Project FORTE - Nuclear Thermal Hydraulics R&D for BEIS

Single-Phase Natural Convection

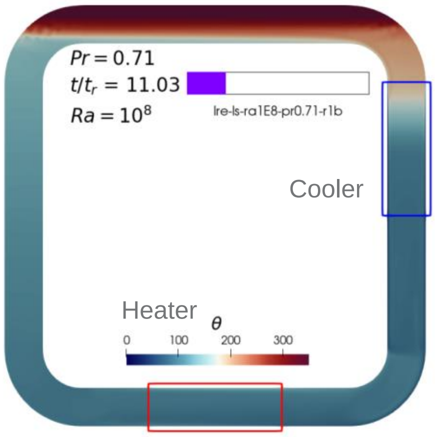
THE CHALLENGE

The design and incorporation of effective passive cooling systems into current and next-generation nuclear reactor designs forms a crucial element in the ongoing effort to ensure the safe and reliable operation of Nuclear Power Plants. For example in the AP1000, a circulation loop attached to the primary coolant circuit exploits natural convection to transport hot fluid from the core to a secondary heat sink elsewhere in the plant. Most experimental studies of such systems have, however, focused on providing integral parameters, correlations or stability analyses, whilst numerical studies are largely carried out using one-dimensional system codes. The application of advanced, multi-dimensional computational tools to these systems will thus be central in driving advanced model development and providing improvements in understanding.

OUR SOLUTION

Our research aims to perform a series of detailed, exploratory numerical simulations into both the transient and steady-state behaviour of natural circulation loops, across a range of relevant parameters and geometric configurations. We have designed a loop which is both simple enough to enable efficient computation using modern numerical approaches (Reynolds-Averaged Navier-Stokes and Large Eddy Simulation CFD) and relevant enough to provide crucial insight into how the resulting flow might affect passive cooling performance. The outline of the technical approach can be summarised as:

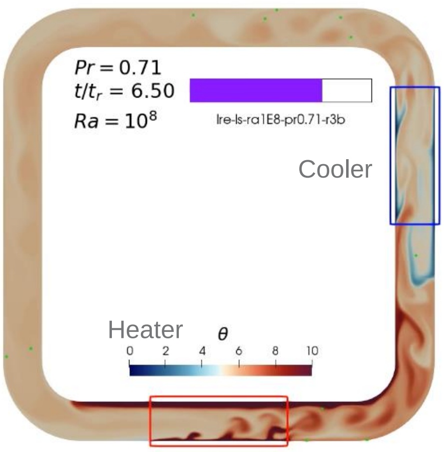
- Conduct a series of exploratory, transient 2D numerical simulations to investigate the effect of:
  - A range of different thermal boundary conditions - the relative strength of the driving buoyancy forces;
  - Different initial thermal conditions - the temperature of the fluid in the loop compared to the source or sink; and
  - Loop geometry - specifically, the aspect ratio of the loop.
- Comparison against high-fidelity, 3D Large Eddy Simulations with our partners at the Science and Technology Facilities Council.



Stratification in a natural convection loop

OUR INNOVATION

By solving our initial exploratory simulations in 2D, we are able to explore a wide range of influential parameters relatively quickly and economically, whilst still capturing the relevant flow physics. This increased efficiency by selecting only the most relevant and most fertile cases for further investigation using the more expensive, but higher fidelity, Large Eddy Simulation. The data that these simulations provide will then enable targeted and innovative routes for model development to be identified.



Complex transient behaviour in a natural convection loop

THE BENEFITS

This research program leads to several key direct outcomes. First, the results will aid and improve our understanding of how the various flow and geometric parameters within a natural circulation loop influence its behaviour, and thus the expected passive cooling performance.

Second, the complex and highly transient nature of the flow serves to highlight scenarios which might not be adequately captured by commonly employed numerical methodologies within the nuclear thermal hydraulics community. A number of journal papers and conference presentations will be produced and it is expected that the high-fidelity data and insight these results provide will help drive further 2D and 3D model development.

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