

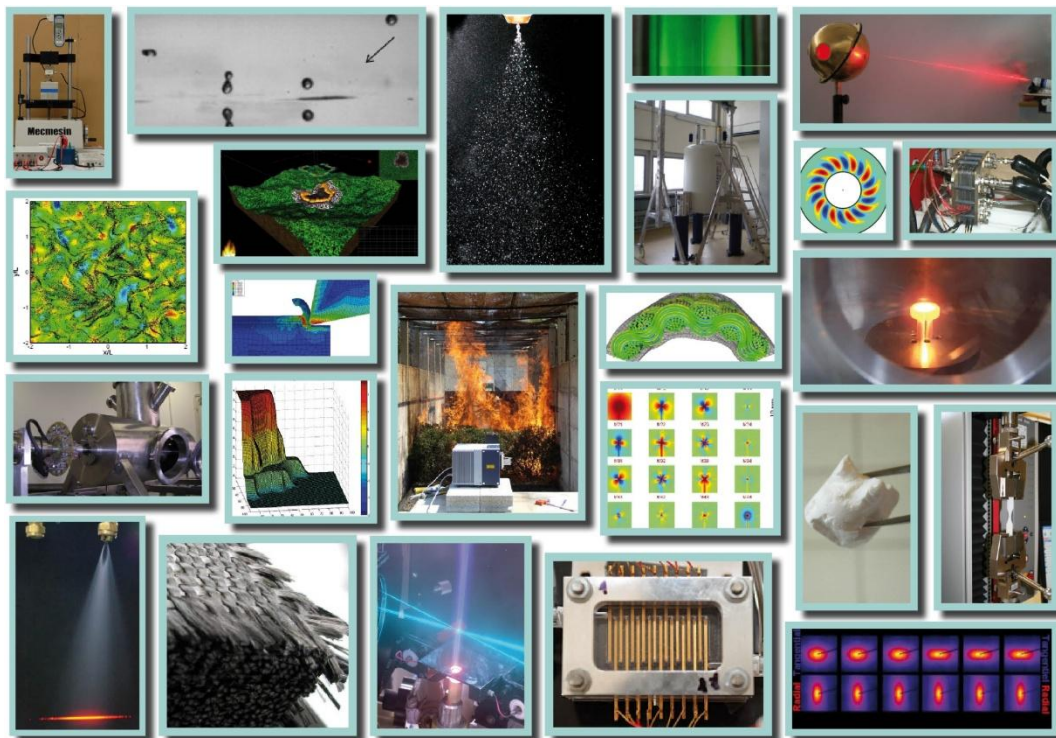
Brief description of internship offers such as Research level M2 at LEMTA or in partnership with LEMTA

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**

Measurement of Pore Size Distribution by NMR Cryoporometry

Supervisor(s): Didier STEMMELEN, Didier.Stemmelen@univ-lorraine.fr

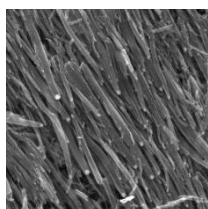
Sébastien LECLERC, Sebastien.Leclerc@univ-lorraine.fr

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

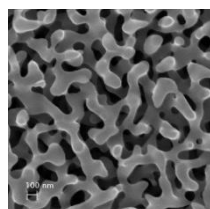
Description

1. Context

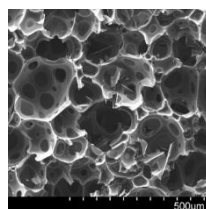
Nano-porous materials (clays, porous silica, carbons, zeolites, carbon nanotubes, etc.) are widely present in our environment and play key roles in filtration, storage, and depollution. Their properties strongly depend on the geometry and size distribution of their pores.



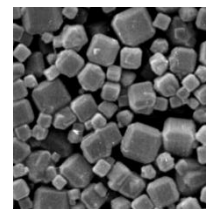
Carbon nanotube



Nanoporous glass



Activated charcoal



Zeolite

Pore size in micro- or nano-porous materials can be determined using microscopy techniques (X- μ CT, 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. Rev. 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 (RésOnance MAgnétique Nucléaire d'Ecoulements 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

- B. Oesterlé ; Ecoulements multiphasiques, *Hermes-Science* 219 p. (2006).
- P. T. Callaghan, Principles of Nuclear Magnetic Resonance Microscopy, *Oxford*, 490 pp. (1994).
- 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).