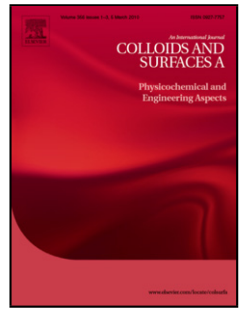
Accepted Manuscript



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PII:	S0927-7757(18)30079-7
DOI:	https://doi.org/doi:10.1016/j.colsurfa.2018.02.003
Reference:	COLSUA 22255
To appear in:	*Colloids and Surfaces A: Physicochem. Eng. Aspects*
Received date:	29-12-2017
Revised date:	1-2-2018
Accepted date:	1-2-2018

Computations of Spontaneous Rise of a Rivulet in a Corner of a Vertical Square Capillary

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Abstract

In this study, the spontaneous rise of a Newtonian liquid in a square capillary with completely or partially wetted walls is investigated using numerical simulations. The flow is modelled using Volume-of-Fluid method with adaptive mesh refinement to resolve the interface for high accuracy. The computations show that for contact angles smaller than 45°, rivulets appear in the corners of the capillary. At large times the length of the capillary growth approaches the one-third power function of time. The same asymptotic behaviour has been identified in the existing experimental observations for corners of different geometries. The computations predict the dependence of the rate of the rivulet growth on the liquid viscosity, gravity, width of the capillary and the contact angle. The flow in the rivulet is described using a long-wave approximation which considers three regions of the rivulet flow: the flow near the rivulet tip which is described by a similarity solution, intermediate region approaching a static rivulet shape, and the bulk meniscus. Finally, a scaling analysis is proposed which predicts rivulet growth rates for the given parameters.

Keywords: capillary flows, capillary rise, interior corner, noncircular capillaries, imbibition

1. Introduction

Capillary rise in corners between any two intersecting surfaces and in capillaries and containers with corners can be found in a wide range of applications in the field of microfluidics, fluid management in space and microgravity, porous media, etc. The capillary rise in the corners can be either detrimental, such as in a microchannel, where it alters the flow by lubricating the channel and also by premature mixing of fluids [1], or beneficial, such as its use to fabricate microstructures used for force measurements by capillary micromolding [2, 3]. In the case of porous or wet granular media, where the pores are of different shapes with varying corner geometries, the water imbibition is influenced significantly by the flows in the corners of the pores [4–8]. Understanding the behavior and optimizing the performance in such applications requires quantitative modelling of the dynamics of capillary flows in corners.

Investigations of the liquid rise by wettable solids started as early as 1710 by Taylor [9] and Hauksbee [10] even before the phenomena of surface tension and wall wettability have been understood [11]. They report the rise of the liquid between two vertical parallel glass plates, in tubes and between the vertical plates forming a small angle. The observed hyperbolic shape of the liquid between two inclined vertical plates has been explained by the theory of Newton, published in his 31*st* *Query* [12], predicting that the height of the liquid between two parallel plates is inversely proportional to the interval between them.

When the contact angle is in the range $\pi/2 - \alpha < \theta < \pi/2$ (where α is the half-angle between the wedge faces) the bulk meniscus shape is nearly spherical and the contact line forms a closed curve on the capillary walls. However, if the contact angle is smaller, $\theta + \alpha < \pi/2$, the near-spherical meniscus solution is impossible. In

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Preprint submitted to Colloids and Surfaces A *February 1, 2018*