Hydrodynamic characteristics of free-flowing non-Newtonian liquid film in open inclined microchannel: Experimental investigation.

Georgios M. Spanos, Department of Chemical Engineering, Aristotle University of Thessaloniki, Greece

Antonios D. Anastasiou, Department of Chemical Engineering & Analytical Science, The University of Manchester, UK

Spiros V. Paras, Department of Chemical Engineering, Aristotle University of Thessaloniki, Greece

Aikaterini A. Mouza, Department of Chemical Engineering, Aristotle University of Thessaloniki, Greece

e-mail: mouza@auth.gr

Abstract

Under the moto “doing more with less” process intensification is an interesting research field of the last decade. Various μ-systems have been developed aiming to build smaller, more compact and less expensive equipment. Falling Film Microreactors (FFMR) offer extended specific surfaces[1], which result to enhanced mass and heat transfer rates, allowing for reactions which cannot be realized with conventional reactors [2]. The improved safety offered by FFMRs relies on the small reactant hold-up and the shift of explosion limits. Although there are many works concerning the efficiency of specific reactions in FFMR, little has been published about their operating parameters[2],[3].Mass and heat transfer rates in FFMRs depend on the film thickness, the gas/liquid interfacial area and the velocity distribution in the film. In previous studies[4] we have experimentally measured the geometrical characteristics of the film formed during the free-flow of a Newtonian liquid and the velocity distribution inside the film. Based on the experimental data design equations that can predict with ±10% the geometrical characteristics of the film were proposed. In a recent study [5] we have extended our previous work by employing non-Newtonian shear thinning liquid and experimentally investigating the geometrical characteristics of the film. In the same work a generalized algorithm for the design of FFMRs, containing a non-Newtonian shear thinning liquid, was proposed.The purpose of the present work is to measure the velocity profile in the film, when a non-Newtonian liquid is flowing in an open inclined μ-channel. The slope of the velocity distribution near the wall is essential for wall shear stress calculation, which is used in mass and heat transfer problems. Experiments were conducted in an open μ-channel with square cross section (1200x1200μm) using shear-thinning liquids, i.e. distilled water (nW) or 25% w/w aqueous glycerol solution (nG25) containing 0.03%w/v of xanthan gum, a polysaccharide that renders the liquid non-Newtonian. The liquid viscosity is described by the Herschel-Bulkley model, while their asymptotic viscosity is 1.50 and 2.45cP respectively. The velocity profile inside the film was measured using μ-Particle Image Velocimetry (μ-PIV), a non-intrusive technique used in μ-fluidics for measuring 2D velocity-fields [4] with high spatial resolution. The dependence of the velocity distribution on the μ-channel inclination, Φ, and the viscosity distribution of the liquid phase at the base of the meniscus was investigated (Fig. 1). It is found that for the thinner films, which correspond either to the lower asymptotic viscosity of the fluid (Fig. 1a) or to the higher inclination angle of the conduit (Fig.1b), the velocity distribution does not follow the usual parabolic profile but exhibits two maxima near the walls (“M”-shape profile). This is in accordance with the results published by Anastasiou et al. [4], who reported that the thinner films exhibit the ‘M’-shape profile. More experiments, currently in progress, aim to clarify the effect of the non-Newtonian behavior on the film characteristics. The effect of the flow rate and the characteristics of the conduit (dimensions and inclination angle) will be investigated. The goal is to contribute to the design of FFMR by proposing design equations suitable for predicting the hydrodynamic characteristics of the liquid phase.

References

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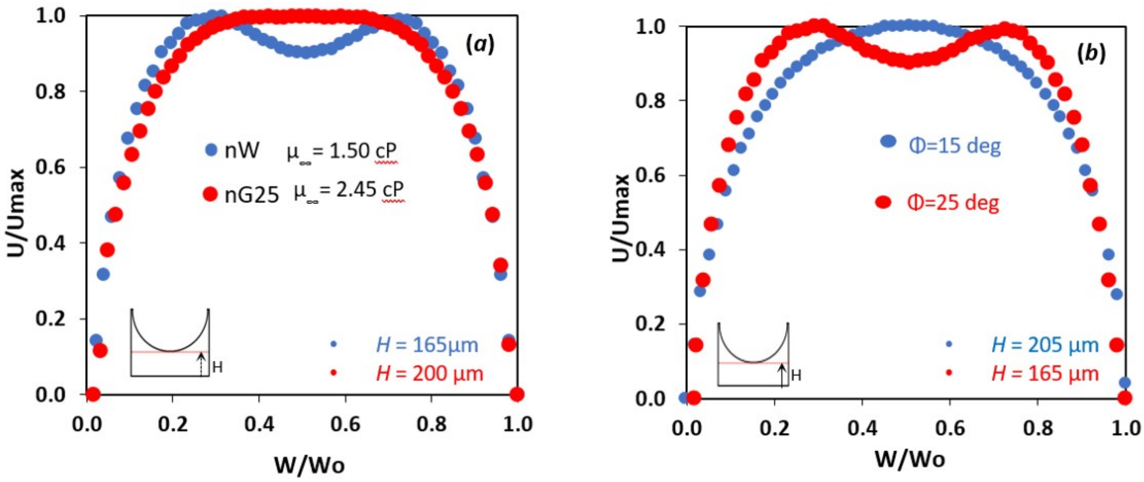

Fig. 1. Typical reduced velocity profiles (with respect to Umax) along the normalized lateral direction (W/Wo) acquired at the base of the meniscus: (a) effect of liquid viscosity, (b) effect of microchannel inclination angle, Φ (Wo=channel width, H=film thickness, liquid flow rate=15mL/h).