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Preferential Flow of Emulsion through Homogeneous Porous Media

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We experimentally identify major preferential paths for emulsion and foam flow, even at steady-state in homogeneous porous media. Therefore, even identical parallel channels cannot be assumed equivalent when emulsion or foam flows through them. This discovery challenges previous approaches that upscale single pore/channel-scale rheology to Darcy-scale simply by linear summation and integration adopting the "bundle-of-tubes"approach.

We construct a general form of emulsion/foam rheology model at single channel scale that is compatible with most reported models. We investigate ΔP - Ca correlation when fixing the dispersed fluid flow rate and droplet/bubble size. Surprisingly, the ΔP - Ca curve under these constraints is non-monotonic, consisting of an ascending segment at low Ca (regime I), a descending segment at higher Ca (regime II), and another ascending segment when Ca goes to infinity (regime III), regardless of exact channel geometry and fluid properties. The origin of preferential flow in homogeneous porous media is rigorously rationalized by linear stability analysis from this non-monotonicity.

Microfluidic experiments validate the abovementioned theory. The non-monotonic ΔP −Ca correlation is experimentally reproduced. Specifically, three different flow patterns are observed in the three curve segments: (1) in regime I, droplets fulfil almost every single pore but only very few droplets are mobilized, by droplet-droplet squeezing (Fig.a); (2) in regime II, not all pores are occupied by droplet, and only few droplets are mobilized, by droplet-droplet replacement (Fig.b); (3) in regime III, droplets distribute sparsely and all droplets independently mobilize along with the continuous phase (Fig.c). Capillarity-viscosity interplay explains the change of droplet flow behavior in different regimes.

Due to the emergence of preferential flow, a stable fluid distribution pattern has to be solved before constructing a rheology model. In addition, regular upscaling methods for non-Newtonian fluid flow in porous media is physically incorrect for emulsion and foam, due to varying phase ratio in different flow paths. This work thus brings light to constructing a physics-based rheology model for emulsion and foam in porous media.

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References

Time Block Preference

Time Block B (14:00-17:00 CET)

Participation

Online

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