Local rheology of aqueous foams in two-dimensional porous media

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Flowing foams are used in many engineering and technical applications. A well-known application is oil recovery. Another one is the remediation of polluted soils: the foam is injected into the ground in order to mobilize chemical species present in the medium. In this context, apart from potential interesting physico-chemical and biochemical properties, foams have peculiar flow properties that applications might benefit of. In particular, viscous dissipation arises mostly from the contact zones between the soap films and the walls. In most experimental studies, no local information of the foam structure is available, and only global quantities such as the effective viscosity can be measured. We present an investigation of the local rheology of the foam, using a two-dimensional (2D) porous medium consisting of circular obstacles positioned randomly in a Hele-Shaw cell. The foam structure is recorded at regular times by a video camera and subsequently analyzed by image processing, which provides us with the velocity field and spatial distribution of bubble sizes. The flow exhibits a rich phenomenology, including flow irreversibility, preferential flow paths, local flow intermittency/non-stationarity (despite the permanent imposed global flow rate). Moreover, the medium impacts the nature of the flowing fluid by selecting the bubble size distribution through bubble fragmentation. Local intermittency results from the fluctuating effective capillary forces felt by bubbles as they travel through the medium. We investigate how preferential flow paths and intermittency depend on the imposed global flow rate and foam quality (the water content), and show that the spatial distribution of bubble sizes is to some extent correlated with the velocity field. We furthermore measure the evolution, along the flow direction, of the probability density function for bubble sizes, and present a fragmentation model to explain that evolution. It is controlled by two statistical distributions: that for the fragmentation frequency of a bubble of given size a, $f(a)$, and that for the size b of a bubble that results from the fragmentation of a bubble of size a, $g(a,b)$. Under simplifying assumptions for the functions $f(a)$ and $g(a,b)$, an analytical resolution of the model's constitutive equation provides a behavior that is qualitatively similar to the experimental observations. For more realistic assumptions, the solution can be obtained numerically and are consistent with the experimental findings.