SELF-BLOCKING VALVE FOR A HIGHLY WETTING FLUID BASED ON PINNING OF GAS ENTRAPMENTS

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ABSTRACT

We present a novel valving principle for a highly wetting fluid in centrifugal microfluidics by self-blocking pinning structures. While usual geometrical stopping valves prove instable for highly wetting liquids, the novel valve reproducibly generates gas entrapments in a fishbone-like structure. Their pinning pressures add up to a total burst pressure p_{burst} that efficiently avoids uncontrolled capillary priming of microfluidic systems. In centrifugal experiments, burst pressures of 14-18 hPa (12 ± 2 Hz) were reproducibly achieved for isopropyl, a completely wetting alcohol ($\theta \sim 0°$; $\sigma = 22$ mNm^{-1}). The same structure also acts as a geometrical stopping valve for less wetting liquids ($\theta = 31°$; $\sigma = 30$ mNm^{-1}) [1].

KEYWORDS: valving, highly-wetting fluids, centrifugal microfluidics, pinning

INTRODUCTION

Highly wetting liquids like certain alcohols can play a significant role in various protocols for diagnostic assays such as nucleic acid extraction. Still, efficient monolithic valving of such liquids is rare: Menisci of liquids with contact angles < 45° are unstable in channels with orthogonal corners [2;3], and hydrophobic patches can only work efficiently for aqueous solutions [4]. But the presented valve makes use of highly wetting properties and complements existing valving principles.

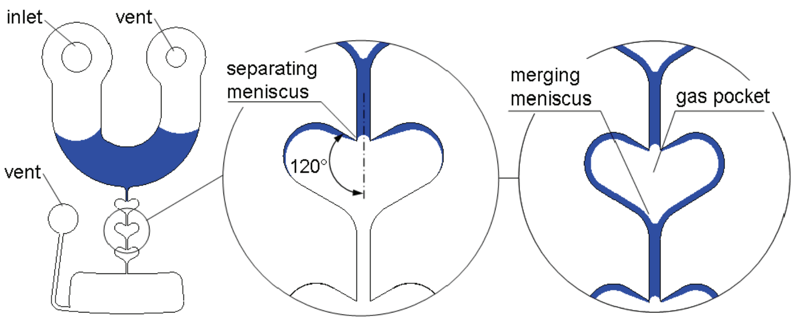

Figure 1. Schematic principle of the valve. Gas entrapments are generated by a separating (middle) and merging meniscus (right) of the highly wetting fluid.

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THEORY AND FUNCTIONAL PRINCIPLE

The novel valve consists of capillary channels leading to a series of widenings with 120°-sideway-corners and a 90° corner at the bottom of the channel (fig. 1). A highly wetting fluid approaching a widening immediately wets just the chamber walls and creeps towards the subsequent capillary. Then the liquid fronts merge again leaving behind n gas entrapments in n widenings leading to n menisci.

For applied pressures $p < p_{\text{burst}}$ the menisci only get deformed. For pressures $p \geq p_{\text{burst}}$ the liquid overcomes the capillary pressure, resulting in liquid flow. It is well known that a series of unwanted gas bubbles in microfluidic systems lead to clogging of channels [5]. Reasons are pinning at the bubble caps and damping by the gaseous phase. Both effects add up with n. Here, this effect is utilized to realize a defined stop. For less wetting liquids, the here described valve also works as a geometric stop [1].

EXPERIMENTAL RESULTS

Cup-shaped structures were manufactured in cyclic-olefin polymer foils applying an established blow-molding process [6]. The inlet chambers were connected to a second chamber by a channel exhibiting three self-blocking valves (fig. 2). A volume of 180 µl isopropyl was chosen as sample liquid ($\theta \sim 0°$; $\sigma = 22$ mNm^{-1}).

Connecting channels were primed immediately by liquid leaving gas entrapments behind. By centrifugation of the foil cartridge, a centrifugal force was applied onto the liquid column and the valve blocked up to a rotary frequency of 12 ±2 Hz (pressures of 14-18 hPa) in 13 out of 13 cases.

In a separate experiment, an aqueous solution, a wetting biological buffer ($\theta = 31°$; $\sigma = 30$ mNm^{-1}), could successfully be valved by means of simple pinning at the valve edges.

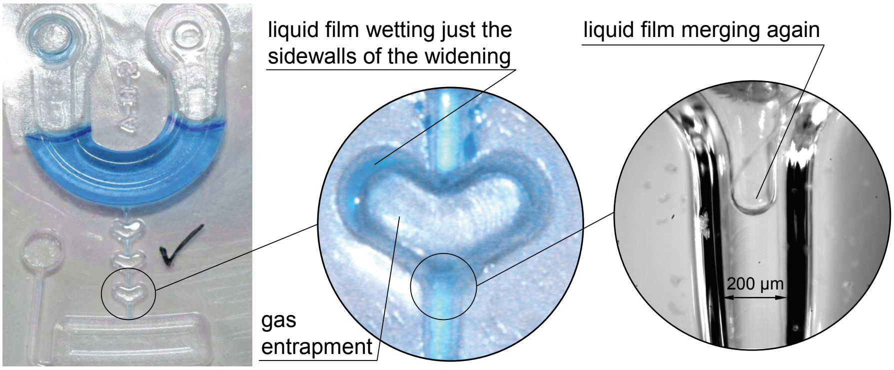

Figure 2. Photographs of the test structure with valves. The gas pockets lead to pinning pressures that add up to a reasonable burst pressure. Middle: a dyed liquid film generated a gas entrapment. Right: close-up of liquid fronts merging again.

CONCLUSIONS

We demonstrated a new valve for a highly wetting liquid. It makes use of the known clogging effect of gas entrapments in microchannels. The valve can be integrated in a monolithical way (fig. 3) and works reproducibly, also for less wetting liquids. It can be regarded as an enabling module for handling of fluids with very low surface tensions on centrifugal microfluidic platforms.

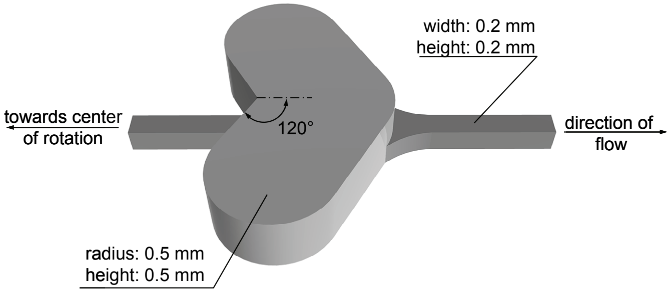

Figure 3. The valves are monolithically integratable due to their simple geometries. They stopped isopropyl, a highly wetting alcohol, at a centrifugally generated hydrostatic pressure of 14-18 hPa (12 ±2 Hz) in 13 out of 13 experiments.

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REFERENCES

[1] C. Lu, Y. Xie, Y. Yang, M. M. Cheng, C. G. Koh, Y. Bai, L. J. Lee and Y. J. Juang, New valve and bonding designs for microfluidic biochips containing proteins, Anal. Chem. 79, pp. 994-1001, (2007)

[2] Finn, R., Equilibrium Capillary Surfaces, Springer-Verlag, Stanford, (1986)

[3] M. Zimmermann, P. Hunziker and E. Delamarche, Valves for autonomous capillary systems, Microfluidics and Nanofluidics 5, pp. 395-402, (2008)

[4] M. Madou, J. Zoval, G. Y. Jia, H. Kido, J. Kim and N. Kim, Lab on a CD, *Annual Review of Biomedical Engineering* 8, pp. 601-628, (2006)

[5] C. W. Wong, T. S. Zhao, Q. Ye and J. G. Liu, Transient capillary blocking in the flow field of a micro-DMFC and its effect on cell performance, *J. Electrochem. Soc.* 152, pp. A1600-A1605, (2005)

[6] M. Focke, B. Faltin, T. Hösel, C. Müller, J. Ducrée, R. Zengerle and F. v. Stetten, Blow molding of polymer foils for rapid prototyping of microfluidic cartridges, Proc. of μTAS 2008, pp. 988-990, (2008)