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Stress-dependence of Porosity and Permeability of Upper Jurassic Bossier Shale: Implications for Gas in Place Calculations and Production

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Information on porosity and permeability at realistic sub-surface (in situ) stress conditions is a prerequisite for successful exploration and production of shale gas. In order to study the effects of elastic pore compressibility on these parameters, porosity and permeability coefficients of three Upper Jurassic Bossier Shale samples were determined at stress levels up to 40 MPa.

Pore volume compressibility α was measured using a gas expansion technique by helium (He) expansion from a calibrated volume into the pore system of the confined sample. The recorded decrease in specific pore volume (Vp) with increasing effective stress was fitted by an exponential function:

Vp = Vp,0 e (-α σ')

Unstressed specific pore volume Vp,0 of the samples corresponds to an unstressed porosity (φ0) between 3 - 7 %. At the in situ effective stress value (σ') of $\sim$60 MPa, Vp had decreased between 8 - 13 %.

Steady-state permeability tests were performed with six different gases and external stress levels up to 40 MPa. Apparent gas permeability coefficients (kgas) increase with decreasing mean pore pressure (pm) due to slip flow (Klinkenberg-effect):

kgas = k∞ (1 + b/pm)

Klinkenberg-corrected (intrinsic) permeability coefficients (k∞) decrease with increasing effective stress while slip factors (b) increase. The experimental results were fitted by exponential expressions:

k∞ = k∞,0 e (-αk σ')

b = b0 e (-αb σ')

Increasing slip factors indicate that the average effective pore diameters of the shale sample are significantly reduced with increasing effective stress.

During production of a shale gas reservoir the pore pressure is reduced. Apparent permeability coefficients will increase due to slip flow whereas poro-elastic deformation will lead to a decrease in permeability during production. Based on the parameters derived from the experimental data the permeability coefficients for CH4 were tentatively modelled for a hypothetical production history of a Bossier shale reservoir. Reduction of pore pressure results in a decrease of permeability throughout most stages of production following the exponential poro-elastic relationship. At pore pressures between 2.5 and 6.5 MPa, apparent permeability reaches a minimum and then, with further decrease of pore pressure, the (apparent) gas permeability coefficient increases due to slip flow.