Experimental study of Saffman-Taylor instability for shear thinning fluids

- BIFD 2011 -

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ABSTRACT

We will present an experimental study on the Saffman-Taylor instability of shear thinning fluids. This instability occurs when a less viscous fluid pushes a more viscous fluid [1]. The relationship between the constitutive equation of complex fluids and the nature of this instability is an open problem [2,3,4] that presents a great interest, not only in a theoretical point of view but also for industrial applications.

We studied the Saffman-Taylor instability of a structural series of model shear thinning fluids. The latter's were prepared by dissolving appropriate amounts of Xanthan polymer in distilled water [5]. Changing the concentration allowed us to modify the rheological behavior from weak shear thinning for low concentrations to strong shear thinning for high concentrations. The shear rate dependence of the viscosity was measured for the solutions using a stress rheometer in the Couette geometry and was modelled using the well-known power-law $\eta(\dot{\gamma}) = K\dot{\gamma}^{n-1}$. We will describe the flow channel consisting of an injection jack fixed on uniaxial displacement controller and connected to a Hele-Shaw cell. The uniaxial displacement controller can move the piston with a speed comprised between 10 $\mu m.s^{-1}$ and 500 $mm.s^{-1}$. Then, the corresponding flow rate can change between 10^{-8} and 5.10^{-4} $m^3.s^{-1}$. The speed is interlocked by a Servostar 300 controller commanded by a specific Labview program. The Hele-Shaw cell consists of two sheets of glass separated by a distance of b = 300 µm and maintained together by a specific aluminium fixation.

We studied the Saffman-Taylor instability at 20°C by injecting air in the Xanthan solutions at different flow rates and for different concentration. For the first time, we characterized by Particles Images Velocimetry (PIV) [6] and Ultra-fast camera the velocity profile in the complex fluids and the air finger growth.

PIV measurements showed that the flow of the complex fluids around the air fingers is potential, but also, that the vorticity is localized at the tip of the fingers. For all the experiments, we measured the non-linear pressure gradients and the terminal velocity in the Xanthan solutions that allow modelling the velocity stream lines by conventional potential flow theory. Ultra-fast visualizations pointed out that the relative width of the finger λ and the radius at the tip are smaller for high shear thinning fluids and higher for low shear thinning fluids. Finally, we will show that the constitutive law governs the shape and the velocity U of the fingers in growth and that the mass conservation imposes the relation $\lambda.U = cste$ for all the fluids.

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