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Theoretical and Experimental Investigation of Water in Oil Transverse Dispersion in Porous Media

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Abstract

Water production is controlled by the size and distribution of water saturation around wells. Reported in this paper is a continuing research into mechanisms causing expansion of the water saturation transition zone (transverse dispersion) in a segregated flow of oil and water approaching a vertical well's completion. The mechanisms – including non-linear (non-Darcy) flow, turbulence, shear rate, flow baffling at grains – all contribute to instability of the oil/water interface resulting in hydrodynamic mixing. Interface instability due to shearing rate has been demonstrated in our recent study on the Hele-Shaw model. In this work, we have evaluated the practical size of the mixing zone around wells, modeled mathematically the effect of flow baffling, and demonstrated transverse dispersion experimentally using a linear physical sand pack.

The maximum size of the mixing zone was evaluated using the turbulence criterion and differential velocity for typical wells' inflow conditions. Critical dimensionless numbers for flow in porous media were used to determine the onset of transverse dispersion. The radial size of mixing zones was then correlated with fluid properties, water cut, and the effective area of well's inflow.

A simple model of "bifurcated flow" was developed to demonstrate the effect of two phase flow baffling in granular porous media. The model shows that the change of flow momentum of the two fluids at collisions with rock grains becomes the major factor causing water dispersion.

A series of segregated (top oil; bottom water) flow runs were carried out using physical model packed with different porous media at a constant pressure drop. The runs were videotaped and analyzed for saturation distribution using a color intensity recognition software. The results clearly demonstrate onset of transverse dispersion of water into the flowing oil. Further dispersion, however, was overshadowed be the dimensional and end-point effects of the model. With a numerical estimation procedure, the initial dispersion rate – computed from the 1-D flow model – is the essential data needed to estimate total dispersion in radial inflow to wells.

Introduction

At high production rates, non-Darcy flow displays a strong indicator that linear flow would change to nonlinear flow such as eddies. Non-Darcy flow coefficient β (Forchheimer, 1901) is commonly regarded as a parameter of intrinsic properties of porous media to describe the intensity of the change. Al-Rumhy et al. (1996), Huang and Ayoub (2006), Haro (2007) and Ma and Ruth (1997) show that tortuosity and core heterogeneity are key factors inducing non-Darcy by In a water oil segregated flow (Figure 1), if the flow driven by inertia force diverts from the main flow across the W/O contact, transverse dispersion may occur. Considering capillary and gravity effects, criteria of transverse dispersion zone near wellbore was developed in this paper.

Immiscible transverse dispersion, described here, is a mixing process caused by uneven concurrent laminar flow in porous media (Duan and Wojtanowicz, 2006). The mechanism of transverse dispersion is important for evaluating the size of mixing zone. Ma and Ruth (1997) and Greenkorn et al. (1964) presented how momentum theory explains dispersion using flow streamline diverting and converging in theoretical models and physical experiments in microscopic scale. A simplified bifurcated flow model associated the momentum balance theory is developed to demonstrate the stream distortion between water and oil flow in this paper. The solutions quantitatively described the fluid's diverted velocity and volume resulting from collisions. For water saturation distribution in macroscopic scale, a coefficient of transverse dispersion is used to describe the effect of mixing after series of mixing (Duan and Wojtanowicz, 2006). The coefficient could be calculated with experimental results.