Gas Adsorption and Wettability Properties of Coal Surfaces

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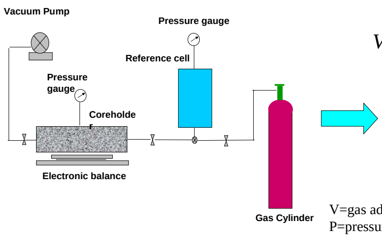
Coal surfaces have a strong affinity for carbon dioxide making them an attractive geological formation for sequestration. Typically, history matches to water and gas flow in CBM reservoirs indicate water wetness, despite the fact that coal macerals are organic and hydrophobic. It is postulated that mineral inclusions alter coalbed wettability by providing water wet pathways. Moreover, CBM production generally occurs in a depletion mode where adsorption/desorption hysteresis is not relevant. Replacement of methane with carbon dioxide on coal surfaces, however, may affect the physical nature of the coal surface. Certainly, aqueous solution pH decreases with the addition of carbon dioxide. Coal properties such as wettability and the degree of hysteresis displayed during adsorption and desorption are a function of the gas adsorbed, aqueous solution pH, and temperature. Establishing the fundamentals of coal adsorption/desorption hysteresis and coalbed wettability is thus important for understanding dewatering of coalbeds under pressure depletion conditions and as a response to carbon dioxide injection.

Adsorption Isotherm

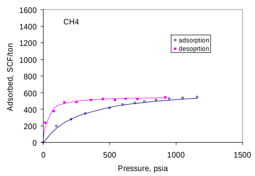
Measurement and modeling

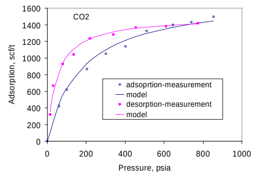


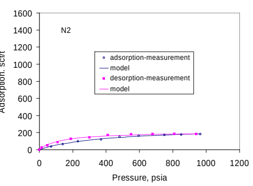
$$V = \frac{V_m bP}{1+bP}$$

$$\frac{P}{V} = \frac{P}{V_m} + \frac{1}{bV_m}$$

V=gas adsorption
P=pressure
Vm=saturation adsorption constant
b=constant



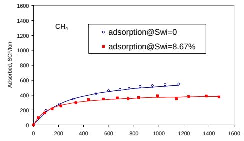


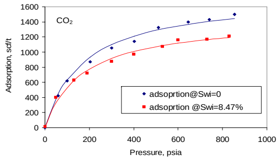


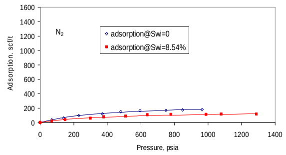
Langmuir Constants

Constants	Vm	b
CH_4	714.8	0.0029
CO_2	1666.7	0.0062
N_2	263.2	0.0025

Effect of Initial water saturation on gas adsorption

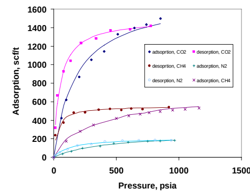


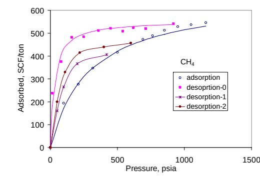




Initial water saturation apparently affects gas adsorption/desorption behavior. Compared to dry coal, gas adsorption on wet coal surfaces decreases about 10-20%. This behavior is ascribed the coverage of coal surfaces by water phase.

Hysteresis

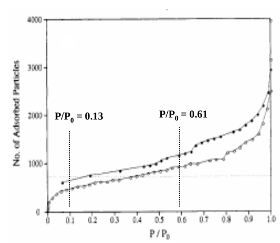


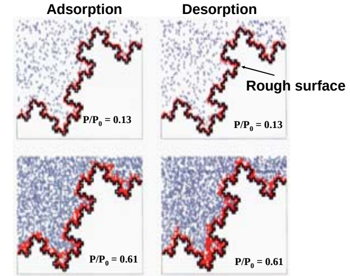


The experimental program has revealed significant hysteresis among adsorption and desorption on powdered coal for all gasses examined. The general trend is of significant retention of gas as pressure is reduced. There are several nonexclusive explanations for adsorption/desorption hysteresis (Adamason and Gast 1997):

- **irreversible change of pore structure accompanying adsorption**
- **contact angle hysteresis**
- **micropores with width less than 200 nm**
- **capillary condensation**
- **heterogeneous surface geometry**

Given our conditions of temperature, substrate, and gasses, the most likely explanation is a combination of capillary condensation and surface heterogeneity as explored by Seri-Levy and Avnir(1993) using Monte Carlo simulations :

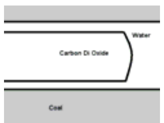




red = adsorbed gas; blue = unadsorbed gas

Wettabilty of Coal Surfaces:

Relatively little is known about the wettability of coal surfaces with large volumes of carbon dioxide adsorbed. Wettability of solid surfaces determines the affinity of water for the surface and affects how easily coal beds are dewatered as well as the fate of water that may imbibe into a dewatered coal bed where CO_2 has been sequestered. We measure wettability in terms of the contact angle that the liquid forms with the coal surface. The lesser the contact angle the more is the spread of the liquid and greater the wettability. To calculate numerically the contact angle, we use the formulation developed by Frumkin and Derjaguin that correlates the disjoining pressure with contact angle formed.



Pore Level scenario for CO_2 injection

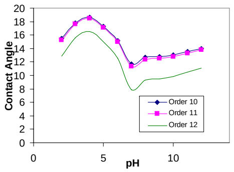
Young-Laplace Augmented Equation

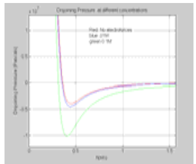
$$P_C = \sigma * \left(\frac{1}{r_1} + \frac{1}{r_2}\right) + \Pi(h)$$

Frumkin Derjaguin equation

$$\cos\theta = 1 + \frac{1}{\sigma}\left(\left(\int_{h^*}^{\infty} \pi(h)dh\right) + \pi(h^*)h^*\right)$$

Variation with Structural Constant

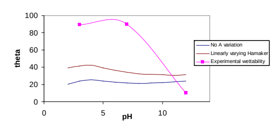




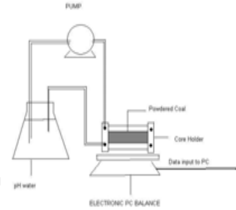
Impact of Electrostatic Pressure on Disjoining Pressure

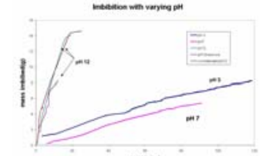
We are most interested in CBM systems in the presence of CO_2. The major impact of CO_2 at these pressures is that it changes the pH of the solution. We are therefore looking at the change in the wettability of the system with change in pH. We have tried to explain this phenomenon based on fundamental theory for the wettability of surfaces.

Calculated and Measured Values of Contact angles



Experiments & Results
•To validate our suggested model, we are in the process of doing imbibition studies for different pH.
•As suggested in literature the curves obtained have a linear relationship between the square root of time and mass imbibed.
•pH 12 imbibes at a much faster rate as compared to pH 7 and pH 3.
•However pH 3 also imbibes faster than pH 7 suggesting that wettability goes through a minimum.





Future Work
•Perform experiments for pH values of 10,8,6,4,2
•Study the effect of initial water imbibition.
•Study effects of CO_2 injection on drainage and imbibition rates.
•Comparison of supercritical CO_2 behavior to low pressure gas.

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