



**SPE 114778**

## **Predicting Sorption-Induced Strain and Permeability Increase With Depletion for CBM Reservoirs**

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This paper was prepared for presentation at the 2008 SPE Annual Technical Conference and Exhibition held in Denver, Colorado, USA, 21–24 September 2008.

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### **Abstract**

It is well known that absolute permeability changes occur in coalbed methane (CBM) reservoirs during primary depletion or enhanced recovery/CO<sub>2</sub> sequestration operations. Sorption-induced strain in CBM reservoirs, also known as matrix-shrinkage or -swelling, may dominate permeability changes at low pressures, as is the case for CBM wells undergoing primary depletion in the Fruitland Coal fairway of the San Juan Basin.

Several analytical models have been developed to predict changes in coal permeability as a function of stress and sorption. Most models, however, utilize an empirical method for estimating sorption-induced strain. Recently, a theoretical model for sorption-induced strain was developed and applied to single-component adsorption/strain experimental data. The new model was developed from basic thermodynamic principles and is more predictive than the empirically-based approaches. In this paper, the theoretical model is expanded to incorporate multi-component adsorption models that are more rigorous, and sometimes more accurate, than the commonly-applied Extended Langmuir equation. This improves predictions of multi-component gas sorption-induced strain, as demonstrated by comparison to experimental data. The new sorption-induced strain model is then used to calculate the sorption-strain component of the popular Palmer and Mansoori equation, which in turn can be used to model permeability changes during both primary (single or multi-component gas) and enhanced recovery operations. Finally, the coupled sorption-strain/permeability model, incorporated into an analytical simulator, is used to predict and match permeability growth in a producing CBM well in the Fruitland Coal fairway, which has a binary (CH<sub>4</sub>+CO<sub>2</sub>) sorbed/produced gas composition.

Matches to field-derived permeability growth using the new model are accurate but non-unique, due to lack of available data, particularly rock mechanical properties. Given the availability of rock mechanics and adsorption isotherm data, the rigorous thermodynamic basis of the new model should allow for more accurate predictions of coalbed permeability changes, but further testing is required.

### **Introduction**

Volumetric change in the coal matrix during the depletion of coalbed gases (matrix-shrinkage) and injection of non-hydrocarbon gases is a well-known phenomenon, and has received a great deal of attention in the recent literature [select references include Chikatamarla et al. (2004); Mitra and Harpalani (2007); Pan and Connell (2007); Karacan (2007); Mazumder and Wolf (2008)] due to the impact on primary and enhanced recovery (or greenhouse gas sequestration) characteristics of CBM reservoirs. Specifically, sorption-induced matrix-shrinkage/swelling, which has been quantified in the laboratory, is known to impact the absolute permeability of coals, due to the change in the aperture dimensions of natural fractures that segregate the coal matrix blocks (**Fig. 1**).

Until recently, empirical approaches have been used to describe volumetric strain changes of the coal matrix associated with adsorption. For example, Levine (1996), used a Langmuir-like curve to fit experimentally-derived linear strain data, that in turn was measured during single-component gas (CH<sub>4</sub> and CO<sub>2</sub>) adsorption on coal. Recently, Mavor et al. (2004) used an expression analogous to the Extended Langmuir equation, to calculate volumetric strain associated with mixed gas adsorption. Other authors [Chikatamarla et al. (2004)] have noted that swelling is proportional to gas content, and have extended this concept to the mixture of gaseous components assuming a linear combination of volumetric strain caused by each gas component. As noted in Cui and Bustin (2005), the relationship between volumetric strain and sorbed gas content may not always be linear.

Recently, Pan and Connell (2007), introduced a theoretical model to describe the volumetric strain associated with gas