SAMOSAFER

Natural Circulation Experiment for Study of Fluid Stability

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Context of the work

Main Objectives of the PhD work

- The development of a numerical methodology capable of performing a thorough stability analysis of natural circulation systems.

- Use of a base case to perform a proof of principle of the methodology.

- Design and construction of a natural circulation experiment and comparison with numerical results for verification of the developed methodology.

Design of a Natural Circulation Experiment

- The main objective of the experiment is to provide a set of dedicated results regarding the behavior of a natural circulation system that allows to both evaluate the performance and the predicting capabilities of the developed numerical tool and to extend the understanding of the underlaying phenomena.

Experimental Design

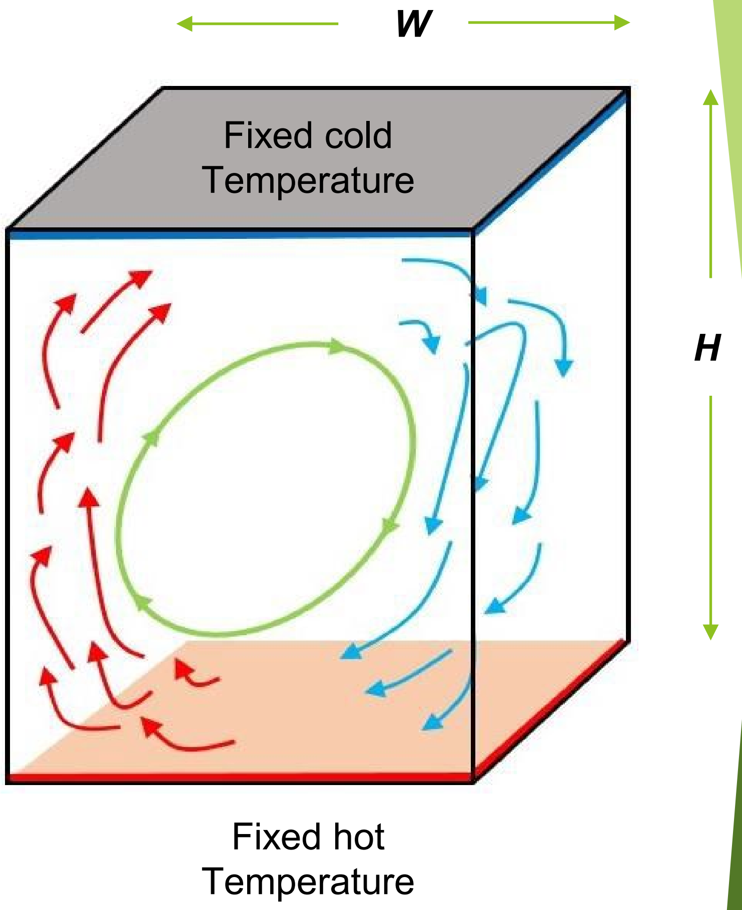
Experimental Design - Requirements

The experiment has been designed according to the following requirements:

- Avoid turbulent and highly 3D dynamic flow (to simplify the numerical modeling effort and decrease the uncertainties of the measurements)
- Exhibit a sufficiently large amount of different dynamic states that allow for a full validation of the proposed methodology
- Allow for the investigate of one of the intrinsic phenomena present in molten salts: volumetric heat source
- Allow for flow field measurements for characterization of the dynamic of the system (such as PIV)
- Ensure adequate control of boundary conditions (heat losses, temperatures at walls, etc.)

Experimental Design – Configuration selection

- During the numerical development stage of the project, the configuration known as the Rayleigh-Bénard convection case was largely studied.
- This type of convection is obtained when a body of fluid is contained within a heat sink and a heat source at the bottom and top boundaries respectively.
- Rich dynamic behavior without resorting to complex geometries or power provision mechanisms.



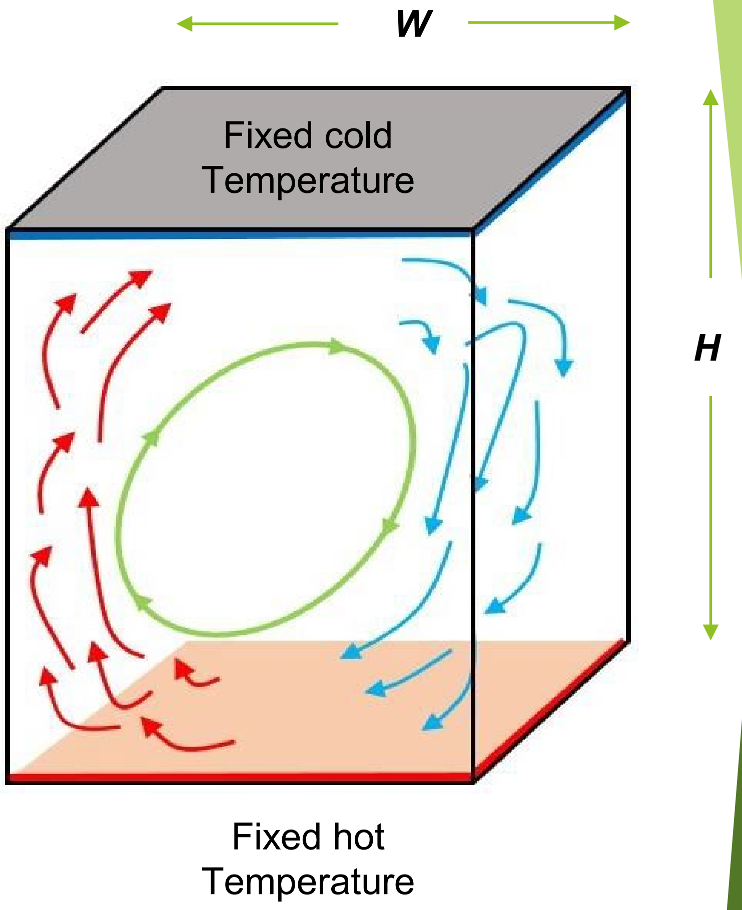
Rayleigh-Bénard convection case

Experimental Design – Configuration selection

- In a RB convection case the number of circulation cells depends on the Rayleigh Number (Ra) and the aspect ratio (A).

$$Ra = \frac{g\beta\Delta T L^3 Pr}{v^2} \qquad A = H/W$$

- With the increase of temperature difference between the boundaries, a dynamic behavior starts to arise, namely in the form of circulation cells. The number and size of these cells is dependent on the temperature difference.
- Additional provisions could make this case suitable for an experimental application.

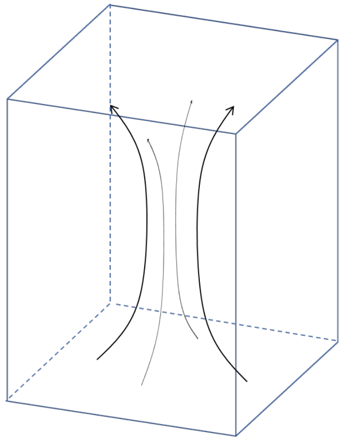


Rayleigh-Bénard convection case

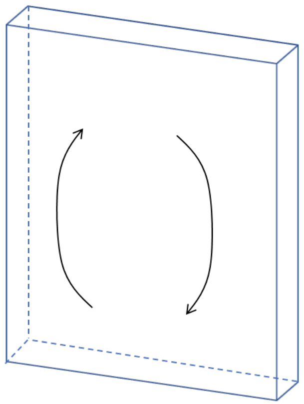
Experimental Design – Configuration selection

- Flat-cavity geometry to:
  - Ensure flow laminar behavior while having sufficiently buoyancy force,
  - Allow for an experimental simulation of a volumetric heat through a heat input at the walls,
  - Allow for PIV measurements.
- Transparent materials and conventional fluids for optical measurements (PIV)
- Heat input through backwall to simulate an internal distributed heat source
- Allow for use of different coolants to extend the range of operational conditions
- Work near room temperature conditions to decrease heat losses

Standard Geometry



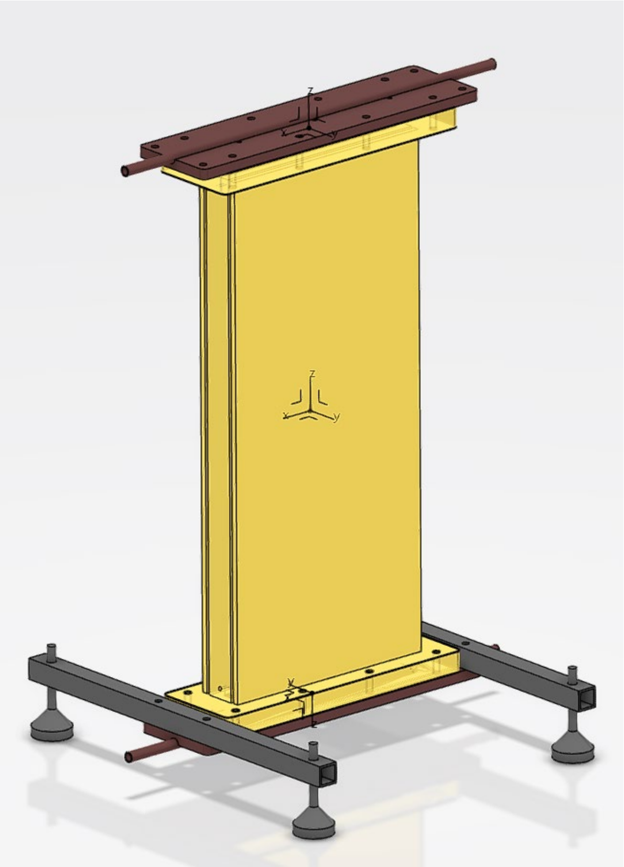
Flat Geometry



Experimental Setup

Experimental Configuration

- Flat-cavity geometry of 400 x 200 x 10 mm.
- Three main structural components: a main central frame and two heat exchange sections. Additional supports for fixing position.
- The main central section provides the overall structure of the experiment
- Built with a transparent acrylic material (PMMA)
- Open at top and bottom and fitted with flanges to be able to fix to the remaining sections.
- Provided with openings in one side to access the inside of the cavity.



Sketch of the final design of the natural circulation experiment

Experimental Configuration

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- Three main structural components: a main central frame and two heat exchange sections. Additional supports for fixing position.
- The main central section provides the overall structure of the experiment
- Built with a transparent acrylic material (PMMA)
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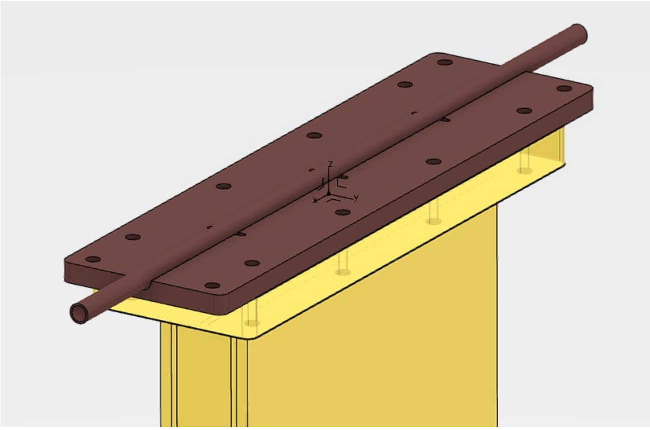
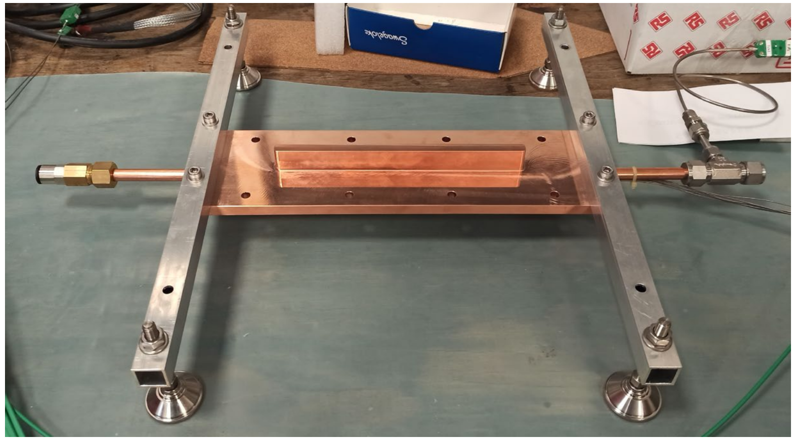
- Provided with openings in one side to access the inside of the cavity.

Experimental Configuration

- The heat exchange sections are identical
- Attached at top and bottom faces respectively
- Built in copper for temperature homogeneity
- Fitted to attach both the main acrylic frame and necessary supports.
- Equipped with a copper tube to provide the temperature control mechanism



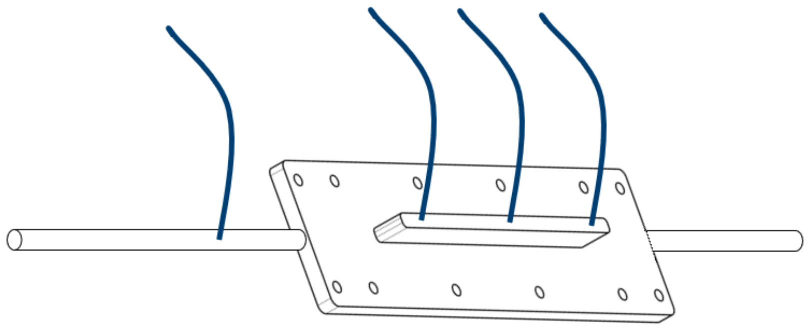
Sketch of the heat exchange section



Heat exchange sections with the attached supports

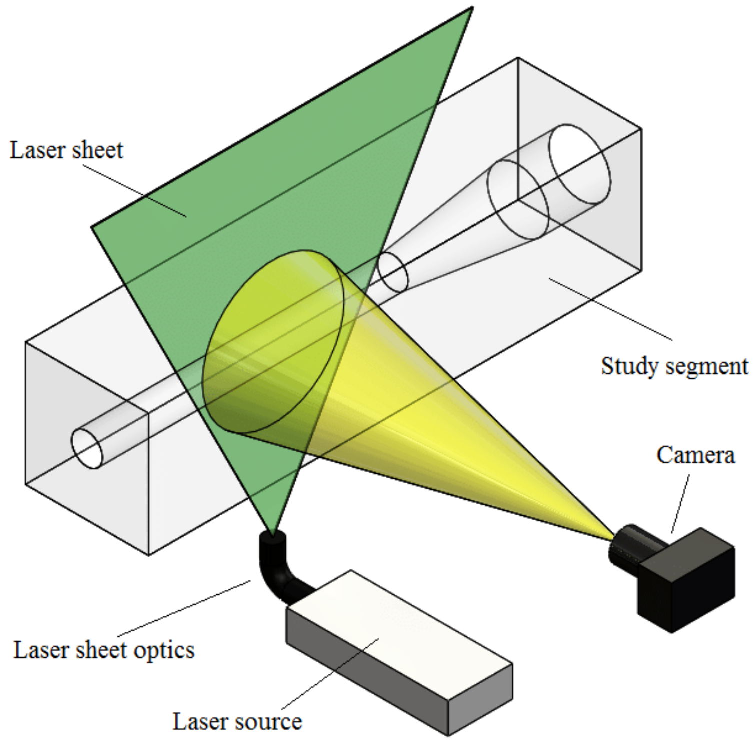
Experimental Configuration – Instrumentation

- The temperature of the setup is monitored at different points of interests. Thermocouples type-K are connected to an acquisition chain to have an online reading:
  - In the interior of the copper sections, to ensure a proper uniformity in the boundary conditions
  - At the entrance of each water loop, to verify its proper performance
  - In the room to estimate the interaction with the environment.
- These measurements are meant for monitoring the correct performance of the experiment but are not sufficient to characterize the dynamic behavior of the system



Experimental Configuration – Instrumentation

- To characterize the dynamic behavior of the system, a measurement of a field variable in the extension of the cavity is required
- For these purposes Particle Image Velocimetry (PIV) is selected as the preferred method:
  - Solid particles are suspended in the bulk of the fluid
  - A pulsed laser is used to highlight the suspended
  - In the room to estimate the interaction with the environment.
- To characterize the dynamic behavior of the system, a measurement of a field variable in the extension of the cavity is required

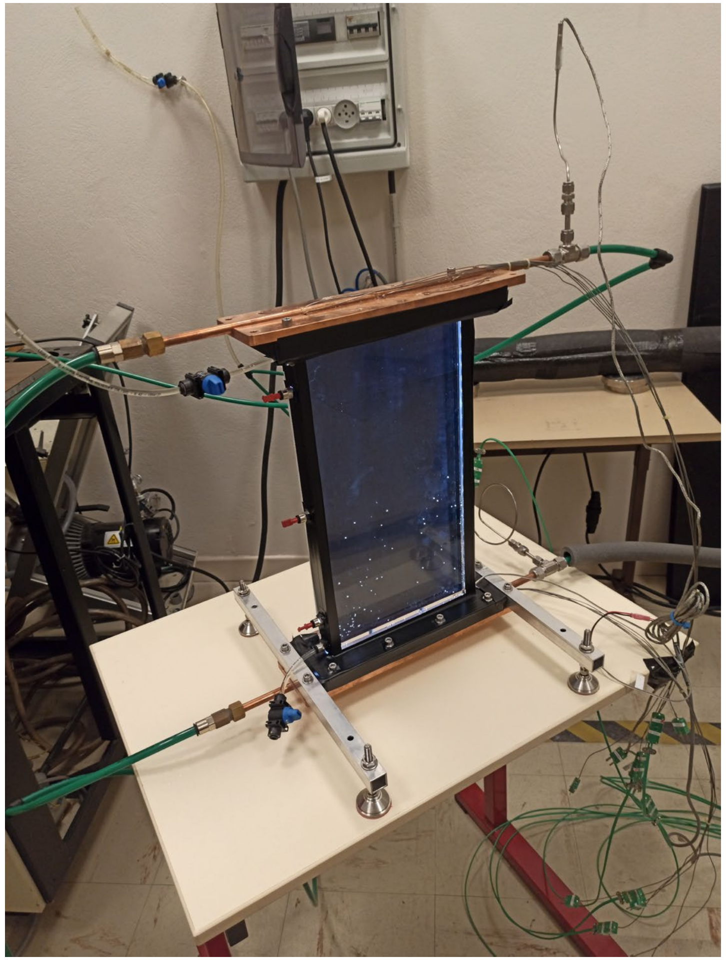


Experimental Configuration – Operational Conditions

- The goal of the experiment is to obtain a series of different flow patterns within the range of operational conditions.
- This can be achieved covering a range of different Ra number

$$Ra = GrPr = \frac{g\beta\Delta T L^3 Pr}{\upsilon^2}$$

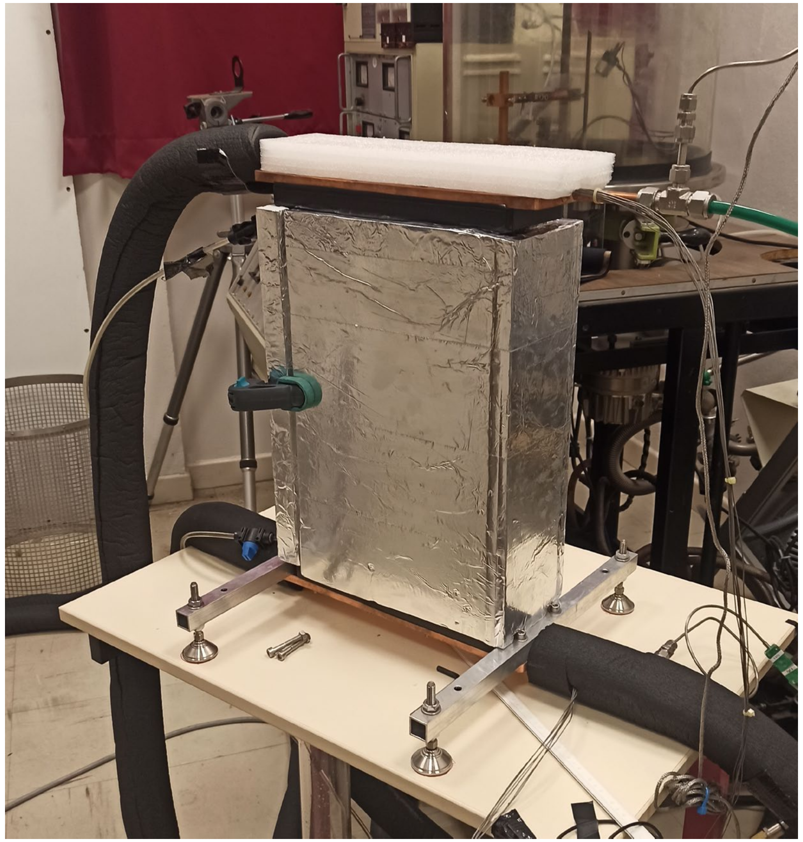
- The variables used for these purposes are:
  - The temperature difference, imposed by adjusting the temperature in our heated sections
  - The properties of the fluid. The use of water, glycerol and different mixtures would allow to obtain a wide range of Ra numbers for the same temperature difference



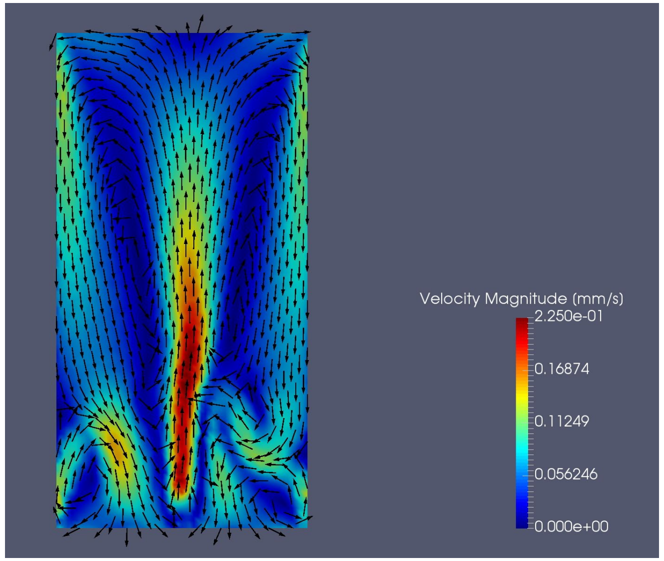
Results

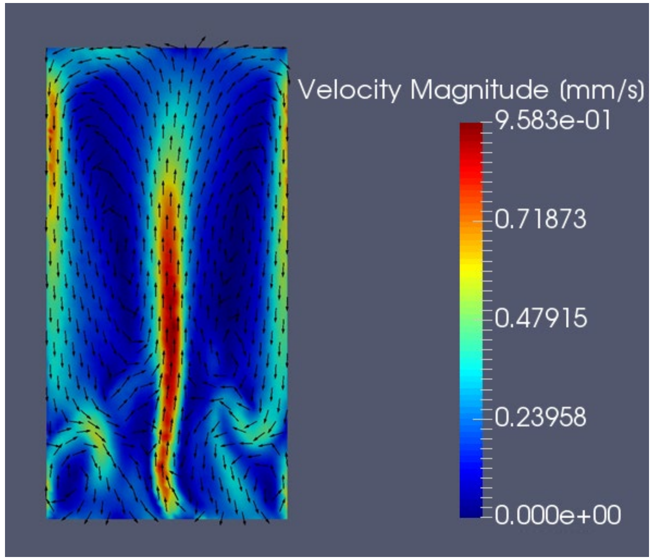
Experimental Results

- Discrepancies were found between the numerical results obtained through simulations and the experimental measurements.
- Some effects initially disregarded have impact in the final experimental configuration, as being a temperature dependence of the viscosity and a significant thermal interaction with the environment.
- Mitigating measures were applied to account for these effects, as well as improvements in the numerical model to capture this phenomena.

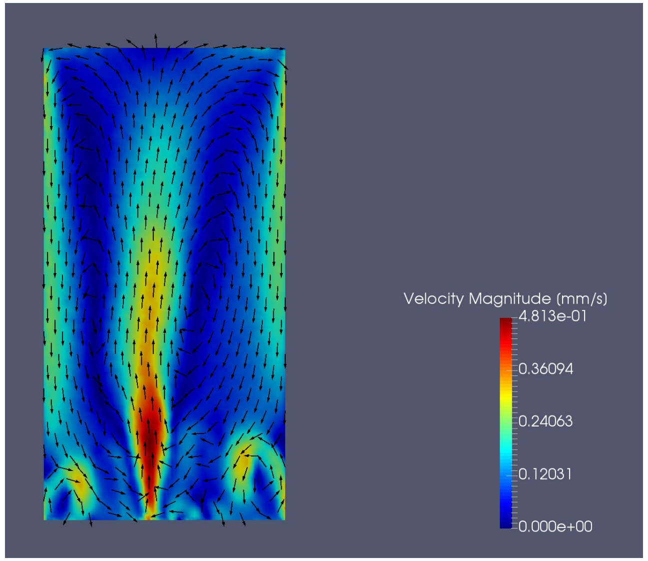


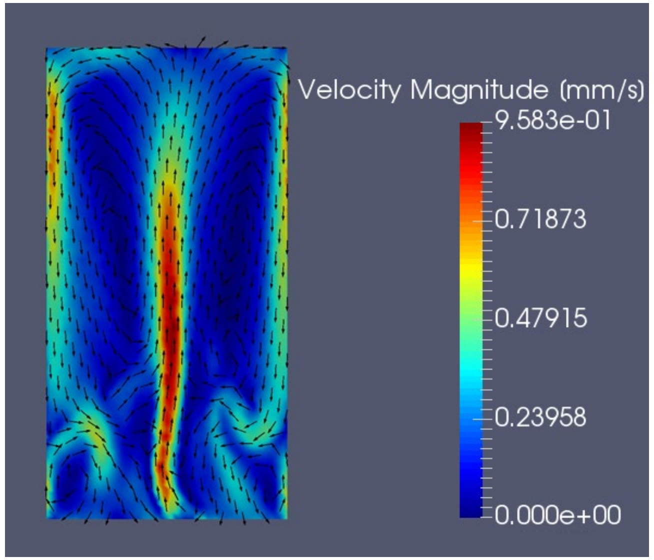
Setup of the natural circulation experiment with additional thermal insulation



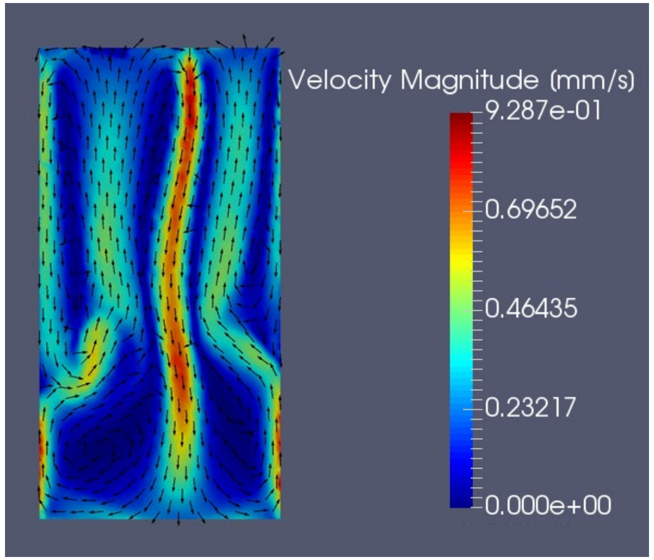


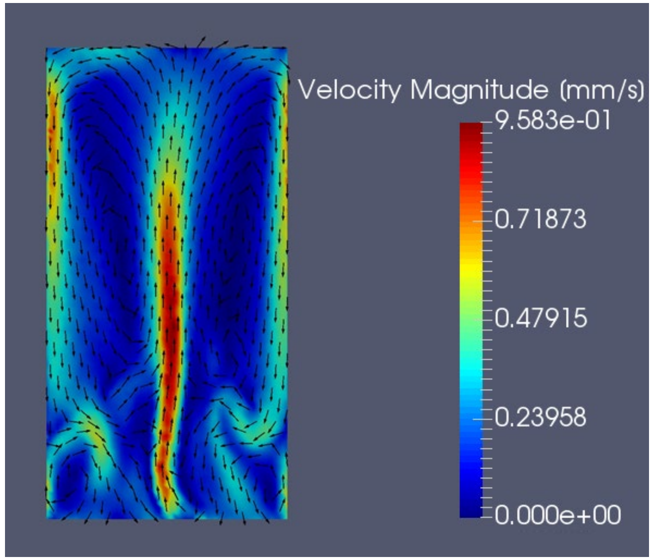
Experimental measurements showing the reproducibility of flow patterns for different working fluids
Pure Glycerol (left) and Mixture of Glycerol-Water 55-45% (right) with a ΔT = 14°C.



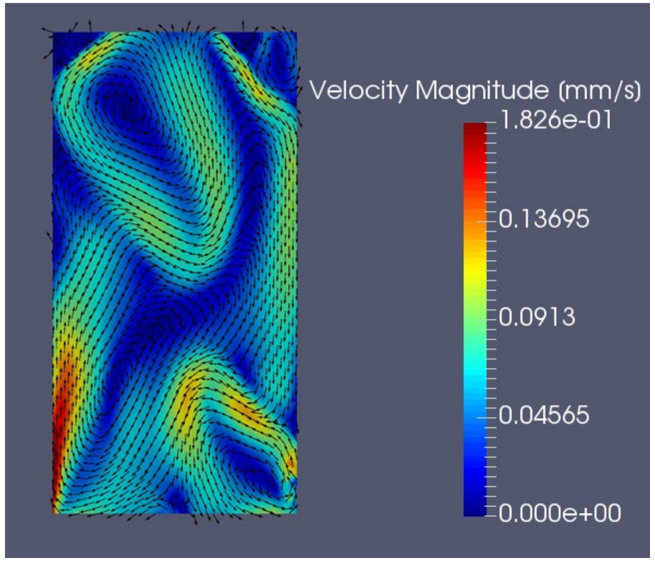


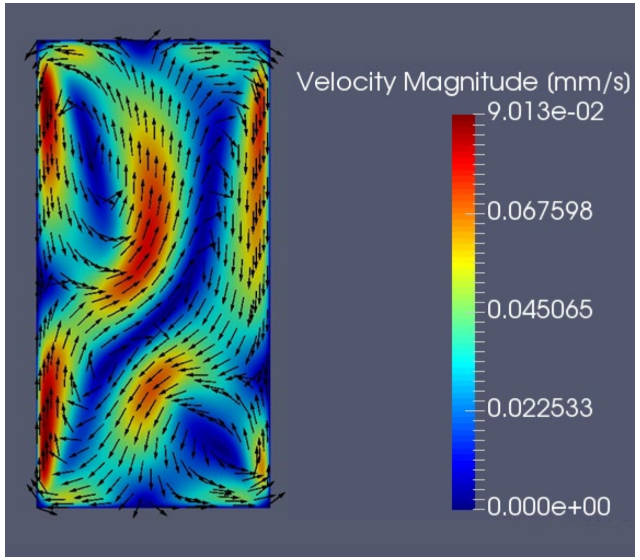
Experimental measurements showing a low dependance of the temperature difference for cases of ΔT = 6°C (left) and ΔT = 14°C (right).





Experimental measurements. Mixture of Glycerol-Water (55-45%) of with a ΔT = 14°C, with the room temperature equal to the average (left) and 2°C below the average (right).





Experimental measurements (left) and numerical results (right) of a case using pure Glycerol with a temperature difference of ΔT = 14°C.

Conclusions

- An natural circulation experiment was design, constructed and operated based on the developed numerical tool.
- Initial discrepancies with the expected results were founded, identifying possible sources and applying mitigating measures, as well as an improvement of the numerical models, allowing to obtain a closer resemblance between numerical and experimental results.
- An additional configuration using a surface heat source to emulate the internal heat generation of a molten salt is under study.

Thank you for your attention