Effect of Water-soluble Solvent Injection on Bitumen/Water Relative Permeability

Maojie Chai
Zhangxin Chen
Sheng Yang
Min Yang
Wei Wu
University of Calgary

Summary

SAGD (steam assisted gravity drainage), which reduces the viscosity of heavy oil by steam injection, is the main heavy oil recovery process used in Canada. However, with the introduction of carbon emission limitation schemes, stricter environmental regulations and low global oil prices, solvent-based heavy oil recovery processes have been proposed as more economical alternative recovery processes. Relative permeability changes in real time during a recovery process have a significant impact on an oil recovery rate. There is a consensus that a relative permeability curve is affected by temperature in SAGD. Usually, a relationship between temperature and relative permeability is an important feature when the saturation of connate water increases. The discussion of relative permeability changes during solvent-based injection for oil recovery has tended to focus on *n*-alkanes because they are still the dominant injected solvents. Recently, DME (dimethyl ether), a slightly water-soluble solvent, has been investigated for use in heavy oil recovery (Sheng et al., 2018). DME has shown high economic value in both ES-SAGD (expanding solvent SAGD) and VAPEX (vapor extraction) due to its slightly water-soluble properties. This is attributed to high recovery and high production rates of DME due to its mass transfer between the oil and water phases. However, the current study of DME is still limited to a mass transfer mechanism, and the effect of its solubility on a relative permeability curve has not been studied.

This work presents results of an ongoing DME injection study for heavy oil recovery. Compared with a conventional solvent (e.g., butane) for heavy oil core flooding displacement, relative permeability alteration has been inversely updated from a DME core flooding experiment. A water-soluble solvent effect on relative permeability has been comparably studied. Focusing on relative permeability alteration, the primary objectives are to determine the relative permeability changes during a water-soluble solvent injection and its effect on oil recovery performance.

Theory / Method / Workflow

The core displacement data is taken from reliable reports of Alberta Innovates displacement experiments, and the experimental setup is shown in Figure 1, with a 45-degree inclined core arrangement simulating a boundary layer flow. A fully reproducible numerical model is built to describe the experimental butane and DME replacement processes. There are two different approaches to translating the production data and pressure drop data into the relative permeability curves known as the “implicit approach” and “explicit approach”. The history matching technique implicitly computes a relative permeability curve. The explicit approach can only be used for measured data after obtaining a breakthrough time and generating a part of the relative permeability curve; however, this issue does not occur in the implicit approach. The history matching technique is an optimization problem in which the relative permeability curves are tuned until the calculated oil production from reservoir simulation matches the experimental data as closely as possible (Chen et al., 2006). The history matching based on such experimental data is commonly used in the literature (Esmaeili et al., 2020). Therefore, an objective function must be chosen carefully and optimized in the history matching technique. In the present study, an in-house reservoir simulator was developed, and a generalized Corey relative permeability model was employed to compute the oil and water relative permeability. A fully implicit scheme with the finite difference method was employed to discretize the governing equations. The gravitational force, fluid compressibility and thermal expansion are also considered in our reservoir simulator.

$$k_{rw} = k_{rw}^0 \left(\frac{S_w - S_{iw}}{1 - S_{or} - S_{iw}}\right)^{N_w}$$

$$k_{ro} = k_{ro}^0 \left(1 - \frac{S_w - S_{iw}}{1 - S_{or} - S_{iw}}\right)^{N_o}$$

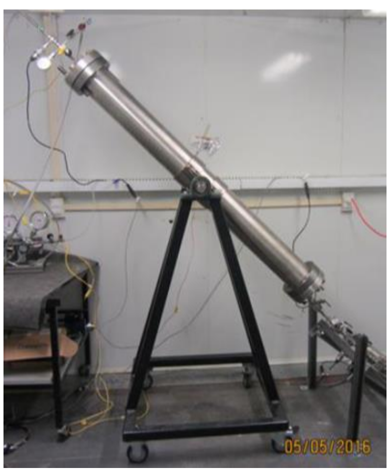

Figure 1. Assembled test apparatus (Deng et al. 2017)

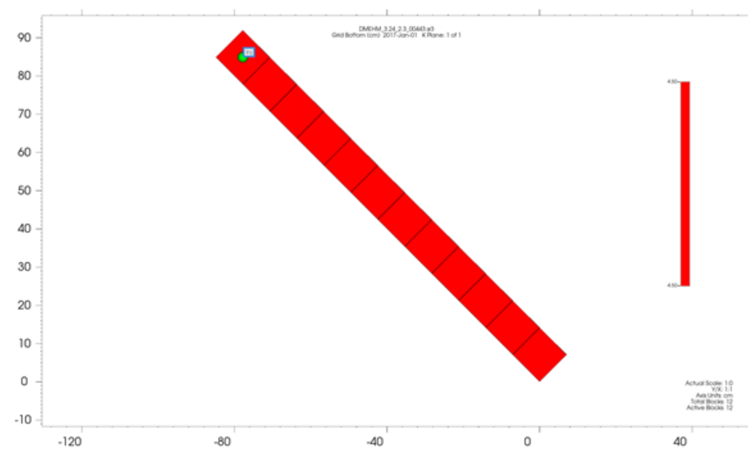

Figure 2. A core-scale numerical model

Results / Observations / Conclusions

In this study, DME was compared with conventional butane as a solvent for core flooding displacement. The changes in the relative permeability curves, as shown in Figs. 3-6, were implicitly obtained by history matching after DME and C_4 solvent injection. Although the physical properties are relatively similar, DME has a faster and higher production rate with its water-soluble characterization. A change in a relative permeability curve shows that the residual oil saturation decreases after butane flooding, but its effect on water relative permeability is not significant. In contrast, DME is slightly soluble in water and its swelling leads to an increase in the connate water saturation, which results in more residual oil being squeezed out and a greater reduction in residual oil. This is another advantage in addition to the excellent mass transfer mechanism of its water solubility.

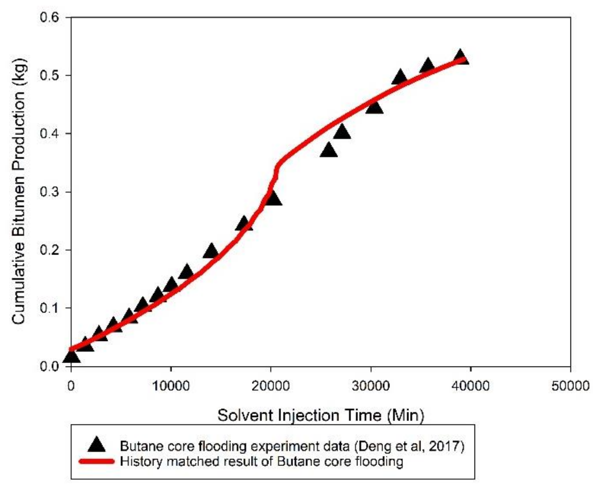

Figure 3. History match of butane core flooding simulation

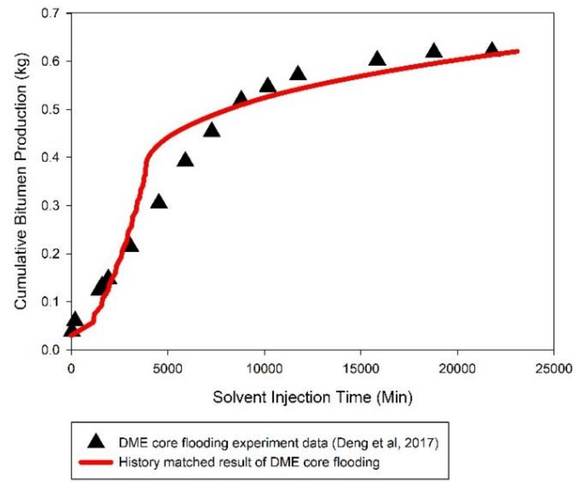

Figure 4. History match of DME core flooding simulation

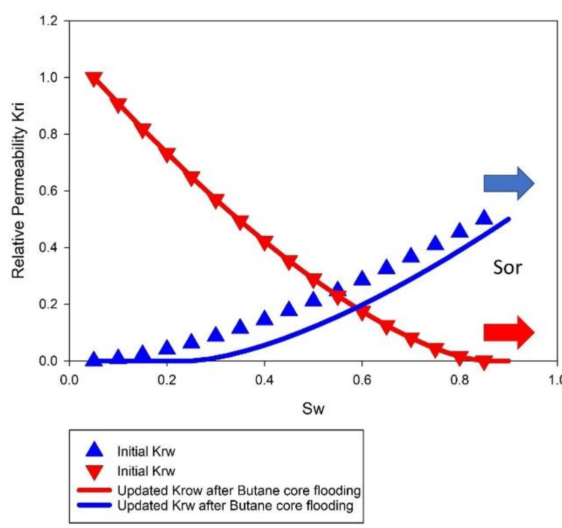

Figure 5. Inversely updated relative permeability by history match of butane core flooding

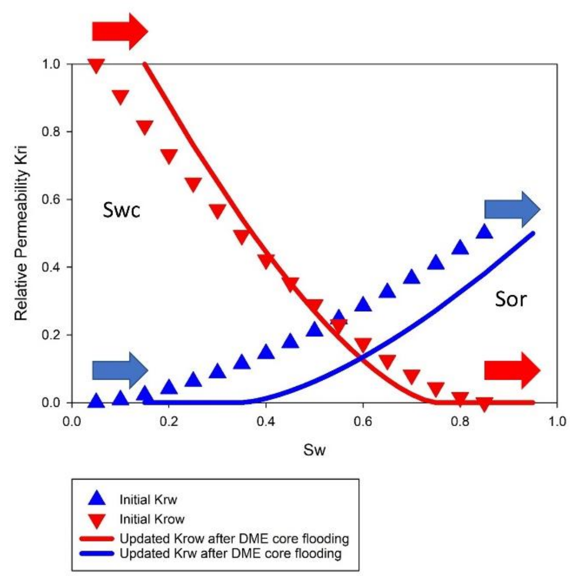

Figure 6. Inversely updated relative permeability by history match of DME core flooding

Novelty / Additional Information

In this study, the effect of a water-soluble solvent on relative permeability curves is presented for the first time, and the changes in relative permeability curves after core flooding are obtained implicitly by historical matching. This study provides a realistic representation of a multiphase flow regime of this water-soluble solvent in heavy oil recovery. The results show that the water-soluble solvent not only provides higher production rates but also have a stronger sweeping effect on residual oil in micro-repellency compared to conventional solvents. This study provides important parameters and a solid foundation for numerical simulation, dynamic prediction, and an effect evaluation of water-soluble solvents on the development of heavy oil resources.

Acknowledgements

The authors would like to thank GV Energy and Mitacs for their financial support. This research has been made possible by contributions from the Natural Sciences and Engineering Research Council (NSERC)/Energi Simulation Industrial Research Chair in Reservoir Simulation, the Alberta Innovates (iCore) Chair in Reservoir Modeling, and the Energi Simulation/Frank and Sarsh Meyer Collaboration Centre.

References

Deng, X., & Huang, H. (2017, May). *Study of Solvent-Assisted in-situ Bitumen Recovery*. Alberta Innovates - the province's full-service innovation engine. https://albertainnovates.ca/wp-content/uploads/2020/04/CHP-RT-2313-N-Comparative-Test-on-Oil-Drainage-Behaviour-under-in-situ-Vapor-Solvent-Extraction-Final-Report.pdf

Esmaeili, S., Sarma, H., Harding, T., & Maini, B. (2020). Experimental study of the effect of solvent addition and temperature on two-phase bitumen/Water relative permeability. *SPE Reservoir Evaluation & Engineering*, *23*(04), 1381-1402. https://doi.org/10.2118/199939-pa

Sheng, K., Okuno, R., & Wang, M. (2018). Dimethyl Ether as an additive to steam for improved steam-assisted gravity drainage. *SPE Journal*, *23*(04), 1201-1222. https://doi.org/10.2118/184983-pa

Z. Chen, G. Huan, and Y. Ma, “Computational Methods for Multiphase Flows in Porous Media”, Computational Science and Engineering Series, Vol. 2, SIAM, Philadelphia, 2006.