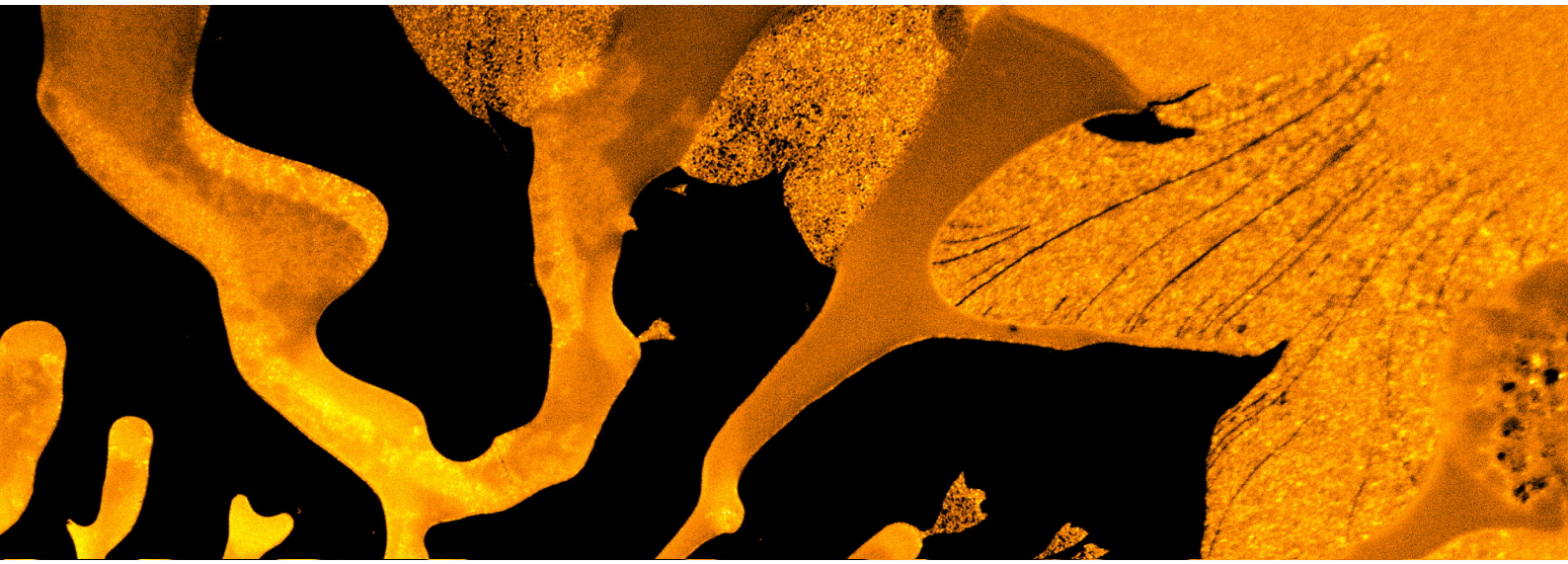
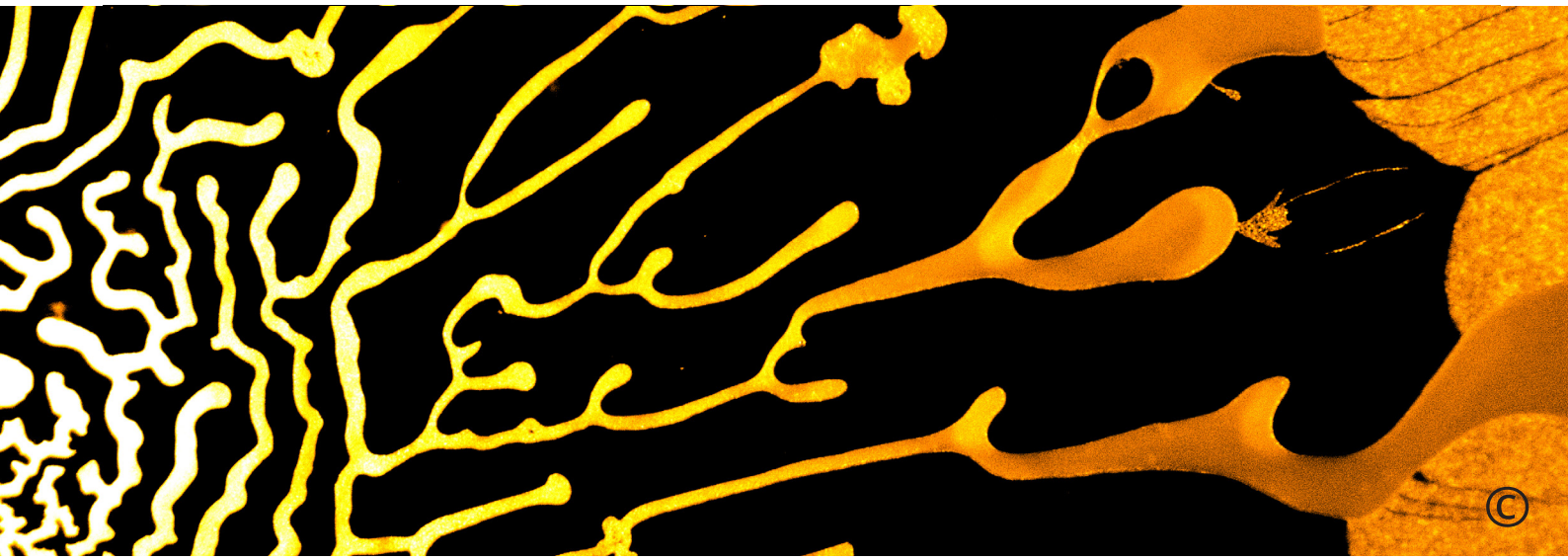
PoreLab
NTNU-UiO Porous Media Laboratory

The Research Council of Norway



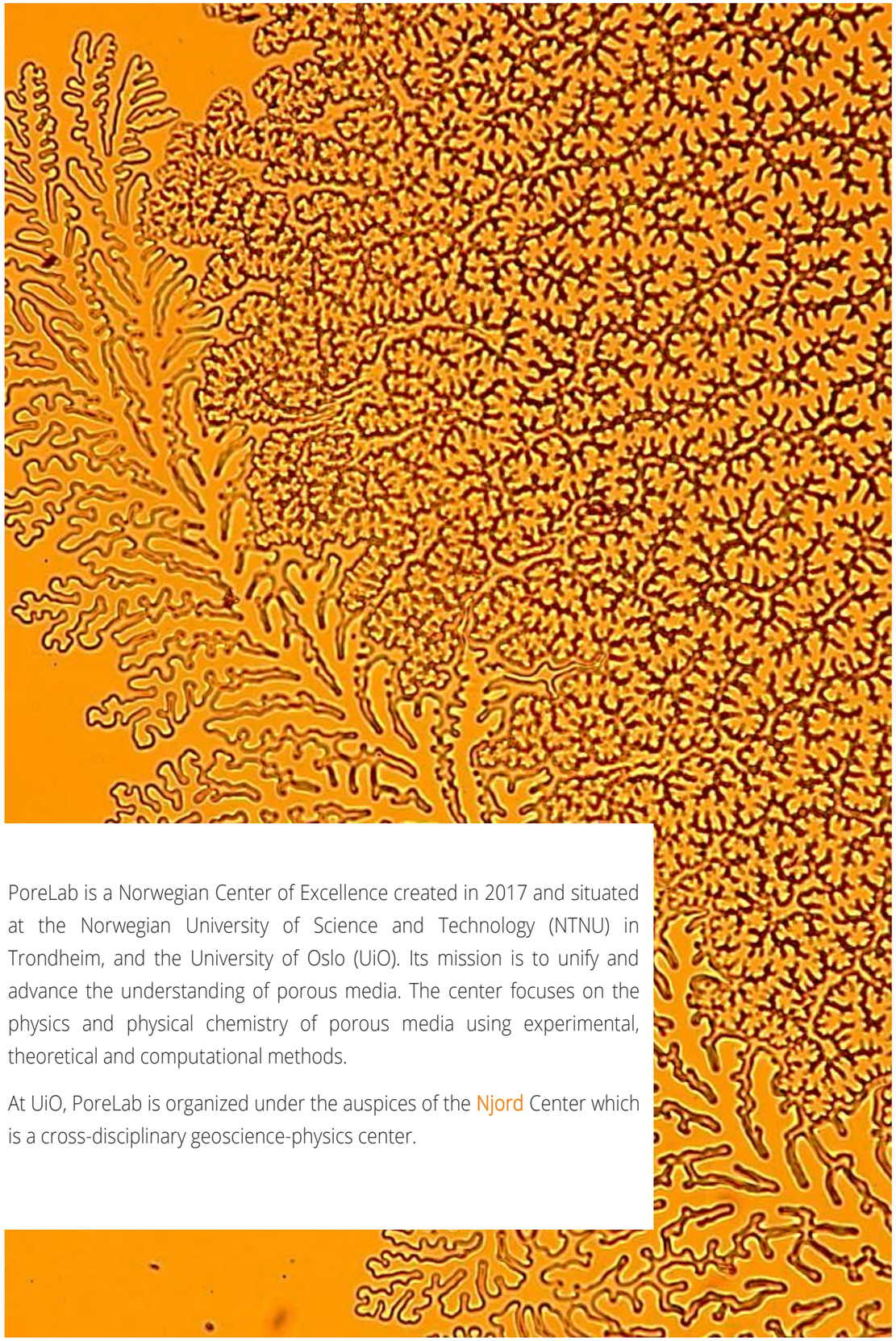
MSc at PoreLab 2025

Opportunities in 2026



NTNU
Norwegian University of Science and Technology

UiO : University of Oslo



PoreLab is a Norwegian Center of Excellence created in 2017 and situated at the Norwegian University of Science and Technology (NTNU) in Trondheim, and the University of Oslo (UiO). Its mission is to unify and advance the understanding of porous media. The center focuses on the physics and physical chemistry of porous media using experimental, theoretical and computational methods.

At UiO, PoreLab is organized under the auspices of the Njord Center which is a cross-disciplinary geoscience-physics center.

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COVER PAGE:
Labyrinthian drying pattern of a colloidal suspension, driven by capillary forces (Photo: © Erika Eiser)

Overview – 2025 MSc students

Name	Title Master thesis	Supervisors
Herborg Jess Sivilevicius	Evaporation Dynamics of Brine in Capillary Tubes	Dag Breiby, Anders Kristoffersen
Xunze Deng	Classical Force Field and Machine Learning Potential In Material Modelling	Raffaela Cabriolu and Alin-Marin Elena
Magnus Olsen	Understanding and Simulation of non-Newtonian Materials	Raffaela Cabriolu and Suman Dutta
Nils Tveit Gjerdåker	Numerical Simulation of Cu–Si Phases in the Rochow–Müller Process	Raffaela Cabriolu and Ingeborg-Helene Svenum
Daniel Aasen Bruland	Extending Revised Enskog Theory to Chain Molecules with Segments Interacting through a Mie-potential	Øivind Wilhelmsen, Morten Hammer, Vegard G. Jervell
Malin Sannerhaugen	Determination of an Equation of State for Solid Hydrogen	Øivind Wilhelmsen and Tage W. Maltby
Hedda Kvammen Rosendal	Modelling and Numerical simulation of Carbonated water Injection	Carl Fredrik Berg and Per Eirik Bergmo
Elias Wiland Lundh	Comparison of Oil and Gas Production Forecasting Methods	Carl Fredrik Berg and Hamidreza Erfani Gahrooei

Name	International Collaboration	Supervisors
Julie Delhaie	Experimental Investigation of Temporal Irreversibility in Immiscible Two-Phase Flow	Erika Eiser
Luca Schmid	Examination of the Power Production and the Lost Work in the Lithium Ion Battery Cell	Signe Kjelstrup and Øystein Gullbrekken
Emma Le Du	Gas Permeability in Porous Rocks: Comparative Study of Two Permeameters	Antje van der Net
Ferdinando Leone	Pressure Dependence of X-ray Attenuation of Xenon in the Presence of Residual Water in Porous Media for in-situ Gas Pressure Measurements.	Antje van der Net

Welcome to PoreLab

PoreLab would like to have more Master students!

We therefore invite potential students to make contact with anybody in our crew. Contact juniors to learn about our environment. Contact PIs and seniors for project possibilities!

The projects listed in the end of this booklet are only a fraction of the possibilities. We like to tailor new projects to the particular student's wishes and can start a new topic this way. The team's cores activities are presented in the Annual Report, and on our homepage. They serve also as useful starting points.

The climate crisis is a fact, and PoreLab is putting its weight behind the UN sustainability goals! With all our skills and ingenuity, we want to contribute to production of clean water and a more energy efficient world. Some of the master projects refer to that.

Norway has a high competence on transport of oil through porous media. PoreLab sees it as a mission to bring this basic competence to other fields of application.

We recently completed a project to study transport of nanoparticles with in cancerogeneous biological tissue. This is an example of a such a change in direction.

Looking forward to seeing you in PoreLab!

Signe Kjelstrup
Leader of graduate school

A Scientifically Inspiring and Including Working Environment

Training of Master and PhD students, as well as Postdoctoral researchers, is a core activity at PoreLab. An essential part of NTNU's and UiO's mission as universities, is student and researcher education. PoreLab is a valuable contributor in this respect. A vital asset of the center from an educational point of view is that it offers each student and junior researcher a scientifically stimulating and inclusive workday, much above the level of a regular MSc/PhD/Postdoc program.

"*Because we are interdisciplinary group, we work with people from different departments and universities and fields of research, which makes it an excellent learning environment*", says Astrid Fagertun Gunnarshaug, former PoreLab fellow and PhD candidate at the Department of Chemistry, NTNU. This is indeed our ambition at PoreLab, to create an interdisciplinary and international training ground for our juniors.

The aim of this catalogue is to provide an overview of the projects performed by our Master students in 2025 and inspire new students to join the team.

Over the years, our principal investigators have built strong collaborations with numerous research groups around the world. These partnerships have proven highly productive and have fostered a continuous exchange of students between PoreLab and our international collaborators. As a result, PoreLab has grown into a truly international community. Our Master students come not only from NTNU and UiO, but also from a wide network of partner institutions abroad. To support this mobility, the Center offers dedicated funding that enables foreign Master students to spend part of their studies with us. Similarly, our own students have the opportunity to carry out research stays abroad through these financial schemes. A comparable arrangement is available for Master students moving between NTNU and UiO. These funding opportunities are made possible through direct support from PoreLab as well as additional research projects initiated by our principal investigators in collaboration with national and international partners.

As a PoreLab Master student, you will get an office space at PoreLab premises. Being part of the PoreLab team, you will be offered to attend and contribute to all PoreLab events, such as the PoreLab lecture series organized usually every other Wednesday at 13:00. We host this event simultaneously in Oslo and Trondheim, and it is open to all. The PoreLab lecture series are now almost always given by external lecturers.

PoreLab started again the Journal club during the Spring 2024 semester. The idea is to present a recent paper with a short preparation time, so that the juniors (PhD candidates and postdoctoral researchers) can learn how to read papers quickly, understand its main content, and explain it to others. The juniors are given a paper 1-2 days before the presentation. The Journal Club is usually organized one or two times a month, on Thursdays. It is our goal that each PoreLab member should participate with at least one presentation during the course of the year. Master students are welcome to attend.

PoreLab provides a research environment that is centered for working as a team and that allows everyone's talents to flourish. Therefore, open communication is crucial at PoreLab, and we designed the organization to achieve this goal. Ailo Aasen, former PhD candidate at PoreLab, provides a good summary: "*It is an open and social atmosphere with genuinely nice people. I especially like how there is so much interaction between the senior and junior researchers".* Hossein Golestan, PhD candidate at PoreLab, says that*: "The working environment is excellent, and the colleagues are so eager to share their knowledge. The best side is its international atmosphere with people from different fields of research (Physics, chemistry, Petroleum and so on) and whenever you have a question there is always someone who can help you finding the answer".*

At PoreLab UiO, the researchers also join forces with the larger team of the Njord Centre, for interdisciplinary collaboration across the fields of physics and geology, as well as larger social gatherings, conferences and other events. As researcher, Marcel Moura puts it: "*The idea 'Simplify it until you understand it', is really in the nature of physics and it has given us quite a lot. However, it is important to remember that sometimes reality is bigger and more complex than our models. Therefore, being in close proximity to scientists who tackle nature at different scales of complexity – geologists, volcanologists, and rock scientists of all types – is excellent to keep our eyes open and our antennas tuned.*"

Though PoreLab has dedicated, eager researchers, being at PoreLab does not only mean hard work. The Pore Buzz at PoreLab NTNU and the Junior club at PoreLab UiO are informal events that aim to strengthen connection within our group and integrate new juniors, Master students and guests. The hottest research topics in the field, as well as pizza, are on the menu of these convivial and relaxing events. For more social interaction, we all meet at 10' every day for our coffee break, as well as at lunchtime. On Mondays, fruits and cake are served. In addition, a ping-pong table, a table soccer and an ever-present thousand-pieces puzzle became popular playgrounds for all at PoreLab NTNU.


1


2


3


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A glimpse of students' activities at PoreLab
1. Coffee break at 10:00 every morning 2. Srutarshi, Hossein, Giulio and Michael take a break. 3. Internal seminar 4. The PoreLab UiO team at the summer's cabin of Joachim Brodin

Herborg Jess Sivilevičius

Department of Physics, NTNU

Evaporation Dynamics of Brine in Capillary Tubes

Fall 2025/Spring 2026

Supervisors: Dag W. Breiby and Anders Kristoffersen (Equinor)

Background:

Evaporation of brine in porous media plays a key role in subsurface processes such as drying, gas migration, and salt precipitation. Salt precipitation is also a key concern for subsea CO_2 storage. A single capillary tube provides an idealized pore-scale system that allows detailed investigation of evaporation-driven transport and crystallization under well-controlled conditions.

Methodology:

Evaporation experiments were performed in vertical round capillary tubes filled with NaCl brine. Time-resolved X-ray micro–computed tomography was used to image the evaporation process in situ, enabling direct observation of the meniscus motion, salt concentration gradients, and precipitation. Image analysis techniques were applied to quantify the temporal evolution of the system.

Results:

The experiments show that the liquid–gas interface moved consistently with evaporation being limited by diffusion in the gas phase. As evaporation proceeded, clear salt concentration gradients developed inside the capillary, with the highest concentration near the evaporating interface (top meniscus). Salt precipitation was observed at different locations in different experiments and appears to be strongly influenced by local conditions. These results show that even a single capillary tube can display complex evaporation-driven crystallization behavior.

Jessica Zeman and Basab Chattopadhyay are thanked for assistance and discussions.

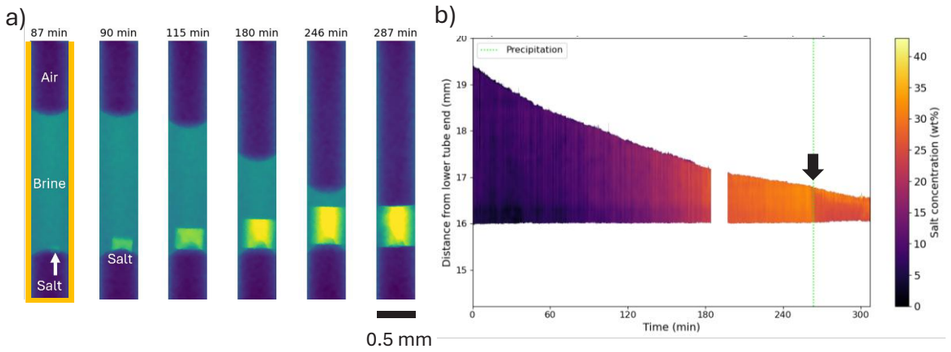


Figure 1: *a) Time series of CT cross sections showing evaporation and salt (NaCl) precipitation. As indicated, the top end was open while the lower end was closed. In this case, the first visible crystal appeared at the lower meniscus and grew into a compact crystal. b) Example of space–time map of the salt concentration inside the brine plug, obtained from CT intensity profiles. The color scale represents the local salt mass fraction. Note the vertical gradient and the sudden change upon the onset of salt precipitation, as indicated by the black arrow. (a and b are from different experiments).*

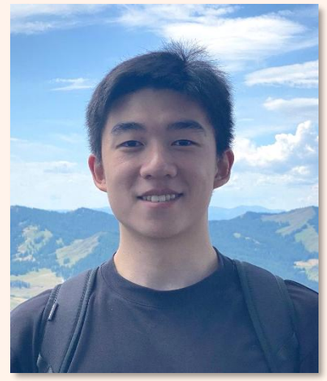
Xunze Deng

Department of Physics, NTNU

Classical Force Field and Machine Learning Potential In Material Modelling

Fall 2025/Spring 2026

Supervisors: Raffaela Cabriolu and Alin-Marin Elena



Metal organic frameworks (MOFs) is a class of nano porous material that consists of metal ions and organic linkers. Their high surface area, tunable pore geometry and chemical modularity make MOFs suitable for a wide range of applications, such as gas storage and catalyst [1]. Therefore, understanding the thermal properties such as the thermal expansion or thermal conductivity of MOFs is crucial. An example structure of a MOFs system is shown in Figure 1.

Molecular dynamics simulation has been studied in understanding the thermal behavior of MOFs, producing results in agreement with the experimental value. However, it is computationally demanding due to the large unit cell of the MOFs. To overcome these limitations, recent work has increasingly focused on machine learning potentials, demonstrated strong transferability and can achieve high accuracy while requiring less computational resources.

This project focuses on the investigation of the thermal properties of metal organic frameworks using both classical and machine learning parameterized potentials. Two MOFs systems MOF-5 and UiO-66 were selected. Molecular dynamics will be performed using LAMMPs with the classic force field UFF4MOF, and the resulting thermal properties will be benchmarked against MACE-MP a machine learning potential. The goal of this project is to compare the accuracy and efficiency of both methods. If time allows, an additional objective is to train a new machine learning potential for a better understanding.

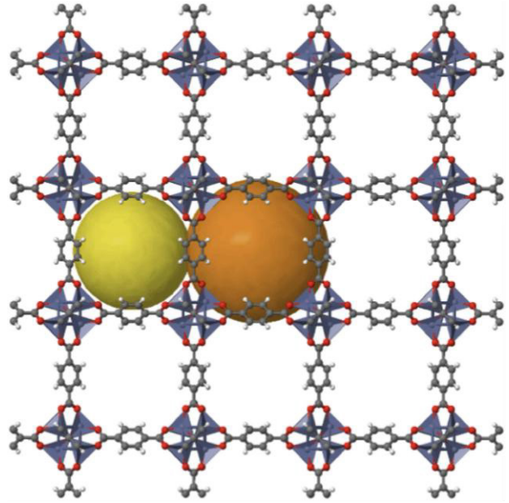


Figure 2: *Structure of MOF-5, the spheres represent the pore structure [2]*

References

[1] V. F. Yusuf, N. I. Malek, and Suresh Kumar Kailasa, “Review on Metal–Organic Framework Classification, Synthetic Approaches, and Influencing Factors: Applications in Energy, Drug Delivery, and Wastewater Treatment,” *ACS Omega*, vol. 7, no. 49, pp. 44507–44531, Dec. 2022, doi: https://doi.org/10.1021/acsomega.2c05310.

[2] “MOF-5 (or IRMOF-1) Metal Organic Framework,” *ChemTube3D*, Aug. 05, 2021. https://www.chemtube3d.com/mof-mof5/ (accessed Jan. 14, 2026).

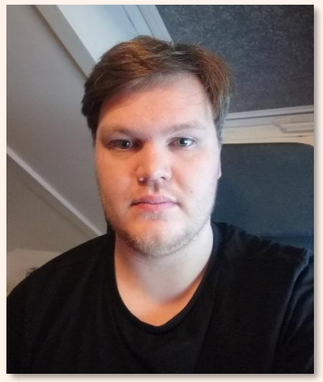
Magnus Olsen

Department of Physics, NTNU

Understanding and Simulations of non-Newtonian Materials

Fall 2025/Spring 2026

Supervisors: Raffaela Cabriolu and Suman Dutta



Understanding the underlying properties of non-Newtonian fluids remains a significant challenge. These materials can respond very differently under external forces, exhibiting either liquid-like or solid-like behavior depending on their intrinsic properties and the applied shear. Molecular simulations can be used to understand those materials because they provide a powerful tool to systematically probe and rationalize the behavior of them at the atomistic scale.

This project focuses on simulations of non-Newtonian fluids using the Yukawa potential in a binary colloidal system as a model for yield-stress materials. Through these simulations, we can obtain a range of results that allow us to investigate the physical properties and emergent phenomena. So far, the simulations have provided clear insight into how the application of shear alters the material's behavior, particularly with respect to particle self-diffusion and the mean squared displacement (MSD).

There is also strong potential to extend this work toward the study of phenomena, such aging and creep, that could exhibit irreversible and reversible behavior depending on the conditions.

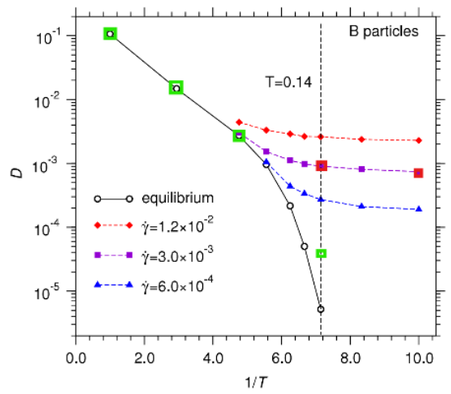


Figure 1: *Self-Diffusion coefficients for different temperatures, with and without shearing. The coefficients are compared to the results found by J. Zausch [1]*

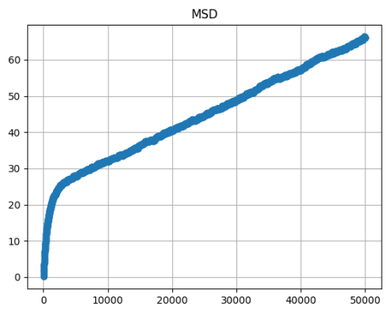


Figure 2: *The MSD value calculated plotted against the timesteps done in the simulations*

Reference:

[1] J. Zausch, J. Horbach, M. Laurati, S.U. Egelhaaf, J.M. Brader, Th. Voigtmann, M. Fuchs. From Equilibrium to Steady State: The Transient Dynamics of Colloidal Liquids under Shear. *Journal of Physics: Condensed Matter*, September 2008, 20 (40), DOI:10.1088/0953-8984/20/40/404210

Nils Tveit Gjerdåker

Department of Physics, NTNU

Numerical Simulation of Cu–Si Phases in the Rochow–Müller Process

Fall 2025/Spring 2026

Supervisors: Raffaela Cabriolu and Ingeborg-Helene Svenum

Understanding The Rochow–Müller process is a key industrial route for producing silicones. Despite extensive research, much remains poorly understood, and any improvement could have a large economic and environmental impact.

This thesis is carried out in collaboration between NTNU and SINTEF, with the goal of building a deeper atomistic understanding of the Rochow Müller process. Under reaction conditions, copper and silicon form alloy intermediates, and multiple Cu–Si phases can coexist.

I will use numerical simulations to identify and analyse relevant bulk and surface structures in the Cu–Si system, combining density functional theory (DFT) as a reference method with large-scale molecular dynamics (MD). To enable MD for realistic system sizes, I will develop and validate classical Embedded Atom Model (EAM) potentials (and potentially extended forms such as MEAM) and compare them to machine-learned interatomic potentials based on MACE.

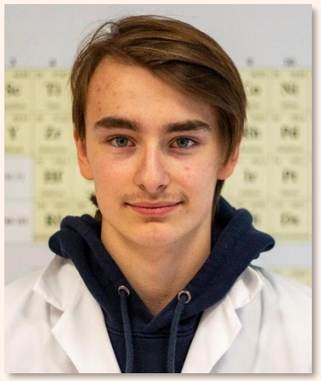
References:

[1] Y. Zhang, J. Li, H. Liu, Y. Ji, Z. Zhong and F. Su, 'Recent advances in Rochow–Müller process research: Driving to molecular catalysis and to a more sustainable silicone industry,' ChemCatChem, vol. 11, no. 13, pp. 3195–3211, 2019. DOI: 10.1002/cctc.201900385.

[2] I.-H. Svenum, S. Gouttebroze and F. L. Bleken, 'Formation of dimethyldichlorosilane (m2) in the Müller-Rochow process at the molecular level,' Catalysis Today, vol. 445, p. 115075, 2025, Accessed: 2025-12-10. DOI: 10.1016/j.cattod.2024.115075. [Online]. Available: https://doi.org/10.1016/j.cattod.2024.115075

[3] D. Seyferth, 'Dimethyldichlorosilane and the direct synthesis of methylchlorosilanes. the key to the silicones industry,' Organometallics, vol. 20, pp. 4978–4992, 2001. DOI: 10.1021/om0109051.

Daniel Aasen Bruland



Department of Chemistry, NTNU

Extending Revised Enskog Theory to Chain Molecules with Segments Interacting through a Mie-potential

Fall 2024/Spring 2025

Supervisors: Øivind Wilhelmsen, Morten Hammer, Vegard G. Jervell

Predicting the shear viscosity, thermal conductivity and diffusion coefficients of chain molecules in the zero-density limit

Understanding the transport phenomena describing the transfer of mass, momentum and energy is crucial when studying thermodynamic systems that are not in equilibrium. When computing the fluxes of mass, momentum and energy it is very useful to be able to have accurate predictions of the viscosity, thermal conductivity and diffusion coefficients.

Revised Enskog theory for soft spherical molecules interacting through a Mie-potential (RET-Mie) has been shown to predict the transport properties of gases with low to moderate densities accurately. The viscosity has also been computed accurately for chain molecules consisting of tangentially joined spherical segments interacting through a hard sphere potential. However, a fully predictive model for the transport properties of chain molecules has yet to be published in the open literature.

This work describes chain molecules with spherical segments tangentially joined and interacting through a Mie-potential, where the fluid is modeled by RET-Mie with a modified radial distribution function at contact to account for the fact that the segments cannot freely collide with every other segment. The scope of this work is limited to the zero density limit, i.e. gases at infinite dilution.

This approach to chain molecules with soft segments allows accurate predictions of the viscosity, thermal conductivity and Fick's diffusion coefficients of pure gases and binary mixtures of gases in the low density limit. The viscosity and thermal conductivity for the n-alkanes from methane to n-decane were predicted with an absolute average relative error of 2.19% and 4.17% respectively, within the temperature range 300 K to 500 K.

The predicted self-diffusion coefficients for methane, ethane and propane were predicted with an absolute average relative error of 4.23% within the same temperature range. This extension of RET-Mie to chain molecules is a promising start into further developing a fully predictive model for the transport properties of chain molecules.

References:

[1] Jervell, Vegard G., and Øivind Wilhelmsen. "Revised Enskog theory for Mie fluids: Prediction of diffusion coefficients, thermal diffusion coefficients, viscosities, and thermal conductivities." The Journal of Chemical Physics 158.22 (2023).

[2] Wilhelmsen, Øivind, et al. "Coherent description of transport across the water interface: From nanodroplets to climate models." Physical Review E 93.3 (2016): 032801.

NTNU - Department of Chemistry

Malin Sannerhaugen

Department of Chemistry, NTNU

Determination of an Equation of State for solid Hydrogen

Fall 2025/Spring 2026

Supervisors: Øivind Wilhelmsen and Tage W. Maltby

Background:

Solid state Hydrogen is the simplest yet one of the most complex molecular systems [1]. The light weight results in considerable quantum effects making zero-point motion and anharmonicities play a considerable role. These effects make solid Hydrogen a highly relevant system for studying quantum theories. A central tool for studying molecular systems is the Equation of State (EoS). Although there have been several attempts at formulating such an EoS for solid Hydrogen, no EoS has been shown to be accurate below the triple point.

Objective and Methodology:

In this work we aim to develop an EoS for solid hydrogen by the use of the quasi-harmonic approximation. To account for the quantum effects, we would like to explore the possibility of applying Feynman-Hibbs (FH) corrections.

Results:

Figure 1 compares the interaction potential between two Hydrogen molecules using both ab-initio and Mie potentials with their corresponding FH corrected forms. The figure shows that the FH corrections reduce the effective well depth while increasing both the effective particle diameter and the range of the potential. It also illustrates that these FH-induced changes become more pronounced as the temperature decreases.

Figure 2 presents the heat capacity predicted by the EoS model alongside experimental measurements reported by Ahlers [2]. The comparison shows good agreement at low molar volumes, while deviations emerge at higher volumes.

References:

[1] McMahon, J. M. *et al.* The properties of hydrogen and helium under extreme conditions. *Reviews of Modern Physics*, 84(4):1607–1653, (2012).

[2] Ahlers, G. Lattice Heat Capacity of Solid Hydrogen. *The Journal of Chemical Physics*, 41(1):86–94, (1964).

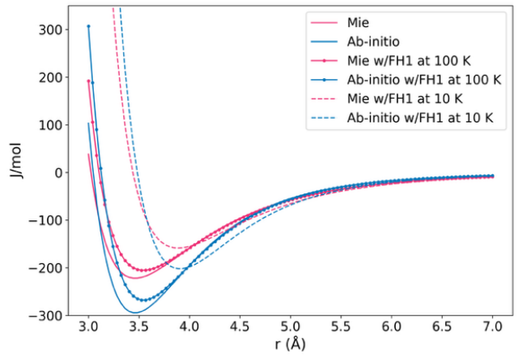


Figure 3: *Comparison of the Mie potential and the Ab-initio potential with and without FH1 at 100 K and 10 K*

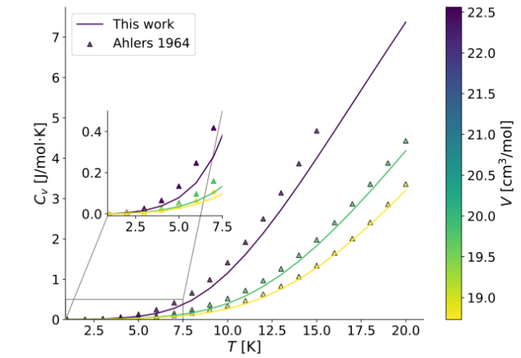


Figure 4: *Isochoric heat capacity (C_V) calculated using the EoS model, compared with experimental data from Ahlers [2]*

Hedda Kvammen Rosendal

Department of Geosciences, NTNU

Modelling and Numerical simulation of Carbonated Water Injection

Fall 2025/Spring 2026

Supervisors: Carl Fredrik Berg and Per Eirik Bergmo (SINTEF)

Background:

Carbonated water injection (CWI) is an attractive method in the petroleum industry as it enhances oil recovery while also enabling CO_2 storage. This study provides an evaluation of the recovery mechanisms during CWI and examines the capability of numerical simulation to reproduce laboratory-scale EOR (Enhanced oil recovery) behavior and CO_2 storage potential.

Objectives:

The objective of this study is to evaluate the effect of carbonated water on oil recovery and CO_2 storage. This study simulates a set of core flooding experiments conducted by SINTEF in 2025, which will be used to determine the effect of CWI on oil production and CO_2 retention in the core. The main objective is to prove what EOR mechanisms are present in the simulations, as accurate simulation of the physics involved in fluid–fluid and fluid–rock interactions is essential to upscale laboratory-scale CWI mechanisms to the field scale to predict reservoir performance and to evaluate its potential for CO_2 storage.

Methodology:

By modeling and simulating the experiments in the ECLIPSE 300 reservoir simulation software, the flow parameters can be history matched and later upscaled and used for field-scale simulations. This can cover a knowledge gap regarding the accuracy and reliability of simulations of CWI EOR mechanisms like wettability, IFT-reduction, viscosity reduction and oil swelling.

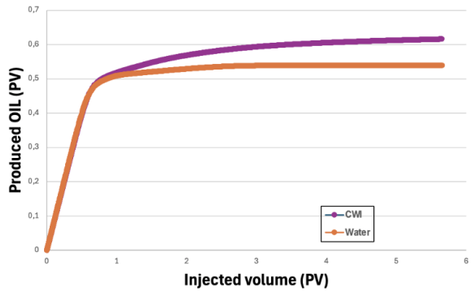


***Figure 1**: Oil produced from simulation of 1D-core with Carbonated water injection vs water injection*

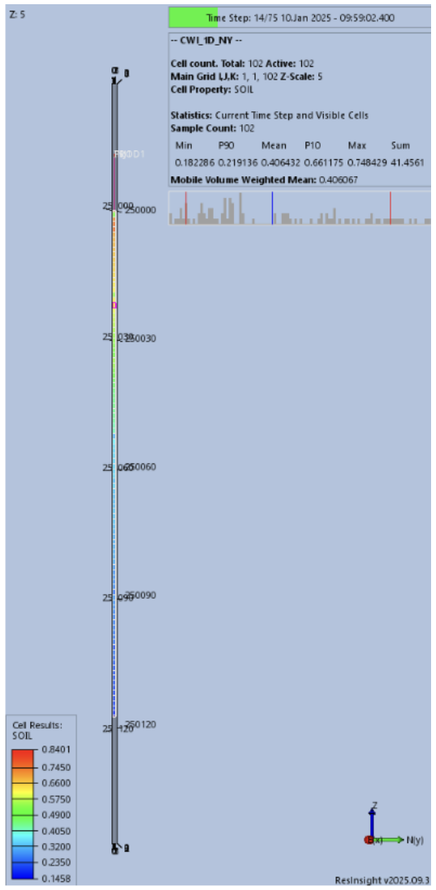


***Figure 2:** Visualization of the 1D-core model.*

Elias Wiland Lundh

Department of Geosciences, NTNU

Comparison of Oil and Gas Production Forecasting Methods

Fall 2025/Spring 2026

Supervisors: Carl Fredrik Berg and Hamidreza E. Gahrooei (Equinor)

Motivation

Having some or complete information of the future production of some field is important for a couple parties; for the company to make future decision of the field, e.g. new wells or to know when to shut down the field as it is no longer economically viable and the government to determine emissions and taxes.

Finally, if the company is listed on some stock exchange they are obliged to publicize their future production and thus their total assets making the stock be evaluated on a fairer basis in the market.

Background

For the project an actual field on the NCS (Norwegian Continental Shelf) has been picked. It initially had two requirements:
1) It had to be in decline and
2) There had to be an FMU (Fast Model Update) model.

Methodology

As the project aims to compare methods production forecasting and the future is an actual unknown, for the sake of the project; it is assumed to be 2020. The time between 2020 and 2025 is the quality control (QC) period since the rates for the wells and the fields history is known. The QC period is to check if the prediction up until that point is sound compared to the real production.

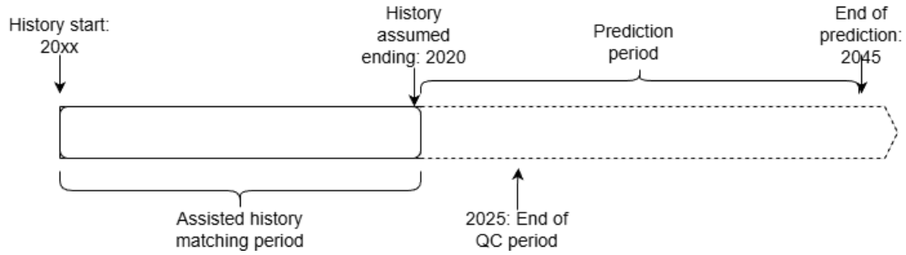


***Figure**: FMU (Fast Model Update) setup*

International Collaboration

Julie Delhaie

Ecole Normale Supérieure de Lyon, France
Department of Physics, NTNU

Experimental Investigation of Temporal Irreversibility in Immiscible Two-Phase Flow

Three-month summer internship, from April to July 2025

Supervisor: Erika Eiser, NTNU

Background:

Understanding two-phase flow in porous media remains a challenge due to the interplay between capillary effects, wettability and pore-scale geometry. While theoretical models predict both spatial and temporal reversibility, experimental observations reveal irreversible behaviour when the pore structure is asymmetric.

Objectives:

The aim of this internship was to experimentally investigate temporal irreversibility in immiscible two-phase flow through 3D-printed porous media composed of triangular pillars. The study focused on evaluating how porosity and geometric disorder affect the degree of irreversibility.

Methodology:

The porous media were designed using FreeCAD and fabricated via 3D printing. To study the role of structure on irreversibility, the samples were produced with controlled porosity and different levels of geometric disorder. Air and dyed water–glycerol were injected at a constant flow rate using a syringe pump. Temporal correlation functions were then computed to evaluate the irreversibility.

Results:

Temporal irreversibility was systematically observed. It increased with porosity and disorder, which suggests that the more freedom the fluids have to explore different pathways, the harder it becomes for the flow to retrace its evolution. In disordered media, the non-wetting fluid followed preferential pathways, forming persistent fingering patterns.

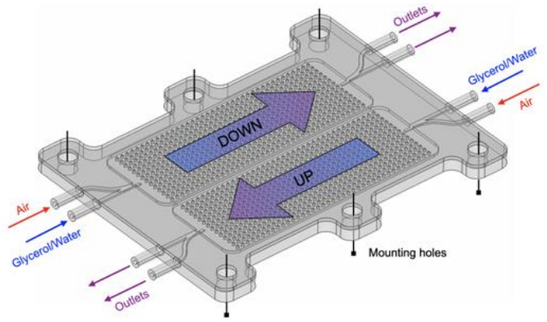


***Figure 1**: 3D model of the porous medium used in the experiments*

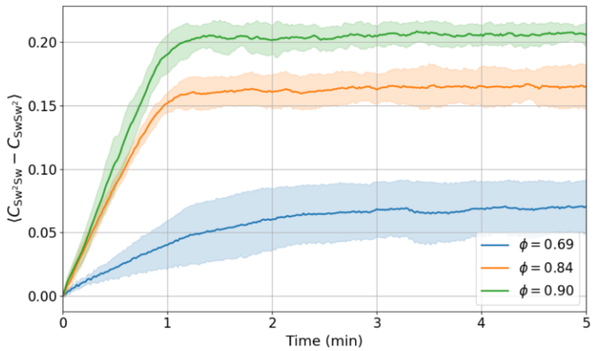


***Figure 2:** Temporal evolution of temporal correlation functions for the different porosity studied*

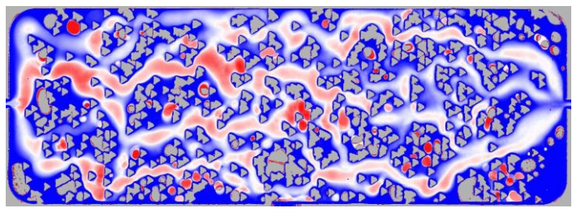


***Figure 3:** Average fluid distribution at steady state with a color LUT: white areas correspond to roughly equal proportions of liquid and air, red tones indicate regions dominated by air, and blue tones show areas mostly occupied by liquid.*

International Collaboration

Luca Schmid

University of Stuttgart and Department of Chemistry, NTNU

Examination of the Power Production and the Lost Work in the Lithium Ion Battery Cell

Four-month Erasmus internship in the fall 2025

Supervisors: Signe Kjelstrup and Øystein Gullbrekken, NTNU

Background:

The theory of non-equilibrium thermodynamics allows for predicting the irreversible losses in processes. Previous projects applied the theory for a lithium-ion battery cell. A model has been created that simulates temperature, potential and concentration profiles within the cell and transport processes.

Objectives:

The objective of this work is to test and use this model to derive what measures could increase the battery performance in terms of efficiency, power output and further aspects. Firstly, the base parameter set is being reviewed, that captures system and material properties. Then sensitivity studies are being done for different variations of parameters and boundary conditions. This should simulate how operation conditions and battery properties can influence the performance.

Results:

The reviewed parameter set points out the importance of the Peltier effect, which has a large influence on the temperature profiles and heat fluxes. This provides further insight into the thermal behavior of the cell.

In addition, the model shows that increased electric and thermal conductivity values for the electrode surfaces can improve battery efficiency. This suggests that a larger electrode surface area can benefit the battery performance.

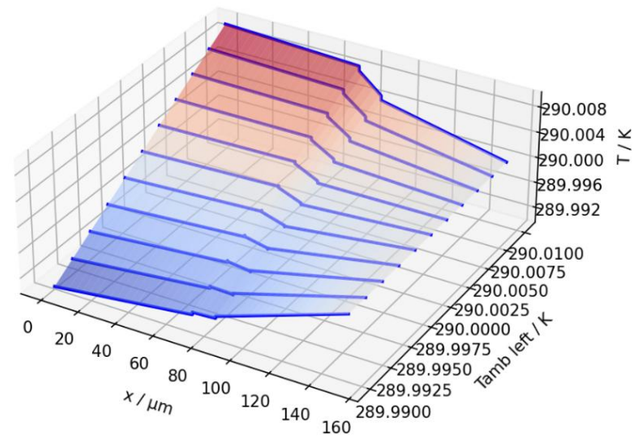


***Figure**: cell temperature profiles for variation of left-hand side boundary temperature*

Emma Le Du

Ecole Centrale of Nantes in France and
Department of Geosciences, NTNU

Gas Permeability in Porous Rocks: Comparative Study of Two Permeameters

One-month summer internship, from June to July 2025

Supervisor: Antje van der Net, NTNU

Background:

Permeability is a key property of porous rocks, crucial for modeling fluid flow in geothermal systems, hydrocarbon reservoirs, and CO_2 storage. It determines how easily fluids can move through the pore network, directly influencing transport efficiency and reservoir performance. Accurate permeability measurements are essential for predicting flow behavior, optimizing extraction or injection strategies, and ensuring long-term viability of subsurface operations.

Methodology:

This internship investigated inconsistencies in gas permeability measurements using two setups: a custom-built IGV permeameter and a commercial device from Top Industrie. Both operate under steady-state flow, with permeability calculated via Darcy's law. For low-pressure conditions, the Klinkenberg correction was applied to account for gas slippage. Tests involved varying inlet and outlet pressures to explore flow regimes and improve reproducibility.

Experimental Work:

Permeability tests were performed on cylindrical rock samples. After initial leak repairs, the IGV system produced the most consistent results when operated under constant differential pressure, showing strong linearity in the Klinkenberg plots. The Top Industrie device showed less reliable results; its closed architecture prevented internal flow path verification, making precise checks impossible and raising concerns about accuracy.

From the graph below, the true permeability can be determined as the y-intercept of the Kguess (1/Pm) line, according to the Klinkenberg correction. Experiment 12, conducted using the IGV permeameter, yields a satisfactory interpolation coefficient (R^2 = 0.9224) and a permeability of 23.7 mD. It also highlights the importance of systematically increasing and decreasing Pin, the inlet pressure of the core, during measurements.

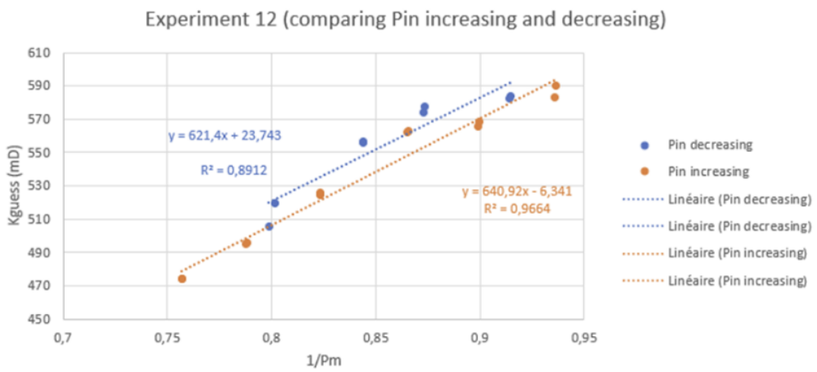


***Figure**: Apparent permeability as a function of inverse mean pressure — experiment 12*

Ferdinando Leone

Department of Energy Engineering, Politecnico di Milano, Italy
and Department of Geoscience, NTNU

Pressure Dependence of X-ray Attenuation of Xenon in the Presence of Residual Water in Porous Media for in-situ Gas Pressure Measurements.

Six-month summer internship, from January to June 2025
Supervisor: Antje van der Net, NTNU

Multiphase flow through porous media has been of major interest due to its application in various fields, ranging from enhanced oil recovery, fuel cells, to CO_2 storage. This investigation aimed to gather further knowledge on the use of Xenon in X-ray imaging in multiphase gas systems, for determining in-situ pore pressure, an important parameter for a multiphase flow description.

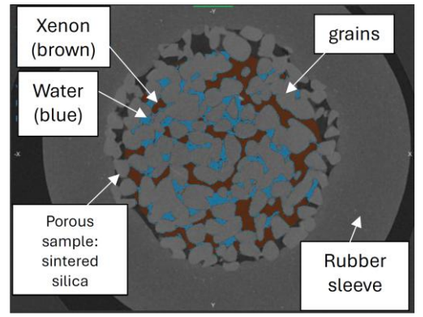
Commonly pressure meters are used to measure externally pressure over the samples. The phases are then assumed to be continuous, which is not always a correct assumption. Currently however there is no method available to measure pressure in situ for discontinuous phases.

In earlier micro-CT studies, it was shown that dry Xenon gas, due to its high molecular weight, displays a linear pressure dependent X-ray attenuation (adsorption) [1] [2]. In this study, steps are made to validate whether pressurized Xenon in the presence of water shows a similar unique pressure dependent signal in the micro-CT scan, Figure 1a. The results in Figure 1b show that Xenon attenuation in presence of residual water saturation shows a similar, but slightly lower linear trend as the repeated dry Xenon case. The cause needs to be further studied.

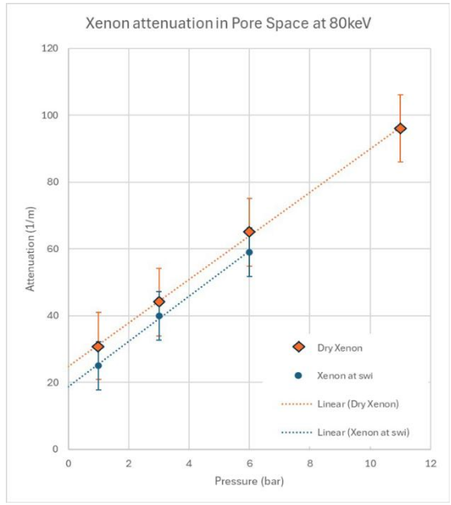
In case of in-situ gas pressure detection using the micro-Ct scan, it is important to distinguish in the images the gas from the liquid as part of the reconstruction (Figure 1.a). According to Henry's law [3] pressure dependent Xenon dissolution in water was detected, but this will only slightly affect the image reconstruction. Overall the results show potential but more data and more accurate measurements are needed to confirm a possible application. Other next steps would be to study the uniqueness of this correlation, e.g. how dependent it is on mineralogy, rock structure and on the amount of water in the porous space.

References:

[1] van der Net, 2005, SPE96988, A New Method for the Determination of Foam Capillary Pressures in Porous Media
[2] Willemsz, 2022, A Micro-Computed Tomography-Study on the Use of Xenon as a Pressure Indicator in Porous Media, MSc. At Pore Lab 2022
[3] Taber, 1999, Applications of Xenon CT in Clinical Practice: Detection of Hidden Lesion



a



b.

***Figure 1**: a. A horizontal cross-section of a reconstructed X-ray image of a confined silica core showing the phase Xenon (in brown) and water (in blue), filling the porous media (gray grains). After water displacement by Xenon, setting residual water saturation, the Xenon pressure is regulated and so a micro CT scan is made. b. shows the obtained Xenon attenuation-pressure correlation without (dry Xenon) and in presence of residual water saturation (Xenon at Swi) in a sintered silica bead membrane*

Inspiration for Master projects

You find in the following pages a few suggestions for master projects to be performed at PoreLab. These are only a fraction of the possibilities. We like to tailor new projects to the particular student's wishes and can start a new topic this way. We invite therefore potential students to make contact with anybody in our crew at PoreLab.

Proposed Master Project at PoreLab NTNU and the Energy Transition Campus in Amsterdam (ETCA)

Underground storage for decarbonisation: ripening effects in liquid-gas displacement processes in multiphase flow in porous media

Contact: Steffen Berg (Steffen.Berg@ntnu.no)

This Master project is a collaboration between PoreLab at the department of Physics, NTNU, and the Energy Transition Campus Amsterdam, the Netherlands (ETCA). To be eligible for this project, the student must be an EU citizen and must hold an Erasmus+ mobility grant.

Motivation

As solutions industrial decarbonisation evolve, the role of large-scale underground storage for energy and climate-related gases – hydrogen, and carbon dioxide – is becoming increasingly relevant. Underground storage of carbon dioxide and hydrogen are considered as viable but technically challenging processes to store large gas volumes in subsurface geological formations. The associated pore-scale transport processes involve displacement between immiscible phases but also ripening. These two processes can lead to a different topological evolution that influence the efficiency at large-scale storage of hydrogen and CO_2 which need better understanding and validation for modelling studies.

Project Description

The project makes use of an existing data set of gas-liquid displacement processes in sandstone rock with nitrogen, hydrogen and methane displaced by saline brine in sandstone rock, imaged by 4D X-ray computed microtomography. The so-obtained time-resolved 3D pore scale fluid distributions show typically first a displacement phase where brine displaces gas which is then undergoing snap-off processes which leads eventually to trapping. This is followed by a dissolution phase driven by ripening processes which involves capillary-pressure dependent partitioning equilibria and respective dissolution and diffusive transport between disconnected gas bubbles. Both processes produce different pore scale fluid topologies. These fluid distributions are characterized by Minkowski functionals and trajectories in the 4-dimensional Minkowski functional space are obtained. Clustering methods will be used to discriminate the displacement from dissolution phases.

Resources

The candidate will learn to work with segmented micro-CT data sets, perform a connected object analysis, and quantify respective morphologies by Minkowski functionals using the QuantimPy Python library. The work will be performed at the Energy Transition Campus Amsterdam (ETCA), the former Shell Research Center Amsterdam. A successful Erasmus+ Mobility application is the pre-condition for funding the research stay abroad.

Required Background

Programming skills in Python and some basic knowledge in fluid mechanics. Background knowledge in integral geometry and Minkowski functionals is helpful but not required.

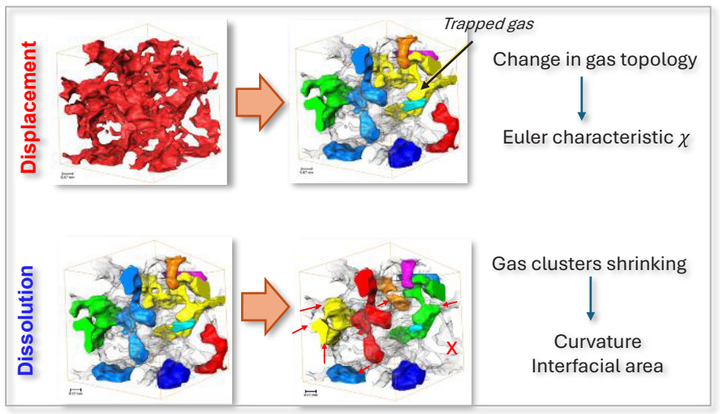


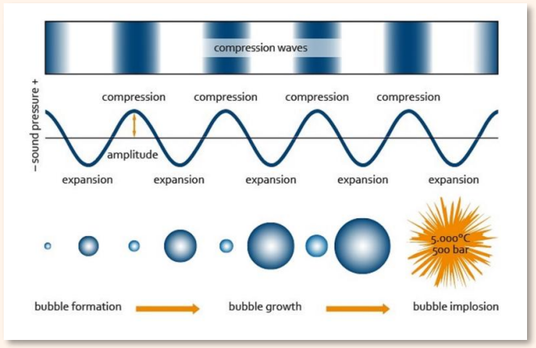
Figure: *Differences in pore scale fluid distribution between displacement and dissolution processes during gas-liquid transport in porous rock, as encountered during underground storage of hydrogen.*

Proposed Master Project at PoreLab NTNU (department of Physics)

Bubbles's nucleation and Sonochemistry

Contact: Raffaella Cabriolu (raffaela.cabriolu@ntnu.no)

This project can be adjusted to 15, 30, 45 and 60 ECTS.



Compression and rarefaction cycles created by ultrasonic longitudinal pressure waves in a liquid give origin to a variety of effects mediated by the vapor bubbles that nucleate, grow, and interact during the expansion stage of the wave oscillation, and, eventually collapse when the pressure turns from negative to positive. The implosive collapse gives rise to extreme temperatures and pressures that have found enormous applications in many fields. For example: ultrasounds are used in water treatments to eliminate pollutants; sonochemistry synthesis of nanoparticles promises more efficient and greener protocols to produce catalysts and to fabricate microelectronics components; furthermore, the ultraviolet light emitted during those processes inactivates microorganisms. Other applications concern food science, medicine, drug delivery and, more in general, bio and nanotechnology. Ideally, the understanding of the nucleation, growth, and implosion of bubbles under ultrasound waves is essential to achieve the best performance for the desired application.

Your Project

The student will use the LAMMPS software to model the formation, growth, and collapse of bubbles in a solution of different types of alcohols (Methanol (MeOH), Ethanol (EtOH), Isopropanol (IPA), 1-butanol (BuOH), and ethylene glycol (EG)) in water [1] . Those solutions are used by experimental collaborators in NTNU [2] that will provide their data against which we can validate our modeling results.

Requirements

A background in computational physics is a great advantage. This project suits a student interested in modeling, simulation, and programming, and is able to work independently. Experience with a programming language like C, C++, Julia, and/or Python is essential. A collaboration with experimental groups can be arranged.

Other aspects

The study will be supervised by Associate Professor Raffaela Cabriolu at the Department of Physics, and depending on the students' preferences, by an experimental counterpart.

References

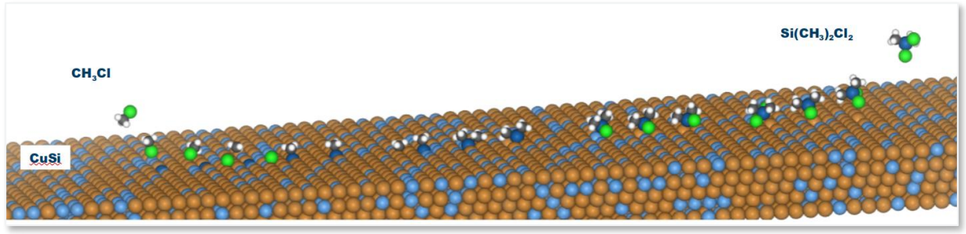
[1] R. Cabriolu, B. Pollet and P. Ballone, *Journal of Physical Chemistry B.*, 127,**7**, 1628-1644, (2023).
[2] Hansen, H. E.; Seland, F.; Sunde, S.; Burheim, O. S.; Pollet, B., *Ultrasonics sonochemistry.* **85,** 105991**,** (2022).

Proposed Master Project at PoreLab NTNU (department of Physics)

Machine Learning Potentials for Catalysis

Contacts: Raffaella Cabriolu (raffaela.cabriolu@ntnu.no)

This project can be adjusted to 15, 30, 45, and 60 ECTS



Motivation

The Rochow–Müller (RM) process is the predominant industrial route for producing methylchlorosilanes, the key precursors for silicone polymers. Silicon, the second most abundant element in Earth's crust, plays a crucial role in modern industry and serves as the primary raw material for the RM reaction. Silicones, derived from these precursors, are versatile synthetic polymers with wide industrial applications, including sealants, lubricants, and electrical and thermal insulation materials.

Norway is Europe's leading producer of silicon, making research on silicon-based processes strategically important. Advancing our understanding of silicone production can improve the utilization of raw silicon and support the development of high-value industrial products. Despite decades of research [1], the fundamental mechanisms of the Rochow–Müller reaction—particularly the role of copper as a catalyst—remain only partially understood [2]. Gaining deeper insight at the atomic scale could significantly enhance catalyst optimization and process efficiency.

Project description
The aim of this project is to elucidate the atomic-scale dynamics of mixed Cu–Si surfaces and to clarify the role of copper in the Rochow–Müller process using molecular modeling and data-driven methods.
The project will combine Molecular Dynamics (MD), Density Functional Theory (DFT), and Machine Learning Potentials (MLPs) to model catalytic processes with both accuracy and efficiency. DFT calculations will provide high-fidelity reference data for the Cu–Si system, while MD simulations will be used to explore the structural evolution and dynamic behavior of the catalytic surfaces under realistic conditions. Machine Learning Potentials will be developed or employed to capture complex interactions and enable simulations on larger spatial and temporal scales. The balance between theory, simulation, and data-driven modeling will depend on the project's scope and credit load. Requirements A background in computational physics is a great advantage. This project suits a student interested in modeling, simulation, and programming, and is able to work independently. Experience with a programming language like C, C++, Julia and/or Python is essential.

Requirements
A background in computational physics is a great advantage. This project suits a student interested in modeling, simulation, and programming, and is able to work independently. Experience with a programming language like C, C++, Julia and/or Python is essential.

Other aspects
This work is part of a larger FRIPRO project focusing on understanding the complexity of the RM process. It will be carried out in collaboration with scientist at SINTEF industry. The study will be supervised by Associate Professor Raffaela Cabriolu at the Department of Physics, Dr. Francesca Bleken at Sintef Industry in Oslo, and Dr. Ingeborg Helene-Svenum at Sintef Industry in Trondheim.

References

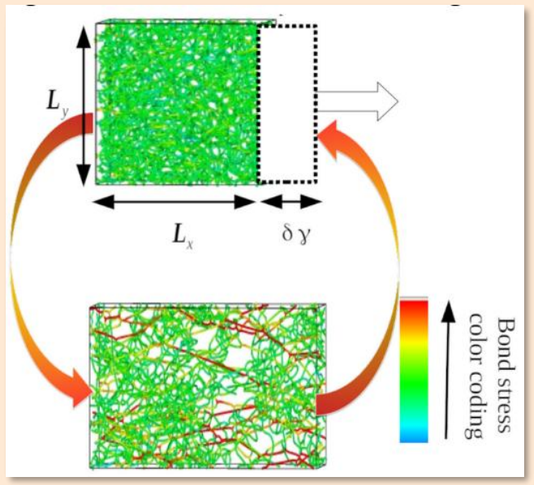
[1] Svenum, Gouttebroze, Bleken, *Catalysis Today*, 2025, 445, 115075
[2] Mahmoodinia, Farooq, Roe, Svenum,Venvik, *Ind.Eng.Chem.* Res. 2023, 62, 21579-21589

Proposed Master Project at PoreLab NTNU (department of Physics)

Understanding Non-Newtonian Materials

Contact: Raffaella Cabriolu (raffaela.cabriolu@ntnu.no)

This project can be adjusted to 15, 30, 45, and 60 ECTS.



Your Project
In this project you will study the stress-strain curves for a Yukawa binary colloidal system representing a typical yield-stress material [2, 3]. In particular, the effect of different friction coefficients and damping parameters on the stress-strain curves will be investigated using Molecular Dynamics simulation. The results will help rationalize complex, irreversible phenomena such as aging and creep in disordered system [3, 4].

Requirements
Background in Soft matter physics would be an advantage. We would like a person interested in modeling, simulation and programming able to work independently. Experience with C or Fortran and/or Python are essentials.

Other aspects
Your study will be supervised by associate professor Cabriolu, who has experience in simulating yield-stress materials. Your computational work will also be supported by Prof. Suman Dutta, whose expertise includes colloidal physics and simulations [4].

Contact:
Raffaela Cabriolu (raffaela.cabriolu@ntnu.no)

Motivation
Non-Newtonian fluids are ubiquitous in everyday life, but the understanding of the fundamental physical process underlying their properties still remains a big challenge [1]. Why are we able to walk (yes, you can!) on a pool filled by a mixture of cornstarch and water or why toothpaste behaves as a liquid when squeezed or sheared? Depending on the applied external force, yield stress materials behave solid- or liquid-like, undergoing peculiar transformations in their dynamics with increasing external load.

References

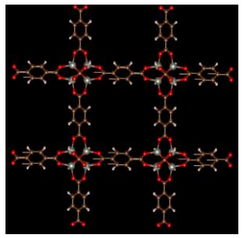
[1] D. Bonn and M. M. Denn , *Science*, **324** , 1401 —1402 (2009).
[2] A. Nicolas, E. E. Ferrero, K. Martens, and J-Louis Barrat, Rev. Mod. Phys., 90, 045006 (2018).
[3] R. Cabriolu, J. Horbach, P. Chaudhuri and K. Martens, Soft Matter, **15**, 415-423, (2019).
[4] S. Dutta, K. Martens and P. Chaudhuri, arXiv:2303.04718 (2023).

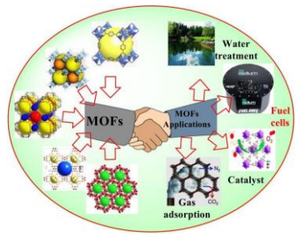
Proposed Master Project at PoreLab NTNU (department of Physics)

Classical Force Fields and Machine Learnt Potentials in Material Modelling

Contact: Raffaella Cabriolu (raffaela.cabriolu@ntnu.no)

This project can be adjusted to 15, 30, 45, and 60 ECTS.





Motivation
Metal Organic Frameworks (MOFs) are nanoporous materials characterized by the combination of organic linkers and metal-ion nodes or vertices. The synthetic and structural versatility of MOFs allows, in principle, to tune their properties through the choice of the linker and/or the metal without changing the underlying topology. This advantage has attracted in the last 20 years large interests for their potential applications in sensing, gas storage and adsorption, chemical separation, and catalysis [1]. Despite the enormous potential in the application and fundamental science, MOF properties are not yet fully understood. Being able to efficiently model those materials, is indeed extremely beneficial to tune and optimize the performances of Metal Organic Frameworks (MOFs) according to our needs.

Your Project
The project will benchmark MACE-MP-0 [1] force field (newly developed Machine Learning potential field) against classical force fields, UFF4MOF, and experimental data to predict the structural and dynamical properties of nanoporous materials. In the first stage, i.e. Specialization project, the students will learn the basics of the Molecular Dynamics technique to predict known structural properties, such as Radial Distribution Function (RDF)m mechanical properties, eg. bulk modulus, and thermodynamical properties, e.g. heat Capacity of mesoporous materials, e.g. MOF-5 [2]. Those properties will be obtained by combining statistical physics and molecular dynamics simulations.

Requirements
Background in condensed matter physics would be an advantage. We would like a person interested in modeling, simulation, and programming able to work independently. Programming experience with Python is essential.

Other aspects
The study will be supervised by Associate Professor Raffaela Cabriolu at the Department of Physics and by Dr. Alin Marin Elena, whose interests include developing new Machine Learning potentials.

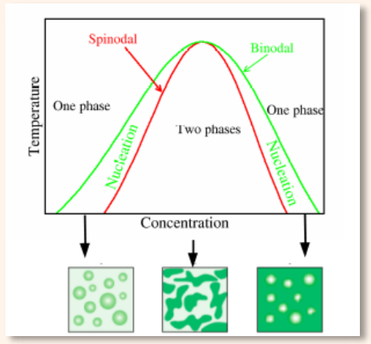
References

[1] https://arxiv.org/abs/2401.00096
[2] https://www.science.org/doi/10.1126/science.1083440

Proposed Master Project at PoreLab NTNU (department of Physics)

Mixing-Demixing and Phase Transitions in Colloidal System

Contact: Raffaella Cabriolu (raffaela.cabriolu@ntnu.no)



This project can be adjusted to 15, 30, 45, and 60 ECTS.

Motivation
Binary colloidal mixtures display a complex and intriguing phase diagram, with a variety of phase transitions which provide the basis for several applications [1]. Among them, mixing / de-mixing and crystallization transitions play an important conceptual and practical role. The localization of the transition lines, the characterization of the new phases, and the analysis of the order parameters depend also on which force fields is used to model the systems.

Project Description
In this project, you will carry out Molecular Dynamics simulations for a binary (A+B) system of Yukawa particles [2], whose cross potential, ϕ_{AB}, is tuned to produce mixing /de-mixing or crystallization transitions as a function of density and temperature. The aim of the project is to observe the difference between the homogeneous and the de-mixed phases, and to characterize both the transition regions and the transition mechanisms. We will also explore using advanced simulation techniques [3] the nucleation stage of mixing / de-mixing and of crystallization under realistic conditions.

Requirements
Background in fundamental physics of phase transitions would be an advantage. We would like a person interested in modeling, simulation and programming able to work independently. Experience with C and/or Python are essentials.

Other aspects
The study will be supervised by Associate Professor R. Cabriolu, in collaboration with Prof. T. v. Erp at the Chemistry Department, NTNU.

References

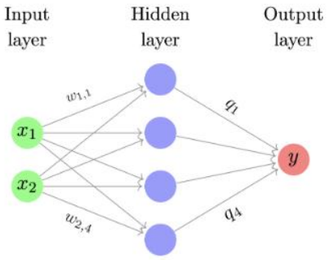
[1] Poon W. C. K., Current Opinion in Colloid and Interface Science, 3 (6), 593-599 (1998)
[2] Sanz E. et al., Physical Review Letters 99, 055501, (2007).
[3] Cabriolu et al. The Journal of chemical physics, 147 (15), 152722, (2017).

Proposed Master Project at PoreLab NTNU (department of Physics)

Monte Carlo Simulation Meets Machine Learning

Contact: Raffaella Cabriolu (raffaela.cabriolu@ntnu.no)

This project can be adjusted to 15, 30, 45, and 60 ECTS.



Motivation

Monte Carlo methods are central to computational statistical physics, but can be slow near critical points or when rare events matter. Machine learning (ML) can (1) extract patterns from high dimensional configurations (e.g., classify phases) and (2) learn effective surrogates or proposals that accelerate sampling. This project combines both directions to give hands-on experience with statistical mechanics, stochastic simulation, and ML.

Project Description

In the first stage, students will implement a baseline two-dimensional Ising or lattice gas Monte Carlo simulation using the Metropolis algorithm. The main objective is to compute standard thermodynamic observables such as magnetization, energy, susceptibility, and autocorrelation times as functions of temperature. Depending on the scope of the project, for example, the number of ECTS credits, students may alternatively use a pre-generated dataset of spin configurations and observables instead of coding the simulation from scratch. This flexibility makes it possible to focus either on simulation development or on data analysis and machine learning, depending on the student's background and time constraints.

In the second stage, students will apply machine learning techniques to analyze the data generated from the Monte Carlo simulations. In particular, supervised learning methods will be employed to train machine learning classifiers—such as logistic regression, random forest, or neural networks—to identify ordered and disordered configurations and to evaluate their accuracy and robustness near the critical temperature. In addition, unsupervised learning and dimensionality reduction approaches, such as Principal Component Analysis (PCA) or t-distributed Stochastic Neighbor Embedding (t-SNE), may be used to visualize phase separation and the onset of the phase transition in configuration space [1],[2].

Requirements

Background in fundamental physics of phase transitions would be an advantage. We would like a person interested in modeling, simulation, and programming, able to work independently. Experience with C and/or Python is essential.

Other aspects

The study will be supervised by Associate Professor R. Cabriolu, NTNU.

References

[1] Carrasquilla J. and Melko R.G.; Nature Physics volume 13, pages 431–434 (2017).

[2] van Nieuwenburg E. P. L.; Liu Y.H., Huber, S. D.; Nature Physics volume 13, pages 435–439 (2017).

Proposed Master Project at PoreLab NTNU (department of Physics)

X-ray phase-contrast microscopy

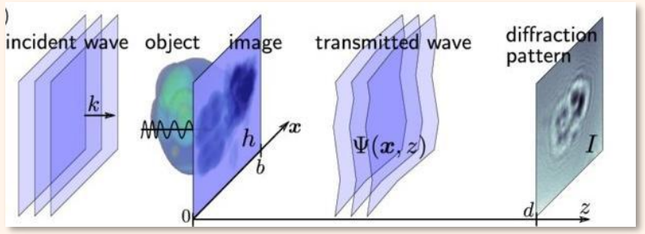
Contacts: Dag W. Breiby (dag.breiby@ntnu.no), Basab Chattopadhyay (basab.chattopadhyay@ntnu.no) and Ragnvald Mathiesen (ragnvald.mathiesen@ntnu.no)

Phase contrast in X-ray images was first described by Einstein. The phase of the electromagnetic field changes upon traversing through materials, as described by the refractive index. This phase-change signal is exploited for imaging materials, in particular biological and other soft organic materials, which often gives a low signal-to-noise ratio for standard absorption-based imaging. We have recently purchased a state-of-the-art X-ray source ("NanoTube" from Excillum) that we will use for phase-contrast microscopy.

Project tasks:

- Implement phase contrast X-ray imaging in 2D!
- Verify that the phase-contrast imaging quantitatively matches theoretical predictions.
- Extend to 3D tomographic reconstructions. Rat brains from the Kavli centre are a particularly relevant sample!

Co-supervision: The project will be done in collaboration with Dr. Basab Chattopadhyay and Prof. Ragnvald Mathiesen.



The project can be tailored to 15 – 60 ECTS.

Figure : *Modeling the transmission and scattering of X-rays through an object. Note how the object introduces ripples in the incoming wavefield, encoding information about the sample structure.*
[Image Ref.: Maretzke & Hohage, SIAM Journal on Applied Mathematics 77 (2016)]

Proposed Master Project at PoreLab NTNU (department of Physics)

Phase contrast microscopy of droplet nucleation

Contacts: Dag W. Breiby (dag.breiby@ntnu.no) and Basab Chattopadhyay (basab.chattopadhyay@ntnu.no)

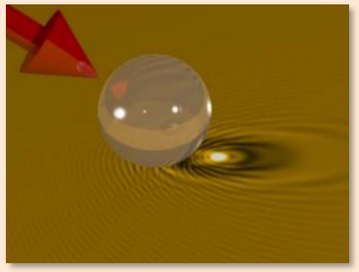


Figure: *Modelling the light scattering from a translucent sphere.*

The scattering of electromagnetic radiation by particles has played an important role in the history of physics, with highlights including Descartes' understanding of the rainbow 400 years ago, Rayleigh scattering by small particles, and Mié's exact solution to the scattering of plane waves by spheres.

In this project, we will study light scattering from liquid droplets on transparent functionalized substrates – relating directly to wetting, environmental physics, and CO_2 storage.

Ultimately, the project aims at measuring the condensation properties of CO_2 under conditions of high temperature and pressure - a challenge of high scientific interest and "green" industrial relevance.

Project tasks:

1. Study the relevant models for light scattering.
2. Study the thermodynamics of liquid wetting and droplet nucleation from gas phase.
3. Implement an efficient computer program for calculating the near- and far-field (static) light scattering from droplets.
4. Develop a climate chamber (aided by our engineer!) for droplet nucleation. Starting with water, we would like to proceed to CO_2 condensation under high *p* and *T*.
5. Work on the inverse problem of parameterizing in 3D the exact droplet shape based on microscopy data, using numerical optimization techniques, including deep learning.

The project can be tailored to 15 – 60 ECTS.

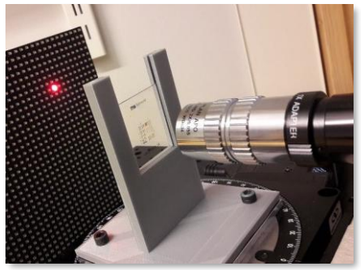
Co-supervision:
The project will be carried out in collaboration with Dr. Basab Chattopadhyay.

Proposed Master Project at PoreLab NTNU (department of Physics)

Fourier-ptychographic microscopy – a computer does half the imaging job!

Contact: Dag W. Breiby (dag.breiby@ntnu.no)

The project can be tailored to 15 – 60 ECTS.



The FP microscope at NTNU

Fourier ptychography [Zheng 2013] is a microscopy technique where the traditional sample illumination has been replaced by a 2D array of partially coherent LEDs, see picture. From each single LED, used one at a time, the light enters the sample with a unique incidence direction. By making one exposure for each LED sequentially, one gets a set of images that can be used to reconstruct both the amplitude and the quantitative phase of the imaged object, with a resolution well beyond the Rayleigh diffraction limit imposed by the hardware. High-resolution phase-contrast gigapixel images with a wide field-of-view huge can be obtained with computational methods.

During the last years, several master and Ph.D. students have developed our Fourier ptychographic microscope, see image above. Now, we are keen to further improve the setup and to collect interesting data!

In this project you will:

- Review & understand the physics of Fourier ptychography.
- Several specific projects are available, including:
  - The mathematics of analytical images, including Hilbert transforms
  - Model the sample using *Deep Learning* ("implicit neural representation")
  - Use GPU programming for image reconstruction
  - Do quantitative polarization-sensitive microscopy for strain mapping
  - Perform 3D imaging of dynamics in *foams, bubbles and droplets.*
  - Quantitative imaging of *fractures in car windscreens* in collaboration with the Dept. of Structural Engineering and European car industry

These projects require good programming skills and an interest in optics.

Co-supervision: The project will be carried out in close collaboration with Prof. M. Nadeem Akram at the University of South-Eastern Norway, located between Horten and Tønsberg.

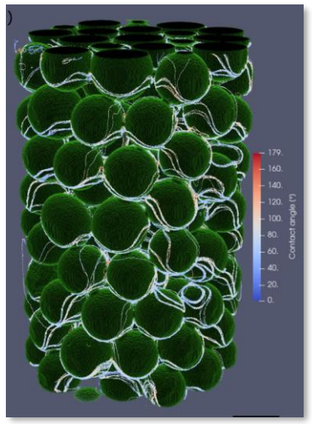
References:

Zheng et al, Nature Photonics, 2013: http://www.nature.com/nphoton/journal/v7/n9/full/nphoton.2013.187.html

Proposed Master Project at PoreLab NTNU (department of Physics)

4D computed tomography ("4D-CT") with Equinor

Contact: Dag W. Breiby (dag.breiby@ntnu.no) and Anders Kristoffersen at Equinor



We offer exciting projects on porous media physics. Liquid flow in porous materials is interesting, complicated and important to society, the environment and industry. Computed tomography (CT) is a well-known experimental technique that gives 3D images of the interior of materials. If the object changes with time, the data will thus be 4-dimensional, hence "4D-CT". There are technical and scientific challenges associated with the 4D-CT measurements. Modelling of the large data sets (often several terabytes of data) is challenging. The current method of choice for analysing the data is Machine Learning.

Examples of specific problems that can be addressed with time-resolved CT are the melting of permafrost, mixing of pollutants in the soil, and medicine uptake in the brain. The project is particularly motivated by CO_2 storage in abandoned oil reservoirs, so-called CCS, which is a prioritized industry in Norway. The project will be carried out in collaboration with Equinor, Norway's leading energy company and a highly attractive workplace for graduates.

The candidate should ideally have a strong background in physics, but also candidates trained in related topics like nanotechnology, chemistry & thermodynamics, computer programming, mathematics, machine learning and artificial intelligence (AI) are welcome.

CT is a technique that is steadily gaining ground in new scientific fields, and the advanced analysis methods that will be used in this project are of high and generic interest. At the same time, the project is of course academically oriented and will be an excellent career step also for further university studies.

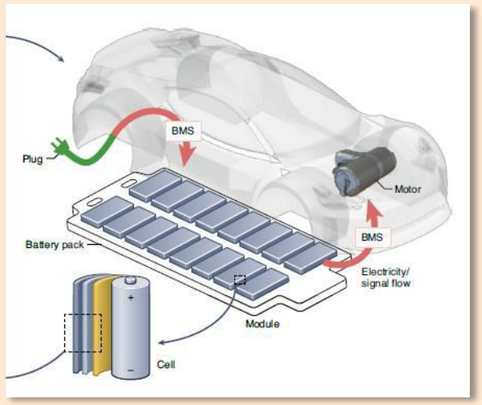
In this project you will:
- Learn the physics of CT
- Use CT to obtain 4D movies of liquids in porous materials
- Use and develop Deep Learning for data analysis and modelling

The project can be tailored to 15 – 60 ECTS

Proposed Master Project at PoreLab NTNU (department of Physics)

Internal dynamics in Li-ion batteries during discharging

Contact: Dag W. Breiby (dag.breiby@ntnu.no)



Lithium-ion batteries have been a game-changer giving rapid technological developments towards a *green*, mobile, and electric modern society.

In this project we will combine X-ray computed tomography (CT) with fibre optical measurements and IR inspection to study the degradation mechanisms taking place as batteries age. CT gives 4D images (3D + *time*) of the developments inside the batteries, while fibre optical sensors can be used to measure parameters like temperature and pH inside the batteries. IR cameras can be used to monitor the temperature distribution on the outer surface of the battery. Properly taken together, these data can be used to get a detailed view of the complex thermodynamical processes taking place inside the battery.

We note that several Norwegian companies, including SINTEF, are strongly involved in developing improved battery technologies. In this project, we will study how Li-ion batteries can be triggered to self-heal from the early onset of degradation.

In this project you will:
- Learn the physics of Li-ion batteries, CT and fibre optical sensing.
- Use CT to study the interior of batteries during operation
- Perform fibre optical measurements.
- Use Machine Learning to analyse and interpret the CT data.

Co-supervision: The project will be carried out in close collaboration with Dr. Basab Chattopadhyay and with the battery expert Prof. Steve Boles from the Dept. of Energy and Process Engineering.

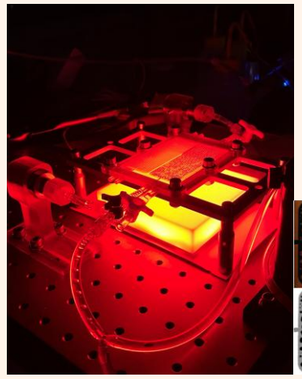
References:
Huang et al, Nature Energy, 2020:
https://www.nature.com/articles/s41560-020-0665-y

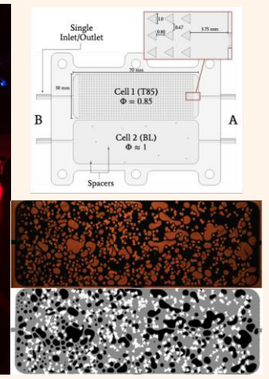
The project can be tailored to 15 – 60 ECTS

Proposed Master Project at PoreLab NTNU (department of Physics)

Experimental two-phase flow in 3D-printed porous flow cells

Contacts: Eiser Erika (erika.eiser@ntnu.no) & Yann Dumay (yann.dumay@ntnu.no)





Motivation
Experimental studies of two-phase flow in porous media have become increasingly important because they are central to many applied systems, including subsurface CO_2 storage, groundwater transport/remediation, and electrochemical energy devices (e.g. porous electrodes and gas-diffusion layers).

At the same time, accessible fabrication methods such as high-resolution 3D printing and laser cutting now make it possible to build transparent porous structures with well-controlled geometry. This enables direct optical imaging of multiphase flow at pore scale, under reproducible conditions.

A key scientific question is how pore geometry controls flow behaviour — including phase distribution, trapping, pressure response, and the degree of reversibility/irreversibility under changing flow conditions.

Your Project
Using a custom optical microfluidics platform, the student will experimentally investigate irreversibility in two-phase flow through porous media. The project includes:
- preparing and testing new 3D-printed flow-cell designs with controlled porosity and pore geometry,
- running systematic experiments while varying key control parameters (primarily flow rate, flow direction, and cell geometry/porosity),
- combining high-speed optical imaging and pressure measurements to quantify flow behaviour,
- analysing how pore-scale processes (interface motion, trapping/remobilisation, local phase rearrangements) contribute to macroscopic transport and reversibility.

This project is a direct follow-up to ongoing work on irreversibility in two-phase flow and will contribute to the next generation of experimental datasets and cell designs.

Requirements
A background in fluid mechanics, soft matter, experimental physics/engineering, or related fields is recommended.

A strong interest in hands-on experiments is essential, including setup development and troubleshooting.

Experience with CAD/3D-printing and basic scientific programming (Python) is an advantage.

Other Aspects
The project is part of an ongoing research effort on two-phase flow in porous media, combining flow-cell design, optical imaging, and quantitative analysis.

The student will work closely with the experimental team and is expected to be motivated, proactive, and comfortable both working collaboratively and independently.

The ability to think outside the box and contribute fresh ideas to experimental design and methodology is highly appreciated.

Proposed Master Project at PoreLab NTNU (department of Physics)

AI/Machine learning for analysis of large two-phase flow datasets

Contacts: Eiser Erika (erika.eiser@ntnu.no) & Yann Dumay (yann.dumay@ntnu.no)

Motivation
Experimental studies of two-phase flow in porous media produce very large datasets: high-speed videos, pressure logs, and derived spatial-temporal observables. These datasets contain rich information on phase distributions, flow intermittency, trapping events, and directional asymmetry, but extracting this information reliably and at scale is a major challenge. Recent developments in computer vision and machine learning open the possibility to build automated, robust pipelines that go beyond manual or simple threshold-based processing, enabling deeper quantitative insights into irreversibility and flow dynamics.

Your Project
The student will develop AI/ML-based tools to analyse large quantities of experimental data from two-phase flow in transparent porous flow cells. Main tasks can include:
- video pre-processing and robust phase segmentation (e.g. gas/liquid regions, interface tracking),
- extraction of quantitative observables such as saturation fields, interfacial metrics, and temporal statistics,
- development and benchmarking of ML methods for pattern detection and flow-state classification,
- integration of image-derived observables with pressure/flow data to identify signatures of irreversibility and hysteresis,
- improving automation, reproducibility, and throughput of the full analysis workflow.

Depending on the student's profile, the project can combine classical image analysis with machine learning/deep learning approaches.

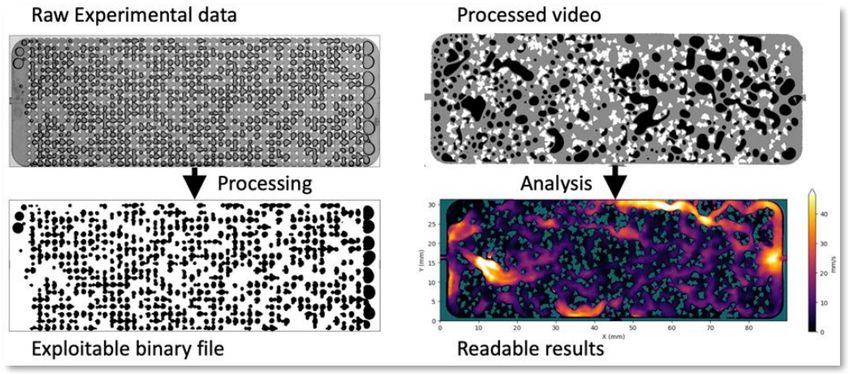
Requirements
A background in data science, applied mathematics, physics, engineering, or computer science is suitable. Essential skills/interests:
- programming (preferably Python),
- strong motivation for image/video analysis and quantitative modelling,
- interest in applying AI/ML to real experimental data.

Experience with OpenCV, scikit-image, scikit-learn, PyTorch/TensorFlow, or scientific Python tools is beneficial but not mandatory.

Other Aspects
The student will work with real, ongoing experimental datasets and collaborate directly with the experimental team, ensuring physically meaningful model development and validation.

The project is particularly suited for a motivated and curious student who is eager to take initiative, propose fresh ideas, and actively shape new analysis strategies.

It offers strong training in scientific machine learning, reproducible workflows, and physics-informed data analysis in a high-impact research context.



Proposed Master Project at PoreLab NTNU (department of Physics)

Effect of gravity on steady-state two-phase flow in porous media

Contact: Santanu Sinha (santanu.sinha@ntnu.no)

Simultaneous flow of two immiscible fluids inside a porous medium shows a wide variety of non-trivial properties. For example, a low-viscosity fluid displacing a high viscosity fluid inside a porous medium at high flow rate creates viscous fingers, the growth of which recently found to depend non-linearly on the local pressure gradient in a certain regime [1]. When a steady state sets in, the total volumetric flow rate in two-phase flow also shows non-linear relationship between the total flow rate and pressure drop in a regime where capillary forces compete with viscous forces. The reason behind these non-linearities is the complex geometrical structure and the wetting properties of the pore space, which create a distribution of capillary barriers at the interfaces between the two fluids.

The importance of two-phase flow lies behind its various applications in industry and geophysics. However, in many applications the porous medium is not horizontal and therefore, in addition to the viscous and capillary forces, the gravitational forces play a significant role when the two fluids have different densities [2].

The goal of this project is to study the effect of gravity on the steady-state two-phase flow by using a dynamic pore-network model [3] where variable gravity can be implemented by adding a tilt to the network. The main tasks will be to find out the relation between the flow rate and the pressure drop, the saturation distribution, and the distribution of clusters in steady-state.

Recommended background:
Adequate skills and interest in programming in C and Python are essential for this project. Furthermore, fundamental understanding of fluid mechanics and statistical physics are recommended.

References:

[1] S. Sinha, Y, Méheust, H. Fyhn, S. Roy and A. Hansen, Phys. Fluids **36**, 033309 (2024).
[2] Y. Méheust, G. Løvoll, K. J. Måløy and J. Schmittbuhl, Phys. Rev. E **66,** 051603 (2002).
[3] S. Sinha, M. A. Gjennestad, M. Vassvik, and A. Hansen, Front. Phys. **8**, 548497 (2021).

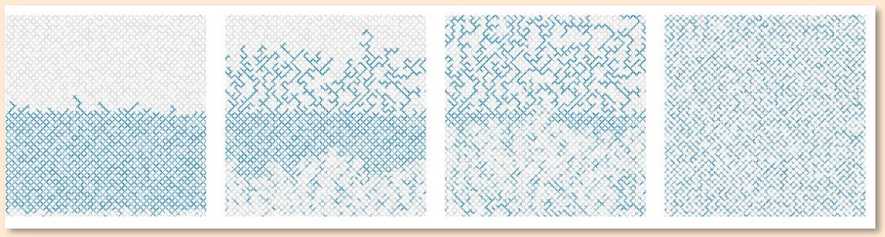


***Figure**: Dynamic pore-network simulation of two-phase flow in a 2-dimensional network of 64×64 links where the wetting and non-wetting fluids are indicated by blue and gray colors. The images from left to right indicate the time evolution of the model where the right most image indicates a steady state.*

Proposed Master Project at PoreLab NTNU (department of Physics) or UiO (department of Physics)

Numerical simulation of mixing in microscale multiphase flow

Contacts: Gaute Linga (gaute.linga@ntnu.no), August Johansson (SINTEF Digital, august.johansson@sintef.no), Eirik G. Flekkøy (e.g.flekkoy@fys.uio.no)

Motivation:
Solute mixing in porous media is essential to a host of industrial and natural processes, as it dictates the speed of chemical reactions by bringing reactants into contact. The mixing dynamics of steady single-phase flows through porous media are becoming well understood. However, for multiphase flows, e.g. when air and water flows together, very little is known. This partly stems from the fact that it is difficult to numerically resolve flows with strong capillary forces and low solute diffusion.

Project description:
In this project, we will employ a combined Eulerian-Lagrangian representation of two-phase flow with solute transport. We will use a finite-element formulation of a phase-field model to represent the interface between the two immiscible fluids and a (Lagrangian) diffusive strip method to resolve the solute transport. This allows us to characterize fluid stretching at unprecedented accuracy, including measuring the Lyapunov exponent which quantifies chaotic mixing. The MSc project will be tailored to the recruited student, but could include:

- Implementing and comparing different discretization schemes for the 3D fluid flow model. This will allow us to answer under which conditions (fully or partially) implicit schemes, with fewer but larger time steps, are advantageous over more explicit schemes, with more but smaller time steps.
- Investigate how chaotic mixing dynamics are influenced by two-phase flow in 3D periodic porous geometries and microfluidic geometries.
- Numerically and theoretically investigate how the mixing dynamics at finite Peclet number relates to the Lyapunov exponent or other flow properties.

Resources
The student will learn how to use HPC infrastructure and have access to Sigma2 and the PoreLab UiO cluster. The project will benefit from comparison to experiments carried out under similar conditions (see other project).

Required background
Strong interest and basic skills in numerical methods, scientific computing, fluid mechanics. Some knowledge of statistical mechanics is an advantage.

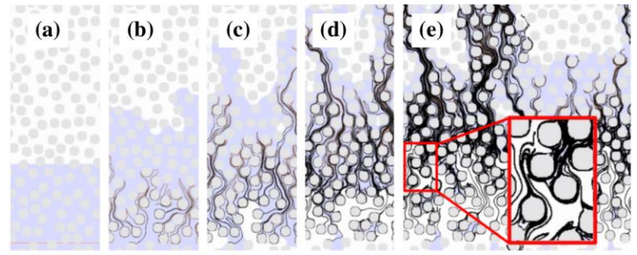
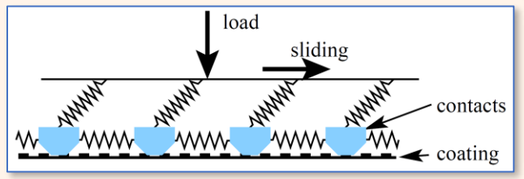


***Figure:** Simulations of chaotic mixing in two-phase flow in a 2D porous medium. (a)–(e) show a strip of solute at various instances of time as it is exponentially elongated by a net upward flow*

Proposed Master Project at PoreLab NTNU (department of Mechanical and Industrial Engineering)

Superlubricity in the real world: modelling multicontact low-friction sliding

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no)



This project is concerned with structural superlubricity. This is a dramatic effect by which friction is reduced enormously due to structural incompatibility between two surfaces at the atomic level. Macroscopic surfaces in contact in the real-world, however, do not have one large flat contact, but consist of many small contacts.

The goal of the project is to investigate how superlubricity behaves in situations where there are multiple contacts. As part of this project, you will modify an existing model for meso-scale multi-contact friction implemented in LAMMPS, a molecular-dynamics and discrete-element method code. You will write and perform simulations of this model, and investigate its behaviour depending on material properties and geometry. If necessary, you will run simulations on highperformance computing facilities.

Recommended background
This project will entail a lot of programming, and it helps if you have good understanding of mechanics.

Supervisor
Astrid S. de Wijn <astrid.dewijn@ntnu.no>
Bjørn Haugen <bjorn.haugen@ntnu.no>

Research group: http://syonax.net/science/research.html.
This project is part of the Gemini Centre for the COmputational multi-Scale materials societY (COSY) https://www.ntnu.edu/cosy/cosy

Work load
This project is intended for a combined specialization project thesis and master thesis, i.e. 45 or 60 ECTS in total.

Proposed Master Project at PoreLab NTNU (department of Mechanical and Industrial Engineering)

Computer simulations of degradation of polymer surfaces into nanoplastics

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no)

In this project, we will investigate the mechanisms by which polymeric materials can degrade under mechanical stress, UV radiation, or a combination of both. In the first stage, we will focus on simulating a small piece of a polymer surface, creating a realistic material with realistic structure. We will randomly break and reform bonds to mimic the effect of UV radiation, and investigate how this impacts the structure. In the second stage, we will subject the simulated material to mechanical stresses.

You will employ the existing openly available molecular dynamics code LAMMPS in combination with python scripting to create the models and to analyze the results.

Recommended background
A basic programming course and an interest in modelling or programming. Basic thermodynamics or classical mechanics.

Supervisor
Astrid S. de Wijn <astrid.dewijn@ntnu.no>

Research group: http://syonax.net/science/research.html.
This project is part of the Gemini Centre for the COmputational multi-Scale materials societY (COSY) https://www.ntnu.edu/cosy/cosy

Resources
The project will make use of high-performance computing resources that are already available through NTNU IT's HPC facilities and Sigma2.

Work load
This project is intended for a combined specialization project thesis and master thesis, i.e. 45 or 60 ECTS in total.

Proposed Master Project at PoreLab NTNU (department of Mechanical and Industrial Engineering)

Modelling viscosity of fluids (theory and/or simulation)

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no)

Viscosity plays a crucial role in the behaviour of fluids, for example air in the atmosphere, water in the oceans, liquids flowing through pipes, and lubricants. For many practical applications, it is important to be able to predict how the viscosity changes depending on the interactions in the fluid, density, temperature, composition of mixtures, etc.

This project is concerned with developing and validating new approaches for predicting the viscosity. Students working on this can be involved in several ways:

- further develop the analytical theory,
- molecular-dynamics simulations of various fluids to compare the theory to,
- developing practical approaches for using our theory to predict viscosity and compare to experiments.

Recommended background
A basic programming course and an interest in modelling or programming. Basic thermodynamics.

Supervisor
Astrid S. de Wijn <astrid.dewijn@ntnu.no>

Research group: http://syonax.net/science/research.html.
This project is part of the Gemini Centre for the COmputational multi-Scale materials societY (COSY) https://www.ntnu.edu/cosy/cosy

Resources
If necessary, the project will make use of high-performance computing resources.

Work load
This project is intended for a combined specialization project thesis and master thesis, i.e. 45 or 60 ECTS in total.

Proposed Master Project at PoreLab NTNU (department of Mechanical and Industrial Engineering)

Thermal aging in fibre bundles

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no)

When materials are exposed to high stresses, they weaken over time. There are many causes for this, but one of them is thermal aging, especially in polymers. Due to thermal fluctuations, bonds break over time, and the material degrades.

In this project, you will investigate thermal aging in a relatively simple model system: the fibre bundle model. You will set up a molecular-dynamics simulation of simple fibre bundle, and study the behaviour under different conditions. For students who are interested, the project can include an analytical compenent to develop theoretical expressions based on transition state theory for comparison to the simulation results.

Recommended background
A basic programming course and an interest in modelling or programming. Classical mechanics and basic thermodynamics.

Supervisor
Astrid S. de Wijn <astrid.dewijn@ntnu.no>

Research group: http://syonax.net/science/research.html.
This project is part of the Gemini Centre for the COmputational multi-Scale materials societY (COSY) https://www.ntnu.edu/cosy/cosy

Resources
If necessary, the project will make use of high-performance computing resources.

Work load
This project is intended for a combined specialization project thesis and master thesis, i.e. 45 or 60 ECTS in total.

Proposed Master Project at PoreLab NTNU (department of Mechanical and Industrial Engineering)

Modelling spreading of misinformation in social networks

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no)

People try to understand the world around them with varying degrees of success. They base their understanding on what they are told by others who they trust, and on what they see happening around them. If some of this information is flawed, or they misinterpret it, people can end up with some very bizarre ideas. They then spread this misinformation to others.

This project is aimed at understanding how misinformation spreads through social networks, similar to how diseases spread. Previous students have built an internally consistent model that incorporates some of the basic dynamics of interactions between people. You will further develop the model and study collective phenomena, such as socially induced charisma and the sudden loss of it. To ensure we keep the model realistic, we will discuss with social scientists.

This project will involve a lot of programming to simulate the model, and statistical analysis of the simulations of the model. It may be necessary to study very large networks, which means that your code will need to be efficient. If necessary, you will run simulations on high-performance computing facilities.

Required background
A basic programming course and an interest in modelling or programming.

Supervisor
Astrid S. de Wijn <astrid.dewijn@ntnu.no>

Research group: http://syonax.net/science/research.html.
This project is part of the Gemini Centre for the COmputational multi-Scale materials societY (COSY) https://www.ntnu.edu/cosy/cosy

Work load
This project is intended for a combined specialization project thesis and master thesis, i.e. 45 ECTS in total.

Proposed Master Project at PoreLab NTNU (department of Mechanical and Industrial Engineering)

Simulating growth of cancer and the immune system

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no)

In this project, we will investigate the effect of the patient's own immune system on the growth and death of tumor cells under treatment. Chemotherapy and many other cancer treatments have the ability to kill or severely limit the growth of cancer cells. However, because these medications are typically toxic, they also limit the patient's immune system, which then is not able to fight the cancer itself to the same degree. This is a problem because the patient's own immune system often contributes to fighting the cancer as well, and because it impairs the use of immunotherapy cancer treatments.

This project will focus on modelling the dynamics of populations of cancerous cells in acute myeloid leukemia. We will include the effects of the treatment as well as the immune system on the growth and death of the cells.

You will write a numerical simulation of a model that we will construct in collaboration with Prof. Ran Friedman, from the Department of Chemistry and Biomedical Sciences, Linnæus University in Kalmar, Sweden. You will run the simulations, perform parameter studies, and analyse the results. If necessary, you will run the simulations on high-performance computing facilities.

Required background
A basic programming course and an interest in modelling or programming. Basic knowledge of thermodynamics or statistical mechanics.

Supervisors
Astrid S. de Wijn <astrid.dewijn@ntnu.no>
Ran Friedman <ran.friedman@lnu.se>

Research group: http://syonax.net/science/research.html.
This project is part of the Gemini Centre for the COmputational multi-Scale materials societY (COSY) https://www.ntnu.edu/cosy/cosy

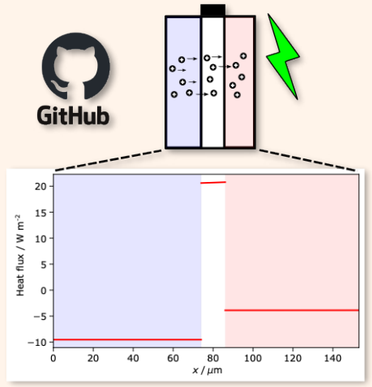
Resources
The project may need to make use of high-performance computing resources that are already available through NTNU IT's HPC facilities.

Work load
This project is intended for a combined specialization project thesis and master thesis, i.e. 45 or 60 ECTS in total.

Proposed Master Project at PoreLab NTNU (Department of Chemistry and Department of Materials Science and Engineering)

Modelling hot spots in battery cells for improved performance and lifetime

Contacts: Signe Kjelstrup (signe.kjelstrup@ntnu.no) and Øystein Gullbrekken (oystein.gullbrekken@nnu.no)



Motivation:
Extreme fast charging of batteries is highly relevant for many current and new applications, such as electric vehicles, electric trucks and electric aircraft. To accelerate the adoption of batteries for existing and new applications, the US Department of Energy has set a target for next-generation batteries of less than 15 minutes charging time to reach 80 % state of charge. We need a better understanding of the internal transport processes of batteries in order to reach this target. However, during real-life battery operations (not inside a laboratory), our knowledge of the internal processes and internal state of the battery is limited. The precise modelling of battery cells is crucial in order to gain a better understanding of the internal processes and to be able to push the performance of the batteries during charging. Fast charging heats the battery and can generate local hot spots inside the cells which are detrimental for the lifetime of the batteries and can be a safety hazard.

Your project:
We have in a previous Master project developed a Python program for the nonisothermal modelling of a battery cell based on nonequilibrium thermodynamics. The battery cell model has a graphite anode and lithium iron phosphate cathode, and a standard mixed carbonate electrolyte with a lithium salt. In the current project, the student will study local heat effects and potential hot spots inside the cells as a function of the current using the existing Python code. Particularly, the student will examine how the properties (e.g. resistances) of the interfaces inside the cells influence the performance. The student will also get the opportunity to expand the program with new functionality, and to study new types of batteries and materials, for example Na-ion batteries, in the existing model framework, if they are interested in doing that.

Recommended background:
Background in thermodynamics is advantageous. An interest in modelling and programming.

Literature:
1. F. Schloms, Ø. Gullbrekken, S. Kjelstrup, Lithium-ion battery modelling for nonisothermal conditions, arXiv. https://doi.org/10.48550/arXiv.2411.14506
2. L. Spitthoff, A.F. Gunnarshaug, D. Bedeaux, O. Burheim, Peltier effects in lithium-ion battery modeling, J. Chem. Phys. 154, 114705 (2021). https://doi.org/10.1063/5.0038168

Proposed Master Project at PoreLab NTNU (department of Geosciences)

Characterization of capillary trapping of CO_2 in micromodels and micro-CT scanner

Contact: Antje van der Net (antje.van.der.net@ntnu.no)

For flow optimization in porous media both for storage and production, an understanding of phase trapping in the porous media is crucial. This can be relevant for reduction of trapping of oil but for also stimulation of gas trapping in CO_2 flooding as one of the storage mechanisms.

For two phase flooding the concept of the capillary desaturation (CDC) curve correlates how the residual gas, water or oil depends on the capillary number (ratio of viscous and capillary forces), mainly for water wet systems. This concept is in simulation tools used to adapt the end point saturations of the relative permeability curves, dependent on how either viscous or capillary force are changing. The CDC curves are measured in the lab, determining residual oil saturation as a function of flow rate. The question is when this concept of CDC curves is applicable. How to use this concept if the wettability changes? Can variations in CDC curve tell anything about the wettability distribution within the core?

The study shall explore the use and dependencies of CDC curves measured, e.g. dependencies on wettability. Micromodels and core flooding will be used to further explore the effect of wettability on the CDC curve.

Proposed Master Project at PoreLab NTNU (department of Geosciences)

Pore scale imaging of CO_2 storage mechanisms using Xenon in a micro-CT scanner

Contacts: Antje van der Net (antje.van.der.net@ntnu.no)

Multiple storage mechanisms act during CO_2 storage in the subsurface where capillary trapping and solubility trapping are two of them. When injected CO_2 forms a gas cap, the dissolution of gas from the gas cap is significantly enhanced by a natural convective motion, driven by the density difference between the formation brine and CO_2 enriched brine. These convective flows are crucial to distribute the CO_2 saturated brine, reduce the CO_2 gas phase and thereby enhancing the long-term storage potential of the reservoir. These convective flows are however not well understood nor described well in porous media.

The objective of this project is to visualize convective flow in 2D and 3D porous media and characterize capillary trapping by in-situ gas pressure measurements. As dissolved CO_2 is not visible in a mCT scan, we opt to use Xenon, as analogue gas. This shall ultimately lead to an improved description of CO_2 storage capacity based on CO_2 solubility and transport. Depending on the availability different research objectives can be targeted:

*O1. Pore scale visualization of convective flow in 1, 2 and 3 D models (see **Figure 1** under for an example)*
O2. Pore scale monitoring of capillary trapping and Ostwald ripening
*O3. Local gas pressure measurements during capillary trapping and Ostwald ripening (see **Figure 2** under)*

The experimental results of O1 and O2 can be used as input for verification of the pore and core scale models. This can be part of the project, or the work can be performed in a team. Collaboration with the University of Oslo is possible concerning the effect of scale of the different 2D models

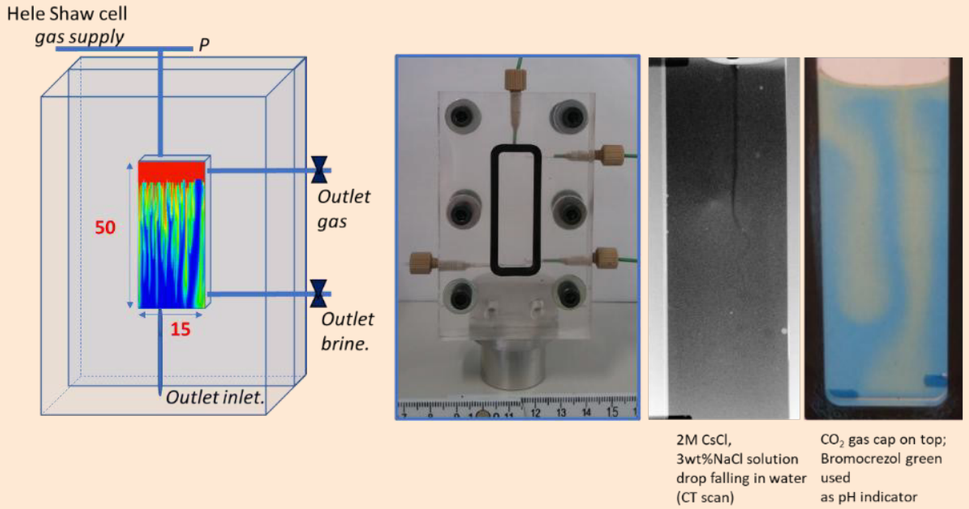


Figure 1; a 2D model to study convective flow, adapted to be used in the microCt scan

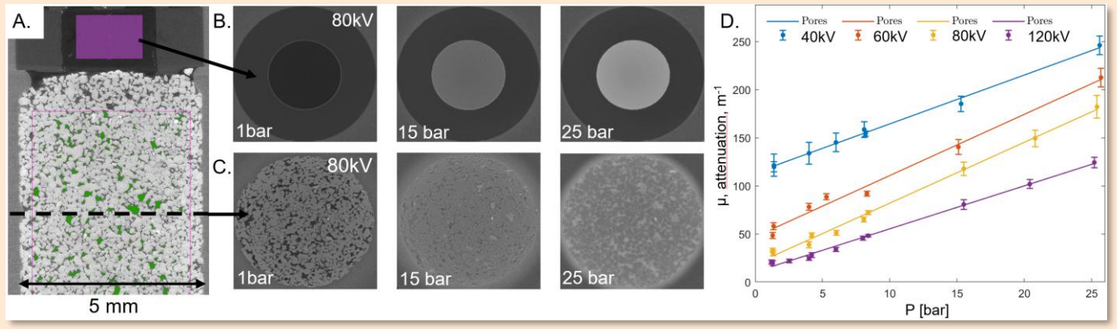


Figure 2; The pressure dependence of Xenon visualized by mCT scanning of a void space in a plastic ring and a cylindrical Bentheimer sandstone core, both seen in A. The resulting cross sections of the void space and the Bentheimer core at set pressure levels of 1, 15 and 25 bar are presented in B. and C. respectively. In D. the linear correlations between static Xenon pore pressure and attenuation inside the pores are presented dependent on X-ray energy levels. The yellow curved for 80 kV is derived from images C. The ultimate objective is to use these curves to derive pressure from microCT scan images of Xenon gas flow in porous media. [Willemsz2022, A micro computed tomography-study on the use of Xenon as a pressure indicator in porous media. Internship report NTNU-TU Eindhoven, supervisor A. van der Net, NTNU]

Proposed Master Project at PoreLab NTNU (department of Geosciences)

Low permeable rock characterization, cap rock and reservoir rock

Contact: Antje van der Net (antje.van.der.net@ntnu.no)

For CO_2 sequestration a sealing cap rock is critical. The sealing ability can be characterized by the capillary pressure of the cap rock, specifically the capillary entry pressure of the rock. This is however not exactly representing the breakthrough pressure of the cap rock, causing the actual leakage. This information is important for sealing predications. Similarly, breakthrough through different low permeable aquifer rock formations is of importance to describe the vertical CO_2 plum migration through the reservoir and predicting its leakage potential. There is to our knowledge no comparison made between the parameters of breakthrough capillary pressure and entry pressure combined with visualization of breakthrough.

O1: In this study we like to set-up and compare different methods of capillary entry and break through pressure determination combined with visualization of the fluid distribution using the micro-CT scan for the description of the sealing ability of a rock.

In order to model effects of CO_2 plum migration or understanding the pore network available for CO_2 mineralization reactions, characterization of the pore-network is crucial. The resolution of visualization methods like micro-CT scanning is limited, so microporosity is hard to characterize.

O2: In this study the pore network is to be analyzed using X ray contrast enhancing phases during visualization in the micro-CT scan. Different contrast enhancers shall be tested and compared, scanning for different rock types, to derive a best practice to be applied in reservoir models.

The projects will be performed in collaboration with professors Philip Ringrose and PhD student Mateja Macut

Proposed Master Project at PoreLab NTNU (department of Geosciences)

CO_2 foam injection, improvement of CO_2 injection volumes by use of foams

Contact: Antje van der Net (antje.van.der.net@ntnu.no)

To store as much CO_2 in the subsurface as possible all the pore space shall be filled with CO_2. While injecting CO_2 or any other fluid in a porous media, not all pores are reached and filled. In order to improve the so-called volumetric sweep efficiency of CO_2 in a given volume, the viscosities of the fluids injected shall match or be higher than the viscosities of fluids in place. Generally, the viscosity of CO_2 in a gas- or supercritical state is always lower than the fluids in the pores. A solution is to inject CO_2 as foam. In these master projects we would like to explore how CO_2 as foam has an effect on the CO_2 injection and storage. Different aspects can be explored with the following objectives (O).

CO_2 stored as a gas cap exerts a gas pressure on the cap rock. This shall not lead to leakage through the cap rock. Gas in the form of foam will reduce the pressure exerted on the rock and will so reduce the risk of leakage.

O1: In this project the objective will be to study the effect of the foam presence and foam structure on the breakthrough pressure of the seal rock.

One CO_2 storage mechanism is dissolution, which occurs after CO_2 stored in the gas cap will diffuse in the aquifer and create a convective flow based on differences in density. It has not been studied how CO_2 stored as a foam (see Figure) will affect the storage mechanism of CO_2 dissolution in the aquifer by convective flow.

O2: In this study a start of this will be made in the 2D visualization cell shown in Figure 1 and different flow patterns will be analyzed dependent on the foam structure, and rock properties.

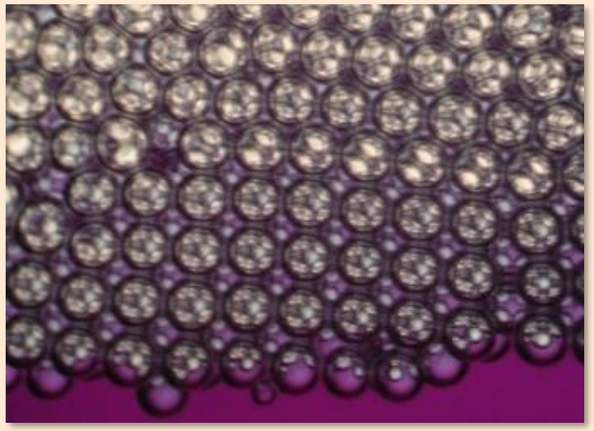


Figure: *Foam with bubbles of similar sizes on top of a liquid*

Proposed Master Project at PoreLab NTNU (department of Civil and Environmental Engineering)

Grounwater Flow in Natural Slopes

Contact: Ali Amiri (ali.amiri@ntnu.no)

Motivation

One of the most critical factors governing the stability of natural slopes is the distribution and evolution of pore-water pressure within the soil mass. Groundwater alters the mechanical response of geomaterials by reducing effective stress, which directly controls shear strength according to classical soil mechanics principles. As pore-water pressure increases, due to rainfall infiltration, snowmelt or groundwater table rise, the available shear resistance decreases, potentially triggering slope failures.

From an engineering perspective, reliable prediction of groundwater flow in slopes is essential for hazard assessment, infrastructure planning, and risk mitigation. Roads, railways, tunnels, and residential developments are frequently located in or near natural slopes where failure can have severe socio-economic consequences. Advanced numerical modelling, combined with field or laboratory data, offers the possibility to better quantify seepage fields, identify critical zones, and improve early-warning or drainage design strategies.

Tasks:

The main objective of this master project is to develop and implement a two-phase flow formulation within the in-house finite element program GeomechX. GeomechX is a Python-based multiphysics finite element package developed for advanced geomechanics research and education. The code is designed to provide a flexible and extensible computational framework for modelling coupled processes in geomaterials at the continuum scale, with particular emphasis on geotechnical applications. The work in this project will focus on modelling coupled groundwater–air flow in porous media and analysing how multiphase seepage processes influence pore-pressure evolution in natural slopes.

Requirement:

A background in finite element method, and experience with Python are essential. This project suits a student interested in modelling, simulation, and programming.

References:

[1] https://www.geplus.co.uk/news/norway-landslide-severs-major-road-and-leaves-one-person-missing-02-09-2025/

Photo: Quick clay landslide – Levanger Aug. 2025 [1]

Proposed Master Project at PoreLab UiO (department of Physics)

Percolation in electric smelting furnaces

Contacts: Eirik G. Flekkøy (e.g.flekkoy@fys.uio.no)

Motivation

The Norwegian ferroalloys industry contributes with 14% of the Norwegian export value (excluding petroleum products) and supplies over a third of European demand in certain segments. It consumes approximately 7 TWh of electricity annually, about 5% of domestic production, and emits around 2.5 million tons of CO_2, about 5.5% of domestic emissions. Current emissions arise almost exclusively from the necessary use of carbon materials as chemical reductants [1] and a future decarbonization of the industry depends on adapting the smelting process to carbon capture and storage or biocarbon reductants [2].

Background

Ferroalloy furnaces are heated by 100 kA currents supplying about 30 MW of heat to a volume of about 500 m³ [3, 4]. Granular raw materials are charged from the top of the furnace, and liquid metal is tapped from the bottom. The descending charge experiences increasing temperatures and pressures. Combined with partial transformation of the material, this increases the conductivity of the charge [5]. The ability of the materials in the furnace to conduct electricity in turn determines the paths of the electric currents.

Your Project

Percolation in a medium of increasing connectivity is known as *gradient percolation* [6, 7]. Your project will adapt the methods of gradient percolation—known from flow in porous media—to electrical conduction in smelting furnace burdens. Cold charge is fairly insulating, whereas partially transformed materials can reach bulk resistivities of about 50 mΩ·m [5]. The main topics of interest for your project will be the location and the width of the transition zone. Obtaining industrially relevant results will depend on taking into account the composition of actual charge mixes and the amorphous structure of the granular material.

Requirements

A solid theoretical background is required. A background in computational physics and an interest in solving industrial problems will be a great advantage.

Other aspects

The project will be associated with the project SAPPHIRE (https://sapphire.norceresearch.no/). It will be supervised by Professor Eirik Grude Flekkøy (flekkoy@fys.uio.no) at the Department of Physics, UiO, and co-supervised by Senior Researcher Vetle Kjær Risinggård (veri@norceresearch.no) at NORCE Research AS.

References

[1]. *Norsk prosessindustri i 2024* (Prosess21, 2024), https://www.prosess21.no/nye-ekspertgrupperapporter/.

[2]. T. Halland and S. Øvrelid, "Roadmap to carbon neutrality," Proceedings of the Silicon for the Chemical and Solar Industry XVII (Social Science Research Network, Trondheim, Norway, 2024), https://doi.org/10.2139/ssrn.4944161.

[3]. S.E. Olsen, M. Tangstad, and T. Lindstad, *Production of Manganese Ferroalloys* (Tapir Akademisk Forlag, 2007).

[4]. A. Schei, J.K. Tuset, and H. Tveit, *Production of High Silicon Alloys* (Tapir forlag, Trondheim, 1998), https://www.nb.no/items/c59f287e4888a6f584756847dbdc578d.

[5]. H. Hoover, *Electrical Resistivity of Materials in the Silicon Furnace*, PhD Thesis (NTNU, Trondheim, Norway, 2023), https://hdl.handle.net/11250/3091823.

[6]. B. Sapoval, M. Rosso, and J.F. Gouyet, "The fractal nature of a diffusion front and the relation to percolation," *Journal de Physique Lettres* **46**, 149–156 (1985), https://doi.org/10.1051/jphyslet:01985004604014900.

[7]. V. Beffara and V. Sidoravicius, "Percolation theory," *Encyclopedia of Mathematical Physics*, page 21–28 (Elsevier, 2006), https://doi.org/10.1016/B0-12-512666-2/00202-9.

(a) **(b)**

Figure: *(a) Pilot-scale manganese production at NTNU, Gaal, SFI Metal Production (2015). (b) Sample charge material mix for silicon production, Hoover et al., "Electrical resistivity of charge materials in the Si process and its effect on energy and CO_2 emissions," Proceedings of the 61st Conference of Metallurgists, COM 2022, page 133–144 (Springer International Publishing, 2023), https://doi.org/10.1007/978-3-031-17425-4_21.*

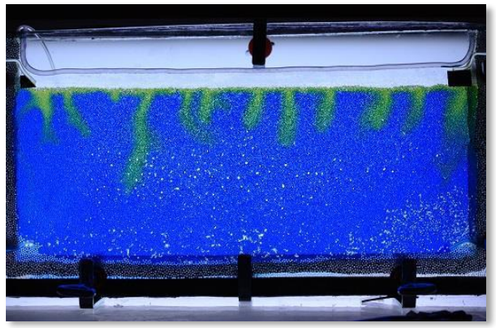
Proposed Master Project at PoreLab UiO (department of Physics)

CO_2 storage and stability of convection plumes in model aquifers

Contacts : Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no)

When CO_2 is injected into a closed water aquifer, which may be a porous medium closed by a caprock, the CO_2 will rise due to buoyancy to top of the reservoir where it will dissolve partially in water by diffusion and convection and form carbonic acid. The density of carbonic acid is higher than the density of pure water and this will cause the carbonic acid to sink due to buoyancy. This will set up an instable convection pattern which will be stabilized by the viscosity of the fluids, the resistance of the porous medium, and the CO_2 diffusion constant. The main tasks of this project will be to perform systematic experiments in quasi 2D experimental models by changing buoyancy and the permeability of the porous medium. This problem is of central importance to mastering CO_2 Storage in aquifers.

Figure: *A layer of CO_2 above a water-saturated porous medium consisting of glass beads. An indicator acid has been added to the water carbonic acid to turn it blue. Where the CO_2 has been absorbed by the water, carbonic acid forms which turns the color to green. The acid has larger density than water and form sinking plumes*



Proposed Master Project at PoreLab UiO (department of Physics)

3D scanning of porous media flows – mobilization of trapped clusters

Contacts : Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no)

The investigation of porous media flows is a topic of pivotal importance for several aspects of human activity. The extraction of water from natural reservoirs, the remediation of contaminated soils and the recovery of oil from subsea rocks are two examples where the knowledge of porous media physics brings immediate economical and societal impact.

Performing experiments in 3D systems in porous media is challenging, as natural rocks and soils are never transparent. At the University of Oslo we have developed an innovative 3D scanning setup that allow us to see inside an artificial porous sample made of glass. (https://titan.uio.no/teknologi-fysikk-goy-pa-laben-innovasjon/2020/splitter-ny-3d-skanner-folger-vaesker-fra-hulrom-til-hulrom).

In this project you will have the opportunity to further develop the technique and to apply it to study how different fluids move inside a porous network. In particular, we will employ the setup to study how trapped clusters of a fluid can be washed away from the porous medium by using another fluid moving fast around the first one. This experimental project will give you useful transferable skills related to fluid mechanics, optics, experimental control and programming.

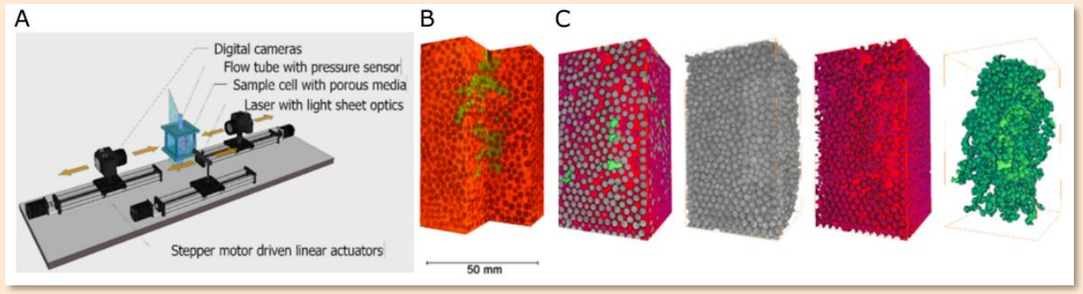


Figure: *A The 3D scanner is based on optical index matching and fluorescence. A random packing of 3 mm glass beads forms the porous medium, index matched with two immiscible fluids. The fluids contain different fluorescent dyes that are excited with a 2D laser sheet that is driven through the sample during a scan. The fluid phases appear on the images with different colors, making them distinguishable through the analysis. B Raw 3D data. The 2D images captured as frames by the cameras are added together to build up the third dimension. C Segmented phases. The porous medium and the two liquid phases are fully separated.*

Proposed Master Project at PoreLab UiO (department of Physics)

Pressure fluctuations in porous media flows

Contacts : Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no)

The investigation of porous media flows is a topic of pivotal importance for several aspects of human activity. The extraction of water from natural reservoirs and the recovery of oil from subsea rocks are two examples where the knowledge of porous media physics brings immediate economical and societal impact. One point that makes experiments in porous media particularly challenging is the fact that natural porous media, such as soils and rocks, are never transparent. By using artificial micromodels, one can overcome this challenge. In this project we will perform experiments in which one fluid will displace another in a quasi-2D porous network. We will take pressure measurements and images of the flow simultaneously and we will try to correlate the outcomes of these two measures. One of the main objectives is to try to use the fluctuations in the pressure signal to obtain indirect information about the properties of the porous network (such as its porosity) and the fluids involved (such as their viscosity contrast). This can provide the means for the development of new measuring techniques based on the pressure signal only, which can be further employed in the investigation of natural porous media

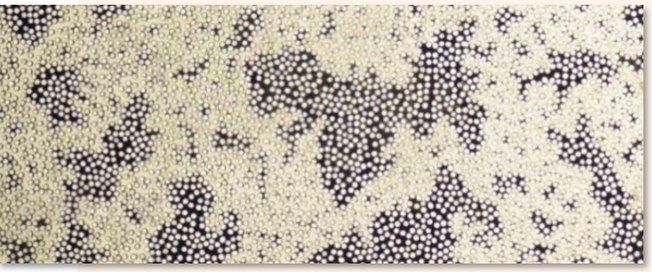


Figure: *Detail of the trapped liquid clusters (blue) left behind after air (white) is slowly injected from the left in a quasi-2D porous network previously saturated with the liquid*

Proposed Master Project at PoreLab UiO (department of Physics)

Pollution spreading in porous media

Contacts : Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no)

When a wet portion of the soil gets dry, say after some hours of sunshine following a storm, thin liquid films remain on the surface of the soil grains. These thin films bring an interesting consequence: they can interconnect different parts of the soil, like a whole set of water bridges forming a large network of water streets and avenues. Plant roots can use this network to obtain nutrients from far away, but pollutants can also take a high-speed road to spread quickly in the soil (see figure). In this project, we are interested in understanding the dynamics of the transport of polluted water through a network of thin water films in a porous medium. This is analogous to the scenario in which some polluted water is spilled on the ground and starts to seep through the porous space. We will employ artificial porous samples in our study (either made of glass or 3D printed in a transparent plastic) which allow us to directly track the motion of the pollutant. We have observed that the residual water content in the sample (how wet or dry the soil is) plays a key role in the pollution spreading dynamics. We have found that for intermediate residual water content, the thin liquid films in the sample behave as a network of tiny pumps, which act to spread the pollution very quickly. Once this behavior is properly understood, we believe it will allow us to understand how we can make use of the thin film network for soil remediation measures. The same transport mechanisms that aid the pollution spreading can be tailored to spread a cleaning agent in the soil, to remediate the damage caused by the pollution.

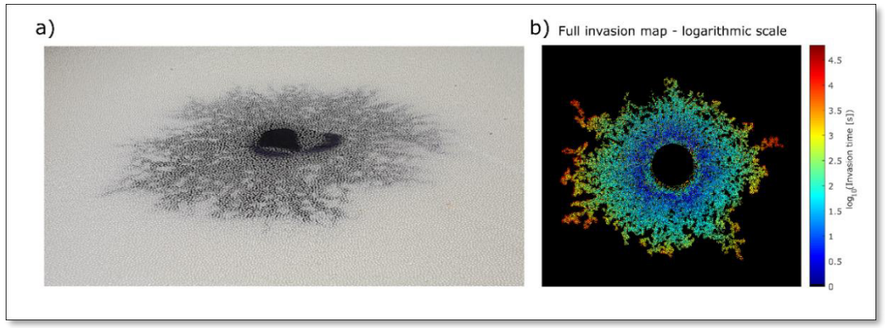


Figure*: a) Experiment illustrating how a source of pollution (central dark blob) spreads through a partially wet porous network (here made of glass beads). Water films covering the internal surfaces of the porous medium can act as a fast pathway for the spreading of pollution. b) Spatiotemporal invasion map of a typical experiment. The color code shows the time (in seconds, logarithmic scale) for the pollution to reach a given point in the network.*

Proposed Master Project at PoreLab UiO (department of Physics)

Steady state two phase flow in a gravitational field

Contacts : Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no)

Simultaneous flow of two fluid phases in a porous medium will after a transient state often lead to a *steady state* regime where all measurable quantities have a well-defined statistical distribution with well-defined averages. Experiments in quasi 2D systems have been performed in the past in our group for horizontal models. The goal of this project is to investigate the influence of buoyancy effects by changing the gravitational constant in the direction of the flow. This will be done by systematic tilting the models. The goal is to measure the fluid saturation and the distribution of trapped fluid clusters, the pressure drop across the model, and the dynamics linked to snap-off coalescence and migration of clusters. This project is of great interest in comparison with theoretical model building in PoreLab. It is also of great technological interest for fluid flow in oil and water reservoirs in addition to CO_2 sequestration in porous media.

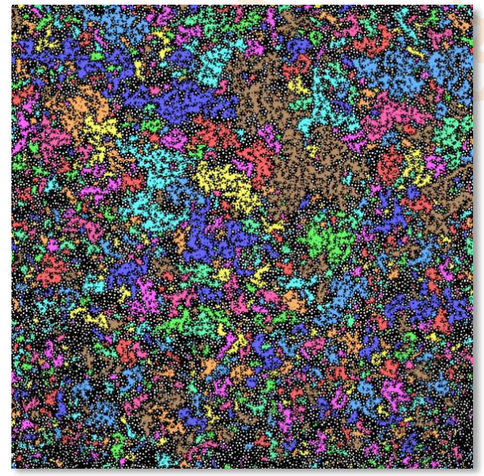


Figure: *Steady state two phase flow experiments in a horizontal quasi 2D porous media. Air and a glycerin water solution are injected simultaneously into the porous medium. The colors indicate different cluster sizes of trapped air*

Proposed Master Project at PoreLab UiO (department of Physics)

Steady state two phase flow experiments in 3D

Contacts : Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no)

The investigation of porous media flows is a topic of pivotal importance for several aspects of human activity. The extraction of water from natural reservoirs and the recovery of oil from subsea rocks are two examples where the knowledge of porous media physics brings immediate economic and societal impact. Since the visualization of flows in porous media can be very challenging, numerical simulations have been used to study the morphology and dynamics of flow structures both in fast and slow injection processes. With the development of modern high-resolution and high-speed imaging techniques, we are now in position to address experimentally questions that previously could only be accessed via numerical simulations. In this project we will investigate, both experimentally and analytically, how the invasion dynamics of a pore are affected by speed of the flow.

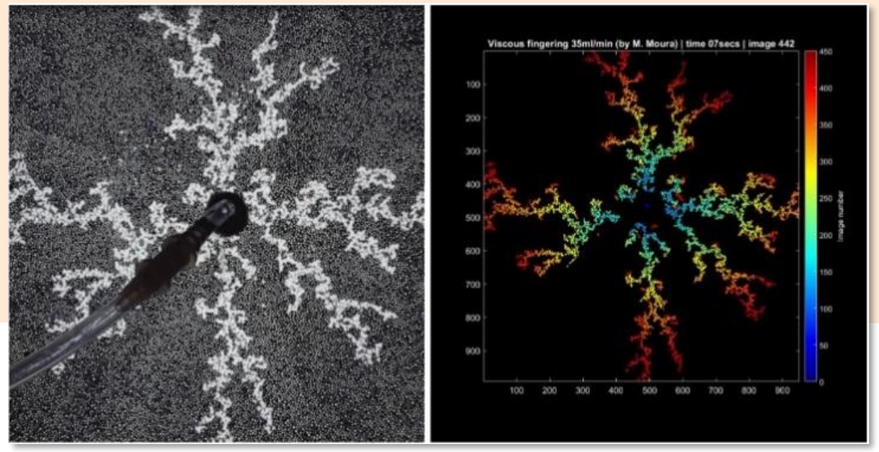


Figure: *Viscous fingering pattern (left) observed when air is injected fast in a porous medium previously filled with a viscous liquid (blue). The image analysis (right) shows the time (image number) of injection of each pore*

Proposed Master Project at PoreLab UiO (department of Physics)

Steady state two phase flow experiments in 3D

Contacts : Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no)

Simultaneous flow of two fluid phases in a porous medium will after a transient state often lead to a steady state regime where all measurable quantities have a well-defined statistical distribution with well defined averages. Experiments in quasi 2D systems have been performed in the past in our group for horizontal models. The goal of this experiment is to perform steady state experiments in 3D with density matched fluids to prevent buoyancy effects. This project is of central importance for comparison with theoretical model building in PoreLab. In two dimensional systems an unusual scaling relation has been found between the flow rate and the pressure, and we want to investigate the relation between the pressure and the flow rate for a three-dimensional system. This project is also of great technological interest for fluid flow in oil and water reservoirs in addition to CO_2 sequestration in porous media.

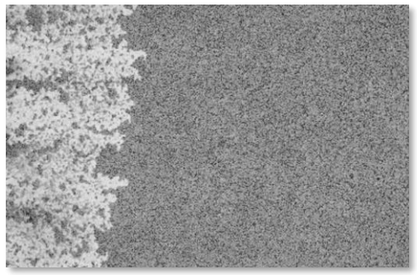


Figure: *Steady state flow in a quasi 2D model system. Simultaneous injection of a glycerol/water (black) solution and rapeseed oil (white)*

Proposed Master Project at PoreLab UiO (Njord center, department of Physics)

Modelling pollutant spreading through capillary bridge networks in soils

Contacts: Paula Reis (p.k.p.reis@mn.uio.no), Marcel Moura (marcel.moura@fys.uio.no), Gaute Linga (gaute.linga@ntnu.no)

Motivation:
When water-saturated granular soils are drained or dried, water in the pore space between grains is replaced by air. This process leaves behind water clusters and bridges which are held in place by capillary forces [1]. These clusters and bridges can together form large-scale connected networks which may act as highways for pollutants or chemical solutes spreading in soils. However, how fast and how far solutes may spread in these networks, under different physical conditions, remains elusive. A better understanding of this process would be of immediate interest e.g. in the context of environmental remediation.

Project description:
In this project, students will develop a numerical pore-network model that incorporates fluid and solute transport in arbitrary capillary bridge networks. We will effectively model flow and solute transport in individual bridges of the network by direct pore-scale simulation in representative geometries. Students will investigate how network structure influences the speed and extent of solute spreading, and characterize and/or theoretically describe the macroscopic behaviour, allowing us to predict critical conditions for pollutant spreading. The candidate will benefit from direct comparison with ongoing experiments at PoreLab UiO (see also the related experimental project).

Resources:
Students will learn how to use national high-performance computing resources (Sigma2) and will have access to Sigma2 as well as the computing clusters of their unit (PoreLab UiO/NTNU).

Required background:
Basic programming skills (Python, MATLAB and/or C++) and basic knowledge of fluid mechanics.

Reference:
[1] P. Reis, M. Moura, G. Linga, P. A. Rikvold, E. G. Flekkøy, K. J. Måløy, A simplified pore-scale model for slow drainage including film-flow effects, Advances in Water Resources 182, 104580 (2023)

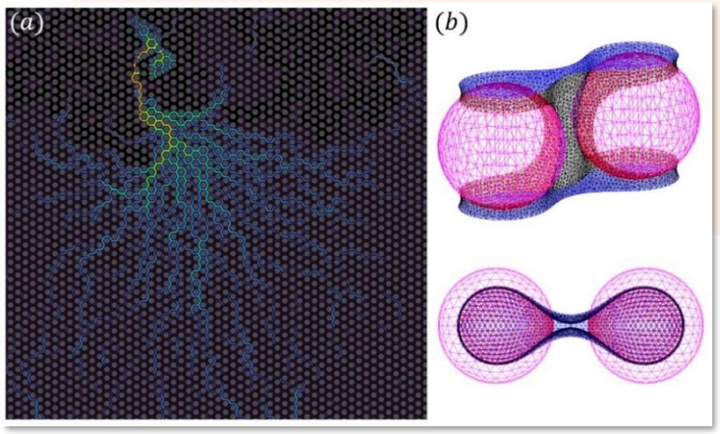


Figure:
(a) Pore-network modeling of a small water cluster draining into a larger cluster via capillary bridge networks. The grains are shown as gray circles, and low (high) local flow rates are indicated by dark blue (yellow)
(b) Example of a single water bridge formed between two spherical grains

Proposed Master Project at PoreLab UiO (Njord center, department of Physics)

Experimental resolution of local flow velocities in multiphase flow through porous media

Contacts : Kevin Pierce (j.k.pierce@mn.uio.no), Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no), Gaute Linga (gaute.linga@ntnu.no)

Motivation:
Simultaneous flow of gases and liquids is ubiquitous in Earth's porous subsurface and governs biogeochemical processes ranging from contaminant degradation in groundwater to nutrient cycling in soils. While the velocities of single-phase flows through porous media are relatively well-understood, our understanding of the local flow velocities in multiphase flows remains limited. Partly, this is due to the challenge of measuring flow velocities simultaneously with the moving interfaces between different fluids.

Project description:
The student will innovate new methods to resolve the local flow velocities and interface dynamics in flows through porous media, using the state-of-the-art imaging and 3D printing facilities at the PoreLab UiO laboratories.

Multiphase flows through 3D-printed transparent models will be seeded with microscopic fluorescent tracer particles, and these particles will be tracked in high-speed videos to resolve real-time velocity fields in porous media. Flow characteristics will be quantified for different multiphase flow geometries (i.e., drainage, imbibition) and physical conditions (i.e., interfacial tensions and applied pressure gradients)

Resources:
The student will have access to the laboratory facilities and experimental expertise at PoreLab UiO to construct particle-tracking velocity experiments. Students will benefit from direct comparison with simulations in identical geometries (see also the related computational project). Dedicated computing resources will be made available for image analysis.

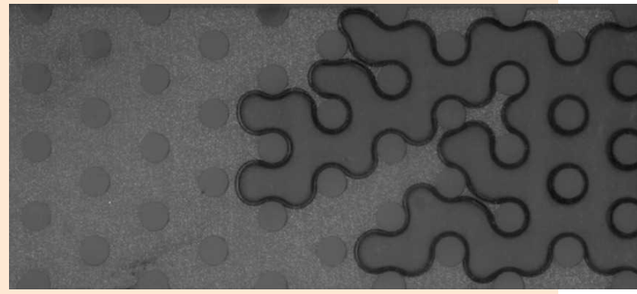


Figure: *Snapshot of microscopic tracer particles in a two-phase flow through a porous model*

Required background:
Interest in fluid dynamics, experimental methods, and data analysis. Students with diverse backgrounds are especially encouraged to apply.

Proposed Master Project at PoreLab UiO (Njord center, department of Physics)

Experimental imaging of chemical transport and mixing in multiphase porous media flows

Contacts : Kevin Pierce (j.k.pierce@mn.uio.no), Marcel Moura (marcel.moura@fys.uio.no), Knut Jørgen Måløy (k.j.maloy@fys.uio.no), Gaute Linga (gaute.linga@ntnu.no)

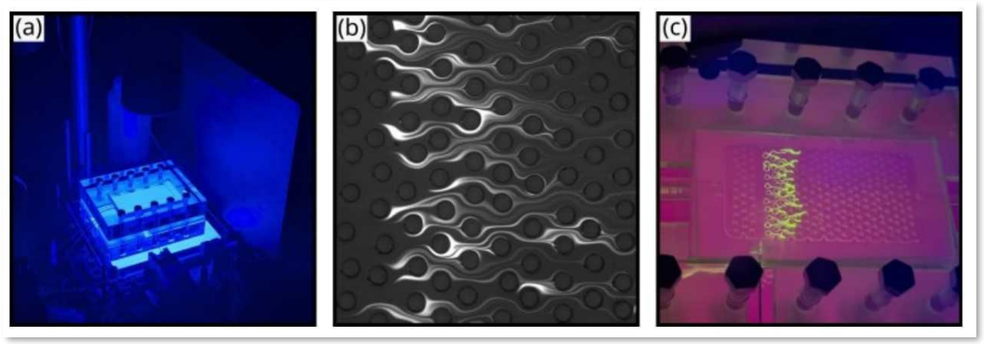


Figure: *(a) Fluorescence imaging experiment, showing blue excitation light; (b) Solute plume in a single phase flow; (c) 3D printed porous model with green fluorescence light from a dye undergoing mixing.*

Motivation:
Solute mixing in porous media is essential to a host of industrial and natural processes, as it dictates the speed of chemical reactions by bringing reactants into contact. The mixing dynamics of steady single-phase flows through porous media are becoming well understood. However, for multiphase flows, e.g. when air and water flow together

below Earth's surface, very little is known, despite the prevalence of these flows in the environment.

Project description:
We will employ state-of-the-art fluorescence imaging and stereolithography 3D printing techniques to study the dynamics of mixing in porous media. Our setup resolves the concentrations of initially segregated chemicals in porous media flows through space and time. Image analysis techniques will be developed to analyse the mixing dynamics, and we will assess how different boundary and flow conditions affect the results. Experiments will be compared to numerical simulations performed under similar conditions. This project will provide insights into the fundamental physics underpinning applications from carbon dioxide sequestration to groundwater remediation.

Resources:
The student will learn to use the fluorescence imaging and 3D printing facilities at PoreLab UiO and will have access to dedicated computing resources for image analysis.

Required background:
Interest in fluid dynamics, experimental methods, data analysis.
Students with diverse backgrounds are especially encouraged to apply.

Education

Why Study Porous Media and What Courses to Choose?

Porous media are all around us. In the ground, water fills the pores of aquifers, and oil is found in porous medium. Pollutants may follow rainwater into the ground which is a porous medium; where do the pollutants end up? When underground water rises during earthquakes, they may push the soil particles apart so that it loses its strength with the results that building topple. Less dramatically, but extremely importantly, the physics and chemistry of nanoporous media is at the core of fuel cells, batteries, and in heterogeneous catalysis. They make up concrete and biological tissue. A better understanding of the flow patterns in these materials will make them much more efficient – an important goal in a world that needs to become greener.

In PoreLab we study phenomena of these and related kinds, aiming to understand, improve and use the porous materials in ways that are more environmentally friendly, and more effective than now. An interdisciplinary PoreLab-environment has been constructed to facilitate contact between different disciplines and speed up this development.

PoreLab offers a range of courses open for all students at our host universities.

The two first courses, PoreLab course 1 and PoreLab course 2 are jointly organized between NTNU and UiO. They were adapted to PoreLab with a special focus on porous media physics.

PoreLab Course 1 – Theory and Simulation of Flows in Complex Media

FYS4465/FYS9465 (Dynamics of Complex Media) at UiO or KJ8210 (Flows in Porous Media) at NTNU

PoreLab course 1 covers hydrodynamics where capillary and viscous forces play a role. It also covers simulation methods, thermodynamics and statistical physics relevant to porous media.

Learning outcome
After completing this course, the student will:

- have knowledge of hydrodynamic and thermodynamic transport processes in porous media.
- have a thorough knowledge of the Navier-Stokes equation and Darcy's law, and also diffusion and dispersion processes.
- be able to program molecular and Brownian dynamics codes as well as the lattice Boltzmann-model and simple network models that are used to simulate flow in complex geometries.
- know the theory behind the simulation models and have an understanding of how small-scale processes affect processes at larger scales. This includes the understanding of percolation theory.

PoreLab course 1 is open for students from both NTNU and UiO. Professor Eirik Flekkøy, PI at PoreLab, is the lecturer for this course.

PoreLab Course 2 – Experimental Techniques in Porous and Complex Systems

FYS4420/FYS9420 (Experimental Techniques in Porous and Complex Systems physics) at UiO

PoreLab course 2 contains four projects that will give students an introduction to important experimental techniques in the field of condensed matter physics. The course will be adapted to the center of excellence PoreLab with a special focus on porous media physics. The teaching is based on four projects in which the students apply techniques on realistic problems in condensed matter physics.

Learning outcome
After completing the course, the student:

- should know how a PID controller works in an experimental setup with a particular focus on temperature control and has experience with how the temperature in a system can be controlled.
- knows the theory of dynamic light scattering and has experience in using light scattering to study diffusing particles and particles in a convective velocity field. The student has experience in using dynamic light scattering to measure viscosity and the particles diffusion constant and size.
- has experience in setting up a 2D experiment for two-phase flow in porous media and is able to perform image analysis to characterize the structure and the dynamics. The student knows fundamental mechanisms for two-phase flow in porous media and how numerical models can be used to understand the observed pattern formations.
- will have experience in performing a porous media experiment at NTNU PoreLab.
- has acquired skills in collaborating in groups with other students.
- has learned to carry out research projects near the research front and to write a scientific report.

PoreLab course 2 is open for students from both NTNU and UiO. Contact is Professor Knut Jørgen Måløy, PI at PoreLab UiO

Additional courses offered at either NTNU or UiO are relevant for porous media.

Irreversible Thermodynamics

KJ8211/TKJ4200, NTNU

The course extends classical thermodynamics beyond equilibrium and introduces the concept of entropy production. The students will learn what the entropy production is, where it comes from and how it can be used to:

- Formulate consistent transport laws for heat, mass and charge transfer that include coupling. These transport laws will be used to explain thermal diffusion (transport in reservoirs), Peltier and Seebeck effects (energy in space and degradation of batteries), reverse electrodialysis (energy from mixing salt-water and fresh-water), membrane transport, fuel cells and other important examples where renewable energy technologies are in focus.
- Identify, characterize, and minimize lost work and exergy destruction in processes and process equipment. Concepts such as exergy and lost work will be explained, and the students will learn to use them in practice to analyze and improve the energy efficiency of processes and process equipment. Scientifically founded guidelines for energy efficient operation and design will be presented and explained.

The course provides a powerful toolbox, both for students interested in transport phenomena, and for students who want to learn how to improve the energy efficiency; a necessary task to reach many of UN's sustainability goals. The coordinator and lecturer for this course is Professor Øivind Wilhelmsen, PI at PoreLab.

Statistical Physics
TFY4230, NTNU

The course provides an introduction to statistical physics, mainly for systems in thermal equilibrium. The student should understand quantum and classical statistical mechanics for ideal systems and be able to judge when quantum effects are important. The student should understand the connection between microphysics and thermodynamics.

Heat and Mass Transfer in Porous Media
EP8208, NTNU

The course content is as follow:
- Physical and chemical effects of contact between fluid and pore wall
- Heat and mass transport with and without chemical reaction and radiation in the pores
- Analogy between heat and mass transport
- Diffusion and convective heat and mass transport, diffusivity
- Transient and stable mass transport in different phases
- Adsorption and desorption, energy conversion
- Capillary pressure, capillary flow
- Radiation exchange inside pores
- Phenomenological consideration
- Side effects such as shrinkage / swelling, deformation, stress condition
- Practical examples from technical processes
- Mathematical modeling of the transport processes.

The content of the course will be tailored to the students taking the course

Applied Heterogeneous Catalysis
KP8132, NTNU

The course is given every second year, next time in the fall term 2027. The course aims to give an understanding of the relation between modern theories of catalysis and the industrial application for the most important groups of heterogeneous catalysts, metals, metal oxides and zeolites. Assessment of the potential developments and limitations of catalysts will be analyzed through examples from industrial applications or processes under development. This includes the catalyst synthesis, a kinetic description of the different processes involved in a catalytic cycle (adsorption, surface reaction and desorption), mass and heat transfer issues, as well as interpretation of results from experimental and theoretical investigations.

Catalysis, Specialization Course
TKP4515, NTNU

The specialization consists of modules giving a total sum 7,5 credits. Modules are chosen from the following list:
1. Environmental catalysis (3.75 credits).
2. Heterogeneous catalysis (advanced course) - (3.75 credits).
3. Industrial colloid chemistry (3.75 credits).
4. Reactor modelling (3.75 credits).
5. Chemical engineering, special topics (3.75 credits).

Modules from other specializations can be chosen given the approval of the coordinator.

Chemical Engineering Thermodynamics
TKP4107, NTNU

Chemical engineering thermodynamics forms one of the basic pillars for understanding chemical engineering process. In this course, we build on basic principles and learning objectives from subjects such as basic thermodynamics and process engineering. The syllabus is based on updated international standards and it will enable the students to calculate thermodynamics properties of ideal and non-ideal pure component systems as well as mixtures. Furthermore, the students will learn to calculate phase and chemical equilibria. The attained knowledge will help the students to model and simulate existing industrial processes as well as analyzing novel solutions in research and technology development. This competence is needed in order to develop and implement new and possibly more complex technologies, which are necessary in order to achieve future sustainable industry development.

Biophysical Micromethods
FY8906/TFY4265, NTNU

The course gives an introduction to different types of instrumentation that are important for studies of biological macromolecules, cells, and other soft materials. The course provides an understanding of the function of the components that the instrumentation consists of, as well as a theoretical and practical understanding of how to operate the instrument, including calibration procedures and maintenance. Professor Erika Eiser, PI at PoreLab, is the coordinator and lecturer for this course.

Mechanics
FY1020, NTNU

This is a new course from the academic year 2025/2026. The course aims at giving the students a solid knowledge of Newtonian mechanics and an understanding of classical mechanics both technologically and within modern science, physics included. It will provide the students with basic knowledge of mechanical oscillations, solid mechanics and ideal fluid mechanics and hydrostatics. Associate Professor Gaute Linga, PI at PoreLab is one of the lecturer for this course.

Geomechanics and Flow in Porous Media
TPG4112, NTNU

The subject should give basic knowledge about flow in porous media related to reservoir engineering and hydrogeological applications, and basic understanding of geomechanics and its importance in mining operations, tunnel constructions and exploitation of georesources.

The course consists of two parts, one flow part (50%) and one rock mechanics part (50%). The flow part deals with porous media characteristics: Porosity, permeability, flow equations for single- and multi-phase flow, capillary pressure and relative permeability. The flow part also deals with applications in earth sciences, such as seepage through the subsurface, CO_2 sequestration, and the production of georesources such as water and hydrocarbons.

The rock mechanic part deals with tensions and pore pressure in the earth crusts, tectonic tensions, normal and abnormal pore pressures, tension determination, rock mechanic field and laboratory experiments, mechanical properties of rocks, tensions close to wells and subsurface holes. Other topics are: Stability of wells during drilling, sand/particle production, hydraulic fracturing, reservoir compaction and surface setting, the significance of rock mechanics in reservoir control and the use of rock mechanics in relation to rock installations. The course coordinator is Professor Carl Fredrik Berg, PI at PoreLab.

Reservoir Simulation
TPG4160, NTNU

The course aims at giving the students basic knowledge of numerical simulation of fluid flow in porous media. Students will understand partial differential equations for single phase and multiphase flow in porous materials, and numerical solution methods of these using finite difference methods. They will be able to use common modeling tools for numerical prediction of reservoir behavior during production or injection and will be able to do derivation of equations for flow in porous media, and numerical solution of these by using finite difference methods.

This course covers the simulation of flow in porous media during production or storage in subsurface reservoirs, e.g., during CO_2 sequestration, hydrocarbon production, or water production from aquifers. The course derives partial differential equations (PDE's) for one-phase and multi-phase flow in porous materials, and numerical methods for solving these. Topics: Summary of material and fluid properties; derivation of PDE's; numerical solution of PDE's using finite differences; methods for solving linear and non-linear equations; discussion of different types of reservoir simulation models; practical sides of reservoir simulation applications.

Professor Carl Fredrik Berg, PI at PoreLab, is the coordinator and lecturer for this course.

Description and Characterization of Porous Media and Flow by Laboratory Analysis
TPG4116, NTNU

The students shall learn basic theory of important fundamental principles of flow in porous media, specifically reservoir engineering including corresponding reservoir properties and determination of main reservoir properties using core analysis. The course content is as follow:
- Basic principles of flow in porous media and corresponding discussion of fundamental properties of the reservoir system to determine fluid distribution, static and dynamic flow properties.
- Determination of fundamental properties of reservoir rock system in the lab.

Topics are;
- Rock properties: Sampling, sample preparation, permeability and porosity, rock types.
- Fluid properties: Density, viscosity, interfacial tension.
- Rock fluid properties: Wettability, capillary pressure, resistivity, relative permeability.
- Additional concepts: Reservoir system, transition zone, Darcy's law, two-phase flow, EOR

Associate Professor Antje van der Net, associated member at PoreLab, is the coordinator for this course.

Numerical Methods in reservoir Simulation
PG8607, NTNU

This course is taught every second year. It gives an introduction to the various numerical formulations applied in reservoir simulators. The course contains:
- Difference methods,
- Control-volume method.
- Linear equation solvers.
- Stability and numerical dispersion

The subject investigates numerical methods used in reservoir simulation models.

The subject contains:
1. Difference methods.
2. Control-volume methods.
3. Linear equation solvers.
4. Stability and numerical dispersion.
5. Streamline methods.
6. Up-scaling methods.

By fulfilling the course, the candidate will have a deeper understanding of the mathematical building blocks that go into various reservoir simulators, different numerical representations and solution methods.

Disordered systems and percolation
FYS4460/FYS9460, UiO

The course provides an introduction to methods and problems in modern statistical physics with emphasis on algorithmic and computational methods. The applications addressed and the computational methods introduced are relevant for material science, complex systems, chemistry, solid-state, molecular-, and bio-physics.

The course aims to build understanding for the macroscopic effects of microscopic interactions using numerical simulations of microscopic models coupled with a concurrent development of a relevant theoretical framework.

Statistical Mechanics
FYS4130, UiO

This course will give the student a thorough introduction to thermodynamics and statistical physics, with an emphasis on the fundamental properties of gases, liquids and solids. The course also gives a theoretical foundation for further studies of systems with many particles or degrees of freedom. By completing the course, the student will be able to compute (numerically and analytically) thermodynamic quantities and correlation functions for quantum mechanical and classical models in statistical mechanics using various techniques and approximations. The student will gain experience with models of gases, liquids, electrons in materials, lattice vibrations, and magnetism as well as being able to deduce and mathematically transform thermodynamic identities. The student can also use thermodynamic stability criteria and can characterize phase transitions. The student will have knowledge about terms and concepts related to the renormalization group (RG) and use it to deduce critical exponents. The student will be able to deduce the master equation and use it to construct various Monte Carlo algorithms.

A large delegation from PoreLab, including professors, researchers, postdocs, PhD candidates, and master's students, attended the 15th Annual International Conference on Porous Media organized by InterPore, held from May 22 to 25, 2023, in Edinburgh, Scotland, UK

Porous Media Laboratory
NTNU, UiO

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