Enhanced mine gas drainage

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Nature of gas storage in coal

• Coal physical structure
  • Has a dual porosity
    • Macropores – the cleat system
    • Micropores – the coal matrix
  • Most of the porosity and surface area is in the matrix (e.g., 85%)

Total porosity is low
Majority of gas is adsorbed to solid structure
Most surface area is within the matrix

• Cleat systems
  • Two main sets - orthogonal
    • Face cleats
    • Butt cleats
  • perpendicular to bedding plane

Laubach et al. 1998
Gas adsorption in coal

- Quantity stored is a function of pressure, temperature
- Coal adsorbs more CO$_2$ than CH$_4$, capacity for nitrogen is low
  - typically 2 molecules of CO$_2$ for each CH$_4$ molecule
  - 4 CO$_2$ or 2 CH$_4$ for every N$_2$

![Graph of gas content vs pressure](attachment:graph.png)

**Bulli seam**
Primary coal seam gas recovery

Initial state – pressure maintains a certain mass of gas adsorbed

Fluid pressure lowered in cleat/fracture system – pressure difference between cleat and matrix

Pressure lowered, gas desorbs and diffuses through matrix to cleat – water and gas flow within cleats
Two-phase flow system around the well

Stage 3: Two-phase flow regime
Stage 2: Unsaturated flow regime
Stage 1: Saturated flow regime

• $K_{\text{effective}} = K_{\text{relative}}$. $K$
Gas drainage effectiveness

- Drainage
  - a complex function of borehole spacing, gas flow, gas desorption with pressure
    - Key reservoir properties - permeability, adsorption isotherm
  - Limited by the ability to lower the pore pressure
Pressure drawdown and gas desorption

- Drawing the reservoir pressure down from 4 MPa to 1 MPa
  - CH4 14 m³/t to 8.8 m³/t
  - CO2 25 m³/t to 19 m³/t – much lower pressures required

Limited by the ability to lower the pore pressure within the coal
  - largest changes in gas content occur at low pressure
Enhanced coal seam gas recovery

- **Primary coal seam gas drainage**
  - Pressure drawdown and gas desorption
  - Limited by the ability to reduce the reservoir pressure
  - Drainage a function of well spacing, reservoir properties and drainage lead time

- **Enhanced recovery using gas injection**
  - A contrasting gas (i.e. not the coal seam gas) is injected into the coal seam and this acts to displace the coal seam gas
Enhanced recovery process

Initial state – pore fluid pressure maintains a certain mass of gas adsorbed

Methane partial pressure lowered in cleat/fracture system by injection of contrasting gas, for example nitrogen

Methane pressure lowered, gas desorbs and diffuses through matrix to cleat – water and gas flow within cleats
Example: Enhanced gas drainage using nitrogen

**Adsorbed gas content**

- **Methane**
  - X Direction (m)
  - Gas content (m³)

- **Nitrogen**
  - X Direction (m)
  - Gas content (m³)

**Gas phase composition**

- **Nitrogen**
  - Gas phase composition (fraction)
  - X Direction (m)

- **Methane**
  - Gas phase composition (fraction)
  - X Direction (m)

**Methane gas drainage rate**

- **Enhanced rate**
  - Time (DAYS)
  - M³/m³

- **Primary**
  - Time (DAYS)
  - M³/m³

Simulation results calculated with SIMEDWin
Enhanced coal seam gas drainage

• Potential advantages
  • Since ECBM relies on gas partial pressure difference to displace gas in place
    • Ultimate drainage can be much higher than primary recovery
  • Also the injected gas acts to maintain the reservoir pressure and increase gas drainage rates
  • Injecting a weakly adsorbing gas (i.e. nitrogen) will increase the permeability through coal shrinkage with decreased total gas content

• Candidate gases for injection
  • Weakly adsorbing gas – nitrogen
  • Gas mixtures – nitrogen & carbon dioxide - for open cut purposes
  • Pure or high percentage CO2 not appropriate – much higher gas contents than in place methane, well known problematic gas for mine drainage, associated with low permeability, lower outburst threshold

• Additional costs of ECBM
  • Well costs (dedicated injection well)
  • Sourcing the injection gases and their compression/injection
Enhanced recovery field trials

- **N2 injection**
  - Tiffany trial San Juan Basin
  - 1998-2002 (intermittent injection)
  - There was a 5x increase in the methane gas rate in response to N2 injection – due to combined effects of methane displacement, pressure maintenance and permeability enhancement.

*Figure 5: Producing History, Individual Tiffany Unit Well*
Enhance recovery field trials

- **Yubari trial – JCOAL**
  - Vertical injection and production wells 66m separation in target seam at 900m depth
  - Short period of N2 injection after longer duration CO2 injection
  - Also N2 breakthrough at production well

Gas injection and production rates during N2 injection

![Graph showing gas injection and production rates during N2 injection](image)
Nitrogen enhanced mine drainage

- Russell Packham as part of PhD at UNSW
- Bowen basin coal mine
- Surface to inseam wells
- An existing nitrogen membrane plant used for goaf inertisation was available for periods within the year
- Injection into one horizontal well while production maintained in neighbouring wells
- Virgin gas content ~7m$^3$/t

See Packham et al 2011 Int. J. Coal Geol. and Packham et al. 2012 in press
Gas drainage rates

[Graphs showing drainage rates with dates and flow measurements]
Gas drainage predictions from modelling Packham trial
Enhanced drainage and permeability

- Series of reservoir simulations comparing primary and enhanced drainage
- 100m spaced horizontal wells
- 600m deep seam at hydrostatic pressure and gas saturated
Initial gas content 50:50 CH4:CO2

Drainage of CO₂ rich coals

Start N₂ injection

0.5 md
0.25 md

Primary
Enhanced

Matrix shrinkage increasing permeability
Enhanced mine drainage for reducing open cut fugitives

- 130m deep seam with reservoir properties from Hunter Valley coal sample; produced gas is used in a power station.

- Differential net present value after 4 years between the no drainage case and enhanced drainage or no drainage and primary drainage.

- For the no drainage case the seam gases become fugitive and incur an emissions penalty.

- There is a positive business case for enhanced drainage above an emissions penalty of $20/tonne CO2e.

- In contrast primary drainage never reaches breakeven and so is not feasible compared to allowing the gases to become fugitive.

From ACARP C17055
Conclusions

- Enhanced drainage acts to maintain gas drainage rates and increase the proportion of gas recovered.
- Nitrogen is a lower adsorbing gas than CH$_4$ and CO$_2$.
- Enhanced drainage with nitrogen also would increase the permeability through coal shrinkage.
- Coals rich in CO$_2$ may have the greatest benefit because of the low pressure drawdowns required to meet safe mining thresholds.
- Initial reservoir permeability will still play an important role.
- Trials are needed to evaluate this process.