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Injection of Water above Gas for Improved Sweep in Gas IOR: Performance in 3D

M. Jamshidnezhad,[1] L. van der Bol,[2,3] and W. R. Rossen[2]
[1] National Iranian South Oil Co.
[2] Delft University of Technology
[3] Now at Chevron North Sea Limited

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Abstract

In gas-injection IOR, simultaneous injection of water and gas from parallel horizontal wells, with water injected from the upper well (sometimes called "modified SWAG"), can give deeper penetration of gas before gravity segregation than simultaneous co-injection of water and gas from the same well ("SWAG"). Most previous studies of this process were limited to 2D, where injection rate is uniform along each well.

In 3D, we find that gas injection can be far from uniform, even in homogeneous reservoirs, the focus of this study. (If gas injection is nonuniform in homogeneous reservoirs, it surely would be in heterogeneous reservoirs.) There is in some cases an inherent instability in uniform injection along the gas well, even as the water well continues to inject nearly uniformly along its length. In our results the uniformity of gas injection increases with increasing total injection rate, and decreasing vertical distance between gas- and water-injection wells. The instability leading to nonuniform injection depends on the relation between gas saturation and gas relative-permeability; we speculate that effects of gas flow on hydrostatic pressure, and therefore on gas-injection pressure, may also play a role. We find that in some cases lateral movement of gas from the injection point partially mitigates the effects of nonuniform gas injection. Injecting gas from separate, independent segments along the horizontal well improves sweep somewhat by increasing the number of points at which gas exits the well.

Introduction

Oil recovery can be improved by injecting a solvent, in most cases gas or supercritical fluid, into the reservoir. The solvent (which for convenience we call "gas" below) can be injected into the reservoir continuously, in slugs alternating with water, or simultaneously with water (Lake, 1989).

The microscopic displacement efficiency of gas IOR can be almost complete (i.e., with residual oil saturation to gas ~ 0). The effectiveness of an IOR scheme then depends on sweep efficiency, which is a measure of the volume of reservoir contacted by gas. In the ideal case the entire reservoir is contacted by gas, but some problems arise to prevent this. These problems are caused by heterogeneities in the reservoir, density differences between gas and oil (and water) and fingering of gas through the oil and water.

In a homogeneous reservoir the flow of fluids is influenced by the density and mobility differences between the injected and resident fluids. In a heterogeneous reservoir permeability differences play a dominant role (Waggoner *et al.*, 1992). The injected fluid(s) prefer to flow through high-permeability layers, which leads to channeling. The low-permeability layers are bypassed and not swept by gas.

If heterogeneities are not significant, gravity governs fluid flow in the reservoir. Gas in general has a lower density than oil (and water) and segregates to the top of the reservoir, leaving the bottom part untouched by gas. At fixed injection rate, gravity segregation of gas and water is more rapid the higher the total mobility of the fluids (Stone, 1982; Jenkins, 1984). Therefore it is common to inject gas and water simultaneously (SWAG, or simultaneous water and gas) or in alternating slugs (WAG, or water-alternating-gas, injection), relying on mixing of those slugs in the reservoir to reduce mobility.

This paper concerns gravity segregation caused by the density difference between gas (or solvent) and water. Stone (1982) and Jenkins (1984) analyze gravity segregation at steady state for uniform co-injection of water and gas. They argue that this model also represents WAG processes as long as slug size is small enough that slugs mix near the well. They assume that at