THERMIC: Revolutionizing Heat Transfer with Two-Phase Flows

Heat transfer is fundamental to our daily lives and countless industries, from warming our homes to cooling powerful electronic devices and even managing temperatures in spacecraft. Traditionally, heat is moved using liquids that remain in their fluid state, relying on basic processes like conduction and convection. However, a far more efficient method involves "phase change" – where a liquid turns into a gas (evaporation) or a gas condenses back into a liquid (condensation). This allows for the transfer of not only regular heat (sensible heat) but also a massive amount of "latent heat" absorbed or released during the phase transition, making these two-phase systems exceptionally powerful.

Despite their superior efficiency, two-phase systems, especially in tiny channels called capillaries, present complex challenges. Factors usually deemed negligible in simpler systems, such as the microscopic roughness of channel walls or external forces like gravity and centrifugal force, become critically important. These influences can unpredictably alter fluid flow and heat transfer. For instance, external forces act differently on liquids and gases due to their varied densities, potentially disrupting the flow structure and affecting performance. Meanwhile, channel roughness impacts flow resistance, the available surface area for heat transfer, and surface tension—all crucial for efficient phase change. Understanding these rapid, dynamic processes in small channels is difficult and not yet fully mastered.

The THERMIC project directly addresses these challenges with a cutting-edge experimental setup. We design transparent sections made from hardened glass, integrated with stainless steel heat exchanger cores. These cores are precisely shaped using advanced metal 3D printing technology, allowing us to meticulously control the microscopic surface features (roughness) of the channels. This innovative manufacturing enables us to study how even tiny imperfections affect fluid flow and heat transfer. Fluid movement within our system will be naturally driven by capillary action and heating.

To accurately observe these complex behaviors, we'll employ high-speed cameras, capturing detailed fluid dynamics during evaporation, condensation, and various flow patterns. A key innovation is the integration of advanced fiber-optic sensors directly into the 3D-printed channels. These sensors will precisely measure temperature distribution in real time, even while the entire experimental setup is rotating. Data will be collected wirelessly, ensuring continuous tracking of thermodynamic changes during motion.

Our experiments will unfold in two main stages: first, stationary studies at Wrocław University of Science and Technology, providing baseline data. Then, a crucial rotational phase will take place at the Center of Applied Space Technology and Microgravity (ZARM) in Bremen, Germany. There, the Large Diameter Centrifuge (LDC) will simulate extreme conditions by generating centrifugal forces up to 10 times greater than Earth's gravity, allowing us to understand how these conditions impact two-phase flow and heat transfer.

All the vast data collected from both these experiments and parallel computer simulations will be organized and stored in a modern, open-access database. This standardized information will be made available to other researchers globally, serving as a rich resource for future studies. By analyzing this extensive dataset, particularly with the help of artificial intelligence (AI) and machine learning (ML) algorithms, we aim to uncover hidden insights, predict system performance, and ultimately pave the way for designing next-generation, highly efficient thermal management systems for diverse applications—from cooling high-performance electronics to advanced space technology.