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Experimental analysis of natural convection in a differentially heated cavity

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Abstract— **Turbulent heat fluxes (THFs) estimation is of paramount importance in the determination of heat transfer in fluids. Numerical models for low Prandtl number fluids are still unreliable and their experimental evaluation is a challenging task since it requires simultaneous measurement of fast velocity and temperature fluctuations. In nuclear applications, a better understanding of THFs in liquid metals could lead to more precise predictions of the primary coolant temperature for the evaluation of nominal operation (forced convection regime) and accidental conditions (mixed and/or natural convection regime). The first part of this work focuses on the selection of the measurement techniques suitable for water, GaInSn and LBE and the thorough literature review required. Tests in different setups led to the choice of sheathed type K thermocouples and fiber Bragg gratings for temperature measurements and Ultrasound Doppler Velocimetry and Hot Wire Anemometry for velocity measurements. The comparison carried out among the different techniques underlines advantages and limitations of each of them. Calibration of each technique is performed and cross-effects of temperature and velocity are evaluated. Uncertainty analyses are also carried out. To conclude, first results obtained in a differentially heated cavity made of stainless steel 316L with an edge of 60 mm are presented. DNS numerical simulations are performed to know the ranges of the quantities to be measured and to have results available for comparison with experiments.**

Keywords **—Natural Convection, Differentially Heated Cavity, Turbulent Heat Flux, Nuclear Power Reactors and Nuclear Fuel Cycle**

I. INTRODUCTION

One of the biggest challenges to be faced nowadays is to fulfill the increasing energy demand while meeting the requirements of carbon neutrality imposed by the Paris agreement [1]. Most of the successful scenarios foreseen by the International Energy Agency see an increase in the use of nuclear energy for electricity production [2] and consequently in the amount of nuclear waste to be treated. To tackle the waste problem, transmutation performed in generation-IV nuclear reactor systems seems a valuable solution.

This paper is conceived in the framework of the design and construction of such a system: MYRRHA (Multi-purpose hYbrid Research Reactor for High-tech Applications), a pool-type fast-spectrum research reactor under design at SCK CEN (the Belgian nuclear research center). In particular, this work aims at the understanding of the thermal hydraulic behavior of its primary coolant, the liquid metal Lead Bismuth Eutectic (LBE). For the design and safety evaluation of MYRRHA, the temperature of the primary coolant and of the reactor core components must be predicted in nominal operation (forced convection regime) as well as in accidental conditions (mixed and/or natural convection regime). For this assessment, the turbulent heat flux (THF) as it appears in the Reynolds Averaged Navier-Stokes equations (RANS) is a term of paramount importance. It describes the convective heat transfer mechanism related to fast and simultaneous turbulent fluctuations of the local fluid velocity (U) and temperature (T). Their evaluation is usually performed with a combination of numerical simulations and experiments [3], leading to the availability of reliable numerical models for common fluids like water or air. On the other hand, for lower Pr number fluids (e.g. liquid metals) the available validation data are still scarce and unreliable, especially in the natural convection regime and therefore new experiments are needed for the development of numerical models [4,5,6].

Measurement of THF is challenging as it requires simultaneous measurement of velocity and temperature fluctuations. Some attempts have been made in air over a vertical backward facing step with Laser Doppler Velocimetry (LDV) and cold wire anemometry, used to measure the velocity and temperature fluctuations respectively [7]. Other papers address the same issue in water, performing measurements of the turbulent natural convection boundary layer on a vertical plate using hot films and thermocouples [8] or in a closed cavity with an isothermal wall using Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) [9]. Despite of the difficulties already encountered in these works, these campaigns do not present the additional challenges that must be faced in liquid metals (LMs), especially with respect to high temperatures, opacity and material compatibility. Nowadays techniques for the individual measurement of velocities and temperatures in LMs exist but simultaneous and fast measurements of these two quantities in such environment have not been published yet. In fact, most of the work addressing liquid metal measurements are focused on average quantities [10], finding correlations in a particular setup [11] or large-scale dynamics [12].

An application more similar to the current project is the turbulence measurement performed in Galinstan (GaInSn) in a non-isothermal vertical confined backward facing step [13]. Both forced and mixed convection regimes have been studied. Velocity measurements have been performed with a newly developed Permanent Magnet Probe (PMP) probe while temperature measurements, useful also for velocity corrections, have been made with standard type K thermocouples. Despite of the high acquisition frequency (5000 Hz with a cutoff frequency of 200 Hz), a full turbulent heat flux measurement has not been performed because the probes were sampled by two different measuring systems. For this reason, synchronization of the two measurements was impossible to achieve and consequently only first order statistics have been calculated.

In this context, the focus of this Ph.D. is twofold:

- Develop a turbulent heat flux sensor (THFS) suitable for THF measurements in liquid metals (EPICURUS, ExPerImental teChnique for tURbUlence in liquid metalS)
- Provide reference data for the development and validation of numerical models for THF in liquid metals

The present paper will give an overview of the selection of the techniques for the measurement of temperature and velocity and will focus on the description of the experimental setup presenting and discussing the first results obtained in differentially heated cavity with water as working fluid.

II. Methods

This section describes the methodology adopted in the paper, starting with a description of the requirements of the sensors and the consequent choices made. At the end, a description of the experimental setup is carried out.

A. Requirements of the sensors

The selected sensors must satisfy specific requirements in terms of spatial and temporal resolution, temperature and velocity measurement range and capability of withstanding high temperature and corrosive environment. All these characteristics are summarized in Fig.1 and translated in physical specifications that the sensor must meet.

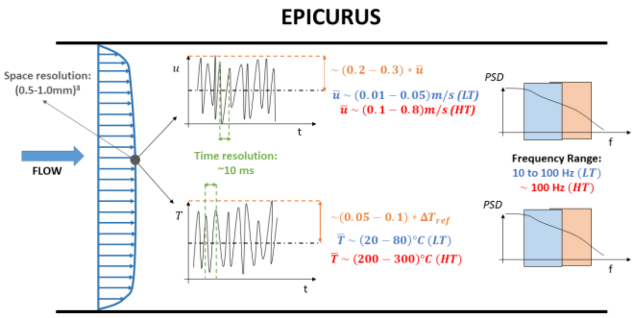

Figure 1 - Sensor requirements with distinction of the low temperature and high temperature cases of the Ph.D. project

Many of these choices are intrinsically related to the physics of the liquid metals. As the experiments presented in this report utilize water, the emphasis of this section will be on discussing the sensor characteristics that are applicable to its use in water. On the other hand, GaInSn experiments are also part of the Low Temperature (LT) phase of the project, therefore the more strict sensor requirements given by the liquid metals are also considered.

The temperature and velocity range needed by the sensor is determined by the characteristics of the turbulent fluctuations. In particular, the natural convection flow regime establishes the oscillations frequencies in the order of 10-100 Hz [9,14,15,16,17] increasing for lower Pr number.

Requirements for water are generally less strict but typical sampling frequencies found in literature for turbulence measurements are in the range 1-95 Hz [9,16,17] and for this reason liquid metals constraints are still taken as a reference here. As a consequence, very strict time response requirements are established for the sensor (ideally lower than 10 ms) to be able to follow the fluctuations even in the fastest case. In general, this will translate in a small dimension of the sensor itself meeting also the constraints given by the spatial resolution. To avoid aliasing effects and alter the frequency content of the signal, it is also advisable to set the target frequency as double of the frequency of the physical phenomenon. Nevertheless, this issue does not affect the time signal, which is of primary interest in this work.

At the same time, an appropriate acquisition system must be chosen. As a rule of thumb, the acquisition frequency should be roughly 10 times higher than the target frequency. A wise choice of commercial systems available on the market should be sufficient in this sense.

In general, the requirements on sensor response time are supposed to be less strict in the LT phase of the project than in the HT. Nevertheless, it is important to consider that every coating or adaptation of the sensor to high temperature is expected to increase its dimension and consequently its response time.

Similar considerations are valid for the velocity magnitude range. Most probable velocities in natural convection are expected in the range of cm/s in GaInSn [18] and mm/s [19] in water. Table 1 reports a summary of the fluctuations characteristics retrieved from the DNS simulation in GaInSn [18].

Table 1 - Fluctuations characteristics

Variable	Max Frequency	Amplitude
Temperature	60 Hz	15%
Velocity	30Hz	16%

In the experiments presented in this paper, the use of water as working fluid could lead to lower fluctuations amplitudes (for a given Gr number) that might be more challenging to be measured.

The smallest scale of the turbulence that is interesting to measure determines the spatial resolution needed. In terms of instrumentation, this is directly related to the size of the sensor. The Kolmogorov scale has been estimated to be in the order of

10μm for GaInSn in natural convection [18] and it is reasonable to think that a similar value can be obtained also in the LBE setup. These values are far smaller than the best achievable with experiments. Moreover, it is not meaningful to reach such small scales since no useful information about the dissipation rate could be deduced anyway. For this reason, numerical results and literature studies suggest that the best compromise would be to resolve turbulent structures with a 1 cm dimension meaning that the probes should have a spatial resolution in the order of 0.5-1mm. Once again, liquid metals requirements are taken as a reference also for water experiments.

B. Choice and characterization of the sensors

According to the requirements expressed in the previous Section, some suitable measurement techniques were selected.
Regarding the velocity measurements, optical techniques like PIV or LDV were discarded because of the opacity of liquid metals and therefore the lack of optical access in the setup even for the water phase of the experiments. Other techniques like LFV, CIFT, X-ray or neutron imaging were also discarded mostly for their scarce spatial or temporal resolution. Among the more reasonable techniques considered, the Pitot tube was considered not suitable for the measurements, mainly for a matter of spatial resolution and instrusivity in the flow. Indeed, is hard to keep the probe smaller than 1 mm

The **Hot Wire Anwmometry (HW)** and the **Ultrasound Doppler Velocimetry (UDV**) were both selected for the project. The former has proved to give very good performances when measuring turbulence and applications in liquid metals (even if not very recent) have been found in literature [20]. The intrusiveness given by the support and the prongs can be overcome with an accurate design of the facility and does not really affect the spatial resolution that is instead given by the dimensions of the wire. The probe was purchased by DANTEC and its main characteristic is to have the sensitive part (a nickel film smaller than 1μm) sputtered around a core in quartz and covered by another quartz layer that ensures electrical insulation and protection.

The UDV has proven to be one of the best technique for velocity measurements when optical access is not available. For this reason, its use in liquid metals is strongly supported by many literature studies [21, 22, 23]. Moreover, the maximum axial spatial resolution of the chosen commercial sensor by Signal Processing is 0.126mm while its volumetric spatial resolution depends on the aperture of the US cone and therefore on the emitting frequency. The temporal resolution can arrive up to few ms. The main limitations will be given by low velocities and working environment and cannot be precisely predicted before. Despite of that, there is no reason to think that they cannot be overcome.

Regarding temperature measurement techniques, **thermocouples** have been used in liquid metals for years and often with good results. Despite the difficulty of finding the best type, there is no reason why they should not be tested in GaInSn and LBE. For GaInSn and water measurements, a sheathed K-type thermocouple with a predicted time response around 30 ms will be tested [24]. The HBM QuantumX MX440B acquisition system was chosen allowing acquisition frequencies up to 5000 Hz thanks to its integrated cold junction compensation.

Fiber Bragg Gratings (FBGs) were also selected for temperature measurements. Preliminary tests [24,25] showed that the time response of bare FBGs could be even better than the one of unsheathed standard K-type thermocouples presenting similar dimensions and therefore intrusiveness and spatial resolution. Another big advantage is that, being made of glass, no particular problem should arise in terms of chemical corrosion in the liquid metal stages. Moreover, applications of coated FBGs up to 500 °C is reported in literature and acquisition frequencies in the order of 1000 Hz are possible with the BaySpec interrogator. Once again it is important to underline that the above mentioned techniques can also be adapted to LBE to withstand the higher temperatures and the chemical corrosion.

C. Experimental setup

In this section, a detailed description of the experimental setup used for the investigation is provided, including some design choices and some procedures followed for its usage. By understanding the experimental setup, we can better interpret and analyze the results obtained from the experiments and draw meaningful conclusions about the behavior of the system under study.

Natural convection was chosen as flow regime to be focused on this first stage, not only because the turbulent frequencies are lower and the facility will be easier to operate [26] but mostly because validated turbulence models for natural convection are not available and experimental data for this flow regime are strongly needed.

Because most of the studies in literature focus on the Rayleigh-Bénard convection [18, 27, 28, 29] the differentially heated cavity setup was chosen for the purpose of this experiment to fill this knowledge gap. A schematic of the setup is shown in Fig. 2.

In differentially heated cavities, a constant temperature difference is maintained between two opposite side walls while all other sides of the cavity are insulated, i.e. ideally adiabatic. This configuration usually gives a flow with similar characteristics to the isothermal vertical plate on its active walls and for this reason it is also called vertical convection (VC) [11] Inside the cavity, the imposed temperature difference triggers a natural convection loop rotating in the direction from the warmer side towards the colder side [30]. The main features of the flow change according to the working fluid but in all cases the main non-dimensional parameters that control the flow and the turbulence phenomena inside the cavity are the Prandtl number (Pr), the Grashof number (Gr) and the Rayleigh number (Ra = Gr*Pr).

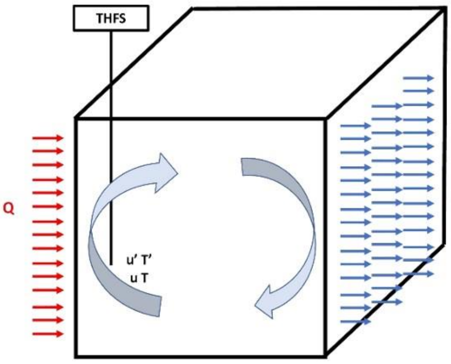

Figure 2 - Differentially heated cavity used as experimental setup for the experiments

In particular, increasing the Gr (Ra) number promotes instabilities leading to fully turbulent flows. Previous studies have shown a critical Grashof number of about 10^8 where the transition to turbulence in buoyant flows in cavities is expected [15,27]. Other studies place the transition further, e.g. Ra from 10^{12} to 10^{14} [8].

The tests performed for this project were conducted in a cubic cavity made of 316L steel with an (inner) edge of 60 mm. The thickness of the walls was 10 mm.

Inside natural convection was established through heated/cooled Peltier elements from Laird Thermal Systems capable of reaching a maximum heating power of 800 W and a maximum cooling power of 300 Wsupplied by an EA-PSI 9000 2U. Full power was not required for the purpose of this experiment. The two elements were positioned oppositely on each side of the cavity in contact with two copper walls inserted in place holders in the cavity.

The copper walls were coated with a 1µm carbon coating deposited through magnetron sputtering at the University of Namur to ensure material compatibility during future tests with liquid metals.

Two fans were added in contact with the Peltier elements to avoid overheating. On the hot wall a fan supplied with 12 V in DC was installed while on the cold wall a fan of 24 V was cooling the hotter face of the Peltier element.

The working fluid (water in the present case) was fed through an opening on the top wall controlled by a ball-valve directly linked to a container filled with the fluid. Another ball-valve placed on the bottom of the cell was instead used to empty the cavity. One last ball-valve can be used to feed inert gas used to work in low-oxygen environment during the liquid metal experiments. All the non-used ingresses on the top needed as temperature instrumentation access are kept closed with a plastic cap screwed during operations.

As already mentioned in this Section, the four walls that are neither heated nor cooled are ideally adiabatic. To ensure the minimum amount of heat loss from these walls, an insulation made of a combination of Insulfrax and aluminium foil was made.

Due to the many irregularities on the cavity surfaces, e.g., valves and openings for instrumentation, it was not possible to place effectively the insulation on every wall. As a result, the adiabaticity of the cavity during the operations was not fully ensured and a global averaged heat transfer coefficient h = 20 W/(m^2 K) was experimentally retrieved.

An important point for the design of the experiment was the access for the instrumentation. In fact, in such a small setup it is not trivial to find the best compromise between the available space and the optimal locations of the sensors. Access for the instrumentation was accurately designed according to previous Direct Numerical Simulations (DNS) performed in GaInSn [18]. The simulations showed that the higher intensities in terms of THFs are concentrated close to the copper plates (i.e. the heated/cooled walls), in particular in the upper part of the hot plate and and the lower part of the cold plate. The same distribution can be retrieved for the temperature fluctuations. A final picture of the real cavity with the main elements highlighted is reported in Fig. 3.

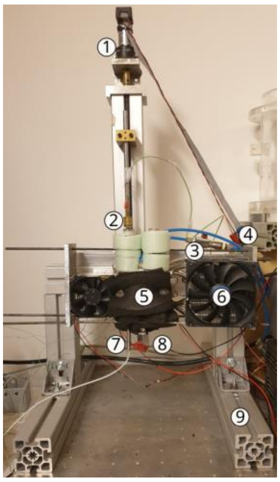

Figure 3 - Natural convection setup: 1) Moving chariot moved by an electrical Maxon Motor 110209; 2) TC + FBG access; 3) Valve to feed the fluid; 4) Valve to feed the inert gas; 5) Cavity; 6) Fan; 7) UDV access; 8) Valve to empty the cavity; 9) Support; the whole setup is mounted on an optical table to ensure stability and precision during the measurements. The non-heated walls are therefore insulated with a layer of Insulfrax®.

In general, the most interesting zones where the sensors should be placed are close to the walls. Here the turbulent phenomena are more accentuated and the higher amplitudes reached by temperature and velocity will be easier to measure.

The x and z coordinates of the measurements are limited to 4 combinations (x = 4 mm; 56 mm and z = 12 mm; 48 mm) while the y direction is in principle fully accessible by all the sensors. The access for the temperature sensors (TC and FBG) was guaranteed from the top, while the UDV was flush-mounted on the bottom wall. In this way, the UDV could acquire the profile of the y-component of the velocity while the other sensors could move along the vertical line through the moving chariot. At the same time, the UDV is placed such that the axis of the cylindrical sensor (i.e. the center of the ultrasonic beam) is in correspondence with the temperature sensor tip so that the last meaningful point of the velocity profile measured by the UDV coincides with the point where the temperature sensors acquire data. In this way, the theoretical need of measuring temperature and velocity "at the same point" to obtain the THF was satisfied the best way possible.

III. RESULTS

In this section, the results obtained in the experimental setup previously described are presented and commented. As the hot wire was not tested in the cavity, a separate section is dedicated to the preliminary results obtained regarding this technique. For more information about the preliminary results obtained with each techniques in other setups and presented at the conference, please contact the author.

A. Hot wire results

The experimental results obtained during the calibration of a hot wire for utilization within a differentially heated cavity are shown in Fig. 4.

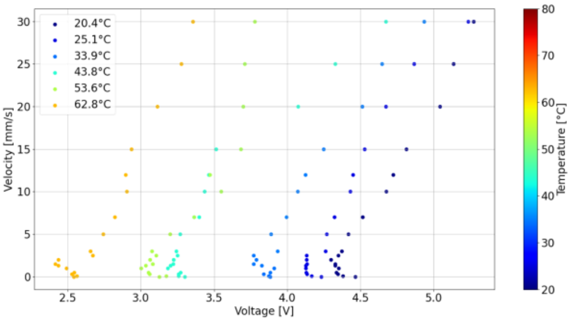

Figure 4 - Hot wire calibration for different temperatures

A distinct correlation emerges between lower temperatures and higher voltage outputs, showcasing a remarkable sensitivity of 50 mV/°C to temperature changes. This high sensitivity, while indicative of the precision of the measurements, provides a significant perspective on the system's thermal dynamics. However, in this specific case, excessive sensitivity to temperature proves to be less advantageous, since my primary interest lies in measuring velocity, and the temperature sensitivity becomes an undesirable and bothersome secondary aspect. Moreover, the tests display an encouraging level of repeatability, validating the robustness of the methodology employed. However, the behavior of the system becomes somewhat ambiguous when operating below 5 mm/s, indicating the need for further investigation in this regime. As the temperature climbs, the trend in the data tends to diminish in clarity, suggesting the emergence of additional influencing factors. These findings collectively emphasize the importance of considering temperature effects, repeatability, and velocity regimes when interpreting the hot wire calibration outcomes for applications within a differentially heated cavity.

B. Results in the differentially heated cavity

Experimental results are therefore available in different points along the vertical lines of the positions shown in Fig 4 to respectively represent the flow behaviour close to the hot and cold wall.

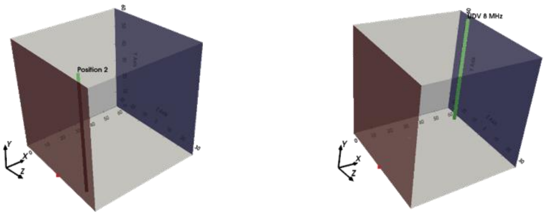

Figure 5 - Vertical positions where the experimental profiles are measured

The results are also presented and compared with Direct Numerical Simulations (DNS) results previously performed in the same setup. More information about how these tests are carried out can be found in the literature [19].

The numerical simulations are performed keeping the cold wall at T = 20°C and the hot wall at T = 80°C, with an average ΔT = 60 °C. On the other hand, due to practical constraints and limitations, the experimental tests were carried out keeping the cold wall at T = 21°C and the hot wall at T = 74°C, i.e., with an average ΔT = 53 °C. Anyway, these conditions still correspond to a Grashof number of $2x10^8$, i.e., to the limit of the transition to turbulence according to some of the studies previously cited [8,15] therefore keeping the results in the same regime of the ones obtained numerically.

The drift of the temperature difference was 0.16 °C /min leading to a maximum change of 0.25°C during the time of the acquisition which corresponded to 50 flow-around times like in the numerical simulations. The imposed ΔT can therefore be considered constant during the measurements. First of all, the average velocity profile along the lines is reported in Fig. 6 and Fig. 7. The experimental data are presented with the uncertainty calculated according to the Guide of of expression of Uncertainty in Measurement [31].

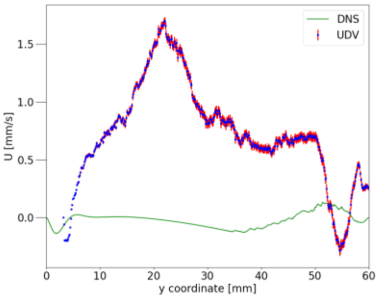

Figure 6 - UDV velocity profile in position 2 (hot wall) compared with numerical results

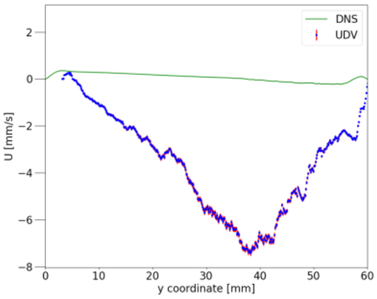

Figure 7 - UDV velocity profile in position 3 (cold wall) compared with numerical results

To establish a meaningful comparison between the experimental and numerical profiles, a careful averaging process was employed to account for the spectral weight of the available DNS data. The velocity data for each point in the UDV profile was obtained by averaging measurements from particles within a cone volume with a 5° aperture angle. While the velocity profiles exhibit the expected direction, aligning with the flow towards the sensor near the cold wall (corresponding to downward motion along the y-axis) and vice versa near the hot wall, there exists a notable order of magnitude difference between the experimental and numerical results. This unexpected divergence in velocities can be attributed to the experimental setup's design for liquid metals, potentially causing limitations in the UDV sensor's ability to accurately measure such low velocities.

Furthermore, distinct features present in the experimental profile are absent in the DNS simulations, potentially stemming from inherent characteristics of the experimental technique. The initial segment of the experimental profile, situated in close proximity to the UDV sensor, is influenced by the near field, often leading to unreliable measurements. To enhance the signal strength farther along the profile, a higher emitting power was employed, exacerbating this near-field effect. Additionally, a discrepancy arises between experimental and DNS results at position 2 near the upper wall (y = 60 mm), where a slight velocity decrease and change in direction occur. This phenomenon, potentially linked to recirculation induced by the impinging jet effect of the horizontal flow against the wall, contrasts with DNS predictions.
Contrarily, the same phenomenon does not manifest in the profile obtained at position 3, warranting further investigation into its physical or artificial nature. Considering the experimental constraints, attempts to attribute physical interpretations to the velocity profile, particularly regarding rms values, yielded inconclusive outcomes due to the risk of electronic noise overpowering genuine turbulent fluctuations at such low velocities. Consequently, exercising caution in drawing conclusions from incompletely understood phenomena is imperative at this stage. Notably, the vast disparity between DNS predictions and experimental measurements, likely attributable to the sensor's limitations, underscores that achieving direct alignment between the two results will not be pursued in the current phase where water serves as the working fluid.

Further considerations regarding the flow in the cavity can be made for temperature profiles. The ΔT imposed to the cavity has already been commented at the beginning of this section. The average temperature profile along the position 2 and 3 inside the cavity is shown respectively in Fig. 8 and Fig. 9.

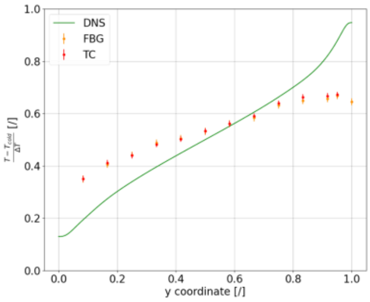

Figure 8 - Temperature profile along position 2 (hot wall) measured with thermocouple and Fiber Bragg gratings compared with numerical results

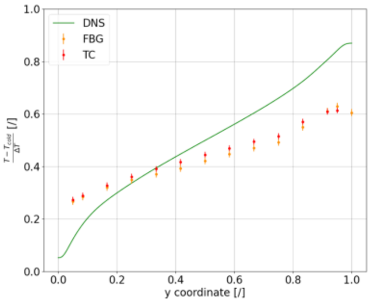

Figure 9 - Temperature profile along position 3 (cold wall) measured with thermocouple and Fiber Bragg gratings compared with numerical results

The comparison between FBG and TC measurements reveals good agreement, accounting for uncertainties [19]. Conversely, it becomes evident that the experimental data generally do not align with the numerical temperature profile, even when considering uncertainties. While the temperature magnitudes are consistent, the slope of the numerical profile is notably steeper. Unlike the velocity measurements, this discrepancy cannot be attributed to sensor sensitivity issues, indicating the reliability of experimental temperature outcomes and enabling certain deductions.
Several factors might contribute to the observed discrepancies. Firstly, the slight difference in imposed ΔT (temperature difference) - $\Delta T_{exp} = 53°C$ and $\Delta T_{DNS} = 60°C$ - could potentially explain the steeper numerical profile. Furthermore, inherent heat losses within the experimental setup, attributed to non-perfectly adiabatic insulated walls, influence the temperature distribution. To account for these losses, measurements were conducted on five out of six cavity walls, excluding the back wall used for support. A global heat transfer coefficient estimation of 20 W m−2 K−1, reasonable for air in natural convection, was obtained through tests filling the cavity with hot water. These heat losses, negligible compared to the Peltier power input (approximately 100 W), were factored into a Biot

number calculation (Bi = 0.007), suggesting that the stainless steel wall's thickness allows for uniform temperature assumption and neglect of conduction losses.

Although neither the numerical nor the experimental analyses reveal distinctive temporal characteristics at a specific point, post-processing of data is omitted due to this lack of differentiation. Further exploration is needed to comprehend the divergence between numerical and experimental results and to conduct meaningful liquid and thi experiments. The discrepancies between experimental and simulated temperature profiles persist, even when accounting for error bars. Multiple potential causes contribute to this disparity, including the influence of heat losses, discrepancies in the temperature difference, and non-uniform temperature distribution on the cavity walls. To address these issues, further analyses are warranted, and symmetric measurements at the cold wall could provide additional insight into the flow behavior within the experimental setup.

IV. CONCLUSION AND FUTURE WORKS

This study addresses the intricate challenge of quantifying turbulent heat fluxes (THFs) within liquid metals, characterized by the rapid and simultaneous fluctuations of fluid velocity and temperature. To unravel this complexity, the research focuses on an initial experimental phase, meticulously crafting the experimental framework and adopting water as the primary working fluid. Commencing with an insightful survey of cutting-edge techniques for velocity and temperature measurements, the paper judiciously evaluates the suitability of each method for application in liquid metals. In this deliberation, Ultrasonic Doppler Velocimetry and Hot Wire Anemometry emerge as the optimal choice for velocity measurements, while temperature measurements find their precision through the utilization of thermocouples and Fiber Bragg Gratings. The spotlight then turns toward the design of the differentially heated cavity, meticulously selected as the platform for investigating natural convection. This section provides an exposition of the cavity's architectural intricacies, accompanied by a lucid exposition of the underlying rationale guiding the chosen configurations. Presenting a significant milestone, the paper presents preliminary outcomes stemming from water-based experimentation, thoughtfully juxtaposed against the backdrop of available Direct Numerical Simulations (DNS) results. These comparisons enable a preliminary assessment of the methodology's viability and provide a foundation for future exploration. The paper's achievements are underscored by the successful development of an innovative experimental apparatus, tailor-made for unraveling the complexities of turbulent heat flux across diverse fluid media. The meticulously devised cavity facilitates accurate measurements, with the initial water-based tests serving as a prudent step to preclude any unforeseen intricacies before embarking upon experiments involving GaInSn or LBE. It is pertinent to note that a comprehensive turbulent analysis is reserved for subsequent stages of the research, as the current phase, constrained by time, has yet to unveil substantial turbulence. This calculated progression epitomizes the paper's commitment to methodical and rigorous scientific inquiry. However, the comparison between experimental and numerical results shows a significant discrepancy at this stage. The authors refrain from drawing major conclusions about the mass and heat transfer phenomena in the cavity until the cause of this mismatch is clarified. They propose and analyze possible reasons for the disparity in the results in the corresponding section which will be crucial for future improvements. Importantly, the mismatch cannot be attributed to design or measurement technique selection errors, as the cavity is designed for GaInSn experiments, and water may not yield identical outcomes. Further investigations are required to fully comprehend the source of the discrepancies. Future work will focus on identifying the main reasons for the mismatch and addressing them. The researchers plan to conduct meaningful experiments with water, comparing the results with DNS data. Additionally, they intend to test the Hot wire technique in the same setup to measure velocity at high frequencies. With synchronized acquisition systems, calculations of THFs will also be possible. After completing this phase, experiments with GaInSn will be carried out, providing THFs data in liquid metals to validate numerical models.

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