Thermocapillary Droplet Actuation on a Wall

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Mathematics

Clusters
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Institute
Mathematical Modeling and Analysis

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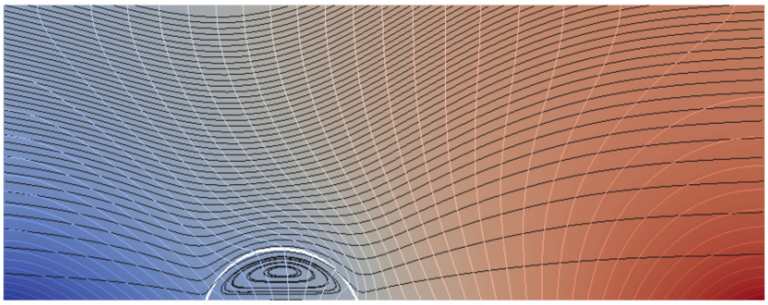

Introduction

MMultiphase flows are present in many applications of industrial relevance. In addition, they are mostly accompanied by a multitude of physical phenomena. The capturing and accurate representation of these physical mechanisms can be achieved by Direct Numerical Simulations (DNS), where all relevant physical time and length scales are resolved. Focusing on the correct mathematical and numerical formulation of the physical laws allows to gain a better understanding and complements theoretical as well as experimental results. The focus of the present work lies on the correct numerical description of fluid motions due to thermocapillary Marangoni stresses.

Methods

Marangoni stresses at the interface occur in free boundary flows in the presence of surface tension gradients. If the non-uniformity of surface tension is caused by interface temperature gradients, the Marangoni-driven flow is referred to as thermocapillary flow. Over the last years droplet actuation is attracting widespread attention because of its promising potential in droplet-based devices developed for various applications in industry. One way to actuate a droplet is to apply a thermal gradient along the solid wall to which it is attached. In order to perform highly resolved Direct Numerical Simulations of multiphase/-physics systems, we employ the Finite Volume Code Free Surface 3D (FS3D).[2] This code framework is expanded to handle dynamic contact angles based on (Afkhami et al. and Schwieder).[1,3] To simulate thermal droplet actuation a droplet is placed on an unevenly heated surface. One can distinguish three motion regimes: motion towards the cold side, the hot side, or no motion at all. The capturing of this phenomenon is quite new and has only been stated recently in (Sui)[4].

Results

Figure 1 shows such a droplet on a heated wall moving towards the cold side. The black lines indicate the streamlines, the coloured lines are isothermal curves, and the white line represents the droplet surface. Figure 2 shows the regime map for such a droplet for different contact angles and different viscosity ratios between the outer and the inner fluid (the outer fluid was changed). As visible in Figure 2 the droplet is not moving if the outer and inner viscosities are the same and the contact angle is 90°. For larger contact angles the droplet moves towards the hot side; for smaller angles the droplet moves towards the cold side. The dashed line shows how the stagnant regime changes with the viscosity ratio. Due to the relevance of micro devices, thermal droplet migration is an ongoing research topic.

Outlook

Future work will also include the implementation of hysteresis in FS3D which will allow a more accurate capturing of the droplet motion in the non-moving regime.

Figures

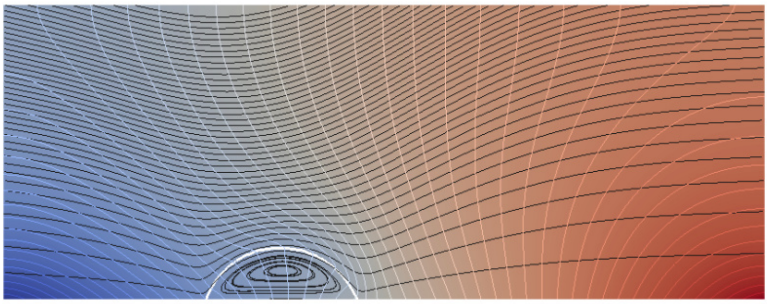

Figure 1: Thermal droplet migration. a.) Migrating droplet θe = 70.

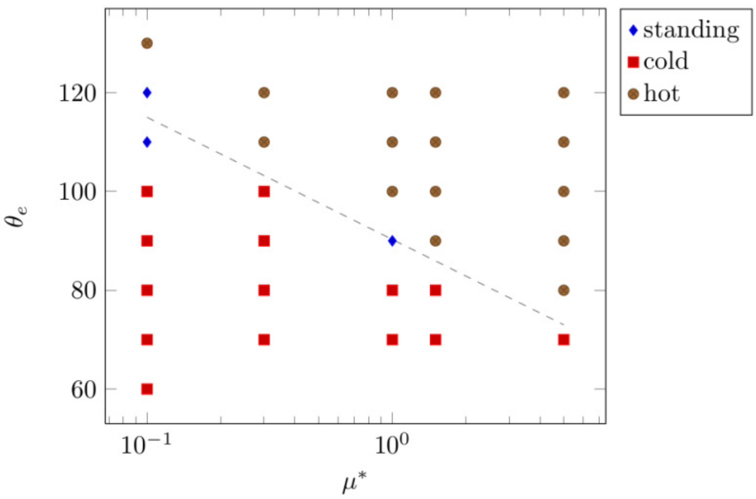

Figure 2: Regime map.

Reference

[1] S. Afkhami, S. Zaleski, and M. Bussmann (2009), A mesh-dependent model for applying dynamic contact angles to VOF simulations. Journal of Computational Physics, 228(15): 5370–5389. https://doi.org/10.1016/j.jcp.2009.04.027

[2] M. Rieber (2004), PhD thesis: Numerische Modellierung der Dynamik freier Grenzflächen in Zweiphasenströmungen. ITLR University Stuttgart.

[3] M. Schwieder (2014), Master thesis: Implementation and Study of a Dynamic Contact Angle Model with the Flow Solver FS3D. Technische Universität Darmstadt.

[4] Y. Sui (2014): Moving towards the cold region or the hot region? Thermocapillary migration of a droplet attached on a horizontal substrate. Physics of Fluids , 26, 9. https://doi.org/10.1063/1.4894077

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