Numerical study of the co-current horizontal flow of a Newtonian and a non-Newtonian fluid in a micro-channel: Effect of non-Newtonian rheology on slug formation.

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There is a growing interest for highly controlled formation of droplets in various microfluidic applications, such as pharmaceuticals processing, chemical analysis and synthesis, thermal management etc.[1] It is known that when two immiscible fluids are brought in contact at the junction of a microchannel regular and well-defined flow patterns are formed, the characteristics of which depend on the operational conditions, the properties of the fluids and the geometrical characteristics of the microchannel [2]. These formations are different from those observed in large-scale flows, since in microfluidic flows the importance of surface tension forces is increased compared to inertial and turbulent effects. ***Slug flow***, in which one liquid is the continuous phase, while the other liquid (dispersed phase) flows in the form of slugs, is extensively studied because it is easily controllable and offers high mass transfer rate. Given that most reported studies concern Newtonian fluids, although fluids with non-Newtonian behaviour are widespread in industrial applications, the aim of this work is to numerically investigate the effects of non-Newtonian rheology during slug flow of two immiscible liquids in microchannels.

A popular microfluidic device used for droplet generation is T-junction geometry [1]. In our study the droplet formation is numerically investigated using the ANSYS Fluent® package and Volume of Fluid (VOF) method. The device used in our simulations is a T-junction composed of cylindrical μ-channels (ID=200μm). The continuous phase flows along the main channel (Q_C=0.07mL/min) and has the physical properties of a non-Newtonian shear-thinning fluid (i.e. aqueous glycerine solutions with xanthan), whose viscosity follows the *Herschel-Bulkley* model. The dispersed phase (Q_D=0.01 to 0.03mL/min) is fed via the side channel and has the physicochemical properties of silicon oil (ρ=920kg/m^3, μ=4.6mPas). It is known [4] that the characteristics of the slugs are affected by the viscosity and flow rate of the continuous phase.

All the simulations are performed in parallel on a Linux cluster by employing 80 processors. Typical clock time for the formation of one slug is 72 h. Flows in microfluidic systems are usually characterized by low values of the Reynolds number therefore the DNS model was employed in transient mode. The CFD code was successfully validated using relevant experimental data [3], i.e. the co-current horizontal flow of silicon oil, as Newtonian liquid, and various aqueous glycerin solutions with a small amount of xanthan gum as typical shear-thinning non-Newtonian liquids.We measure the dimensions of the slugs, the frequency of slug formation, slug velocity as well as the velocity, viscosity and shear rate distributions in the space between two consecutive slugs. ***Figure 1*** presents an instant of the two-phase flow that shows the shape and the dimensions of the slugs.

Simulations currently in progress aim to investigate the effect of the physical properties and the flow rate of the continuous non-Newtonian phase on the slug geometry. The ultimate goal of the study is to formulate correlations that will be able to predict the slug dimensions and flow characteristics during co-current horizontal flow of a Newtonian and a non-Newtonian fluid in a μ-channel.

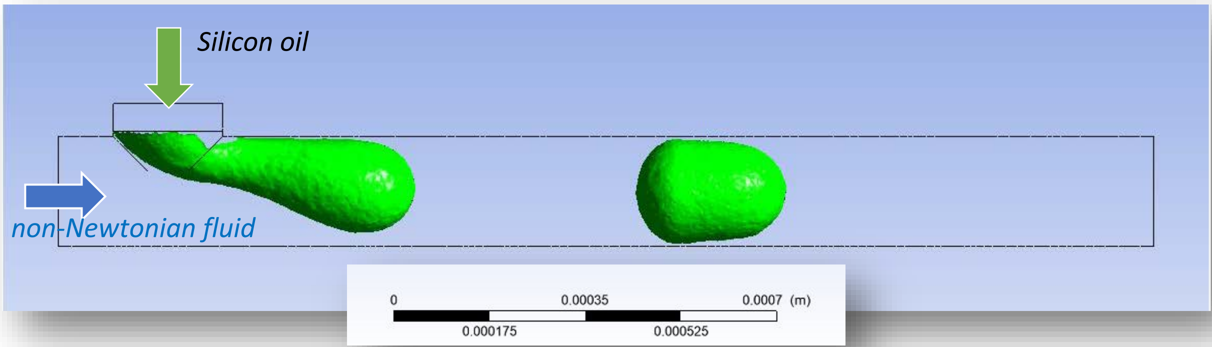

Figure 1. Typical instant of slug formation in the microchannel (I.D.=200μm). Continuous phase: non-Newtonian fluid (aqueous xanthan solution, Q_C=0.07mL/min, Dispersed phase: Newtonian fluid (Silicone oil Q_D=0.03mL/min).

References

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