Simultaneous Measurements of In-Situ Effective Permeability and Porosity Under Reservoir Conditions: A Consistent Approach to Characterize Unconventional Gas Reservoirs

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Accurate estimation of gas-in-place is crucial for successful evaluation and exploitation of unconventional gas reservoirs such as tight sand, gas shale and coal-seam reservoirs. To do so, it requires appropriate determination of in-situ reservoir effective porosity along with other critical parameters. However, effective porosity, one of the most important parameter in estimating gas in-place, is commonly measured on crushed samples of cores or cuttings at ambient pressure and temperature even though many studies have shown that the porosity and permeability of conventional reservoirs rocks decreases with increasing effective stress. Due to the stress relaxation during coring process and sample recovery, it is anticipated that the porosity measured on crushed samples at ambient conditions will be larger than the porosity under in-situ reservoir stress condition. Normally the stress-dependence of porosity is simply accounted for by applying linear poro-elastic theory, which our studies show to be an over-simplification. Furthermore, crushing samples for measurement of effective porosity as done in commercial laboratories destroys larger pores and opens inaccessible isolated pores of intact samples. The net effect of pore destruction or opening by crushing is uncertain and can vary significantly from sample to sample due to the strong heterogeneity in mineralogy and fabric of unconventional reservoir rocks. Our novel protocol provides a method for routine characterization of effective porosity, permeability and diffusivity under near reservoir conditions. Our results show that the stress dependence of porosity (pore volume compressibility) of fine grained reservoir rocks follows unique trends, which cannot be simply described by the existing linear poro-elastic models. The measured in-situ porosity is also significantly different from the porosity measured on crushed samples under ambient conditions, underscoring the significance of measurements of in-situ porosity in rigorous estimation of gas-in-place. Meanwhile the simultaneously determined permeability agrees well with the permeability determined by the pressure pulse-decay technique. Overall, our approach of simultaneously measuring effective porosity and permeability under reservoir conditions offers a more internally consistent porosity-permeability data set to describe unconventional reservoirs better.