MODELLING DROP MOBILITY ON LUBRICATED SURFACES USING A TERNARY FREE ENERGY LATTICE BOLTZMANN ALGORITHM

Sirio Orozco-Fuentes[1] and Ciro Semprebon[1]

[1]Smart Materials & Surfaces Laboratory, Northumbria University,
Newcastle upon Tyne, United Kingdom, NE1 8ST

ABSTRACT

Slippery Liquid-Infused Porous Surface (SLIPS) and Lubricant-Impregnated Surfaces (LIS) consist of a nano/micro-structured porous material infused with a lubricant fluid whose purpose is to facilitate the removal of material defects and imperfections from the surface. This feature places them at the forefront of many fields including anti-biofouling, anti-icing, anti-corrosion and droplet manipulation[1].

The properties of the infused lubricant layer and its interaction with the substrate and the fouling fluid become an integral part of their success in achieving these features. The viscosity of the lubricant layer of a SLIPS/LIS surface plays a fundamental role in drop mobility[2,3]. For practical applications, a compromise is necessary: lubricants with small viscosity favour large mobility, but easily leak out under shear[4], and lubricants with large viscosity are more stable but reduce drop mobility. The apparent viscosity in non-Newtonian liquids varies due to the local shear rate, thus we hypothesise that SLIPS/LIS made of non-Newtonian lubricants may eliminate this drawback, offering new opportunities to control droplets and their motion. For example, non-Newtonian lubricants could allow for enhanced drop mobility and prevent lubricant leakage.

The gathering or depletion of the lubricant is related to the redistribution by capillary flows. When a droplet sits on a SLIPS/LIS, the lubricant is gathered around its edge forming a meniscus. As the droplet moves, it leaves a wake and the menisci break their symmetry making a distinction between the advancing and receding sections. This plays a key role in the resilience of the SLIPS/LIS to maintain its functionality. An example of this effect can be seen in **Fig. 1**, in which the advancing meniscus grows larger than the receding meniscus leaving a depletion wake. Upon adjusting the rheology of the lubricant, this effect can be reversed so that the lubricant layer can recover its thickness more quickly.

In this work, we use a high-density ratio ternary lattice Boltzmann method[5] to model SLIPS/LIS as a flat surface coated with a lubricant layer. We validate the numerical method for a variety of non-Newtonian fluid models in the shear-thinning or shear-thickening regimes, such as the power-law and Carreau-Yasuda[6]. We study the system behaviour under actuation by external forces by quantifying the dissipative forces and by measuring the response of the apparent contact angle of a droplet when actuated by a body force.

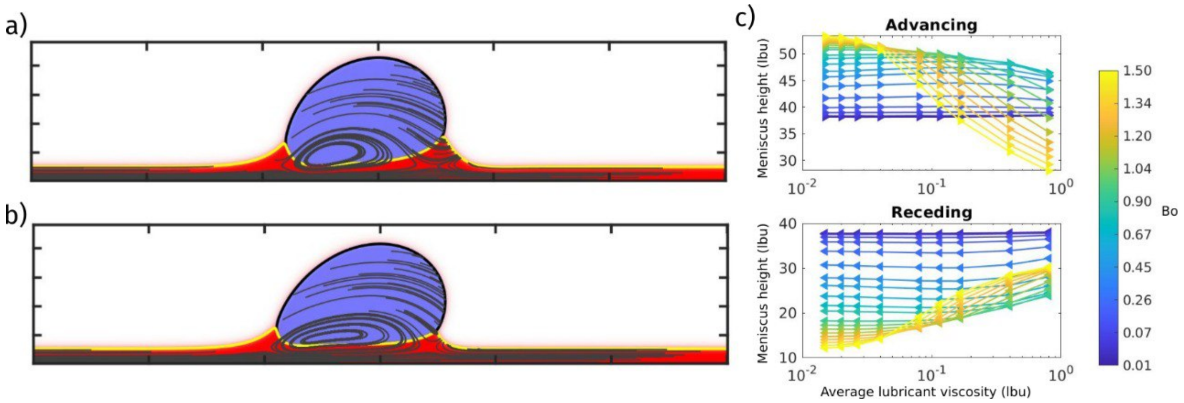

Figure 1: Droplet sliding on a LIS with an average viscosity (a) $\langle\mu_{lub}\rangle = 50\mu_{drop}$ and (b) $\langle\mu_{lub}\rangle = 2\mu_{drop}$ for $\mathrm{Bo} = 0.8$. (c) Advancing and receding ridge heights as a function of the average lubricant viscosity under the effect of an external body force actuating on the LIS.

ACKNOWLEDGEMENTS

This project is supported by EPSRC Grant Number: EP/S036857/1.

REFERENCES

1. S. Peppou-Chapman, J.K. Hong, A. Waterhouse, C. Neto. Life and death of liquid-infused surfaces: a review on the choice, analysis and fate of the infused liquid layer.
2. J. D. Smith, R. Dhiman, S. Anand, E. Reza-Garduno, R. E. Cohen, et al. Droplet mobility on lubricant-impregnated surfaces. *Soft Matter*, **6**, 2013.
3. Keiser A., Keiser L., Clanet C., Quéré. Drop friction on liquid-infused materials. *Soft Matter*, **39**, 2017.
4. J. S. Wexler, I. Jacobi and H. A. Stone. Shear-Driven Failure of Liquid-Infused Surfaces. *Phys. Rev. Lett.* **114**, 168301 *Chem. Soc. Rev.*, **49**, 3688, 2020.
5. Sadullah M.S., Semprebon C. and Kusumaatmaja H. Drop Dynamics on Liquid-Infused Surfaces: The Role of the Lubricant Ridge. *Langmuir*, **34**(27):8112-8118, 2018.
6. J. Boyd, J Buick, S. Green. A second-order accurate lattice Boltzmann non-Newtonian flow model. *J. Phys. A: Math. Gen.* **39** (2006), 14241-14247.