Foam flow in model porous media

Alexis Mauray[a], Max Chabert[b], Hugues Bodiguel[a]

[a]*Univ. Grenoble-Alpes, CNRS, Lab LRP UMR 5520, F-38610 Gières, France*
[b]*Solvay, Novecare, The EOR Alliance, Aubervilliers, France*

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1 Introduction

Foam are used in porous media to decrease the gas mobility (e.g. in enhance oil recovery or soil remediation), and consequently limits viscous fingering and channelization [1,2]. They are produced by co-injection of a gas phase and an aqueous solution of surfactants. The mechanisms responsible for mobility reduction involve various phenomena such as lamellae division, bubble formation and coalescence, interfacial friction, buoyancy segregation, capillary pressure heterogeneities, flow and saturation heterogeneities … Yet, there is no uniform picture that can account for high mobility reduction that are observed and reported in core-flood experiments. We propose in this work to use micromodels of porous media, made using standard microfluidics techniques, in order to be able to combine mobility reduction measurements with direct observations, and thus to hierarchize and better understand the respective roles of the above-mentioned mechanisms.

2 Results

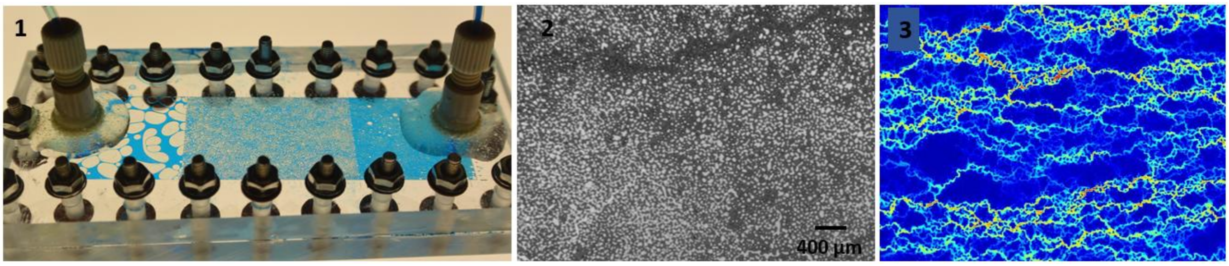
The device used consists in a random structure of heterogeneous pillars of arbitrary shape, mimicking porous media (see Fig. 2). It is obtained by standard microfabrication techniques [3] and is made of NOA, a transparent photosensitive glue which is made hydrophilic by plasma exposure. The thickness is 180 μm, the typical distance between pillars is about 150 μm and the porosity is 0.7. The total dimension of the porous structure is 2x3 cm. In order to control independently the global flow rate and the gas relative flow rate (referred to as the foam quality q), a bubble train is pre-formed in a surfactant solution in a long tube before the experiments. It is then injected at a constant flow rate Q in the device. The capillary number is defined as , where is the liquid viscosity, the total cross section, and the surface tension. Once steady state is reached, we perform global pressure drops measurements and direct observations using a fast camera.

In a first series of experiments, we focus on foam formation by injecting bubbles much bigger than the pore size. We observe that bubbles divide inside the porous structure. As a consequence, and for , the bubble size measured at the outlet of the porous domain is roughly equal to the pore size, and the size distribution is narrow. For lower capillary numbers, only a fraction of the gas phase is dispersed into small droplets. Bubble size distribution at the outlet is much wider as big bubbles coexist together with small ones. This is consistent with the mechanism of bubble breakup by viscous forces [4].

In a second series of experiments, we focus on pressure drop and flow characteristics, on a pre-formed foam obtained by reinjecting bubbles that have been produced by a flow at high Ca in the device ($Ca \sim 10^{-4}$). We find that Ca has a very strong influence on the mobility reduction, defined as the pressure drop normalized by the pressure drop due to water at the same flow rate. Strikingly, the pressure drop do not increase significantly for Ca between 10-6 and 10-4 and the mobility reduction reaches very high values (1000 at Ca=10-6). The pressure drop also increases when the foam quality is increased, but this increase is rather weak. Flow characterization by image analysis reveals that bubbles are moving in some channels while others ones are stopped in some area. The flow is highly heterogeneous and is concentrated in some preferential paths, as illustrated in Fig. 3. This effect could contribute to the mobility reduction as local velocities in the preferential paths is much higher than in the case of a homogeneous flow. We quantify the number of these paths as a function of Ca and foam quality. To do so, we estimate local velocities by image differences, and count the fraction of the pores where the local velocity exceeds the mean value. We report that the higher the foam quality, the more homogeneous the flow is. The number of preferential paths roughly equals the number of channels of the porous medium when q=0.9, whereas it is only a third for q=0.3. However, we find rather weak variations of the number of preferential paths when Ca is varied.

3 Discussion and conclusion

High foam quality seems thus needed in order to obtain a homogeneous flow, which is one the required property in the context of oil recovery. The fact that the mobility reduction is very high at low capillary number remains an open issue and cannot be explained by the existence of preferential paths neither by standard theories available for bubble displacements in model geometries (ie Bretherton law [5]). We propose and discuss the role of channel size variations to interpret our experimental results. Outlooks of this work deal with oil mobilization by foam. By co-injecting oil droplets together with the bubble trains in our device, we should be able to discuss the role of the various parameters involve in such a triphasic flow.



Figures: 1) Microfluidic device used for the experiments. 2) Magnified Image of foam in the porous medium: the bubbles appear in withe. 3) Illustration of preferential paths at Ca = 1,2.10-5 and foam quality q=0,65: the highest velocities are the brightest.

References

[1] W.T. Osterloh, M.J. Jante, Effects of Gas and Liquid Velocity on Steady-State Foam Flow at High Temperature, SPE/DOE, 24179, 237-248 (1992).
[2] C.A. Conn, K. Ma, G.J. Hirasaki, S.L. Biswal, Visualizing oil displacement with foam in a microfluidic device with permeability contrast, Lab on a Chip, 14, 3968-3977 (2014).
[3] B. Levaché, A. Azioune, M. Bourel, V. Studer, D. Bartolo, Engineering the surface properties of microfluidic stickers, The Royal Society of Chemistry, 4, 1-4.
[4] C. Cohen, L. Menetrier, P. Tabeling, M.-C. Jullien, M.-J. Tsang Mui Ching, Brisure de gouttes dans une jonction en T à faible nombre capillaire, 19ème Congrès Français de Mécanique, 24-28 août 2009.
[5] F.P. Bretherton, The motion of long bubbles in tubes, 1960.