Tommaso CARLESI PhD Thesis
Abstract

Development of an advanced experimental technique for the measurement of the turbulent heat flux in liquid metals

By Tommaso CARLESI

Supervisor: Prof. Patrice MEGRET, UMONS

Co-supervisor: Prof. Delphine LABOUREUR, Von Karman Institute for Fluid Dynamics (BE)

One of the main challenges today is meeting the global energy demand while pursuing the carbon neutrality goals set by the Paris Agreement (COP21). Several successful energy scenarios by the International Energy Agency (IEA) depend on expanding the role of nuclear energy in electricity generation, which inherently increases nuclear waste production. A promising approach to address this challenge is nuclear waste transmutation, achievable through advanced fourth-generation reactors. A leading project in this field is MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications), a pool-type, fast-spectrum research reactor being developed at the Belgian nuclear research center, SCK CEN. MYRRHA employs lead-bismuth eutectic (LBE) as its primary coolant, which contributes to both its safety and operational efficiency.

Currently, the thermohydraulic behavior and modeling of liquid metals like LBE remain uncertain, especially in low-velocity regimes such as mixed and natural convection, which correspond to the accident conditions of the reactor. Addressing this issue requires accurately estimating the turbulent heat flux, which represents the heat transfer due to turbulence characterized by fast fluctuations of temperature and velocity in the fluid. While numerical simulations provide reliable estimates for fluids like water or air, validation data for low-Prandtl-number fluids, such as liquid metals, remain scarce. Consequently, new experiments are essential to establish a reference database for model validation. This PhD project thus aims to develop an advanced experimental technique capable of simultaneously measuring velocity and temperature fluctuations, i.e., the turbulent heat flux, in liquid metals.

Ultrasound Doppler Velocimetry (UDV) and Hot Film Anemometry (HFA) were selected for velocity measurements, while sheathed type K thermocouples (TC) and fiber Bragg gratings (FBGs) were used for temperature measurements. After initial calibration and characterization tests in liquid metals, these measurement techniques were applied in a differentially heated cavity used as a natural convection setup. The experimental results generally reached a good agreement with RANS and DNS simulations in terms of average fields for both fluids used, water and Galinstan. Nevertheless, velocity fluctuation measurements in Galinstan presented significant challenges, yielding results that reflect such uncertainties and limited the feasibility of directly quantifying turbulent heat flux values. Despite this, the experimental and numerical findings in this study provide valuable insights into the characteristic trends of liquid metal flows under natural convection conditions.