Instabilities in immiscible multi-layer viscous shear flows in the presence of interfacial slip

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ABSTRACT

Unlike single phase Couette flows, which are known to be linearly stable at all Reynolds numbers, in the case of two superposed, immiscible, viscous fluid layers the interface might be rendered unstable at all non-zero values. For most of the common fluid pairs a no-slip condition is appropriate to describe the liquid-liquid interface and under this assumption both the linear and the non-linear stability of such configurations (including direct numerical simulations and consideration of surfactants) has been extensively addressed [1,2,3].

More recent experimental studies[4,5] on coextruded multilayers of polymer-polymer systems, reveal that presence of slip at the interfaces of such fluids is possible and leads to unexpectedly increased flow-rate measurements. Molecular dynamics simulations[6,7] have also demonstrated the presence of slip at liquid-liquid interfaces for both Couette and pressure-driven flows. The MD simulations also demonstrated that a Navier-slip law is very successful in describing the data.

Attempting to extend the existing studies on multi-layer shear flows[1] by consideration of the aforementioned experimental findings, the present work is a theoretical study of the effects of Navier slip at liquid-liquid interfaces. Following the experiments we focus on Newtonian flows and undertake a comprehensive study of stability of two-fluid Couette flows, where in the presence of slip the basic flow undergoes a slip-length-dependent velocity jump at the interface. Asymptotic solutions are constructed for short and long wave disturbances to isolate the instability mechanisms.

So far, as it has already been presented elsewhere, at the limit of large slip the system has been found to exhibit a novel instability, viscous analogue of the Kelvin-Helmholtz, albeit with a bounded growth rate. In this talk the aim is to focus on arbitrary slip values of order $\mathcal{O}(1)$. Here, analytical solutions are obtained in the form of integrals of Airy functions, and the results are successfully compared with those constructed asymptotically. The effect of each one of the eight parameters involved (viscosity ratio, density ratio, position of the interface, Reynolds number, Froude number, Capillary number, slip length and wavenumber) on the growth rate and the phase speed of the interfacial instability is diligently tracked to reveal that slippage may destabilise all wavenumbers and even trigger a Turing-type instability.

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