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Isogeometric analysis of droplet deformation in shear flow

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ABSTRACT

Because of high industrial applicability, droplet deformation has taken a considerable part of research attention in previous decades. In order to solve the governing equations (i.e. Stokes), we employ the Boundary Integral Method [1] in which, for every point \( x_0 \) on the droplet membrane \( S \subset \mathbb{R}^3 \) the velocity, \( u(x_0) \in \mathbb{R}^3 \), is given by

\[
u(x_0) = u_\infty(x_0) - \frac{1}{8\pi} \int_S G(x, x_0) f(x) dS
\]

in which \( G(x, x_0) \in \mathbb{R}^{3\times3} \) is the Green’s function (or Stokeslet), \( u_\infty(x_0) \) is the imposed velocity and \( f(x) \in \mathbb{R}^3 \) is stress discontinuity across the membrane which is given by

\[
f(x) = \frac{2}{Ca} \kappa(x) n(x)
\]

where \( \kappa(x) \) is the local (scalar) mean curvature, \( n(x) \in \mathbb{R}^3 \) is the normal vector to the surface and \( Ca \) is the Capillary number which is a measure of the ratio between viscous and surface tension forces. For a drop with radius \( R \), the non-dimensional Capillary number is

\[
Ca = \frac{R \dot{\gamma} \mu}{\sigma}
\]

where \( \dot{\gamma} \) is the shear rate, \( \mu \) is the matrix fluid viscosity and \( \sigma \) is the interfacial tension. Note that, in the current case, the viscosity of the internal and external fluids are assumed to be identical, which results in the convolution equation (1) (see e.g. [1] for the general expression).

It is customary that the droplet surface, \( S \), is represented by a linear triangular mesh. Efficient methods have been developed for the evaluation of the non-uniquely defined normal vectors and curvatures in the nodes [2]. In this contribution, we aim at developing a parametric spline representation of the droplet surface, which will facilitate direct evaluation of normals and curvatures and will open the doors for incorporating higher-order surface derivatives in the formulation. In combination with the boundary integral formulation outlined above this results in our isogeometric analysis [3] approach to droplet deformation. From an implementational standpoint, we use the concept of Bézier extraction [4] to represent the surface in an elemental format. It is worthy to mention that an \( L_2 \)-projection is used to determine the control point velocities, which, in contrast to the nodes in the traditionally used meshes, are not interpolatory.
Figure 1 shows how the Taylor deformation parameter, $D = \frac{L-B}{L+B}$, behaves while the drop is deforming in shear matrix flow. The parameters $L$ and $B$ are defined as twice the maximum and minimum distances from the drop center respectively. The center of the spherical droplet is located initially in the center of the geometry and approximately remains in the same position during the whole simulation. It is observed that the droplet starts deforming and deviating from the initial spherical shape. Then it elongates as an ellipsoid and orients itself in the fixed direction. The obtained results are in good agreement with results reported in literature, e.g. [5].

![Figure 1: Taylor deformation parameter in time for Ca = 0.2](image)

Our preliminary results show that an isogeometric approach to modeling droplet deformation using the boundary integral method is a viable option. A detailed study of the convergence properties of the proposed approach is required to obtain a meaningful comparison with the traditional approach in terms of accuracy and computational effort. The ability of the isogeometric approach to unambiguously define curvatures, and even higher-order parametric derivatives, is a favorable property of the method and motivates further study.

References


