Gas Adsorption, Permeability Reduction, and Gas Flow in Coal

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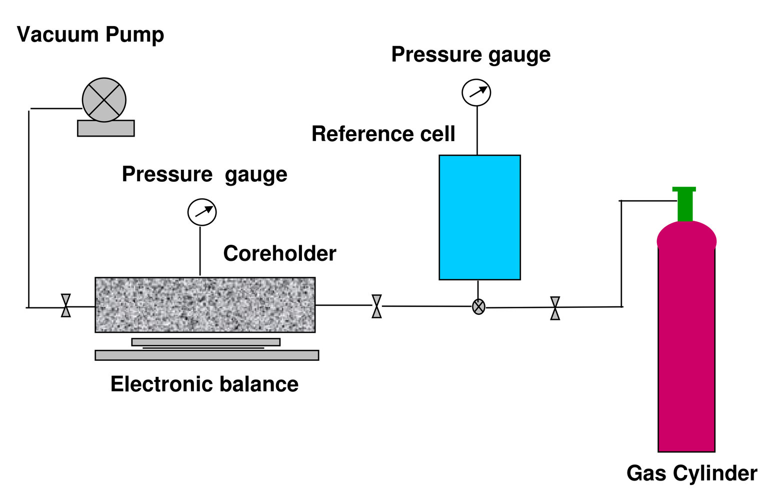
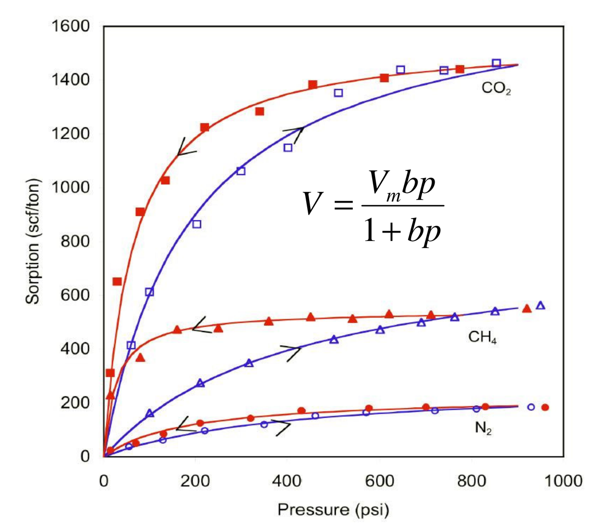
Enhanced coalbed methane (ECBM) recovery by injection of CO_2 or mixtures of CO_2 and N_2 is an attractive method to recover additional natural gas resources while at the same time sequestering CO_2 in the subsurface. The permeability of coal and the dynamics of ECBM recovery processes are determined in large part by the sorption behavior of mixtures of CH_4, CO_2 and N_2 on the coal surface. Pure gas adsorption is represented well by the Langmuir isotherm. For multi-component adsorption, however, the extended isotherm is not sufficient to represent adsorption behavior faithfully.The ideal adsorbate solution (IAS) model was used to model multi-component adsorption during gas flow through coal. IAS is proved superior to the extended Langmuir isotherm.

Adsorption Isotherm

Measurement and Modeling



Schematic of experimental components for measuring gas adsorption on coal.



Sorption characteristics of Powder River Basin (Wyoming) coal. Adsorption indicated with open symbols and desorption with closed symbols. Measurement conducted at 22 ºC.

Adsorption Isotherms

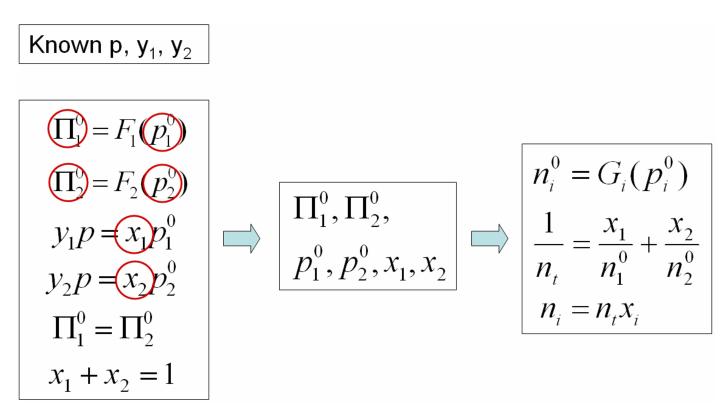
Langmuir and Extended Langmuir Isotherms

$$V = \frac{V_m bp}{1+bp} \qquad V_i = \frac{V_{mi} b_i p_i}{1+\sum_{j=1}^{n} b_j p_j}$$

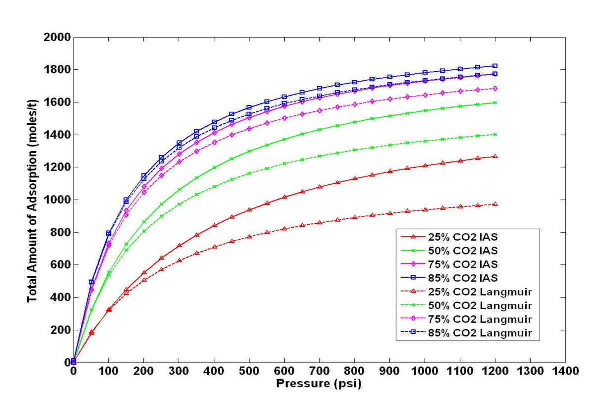
V = amount of gas adsorption, SCF/ton;
P = pressure;
V_m = saturation adsorption constant;
b = Langmuir constant;
V_i = adsorption volume of component i;
i, j = components;
n = number of components.

Ideal Adsorbate Solution (IAS) Model

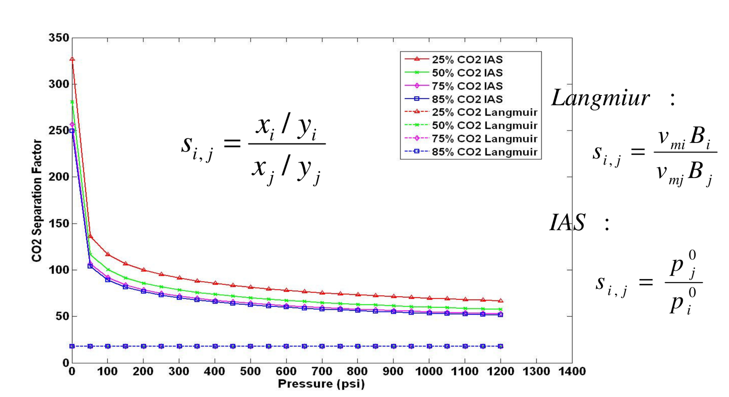
$$py_i = p_i^0(\Pi)x_i \quad (constant\ T)$$



Multi-component Adsorption Calculation



Total amount of adsorption calculated using the extended Langmuir isotherm and the ideal adsorbed solution model.

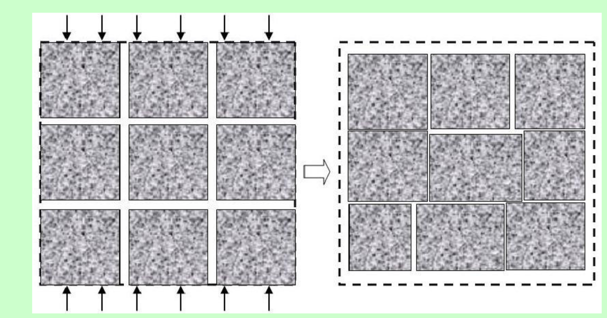


The calculated separation factor of CO_2 over N_2 using the extended Langmuir isotherm and the ideal adsorbed solution model. Extended Langmuir shows no sensitivity to gas composition or pressure.

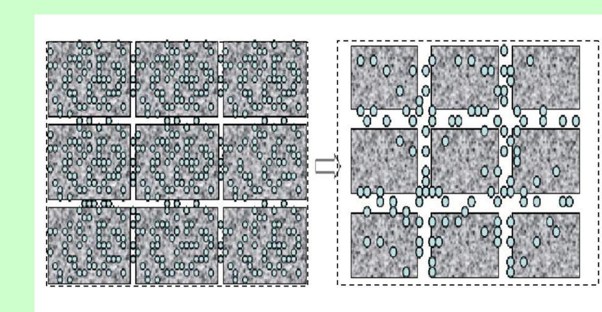
1. The adsorption of pure methane, nitrogen, and carbon dioxide on crushed Wyoming Powder River Basin coal is well represented by the Langmuir isotherm. The adsorption capacity of coal to carbon dioxide is about 3 times of methane and 7 times of nitrogen.
2. Among many isotherms in the literature for gas adsorption, the question remains open as to which isotherm gives better prediction for multi-component adsorption. The extended Langmuir isotherm and the ideal adsorbate solution model gave different predictions in terms of the total amount of adsorption, and amount of adsorption for different gas species. IAS model was considered thermodynamically superior to the extended Langmuir isotherm.

Permeability Evolution

Mechanisms

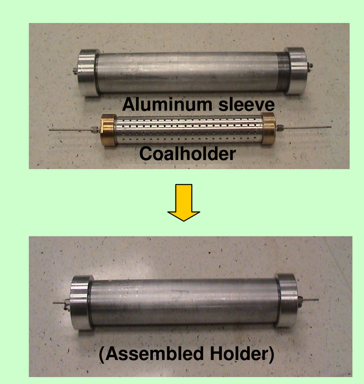


a) Permeability change of coal due to change of effective stress;

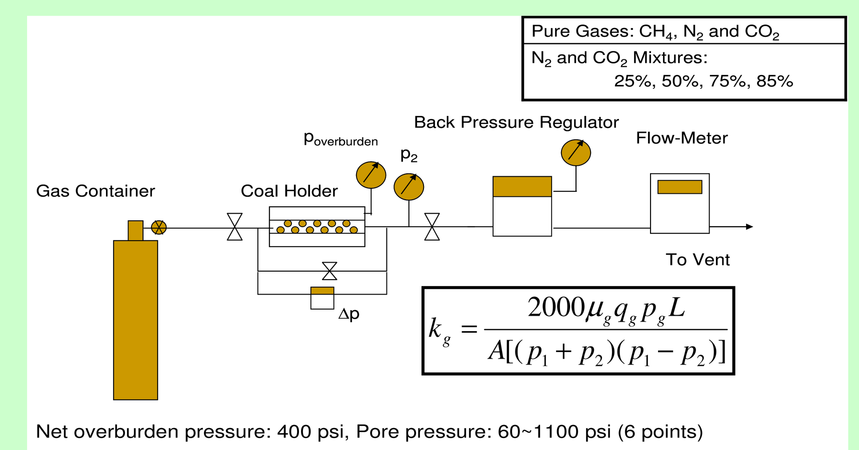


b) Permeability change of coal due to sorption of gases.

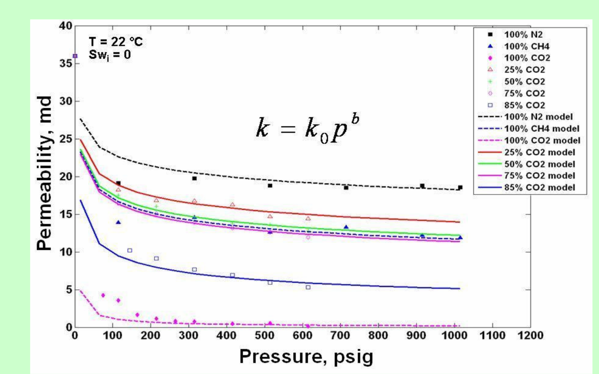
Experiments on Coal Pack



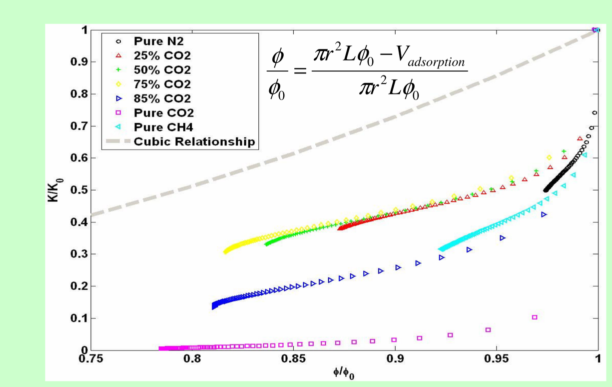
The coalholder system.



Schematic of experimental components for permeability experiments.

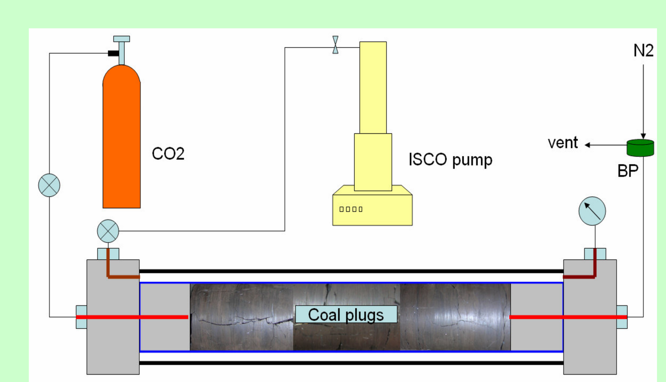


Permeability of the coal pack vs. pressure, injecting different gas at room temperature, net overburden pressure = 400 psi.

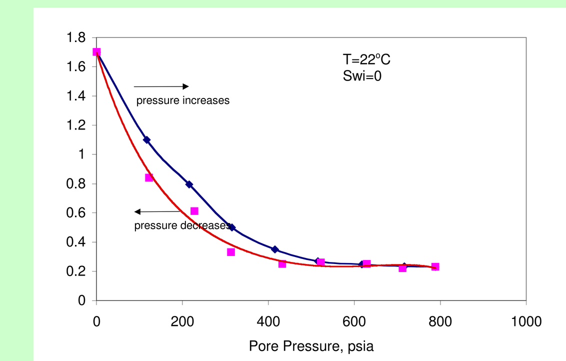


Correlation between the (calculated based on IAS adsorption model) change of effective porosity and the (measured) change of permeability.

Experiments on Composite Coal Core



Schematic of experimental components for permeability experiments on a composite coal core.

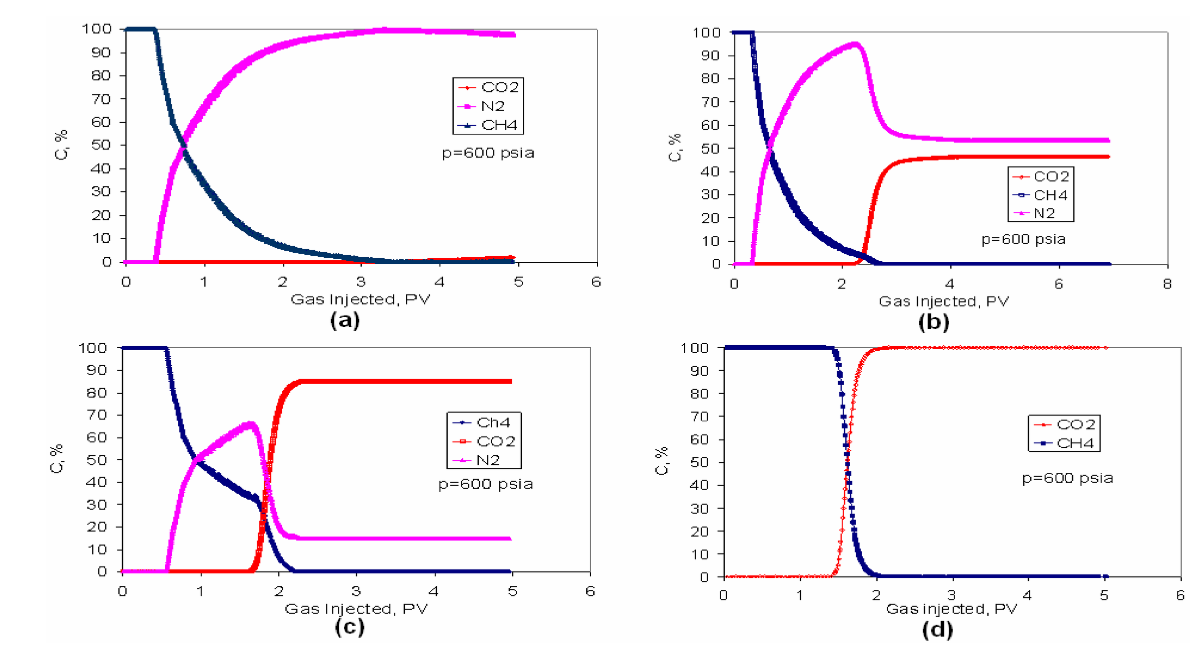


Permeability to CO_2 vs. pressure at room temperature, and net overburden pressure = 300 psi.

1. Permeability of coal is sensitive to pressure and the type of the injection gas. At the same pore pressure, with an increase of the fraction of CO_2 in the injected gas, permeability reduction is more significant. Permeability may be preserved by having some amount of N_2 (10 ~ 20% by mole fraction) in the injection mixture.
2. Permeability change due to gas sorption displays hysteretic behavior.
3. The change of porosity (calculated based on IAS adsorption model) and change of permeability for various gas composition do not have a unique correlation.

Gas Flow in Coal

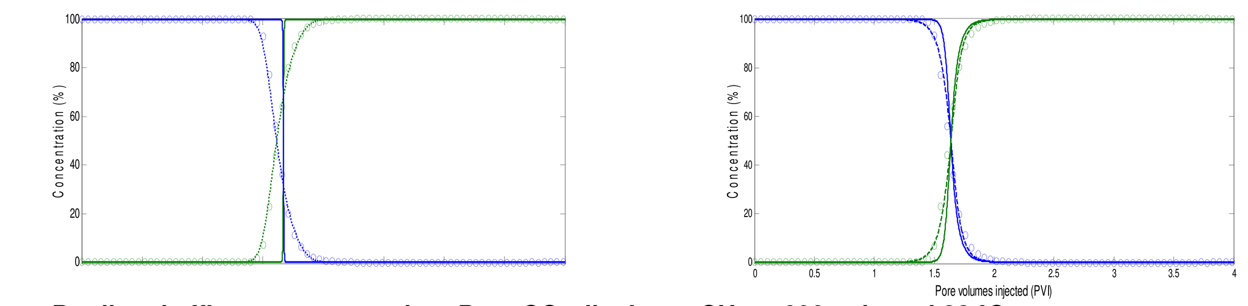
Effect of Injected Gas Composition (Dry Coal)



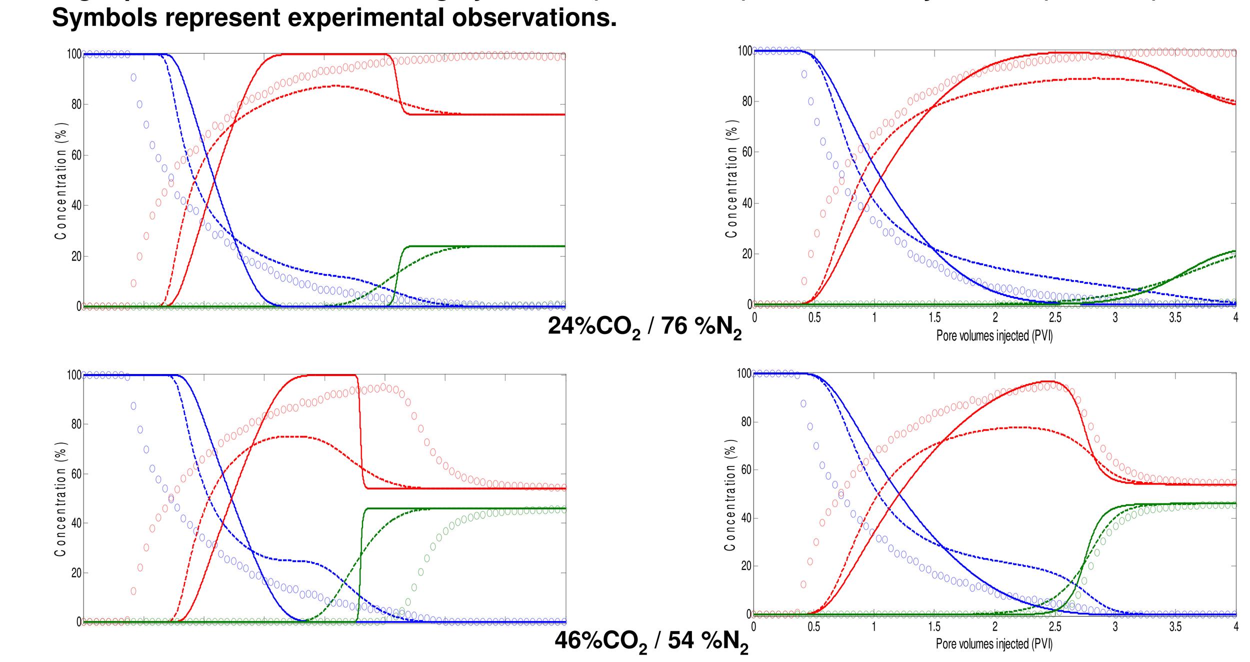
Injection gas composition: (a) 24% CO_2+76% N_2, (b) 46% CO_2+54% N_2, (c) 85% CO_2+15% N_2, (d) 100% CO_2. Results show that coal beds effectively separate mixtures of CO_2 and N_2. There is opportunity for mixed gas and contaminant gas injection.

Modeling Gas Displacement in Coal

- one dimensional, dual-porosity formulation;
- gas sorption, transport, and dispersion;
- gas sorption, including hysteresis among adsorption and desorption;
- implementing extended Langmuir and IAS models.



Predicted effluent concentration: Pure CO_2 displaces CH_4 at 600 psia and 22 ºC.
Left panel: Langmuir model including hysteresis (dotted lines) and without hysteresis (full lines);
Right panel: IAS model including hysteresis (dotted lines) and without hysteresis (full lines);
Symbols represent experimental observations.



Ternary displacement: CO_2 / N_2 mixtures displaces pure CH_4 at 600 psia and 22 ºC.
Left panels: Langmuir model including hysteresis (dotted lines) and without hysteresis (full lines);
Right panels: IAS model including hysteresis (dotted lines) and without hysteresis (full lines);
Symbols represent experimental observations.

1. The match between experimental and modeling results improves as physically realistic complexity is added to the model.
2. Sorption hysteresis must be included in displacement calculations to improve the predictive capabilities of both the extended Langmuir and the IAS approach.
3. For all ternary displacement calculations, the IAS model predicts more accurately the timing of composition fronts arriving at the outlet.

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