovery by N\textsubscript{2} flushing – Field trials

Surface Nitrogen Generator

Nitrogen

CO\textsubscript{2}/CH\textsubscript{4} Production

CO\textsubscript{2}/CH\textsubscript{4} Production

In-seam boreholes

Borehole 2

Borehole 1

Borehole 3

CO\textsubscript{2} rich and low permeability seam
Conclusions

- **Fundamental studies of hard-to-drain coals**
  - highly under-saturated (low saturation degree) with high CO2 content > 80%
  - Tight microstructures under Scanning Electron Microscope (SEM)
  - permeability <1 mD
  - Geological variation, including fault presence and cleat system variation; coal mineralisation, mylonite presence
  - Other factors ....

- **N2 flushing tests demonstrate N2 injection can be used to recover CO2 and CH4 gas from tight coals**
  - gas drainage to meet mine schedule requirements
  - enable pre-drainage of coal reserves with very low permeability

- **Field trials of N2 flushing**
Acknowledgements

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