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Abstract

Contact Angle Measurement through Liquid Flow in Curved Open Microchannels †

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Abstract: Whether liquids in open microchannels show spontaneous capillary flow or not crucially depends on the involved surface energies and the shape of the microchannel. In this study, we present a two-dimensional model based on the Gibb's free energy of a system that predicts the presence of spontaneous capillary flow in open microchannels. We expand our model to include curved microchannels and verify our findings using simulations of a liquid surface with Surface Evolver. Finally, we comment on how these results can be used to measure the liquid contact angle through open capillary flow.

Keywords: open microfluidics; liquid contact angle; capillary flow; curved microchannels; Gibbs free energy

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1. Introduction

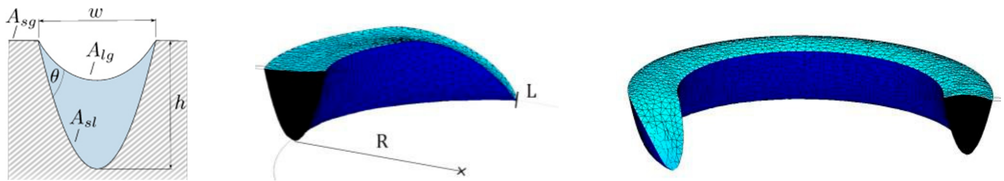
Liquid flow in closed capillaries has become an important tool for various applications in biology, medicine or chemistry. In comparison to closed microfluidic channels, open microfluidic systems rely on the design of the microchannels to drive the liquid through capillary forces.

While closed microfluidic channels are filled if the contact angle between the liquid and the substrate lies below 90° (i.e. when the liquid wets the substrate) the condition for spontaneous capillary flow in open microfluidic channels is strongly related to the shape of the microchannel. This allows us to define a 'critical contact angle' for each microgroove that depends on the shape of its cross-section alone [1]. Only liquids with a contact angle below this critical contact angle will show spontaneous capillary flow and thus fill the microchannel.

In this study, we expand this two-dimensional model for straight microchannels to curved microchannels and compare the results with finite element simulations using the Surface Evolver [2]. By doing so, we not only give a criterion for spontaneous capillary flow in curved open microchannels but also show how liquid flow in curved open microchannels can be used to easily measure the liquid contact angle of a substrate.

2. Materials and Methods

The question of whether or not liquids fill open microchannels can be simplified to the problem of minimizing the surface free energies of a two-dimensional model, as shown in Figure 1. The total energy of the system is categorized into a two-dimensional part scaling with the filling length L and a constant 'front part': $G_{3D} = G_{2D}\,L + G_{\text{front}}$.

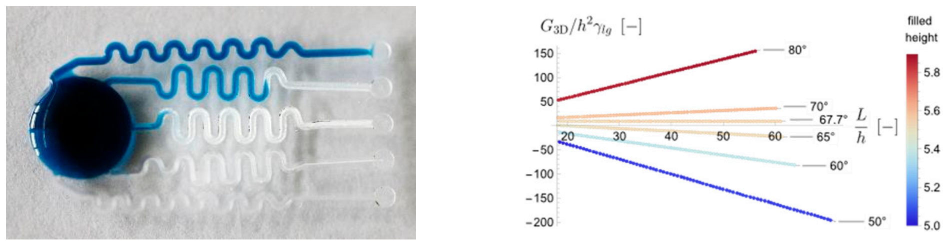


(**a**) (**b**) (**c**)

Figure 1. (**a**) Cross-section of a parabolic microgroove with the surface areas between the liquid and the gas (A_{lg}), the liquid and the substrate (A_{sl}) and the substrate and the gas (A_{sg}). The Gibbs free energy of the system is calculated by $G_{2D} = A_{lg}\,\gamma_{lg} + A_{sl}\,\gamma_{sl} + A_{sg}\,\gamma_{sg}$ with the corresponding surface energies; (**b**) Surface Evolver simulation of a liquid in a parabolic microgroove with bending radius R and liquid contact angle $\theta = 50°$. The interface between the liquid and the microgroove is colored dark blue, whereas the free liquid surface is colored light blue. The black surface is connected to a pressure-free liquid reservoir; (**c**) Simulation of a liquid with a contact angle of $\theta = 80°$.

3. Discussion

We found that the two-dimensional model correctly predicts the critical contact angle of curved microchannels. Thus, curved open microchannels can be used to measure the contact angle of a liquid on a substrate, as indicated in Figure 2.



(**a**) (**b**)

Figure 2. (**a**) Contact angle measurement through open capillary flow. In accordance with the theoretical model, only certain parabolic microchannels allow the spontaneous capillary flow of the test liquid. Evaluation of the filled microchannels allow us to estimate the liquid contact angle. (**b**) The scaling of the Gibbs energy G_{3D} for curved parabolic microchannels depending on their filling length. Note, that the liquids with a contact angle below the critical contact angle $\theta = 67.7°$ show capillary filling, indicated through a decrease in energy for increased filling length.

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