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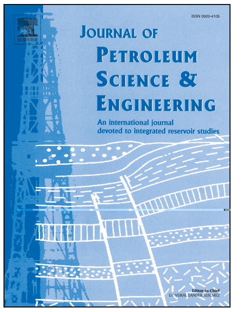

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Modeling the Swelling of Shale Matrix in Unconventional Reservoirs

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Abstract

The imbibition of the injection water into shale matrix may result in shale swelling affecting oil recovery from the rock matrix and the transport properties of the fractures. The expansion of rock due to the swelling of shale matrix compresses the pore space in the rock matrix and the surrounding fractures. This reduces fracture and matrix porosity and permeability. The reduction of matrix pore space can reduce the rate of oil recovered from the rock matrix. On the other hand, it also forces the oil out of the matrix pore space increasing oil recovery. However, this effect has not been evaluated and integrated in reservoir modeling.

This study presents a coupled fluid flow and geomechanics model for modeling shale swelling to quantitatively investigate the effect of swelling on transport properties of rock matrix and fractures. The main objective is to quantitatively determine the effect of shale swelling on the oil recovery from the rock matrix. A numerical solution is presented to solve the coupled equations simultaneously for the phase pressure, fluid saturation, stress, and strain. We show that the mechanical properties of the rock matrix vary significantly as the result of water imbibition. The reduction of the fracture and matrix permeability and porosity due to swelling is considerable. This results in the reduction of more than 50% of the oil recovered from shale matrix. Hence, shale swelling should be prevented in any water injection operations.

Introduction

The recovery from unconventional reservoir is often very small, typically in the range from 3% to 7% EIA (2013). Shale matrix is often characterized by very low permeability, in the nano-Darcy (nD) scale. To economically produce from this type of reservoir, fracture-stimulation is widely used. During the hydraulic fracturing operation, fracturing fluid is pumped at high pressure into the formation to generate the hydraulic fractures. A portion of this fluid imbibes into the shale matrix and a portion returns to the surface through the wellbore after the hydraulic fracturing operation. The fluid recovered during the clean-up phase is called flow-back fluid or flow-back water. The volume of water flow back is often less than the injected volume. The retention of water in shale matrix may cause the swelling of the shale matrix affecting production from the reservoir.

Shale swelling may have a significant effect on the economics of water injection into shale formations. To demonstrate the significant role of the swelling, we consider an unconventional reservoir with average porosity of 7%, initial oil saturation of 80%, and 5% recovery factor. The volume of oil that we can produce from this reservoir is estimated to be 0.28% of the reservoir volume. For simplicity, we take out a very small portion of the total reservoir volume. This volumetric depletion is compensated during the production by the expansion of rock and fluids in the pore space. The volumetric change of the rock due to shale swelling may be higher than this volume depletion and pore pressure can be maintained by swelling-induced pressure. In other words, swelling may enhance recovery from shale formations.

There is experimental evidence of the swelling behavior of shale when it contacts water (Emadi et al. 2013). The displacement in different directions of an Eagle Ford shale sample when contacted with water, presented in Figure 3, indicates that shale does swell. The experimental results for the Eagle Ford samples by Emadi et al. (2013) also show that the maximum volumetric swelling strain is about 0.69% when submerged into distilled water and about 0.15% when submerged into 7% KCl water for seven days. For their drilling calculations, this value is considered to be small. However, for reservoir engineering calculations, this is more than the volumetric percentage of oil produced from the reservoir depending on the volume of shale matrix in contact with injection water. Therefore, accounting for the effect of shale swelling is important for any water injection modeling.