Modeling of wettability alteration during spontaneous imbibition of mutually soluble solvents in mixed-wet fractured reservoirs

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Introduction:

Mutually-soluble solvents can enhance oil recovery both in mixed-wet fractured reservoirs. When a partially water-wet matrix is surrounded by an immiscible wetting phase in the fracture, spontaneous imbibition is the most important production mechanism. Initially, the solvent moves with the imbibing brine into the core. However, upon contact with oil, as the chemical potential of the mutual solvent is different in both phases, diffusion occurs and the solvent is transported in the oleic phase. Through the migration of the mutually soluble component from the aqueous phase into the oleic phase, oil properties and/or rock-fluid interactions are modified. The hypothesis in this work is that a mutually-soluble solvent improves the ultimate recovery and the imbibition rate in mixed-wet cores. The main recovery mechanisms are the wettability change of the mixed-wet cores, oil swelling and oil viscosity reduction.

In this paper the numerical modeling of spontaneous imbibition of Mutually soluble solvent in mixed-wet cores in presented. We implemented the wettability alteration, the oil swelling mechanism, the oil viscosity reduction mechanism, the IFT reduction, and the density reduction mechanisms in the numerical model. Our numerical studies show that the most important production mechanism in the mixed-wet systems are the oil swelling and the wettability alteration and the second most important mechanism is the oil viscosity reduction. The effect of the IFT reduction and the density reduction in the oil production is not significant. The numerical results show an improvement of 27%.

Figure 1. The process of penetration (Countercurrent imbibition) of MSS into an oil-filled core sample. Oil is produced from all boundaries.

Mathematical Model:

$$\sum_{\alpha=1}^{N} \left(\frac{\partial}{\partial t}(S_\alpha V_{\alpha c}) + \nabla.(V_{\alpha c} u_\alpha(S_a, V_{aw}, P_a)) - \nabla.(\varphi D_{sc} S_\alpha \nabla.V_{\alpha c}) \right) = 0, \quad \alpha = o,a; \quad c = h,w,s,$$

$$\sum V_{ac} = 1, \qquad c = w,s,$$
$$\sum V_{oc} = 1, \qquad c = h,s,$$
$$\sum S_\alpha = 1, \qquad \alpha = o,a,$$

$$P_c(S_a(t)) = \left(1-\omega(t)\right) P_c^i(S_a(t)) + \omega(t)\, P_c^f(S_a(t))$$
$$k_r(S_a(t)) = \left(1-\omega(t)\right) k_r^i(S_a(t)) + \omega(t)\, k_r^f(S_a(t))$$

$$P_c(S_\alpha) = P_{ct} S_e(S_a)^{(-1/\lambda)}$$
$$P_{ct} = \gamma\sigma\sqrt{\frac{\varphi}{K}}(\frac{0.5 - S_{wc}}{1 - S_{wc} - S_{or}})^{(1/\lambda)}$$

$$k_{ra}(S_a) = k_{ra}^e S_e(S_a)^{(3+2/\lambda)},$$
$$k_{ro}(S_a) = k_{ro}^e(1 - S_e(S_a))^2(1 - S_e(S_a)^{(1+2/\lambda)}),$$

$$u_\alpha(P_\alpha, V_{aw}, S_a) = -\frac{K k_{r\alpha}(S_a)}{\mu_\alpha(V_{aw})}\nabla.(P_\alpha + \rho_\alpha(V_{aw})gz),$$

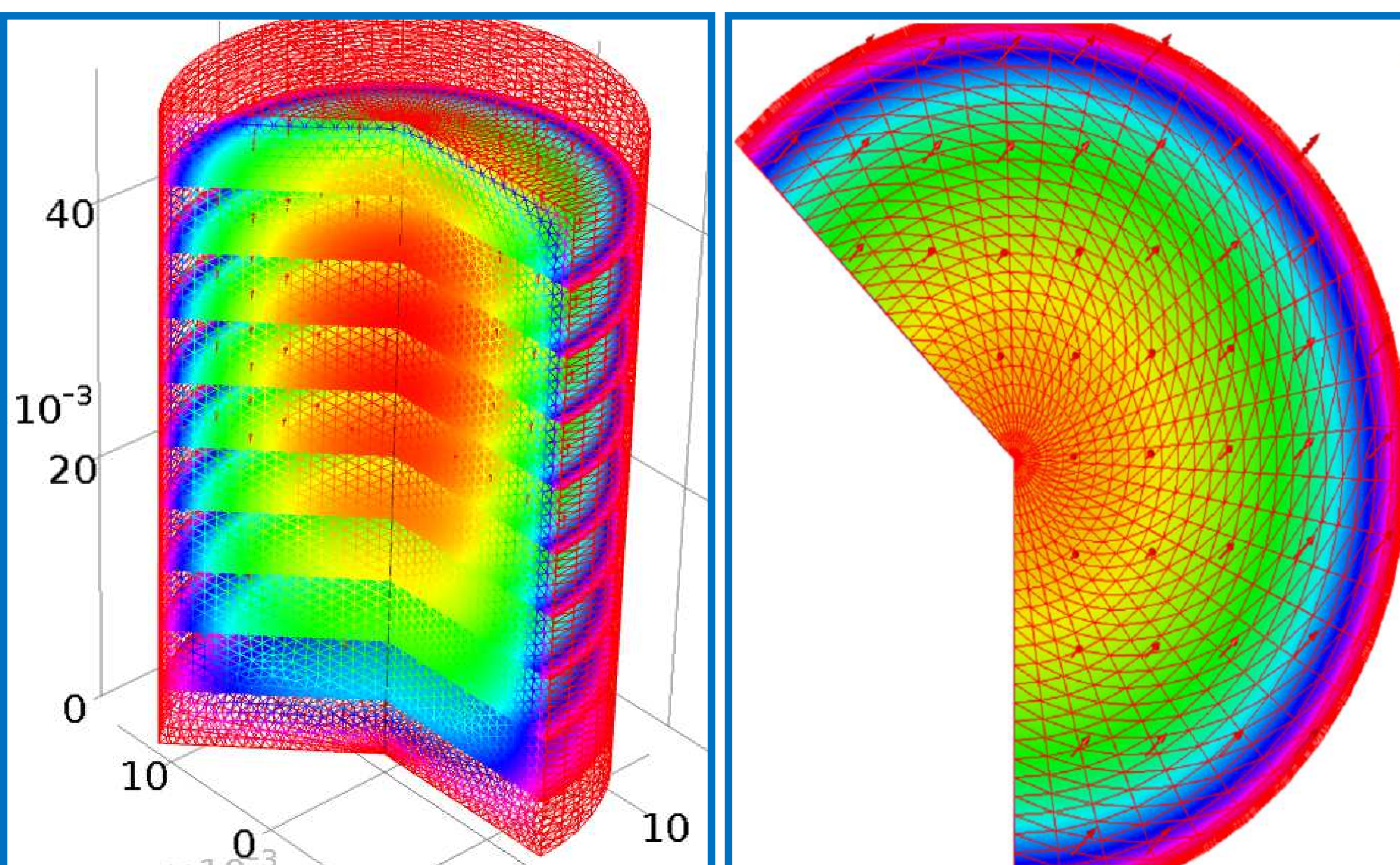**Figure 2**. The distribution of the concentration that is obtained form the solution of the numerical model at time $2.4*10^6$ seconds.
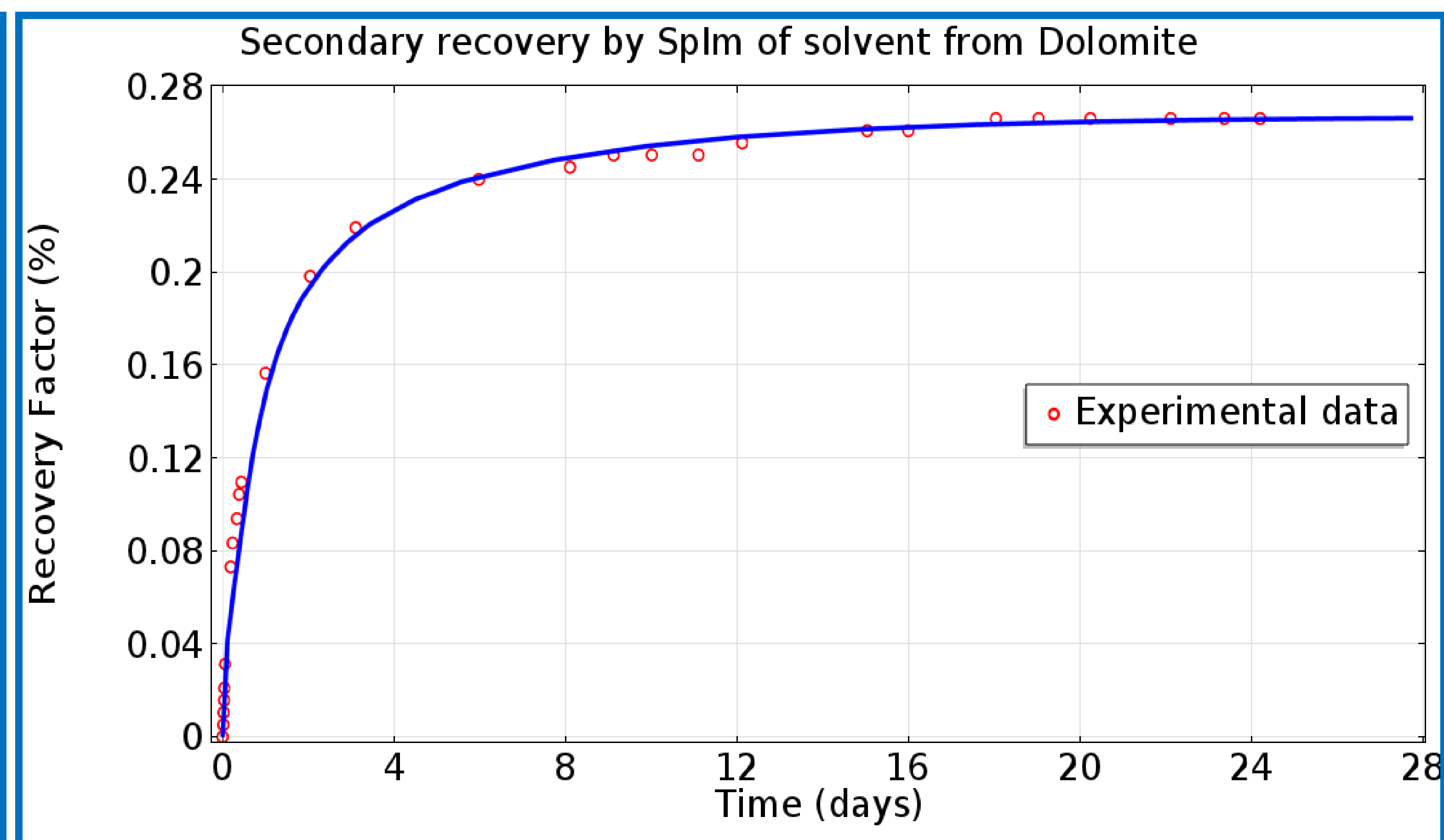

Figure 3. The numerical modeling of the primary oil recovery by spontaneous imbibition of brine into an oil-filled mixed-wet Dolomite core (MWD1).

Conclusion:

The presence of a MSS solvent can enhance the spontaneous imbibition oil recovery. For mixed-wet dolomite the primary and secondary recovery is 7% and 27% respectively. A numerical model is developed that describes the wettability alteration during the solvent enhanced imbibition process.

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