Designing Re-entrant Cavities for Robust Liquid-Infused Surfaces

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Omniphobic surfaces, capable of repelling all types of liquids in addition to water are a great value addition in various applications ranging from self-cleaning, anti-icing , anti-biofouling, and hydrodynamic drag reduction to oil repellent coatings and oil/water separation. The texture design consists of a re-entrant topography that is vital to achieve oleophobicity as it enhances the stability of the composite liquid-solid-air interface. These surfaces are however prone to failure due to external pressure resulting in the loss of functionality.

Liquid Infused Surfaces (LIS), another class of super wettable surfaces, consist of a micro/nanotextured surface infused with a lubricating liquid to achieve liquid-repellent properties. The lubricant used is incompressible and immiscible with the external liquid, thereby creating a stable pressure phase. Thus, the presence of the infused lubricant within the cavities is integral to the success of LIS. In bulk flow, LIS, however, are susceptible to drainage failure caused by external shear imposed at the liquid–lubricant interface.

In this work, we combine the re-entrant topography (dovetail-shaped cavity) with a lubricating liquid and numerically evaluate the shear-flow-induced liquid-lubricant interface dynamics in a microchannel. The results show that when the lubricant is kept fixed, a less viscous external liquid aids in better lubricant retention. Due to the shear imparted, three stable and two failure meniscus shapes have been distinguished. Additionally, it was evident that, as the viscosity ratio was reduced, the effect of the cavity opening was no longer dependent on the flow rate.

Further, to understand the durability of LIS, we focus on the interface dynamics of LIS during transport for food packaging applications. We analyse the lubricant retention within the cavities when subjected to pure oscillations (zero net flow). The microchannel is excited longitudinally at f = 0.1 - 10 Hz for viscosity ratios (μ_r = 0.4 – 1.0 and μ_r = 1.8) for a dovetail cavity with a lubricant of two different densities. The results show a strong dependence on the viscosity of the external liquid and the density of the lubricant. A more viscous external liquid and a denser lubricant dampen the vibration effects and thereby exhibit a stable state with an intact meniscus.

Next, to demonstrate the performance of LIS with Newtonian and non-Newtonian liquids, 1D textures (ribs) are fabricated using a femtosecond laser and the drop movement is evaluated by varying the lubricant viscosity and tilt angle. The results show that increasing the tilt angle, the drop velocity increases whereas, the increase in lubricant viscosity enhances the drag and reduces the drop velocity. In addition, the surface is subjected external vibrations and shows a strong dependence on lubricant viscosity. A more viscous lubricant dampens the vibrations effects and does not deplete from the cavities, thus retaining the functionality of LIS.