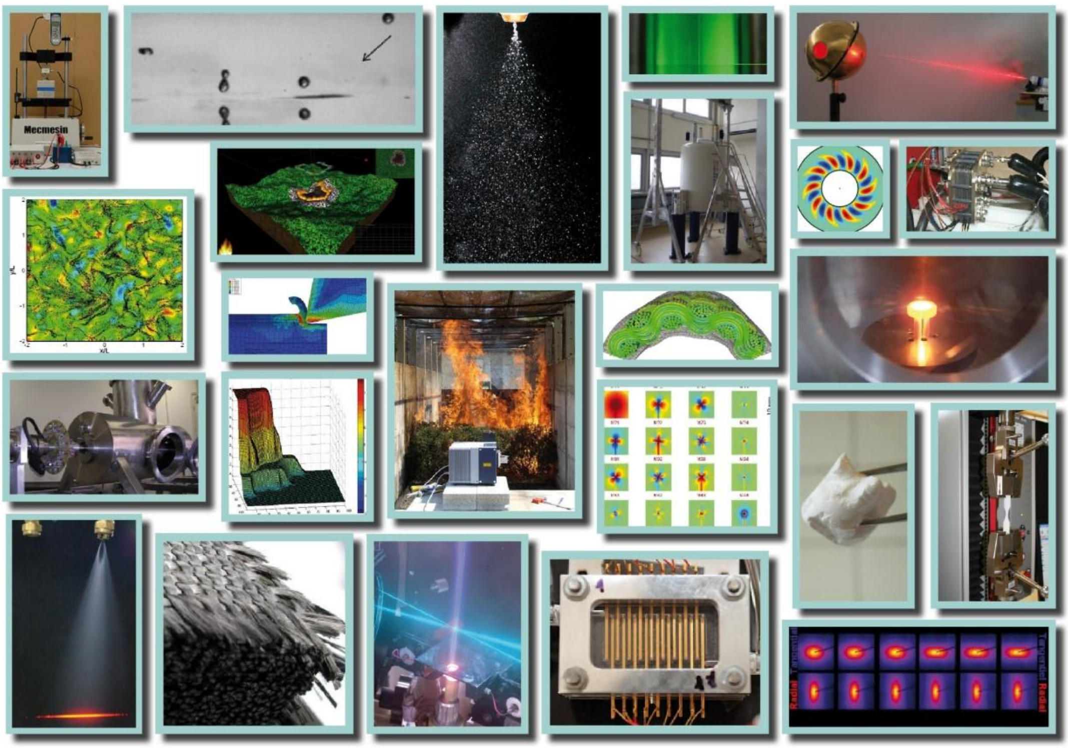
Brief description of internship offers such as Research level M2 at LEMTA or in partnership with LEMTA

The topics presented below are offers by LEMTA research groups:

- Fluid Media, Rheophysics;
- Energy and Transfer;
- Energy Carriers ;
- MRI for Engineering.

The topics are briefly described and accompanied by the contact information. This will allow you to find out more if you are interested, and to apply directly.

Note: for some subjects there is only the French version available.



Academic year 2024/2025

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Measurement of Pore Size Distribution by NMR Cryoporometry

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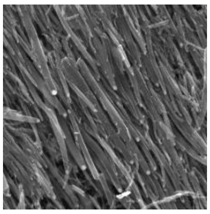
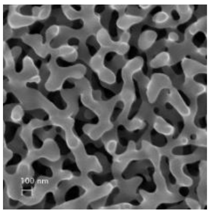
Main fields: Thermodynamics; Heat transfer; Porous Media; Low-field NMR

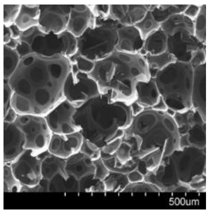
Description

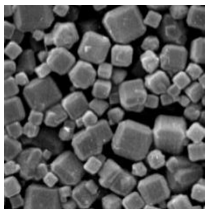
1. Context

Nano-porous materials (clays, porous silica, carbons, zeolites, carbon nanotubes, etc.) are widely present in our environment and play key roles in filtration, storage, and depollution. Their properties strongly depend on the geometry and size distribution of their pores.


Carbon nanotube


Nanoporous glass


Activated charcoal


Zeolite

Pore size in micro- or nano-porous materials can be determined using microscopy techniques (X-µCT, SEM, FIB-SEM, synchrotron imaging) or through more global and less costly methods such as mercury intrusion, gas adsorption, NMR relaxation, or NMR cryoporometry.

NMR cryoporometry allows the characterization of pores ranging from 1 to 100 nm. It is based on the Gibbs–Thomson law, which states that the melting temperature of a liquid decreases when it is confined within small pores. Low-field NMR, which is sensitive only to liquid phases, measures the volume of liquid contained in these pores. By monitoring the progressive melting of the liquid during a temperature ramp, the pore size distribution can be determined. This distribution can then be compared with that obtained from NMR T_2 relaxation measurements, which probe a wider range of pore sizes (10 nm to 1 mm) using the same NMR equipment.

2. Work

The aim of the internship is to contribute to the laboratory development of the NMR cryoporometry method using the available low-field NMR instruments. The method will be applied to reference porous media (sintered glass, silica gel, Vycor, nano-powders, etc.) and various fluids (water, ionic solutions, cyclohexane, dodecane, etc.). The study will also focus on ice/liquid interfacial tension effects, which play a crucial role in the interpretation of cryoporometry results.

3. References

J.H. Strange, M. Rahman, E.G. Smith; Characterization of porous solids by NMR. *Phys. Rew. Lett.* V.71, n°21 (1993).

J. Mitchell, J.B. Webber, J.H. Strange; Nuclear magnetic resonance cryoporometry. *Phys. Reports* 461, 1-36 (2008).

O.V. Petrov, I. Furo ; NMR cryoporometry : principles, applications and potential. *Progress in NMR Spectroscopy* 54, pp. 97-122 (2009).

Bubble flows observed by MRI

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Main fields: Thermodynamics; Heat transfer; Porous Media; Low-field NMR

Description

1. Context

Magnetic Resonance Imaging (MRI) is a visualization technique that has long been used in the medical field and is now increasingly applied to the study of fluid flows. At LEMTA, in collaboration with EDF, ongoing research aims to evaluate the potential of MRI techniques for characterizing bubbly flows in complex geometries. The focus is on flows similar to those found in the core of nuclear reactors: specifically, an upward vertical liquid-gas two-phase flow with dispersed bubbles inside a bundle of parallel tubes. The goal is to provide experimental data for the validation of two-phase CFD codes.

2. Work

The objective of the internship is to participate in measurement campaigns carried out on the ROMANE loop (**R**és**O**nance **MA**gnétique **N**ucléaire d'**E**coulements diphasiques), which passes through an NMR spectrometer equipped with a high-resolution imaging system. The studied geometry corresponds to a vertical sub-channel bounded by four tubes of similar dimensions to those found in a nuclear reactor. The work will include testing a new injector designed to generate bubble trains. A key part of the internship will be processing MRI data (essentially image processing) using Matlab or Python software. This will be followed by an interpretation of the results in terms of velocity, void fraction, and bubble size.

Photo of the ROMANE loop passing through an NMR spectrometer

3. References

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L.F. Gladden et al. Dynamic MR imaging of single- and two-phase flows, *Chem. Eng. Res. Design* 84 (2006) 272–281.

A. Oliveira, D. Stemmelen, S. Leclerc, T. Glantz, A. Labergue, G. Repetto and M. Gradeck, Velocity field and flow redistribution in a ballooned 7x7 fuel bundle measured by magnetic resonance velocimetry, Nuclear Engineering and Design, 369, pp.110828 (2020).

Determination of transport properties of the Porous Transport Layer in PEM Electrolyzers

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Main fields: PEM Electrolyzers, Porous Transport Layer, X-ray tomography, Transport properties

Description

1. Context

Proton Exchange Membrane Water Electrolysis (PEMWE) technology shows great promise owing to its flexibility and rapid response to load variations. However, large-scale industrial implementation still faces significant challenges, particularly in terms of efficiency and durability [1]. Some limitations are governed by mass transport and charge transfer phenomena within the porous materials. Inadequate water supply to the anode catalyst layer, often caused by insufficient oxygen removal, leads to high overpotentials and reduced device performance. The Porous Transport Layer (PTL) plays a crucial role in PEMWE operation by conducting electrons from the catalyst layer, supplying water to the reaction sites, and facilitating the removal of generated oxygen. The efficiency of these transport processes within the PTL strongly depends on their microstructural characteristics. For example, PTLs with larger pore sizes can enhance water and gas transport but may increase electrical resistance due to extended electron pathways. Conversely, smaller pore sizes reduce resistance but can impede fluid transport [1], [2]. Therefore, understanding the relationship between the PTL microstructure and its transport properties is essential for optimizing device performance and advancing PEMWE technology.

2. Work

This internship aims to characterize several commercial Porous Transport Layers (PTLs) with different microstructures. X-ray tomography will be employed to obtain 3D images of these porous materials. The images will then be processed and segmented using the Avizo software to distinguish between the solid and pore phases. At this stage, key structural parameters such as porosity and connectivity of the PTLs will be determined.

The segmented 3D images will subsequently be used to compute various transport properties, including the effective diffusion coefficient, permeability, relative permeability and capillary pressure curve. These simulations will be carried out using the GeoDict software. The results will provide valuable insights into the transport efficiency of these porous materials

3. References

[1] J. Parra-Restrepo *et al.*, Influence of the porous transport layer properties on the mass and charge transfer in a segmented PEM electrolyzer, *Int. J. Hydrog. Energy*, 45, 8094-8106 (2020).
[2] B. Amoury *et al.*, Experimental study of gas invasion mechanism in the porous transport layer of a PEM electrolyzer, Transport in Porous Media, 152:16 (2025).

Characterization of Wall Heat Transfer During Spray Cooling

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Main fields : interfacial heat transfer, energy efficiency, infrared thermography

Description

1. Context

Electronic devices (data centers, AI, electromobility, aeronautics, medical, etc.) and energy conversion systems in industries (solar, nuclear, electric motors, etc.) are experiencing exponential growth. However, they face a major challenge: heat, which disrupts their operation and affects performance[1-2]. These systems therefore require effective cooling, which is becoming even more critical as the required cooling power is expected to exceed 1000 W/cm² in the near future, compared with only 10 to 100 W/cm² currently[3]. Among current limitations, heat extraction is often far from the heat source. Moreover, only forced convection is usually exploited, whereas using liquid boiling would enhance cooling through the latent heat of vaporization. This project aims to develop a more efficient direct-contact cooling solution by spraying the coolant (such as water) in the form of fine droplets directly onto the surface to be cooled. Furthermore, to enhance cooling performance, the solid exchange surface properties can be optimized through specific texturing and material choice.

2. Work

To experimentally characterize wall heat transfer, we developed dedicated test benches designed to observe the cooling process in configurations of increasing complexity: single droplet, droplet array, and finally spray (Figure 1)[4-5]. At each stage, the measurements aim to determine the temporal evolution of the wall temperature, in order to deduce the heat flux extracted by the droplets and thus assess the cooling efficiency. The characterization can be performed using **infrared thermography (IRT)**, which provides both spatial and temporal resolution, in the cases of single or multiple droplets (Figure 2)[5]. For these two configurations, side-view observations using **high-speed shadowgraphy** can be combined with IRT to correlate droplet deformation with the underlying thermal phenomena (Figure 2).

Figure 1: Configurations for studying droplet impact on heated surfaces available for the internship work.

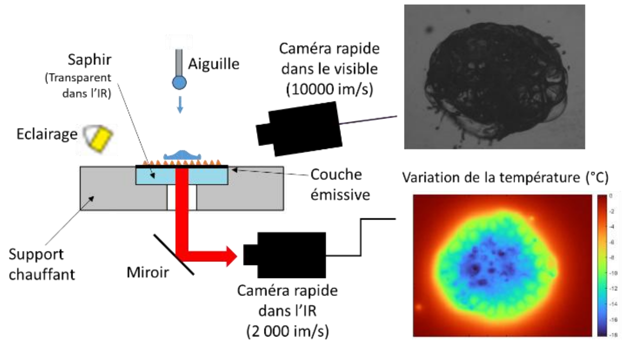

Figure 2 : Wall heat flux measurement by infrared thermography[5].

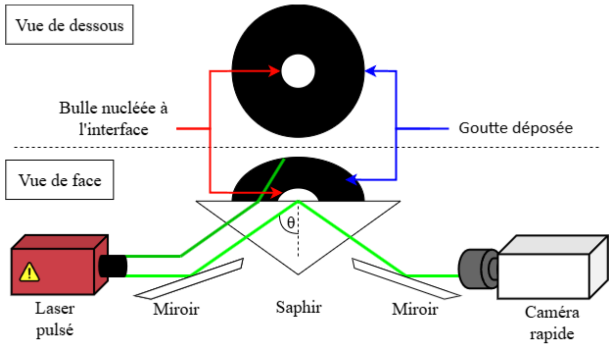

Figure 3 : Evaluation of the wetted surface area by total internal reflection.

In addition to infrared thermography and shadowgraphy, the **total internal reflection (TIR)** visualization technique can be employed when the wall is transparent (for example, made of sapphire). This method relies on the refractive index contrast between the wall and the liquid. When the surface is dry, the incident light is totally reflected, whereas the presence of a liquid film locally alters the refractive index and breaks the condition for total internal reflection, leading to the disappearance of the reflected signal. Analysis of the resulting images thus enables mapping and quantification of the wetted areas on the wall surface (Figure 3).

In this study, the heat flux extracted at the wall will be measured as a function of the impact parameters (droplet size and velocity), wall temperature, and surface characteristics (smooth or textured) in the case of a single droplet. The objective is to evaluate the influence of these parameters on cooling efficiency.

The images obtained by shadowgraphy and infrared thermography (IRT) will complement the measurements performed using the total internal reflection (TIR) method, in order to highlight the coupling between droplet spreading dynamics and wall heat transfer.

The experiments may then be extended to multiple droplets, where interactions during spreading are expected to affect cooling efficiency.

These measurements will contribute to enriching the experimental database, in continuity with the PhD work of Thomas Potaufeux, whose defense is scheduled for December 17, 2025.

3. References

[1] Z Zhang et al., A review of the state-of-the-art in electronic cooling, e-Prime - Advances in Electrical Engineering, Electronics and Energy 1 (2021) 100009

[2] Huan Chen et al., Application status and prospect of spray cooling in electronics and energy conversion industries, Sustainable Energy Technologies and Assessments, 52(2022) 102181.

[3] J. Yin et al, Spray Cooling as a High-Efficient Thermal Management Solution: A Review. *Energies* **2022**, *15*, 8547.

[4] G. Castanet et al., The Leidenfrost transition of water droplets impinging onto a superheated surface, Int. J. Heat Mass Transf. 160 (2020) 120126.

[5] W. Chaze et al., Heat flux reconstruction by inversion of experimental infrared temperature measurements – Application to the impact of a droplet in the film boiling regime, International Journal of Heat and Mass Transfer (128) : 469-478, 2019.

Thermosensitive paints for the study of heat transfer at the liquid–surface interface

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Main fields: Interfacial heat transfer, energy efficiency, thermography, spectroscopy, luminescent coatings

Description

1. Context

Local surface temperature measurement remains a major experimental challenge in many scientific and industrial applications. Although infrared thermography is often considered the reference technique, it faces strong limitations for fast phenomena occurring at low or moderate temperatures.
This is the case, for example, for droplet impact or liquid film flow over surfaces that are cold or only moderately heated. Such phenomena are ubiquitous in nature and in industrial processes (spray cooling, condensation, defrosting, etc.), yet the underlying heat transfer mechanisms remain only partially understood.
Temperature-Sensitive Paints (TSPs) represent a promising approach for non-intrusive, high-resolution surface temperature mapping. These coatings contain luminescent dyes whose emission properties (intensity, wavelength, or lifetime) vary with temperature. However, the practical use of TSPs remains limited due to issues related to paint robustness, ageing under harsh environmental conditions (humidity, icing, rapid thermal gradients), and the difficulty of forming thin, uniform layers with low thermal resistance.

2. Objectives:

The main objective of this internship is to develop and characterize temperature-sensitive paints suitable for studying heat transfer during droplet impact and liquid film flow, with future applications in aeronautical icing research.

3. Work Plan:

The internship will focus on the formulation, deposition, and characterization of luminescent temperature-sensitive paints. The main steps will include:

- Designing and testing different paint formulations by varying both the luminescent dye (luminophore) and the polymer matrix,
- Ensuring good dispersion of the dye and uniform deposition of the paint film,
- Characterizing each formulation experimentally to determine:
    - The luminescence response as a function of temperature,
    - The spectral emission and thermal sensitivity,
    - The signal amplitude and optimal excitation wavelengths.

A protective overlayer will then be investigated to improve durability and enable optical measurements through transparent substrates, as illustrated in Figure 1. This will involve collaboration with IJL and IMFT, project partners providing expertise in advanced coating techniques such as spin coating and bar coating, for the controlled deposition of thin, homogeneous layers.
In the final stage, the most promising formulations will be tested under representative thermal conditions, such as the evaporation of a sessile droplet or droplet impact on a cold surface, which serve as benchmark cases in the literature (Figure 2).

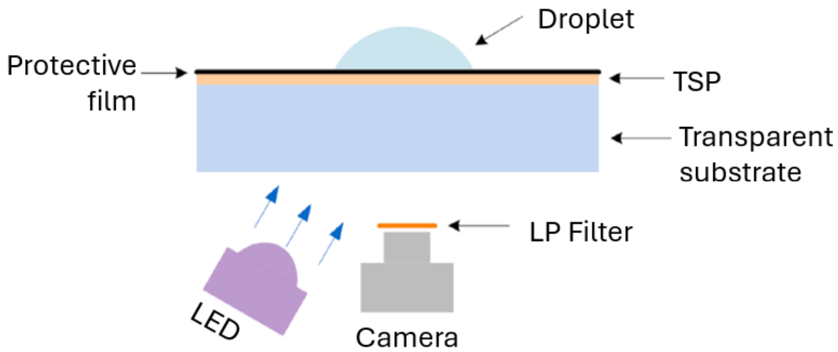

Figure 1: *Illustration of the experimental setup for surface temperature measurement beneath a droplet.*

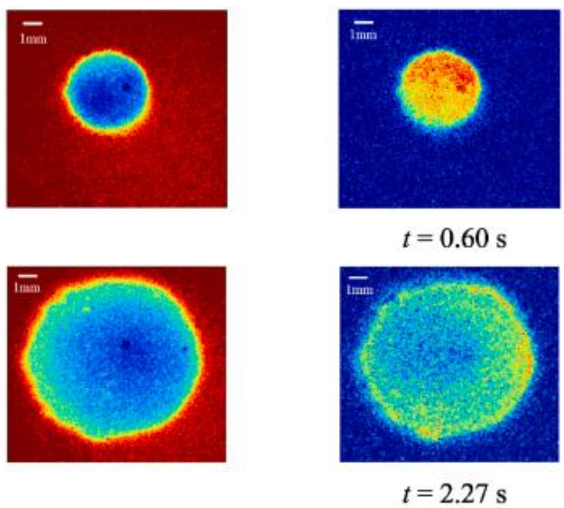

Figure 2: *Example of temperature images obtained during the evaporation of an HFE-7100 droplet, a liquid coolant commonly used for electronic system cooling [1]*

4. Reference:

Lu Liu, Kaiqi Zhang, Haiyan Liu, Shulei Zhang, Menglong Mi, *Experimental study on the interfacial heat transfer of sessile droplet evaporation using temperature-sensitive paint,* Experimental Thermal and Fluid Science, Volume 128, 2021, 110436. https://doi.org/10.1016/j.expthermflusci.2021.110436

Effects of current transients on the performance and lifetime of PEM fuel cells

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Field/nature: fuel cells, electrochemistry, bibliographic study, modeling, numerical simulation, experimental measurements

Description

1. Context

The effects of applying high current transients or "short circuits" (SC) to the terminals of a fuel cell in operation are poorly documented or at least subject to various interpretations [1-6]. However, this technique has been used for many years by several manufacturers of low-power open-cathode proton exchange membrane fuel cells (PEMFC) to improve their performance. Beyond a patent filed by Ballard on the subject [7], only a few scientific publications offer various explanations, ranging from membrane humidification to catalyst deoxidation, to account for the observed performance improvements [1,2,5].

This project topic is part of a collaboration between the FEMTO-ST and LEMTA laboratories, which has been ongoing since 2023, aimed at highlighting the physical phenomena at play, and more specifically within the framework of the ongoing FCLAB ESCAPADE project. Previous work has made it possible to systematically characterize the effect of controlled short circuits on the performance of a 10-cell closed cathode fuel cell in operation and to study the long-term effects [8]. An initial approach to modeling impedance using impedance spectrometry and equivalent electrical circuits (EEC) has made it possible to explain some of the phenomena observed. Work carried out in 2025 enabled a more in-depth analysis. It focused on the use of a single PEMFC cell coupled with several electrochemical characterization techniques (EIS, cyclic voltammetry, H2 permeation current) and high-frequency measurement of electrode potentials. These specific measurements required a cell equipped with a hydrogen reference electrode (HRE) designed by LEMTA and combined with the SC generator developed by FEMTO-ST. These measurements provided a more detailed understanding of the electrochemical mechanisms at play, in particular identifying the characteristic times of oxygen reduction and air diffusion at the cathode, which play an important role in the phenomena observed. In addition, the measurement of electrode potentials made it possible to identify electrochemical reactions that could have an impact on battery degradation. Further analysis is needed to fully interpret the physics of the processes involved and verify the hypotheses put forward.

To this end, the ESCAPADE project and the internship aim to systematically identify the transfer phenomena involved in SC application according to the operating point (current, gas humidification, pressure, temperature) and the length of a short circuit [5, 9, 10]. Based on these results, a second objective will be to study the impact of SC sequences on the degradation of battery performance in relation to that of its components.

2. Proposed work

The first step is to familiarize yourself with the subject and learn about the state of the art concerning the impact of short circuits and, more generally, potential cycling on the performance and degradation of PEMFCs, based on the literature and previous work. This will enable you to interpret the impact of short circuits in terms of transfer phenomena in fuel cell components.

The second part of the internship will focus on the experimental study of a single PEMFC cell at LEMTA under transient high current stress. In addition to performance (cell current and voltage), the aim will be to measure high-frequency electrode potentials during dynamic stress phases. These measurements, taken at different operating points of the cell (current, gas humidification, pressure, temperature), should provide a more detailed understanding of the electrochemical mechanisms at play as a function of the parameters selected and, in particular, identify any possible induced degradation. These new characterizations will be combined with impedance spectroscopy measurements and interpretation by EEC [11].

The experimental study will be accompanied by modeling of the behavior of a PEMFC following a short circuit.

3. References

1. Jincheol Kim, Dong-Min Kim, Sung-Yug Kim, Suk Woo Nam, Taegyu Kim. Humidification of polymer electrolyte membrane fuel cell using short circuit control for unmanned aerial vehicle applications. *International Journal of Hydrogen Energy* – 39, 7925-7930, 2014. https://doi.org/10.1016/j.ijhydene.2014.03.012
2. Yuedong Zhan, Youguang Guo, Jianguo Zhu, Li Li. Current short circuit implementation for performance improvement and lifetime extension of proton exchange membrane fuel cell. *Journal of Power Sources* – 270(15), 183-192, 2014. https://doi.org/10.1016/j.jpowsour.2014.07.104
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