Reservoir Characteristics of Low-Permeability Sandstones in the Rocky Mountains[1]

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ABSTRACT

Understanding gas production from low-permeability sandstones requires an understanding of the *in situ* porosity, brine saturation, and effective gas permeability at reservoir brine saturation. Analysis of data from hundreds of cores from numerous western U.S. basins indicates that petrophysical properties of well-defined lithofacies (or log-facies) are often unique within a narrow range. Diagenesis in these sandstones commonly resulted in the destruction of much of the original intergranular porosity and left dissolved grains, clay-filled pores, and sheet-like connecting intergranular pore throats. Pore throats or channels that connect larger pores typically range in size from 1 to 0.1 micron and represent only a small portion of the total porosity.

In most low-permeability sandstones, porosity is not significantly changed by confining stress changes, but *in situ* effective gas permeabilities range from 10 to 1,000 times less than routine air permeability. The influence of confining stress on permeability can be attributed primarily to the decrease in size of the thin, tabular pore throats that connect the larger pores. Under stress, pore throats decrease in diameter by up to 50% to 70% resulting in permeability decreases of 10 to 40 times. Gas effective permeabilities also decrease rapidly to less than 1% of absolute values at water saturations above approximately 40% to 50%. "Irreducible" water saturations increase with decreasing porosity and permeability, and, in sandstones with less than 0.01 md permeability, "irreducible" water saturations increase dramatically.

Cumulative flow and storage capacity plots indicate that very thin higher permeability intervals typically yield a large percentage of the cumulative flow capacity. Increased water saturations due to drilling or stimulation result in lower effective gas permeabilities and can unknowingly be stabilized by capillary pressure forces if pore pressures are decreased. This type of formation damage can be remedied by increasing the gas pore pressure to displace mobile water.

INTRODUCTION

Fundamental to effective production of gas from low-permeability sandstones is understanding their *in situ* petrophysical properties, the most important of which are porosity, brine saturation, and effective gas permeability at reservoir brine saturation. False assumptions concerning values for these petrophysical properties, or the nature of their distribution, can result in significant costs due to inefficient completion, stimulation, or exploration. Misconceptions arise primarily because some *in situ* reservoir properties differ significantly from the more economic and easily available routine core analysis properties. For low-permeability sandstones, the response of the sandstone to removal from *in situ* chemical and stress conditions affects some properties significantly while others are only affected nominally. This can be understood by studying the properties of cores under conditions similar to those in the reservoir. It is then possible to develop predictive equations that can be utilized with routine petrophysical data to predict *in situ* values.

Numerous studies have been published concerning the reservoir properties of low-permeability sandstones. Early work by Vairogs et al. (1971) and Thomas and Ward (1972) illustrated how increasing confining stress and water saturation decreases permeability. Their work also showed that pore volume compressibility is small. The work of Jones and Owens (1980) provided a confirmation and quantification of these influences for a larger sample set of low-permeability sandstones and indicated