Investigations of Hard (difficult) to drain Seam

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Industry Drives

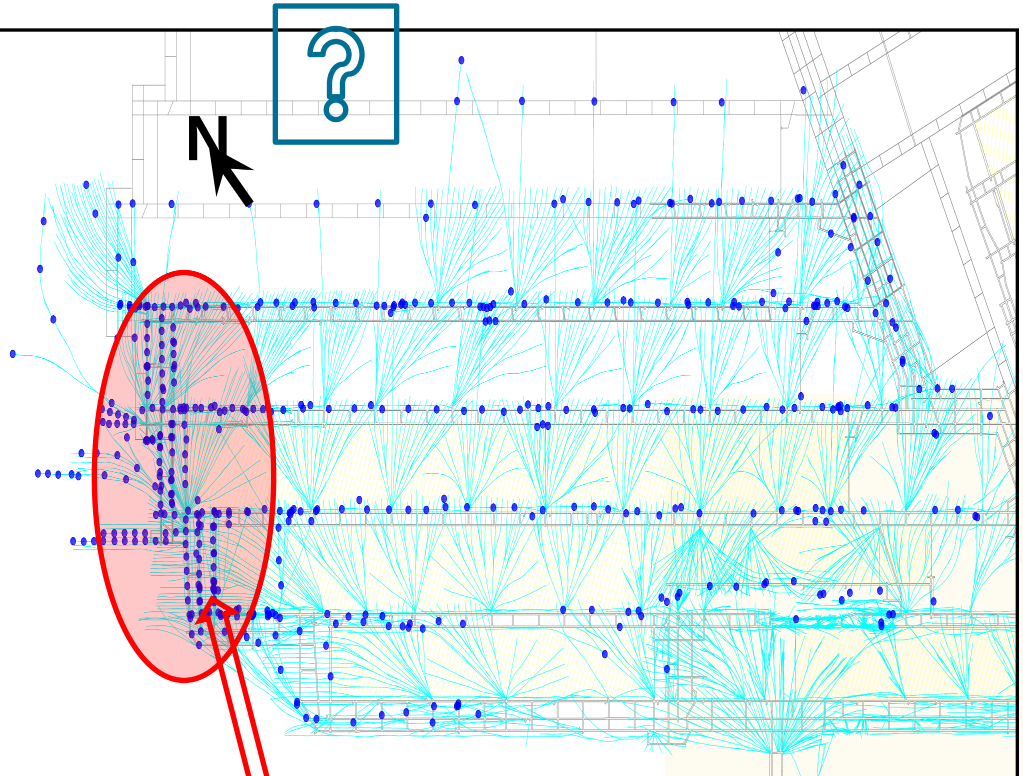
- **Safety of Coal Mining**
  - Outburst hazards
  - Frictional ignition for development drivage

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

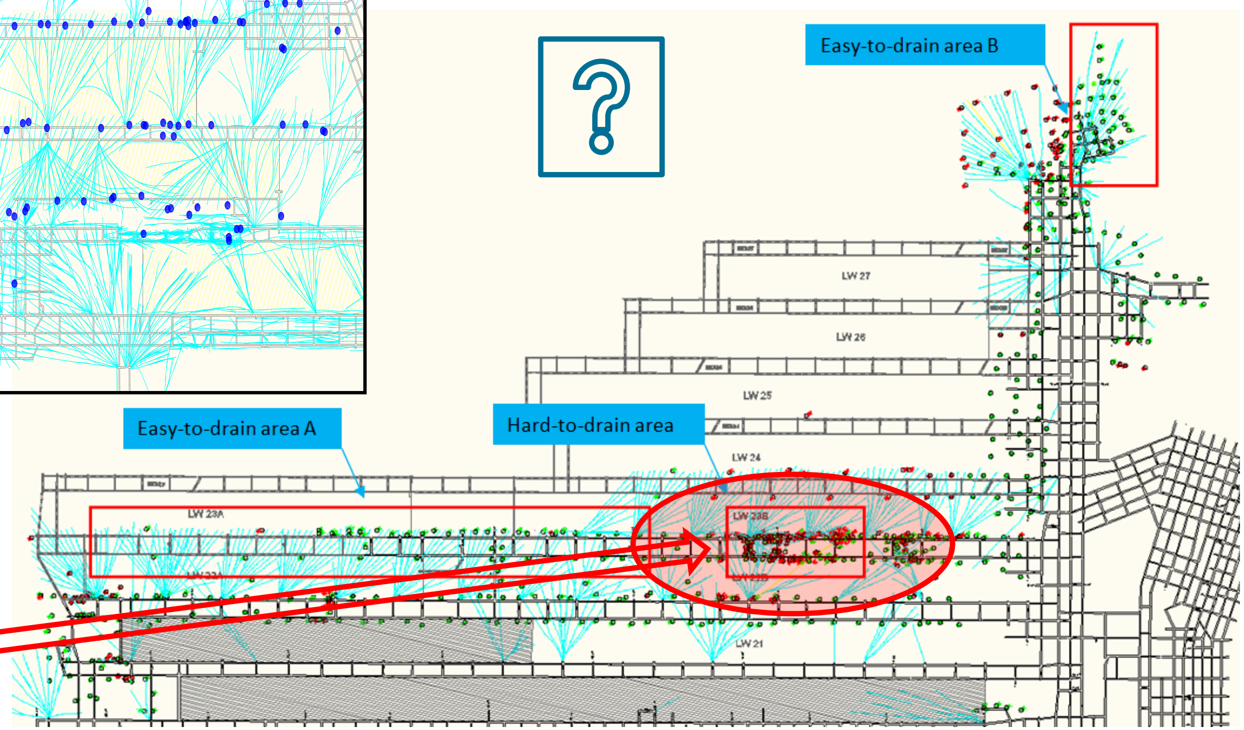
- **Management of fugitive emissions**
  - Carbon pricing

- **CBM/CMM/Coal Seam Gas**
  - Gas recovery from tight seams for energy use

Industry Drives – Coal Mines around Wollongong



Future Areas?

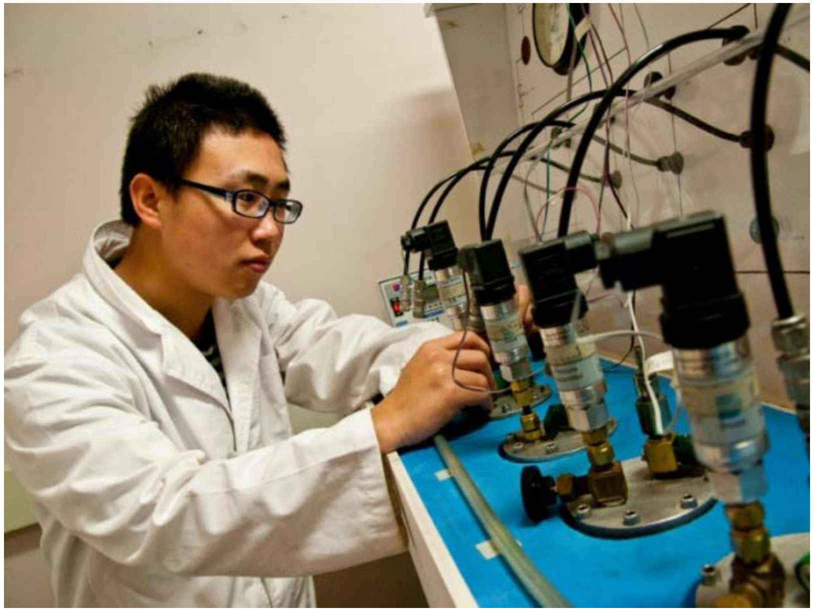


Hard to drain areas with
High CO_2 content

Research Objective

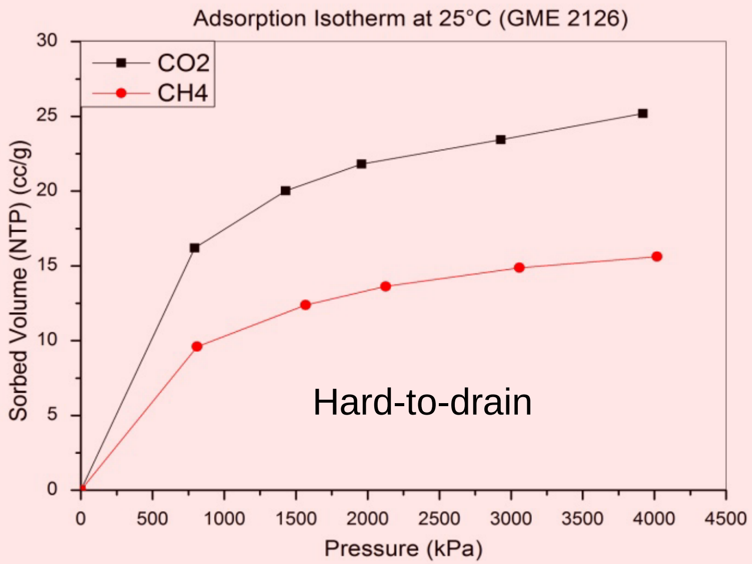
- Identifying the main reasons contributing to “hard-to-drain” in coal seams;
- Establishing the ‘fingerprints’ of hard-to-drain coals to give early warning signs for future drainage process;
- Investigating a new method based on nitrogen flushing to enhance gas drainage in these ‘tight’ areas.

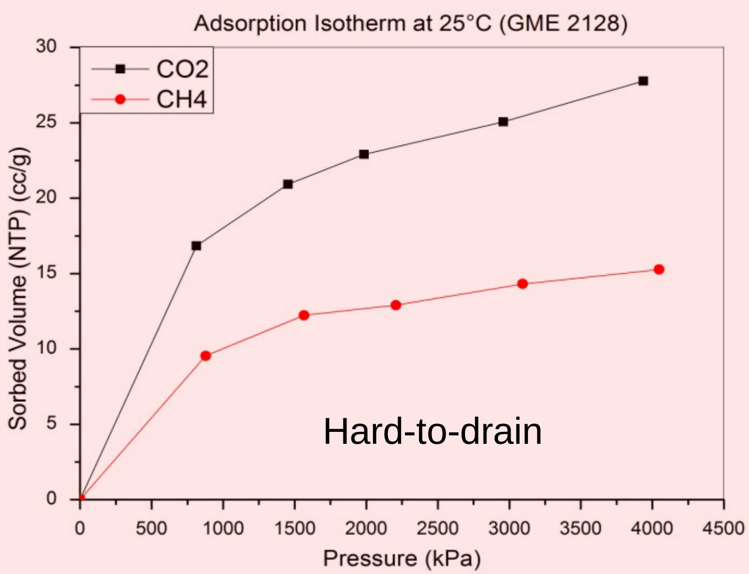
Adsorption Capacity Study - Isotherms

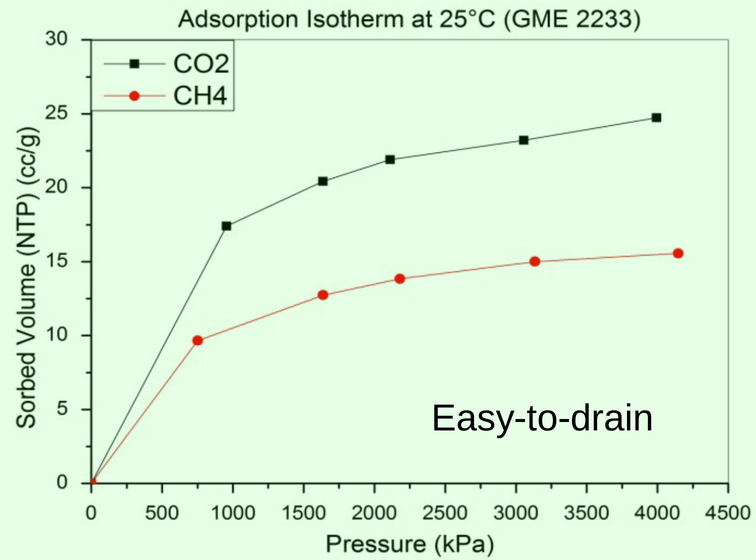


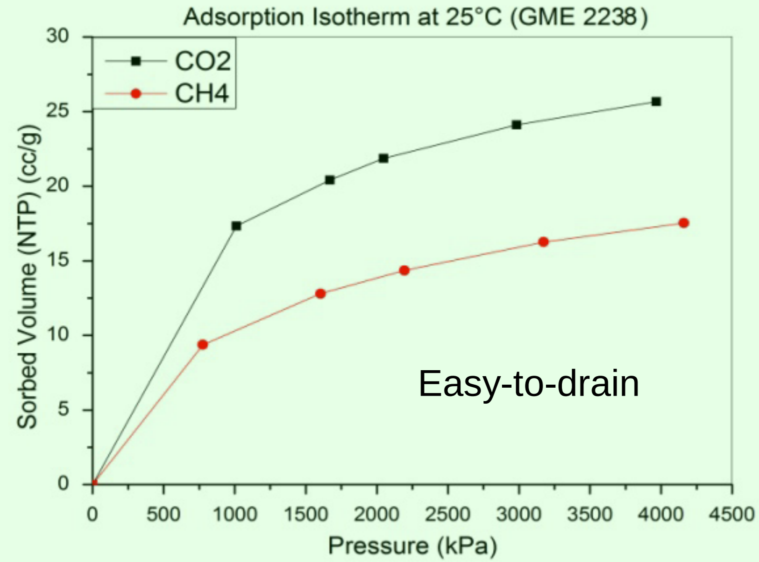
- Indirect gravimetric method to calculate the volume of gas adsorbed.
- Coal samples from hard-to-drain area and easy-to-drain areas tested for comparative isotherms.

Adsorption Capacity Study – Isotherms for Hard-to-drain and Easy-to-drain









Langmuir parameters for the tested samples in terms of CO_2 and CH_4

Samples from hard-to-drain area

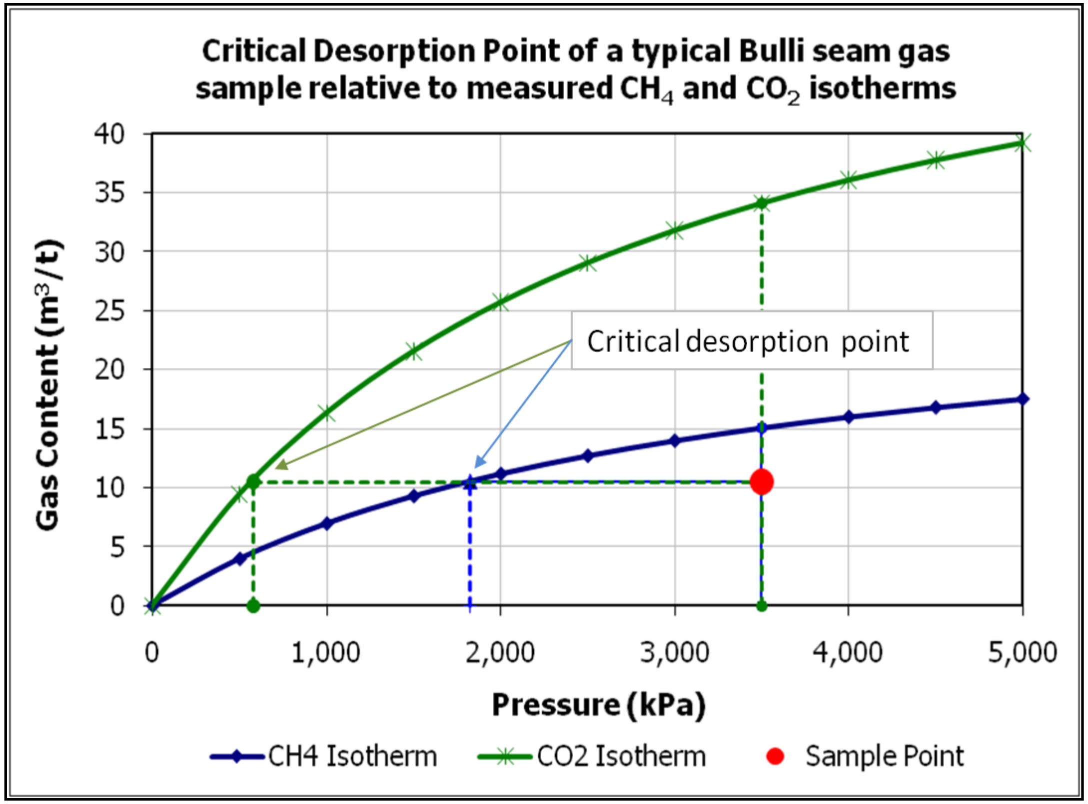
Langmuir parameters	**GME 2126**	**GME 2127**	**GME 2128**	**GME 2130**
Drainage area	Hard-to-drain	Hard-to-drain	Hard-to-drain	Hard-to-drain
Langmuir volume for CO_2 (cc/g)	29.2	35.2	33.1	31.4
Average Langmuir volume for CO_2 (cc/g)	**32.2**			
Langmuir pressure for CO_2 (kPa)	653.4	992.1	845.0	704.4
Langmuir volume for CH_4 (cc/g)	18.6	23.4	18.2	15.3
Average Langmuir volume for CH_4 (cc/g)	**18.9**			
Langmuir pressure for CH_4 (kPa)	774.4	1213.5	812.8	1457.5

- **Isotherms- no significant difference**
- **Average Langmuir volume of CO_2 for the hard-to-drain area is slightly higher than the easy-to-drain areas**
- **Higher adsorption capacity for CO_2**
- **Hard to drain samples are highly under-saturated – maximum in-situ total gas content around $10 m^3/t$?**

Samples from easy-to-drain area

Langmuir parameters	GME 2192	GME 2233	GME 2238	GME 2198	GME 2203	GME 2213	GME 2218	GME 2225
Drainage area	Easy-to-drain A	Easy-to-drain A	Easy-to-drain A	Easy-to-drain B	Easy-to-drain B	Easy-to-drain B	Easy-to-drain B	Easy-to-drain B
Langmuir volume for CO_2 (cc/g)	36.5	28.4	30.9	32.0	31.5	31.5	33.0	29.7
Average Langmuir volume for CO_2 (cc/g)	**31.9**			**31.54**				
Langmuir pressure for CO_2 (kPa)	776.9	626.1	827.3	878.9	636.4	582.7	741.0	635.7
Langmuir volume for CH_4 (cc/g)	20.2	18.1	22.1	19.8	18.4	17.2	19.5	17.4
Average Langmuir volume for CH_4 (cc/g)	**20.1**			**18.5**				
Langmuir pressure for CH_4 (kPa)	1415.8	667.5	1120.7	971.4	1288.3	1194.8	1508.5	1396.9

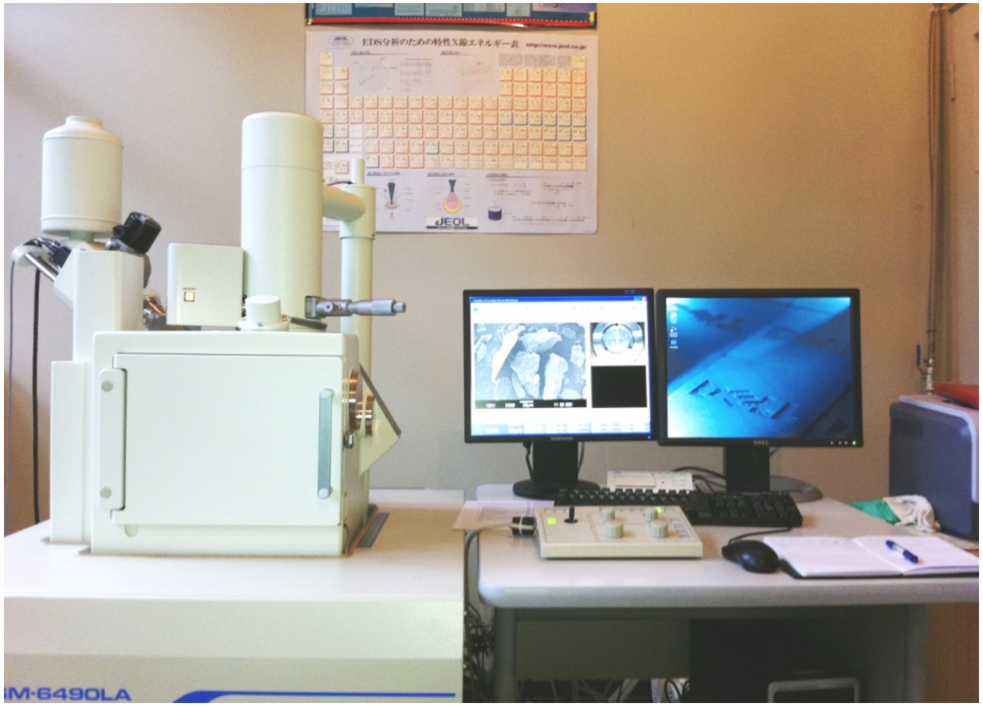
Gas Saturation Degree and gas drainability

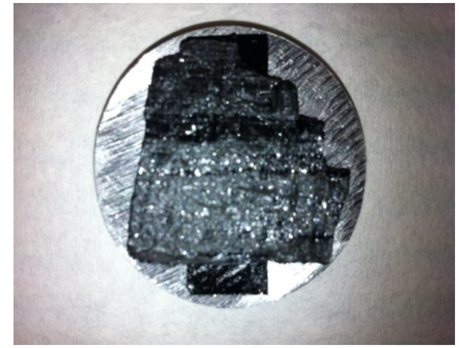


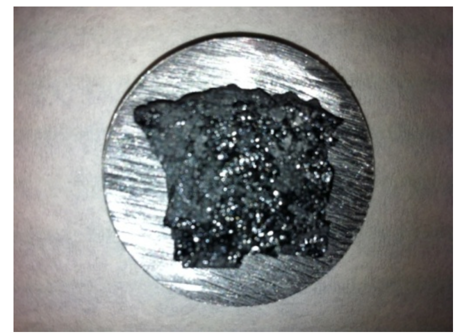
(Black and Aziz, 2010)

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 CO_2 rich coal requires far larger reservoir pressure reduction to reach the critical desorption point than that for an equivalent CH_4 rich coal

Coal Microscopy Study

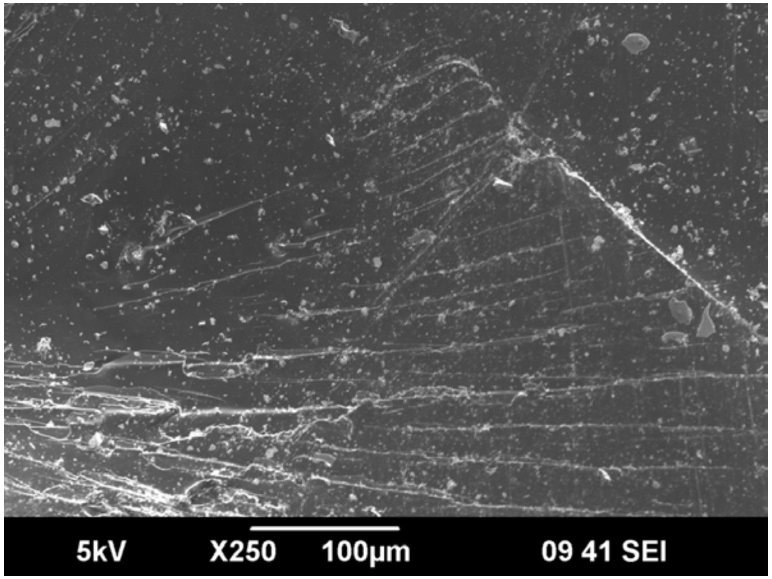






- Scanning Electron Microscope (SEM) technology to analysis the coal matrix system and the microstructures difference between the hard-to-drain area and easy-to-drain coal samples.

Coal Microscopy Study – Hard-to-drain



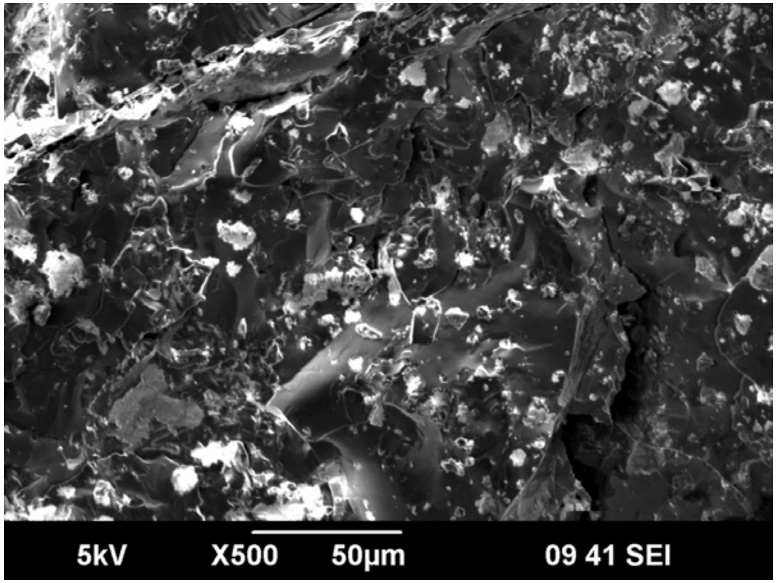


Image showing the coal solid surface and porous structure

(hard-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

>> 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

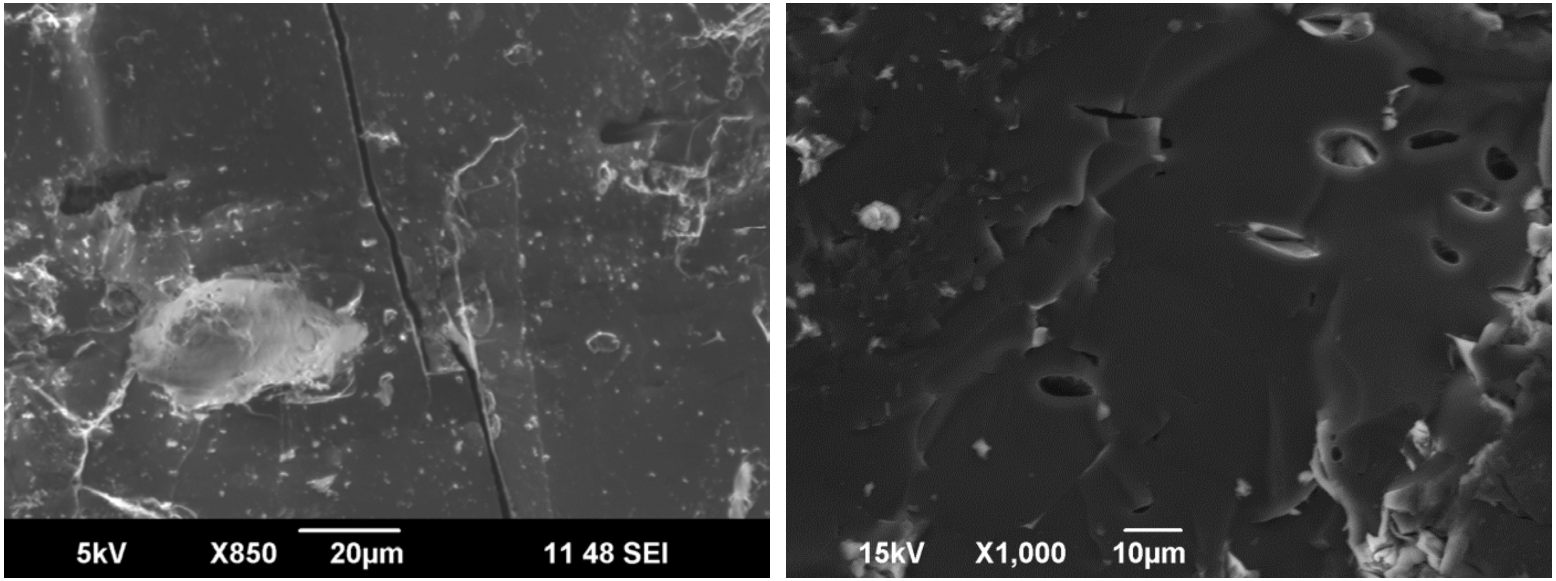
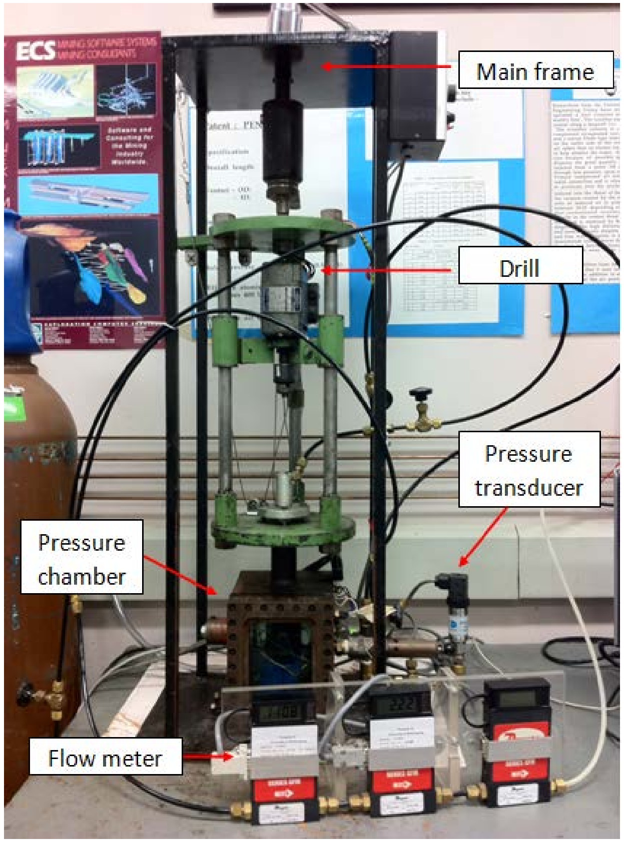


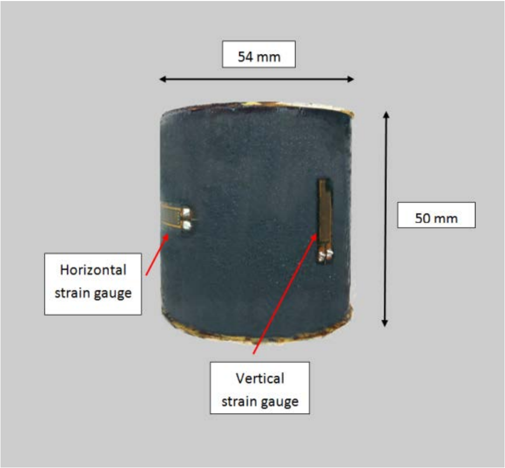
Image showing the coal fracture and open porous structure
(easy-to-drain area)

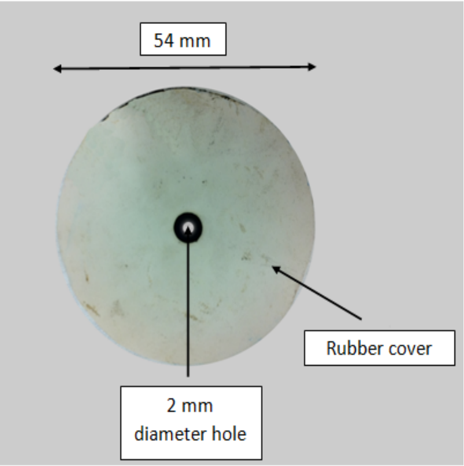
Generally **fracture and open pore structure** were easily captured in the SEM scan from both perpendicular and parallel directions of **easy-to-drain** samples.

These porous structures will act as the main gas flow and transportation media when the gas drainage process is carried out.

Permeability Study



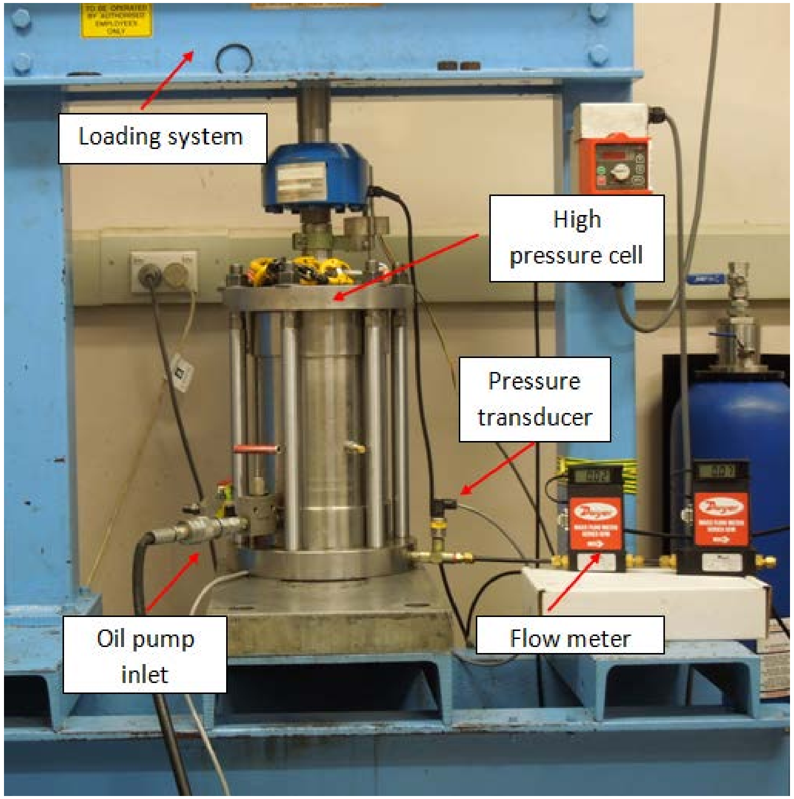


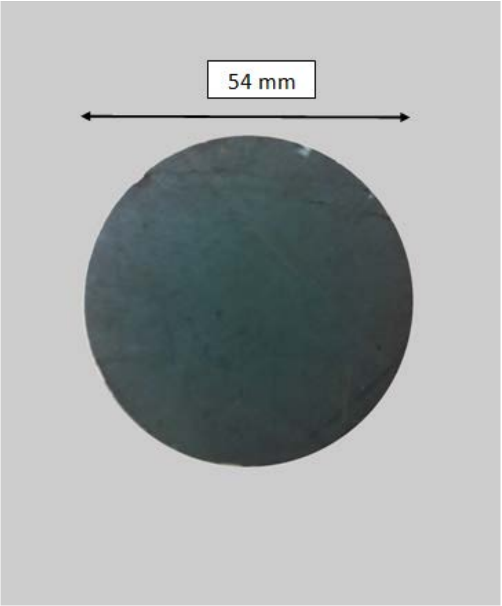


$$K = \frac{\mu Q \ln\left(\frac{r_0}{r_i}\right)}{\pi L ({P_1}^2 - {P_2}^2)}$$

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

Permeability Study

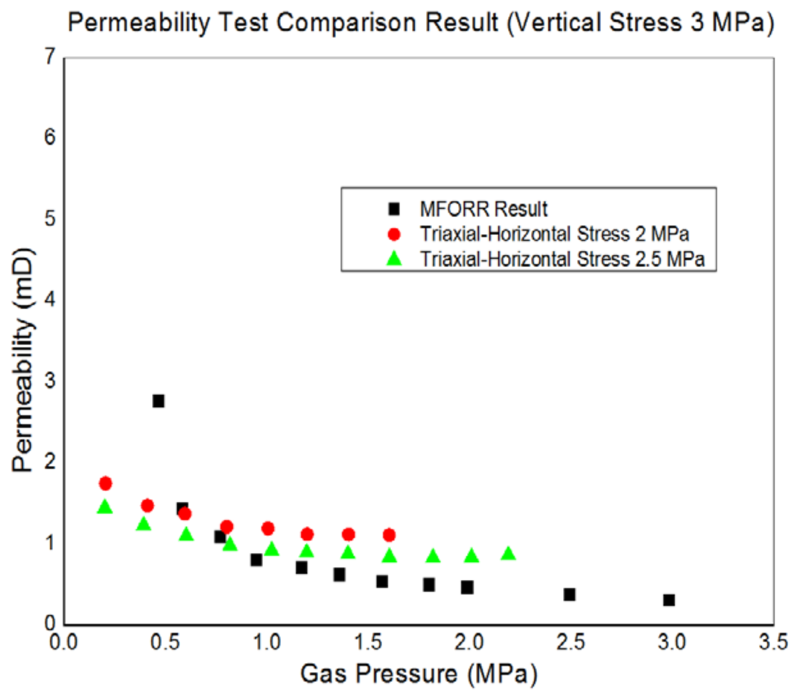


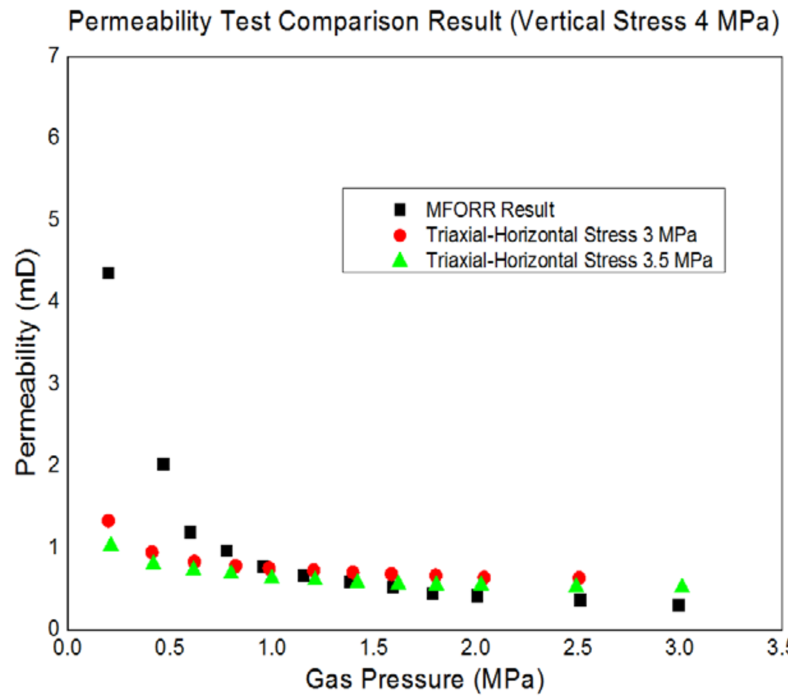


$$K = \frac{2Q\mu L P_2}{A(P_1^2 - P_2^2)}$$

Triaxial Compression Apparatus and tested coal samples

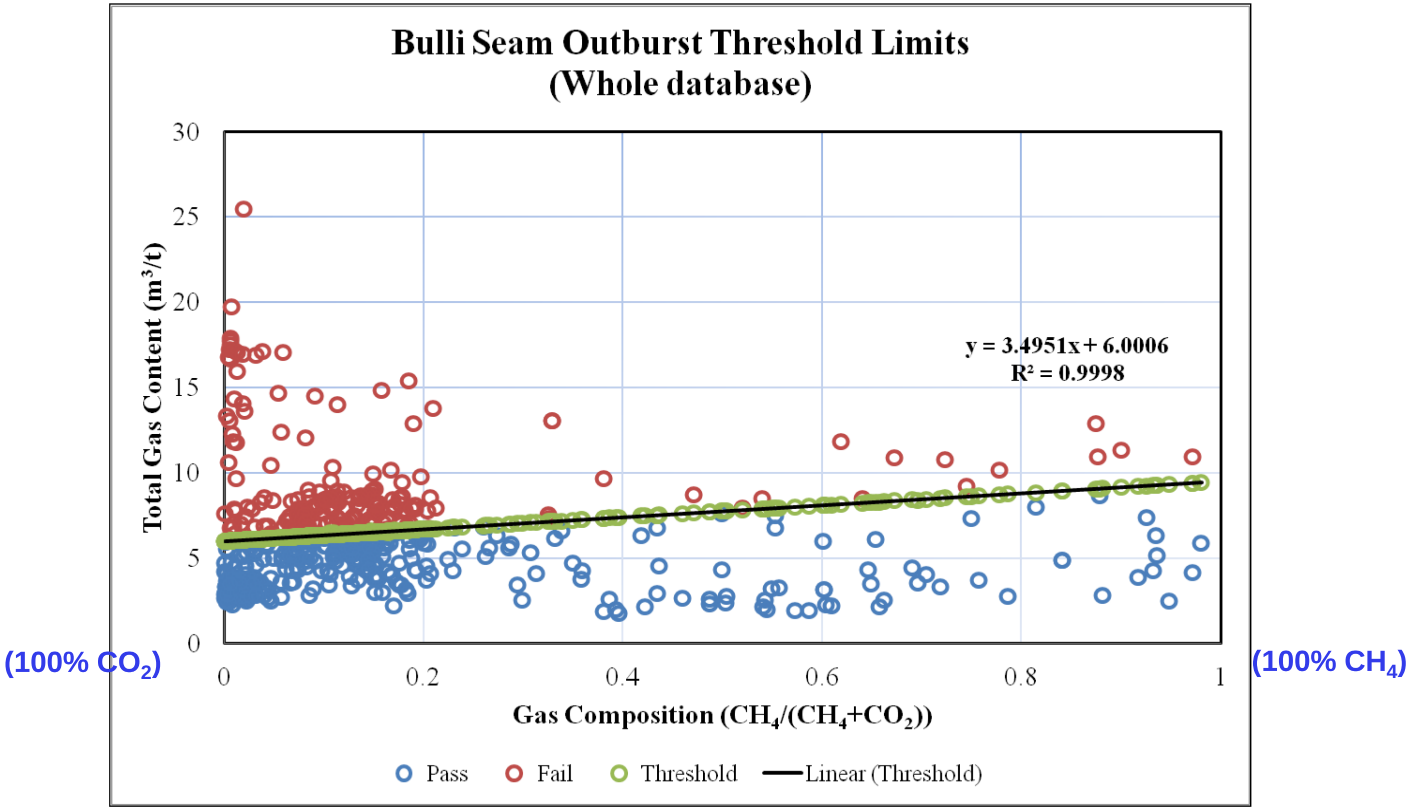
Deep and hard to drain seams – Bulli Seam – permeability test





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.

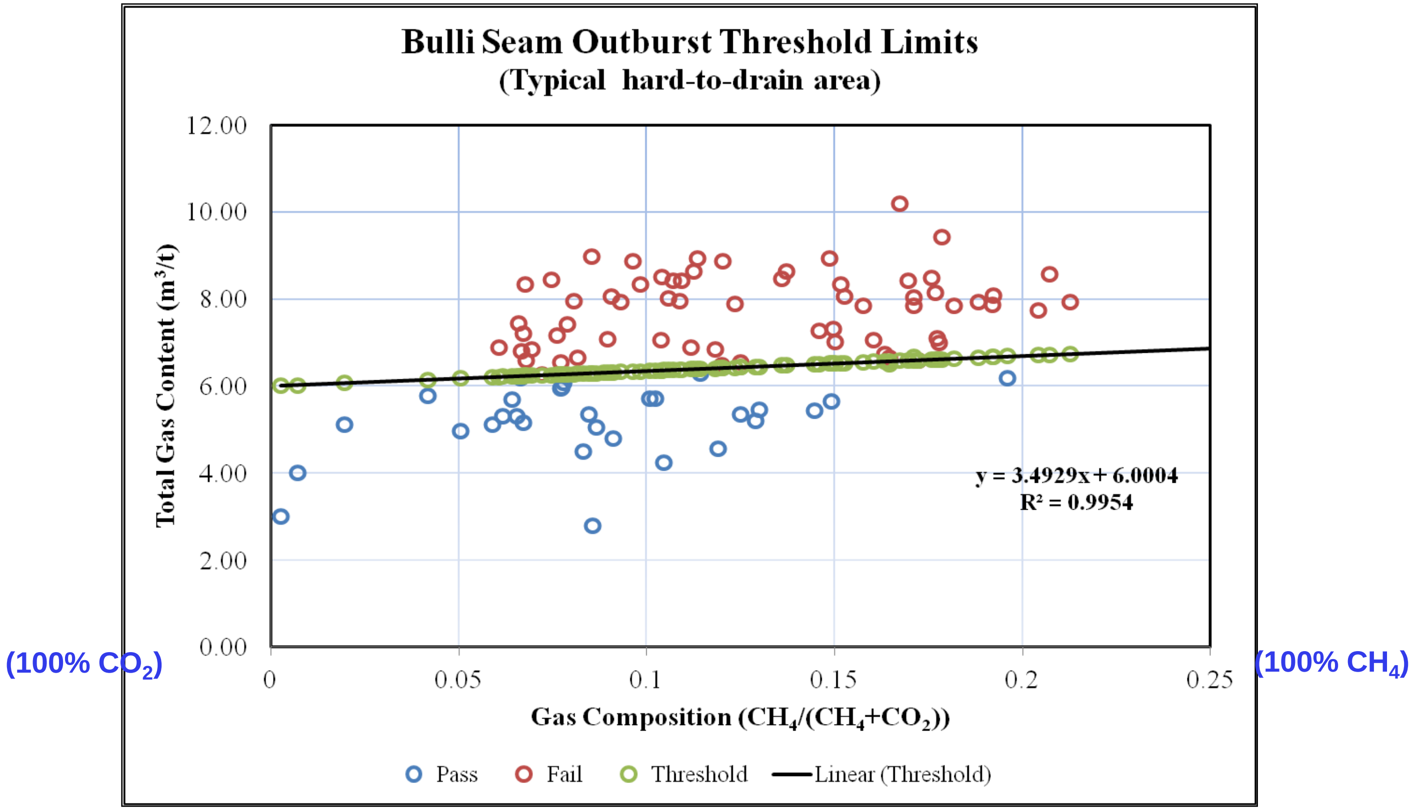
Study of Gas Content and Composition



- 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.

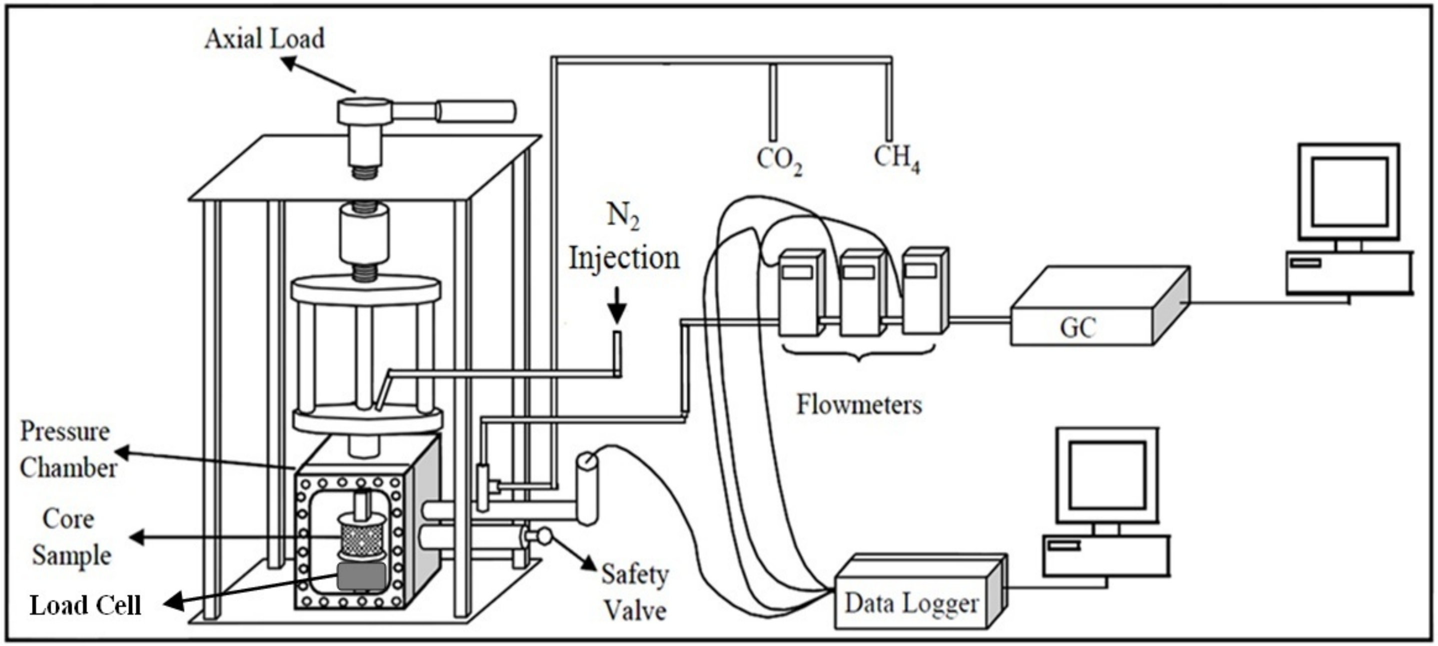
Gas Content and Composition Study



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.

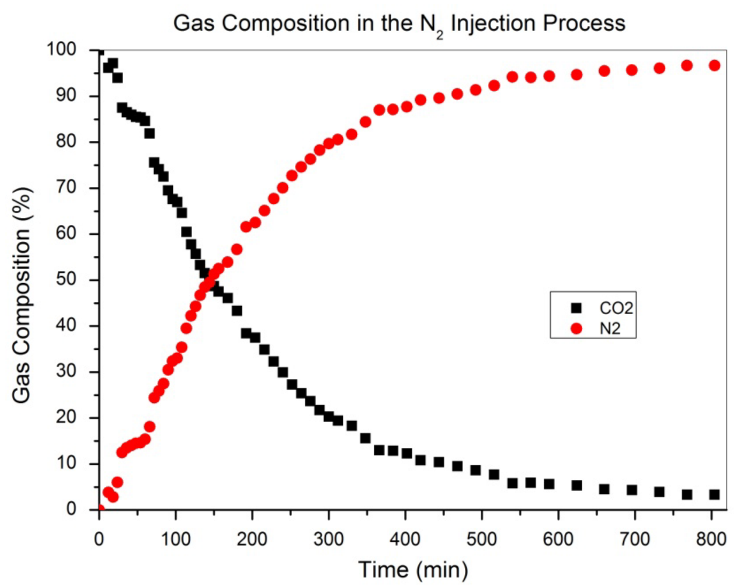
N_2 Gas Flushing Test to Enhance Gas Recovery

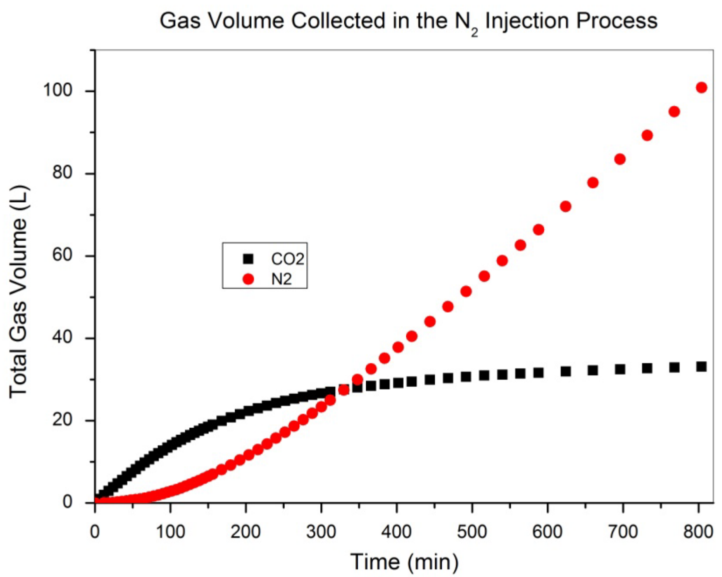


A special high pressure triaxial cell was used to carry the CO2 and CH4 recovery by N2 injection process. The tests aim to

- 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.

N_2 Gas Flushing Test to Enhance CO_2 Recovery

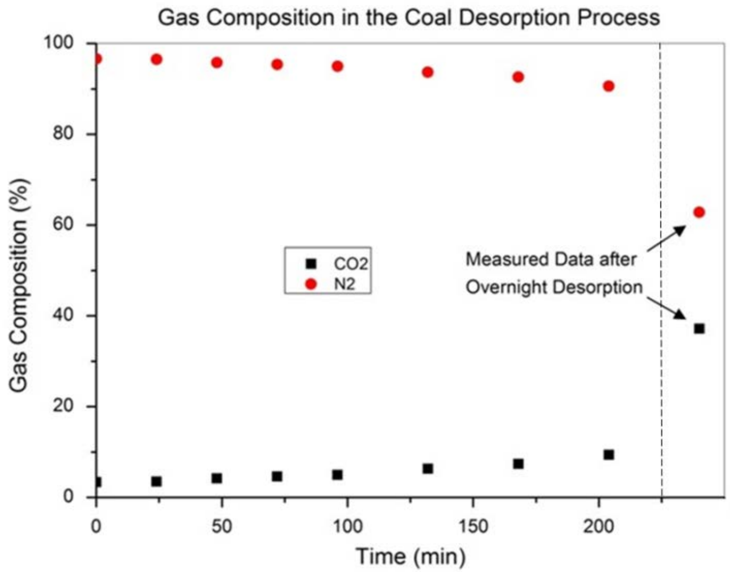


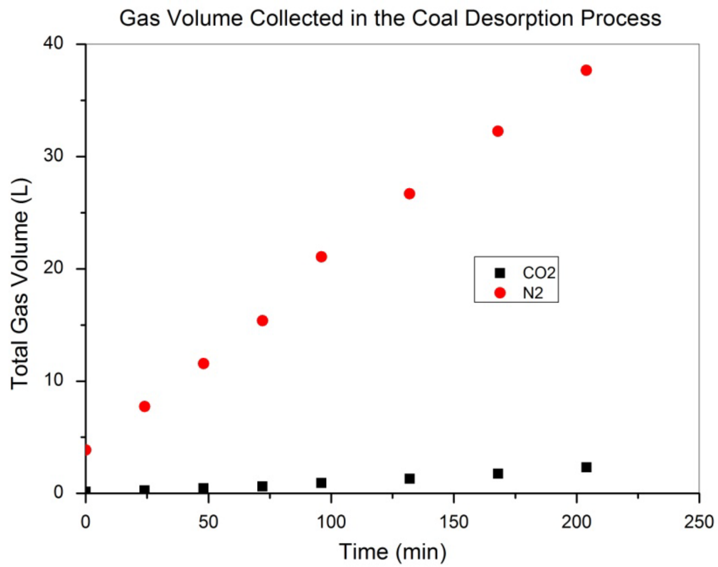


- During the N2 flushing process, CO2 composition of the chamber gas gradually decreases and N2 composition increases during the N2 flushing test, which indicates that CO2 gas continues to be flushed out by N2.

- 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.

N_2 Gas Flushing Test to Enhance CO_2 Recovery

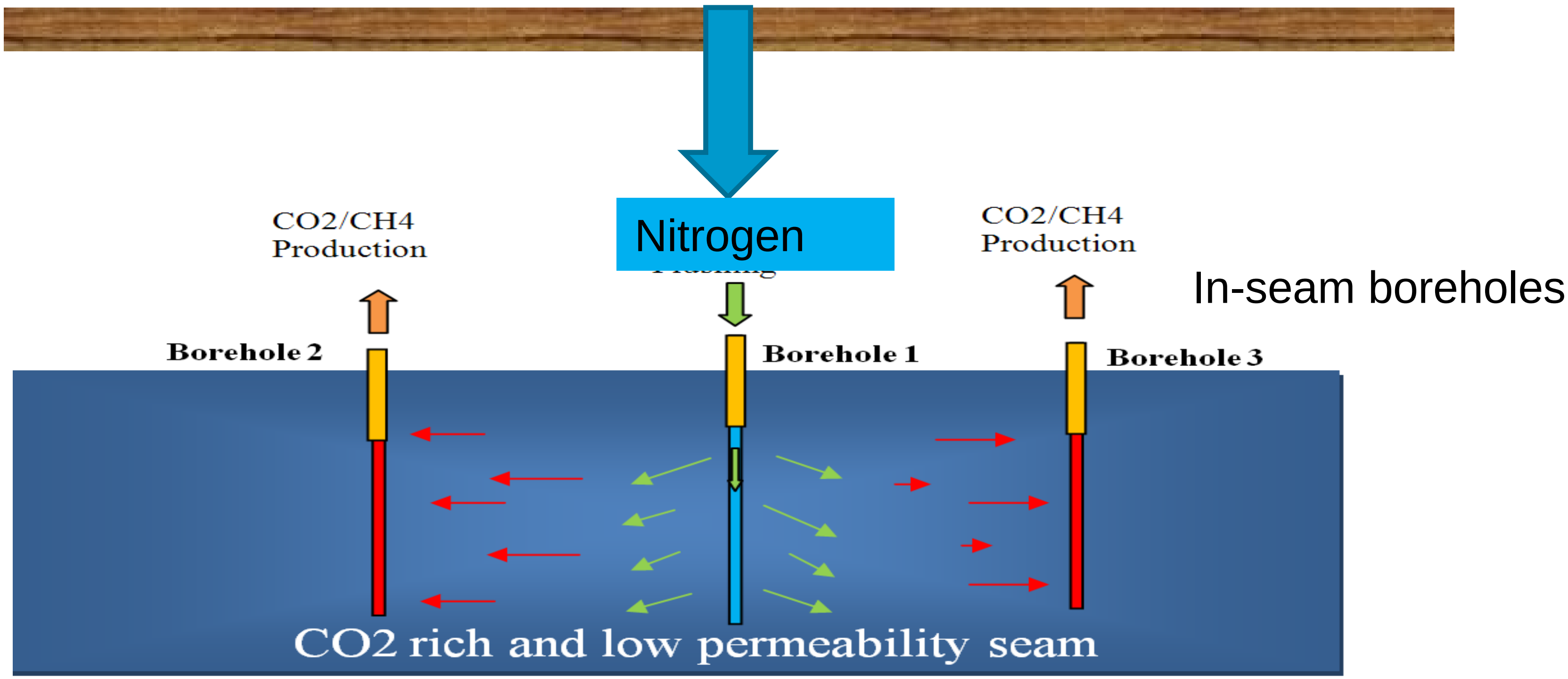




In the desorption process, CO_2 composition starts to increase from 3.4% to 9.4%, while N_2 composition deceases from 96.6% to 90.6% over a period of around 3 hrs (200 min) time. At the end of test a total 37.7 L of N_2 and 2.3 L of CO_2 is collected.

Enhanced seam gas recovery by N_2 flushing – Field trials

Surface Nitrogen Generator



Conclusions

- **Fundamental studies of hard-to-drain coals**
  - highly under-saturated (low saturation degree) with high CO_2 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 ....

- **N_2 flushing tests demonstrate N_2 injection can be used to recover CO_2 and CH_4 gas from tight coals**
  - gas drainage to meet mine schedule requirements;
  - enable pre-drainage of coal reserves with very low permeability

- **Field trials of N_2 flushing**

Acknowledgements

1.Support and data/information from Metropolitan Colliery, Tahmoor Colliery and West Cliff Colliery;

1.Research team of UOW, particularly Lei Zhang, Zhongwei Wang, Fangtian Wang and Frank Hungerford.

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