# Modelling Foam-Based Displacements in Enhanced Oil Recovery

O. Gassara[a], F. Douarche[a], B. Braconnier[a], B. Bourbiaux[a]

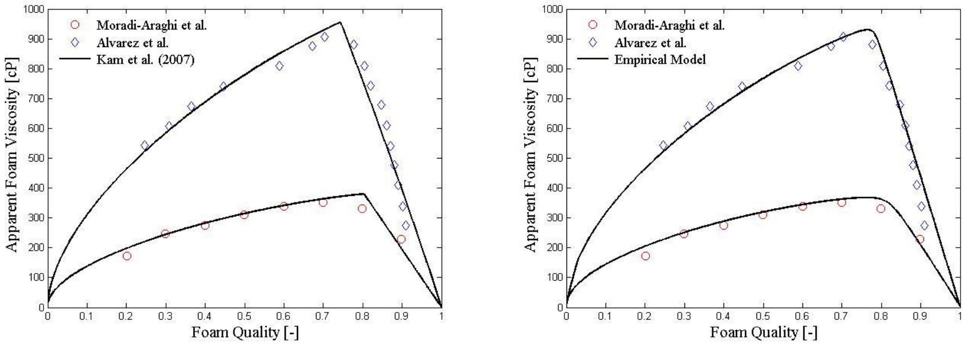
[a]*IFP Energies nouvelles, 1 et 4 avenue de Bois-Préau – Rueil-Malmaison Cedex, 92852 – France*

*Keywords:* foam flow in porous media, reservoir simulation, enhanced oil recovery

Conventional techniques of oil recovery consist in injecting water and/or gas into the geological formation to force out the oil. These methods may reveal ineffective because of high permeability contrasts, unfavorable mobility ratio between the driving fluid and the oil in place which generally generates viscous fingering, and gravity segregation. In this context, foam has shown a great potential to overcome all these detrimental effects and thereafter to improve the volumetric sweep efficiency [1]. Still, some key points need to be addressed regarding the predictive calculation of multiphase foam flow in porous media.

Methods for modelling foam flow in porous media fall into two categories: population balance models (PBM) and empirical models (EM). On the one hand, PBM describe foam lamellas transport in porous media and predict the evolution of foam microstructure as the result of pore-scale mechanisms of lamellas generation and destruction. Within this framework, the modelling of the foam effects on gas mobility is directly related to foam texture (number of lamellas) and the fraction of trapped foam. On the other hand, EM, which are implemented in industrial simulators, are not based on an explicit relationship between foam texture and gas mobility, which dramatically reduces modelling complexities. Instead, the gas relative permeability and/or gas viscosity is modified using a multi-parameter interpolation function that takes into account the effect of each parameter impacting the foam performance (foaming agent concentration, fluids saturation and velocity, and permeability of porous media). Such a formulation has to be calibrated from foam flow experimental data on a case-by-case basis, which is usually a very cumbersome task. Furthermore, EM are not based on mechanistic laws driving lamellas transport in porous media, and their predictive capacity remains low because too few laboratory data are generally available for their calibration. The reservoir engineer nonetheless needs a reliable foam model in order to design, assess and optimize foam Enhanced Oil Recovery (EOR) processes for field application.

The aim of this work is to develop methods for further constraining and calibrating the EM of foam flow in porous media. These methods are drawn from PBM principles and validated from experimental data. The working assumptions include local equilibrium between generation and destruction rates of foam lamellas and steady-state foam flow as assumed by EM. In addition, we are interested in studying the impact of foam quality on the apparent foam viscosity $\mu_{app}^{f} = k|\nabla P|/u_t$ at fixed total injection rate, where $|\nabla P|$ is the gas phase pressure gradient modulus, $k$ the permeability of the porous media and $u_t$ the total superficial velocity. Under these assumptions, we propose an analytical approach to solve the foam flow parameters both within EM and PBM. The preliminary results shown in Figure 1 are obtained using Kam et al [2] model (PBM) and empirical model, and validated from Lotfollahi et al [3] calculations for two sets of experiments (Moradi-Araghi et al [4] and Alvarez et al [5]).




*(a)* *(b)*

Figure 1: model fit to experimental data using *(a)* Kam et al. model (PBM), and *(b)* empirical model.

Then, the two modelling approaches are confronted by identifying their respective formulations of the gas mobility reduction. The equivalence of the two approaches was investigated by deriving the corresponding interpolation functions in PBM. We found that the EM and the PBM at local equilibrium describe a similar foam flow physics in porous media, with different degree of complexity.

Finally, the analogy between the two models allows us to identify the EM functions to physical ones derived from the PBM at local equilibrium. This physically based methodology allow us to calibrate the parameters of EM and consequently to strengthen their predictive capacity with lesser resort to experimental data.

## References

[1] Holm, L. W., Foam Injection Test in the Siggins Field, Illinois, *Society of Petroleum Engineers,* Volume 22, page 1 499 - 1 506 (1970).
[2] Kam, S. I.; Nguyen, Q. P.; Li, Q.; Rossen, W. R., Dynamic Simulations With an Improved Model for Foam Generation. *In SPE Journal* 12 (01), page 35 - 48. (2007).
[3] Lotfollahi, M.; Farajzadeh, R.; Delshad, M.; Varavei, A.; Rossen, W. R., Comparison of implicit-texture and population-balance foam models. *In Journal of Natural Gas Science and Engineering*, Volume 31, page 184 – 197 (2016).
[4] Moradi-Araghi, A.; Johnston, E. L.; Zornes, D. R.; Harpole, K. J., Laboratory Evaluation of Surfactants for CO2-Foam Applications at the South Cowden Unit. In : *International Symposium on Oilfield Chemistry*. Houston, Texas, (1997).
[5] Alvarez, J. M.; Rivas, H. J.; Rossen, W. R., Unified Model for Steady-State Foam Behavior at High and Low Foam Qualities. In *SPE Journal* 6 (03), page 325 – 333 (2001).