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Characterizing Liquid Metal Performance in Tokamak Plasma-Facing Components Through Lorentz Force-Applied Turbulent Channel Flow and Stuart Number Analysis

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Next-generation fusion reactors pose challenges for plasma-facing components (PFCs) made from solid materials due to the high heat and particle fluxes. To overcome these limitations, liquid-metal (LM) PFC concepts have been proposed recently, with electromagnetic restraint (Lorentz force) as a key mechanism to keep free-surface LM flows attached to reactor surfaces [1]. Therefore, the investigation of the potential of electromagnetic control for LM-PFCs is crucial.

The Stuart number, $\mathrm{St} = J0B0\ \delta/\rho * u\tau 2$, represents the relative strength of the Lorentz force compared to the inertia force in electromagnetohydrodynamic (EMHD) flows, where J0 and B0, represents the current, and magnetic flux density at the wall, respectively. While δ, ρ, and uτ are the half channel height, density of the fluid and wall shear velocity. Regarding the fluid used, the St number is influenced by the properties of the fluid, i.e, its electrical conductivity, magnetic permeability, and density. Liquid metals, which typically have high electrical conductivity and magnetic permeability, tend to exhibit higher St numbers.

This study investigates the behaviour of the liquid under the Lorentz force effect to determine optimal St numbers for selecting liquid metal as the LM-PFC in tokamak reactors. To achieve this, spanwise oscillated Lorentz force is applied to a turbulent channel flow. The Lorentz force is obtained by solving Maxwell Equations for appropriate boundary conditions. A range of St numbers are used between St = 18 to 72 (Fig. 1 (a)). The applied Lorentz force reduces skin friction, resulting in lower viscous effects (Fig. 1(b)), therefore provides insights into obtaining suitable LM fluid that attaches to the reactor surface. Entropy generations are also investigated (Fig. 1(c)). Therefore, the findings of this study contribute to the understanding of the controllability of LM-PFCs through the application of Lorentz force, which aids in the selection of suitable LM-PFC design, and implementation in next-generation fusion reactors.

Future studies will focus on optimizing the Lorentz force parameters for LM-PFCs and conducting stability analyses that aim to enhance heat transfer efficiency and reliability of LM-PFC configurations in fusion reactors.

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