Modeling of Solvent enhanced spontaneous imbibition process in fractured reservoirs

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Oil recovery in fractured reservoirs by water flooding critically depends on the wetting properties of the matrix blocks between the fractures. The recovery from oil-wet reservoirs is small. In incompletely oil-wet systems, the presence of initial water may change the wettability characteristics, so that imbibition and some oil recovery can occur. The hypothesis in this work is that water-soluble solvent (diethyl ether) improve the ultimate recovery and the imbibition rate in partially and completely water-wet cores. The main recovery mechanisms are the wettability change of the partially water-wet cores and oil swelling and the oil viscosity reduction in both partially and completely water-wet cores.

We derive a simplified model for imbibition of water that contains solvents that are both soluble in water and oil can improve the recovery. We consider a cylindrical core that is initially filled with oil. The completely water-wet core does not contain water. However the partially water-wet core contains connate water in addition to the oil. The core is immersed in a water bath (Amott-cell). Water penetrates in the core and releases some oil, which rises to the top and can be monitored. The model consists of a two phase flow problem and includes interchange of the solvent between the oil and the water phase. The model includes gravity and capillary effects. The boundary conditions are pressure continuity between the boundary of the core and the fluid surrounding the core. The model can quantify the amount of oil that is capillarity displaced from the core both due to imbibition and molecular diffusion.

We implemented the model in COMSOL. Comparison between the theoretical and experimental production curve shows that the imbibition is occurring much faster than in the experiment. This indicates delayed imbibition, which can in principle be modelled using dynamic capillary pressure and relative permeability effects. We will formulate the extended model that includes the dynamic constitutive relations and show how these model equations can in principle be incorporated in the COMSOL model.

Introduction

In fractured reservoirs, much of the oil is stored in low permeable matrix blocks that are surrounded by a high permeability fracture network. Therefore, production from fractured reservoir depends on the transfer between fracture and matrix, which is critically dependent on their interaction(Chahardowli, Tabatabaei Nejad, & Sahraei, 2007). When a strongly or partially water-wet matrix is surrounded by an immiscible wetting phase in the fracture, spontaneous imbibition is the most important production mechanism (Chahardowli, Zholdybayeva, Farajzadeh, & Bruining, 2013). The recovery from a matrix depends on the transfer rate between matrix and fracture (Chahardowli et al., 2007). Many parameters affect the transfer rate between matrix ad fracture and as a result the spontaneous imbibition. The most important parameters are wetting properties of the matrix – fluid, two phase flow properties, i.e., kr and Pc functions(Chahardowli & Bruining, 2012), the matrix permeability, viscosities of the phases, the initial water saturation and the boundary condition. The dominant force in the transfer between matrix and fracture can be either capillary forces or gravity forces. Mutual solvent injection could improve oil recovery in oil reservoirs (Chahardowli et al., 2013).

Governing equations of the counter-current spontaneous imbibition of a mutual solvent could be written as

$$\varphi\, \partial_t\, \left(V_{oh}\, (V_{aw})(1 - S_a)\right) + \nabla.(- V_{oh}\, \lambda_o(S_a\, ,V_{aw})\, (\nabla.P_a + \nabla.P_c(S_a) + \rho_a(V_{aw})\, g) - \varphi\, \nabla.(D_{sh}^{a}\, (1 - S_a)\nabla.V_{aw}) = 0,$$

$$\varphi\, \partial_t\, (V_{aw}\, S_a) + \nabla.(- V_{aw}\, \lambda_o(S_a\, ,V_{aw})\, (\nabla.P_a + \rho_a(V_{aw})\, g) - \varphi\nabla.(D_{sw}^{a}\, S_a\, \nabla.V_{aw}) = 0,$$

$$\nabla.\left(- \lambda_o(S_a\, ,V_{aw})(\nabla.P_a + \nabla.P_c(S_a) + \rho_a(V_{aw})g) - \lambda_a(S_a\, ,V_{aw})(\nabla.P_a + \rho_a(V_{aw})g)\right) = 0.$$

Where primary variables are V_{aw} , S_a and P_a.
COMSOL Multyphisics was implemented to model the process of penetration of the aqueous phase into an oil-filled core due to both capillary and gravity forces. First, the governing equations were transformed into a weak formulation system. Afterwards, using a weak form PDE module, the process was simulated using proper initial and boundary conditions. Figure 1 shows there is a discrepancy between the results of the experiment and the model. This is due to the fact that there is a delayed imbibition process in the core. In order to include this effect, we will implement the barenblatt's model for the effect of non equilibrium condition in the fluid flow trough porous medium.

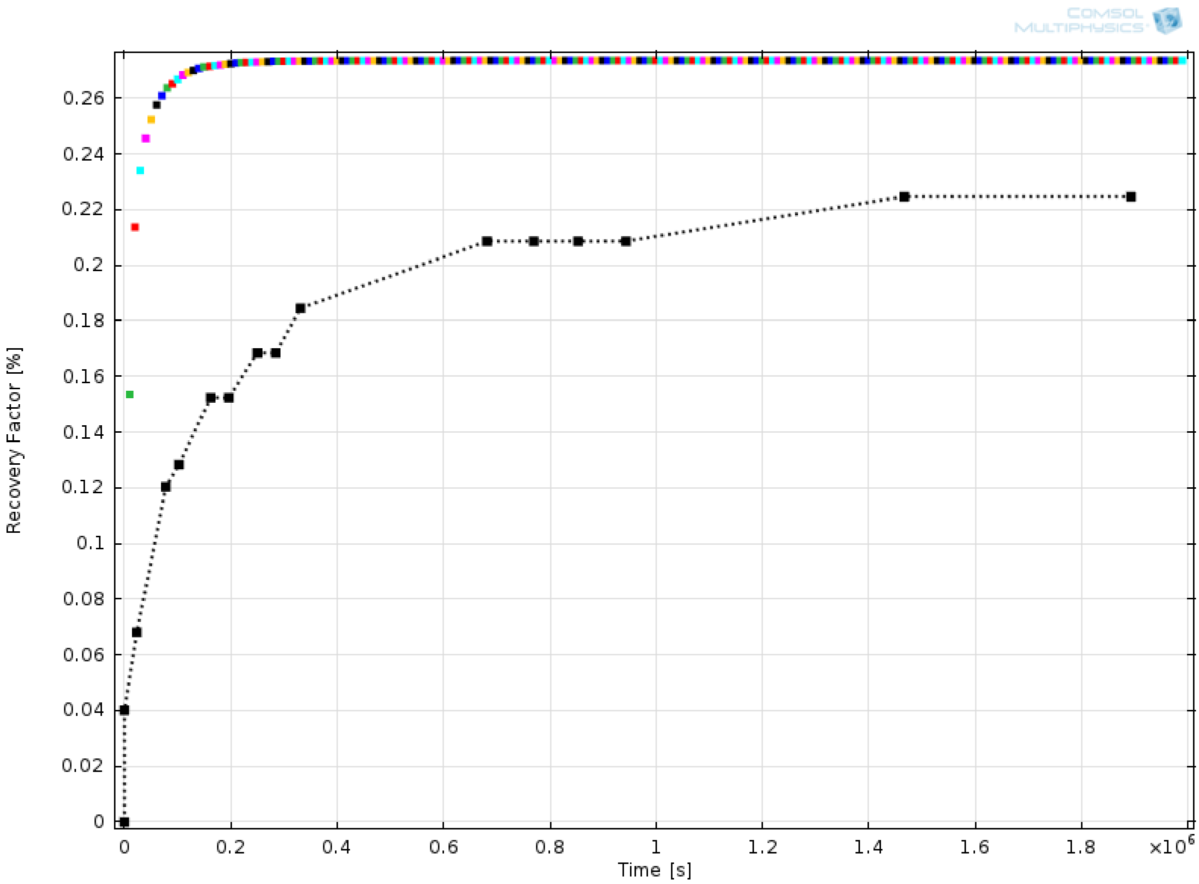

Figure 1: comparison between the results of the experiment and the model

Conclusion:
The process was modelled using COMSOL Multiphysics . The theoretical imbibitinon production curve is faster than the experimental production curve, which implies that the

imbibition is occurring much faster than in the experiment. This indicates delayed imbibition, which can in principle be modelled using dynamic capillary pressure and relative permeability effects. We will formulate the extended model that includes the dynamic constitutive relations and show how these model equations can in principle be incorporated in the COMSOL model.

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