Characterization of the oxidized surface of a liquid metal (Caractérisation d'une surface de métal liquide oxydée)

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Internship proposal

This master internship (M2 level) is proposed within the framework of a collaborative project supported by EPSRC and Grenoble-Alpes University. The aim is to mechanically characterize the oxidized surface of a liquid metal bath (Galinstan) under ambient temperature and pressure conditions.

The research context is broad and multidisciplinary, with potential applications in metallurgy [5], microelectronics [1], and liquid metal microfluidics [3].

An in-house experiment — named Madip — has been developed in Grenoble at SIMaP laboratory, within the EPM team (Figs.1-2). It enables the generation of a controlled annular shear flow of liquid metal sandwiched between two static cylindrical walls. This is achieved by placing a magnetic ring at the bottom of the annular channel, which is driven by induction with an external ring of permanent magnets connected to a motor. The shear imposed by the rotating magnetic ring is viscously transmitted through the liquid metal bath up to the liquid surface, which itself experiences lateral shear between the two static cylindrical walls.
Since liquid metals such as Galinstan naturally develop an oxide layer, the surface becomes patterned with oxidized patches. These can be tracked over time using a Lagrangian approach, leading to a non-intrusive surface velocimetry technique. This allows for mechanical characterization of the oxidized liquid surface, for instance, through the identification of a surface shear viscosity.

The first objective of the internship will be to reassemble and validate the Madip setup and to reproduce previous surface velocimetry measurements obtained for Galinstan under steady rotational conditions. In a second phase, unsteady experiments will be carried out by imposing rotational pulses, in order to quantify shear transport both through the bulk and along the interface. To this end, a fast and sensitive CCD camera will be used to image the surface dynamics even under unsteady conditions. The open software ImageJ is expected to be used to develop particle tracking velocimetry (PTV) of the oxidized patches. The ultimate goal is to determine the experimental conditions that allow one to distinguish between propagative and diffusive regimes, knowing that several characteristic time scales can be considered: the time scale associated with bulk viscosity, the one related to surface viscosity, and finally, the fast time scale associated with the unsteady injection of shear momentum at the bottom ring.

Non-dimensional models, currently developed at Aston University [2] and SIMaP laboratory [4], aim to describe viscous shear diffusion both across the bulk and along the surface. Within the framework of this internship, the model may be extended to account for the unsteady conditions observed experimentally. As part of this proposal there will be an opportunity to spend time at Aston University (UK). During this time, the successful candidate will have the opportunity to develop modeling skills (both analytical and computational) with the aim being to reproduce the associated experimental findings. There will also be the opportunity to collaborate with the Aston Fluids Research Group.

References

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[4] K. Patouillet and L. Davoust. Between no slip and free slip: A new boundary condition for the surface hydrodynamics of a molten metal. *Chem. Eng. Sci.*, 231:116328, 2021.

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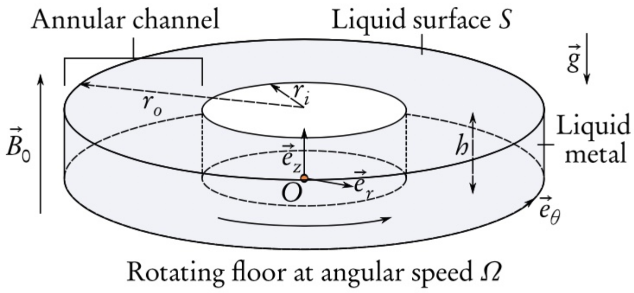
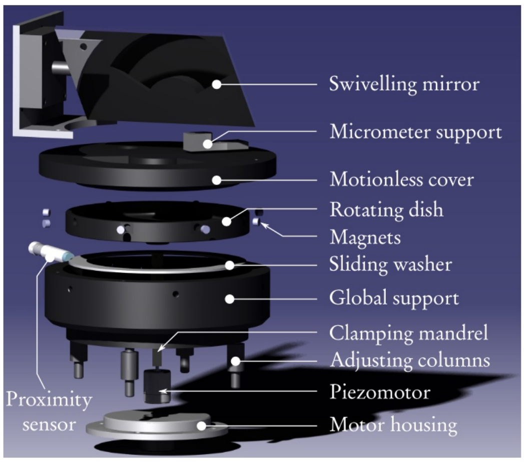
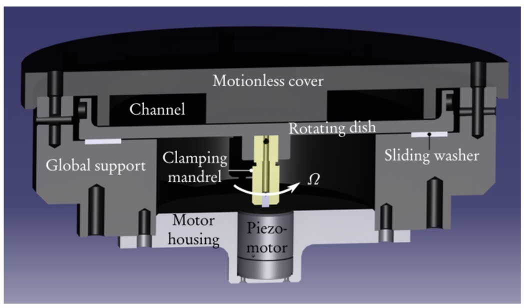


FIG. 1: End-driven annular MHD flow under consideration (inner radius: $r_i = 2.5$ cm, outer radius: $r_o = 6.5$ cm, depth: $h = 0.65$ cm).



(a)CAD view of the annular viscometer.



(b)Cross-sectional CAD view of the annular channel and the motor block.

FIG. 2: CAD views of the annular viscometer.