Viscous flow over a chemically patterned surface

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March 2007

Abstract

The flow of liquids over smooth, but chemically patterned surfaces is an exciting new area of fluid mechanics with applications in many emerging technologies [1]. Such flows are of particular interest in microfluidics where an increasing fluid's surface-to-volume ratio means that surface effects become of greater significance [2]. The correct description of the physics at solid-liquid interfaces, including the effects of variable wettability of the solid substrate, then becomes imperative to the success of any applications [3].

In continuum mechanics, the classical boundary condition of no-slip suggests that variation in the wettability of a solid should not affect the flow of an adjacent liquid in any way. However experiments and molecular dynamics simulations indicate that this is not the case. For example, as shown by molecular dynamics simulations [4, 5] a change in wettability does affect the flow, most notably by producing a component of velocity normal to the solid surface.

Given that "wettability" can be introduced as a macroscopic characteristic of a liquid-solid system, one should be able to model the effects discovered by molecular dynamics macroscopically using an appropriate formulation in the framework of continuum mechanics. In the present work, we show how flow over a solid substrate with variations of wettability can be described in a continuum framework using the interface formation theory [6]. The obtained results demonstrate that a shear flow over a perfectly flat solid surface is disturbed by a change in its wettability, i.e. by a change in the chemistry of the solid substrate. If one uses as a macroscopic measure of wettability the equilibrium contact angle θ that a free surface would form with the solid substrate then it can be shown that the magnitude of the effect due to a change in wettability is proportional to $\cos\theta_1 - \cos\theta_2$ where θ_1 and θ_2 are the equilibrium contact angles that a free surface would form with the two chemically different parts of the solid surface.

Importantly, the model we use does not assume *actual* slip between the fluid and the solid, i.e. a difference between the velocities on the solid-facing side of the fluid-solid interface and the velocity of the solid. However, there appears a certain degree of *apparent* slip, i.e difference in velocity between the solid-facing and liquid-facing side of the fluid-solid interface, determined by the interaction in the surface phase and between the surface phase and the bulk.

158 An interesting feature of the results is that 'apparent' slip, results primarily from the disturbance of the balance of forces in the 'surface phase' and not from the tangential stress. This is completely different from what would follow from the application of a standard Navier condition [7], where one assumes actual slip, which is caused entirely by the tangential stress. Importantly, it is also shown that the disturbance, caused by the surface patterning, runs well outside the transition region, in both the upstream and downstream directions.

The analysis is extended to the case of periodically intermittent wettability of the solid substrate, which is the situation previously considered in molecular dynamics simulations [4, 5].

Experimentally it has already been shown that by deliberately patterning a substrate with hydrophillic and hydrophobic regions it is possible to confine a liquid to a microchannel [8], to improve the accuracy of droplet deposition [9] or to create a structured film [10]. Importantly, in this investigation, we provide a predictive tool for uncovering the effect that properties of the liquid, solid and periodicity of patterning have on the flow. Controlled manipulation of a given flow may then involve an impulsive change to the flow field via one change in wettability or, alternatively, a change in the global characteristics of a flow, using intermittent patterning.

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