Complex behavior of a yield stress fluid in model porous media

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Abstract:

Yield stress fluids, such as concentrated emulsions, cement or toothpaste, display interesting flow behavior. In some applications, the yield stress fluid is required to flow in porous media. For example, emulsion flow in oil recovery processes, cementing operations in the ground, or for the cleaning of sludge in contaminated soil. In such cases the flow behavior of the fluid is further complicated by the complexity of the geometry. However, few studies have directly observed yield stress fluid flows in porous media. For many applications, it could be interesting to know the pressure required for a desired flow rate. Models developed in order to describe Darcy's law assume a rheological law applied locally [1] but these models do not take into account the complex effects such as thixotropy or wall slip. We are looking for a general relation between pressure and flow rate.

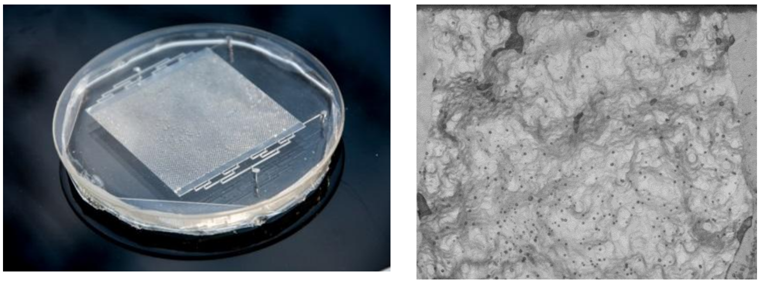

Fig. 1. a) Model porous media, b) Model Fracture

To investigate the flow behavior of yield stress fluids in porous media, we use Carbopol (ETD 2050) as a model yield stress fluid (yield stress ~ 20 Pa). This fluid is injected into various model porous media. Two different types of geometry are studied: model 2D porous media obtained by a microfluidic process (fig 1.a) or model fractures carved in Plexiglass blocks using a computer controlled milling machine (fig 1.b).

The main objective of our experiments is to measure the local fluid velocity as a function of the global pressure applied. However, this is complicated by the fact that we want simultaneously observe local fluid velocities at the size of the channel (~200 µm) and have a global view of the entire porous geometry (typically 5cm x 5cm for the microfluidic device). To do this, we add small concentrations of

PMMA particules (size~20µm) into the fluid. The pixel resolution of the camera is 10µm, therefore we are unable to track individual particules. However, by placing a grid (hole size 40µm) on top of the porous geometry, we can observe intensity fluctuations when the fluid flows for each passage of beads (the Schlieren method). The autocorrelation function over time for each pixel gives us a map of velocity. This allows us to deduce the local rheological behavior -- solid or liquid -- of the fluid in the porous media. For high pressures, the fluid flows throughout the entire porous medium (fig 2. first image). As we decrease progressively the pressure we observe the velocity decreasing in each channel until flow is observed in just one preferential path (fig 2), already observed in numerical simulation [2].

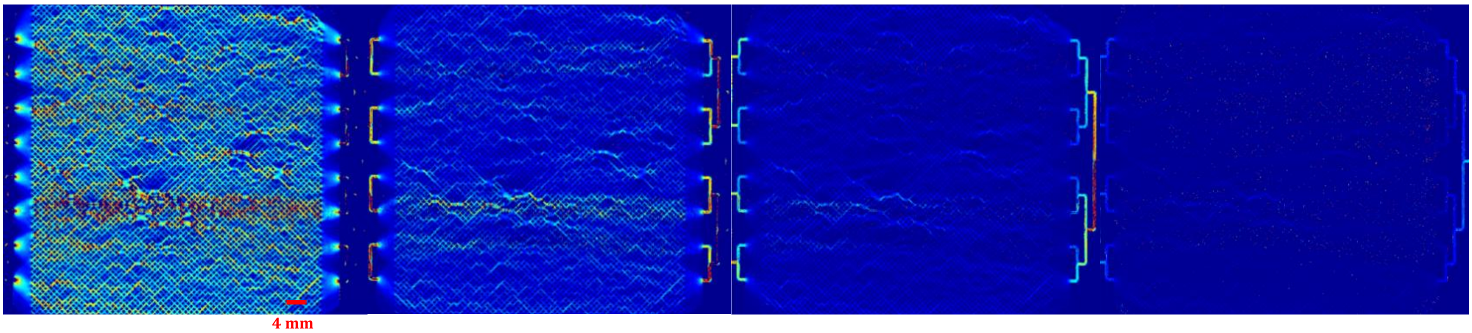

Fig. 2: Velocity mapping with decrease flow rate from left to right.

Mots clefs: Yield Stress Fluid, Porous Media, Microfluidics, Velocimetry

Références

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[2] Talon L. and Bauer D. On the determination of a generalized Darcy equation for yield-stress fluid in porous media using a Lattice-Boltzmann TRT scheme, Eur. Phys. J. E 36(139), (2013).