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Influence of Gas/Solid Surface Fraction on Drag Reduction of Partially Substrateless Microchannels

Ellen Bold[1], Sebastian Zimmermann[2], Clarissa Schönecker[2], Egbert Oesterschulze[1]
[1]Rhineland-Palatinate Technical University (RPTU) Kaiserslautern
Department of Physics, Physics and Technology of Nanostructures
Erwin-Schrödinger Str. 46, Kaiserslautern, Germany
[2]Rhineland-Palatinate Technical University (RPTU) Kaiserslautern
Department of Mechanical Engineering, Microfluidics,
Gottlieb-Daimler Str. 46, Kaiserslautern, Germany
bold@rptu.de; s.zimermann@mv.rptu.de;
c.schoenecker@mv.rptu.de; oester@rptu.de

Extended Abstract

Drawing inspiration from biomimetics, significant drag reduction was achieved for superhydrophobic [1, 2] and liquid-infused surfaces [3]. However, these structures have certain inherent disadvantages. These include the high cost of manufacturing of complex and delicate micro- or nano-components, the vulnerability to lubricant abrasion or plastron depletion. Consequently, the anticipated drag reduction effect is reduced or even eliminated [4, 5].

We present the construction of a partially substrate-less microchannel utilising environmentally friendly materials, which results in the formation of a large, continuous air/water meniscus kept at atmospheric pressure. The wall was perforated by structuring silicon wafers using laser lithography, followed by dry DRIE etching and bonding of OTCS (octadecyltrichlorosilane) to create rectangular slits on a hydrophobic wall. Subsequently, these were installed as walls of a rectangular microchannel, with the long side of the slit oriented in the direction of flow.

The stability of the formed meniscus spanning the open slit was demonstrated by flow measurements conducted over a 24-hour period. In the event of rupture, the meniscus exhibited the capacity to heal by reducing the flow rate for a few seconds, thereby enabling measurements to be resumed. Additionally, sensor pressure measurements indicated that the introduction of the meniscus interface resulted in a notable drag reduction of up to 25%, despite a gas fraction of only 4%. Moreover, we utilised optical contact-free imaging with a white light interferometer to visualise the meniscus topology. The associated radii were employed in conjunction with the Young–Laplace equation, which includes the contributions of the fluid-static and fluid-dynamic pressure during flow measurements [6], in order to conduct a contact-free evaluation of the spatially resolved static pressure distribution. The meniscus profiles were then utilised to perform simulations based on the corresponding geometric data. The results demonstrated that the consideration of the protrusion is of significant importance, while the drag reduction is primarily attributable to the no-shear interface. We present further investigation of the microchannel configuration with slit structures on both the top and bottom sides of the microchannel at the poster of Bold, Gutheil and Oesterschulze.

References

[1] Rothstein, Jonathan P., "Slip on Superhydrophobic Surfaces." Annu. Rev. Fluid Mech., vol. 42, no. 1, pp. 89–109 ,2010.
[2] Lee, Choongyeop; Choi, Chang-Hwan; Kim, Chang-Jin, "Superhydrophobic drag reduction in laminar flows: a critical review." Exp Fluids, vol. 57, no. 12, pp. 1–20, 2016.
[3] Vega-Sánchez, Christopher; Peppou-Chapman, Sam; Zhu, Liwen; Neto, Chiara, "Nanobubbles explain the large slip observed on lubricant-infused surfaces." Nat Commun, vol. 13, no. 1, p. 351, 2022.
[4] Butt, Hans-Jürgen; Roisman, Ilia V.; Brinkmann, Martin; Papadopoulos, Periklis; Vollmer, Doris; Semprebon, Ciro, "Characterization of super liquid-repellent surfaces." Current Opinion in Colloid & Interface Science, vol. 19, no. 4, pp. 343–354, 2014.

[5] Kim, Jeong-Hyun; Rothstein, Jonathan P., "Delayed lubricant depletion on liquid-infused randomly rough surfaces." Exp Fluids, vol. 57, no. 5, 2016.
[6] D. Langbein, Capillary surfaces. Berlin ; New York : Springer, 2002.