INFLUENCE OF PARAMETERS IN ELECTROHYDRODYNAMIC INTERFACIAL INSTABILITIES FOR MICROFLUIDIC APPLICATIONS

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Summary The use of an electric field in a microfluidic channel has been shown to trigger the interface between two liquids to become unstable, i.e., to deflect. Such a deflection can, in turn, lead to droplet formation if the liquids used are immiscible and fluid mixing in the case of miscible liquids. In this study, the linear instability of a flat interface between two viscous, Newtonian liquids of different physical properties in plane Poiseuille flow is studied in the presence of an electric field either normal or parallel to the flat interface. In addition to the fluids properties, both the strength of the applied voltage and the ratio of the liquid layers depth can dramatically influence the instability onset as well as the growth rate of the disturbance.

INTRODUCTION

Multiphase flows enable the generation of droplets of a dispersed gas or liquid phase in a continuous liquid stream, and can be used in the production of polymer particles, emulsions, or foams. Potential applications of droplet-based microfluidics in various fields such as chemical or biochemical analysis, fabrication of microparticles, and the formation and manipulation of microdroplets have received increased interest over the past decade. Various techniques to generate droplets in microchannels, which can be regrouped as passive and active methods, have been reported in the literature. Passive methods make use of channel geometries, with the most commonly used geometries being T-channels and flow focusing channels. In our work, we generate droplets actively, specifically by applying an external electric field to an interface separating two viscous, immiscible and incompressible liquids. The mechanism of droplet formation has been shown to be triggered by an interfacial electrohydrodynamic instability which was then studied theoretically [1,2]. The droplets were found to be monodisperse, with their size depending on the applied voltage and the flow rates [3]. The linear instability is further analyzed in the present study [4] which shows that the instability strongly depends on the fluids properties, electric field strength and depth ratio of the liquid layers. The cases of an electric field both parallel and normal to the interface are considered. Such instabilities have also been used experimentally to enhance fluid mixing in microchannels.

PHYSICAL SYSTEM AND THE MODEL

The purpose of this study is to investigate the interfacial instability between two Newtonian fluids under the influence of an electric field either normal or parallel to the interface. The liquids flow in a microchannel due to a pressure gradient and are assumed to be incompressible, viscous, immiscible, and leaky-dielectric. The physical system is shown in Fig 1.

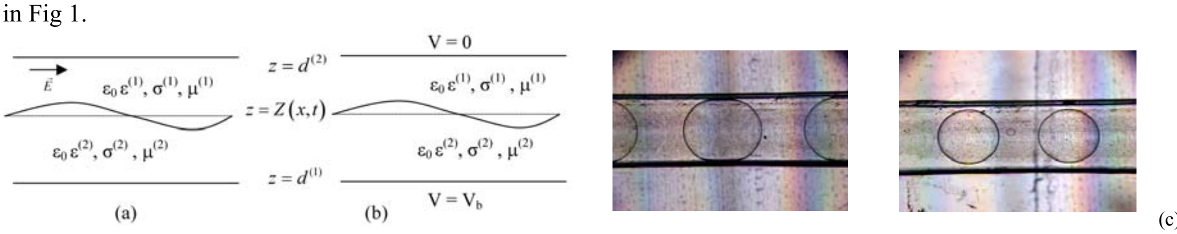

Figure 1. Sketch of the physical problem where V is the voltage, μ the viscosity, σ the electrical conductivity, ε_0 and ε the electrical permittivity of the vacuum and the relative electrical permittivity of the liquid, respectively. The electric field is either (a) parallel or (b) normal to the flat interface. (c) The interface deflection leads to droplet formation in case of a normal electric field. The size of the droplet is adjusted by varying the electric field in experiments [3].

The governing equations are the classical ones, the Navier-Stokes for the fluid dynamics and the Laplace equation for the voltage field. In this work, we use the surface-coupled model in which the interface is assumed to be sharp with a jump of the physical properties of the two fluids across the interface [1]. The governing equations are linearized and turned to an eigenvalue problem using Taylor series expansion. The eigenvalue, ω, represents the growth rate of the

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disturbance and if the real part of ω is positive the system is linearly unstable to the given disturbance. The eigenvalue problem is solved using a spectral method with Chebyshev grid points.

RESULTS

When the ratio of the fluid to electric time scale is large, i.e., fast electric times, it is interesting to note that conclusions can be drawn without solving the eigenvalue problem. This is performed by simply comparing the sign of the electrical term with that of surface tension and, knowing that the latter is always stabilizing, the phase space displayed in Fig. 2 can be readily deduced [1]. The liquids' permittivity ratio, ε_r, and the conductivity ratio, σ_r, determine whether the normal (N) or the parallel (P) electric field has a destabilizing effect. For example, in regions 3 and 6, independently of whether the electric field is normal (N) or parallel (P), the interface cannot be destabilized. In regions 2 and 5, only the normal field is destabilizing and in regions 1 and 4 both normal and parallel fields are destabilizing. When the eigenvalue problem is solved, the results are found in agreement with the analysis in Figure 1 (see Fig. 3).

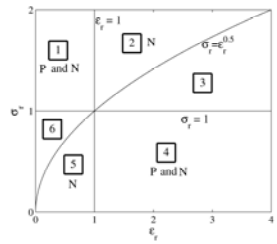

Figure 2. Stabilizing/destabilizing effect of the electric field in the conductivity ratio/permittivity ratio space for equal depths of the layers. P and N refer to the destabilizing effect of the parallel and normal electric fields, respectively [1].

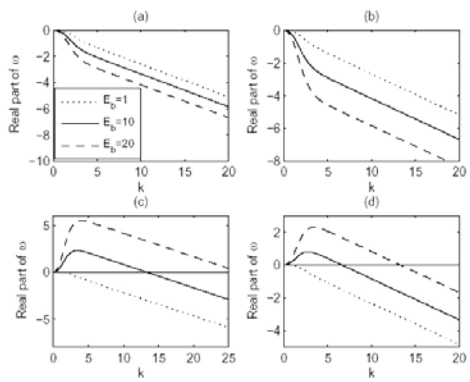

Figure 3. Validation of the results in Figure 2 for the normal field by solving the eigenvalue problem. a) $\sigma_r = 0.5$, $\varepsilon_r = 0.5$; b) $\sigma_r = 2$, $\varepsilon_r = 3$; c) $\sigma_r = 0.2$, $\varepsilon_r = 3$; d) $\sigma_r = 5$, $\varepsilon_r = 0.5$.

A similar analysis, carried out for various liquid layer depth ratios, shows that the depth ratio can also dramatically influence the instability. This can be used, for instance, to generate droplets of a certain size [3] when the latter cannot be reached by simply tuning the voltage if, for instance, the maximum capacity of the power supply has been reached.

CONCLUSIONS

It was shown that the presence of an electric field, either normal or parallel, can destabilize the interface. The physical properties of the fluids have a significant effect on the growth rate of the disturbance. The dimensionless electric number and depth ratios (or volumetric flow rates of the fluids) are the two free parameters once the fluids have been selected. In fact, an advantage of this active destabilization method, is indeed to introduce the electric field as an extra parameter. It should be noted, however, that the absolute voltage needed in the case of a parallel electric field is much larger than the normal one as in the former case the gradient is across the channel length which is much longer than the channel width.

References

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