



National Iranian Oil Refining and Distribution Company
(NIORDC)



Journal of Farayandno

Research Paper



DOI: 10.22034/farayandno.2024.2038025.1970



This journal is an open access journal licensed under an
Attribution-Non Commercial 4.0
International Licenses (CC BY-NC 4.0).

Investigating the effect of parameters of wettability, fracture aperture and interfacial tension during counter-current spontaneous imbibition at pore-scale

Iman Jafari¹

¹ Assistant Professor, Department of Chemical Engineering, Jask Branch, Islamic Azad University, Jask, Iran

Received: 30 May 2024 Accepted: 9 Aug 2024

1. ABSTRACT

Counter-current spontaneous imbibition (SI), in which water and oil flow through the same face in opposite directions, is known as one of the most significant oil recovery mechanisms in naturally fractured reservoirs; however, this mechanism has not received much attention. Understanding the dynamic of water-oil displacement during counter-current SI is very challenging because of simultaneous impacts of multiple factors including geometry complexity and heterogeneity of naturally fractured reservoir materials, This study investigates the effects of wettability, fracture aperture and interfacial tension during counter-current SI at pore-scale, the obtained results showed that the wettability of the porous medium changed from a neutral state to a highly hydrophilic state, and it was observed that for contact angles higher than 60 degrees, It was observed that the water mass imbibed into the matrix block varies linearly with time before the water front meets the outlet, which is captured for the first time in a numerical study. Also, It is revealed that increasing the fracture aperture reduces water breakthrough time and oil recovery, known as “filling fracture” regime, The developed model can be used as a basis for phase-field counter-current simulations and would be useful to study the qualitative and quantitative nature of this phenomenon.

Keywords: Simulation, Counter-Current Spontaneous Imbibition, Wettability, Fracture Aperture, Interfacial Tension.

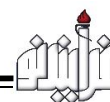
2. INTRODUCTION

Two-phase flow in subsurface porous media has received significant attention since the last decades due to its application in a variety of fields such as hydrocarbon recovery, CO₂ sequestration, and waste disposal [1]. Thus, it has been of great interest to understand the effects of different parameters such as viscosity, capillarity, wettability, and heterogeneity on this process to reduce the flow instabilities which cause inefficient immiscible displacements [2]. Other key parameters affecting the process are rock fractures and their geometrical characteristics [3]. The interaction between the capillary, viscous, and gravity forces determine the pore-scale process and macroscopic configuration of the multiphase flow [4]. It is known that displacement of the wetting phase by the non-wetting phase is referred as drainage process, and on the other hand displacement of the non-wetting phase by the wetting phase is called imbibition [5]. Spontaneous imbibition (SI) refers to a process through which the wetting phase is sucked into a porous medium by the action of capillary forces, and the non-wetting phase is expelled into the fracture SI of water into the oil-saturated matrix blocks is regarded as a fundamental mechanism for oil recovery in water-wet fractured reservoirs [5]. This process can be either co-current or

* Jafari3760@gmail.com

Please Cite This Article Using:

Jafari, I., “Investigating the Effect of Parameters of Wettability, Fracture Aperture and Interfacial Tension During Counter-Current Spontaneous Imbibition at Pore-Scale”, Journal of Farayandno – Vol. 19 – No. 86, pp. 53-66, In Persian, (2024).



counter-current SI. Co-current SI occurs when oil and water are flowing in the same direction in the porous medium. While, in the counter-current SI, fluids flow in the opposite directions [6].

3. MATERIALS AND METHODS

The system considered in this study is a 2D rectangular heterogeneous porous medium including a fracture. A rectangle with the dimension of $15 \times 9 \text{ mm}^2$ was constructed to simulate a matrix block and, the porosity and permeability of which are 35% and $8.9 \text{ e}^{-10} \text{ m}^2$, respectively. An equilateral triangular array of circles with different diameters was used to represent grains distribution. A rectangle with the dimension of $15 \times 0.9 \text{ mm}^2$ was located close to the porous matrix to represent the fracture. The average pore and throat diameter were set to 1.3 e^{-3} and $2.2 \text{ e}^{-4} \text{ m}$, respectively. Figure 1 illustrates constructed domain for the numerical experiments. The 2D computational domain was discretized into triangular elements with predefined “normal” mesh density, which refers to a specific refinement level of the physics-controlled meshing techniques built into the software. Figure 2 depicts a magnified view of the discretized system. Considering coarser mesh grids in the bulk and denser mesh grids covering the boundary layers will reduce computational time and results in better convergence [45]. This is employed in the proposed model.

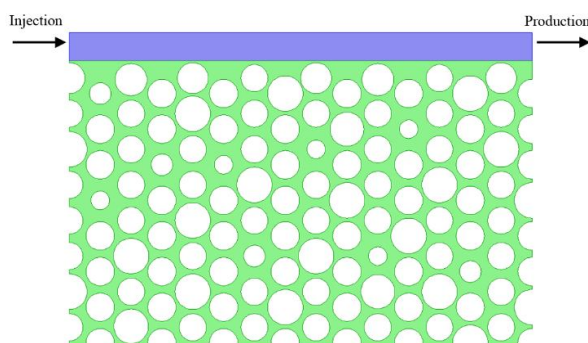


Figure 1. Schematic representation of constructed fractured heterogeneous porous media. The green and blue areas represent the matrix block and fracture, respectively.

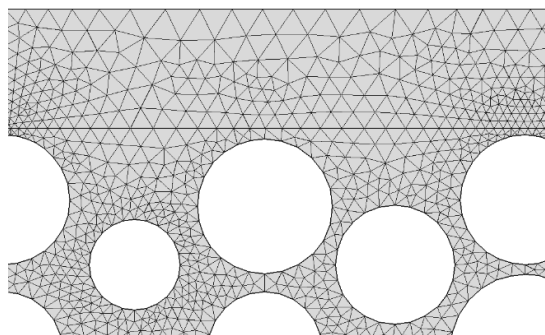


Figure 2. Mesh generation for the simulated domain. Note how meshes are refined at the boundaries.

4. RESULTS AND DISCUSSION

4.1. Effect of wettability on the fluid flow in the porous media

Figure 3 shows the water-oil distributions in the extremely water-wet model $\theta = \pi/10$ at different times during the imbibition process. Firstly, the matrix and the adjacent fracture were saturated with the oil phase and then water was injected through the inlet (Figure 3a). The red and blue colors represent the oil and water phases, respectively and the color gradient represents the interface mixing zone. Through water injection into the fracture, water was sucked into the porous medium with the sizes of 2-3 pore bodies and also progressed to the fracture (Figure 3b). As it is shown in Figure 3c, water phase displaced the matrix oil and the water front was narrowed from 4 pore bodies to a pore body. It can be seen that the wetting phase firstly occupies the smaller size pores and throats, which is in accordance with micromodel observations conducted by Hatiboglu and Babadagli. Water phase gradually floods the fracture and displaces the resident oil. Figure 3d shows that the water phase is progressed by forming a capillary finger with an average width of 1-3 pore bodies. This type of instability takes place in the form of wide forward and lateral moving fronts of displacing phase with an average width of more than 1-3 pore bodies, which is in agreement with micromodel observations by Lenormand et al.. Afterwards, another capillary finger is formed in the right-hand side of the medium and the formed finger is thickened through occupying more pore bodies (Figure 3e). It can also be seen that a small oil droplet is trapped between three grains because of water bridging between adjacent grains. The imbibition process is stabilized after 65 s and 40% of the matrix oil is recovered (Figure 3f). In different zones of the porous medium, water-oil interface stops progressing as it reaches wider pores and throats.

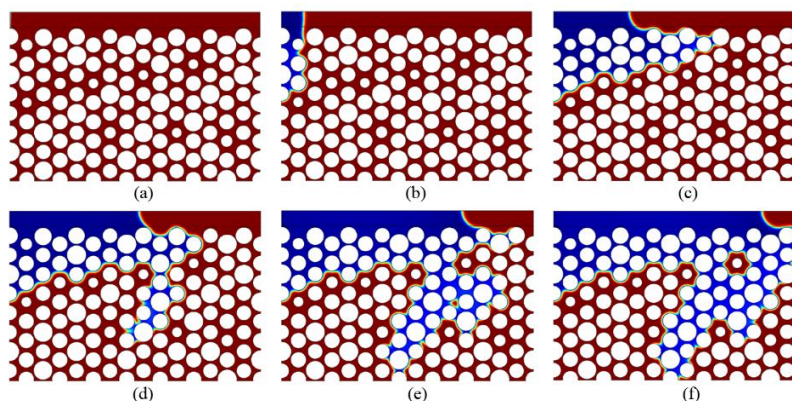


Figure 3. Fluid distributions at six different times during counter-current SI for the simulated model with $\theta_c = \pi/10$ (a) $t = 0$ s, (b) $t = 6$ s, (c) $t = 25$ s, (d) $t = 40$ s, (e) $t = 55$ s, (f) $t = 65$ s.

5. CONCLUSION

Different sensitivity analyses were performed to investigate the effects of wettability, fracture aperture, IFT, and water injection velocity on the displacement process. For the models with $\theta > \pi/6$, water just progressed in the fracture and could not penetrate into the matrix block. While, for the strongly water-wet mediums $\theta \leq \pi/6$, water invaded more pore bodies and capillary fingers propagated into the matrix. It was found that both imbibition rate and ultimate oil recovery were significantly affected by decreasing the contact angle. It was also observed that the water mass imbibed into the matrix block scales linearly with time before the water front meets the outlet, which was characterized as “filling fracture” regime. Increasing the IFT resulted in both higher imbibition rate and ultimate oil recovery. As an example, in the first 50 s, the matrix oil is recovered by 16% in the model with the lowest IFT ($\sigma = 5$ m N/m). While for the case of the highest IFT ($\sigma = 50$ m N/m), ultimate oil recovery was higher than 30%. Increasing the fracture aperture led to an earlier water breakthrough time and also lower oil recovery; however, the ultimate recovery was not significantly affected.

6. REFERENCES

- [1] Gauteplass, J., Follesø, H., Graue, A., Kovscek, A., and Fernø, M., Visualization of pore-level displacement mechanisms during CO₂ injection and eor processes, 2013.
- [2] Amiri, H. A., and Hamouda, A., Pore-scale modeling of non-isothermal two phase flow in 2D porous media: Influences of viscosity, capillarity, wettability and heterogeneity, *Int. J. Multiphase Flow.*, Vol.14, 2014.
- [3] Farzaneh, S., Kharrat, R., and Ghazanfari, M., Experimental study of solvent flooding to heavy oil in fractured five-spot micro-models: the role of fracture geometrical characteristics, *J. Can. Pet. Technol.*, Vol. 49, pp. 36, 2010.
- [4] Zhang, C., Oostrom, M., Wietsma, T. W., Grate, J. W., and Warner, M. G., Influence of viscous and capillary forces on immiscible fluid displacement: Pore-scale experimental study in a water-wet micromodel demonstrating viscous and capillary fingering, *Energy& Fuels.*, Vol. 25, pp. 3493, 2011.
- [5] Behbahani, H. S., Donato, G. Di., and Blunt, M. J., Simulation of counter-current imbibition in water-wet fractured reservoirs, *J. Pet. Sci. Eng.* Vol. 50, pp. 21, 2006.
- [6] Delijani, E. B., and Pishvaie, M. R., Green Element solution of one-dimensional counter-current spontaneous imbibition in water wet porous media, *J. Pet. Sci. Eng.* Vol. 70, pp. 302, 2010.