CONTACT ANGLE HYSTERESIS EFFECTS ON THE RELATIVE PERMEABILITY OF GAS AND CONDENSATE IN THREE-DIMENSIONAL PORE NETWORKS

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***Abstract* -- The effect of contact angle hysteresis on the relative permeability of gas and condensate is studied with a mechanistic pore-level model of retrograde condensation in three dimensional pore networks under gravitational forces. We examine the effects of changing the wettability of the fluid-solid system from strongly liquid-wet to intermediate gas-wet.**

***Keywords* -- capillary condensation, network modeling, relative permeability, contact angle hysteresis, wettability, Monte Carlo simulation**

I. INTRODUCTION

A better understanding of phase distribution and flow in gas-condensate reservoirs is essential for optimum exploitation strategies. When pressure, either in the wellbore or in the reservoir, drops below the dew point a new phase appears, a phenomenon known as retrograde condensation. At first, the new condensate phase remains immobile blocking few gas paths; the gas effective permeability remains high. As the pressure decreases, condensate dropout tends to occupy more and more gas paths, attaining the so-called critical condensate saturation at which the liquid phase becomes mobile for the first time, and the gas effective permeability decreases. How abruptly it decreases depends on the pore structure, fluid properties and operating conditions. The critical condensate saturation and the relative permeability of gas and condensate are essential parameters for the evaluation and development of new designs of gas and condensate recovery strategies.

Literature reviews of laboratory studies of critical condensate saturation and relative permeability of gas and condensate are provided by Wang and Mohanty (1999), Blom *et al*. (2000), Jamiolahmady *et al*. (2000) and Li and Firoozabadi (2000).

Pore-level models of condensation dealing with the various aspects of the process have been developed by Mohammadi *et al*. (1990), Fang *et al*. (1996), Toledo and Firoozabadi (1998), Wang and Mohanty (1999), Li and Firoozabadi (2000) and Jamiolahmady *et al*. (2000). Recently we developed a mechanistic model of the retrograde condensation process in three-dimensional pore networks under gravitational forces (Bustos and Toledo, 2002a). In that work we reported new gas and condensate relative permeabilities as a function of condensate saturation for various system and simulation parameters and conditions. In a companion work (Bustos and Toledo, 2002b), we used the model to study the sensitivity of relative permeability of gas and condensate to pore size distribution.

In this paper we use the condensation model to examine the effects of changing the wettability of the fluid-solid system on the distribution of gas and condensate and thus on their relative permeabilities. Wettability is changed from strongly to intermediate liquid-wet. Li and Firoozabadi (2000) first studied this aspect from a modeling point of view, although restricted to two-dimensional networks.

II. NETWORK MODEL

A summary of the model is presented emphasizing key aspects for the work here. A three-dimensional cubic network of pore segments represents porous media. Nodes at which the pore segments are connected act only as volumeless junctions with infinite conductance. Pore segments are rectilinear with polygonal cross sections circumscribing circles with distributed radii. Pore segment radius r_t is randomly assigned according to a given probability density function. Condensate accumulation in pore corners allows for condensate connectivity throughout the network, no matter how high the pressure is. We allow for contact angle hysteresis, which is characterized by advancing, θ_A, and receding, θ_R, contact angles; the advancing contact angle being always greater than the receding contact angle. Contact angle hysteresis arises when the liquid-vapor interface is unable to retrace its original path when it recedes on a solid surface. Pore segment length l is constant and chosen to accommodate the highest stable condensate column in vertical pore segments without overflowing.

The volume of condensate residing in the corners of a pore segment of arbitrary polygonal cross section is given by the general formula (see Fig. 1),

$$V_c = n\, r_w^2\, l \times \left[\sin(\alpha+\theta)\cos(\alpha+\theta) + \frac{\cos^2(\alpha+\theta)}{\operatorname{tg}\alpha} - \frac{\pi}{2} + \alpha + \theta \right] \quad (1)$$

where V_c is the volume of condensate at the corners of a pore, n is the number of sides of the polygonal cross section of the pore, r_w is the radius of curvature of the longitudinal meniscus, defined as