THE EFFECT OF SOLUBLE SURFACTANTS ON LIQUID FILM FLOW

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ABSTRACT
We investigate experimentally the modifications in the dynamics of liquid film flow, resulting from the addition in water of the soluble surfactants iso-propanol (IP) and Sodium Dodecyl Sulfate (SDS). Recent experiments indicate that, the primary instability of film flow in channels of finite width depends on surface tension. Using IP solutions of varying concentrations, we have shown that this dependence scales with Kapitza number. Based on the high solubility and diffusivity of iso-propanol in water, we argue that these solutions behave as pure liquids with reduced surface tension. Indeed, low-frequency inlet disturbances turn in the unstable regime into solitary humps preceded by capillary ripples, with the scaling predicted by theory for simple liquids. Aqueous solutions of SDS exhibit a remarkably different behavior, with more pronounced feature of strong damping of all inlet disturbances. The dominant structures for the entire range of inlet frequencies tested, even at surprisingly high Re, are sinusoidal traveling waves of very small amplitude.

Key Words: soluble surfactants, film flow

1. INTRODUCTION
Falling liquid thins film have been studied for many years, due to their appearance in a large number of industrial systems, and environmental and biological flows. The effect of surfactants on the stability and on the flow characteristics of falling thin liquid films is also of interest, both because of industrial considerations and because understanding these effects can provide some information about the physical chemistry of interfaces.

2. EXPERIMENTAL METHOD
Experiments were performed in two inclined flow facilities, a 3000 mm long by 450 mm wide channel and a 800 mm long by 250 mm wide channel made of Plexiglas. Both facilities may operate with adjustable width up to the above maximum values. The experimental method used is electrical conductivity by local probes that detect temporal evolution of film thickness as described in detail by Vlachogiannis et al. (2010). At the inlet of the channel, a perturbation at desired frequency is created, in the range of 0.15-1.5 Hz. A system of perturbing the entrance flow rate at desires frequency is used, based on the periodic obstruction of a by-pass liquid stream. The liquids used are Isopropanol aqueous solutions (IP) and SDS (Sodium Dodecyl Sulfate) surfactant solutions. Surface tension is measured by maximum bubble pressure, and ring method several times during an experiment to ensure that it does not change.

3. RESULTS

Both IP and SDS are soluble surfactants. However, apart from reducing surface tension, surfactants modify the surface properties. Differences in the behavior of those surface active agents (IP is an alcohol and SDS is an anionic surfactant), that will be observed in detail at the following subsections, are interpreted in terms of surface properties, by introducing surface elasticity and surface viscosity expressed respectively as the real and imaginary component of a complex surface dilatational modulus (Lucassen-Reynders and Lucassen (1970) and Lucassen (1982)). The addition of Isopropanol in water is expected to reduce surface tension without significant surface elasticity or viscosity, and the solution practically behaves as a pure liquid with lower surface tension.

3.1 Isopropanol Aqueous Solutions

Recent experiments (Vlachogiannis (2010)) indicate that, unlike classical predictions based on Squire's theorem, the primary instability of film flow in channels of finite width depends on surface tension. Using IP solutions of varying concentrations, we have shown (Georgantaki (2011)) that this dependence scales with Kapitza number, which expresses the ratio of capillary to viscous stresses. Based on the high solubility and diffusivity of iso-propanol in water, we argue that these solutions behave as pure liquids with reduced surface tension (Lucassen-Reynders and Lucassen (1970)). Indeed, low-frequency inlet disturbances turn in the unstable regime into solitary humps preceded by capillary ripples, as predicted by theory for simple liquids (Chang and Demekhin (2002)). The characteristics of these coherent structures correlate satisfactorily with the reduced Reynolds number, $\delta = Re^{11/9}5Ka^{1/3}3^{7/9}$.

3.2 SDS

Aqueous solutions of SDS exhibit a remarkably different behavior, with more pronounced feature the strong damping of all inlet disturbances. In particular, the typical for simple fluids steepening and acceleration of wave crests (which is arrested by the development of front-running capillary ripples and leads to viscous solitary waves) is never observed even at very high Re. The dominant structures for almost the entire range of inlet frequencies tested are sinusoidal traveling waves of very small amplitude. The characteristics of these waves are documented, and are interpreted in terms of the visco-elastic properties of the surfactant monolayer, and in particular the dilational surface elasticity. Though most relevant wavelengths are in the gravity regime, the effect of the surface layer is critical, as has already been shown in a different context (Lucassen (1982)).

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