Numerical and Experimental Studies of a Capillary Channel

M. Xu[1], Z. Wu[1], X. Wang[1]

[1]Tsinghua University, Beijing, China

Abstract

Capillary effects are common in microfluidics due to large surface-to-volume ratio of flows inside microchannels. In biological or chemical analysis, capillary flow is used for the transport of liquid and mixing enhancement, without applying any external means. It's also applied to drug delivery, DNA analysis, and protein crystallization, where minute amount of liquids are precisely guided towards targeted reservoir. In this work, we design a capillary channel for transporting methanol in fuel cell, and investigate its performance both numerically and experimentally.

As illustrated in Figure 1(a), our design consists of a capillary channel between two reservoirs, represented by loading pad and vent respectively and connected to the main channel through micro parallel channels. Once loaded on the pad, methanol will automatically move towards the vent driven by capillary force. An SEM photo of typical structures is shown in Figure 1(c).

A CFD simulation is carried out with COMSOL Multiphysics® software. Figure 1(b) presents the model defined in COMSOL, which is smaller than that used in the experiment to reduce the calculating time. Initially the main channel is filled with air and a methanol volume fraction value of unity and zero is specified at the inlet and outlet respectively.

Figure 2(a) extracted from simulation movie shows the movement of the methanol-gas interface. During the capillary filling process the moving speed of the interface is about the same, with a drastically changed surface shape. Initially due to the trapezoid inlet, the meniscus interface has a convex shape, which gradually disappears as more methanol filled in. When half of the channel is filled with methanol, the interface is almost straight. The capillary flow speed is a little bit faster in both sides than that in the central, since liquid in the center could go both way forwards while liquid beside the wall could have only one direction. Consequently when this is achieved, the meniscus interface gets a concave shape. The channel is tested with water and methanol respectively and the results are consistent with experiments as shown in Figure 2(c). Note that in Figure 2(b) no concave front is observed, possibly because the channel is not long enough to present the entire process.

It takes a considerably longer time to fill the channel with water than methanol mainly due to different contact angles of these two liquids. To further investigate this assumption, we test the channel with methanol solution of different concentration in COMSOL and experiment, as shown in Figure 3(a). Both flow rate and time for pure methanol to fill the channel is defined as 1.00 to

better compare numerical and experimental results. The results show a good consistency in Figure 3(b) and Figure 3(c), confirming an increased flow rate with a reduced contact angle.

This capillary channel can be adapted for other minute liquid transport besides methanol. The experimental and numerical methods presented in this work can serve as guidelines for further investigations of capillary transport.

Reference

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[2] Saha Ashish, et al. "Effect of dynamic contact angle in a volume of fluid (VOF) model for a microfluidic capillary flow.", Journal of colloid and interface science, 339, 461-480 (2009).
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Figures used in the abstract

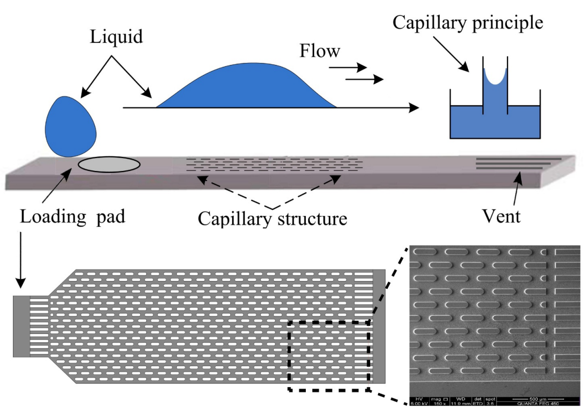

Figure 1: Principle, model and SEM photo of the capillary channel.

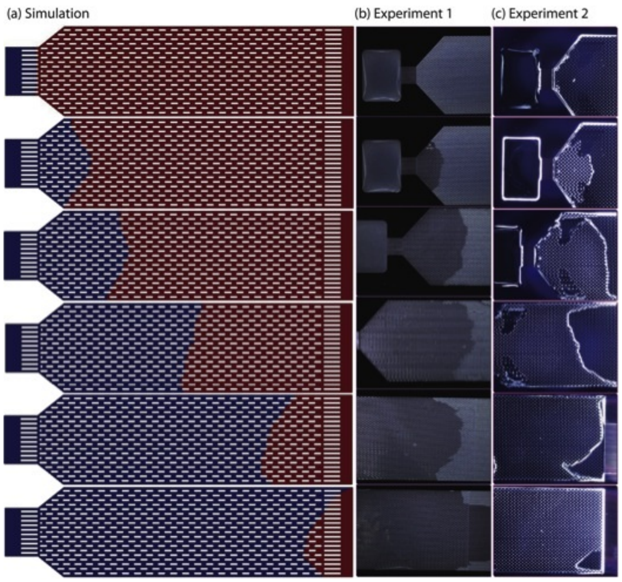

Figure 2: Numerical and experimental results of capillary flow in the channel.

(a)

	Pure Methanol	10M Methanol	5M Methanol	2M Methanol
Contact Angle *(Degree)*	15	22	31	49
Time *(experiment)*	1.000	1.310	1.862	2.931
Time *(simulation)*	1.000	1.163	1.581	1.744

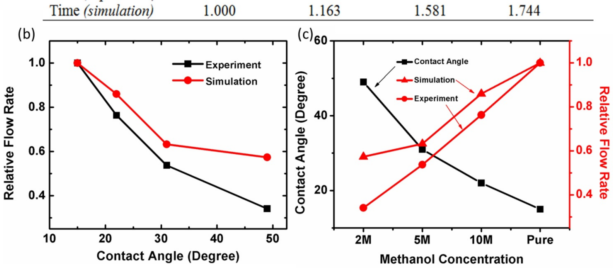

Figure 3: Flow rate vs. methanol concentration.