Development of a Multiphase Solver for Numerical Simulations of Thermally Driven Marangoni Flows

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Motivation and Objectives
- Development of a CFD solver within the framework of the open source tool box OpenFOAM for the simulation of thermal Marangoni convection
- Applications: Crystal growth, metal welding, metal and organic alloys processing, droplet coalescence,...
- Solver Validation: simulation of the migration of droplets in a reduced gravity environment
- Extend the capability of the code to non-Newtonian viscoelastic liquids

Methodology
- We use a semi-coupled Level-Set-VOF approach implemented into OpenFOAM
- The stresses at the interface are modelled by using a CSF (Continuum Surface Force) approach
- The energy transport equation is also solved: velocity and temperature fields are strongly coupled

\[ \rho \left( \frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) = -\nabla p + \frac{1}{Re} \nabla \cdot \left( \mathbf{u} \left( \nu \nabla \mathbf{u} + \nabla \mathbf{u}^T \right) \right) + \frac{1}{Re \cdot Ca} \left( \sigma^* (T) k \delta n + \nabla \left( \sigma^* (T) \delta \right) \right) \]

\[ \rho c_p \left( \frac{\partial T}{\partial t} + \mathbf{u} \cdot \nabla T \right) = \frac{1}{Ma} \nabla \cdot \left( \mu_k \nabla T \right) \]

Validation Problem
- Thermal Marangoni convection of a fluorinert droplet placed in a box filled with silicone oil in a reduced gravity environment
- A temperature gradient is imposed along the box

- Marangoni stresses caused by interfacial tension gradients along the interface cause the droplet to move from the cold side to the hot side
- The flow is governed by the following dimensionless parameters:
  \[ Re = \frac{\text{Interfacial Stress Gradients}}{\text{Viscous Stresses}} \]
  \[ Pr = \frac{\text{Kinematic Viscosity}}{\text{Thermal Diffusivity}} \]
  \[ Ma = Re \cdot Pr = \frac{\text{Thermal Convection Rate}}{\text{Thermal Diffusion rate}} \]
  \[ Ca = \frac{\text{Viscous Forces}}{\text{Interfacial Forces}} \]

- We performed a set of simulations by varying the Marangoni number “Ma” whilst the Prandtl and Capillary numbers have been kept constant

Droplet migration at vanishing Marangoni and Reynolds numbers

Effect of Marangoni number on droplet migration under reduced gravity conditions

Conclusions and Future Work
- The Solver has been tested for a wide range of Marangoni numbers
- In the case of vanishing Marangoni and Reynolds number we successfully matched the analytic solution of Young with an error < 1%
- Our predictions are in excellent agreement with the experimental measurements of Hadland [1]
- Next, we aim to investigate the effect of the shear dependent viscosity and elasticity on the thermocapillary motion of droplet

References: