Physics of Fluids 2003 vol.15 N10, pages 3134-3143

Meniscus motion in a prewetted capillary

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Abstract

A conventional description of the effect of meniscus friction is based on the concept of the dynamic contact angle θ, which depends on the meniscus velocity V according to the Tanner law, θ∝ V1/3. However, recent high-resolution experiments on spontaneous uptake of wetting fluids by capillaries have questioned the universality of the Tanner law. We analyze a mechanism underlying the phenomenological concept of meniscus friction, which finds experimental confirmation. As a case study system, we consider a forced flow of meniscus in a cylindrical capillary. It is assumed that the capillary is prewetted and the coating uniform film could coexist with the static meniscus. Numerical analysis is restricted to van der Waals fluids for which the disjoining pressure Π as a function of film thickness h has the form Π ∝ h-3. For these fluids, the equilibrium apparent contact angle is zero. Within the lubrication approximation of the film flow, we show that the nonzeroth dynamic contact angle first appears when the fluid velocity exceeds a certain characteristic value. For smaller velocities, there is no appreciable distortion of the meniscus shape, compared to the equilibrium static configuration. The deformations of the film profile are concentrated at the transition zone between the macroscopic meniscus and the submicron precursor. While the concept of dynamic contact angle seems to be inappropriate for slow flows, the concept of contact line friction serves as a practical alternative to it. We show that when the velocity is slow and there is no visible contact angle, the friction is Newtonian, i.e., the relation between the pressure drop Δ P and the meniscus velocity is linear. As the velocity increases, the linear relation transforms into a nonlinear asymptotic law Δ P ∝ (V In V)2/3. © 2003 American Institute of Physics.

http://dx.doi.org/10.1063/1.1604392