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The Influence of Viscoelasticity on Displacement Efficiency—From Micro- to Macroscale

D. Wang, SPE, G. Wang, SPE, Daqing Oilfield Company, and W. Wu, SPE, H. Xia, SPE, and H. Yin, SPE, Daqing Petroleum Institute

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Abstract

The displacement efficiency (De) in porous media is usually analyzed by the ratio of the macro pressure gradient driving force and interfacial tension (IFT) between the driving fluid and residual oil. However, when the pressure gradient is constant, macro forces cannot explain the increase in De by driving fluids with elastic properties. Therefore, the change of micro forces acting on residual oil between driving fluids with and without elastic properties is analyzed.

This paper shows the influence of viscoelasticity on De; the difference in the stress of non elastic fluids and fluids with elastic properties when flowing is analyzed; the effect of this stress difference on the micro flow lines in pores is mathematically simulated; the affect of the changes in micro forces caused by the change in micro flow lines on residual oil is shown; this enhanced micro force (without changing the macro pressure gradient) mainly acts on the protruding portion of different types of residual oil in pore(s), causing the protruding portion to change shape and move (mobilize); results on visualization core models confirm the above calculation and analysis; the displacement results on cores by fluids with different elastic properties in the lab are shown; the results of considering the phenomena that elasticity increases the De in numerical simulation are shown and compared with field results; large scale field results on polymer flooding and pressure coring are also shown.

The above mathematical simulation, analysis, lab tests and field results all show that the micro forces acting on residual oil is different when the elastic properties of the displacing fluid varies, resulting in an increase in De for viscoelastic displacing fluids at constant pressure gradient conditions.

This method of micro flow line and force analysis and its conclusions should be useful to further understand the mechanism of De in porous media; should be useful in designing, screening and developing better chemical flooding products, methods and projects to further increase oil recovery; should be useful in the analysis of phenomena associated with injecting non Newtonian fluids and gels.

Introduction

The most commonly accepted mechanism on Displacement Efficiency is that for a certain fluid – rock porous media system, De is determined by the ratio between viscous driving force (macro pressure gradient) and retention force (mainly caused by the IFT). The pressure gradient is proportional to the viscosity (μ) and flow velocity (v) of the driving fluid, and the retention force is proportional to the IFT (σ) between the displacing and displaced fluid. The ratio of $v\mu$ and σ is termed the Capillary Number Nc ($Nc = v\mu/\sigma$).

The IFT between polymer fluids and crude oil is near to the value of that between water and crude oil, and when the pressure gradient for polymer flooding is maintained constant (compared to water flooding), the Nc is constant. Therefore, by the commonly accepted mechanism, the Displacement Efficiency for polymer flooding should be the same as that for water flooding, which means that polymer flooding should not increase De.

However, numerous test results in the lab and field show that the De of polymer flooding is higher than that of water flooding. The viscosity of the polymer fluid is much higher than water, this might increase the viscous driving force $v\mu$, but this would also increase the pressure gradient of the system and field. Some papers (1, 2) have noted that the residual oil saturation is lower after polymer flooding. However, either the mechanism of this lowering of saturation was not given or the explanation would require an increase in pressure gradient. Since most actual oil fields cannot significantly increase the reservoir pressure gradient, therefore the pressure gradient and the macro viscous driving force should be maintained constant (or relatively constant) when analyzing the affect of elasticity on De. The following work and analysis are based on constant pressure gradient in the system. Therefore the higher De for polymer flooding can only be caused by micro forces that do not increase the pressure gradient.

Numerous mathematical simulation calculations and visualization core flood test were performed on the micro flow behavior of viscoelastic fluids in porous media. The results show that the flow lines in different types of pores are all different from that of non elastic fluids. When cores are flooded,