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Geetanjali Chattopadhyay, R. Usha

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On the Yih-Marangoni instability of a two-phase plane Poiseuille flow in a hydrophobic channel

Geetanjali Chattopadhyay and R.Usha [1]

Department of Mathematics, Indian Institute of Technology Madras, Chennai 600036, India

Abstract

The linear stability analysis of a plane Poiseuille flow of two immiscible, incompressible fluids of different viscosities and densities in a hydrophobic channel, in the presence of an insoluble surfactant at the interface is examined, within the framework of Orr-Sommerfeld system. The walls of the channel are modeled as walls with velocity slip/no-slip. The equations governing the flow system are solved numerically by a Chebyshev collocation method for a wide range of dimensionless parameters describing the flow system. The effects of slip on the neutral stability boundaries for the interface modes in the presence/absence of an insoluble surfactant at the interface are examined for different thickness ratios of the two layers, with density and/or viscosity stratification. Slip conditions at the wall show a promise for control of the Yih-Marangoni instability of the corresponding flow system in a rigid channel. The influence of the parameters on the critical Reynolds number for the shear mode is assessed. The study reveals that it is possible to control instabilities in interface dominated rigid channel flows by designing the walls of the channel as hydrophobic/rough/porous or undulated surfaces as these can be modeled as one with slip at the substrates.

Keywords: Viscosity stratified flow, Velocity slip, Stability, Interfacial Instability, Marangoni effects

1. Introduction

There are numerous practical applications such as manufacturing of photographic films (Wang *et al.* [12]), de-icing of fluids on airplane wings (Yih [17]), in gas-liquid flows (Daniel [39]) which involve two-fluid parallel flows in plane channels. Such interfacial flows, mostly in biomedical and industrial applications (Otis *et al.* [20]) are accompanied by surface-active agents or surfactants and they play a crucial role in flow instability.

It is important to understand and predict the parameter regimes where the flow is stable, namely, the stable regions of operation, since this knowledge is crucial for many technological applications. Interface-dominated two phase viscous shear flow in a two-dimensional channel exhibits interfacial instabilities at finite but non vanishing values of the Reynolds number. The theoretical study of the long-wave linear stability of the flow of two-layer Poiseuille flow in a channel investigated by Yih [16] for equal density fluids occupying equal volumes revealed that instability exists due to an interface mode. This unstable mode occurs even in the limit of vanishing small Reynolds numbers for suitable thickness ratios of the fluid layers. The primary instability occurs at wave numbers of order one for sufficiently thick channels hosting an air-water system (Blennerhassett [49]). Yiantsios and Higgins [56] have examined the linear stability of plane Poiseuille flow for arbitrary fluids and volume fractions, within the framework of Orr-Sommerfeld analysis and found that for sufficiently small shears, one can stabilize the instability arising due to viscosity contrast by hydrostatic effects. Further, the shear modes were observed to be unstable at high Reynolds numbers. Their results have been shown to agree qualitatively with the experimental results of Kao and Park [64]. Tilley *et al* [10] have extended the analysis by Yiantsios and Higgins [56] for horizontal air-water system in a rigid channel as a precursor to an inclined channel configuration. They have examined the influence of the channel

[1] Author to whom correspondence should be addressed. Email: ushar@iitm.ac.in