# 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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# Title: Study of the risk of damage to buried networks during vegetation fires

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**Main field:** Heat transfer, numerical and experimental approaches

**Description**

**1. Context**

Initially, wildfires were one of the natural regulators of our ecosystems, shaping and renewing our landscapes. However, these fires are becoming more and more frequent, and their intensity tends to increase over time. This deregulation has a significant negative impact on flora and fauna (disappearance of endemic plant cover, clouds of smoke and dust that cover a large part of the globe) and on our societies (physical and financial damage, impact on the health of exposed populations).

Figure 1 - Increasing numbers of wildfires around the world

The intensification of these fires is leading to their spread to urban areas, raising new issues such as the vulnerability of forest/habitat interfaces. These are sensitive areas, where the risk of fire is a cause for concern due to an increase in ignition sources (agricultural abandonment, urban expansion and repeated drought) and the vulnerability of infrastructures. For example, the "Paradise" fire in California in 2018 destroyed 19,000 building structures. In France, the most critical fire for forest/habitat interfaces was the Gonfaron (Var) fire in 2021, where 50 buildings were destroyed. If these structures are vulnerable, then they no longer offer protective refuges for the population, and evacuation of fire-affected areas becomes an obligation.

Figure 2 - Overhead telecommunications network destroyed in 2021 in California

Within this safety framework, numerous studies are underway to redefine regulatory obligations for homes in these sensitive areas. The same applies to securing overhead networks, such as electricity and telecommunications. One technical solution is to bury electrical networks, like the water network. However, in the event of a violent vegetation fire, these networks can also be affected by extreme thermal conditions, with a heat wave propagating through the ground and potentially jeopardizing the continuity of services. The aim of this internship is to address this issue both experimentally and numerically, by defining the conditions under which these networks can be impacted).

## 2. Proposed work

Two aspects are proposed in this internship to answer the initial question:

- The experimental part of the project will have a twofold objective: firstly, field tests will enable us to reproduce vegetation fires (soil fires). Under given vegetation load conditions (mass per unit area), these tests will enable us to define the flux density and duration at which soils are impacted by fire. Then, on a smaller scale, fictitious soils (non-reactive to fire) of the sand bed type will be exposed to different thermal stresses (via gas-fed radiant panels) and fitted with thermocouples. These tools will be used to monitor the propagation of the heat front within the soil, and to define a soil impact distance based on surface thermal conditions. For this last part, it will be necessary to develop the experimental setup in its entirety during the internship.

- A numerical part will enable us to reproduce the exposure of a subsoil to thermal conditions representing the contribution of a vegetation fire. In a first step, in 1-D, the model should be able to reproduce the results of small-scale tests. In a second step, the model will be developed in 2D or even 3D, to take account of possible edge effects.

This internship will initiate the research work of the LEMTA "Fires" Team in the field of underground fires, both experimentally and numerically. Collaboration with LEMTA's "Soil" team, as well as with SDIS 54 for the "field tests" part of the project, is envisaged.

## 3. References

[1] Rein G, Huang X, Smouldering wildfires in peatlands, forests and the arctic: Challenges and perspectives, Current Opinion in Environmental Science & Health, 2021, Vol:24, ISSN:2468-5844, Pages:1-10.

[2] Santoso MA, Cui W, Amin HMF, et al., Laboratory study on the suppression of smouldering peat wildfires: effects of flow rate and wetting agent, International Journal of Wildland Fire, 2021, Vol:30, ISSN:1049-8001, Pages:378-390.

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# Title: Numerical simulation of surface protection using sprays

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**Main Field:** fluid mechanics

## 1. Description

Spraying - the term used here to designate the spraying of water to limit or extinguish a fire - is one of the active fire-fighting methods that play a major role in protection systems. These means are varied and depend on both the fire scenario and the type of property involved. However, whether it's to protect a building or fight a wildfire, the use of sprinklers can be a means of limiting the fire, protecting structures and preventing the fire's transition to the habitat. The aim of this project is to evaluate the Fire Dynamics Simulator (FDS) computational code for simulating expected temperatures on surfaces subjected to spray cooling. Using data from experimental campaigns conducted at the Laboratory of Energy and Theoretical and Applied Mechanics (LEMTA), this research project will analyze different orientations of heated metal surfaces and their spray cooling.

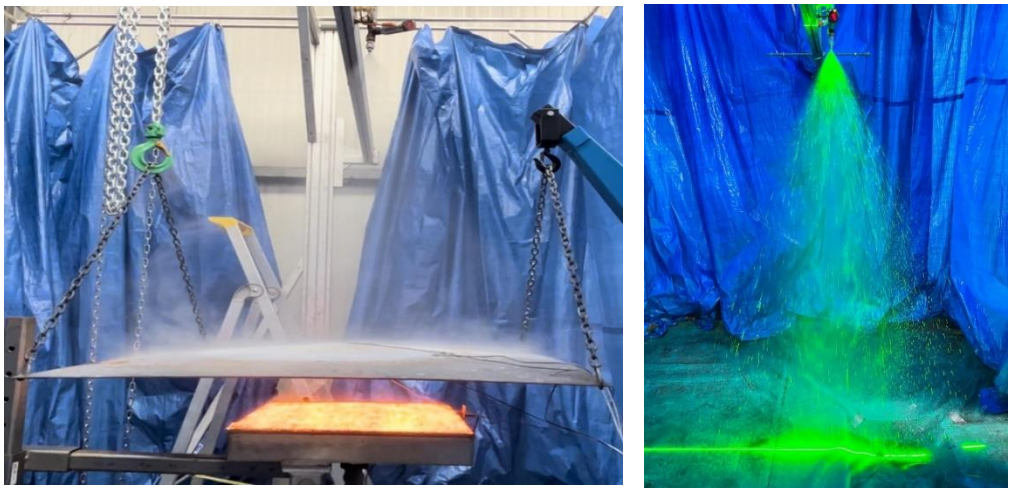

Fig 1 : Example of experiments carried out at LEMTA

## 2. Context

On a laboratory scale, it has been shown that water is best used in divided form (droplets) [1]. The mechanisms of action are well known: (1) cooling of the flame, in particular by evaporation, (2) inerting effect associated with evaporation and the production of steam which dilutes the fuel/oxygen mixture, (3) cooling of surfaces by impact and run-off with associated heat transfer effects which can limit pyrolysis of surfaces feeding the combustion with combustible gases, (4) attenuation of flame radiation through absorption and scattering by droplets, and (5) impact on flow dynamics through drag effects and interaction with turbulence. While these mechanisms have been well identified, the associated models remain open to improvement, and are even being called into question in the case of evaporation,

drag and drop/wall exchanges [2]. In any case, these effects are poorly quantified and deserve fundamental work to improve their modeling and their inclusion in simulations. On an application level, this upstream work is necessary both to optimize the means of protecting structures by spraying, or to prevent the transition from vegetation fires to habitat (Wildland Urban Interface Fires).

## 3. Work

The student will start his/her research work with a bibliographical study of spray sub-models, learning to use FDS. He/she will help set up the experimental bench (see illustration in figure 2) and conduct the experiments.

He/she will test a selection of submodels, evaluating their ability to reproduce a spray, their radiative attenuation capacity and their cooling properties. He/she will benefit from the EXPLOR computing platform (Université de Lorraine cluster) to handle the expected high computing times. The final part of the project will involve full-scale simulations.

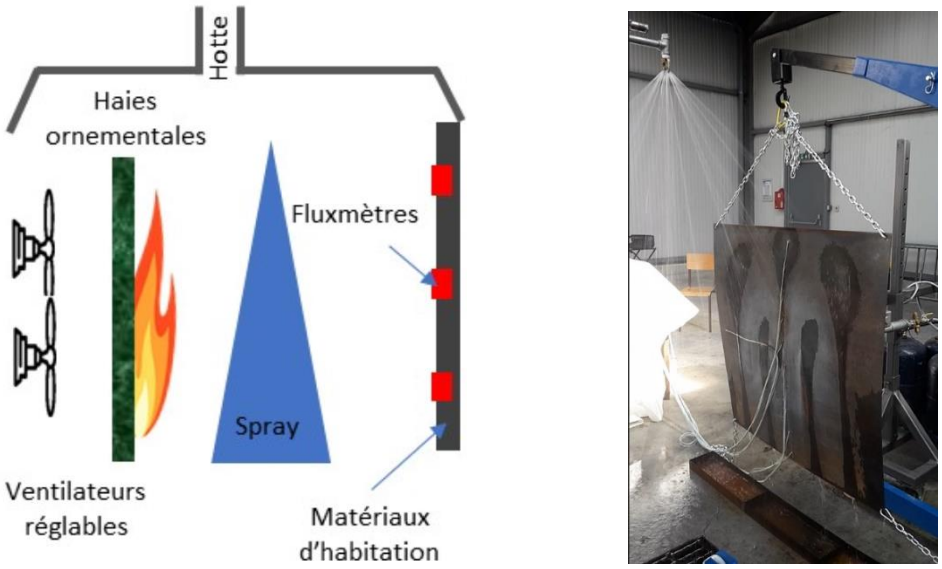


Fig 2 : illustration of the experimental configuration to be set up

## 4. References

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[2] Y. Liu et al., Numerical analysis of a water mist spray: The importance of various numerical and physical parameters, including the drag force. Fire Safety Journal, Vol. 127 (2022), 103515

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[5] Y. Pérez-Ramirez et al., Numerical characterization of structures heat exposure at WUI, IX International Conference on Forest Fire Research (Coimbra, Portugal 11-18 Nov, 2022

# Title : Design and testing of a High Temperature segmented test bench and cell.

**Supervisor(s) :** **Jérôme Dillet, jerome.dillet@univ-lorraine.fr**

**Olivier Lottin, olivier.lottin@univ-lorraine.fr**

**Main fields:** fuel cells, PEMFC, hydrogen, aircrafts & aeronautics, high temperature (160°C)

**Description :**

## 1. Context

A collaboration has been established between the LEMTA Laboratory of Energy & Theoretical and Applied Mechanics and Safran Power Units to advance the development of high-temperature (160°C) proton exchange membrane fuel cells. Traditionally, PEMFCs with fluorinated membranes operate between 60°C and 90°C. Increasing the operating temperature aims to improve water management by eliminating the inlet air-hydrogen gases humidification, and to reduce system size, particularly by simplifying cooling requirements. This involves using materials that differ from conventional assemblies, which are less understood in terms of local operating conditions (uniformity across the active surface) and aging effects.

The partnership aims to quantitatively assess, over several years, the transfer phenomena (mass, charge, and heat) that limit performance and contribute to major degradation in high-temperature membrane-electrode assemblies, using both numerical and experimental methods. The PBI (Polybenzimidazole) membrane, which is impregnated with phosphoric acid to conduct protons (H+), experiences significant degradation during start-stop phases and at open circuit voltage (OCV). Consequently, the focus will be on developing start-stop protocols that minimize degradation of the membrane and electrodes without using inert gases (such as nitrogen) during temperature transitions (from ambient to 160°C), thus preventing acid loss into liquid water.

## 2. Work

The M2 internship (5 months) will primarily focus on experimental work, concentrating on the design and development of a new 50 $cm^2$ segmented and instrumented cell, along with an experimental setup compatible with the high-temperature PEM environment (160°C and corrosive atmosphere). By the end of the internship, the intern will be ready to conduct initial tests of both the setup and the cell, measuring local performance over time based on various operating conditions, including pressure, temperature, feed stoichiometry, hydrogen recirculation, blocked-mode feeding, and co-flow or counter-flow configurations.

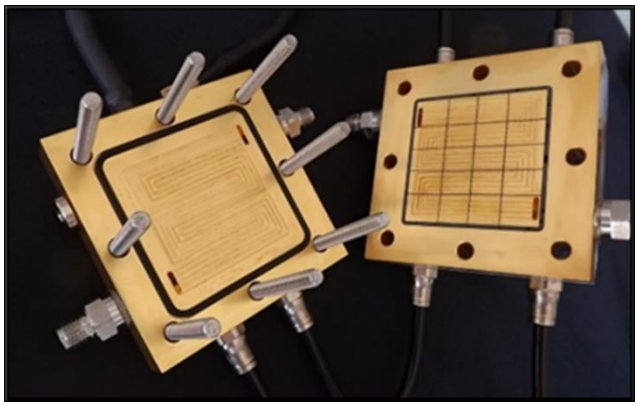

Fig. 25 cm² segmented cell manufactured at LEMTA.

The internship is open to final-year students from engineering schools (general or specialized) or universities in thermal, mechanical, or electrochemistry fields. Applicants should possess a solid understanding of instrumentation, characterization, and fuel cells based on their educational background and/or previous experiences. You will be part of a dynamic team of about fifteen researchers at LEMTA focused on the scientific study of hydrogen's electrochemical conversion. The internship will also involve collaboration with Safran Power Units in Toulouse, an international high-tech group operating in aeronautics (propulsion, equipment, and interiors), space and defense.

## 3. References


Anode aging in polymer electrolyte membrane fuel Cells I: Anode monitoring by ElectroChemical impedance spectroscopy, S. Touhami et al., Journal of Power Sources, Volume 481, 2021, https://doi.org/10.1016/j.jpowsour.2020.228908.

Comparing shut-down strategies for proton exchange membrane fuel cells, A. Oyarce et al., Journal of Power Sources, Volume 254, 2014, https://doi.org/10.1016/j.jpowsour.2013.12.058.

Étude et optimisation des phases de démarrage et d'arrêt des piles à combustible de type PEM haute température en vue de maximiser leur durée de vie, M . Durand, Thesis 2022

Polybenzimidazole (PBI)-based membranes for fuel cell, water electrolysis and desalination, A. Das et al. Desalination, Volume 579, 2024, https://doi.org/10.1016/j.desal.2024.117500.

# Title : Thermal convection in structured porous solid foams

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**Main fields :** Fluid mechanics, energy and thermal systems

## Description

### 1. Context

Thermal convection in porous media is a key aspect in many natural phenomena and engineering applications. In industry, examples include insulation systems and thermal energy storage systems. In the case of thermal energy storage systems, porous media can be combined with phase change materials to form composite systems in which heat is stored and released more efficiently [1]. In this case, the most widely used porous media are open-cell solid foams, which can store a large amount of phase change material, have a large surface area to volume ratio, and improve the melting rate. These foams are made of different materials and typically have a randomly organized solid structure or are characterized by unit cells with a specific geometry. When these composite systems are subjected to a temperature gradient, heat is transferred by conduction and, depending on the system and boundary conditions, by convection. The competition between the two heat transfer mechanisms depends on the thermal properties of the materials employed, the ability of the fluid to flow between the pores, and the temperature gradient [2].

Despite the importance that convection can have in such systems, detailed analyses on the role of the porous media properties on the convective heat transfer are still rare in the literature. This is largely due to the challenges of carrying out experiments with conventional flow visualization tools. Similarly, fluid dynamics simulations are subject to various thermodynamic and fluid mechanical problems (e.g. thermal non-equilibrium effects at the boundaries, presence of different pore scales, etc.).

### 2. Work

We propose to investigate thermal convection in a fluid-saturated highly porous foam through numerical simulations. The focus will be on a configuration analogous to Rayleigh-Bénard convection in porous media, that is, a system characterized by a thermo-convective flow that combines temperature gradients and fluid dynamics. The first step will involve developing a numerical model using COMSOL Multiphysics software (fig. 1), replicating previous experiments conducted at LEMTA [3] to enable a direct comparison between numerical and experimental results. In this way, a proper comparison between numerical and experimental results will be made. Once validated, the model will be tuned to explore the effects of various foam properties on both transient and steady-state convective regimes. We will examine how different thermal properties of the foam, such as higher or lower thermal conductivity relative to the fluid, influence heat transfer, and how different porous structures impact convective fluid flow due to the flow resistance near the porous matrix.

These simulations will provide detailed insights into pore-scale flow dynamics, addressing accuracy limitations commonly faced in laboratory experiments.

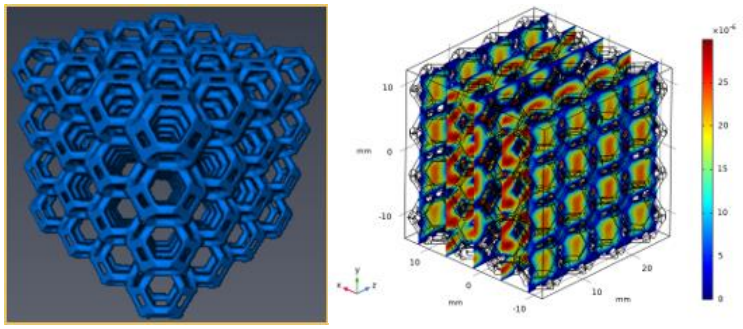

Figure 1: Structured porous foam (left) and local velocity field for Stokes flow induced by a pressure drop (right)

## 3. References


[1] F. Agyenim, N. Hewitt, P. Eames, M. Smyth, A review of materials, heat transfer and phase change problem formulation for latent heat thermal energy storage systems (LHTESS), Renew. Sustain. Energy Rev. 14 (2010) 615–628.

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[3] Sgreva, N. R., Métivier, C., Teixeira, A., Le, T. D., & Leclerc, S. (2024). Experimental velocity and temperature measurements for natural convection in a highly porous medium. International Journal of Thermal Sciences, 205, 109257.

# Title: Effects of current transients on the performance of PEM fuel cells

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**Fabien Harel, fabien.harel@univ-eiffel.fr**

**Field/nature:** fuel cells, electrochemistry, bibliographical study, modelling, digital simulation, experimental measurements

## Description

### 1. Context

The effects of applying strong current transients or "short circuits" to the terminals of a fuel cell in operation is little documented, or at least subject to varying interpretations in the bibliography [1-6]. However, this technique has been used for many years by several manufacturers of low-power open-cathode proton exchange membrane fuel cells (PEMFCs) to improve their performance. Apart from a patent filed by Ballard on the subject [7], only a few scientific publications report various explanations between membrane humidification and catalyst deoxidation to explain the performance improvements observed.
This project is part of the work being carried out as part of the FCLAB UPPERCUT (2023) and EDELWEISS (2024) projects, which aim to shed light on the physical phenomena involved. The UPPERCUT project, carried out in 2024, has enabled us to systematically characterize the effect of controlled short circuits on the performance of a closed-cathode fuel cell in operation, and to study the long-term effects. An initial approach to impedance modelling using impedance spectrometry and equivalent electrical circuits has made it possible to explain some of the phenomena observed, but a more in-depth analysis seems necessary to fully interpret the physics of the processes involved and verify the hypotheses put forward. To this end, the EDELWEISS project, which will run through 2025, will investigate the effect of short circuits in greater detail, using techniques to measure electrode potentials during transient current stress. Beyond physical understanding, the project aims to determine the impact of other parameters such as the duration of a short circuit [5, 8, 9], or the air supply mode (open or closed cathode).

### 2. Internship topic

In a first step, the aim is to carry out a bibliographical study of what is currently known about the impact of short circuits and, more generally, potential cycling on the performance and degradation of PEMFCs. Particular attention will be paid to identifying the potentials at which carbon and catalyst corrosion reactions take place. This will enable us to interpret the impact of short circuits in terms of material degradation reactions.

The second part of the internship will focus on the experimental study of a PEMFC single-cell (LEMTA or FEMTO-ST, to be defined) under high-current transient loading. In addition to performance (cell current and voltage), the aim is to measure high-frequency electrode potentials during dynamic loading phases. These measurements should enable us to gain a

more detailed understanding of the electrochemical mechanisms at play, and in particular to identify the oxygen reduction reaction times whose time constant plays an important role in the phenomena observed. These new characterizations will be combined with impedance spectroscopy measurements and equivalent electrical circuit simulations [10].

The experimental study will be accompanied by modeling of the dynamic current and potential behavior of a PEMFC following a short-circuit. Numerical simulation can be carried out using Python or Matlab.

## 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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# Title: Management of flow and electrochemistry in redox flow batteries

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**Main fields:** Energy, electrochemistry, Multiphysics modelling

## Description

### 1. Context

Redox flow battery (RFB) is considered as a low-cost alternative for stationary energy storage, which is essential for keeping the green energy (*e.g.* wind, solar) that have intermittent nature. The energy storage in RFB is achieved by changing the redox state of the electrolytes in the tanks, which is governed by electrochemical reactions. To increase the current density for charging/discharging of RFB, three strategies are spotted: (1) Increase the charge transfer kinetics on the electrode. This depends on the chosen electrolyte and electrode material. (2) Increase the active surface area of the electrode. This is usually achieved by using porous electrodes such as carbon felt. (3) Improve the mass transport of electrolyte by flow management. This is a key issue in RFB. On one hand, the flow may accelerate the mass transport of the electrolyte to increase the current density of charging/discharging, but on the other hand the flow is also intrinsically a source of loss of energy. The high pressure in the flow may also induce technical challenges, such as the leakage of electrolyte. It should be noted that (2) and (3) are sensitively dependent on the geometry of the electrode, which clearly sees high importance in the battery design. The internship is in the framework of PEPR project Radical that aims at designing a new generation of aqueous organic redox flow battery for renewable energy storage. Following the master training, we already have the funding for a three years PhD program.

### 2. Work

The work will be intensively based on numerical simulations of the electrochemistry and the flow. The general workflow of the internship is: design of electrode geometry → Simulation of flow by CFD → Simulate electrochemical processes with charge transfer kinetics, and mass transport from the flow → Experimental validation of simulation results (in close collaboration with experimentalists).

The design of electrode geometry may start from literature. Then, modifications will be implemented considering the experimental processability. Static flow will be considered, and the velocity and pressure distribution will be simulated. This may indicate the structural stability of the electrode, the risk of leakage, as well as the energy consumption on the flow. With the results, one may further simulate the electrochemical behaviour, obtaining the current distribution. This is another important indicator of the system, as it may affect the local heating and the stability of the system. If the progress allows, one may also consider the heat management of the system.

At the end, the modelling results will be validated by 3D printing of the electrodes by experiments, with the support from fellow experimentalists working in RFB. The triangle interactions of design ↔ modelling ↔ experiments will eventually converge to an optimized electrode design for high current density RFB.

## 3. References

F. Zhang, M. Cazot, G. Maranzana, J. Dillet, S. Didierjean, J. Energy Storage 55 (2022) 105704.
V. Feynerol, R. El Hage, M. Brites Helú, V. Fierro, A. Celzard, L. Liu, M. Etienne, Electrochim. Acta 421 (2022) 140373.

# Title : Characterization of wall heat transfer during spray cooling.

**Supervisor(s) :** **Ophélie CABALLINA , ophelie.caballina@univ-lorraine.fr**

**Guillaume CASTANET , guillaume.castanet@univ-lorraine.fr**

**Main fields :** heat transfer at interfaces, 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 critical challenge: heating, which disrupts their operation and degrades performance. Consequently, these systems require efficient cooling solutions, especially as cooling demands are projected to exceed 1000 W/cm² in the near future, compared to only 10 to 100 W/cm² today. One of the key limitations of current cooling systems is that heat extraction often occurs far from the heat source. Furthermore, existing cooling methods rely solely on forced convection, while incorporating boiling of the liquid coolant could significantly enhance cooling efficiency by utilizing the latent heat of vaporization.

This project is part of a research initiative aimed at developing a more effective cooling solution through direct contact. This involves spraying the coolant (such as water) in fine droplets directly onto the surface that needs to be cooled. Additionally, to optimize cooling performance, the properties of the solid heat exchange surface will be enhanced through specific texturing and careful selection of appropriate materials…

### 2. Work

To quantify heat transfer at the wall, several test benches were set up to observe cooling in several configurations: individual droplet, group of droplets, and finally, spray.


The objective of the measurements is to determine the time evolution of the wall temperature during the cooling, in order to deduce the heat flux extracted by the droplets and thus evaluate the cooling efficiency. The characterization can be performed using infrared thermography, providing both spatial and temporal resolution, in the cases of individual or multiple droplets. For the spray, the analysis relies on a network of thermocouples strategically placed at different points under the wall surface to capture temperature variations.

As part of this internship, the proposed work will include:

• **Improving the experimental setups**: The bench designed for studying droplet groups is in its final stages of development, while the spray cooling system has been dimensioned but still requires testing. The intern will be tasked with finalizing the injection devices and ensuring they function correctly to support the experiments.

• **Conducting measurement campaigns**: The heat flux extracted from the wall will be measured as a function of various impact parameters, such as droplet size and velocity, wall temperature, and the type of surface (smooth or textured). The objective is to evaluate the influence of these factors on cooling efficiency.

## 3. References


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[2] 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

[3] 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.

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[6] Y.T. Aksoy et al., Experimental investigation of the influence of nanoparticles on droplet spreading dynamics and heat transfer during early-stage cooling, Experimental Thermal and Fluid Science (149) : 111023, 2023.

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# Title : Optimization of operating parameters in anion exchange membrane fuel cell (AEMFC)

**Supervisor(s) :** **Feina XU, feina.xu@univ-lorraine.fr**

**Main fields :** Hydrogen fuel cells, AEMFC, electrochemistry, process, materials

**Description**

## 1. Context

Hydrogen fuel cells, such as PEMFC (Proton Exchange Membrane Fuel Cell) and AEMFC (Anion Exchange Membrane Fuel Cell), are electrochemical cells, which produce electricity and water as a by-product [1]. Unlike PEMFC, AEMFC operates in an alkaline environment, and the oxygen reduction reaction at the cathode requires the consumption of a molecule of water. Although AEMFC is still undergoing research and development, it offers the possibility of using platinum-free catalysts, and will ultimately reduce production costs compared with PEMFC.

## 2. Work

In order to gain a better understanding of AEMFC operation, we need to optimize the operating parameters of this fuel cell, either by modifying the composition of the catalyst layer of the membrane-electrode assembly (MEA) and/or by varying the operating conditions of the AEMFC cell.
The candidate for this Master 2 internship will be required (1) to carry out stack tests with MEAs prepared and formulated at LEMTA under predefined conditions, and (2) to process and analyze the results using Matlab.

The 6-month internship is based at LEMTA (UMR 7563) in Nancy.

**Profiles soughts:**

- Master 2 degree, preferably in process engineering, materials chemistry or electrochemistry.
- Knowledge of electrochemistry, processes and catalytic materials would be appreciated.
- Good level in English.
- Rigor, curiosity, critical thinking, teamwork, versatility, willingness to learn.

## 3. References

[1] : Gutru, Rambabu, Zarina Turtayeva, Feina Xu, Gaël Maranzana, Brigitte Vigolo, et Alexandre Desforges. « A Comprehensive Review on Water Management Strategies and Developments in Anion Exchange Membrane Fuel Cells ». International Journal of Hydrogen Energy 45, n° 38 (juillet 2020): 19642-63. https://doi.org/10.1016/j.ijhydene.2020.05.026.

# Title : Development of Constitutive Laws for Polymers Subjected to Combined Tension/Torsion Loading in the Framework of Nonlinear Viscoelasticity and Finite Strains

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**Main fields :** Mechanics of polymers

## 1. Context

The development of constitutive laws valid for multiaxial loading and finite deformations remains a largely unexplored area in polymer mechanics. To advance research in this field, the solid rheology team at LEMTA has conducted several preliminary studies, made possible by their access to a tension/torsion testing machine. Experimental procedures have been developed to allow for the machine to be controlled by an external signal, obtained in real-time through 3D image correlation measurements. This setup enables precise control of the loading path applied to the material within the effective area of tubular specimens.

During a previous master's internship, it was possible to model the tension/torsion coupling using a phenomenological model within the framework of small strains (see Figure 1).

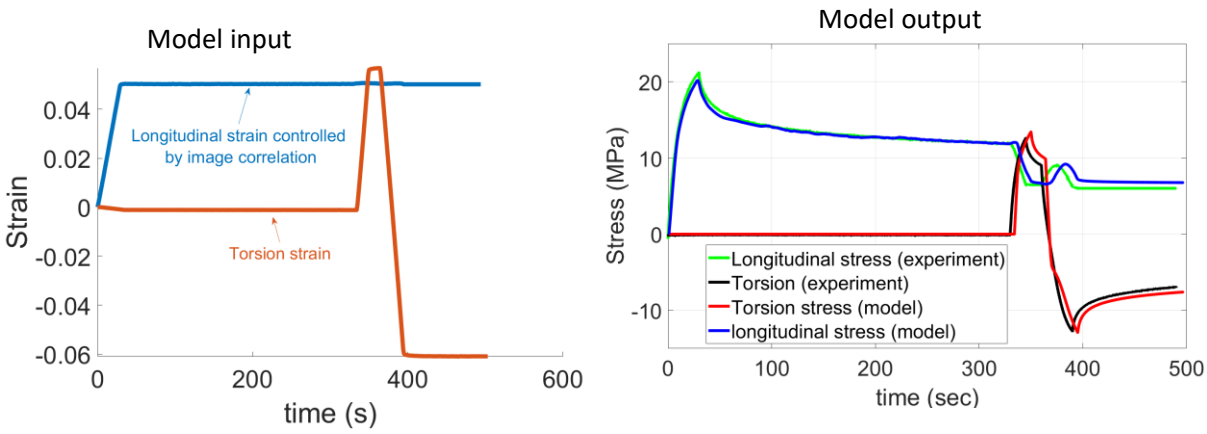


*Figure 1: Modeling of a Tension-Torsion Coupling Experiment*

The objective of the internship is to develop a rigorous modeling approach within the framework of finite strainss. To achieve this, original data-processing procedures have already been developed to estimate the "transformation gradient" tensor, including for points located within the volume of the hollow tube, not just on its outer surface. This approach enables the calculation of all strain tensors used in finite strain analysis, whether Eulerian or Lagrangian,

as well as the associated stress tensors. The ultimate goal is to establish relationships between strains and stresses in order to formulate multiaxial constitutive laws.
This internship could potentially lead to a doctoral thesis.

## 2. Work

The intern's work will primarily involve:

1. First, becoming familiar with the tools and procedures already developed, improving them as needed, and beginning to build a large and relevant experimental database.
2. Next, starting to develop constitutive laws within the framework of nonlinear viscoelasticity under finite deformations. This may draw inspiration from certain polymer behavior models, which are relatively easy to adapt to our approach and were initially designed to be integrated into finite element simulation codes.

## 3. References

1 Bonet, J. (2001). Large strain viscoelastic constitutive models. *International Journal of Solids and Structures*, *38*(17), 2953-2968

# Title : Drying and shrinkage of super-absorbent polymer hydrogels

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**Main fields:** Soft matter – Polymer – Poro-mechanics – Physico-chemistry - NMR / MRI

## Description

### 1. Context

The study focuses on super-absorbent polymeric hydrogels, which can swell to more than 100 times their initial volume. They are made up of polymer chains linked together to form a loosely cross-linked network. These chains have a high affinity for water, due to the existence of hydrophilic groups [1]. When a dry hydrogel is immersed in water, water molecules occupy the hydrophilic sites, leading to an unfolding of the polymer network and a macroscopic swelling of the hydrogel that can be quite spectacular. The cross-linking of the network chains nevertheless enables the hydrogel to retain a certain rigidity without disintegrating.

These hydrogels are used in many applications: in the medical field (dressings for burns, drug delivery, contact lenses, tissue engineering), in the personal hygiene sector (diapers, sanitary napkins), in the development of micro-systems (sensors, actuators, microvalves) and in agronomy and the environment (moisture retention, targeted fertilizer supply, water or soil depollution).

### 2. Work

Up to now, we have been working on the hydration/swelling of spherical hydrogel beads. A particular phenomenon during the swelling process caught our attention, namely the appearance of lobes, then their coalescence, leading once again to a spherical geometry of the waterlogged hydrogel bead [2-4]. It seems that this phenomenon does not occur during a drying/shrinking process, which raises questions of hysteresis or irreversibility.

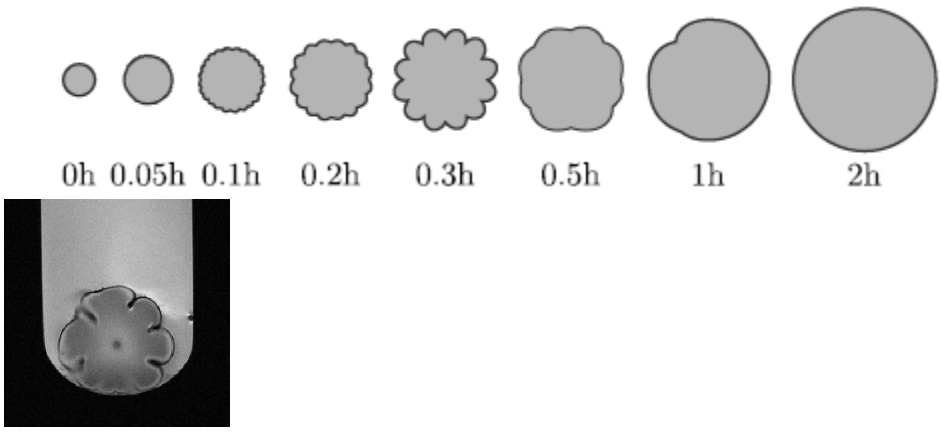


*Diagram of the transient swelling process of a hydrogel bead and MRI obtained after 30 minutes of swelling.*

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The proposed work will involve observing the swelling/hydration and shrinkage/drying of hydrogel beads under set conditions, using conventional techniques (weighing, calibration, dosing, photography) or NMR (relaxation, MRI). MRI imaging of hydrated hydrogel requires the use of a contrast agent (paramagnetic ions).

In fact, the NMR signal of water and that of a hydrated hydrogel are too close to each other to be distinguished, as hydrogel can contain more than 99% water. The contrast agent (paramagnetic ions) enables the hydrogel to be differentiated from the solution in which it is immersed (see MRI above). However, the presence of ions in solution can significantly modify the hydration process of the hydrogel [4]. Several previous studies have tested the extent to which the nature of the ions and their concentration influence the swelling-shrinkage mechanisms of the hydrogel. For this reason, this internship will focus on the dehydration/shrinkage mechanism, and in particular on the osmotic dehydration of hydrogel beads, which consists in deswelling a bead by immersing it in a high-concentration saline solution. Hydrogel beads can also be dehydrated using more conventional drying techniques (air flow, heating).

## 3. References


[1] T. Tanaka et al., Nature, 325, pp. 796-798 (1987)

[2] T. Bertrand, J. Peixinho, S. Mukhopadhyay, C. MacMinn ; Physical Review Applied 6, 064010 (2016)

[3] W. Barros, E. Azevedo, M. Engelsberg ; Soft Matter, 8, 8511 (2012)

[4] D. Stemmelen, F. Xu, A. Bchini, S. Leclerc, J. Peixinho, Observation par IRM du gonflement d'hydrogels, 25ème Congrès Français de Mécanique (2022) https://hal.univ-lorraine.fr/hal-03815085

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