# Response of relative permeability to coal surface chemistry and effective pressure through steady-state flooding measurements using X-ray CT Scanner and artificial Australian coal cores

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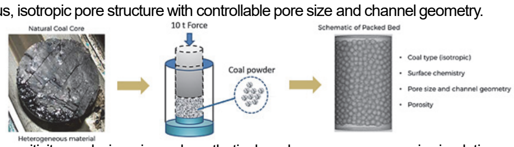
## Introduction

The relative permeability behaviours of gas and water in coal are primary factors in the productivity of a coal seam gas reservoir. It is dependent on many factors including fluid saturations and pressure, cleat geometry and network, and wettability (surface chemistry). In this study, we performed steady-state relative permeability measurements using an X-ray CT scanner on packed beds of coal particles to allow systematic investigation of coal surface chemistry on permeability behaviour. The packed bed approach provides a homogeneous, isotropic coal sample with controllable coal surface properties. This includes pore size and channel geometry (by control of particle size), and also removes the natural cleat geometry effects from the experimental measurement.

## Research aims

1. Improve gas and liquid relative permeability predictions by experimentally measuring gas-liquid relative permeability, taking into account surface chemistry of the coal.
2. Design and build an X-ray transparent core flood cell to calculate water saturation ($S_w$) during gas-liquid relative permeability measurements on artificial packed bed cores.
3. Study the effect of coal surface chemistry on relative permeability by using packed beds that provide homogeneous, isotropic pore structure with controllable pore size and channel geometry.




4. Carry out a sensitivity analysis using a hypothetical coal seam gas reservoir simulation model using Petrel and Eclipse to investigate the effects of surface chemistry on water production.

## Coal selection and characterisation

Coal Properties

Table 1. Petrographic and proximate analyses.

| | Components (%) | IPN | BRDM |
|---|---|---|---|
| Petrographic Analysis (air dried basis) | $R_{max}$ | 0.99 | 1.06 |
| | Vol. Vitrinite | 31 | 73 |
| | Vol. Liptinite | 6 | 1 |
| | Vol. Inertinite | 56 | 22 |
| | Vol. Mineral | 7 | 4 |
| Proximate Analysis (air dried basis) | Moisture | 2.2 | 2.3 |
| | Ash | 9.7 | 18.0 |
| | Volatile Matter | 24.7 | 21.3 |
| | Fixed Carbon | 63.4 | 64.6 |

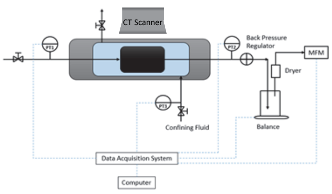
Packed Bed Characterisation

Table 2. Summary of the skeletal density, bulk density and porosity of packed coal cores.

| | Skeletal density (g/mL) | Bulk density (g/mL) | Porosity (%) |
|---|---|---|---|
| BRDM | 1.35 | 1.12 | 17.1 ± 0.9% |
| IPN | 1.46 | 1.16 | 20.5 ± 1.1% |


Figure 1. Location of each mine within the Bowen Basin, Queensland, Australia.

## Relative permeability measurement




- Triaxial aluminium core holder
- Steady-state method
- 4 wt.% KI solution and nitrogen

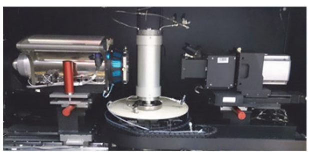


Figure 2. Photograph of x-ray transparent aluminium core holder (shown in vertical orientation) inside the Xradia XRM500 instrument.

Gas and liquid effective permeability and water saturation calculation:

$$k_L = \left(\frac{500,000}{3}\right)\left[\frac{4Q_L L \mu_L}{\pi D^2 (P_1 - P_2)}\right] \qquad k_g = \left(\frac{500,000}{3}\right)\left[\frac{8Q_g L \mu_g P_g}{\pi D^2 (P_1^2 - P_2^2)}\right] \qquad S_w = 1 - \left(\frac{CT_{fullysat} - CT_{imb\_x}}{CT_{fullysat} - CT_{dry}}\right)^*$$

## Results

Contact Angle Measurements:

Table 3. Contact angle using CFC technique.

| BRDM | | IP | |
|---|---|---|---|
| L (°) | R (°) | L (°) | R (°) |
| 129.7 | 119.1 | 124.8 | 125.5 |

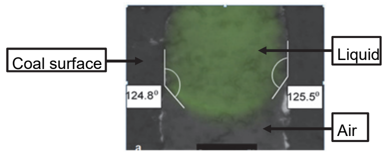



Figure 3. Average contact angle for the IP coal sample.

Response of relative permeability to coal surface chemistry:

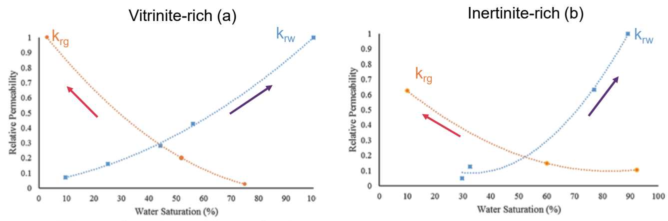



Fig 4. Relative permeability of BRDM (a) and IP (b) coal from Bowen Basin using packed beds. Constant effective pressure at 22 bar.

Response of relative permeability to effective pressure:

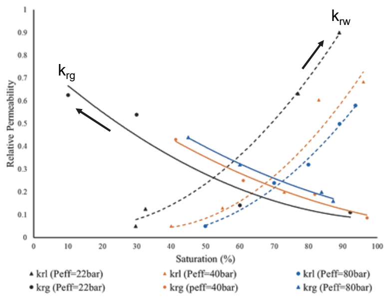



Fig 5. Relative permeability of IP packed coal bed at different effective pressures (22, 40 and 80 bar).

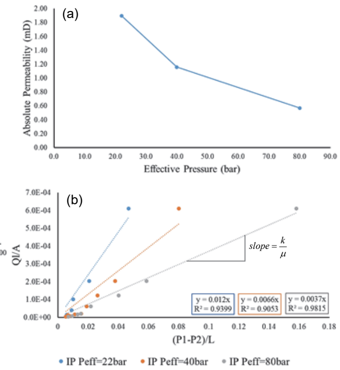



Fig 6. Change in absolute permeability with effective pressure (a), and measured water injection versus measured water injection pressure (b).

Reservoir simulation:

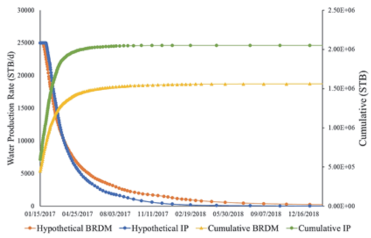



Fig 7. Sensitivity analysis using a hypothetical reservoir model (Eclipse) to simulate water production using the relative permeability curves of BRDM and IP packed coal samples.

## Conclusions

1. The packed bed method has enabled the construction of repeatable cores to study relative permeablity in isolation from the effects of natural coal cleat network geometries and heterogeneity.

2. The relative permeability curves suggest that the vitrinite-rich coal (BRDM) is gas wet and the inertinite-rich (IP) coal is water wet.

3. The increase of effective pressure by two times reduces the absolute permeability by 45% ($k_{22bar}$ = 1.89 ± 0.08 mD; $k_{40bar}$ = 1.16 ± 0.09 mD; $k_{80bar}$ = 0.57 ± 0.03 mD).

4. The Darcy flow within the packed coal bed is confirmed by the straight lines shown in Figure 6b, and the slope indicates the resistance in each effective pressure condition.

5. The hypothetical simulation using Eclipse shows that the cummulative water production for the IP can be 40% higher than the BRDM over a period of 30 years of gas production, due to its water wet behaviour.

## References

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