Extended discontinuous Glerkin methods for the simulation of three-phase contact line problems

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A generic experiment, where a three-phase contact line could be observed is e.g. a droplet sitting on a plate, see Figure 1. The contact line is the location where solid, liquid and gas meet. An equilibrium contact angle between the solid and liquid interface can be predicted by Young's theory. At this angle, the different tensions between solid and liquid, solid and gas as well as liquid and gas are in balance. When the plate is tilted, it can be observed experimentally that the contact line remains stationary and apparently resists the gravitational forces while the drop tilts to one side. As the plate is tilted further, the contact angle between the liquid and solid surfaces becomes blunter on one side and narrower on the other. At a certain angle, the contact line begins to move, initially in the so-called creeping regime. The stationary stay of the contact line within certain limits for the contact angle is called contact angle hysteresis. If the plate is tilted further, the creep movement finally changes into a rolling movement. Due to contact line hysteresis, the equilibrium contact angle is hardly ever observed. A close model for the prediction of contact line behavior is still a matter of active research.

We are going to present a sharp-interface, eXtended discontinuous Galerkin (XDG) solver (also referred to as cut-cell DG or unfitted DG) for the simulation of three-phase contact lines. The position of the liquid-gas interface is described by a level set. The XDG discretization allows to represent the jumps in pressure and velocity gradient with a convergence accuracy of h^k, resp. h^{k+1}, where $k-1$ and k are the polynomial degrees pressure and velocity, respectively.

In order to model the dynamics of the contact line, we are using a model proposed by Reusken et al. [2017]. It mainly consists of a slip boundary condition at the liquid-solid and liquid-gas interface and an additional force at the contact line itself. Due to the XDG approach, this singular force, which is acting only on a manifold of dimension 1, can be implemented without regularization.

We are going to present the contact line model and it integration into the variational XDG framework. After showing preliminary results, see e.g. Figure 2, the validity of the model as well as its limitations will be discussed.

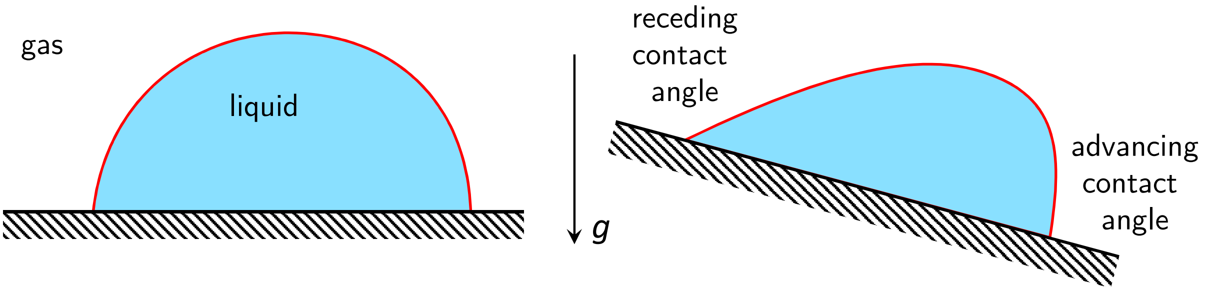

Figure 1: Droplet sitting on a surface; if the plane is tilted, advancing and receding contact angel can be observed.

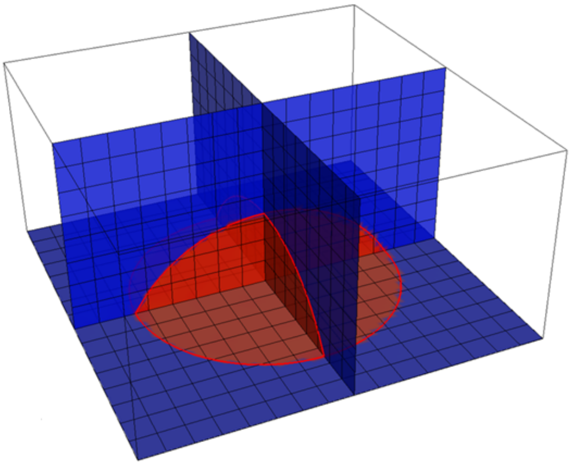

Figure 2: Three-dimensional pressure profile of a droplet on a solid surface.

Acknowledgements

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References

Arnold Reusken, Xianmin Xu, and Liang Zhang. Finite element methods for a class of continuum models for immiscible flows with moving contact lines. *International Journal for Numerical Methods in Fluids*, 84(5):268–291, June 2017. ISSN 02712091. doi: 10.1002/fld.4349.