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Enhancement of coal seam gas by N2 injection - a laboratory study

Naj Aziz  
*University of Wollongong, naj@uow.edu.au*

Raul Florentin  
*University of Wollongong, rmmf934@uowmail.edu.au*

Lei Zhang  
*University of Wollongong, lz755@uowmail.edu.au*

Ting Ren  
*University of Wollongong, tren@uow.edu.au*

Dennis Black  
*PacificMGM*

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Enhancement of Coal Seam Gas by N₂ Injection- A laboratory study

Naj Aziz

Raul Florentin, Lei Zhang, Ting Ren and Dennis Black

School of Civil, Mining and Environmental Engineering
University of Wollongong Australia
Recoverable economic **demonstrated** resources of black coal: **73.2 bt**
Recoverable **inferred** resources: **125.160 bt.**

**Brown Coal:** > **68 bt** mainly in Vic. and small quantity in SA
Australia is 4th largest producer of black coal, after China, USA & India.

5th largest producer of brown coal, after Germany, Russia, Turkey and USA.

Brown Coal Output: 68 Mt in 2010 (Vic and S/A)
Almost 98% of black coal is sourced from Queensland & NSW. Australia produces and exports both metallurgical (COKING) and thermal (STEAMING) coal in almost equal proportions. **Queensland** produces the majority of Australia’s metallurgical (coking) coal, **New South Wales** produces predominantly thermal (steaming) coal.
AUSTRALIAN RAW COAL PRODUCTION BY METHOD OF MINING

No of Longwall: 30-31
Production 2010: 100 Mt
Total Underground: >100 Mt

Million of Tonnes

Year

1983 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 2000 01 02 03 04 05 06 07 08

Open Cut
B & B, Development
Longwall

Coal Services Pty Limited

Open Cut
Currently there are around 30 longwall operations in Australia. 45% of the longwall mines require regular gas drainage to manage coal seam gas emissions within the mine.

Coal seam gas represents potentially a significant risk to the safety and productivity of underground mines.

**Queensland Mines**
- Grasstree,
- North Goonyella,
- Moranbah North,
- Oaky No.1,
- Oaky North
- Newlands
- Carborough Downs

**New South Wales Mines**
- Appin,
- Integra
- Mandalong,
- Metropolitan,
- Beltana,
- Tahmoor,
- West Cliff,
- Whitehaven.
Intensive Underground Gas Drainage Drilling

Typical Bulli Seam Colliery Gas Drainage
- Total Drilling ~145,000 metres per year
- Total budget ~A$6-7M per year
- Drilling cost ~A$50-100 per metre
- Drilling rate ~60-65 metres per rig shift
- Borehole diameter = 96mm

65 metres per rig
<table>
<thead>
<tr>
<th>Colliery</th>
<th>Date</th>
<th>Seam</th>
<th>Basin</th>
<th>Depth (m)</th>
<th>No of O/B</th>
<th>No. Killed</th>
<th>Gas</th>
<th>Ejected coal size (t)</th>
<th>Work Place</th>
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<td>1895-1995</td>
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<td>Sydney</td>
<td>425</td>
<td>154 (tot)</td>
<td>-</td>
<td>CO₂, Mainly with CH₄</td>
<td>200</td>
<td>Pick</td>
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<td>Sydney</td>
<td>425</td>
<td>3</td>
<td>-</td>
<td>Firedamp</td>
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<td>Single shot</td>
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<td>Sydney</td>
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<td>CO₂</td>
<td>90</td>
<td>Undercutting</td>
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<td>425</td>
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<td>CO₂ + CH₄</td>
<td>300</td>
<td>2</td>
<td>Induced shotfiring</td>
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<td>Sydney</td>
<td>370</td>
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<td>CH₄</td>
<td>1</td>
<td>Pick-delayed</td>
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<td>Sydney</td>
<td>450</td>
<td>2</td>
<td>CO₂ + CH₄</td>
<td>2</td>
<td>140</td>
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<td>50</td>
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<td>Appin</td>
<td>1966</td>
<td>Bulli</td>
<td>Sydney</td>
<td>520</td>
<td>5</td>
<td>CH₄</td>
<td>60</td>
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<td>Bulli</td>
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<td>Sydney</td>
<td>460</td>
<td>253</td>
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<td>4-300</td>
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<td>Bowen</td>
<td>220</td>
<td>19</td>
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<tr>
<td>C.C.C.P</td>
<td>1978</td>
<td>Bulli</td>
<td>Bowen</td>
<td>280</td>
<td>4</td>
<td>CH₄</td>
<td>25</td>
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<td>Bowen</td>
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<td>90*</td>
<td>CH₄</td>
<td>500</td>
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<td>Bulli</td>
<td>Sydney</td>
<td>90*</td>
<td>1</td>
<td>CO₂</td>
<td>Cont Miner</td>
<td>1</td>
<td>*Since 1981</td>
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<td>Sydney</td>
<td>3</td>
<td>3</td>
<td>CO₂</td>
<td>300</td>
<td>2</td>
<td>Development</td>
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<td>3</td>
<td>3</td>
<td>CO₂</td>
<td>300</td>
<td>2</td>
<td>Development</td>
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<td>German Ck</td>
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<td>400</td>
<td>1</td>
<td>CH₄</td>
<td>60-80</td>
<td>1</td>
<td>Development</td>
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<td>Sydney</td>
<td>2</td>
<td>2</td>
<td>CH₄ + CO₂</td>
<td>10</td>
<td>2</td>
<td>Development</td>
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<td>Kemira</td>
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<td>2</td>
<td>2</td>
<td>CH₄</td>
<td>6-100</td>
<td>2</td>
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<td>Tower</td>
<td>1981-2000</td>
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<td>Sydney</td>
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<td>19</td>
<td>CH₄</td>
<td>1-80</td>
<td>3</td>
<td>Development</td>
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<tr>
<td>Appin</td>
<td>2010</td>
<td>Bulli</td>
<td>Sydney</td>
<td>3</td>
<td>3</td>
<td>CH₄ + CO₂</td>
<td>3</td>
<td>3</td>
<td>Development</td>
</tr>
</tbody>
</table>

* Total Number of outbursts > 730

No of O/B since 1895 > 730
Problem: Coal seams with difficult to drain sections

- Some sections of some coal seams are difficult to drain of gas.
- Bulli seam, Illawarra Coal Measure formation, Sydney Basin
## Bulli Seam Coal property Values

<table>
<thead>
<tr>
<th>Coal Property</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CH}_4/(\text{CH}_4+\text{CO}_2)$ (%)</td>
<td>6.5</td>
<td>97.8</td>
</tr>
<tr>
<td>Gas Content (m$^3$/t)</td>
<td>5.2</td>
<td>15.7</td>
</tr>
<tr>
<td>Permeability (mD)</td>
<td>0.05</td>
<td>6.0</td>
</tr>
<tr>
<td>Seam Thickness (m)</td>
<td>2.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Ash Content (%)</td>
<td>9.4</td>
<td>14.8</td>
</tr>
<tr>
<td>Moisture Content (%)</td>
<td>0.7</td>
<td>1.3</td>
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<tr>
<td>Vitrinite Reflectance ($R_{V_{\text{max}}}$)</td>
<td>1.23</td>
<td>1.36</td>
</tr>
<tr>
<td>Vitrinite (%)</td>
<td>28.9</td>
<td>54.5</td>
</tr>
<tr>
<td>Inertinite (%)</td>
<td>45.5</td>
<td>71.1</td>
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<tr>
<td>Mineral Matter (%)</td>
<td>1.8</td>
<td>5.8</td>
</tr>
<tr>
<td>Volatile Matter (%)</td>
<td>19.7</td>
<td>25.3</td>
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</table>
Gas content contours relative to mine workings

90% CO2                  60% CO2                                        90% CH4

Difficult to Drain zone                                                                        Easy to drain

521 Panel
520 Panel
519 Panel
518 Panel
517 Panel
516 Panel
Permeability contours (mD) relative to mine workings

90% CO2                  60% CO2                                        90% CH4
Low Permeability

CO₂ rich area
90%

Intermediate area

Perm: 3.3 mD

60% CO₂

High Permeability

CH₄ rich area
94%

Panel length: 3 - 3.5 km

519 31B

519 21B

520 3B
N₂ injection and recovery of the inherent gases;
Seam Gas:
- CO₂ or
- CH₄ or
- CH₄ / CO₂

• Laboratory study
MFORR
Laboratory Experimental study - N2 Injection

Nitrogen Injection methods

Axial N2 Charge (Reverse/Direct)               Lateral N2 Charge (Indirect)
Triaxial permeability apparatus and MFORR

Lateral Injection

Axial Load

Pressure Chamber
Core Sample
10 t Load Cell

Gas Outlet

Flowmeters

Data Logger

N₂ CO₂ CH₄

GC

Gas Outlet

0-180mL/min
0-2 L/min
0-15 L/min

Flowmeters

Hole Dia: 2.0 mm

10th IMVC-SA

University of Wollongong
Test 4 - Gas flow through core sample saturated at 3000 kPa
Mine A - Sample 519-2122 (Size 54 mm diameter)
Carbon dioxide vs Nitrogen

1 day = 1440 min

Flow: 0.4 L/S = 3.3 m3/d
Per: 3.3 mD

Initial CO2 Sat Time: 10.8 days (15550 min)

N2 Charge Time:
- 110 min
- 215 min

CO2 increase: 50%
N2 drop: 50%

Pressure:
- 15550 min
- 15600
- 15650
- 15700
- 15750
- 15800
- 15850

Gas composition:
- CO2 AirFree (%)
- N2 AirFree (%)

Time (min):
- 15550
- 15600
- 15650
- 15700
- 15710 - 15730
- 15750
- 15800
- 15850

Flow: 0.4 L/S = 3.3 m3/d
Per: 3.3 mD

CO2 increase: 50%
N2 drop: 50%
Panel length: 3 - 3.5 km

CO₂ rich area
90%

Intermediate area
60% CO₂

Perm: 3.3 mD

CH₄ rich area
94%

519 31B

519 21B

520 3B
**CO2:** Saturation Time =10.8 days
0-50%: 20 min.
Hence 50% composition point occur at 15 730 min (10.9 days)
@ 3200 kPa the Maximum CO2 flowing through the sample = 0.04 l/sec (3.3 m3/d)
with Cleat permeability of 0.5-1.5 mD

**CH4:** Full saturation= 5760 min (4d)
Flow @ 3200 kPa = 0.04 l/sec (3.3 m3/d)
with cleat permeability of 2.5 mD
CH4 drainage improvement = 20 % after 90 min

**CO2/CH4:** Initial Saturation Time = 7630 min (5.3 days)
Time for full N2 Charge at zero reduction of CO2 /CH4= 30 min
Permeability contours (mD) relative to mine workings and measurement locations.
1. Seal gas chamber and evacuate to near zero pressure
2. Load the coal sample axially to 750 kg Force (3 MPa pressure)
3. Charge the cell with CO₂ and monitor. Maintain gas sorption equilibrium at 2 MPa.
4. Charge N₂
5. Release permeated gas out of the gas chamber at every 6 min to pass through flowmeters and to GC for gas composition analysis.
During the N₂ flushing process, CO₂ composition of the chamber gradually decreased as N₂ composition increased. The whole flushing test took more than 13 hrs (800 min).

- Press. Gradient for gas collection = 50 kPa
- Time for 1.0 L gas collection: 10 sec.
- N₂ consumed during flushing: 101 L
- CO₂ liberated: 33 L.

Ratio: 3:1
In the desorption process, CO$_2$ composition starts to increase from 3.4% to 9.4%, while N$_2$ composition decreases from 96.6% to 90.6% over a period of around 3 hrs (200 min) time.

The collected gas volume of CO$_2$ and N$_2$ in the desorption process was 37.7 L of N$_2$ and 2.3 L of CO$_2$, a ratio $16.3 : 1$. 
The microstructures of the hard-to-drain coal samples appear to be less generated or fractured as compared with the easy-to-drain samples. This may explain another reason for the difficulty of draining gas from coal sections of Bulli seam in hard-to-drain area, where the coal structure is less fractured.
CONCLUSIONS

- $N_2$ Injection is a viable method of gas recovery from coal particularly from hard to drain sections of coal seams.

- Higher quantities of $N_2$ gas is required to remove $CO_2$ gas during both forced and reversed method of $N_2$ injection.

- Coal structure and permeability are important factors in the drainability of gas from coal.
Now Online:

http://ro.uow.edu.au/coal
[All papers since 1998]

UOW Coal Mining websites:

http://research.uow.edu.au/coal

Next Conference (Coal 2015), February 11-13, 2015:

http://www.coalconference.com.au
http://research.uow.edu.au/coal

http://www.uow.edu.au/eng/longwall
http://www.uow.edu.au/eng/outburst
http://www.uow.edu.au/eng/pillar
The next Coal Operators’ Conference ‘Coal 2015’ is scheduled for February 11 and 13th, 2015, at the University of Wollongong. The Conference will address issues related to various aspects of modern coal mining operations both surface and underground. Accordingly, papers are invited from the following topics:

- Surface mining.
- Geology.
- Heading development,
- Mining methods; longwall, bord and pillar, top coal caving and hydraulic mining,
- Equipment and machinery performance or innovations,
- Ground control and strata management,
- Longwall and roof fall recovery,
- Instrumentation and monitoring,
- Rock bolting, cable bolting or other roof support techniques,
- Mine subsidence,
- Mine ventilation, mine gas drainage and outburst control,
- Mine fires and explosions,
- Mine flooding,
- Risk management,
- Mine management and mine contract,

We strongly encourage receiving papers from coal mine operations, as well as fundamental and applied coal mining research.

<table>
<thead>
<tr>
<th>Abstract submission</th>
<th>August 28th, 2014</th>
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<tbody>
<tr>
<td>Acceptance of the paper based on abstract</td>
<td>September 15th, 2014</td>
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<tr>
<td>Date of full paper submission</td>
<td>November 27th, 2014</td>
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<td>Conference day</td>
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Contact:

Technical:
Naj Aziz (Chairman and Convenor)
University of Wollongong
Wollongong, NSW 2522
Tel: (02) 4221 3449 M: 0466 613 184
Email: naj@uow.edu.au

Conference secretariat:
Peter Vrahos (Conference Manager)
eventico
Tel: 0424 193 520
Email: petervrahos@eventico.com.au
www.eventico.com.au

http://www.coalconference.com.au
Soma Mine Accident, June 2014
Thank You