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Comparison of Numerical Simulations and Laboratory Waterfloods in Fractured Carbonates

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Abstract

Recovery mechanisms in fractured carbonate rocks have been investigated by comparing laboratory experiments with numerical simulations. The experimental data include waterfloods in blocks of carbonate rock with 2D, *in-situ* fluid saturation of the advancing waterfronts. The waterfloods were initially performed on the whole block, and then repeated on the same block with a fracture network containing both closed and open fractures to isolate the effect from fractures.

The primary objective for the experiments was to investigate how the presence of fractures altered the dynamics of the propagating waterfront. A numerical, grid based model of the block was created and a sensitivity study of the representation of fractures was carried out. Especially the impact of the degree of capillary contact over fractures was studied. Matrix capillary pressure and relative permeability curves were determined by history matching both average oil production *and* the *in-situ* fluid saturation profiles from the unfractured block experiment. These were in turn used as input for the matrix properties in the fractured block simulations.

The results show how the degree of capillary contact between matrix blocks controlled fluid saturation development and influenced the waterflood oil recovery in fractured limestone. Sensitivity studies on the degree of capillary contact over fractures showed this to be the most significant parameter for the frontal propagation during waterfloods. Numerical simulations together with experimental data gave increased understanding of the waterflood oil recovery mechanisms in fractured carbonate rock.

Introduction

Oil production from water flooded fractured reservoirs is generally considered to be governed by spontaneous imbibition of water from the water filled fractures into the matrix blocks, causing the oil to be expelled into the more conductive fractures by counter-current imbibition. In addition, laboratory observations have indicated that capillary contact between matrix blocks may extend a viscous pressure across fractures, thus increasing oil recovery above the spontaneous imbibition potential for each isolated matrix block. Graue et al.[1,2,3], Viksund et al.[4] and Moe et al.[5] found this process to be dependent on wettability in low-permeability chalk samples. They reported fractures to be barriers to flow for water at strongly water-wet conditions reflecting that the recovery mechanisms are capillary dominated. For less water-wet conditions, however, capillary contact across fractures may be established during waterfloods. The capillary contact transmits viscous pressure gradients across the fracture through wetting phase bridges before the fracture is filled with water, thus accelerating and adding a viscous component to the recovery of oil. The viscous component has been shown to compensate for loss of oil production due to reduced spontaneous imbibition at less water-wet conditions.

Aspenes *et al.*[6] recently showed how fluid flow in fractures was dependent on the fracture surface wettability during waterfloods in chalk plugs ranging from strongly water-wet to neutrally-wet using high resolution MRI. At gradually less water-wet conditions the formation of wetting phase bridges was observed. The wetting phase bridges transported a flow of water and transmitted a viscous pressure component across fractures to adjacent matrix blocks across fractures up to 2 mm in aperture.

Objective

The primary aim for the experiments was to investigate how the presence of fractures altered the dynamics of the propagating waterfront. This was investigated in larger scale experiments in limestone blocks. In addition, the experimental results were used as basis for numerical simulations to perform a sensitivity study related to the importance of capillary contact across the fractures.

Experimental Procedures

An outcrop limestone block (L x W x H = 15cm x 5cm x 9cm) from the Edwards formation in New Mexico, USA was cut