MHD liquid-metal-flow experiments and simulations for nuclear fusion applications

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Liquid metals are alternatives to solid reactor surfaces that offer advantages: self-healing properties, increased heat removal capacity, and improved particle recycling when operating with liquid lithium. Given the reactor heat fluxes, liquid metal divertors can only be achieved with a recirculating flowing LM divertor, causing liquid metal pileups due to high MHD drag and splashing. Design of LM divertors requires prediction of these flows. The Liquid Metal eXperiment - Upgrade (LMX-U) is a free-surface liquid-metal channel flow test loop at Princeton Plasma Physics Laboratory (PPPL). It is used to study flows under transverse magnetic fields to validate analytic models and numerical simulations. It operates with galinstan through a rectangular duct (10 cm wide x 100 cm long) under the effect of width-wise magnetic fields (0 - 0.33 T). Experimental results of free surface flows on LMX-U and comparisons to the state-of-the-art numerical MHD simulations are presented.

To understand MHD flows, experiments were performed with varying inlet height, flow rate, magnetic field strength, and wall conductivities. Experiments were run with chutes made from different materials: copper, stainless steel, brass, and acrylic. Observations are explained with simple analytical models. Different numerical simulation software was used to reproduce these experiments. The focus of these experiments was to quantify the MHD drag that causes liquid metal accumulation in the channel.

Given the issues identified with experiments at small magnetic flux densities, the operation fast-flow concepts are expected to encounter complications at the reactor scale. An alternative to the straight linear poloidal flow, the divertorlets concept consists adjacent narrow channels with direction-alternating liquid metal flow, separated by toroidally oriented slats. A single electrode drives external electric current in the radial direction and strategically placed conductors modify the current density in the liquid metal in every other channel. With a toroidal magnetic field, a Lorentz force (jxB) is generated in the liquid metal and drives the flow around the slats in a cyclical manner. The performance of a divertorlets prototype was tested against externally applied current and magnetic flux density in LMX-U. COMSOL simulations and analytical verification of results were used to validate experimental results and agreement between theory, simulations and experiments was attained. With the information collected, projections for operation of a divertorlets system at the reactor scale were calculated.

This study in the simulation validation is an essential first step to design free-surface liquid metal divertors in a complicated magnetic field environment for future reactors.

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