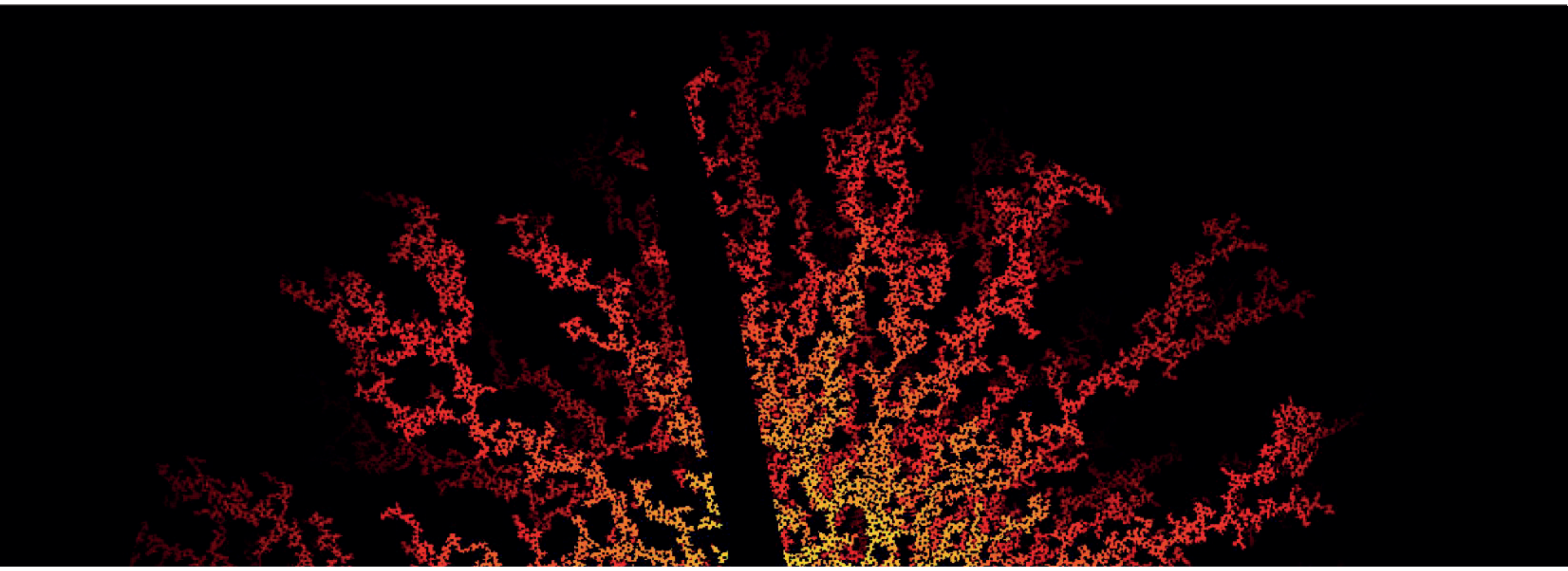
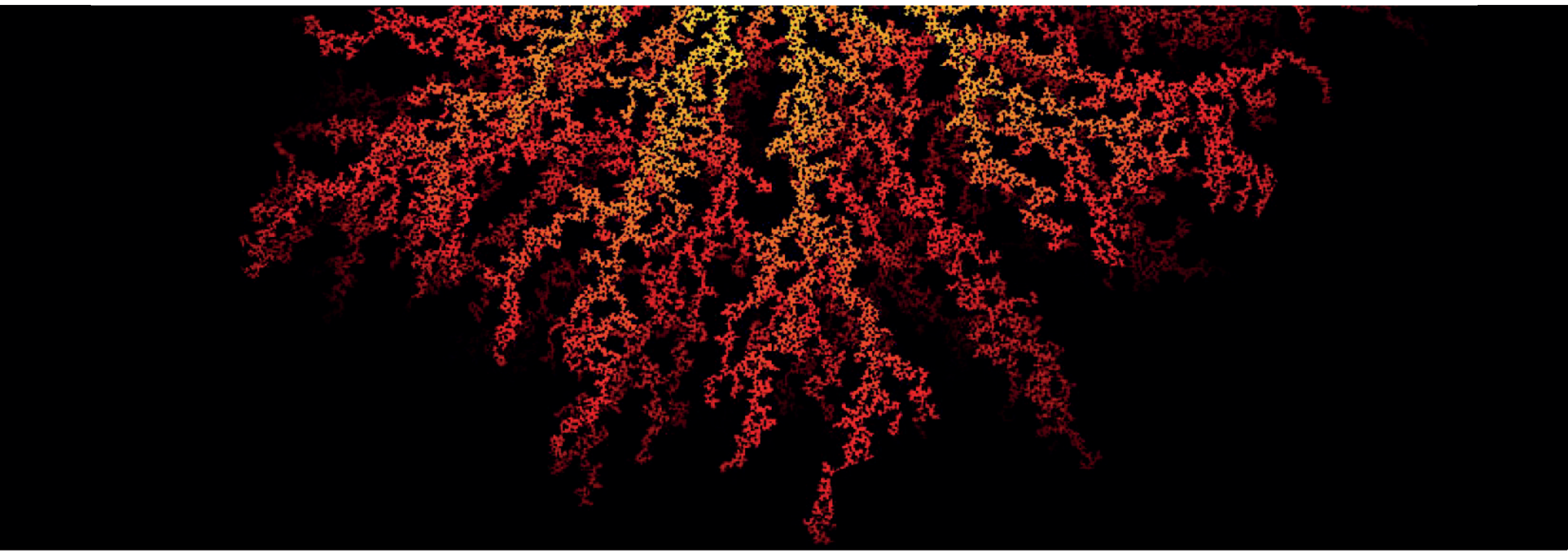
PoreLab
NTNU-UiO Porous Media Laboratory

Norwegian Centre of Excellence
The Research Council of Norway



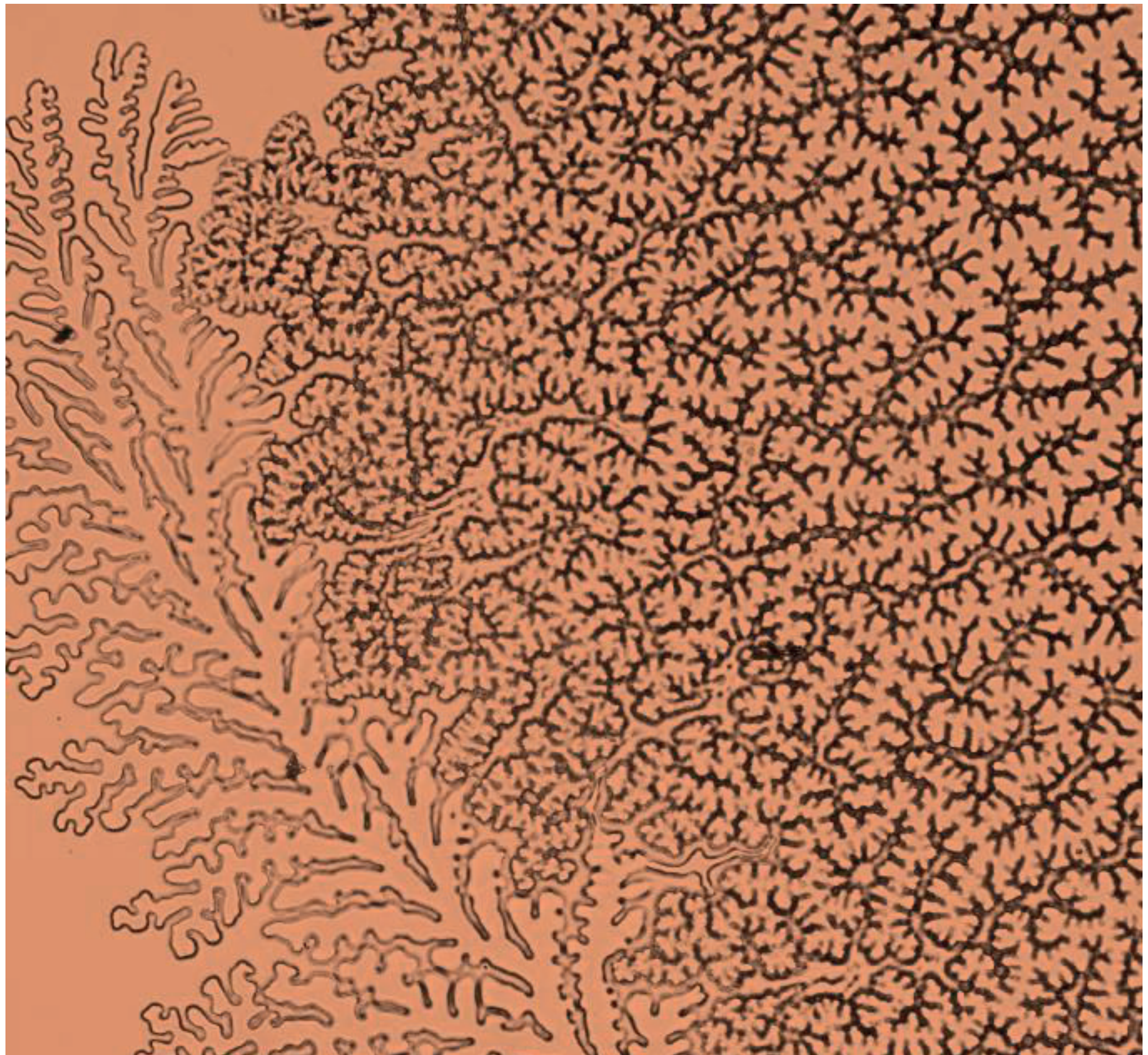
MSc at PoreLab 2022

Opportunities in 2023



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:

Invasion pattern resulting from the injection of pressurized air at the center of a circular cell containing a porous medium that is initially saturated with a viscous liquid. The color is added digitally and signifies the time a given pore is first reached by air, with warmer colors showing early times and colder colors for late times. More information about this experiment on page 28 of the PoreLab annual report 2022.

Overview – 2022 MSc students

Name	Title Master thesis	Supervisors
Elias Lundheim	Stress concentration in the local load sharing fiber bundle model	Alex Hansen, Santanu Sinha
Zehra Saleh	Sticky Two-Component Colloid Systems: A 3D Model	Alex Hansen, Hans Herrmann, Erika Eiser
Andreas Andersen Hennig	Effect of Yield Stress in a Two-Phase Flow in Porous Media	Alex Hansen, Santanu Sinha, Federico Lanza, Laurent Talon, Alberto Rosso
Parul Parul	Developing Bio-inspired Nanocomposite (Organic and Inorganic Phase) Films	Erika Eiser and Kristin Syverud
Cippora Magagnin	Colloidal Systems with Structural Colors	Erika Eiser
Emma Ditaranto	Thermo-osmosis and the Thermal Marangoni Effect in Porous Media	Øivind Wilhelmsen, Bjørn Hafskjold and Signe Kjelstrup
Christian Børre Ulrichsen	Electrochemical Noise Monitoring of Corrosion Rates under Insulation	Øivind Wilhelmsen, Signe Kjelstrup, Åsmund Ervik, Ole Meyer, Andreas Erbe
Emmanuel Paul Azebeokhai	Application of the Pressure Dependence of Ideal Gas Xenon to Hydrogen and CO_2 Storage Challenges using the micro CT scan	Antje van der Net
Jonathan Kings	GPU-based Numerical Simulation & Analysis of Constrained Folding Dynamics	Eirik Flekkøy and Xing Cai
Marlo Kunzner	Aging of Nanoclay dispersions analyzed with Optical Tweezers	Diethelm Johannsmann, Erika Eiser
Mark Willemsz	A Micro Computed Tomography-Study on the Use of Xenon as a Pressure Indicator in Porous Media	Maja Rücker, 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 obtained a new 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, 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 2022 and inspire new students to join the team. PoreLab is an international community. Master students at PoreLab do not only come from NTNU and UiO, but also from our international partners. The Center offers some funds that allow foreign Master students to spend some time with us, as well as to send our own students abroad. The same offer is available for Master students between NTNU and UiO.

We have recently developed a new project in collaboration with the French University Paris-Saclay and the Universidade Federal do Ceara (UFC) in Fortaleza, Brazil about non-Newtonian flow in porous media. Funds are available for Master students to do their thesis research at either laboratory of the three institutes: PoreLab NTNU/UiO, Laboratoire FAST at the University of Paris-Saclay and Complex Systems Group at UFC, Brazil.

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 Thursday's Talks and the PoreLab lecture series. We host both types of events simultaneously in Oslo and Trondheim, and they are open to all.
Our Wednesday seminars - or PoreLab lecture series - are now almost always given by external lecturers. The Thursday's talks aim to promote internal speakers who are given the possibility to present their own activities or give a lecture. It is our goal that each PoreLab member should participate with at least one presentation during the course of the year. The Thursday's talks take place once every two weeks.

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 aims 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 lunch time. 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


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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

Elias Lundheim

Department of Physics, NTNU

Stress Concentration in the Local Load Sharing Fiber Bundle Model

Fall 2022 / Spring 2023

Supervisors: Alex Hansen and Santanu Sinha

The fiber bundle model represents materials as a system of Hookian springs that break when stressed. The model consists of two plates connected by fibers arranged in a square lattice. See figure 1. How these springs break determines a lot about how realistic and useful the model is. This thesis explores a novel way to guide the breaking of fibers.

A popular model is the Local Load Sharing (LLS) model. It distributes the load of broken fibers equally among all the fibers that are adjacent to the broken fibers. A visualization of what this looks like can be seen in figure 2. Coloured pixels are broken fibers. Black pixels are non-broken fibers. My thesis explores how this model changes if we introduce some neighbour dependence. It is not unreasonable to say that isolated fibers are more susceptible to breaking than fibers surrounded by other fibers. Introducing this idea into the LLS model, we get denser holes in our bundle as seen in figure 3. We call this new model Corner Load Sharing (CLS). Figure 4 shows a larger system.

It turns out that this change has more than just visual effects! Not only is the strength of the bundle is drastically reduced, but the way the bundle loses strength is also completely different. Whereas the LLS model loses strength quite gradually, the CLS model loses a significant amount of strength as soon as the critical strength of the bundle is exceeded. This is similar to how many natural and artificial materials break!

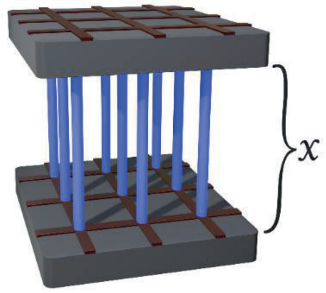


Figure 1: A 3D illustration of a 2D 3×3 bundle.

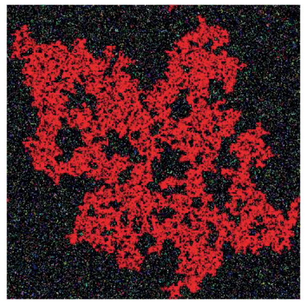


Figure 4: A 1024×1024 CLS fiber bundle.

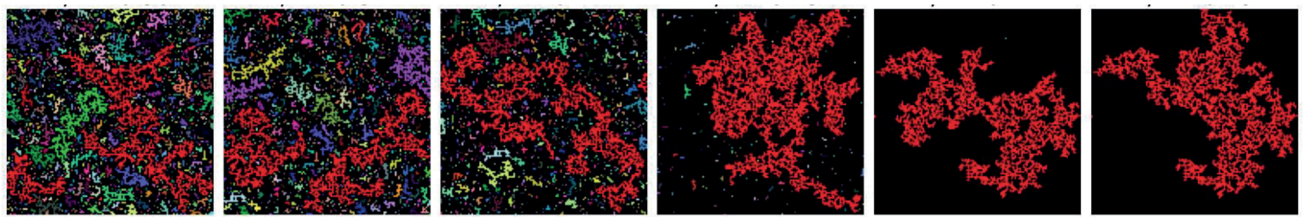


Figure 2: Typical situations for the standard local load sharing model.

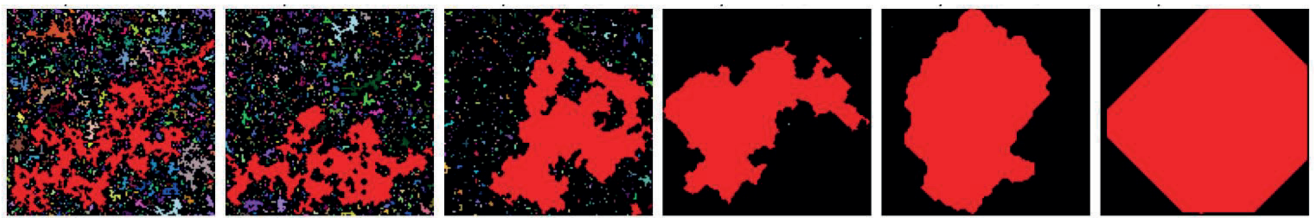
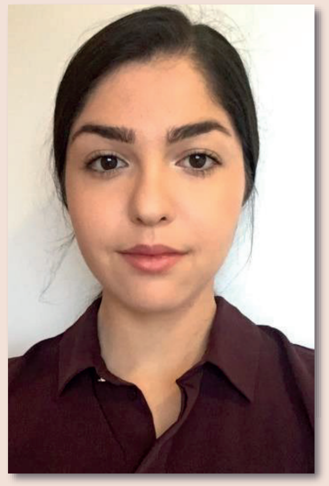


Figure 3: Typical situations for the corner load sharing model.

Zehra Saleh

Department of Physics, NTNU

In collaboration with Universidade Federal do Ceará, Brazil



Sticky Two-Component Colloid Systems: A 3D Model

Fall 2022

Supervisors: Alex Hansen, Hans Herrmann (UFC), Erika Eiser

Background:

Earlier research done on percolation processes display interesting behaviors when two different components are present in the same system and lead to double percolation. The interactions between these two spanning clusters and the effect they have on the percolation system as a whole is of high interest. The aim is to seek a deeper understanding of the critical properties of percolation in these systems.

Methodology:

An initializing of a cubic lattice with some constraints is necessary. There are open boundary conditions on the direction of percolation and periodic boundary conditions on the two remaining spatial dimensions. The concentration of the two species in the system are equal and filling the entire cubic system, and a specific particle can only bind to particles of the same kind.

Results:

The results in figure 2 show a linear convergence as the system size approaches infinity and an extrapolation of this suggests a convergence to zero. Implying that the existence of two spanning clusters does not have a significant effect on the properties within the phase-transition range. Though further work is needed to make a definite conclusion.

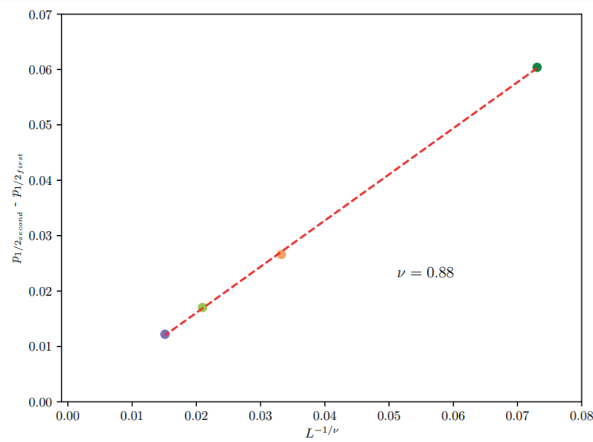


Figure 2: The differences in the estimated percolation thresholds for the second percolating cluster and the first percolating cluster plotted for different system sizes.

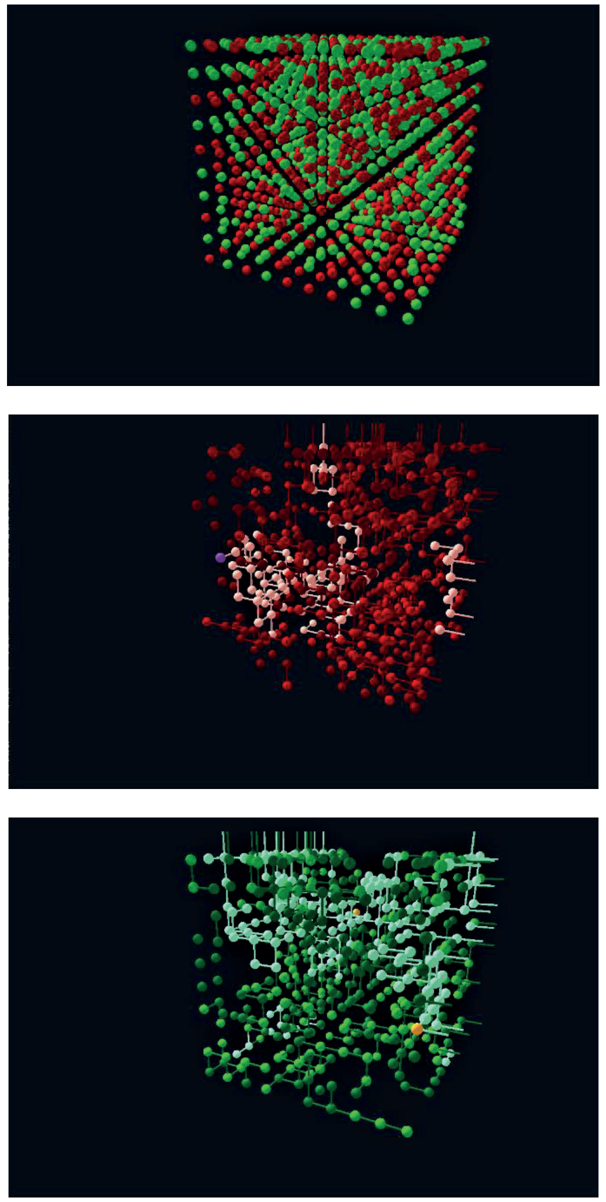
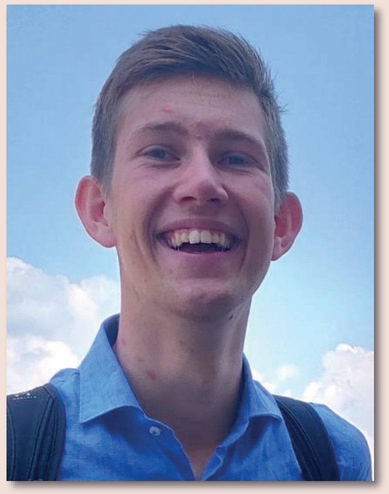


Figure 1: The first picture shows a visualization of the particles for a system size of L = 10 at the beginning of the simulation, no particles have yet diffused and there are no bonds in the system. The different particles are shown separately in the second and third picture at the end of the simulation when there is percolation. The percolating clusters are displayed with a brighter color.

Andreas Andersen Hennig



Department of Physics, NTNU
In collaboration with the CNRS at the University of Paris-Saclay, France

Effect of Yield Stress in a Two-Phase Flow in Porous Media

Fall 2022/Spring 2023
Supervisors: A. Hansen, F. Lanza, A. Rosso, S. Sinha, L. Talon

NTNU - Department of Physics

Background:

Non-Newtonian fluids in porous media flows offers complex interplays that are not fully understood and is an active field of research. One non-Newtonian effect is the yield stress effect, prominent in fluids such as mayonnaise and toothpaste, preventing the fluids from flowing until an external force is applied. A two-phase porous media flow with a yield stress fluid has found applications in several engineering processes, like soil reinforcement [1] and fracking processes [2], but they are challenging to study numerically due to the nonlinear rheology in a disordered network.

Objectives:

The main objective is to characterize the different phenomena and patterns occurring in these systems for a wide range of parameters, and to finally produce a phase diagram to summarize the findings. We also intend to study the details of the phenomena with the language of statistical physics, searching for scaling relations effective properties.

Methodology:

A pore-network model is used to study the average properties of a two-phase flow, enabling us to study larger systems by sacrificing microscopic pore-scale properties. The model is integrated with a method recently presented by Talon and Hansen to solve the system of coupled nonlinear equations by an Augmented Lagrangian Method [3], thus handling some simple non-Newtonian models, like the Bingham fluid model.

References:

[1] Coussot, P.: Rheometry of pastes, suspensions, and granular materials: applications in industry and environment. *John Wiley and Sons*, New York, NY (2005)

[2] Talon, L., Auradou, H., Hansen, A., 2014. Effective rheology of Bingham fluids in a rough channel. *Frontiers in Physics 2.* https://doi.org/10.3389/fphy.2014.00024

[3] Talon, L., Hansen, A., 2020. Effective rheology of bi-viscous non-Newtonian fluids in porous media. *Frontiers in Physics 7.* doi:10.3389/fphy.2019.00225.

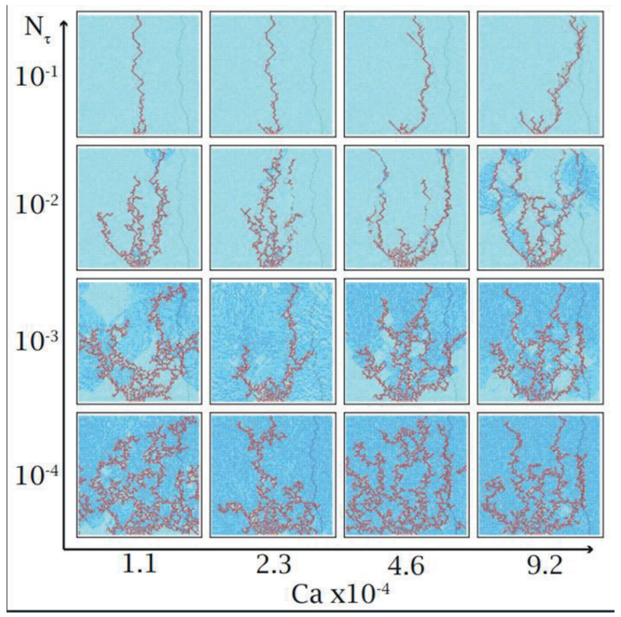


Figure: *Snapshots of simulations with a Newtonian fluid (red) displacing a Bingham fluid (blue) in a pore-network model. The light blue color indicates that the fluid is immobilized, due to the yield stress effect. Varying the capillary number (proportional to the imposed flow rate) and the yield number N (relative strength of yield stress) produces qualitatively different patterns.*

Cippora Magagnin

Department of Physics, NTNU

Colloidal Systems with Structural Colors

Fall 2022
Supervisor: Erika Eiser

Background:

Colors in nature have different sources. While the colors of pigments or dyes arise directly from molecules absorbing certain wavelengths, structural colors are dependent on the underlying microstructure of certain materials. Made of repeated units that are periodically ordered exposing a crystal structure, the materials have specific optical properties due to diffraction and the interference of light within its inner arrangement (figure 1). This phenomenon produces intense colorations observable in butterfly wings, beetles (figure 2), or opals.

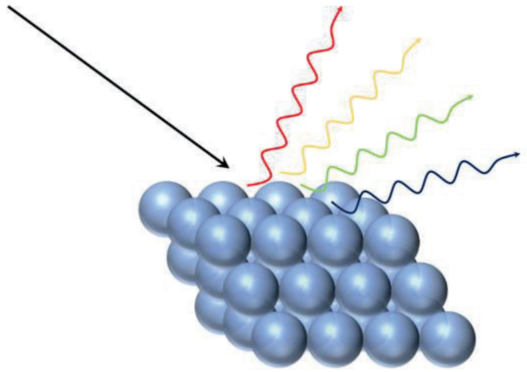


Figure 1: *Simple illustration of the reflected light from an ordered microstructure.*

Figure 2: *Colors arising from the shell structure of the beetle (Wikipedia).*

Objectives:

Based on the structure observed in opals originating from the self-assembly of silica beads, a colloidal solution of fluorinated latex (FL) spheres of 200nm in diameter was developed. In an aqueous solution, the suspensions form charge-stabilized, face-centered cubic crystals. With this project, the coloration properties of these solutions will be investigated to obtain controlled reflections. Additionally, the aim is to solidify them into mechanically stable materials for further applications.

Methodology:

The first step to this development is the synthesis of the FL spheres. The effect of the concentration of the aqueous solutions on the reflected colors is assessed. A matrix consisting of specific ratios of natural polymers and clay platelets is created to incorporate the particles into the solid matrix.

NTNU - Department of Physics

NTNU - Department of Chemical Engineering

Parul Parul

Department of Chemical Engineering, NTNU

Developing Bio-inspired Nanocomposite (Organic and Inorganic Phase) Films

Fall 2022
Supervisors: Erika Eiser (Dept. of Physics) and Kristin Syverud

Background:
The world's growing environmental pollution from synthetic, non-compostable plastics is posing an ever-increasing problem. As a result, natural polymers such as plant-based cellulose or alginate are preferable. They do not, however, produce mechanically strong materials, which are required in packaging and coatings. As a possible substitute for synthetic polymers, the Eiser group recently developed bioinspired, nanostructured composite materials with a microscopic architecture that resembles the brick-and-mortar structure of mechanically tough, iridescent nacre in seashells [1].

Objective:
We did investigate the possibility of using different natural clays (2D-crystals; see Figure 1 for an example of Laponite and other clays like Bentonite, Kaolin) and biopolymers (Carboxymethyl cellulose (CMC), xanthan gum (XG), polyvinyl alcohol (PVA)) to further develop such recyclable nanocomposite materials as transparent coatings. Overall, we tried to formulate various combinations between clays and biopolymer to make a film.

Methodology:
Fabrication of the films was done by forming a clay dispersion followed by a biopolymer dispersion and then mixing them on a magnetic stirrer. Next, pour the suspension of clay and biopolymer into a petri dish and leave it for evaporation. Once, it dry forms a thin film. The following evaluation of the film was done through a pH Test, atomic force microscopy (AFM) and scanning electron microscope (SEM).

Results:
Figure 3 illustrates the films that were formed during the experimental work in the lab.

Reference:
[1] P. Xu, T. Erdem, and E. Eiser, 'A simple approach to prepare self-assembled, nacre inspired clay/polymer nanocomposites' Soft Matter 16, 3385–3388 (2020)

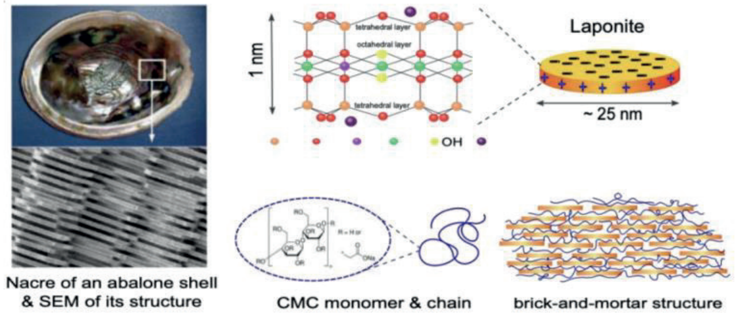


Figure 1: Alternative materials

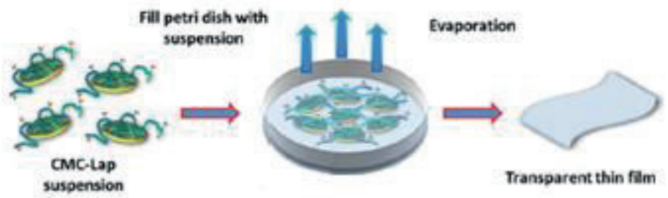


Figure 2: A schematic illustration of CMC-lap hybrid film formation by evaporation.

Figure 3: (a) Film made of Laponite and PVA. (b) Film made of Laponite and CMC

Emma Ditaranto

Department of Chemistry, NTNU

Thermo-osmosis and the Thermal Marangoni Effect in Porous Media

Fall 2022 / Spring 2023
Supervisors: Øivind Wilhelmsen, Bjørn Hafskjold and Signe Kjelstrup

A recent study carried out by Hafskjold, Bedeaux, Kjelstrup and Wilhelmsen [1] developed the research on the Soret effect and thermo-osmosis in porous media. A yet unexplainable behavior of thermo-osmosis occurs at low porosities, as seen in *Figure 1* by the dip in the thermo-osmotic coefficient for porosity φ=0.4. A hypothesis is that the permeability affects thermo-osmosis. My master's thesis is to study this further, by simulating a two-component fluid flow through slit pores of varying permeability under non-isothermal conditions. A previous study by Hafskjold and Wold [2] that simulated non-isothermal fluid flow through slit pores observed a thermal Marangoni effect; a mass flow driven by a gradient in surface tension at the pore walls which is magnified by the thermal gradient. The effect creates circular flow patterns, visualized by *Figure 2*, where the fluid near the pore walls flows against the temperature gradient. The fluid flows back in the pore driven by either a temperature or pressure gradient. The latter driving force caused by thermo-osmosis. Thus, an additional aim of the master's thesis is to investigate the coupling of thermo-osmotic pressure and the thermal Marangoni effect.

[1] Soret separation and thermo-osmosis in porous media. Hafskjold B., Bedeaux D., Kjelstrup S., Wilhelmsen Ø. s.l. : *The European Physical Journal* E, 2022, Vol. 45:41. 10.1140/epje/s10189-022-00194-2

[2] Nonequilibrium Molecular Dynamics Simulations of Coupled Heat and Mass Transport in Binary Fluid Mixtures in Pores. Hafskjold, Inge Wold and Bjørn. s.l. : *International Journal of Thermophysics,* 1999, Vol. 20:3.

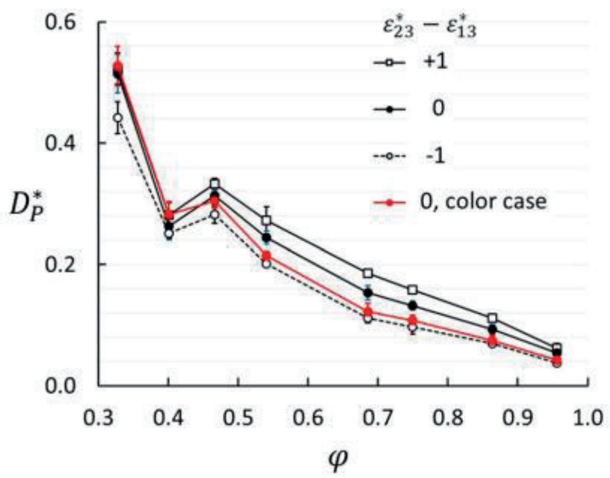


Figure 1: Thermo-osmotic coefficient as a function of porosity.

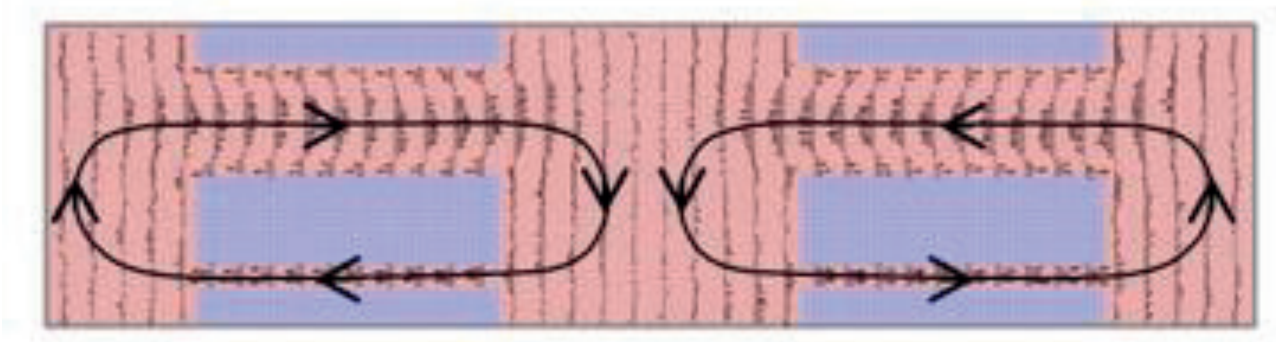
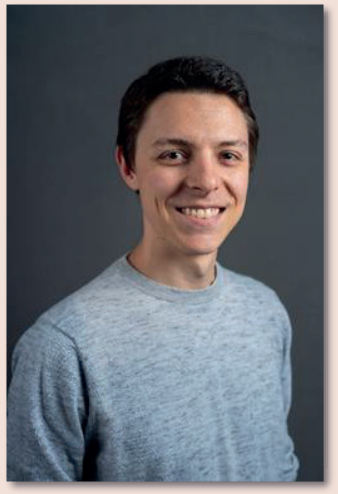


Figure 2: A double slit pore with arrows to visualize the circular mass flow

NTNU - Department of Chemistry

Christian Ulrichsen



Department of Chemistry, NTNU
In collaboration with SINTEF Energy AS

Electrochemical Noise Monitoring of Corrosion Rates under Insulation

Fall 2022/Spring 2023
Supervisors: Ø. Wilhelmsen, S. Kjelstrup, Å. Ervik, O. Meyer, A. Erbe

Corrosion under porous media is relevant for a number of industrial applications, for example in any situation where pipelines are insulated, and water can travel through the porous insulation to the surface of the pipe. Monitoring the corrosion on the metal surface is made difficult by the insulation inhibiting direct observation, and the already complex corrosion process is further complicated by the need to also consider transport of corrosion factors such as water, oxygen, and electrolytes through the porous medium to the surface of the metal.

In this work, electrochemical noise monitoring techniques will be combined with theoretical modelling to monitor and estimate corrosion rates under mineral wool insulation. Custom test cells will be designed and 3D-printed for use in the experiments. In addition, a mathematical model will be developed and compared to the experimental results. The experiments and the model will be used to explore correlations between relative humidity, adsorption isotherms of the insulation, and corrosion rate. The work falls under PoreLab's Research Theme 7.

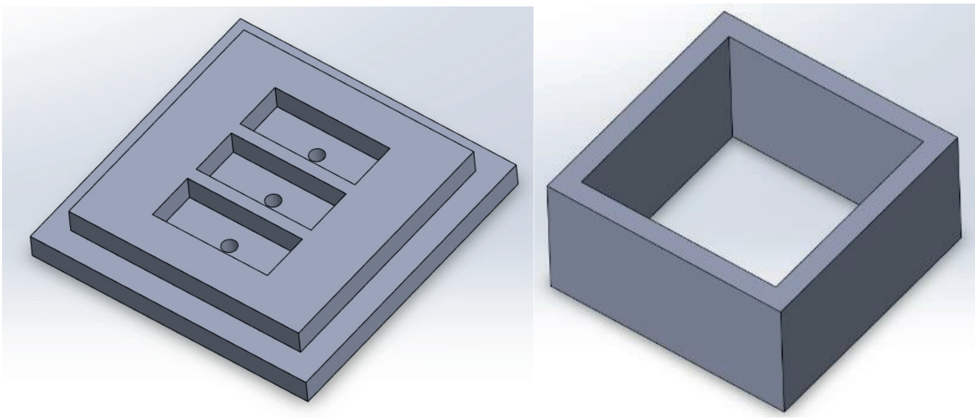


Figure: *Modular corrosion cell design.*
The base portion (left) will have metal samples slotted into the indentations, connected to electrical leads passing through the holes in the bottom for electrochemical monitoring.
The wall portion (right) can then be slotted over the base, and is intended to hold insulation material in place on top of the metal samples during testing.

Emmanuel Paul Azebeokhai

Department of Geoscience and Petroleum, NTNU

Application of the Pressure Dependence of Ideal Gas Xenon to Hydrogen and CO_2 Storage Challenges using the micro CT Scan

Fall 2022
Supervisor: Antje van der Net

Unique micro-CT scan experiments in our lab by Mark Willemsz[1] have shown that the ideal gas Xenon gives a pressure dependent signal (attenuation) at pore scale in a sandstone. As part of the project, this research shall be continued to exploit to what extend this physical effect can be applied to understanding multiphase gas flow in porous media. It might open up the unique opportunity to visualize local pressure variations in various kind of fluid-gas flow experiments in porous media or to use Xenon as a gas tracer. Applications to explore are for example foam flooding for control of the gas mobility for hydrogen or CO_2 storage, capillary pressure curve determination of caprock and use of Xenon as tracer in gas trapping studies.

The Xenon pressure dependent microCT scan signal has been studied as single phase in sandstone[1]. The next step is to introduce brine as 3rd phase, beside gas and rock and observe whether similar Xenon pressure - attenuation correlations can be found, as finally we want to prove the concept for a multiphase flow application.

By introducing brine also the interaction of Xenon with brine is to be studied. Theoretically Xenon has a solubility in brine, which likely is not neglectable and therefore can affect the contrasts.

Additionally, to enable an analysis of all phases, a suitable contrast between rock and brine and the gas phase needs to be obtained, where the gas phase adsorption will vary, depend on the gas pressure. Normally contrast enhancers are added to the brine to enhance its X-ray adsorption or named attenuation, see Figure. The brine attenuation dependence on the Xenon solubility is to be derived and additionally brine attenuation is planned to be measured at 100% brine saturation in a core with different contrast enhancer concentrations. With a correlation of contrast enhancement and predicted effect of the Xenon solubility, a suitable brine enhancement can be chosen. Calibration curves of Xenon pressure versus Xenon attenuation at residual brine saturation are the initial aimed goal. Challenges that were identified in the initial work, like pore size dependence of the signal needs also here attention in the data analysis.

Depending on the results, the next phase will be to proof the concept studying the effect under dynamic conditions or for a specific application.

[1] Willemsz M., June 24, 2022, *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, Norwegian University of Technology.

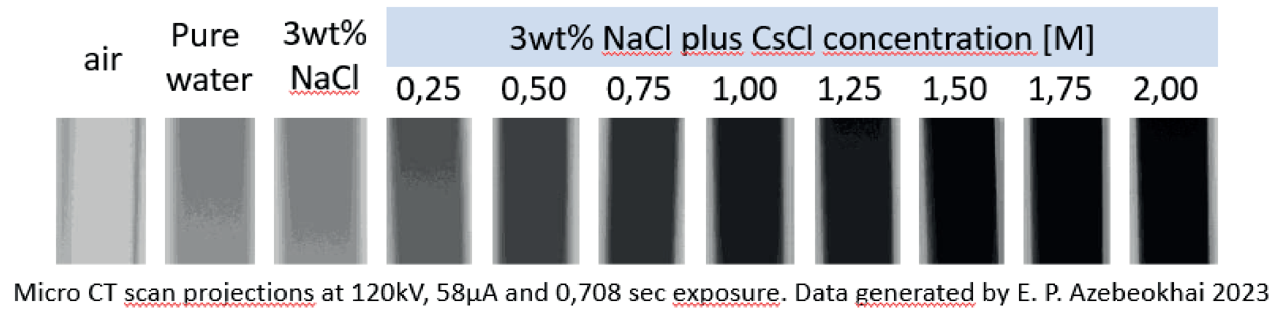


Figure. *The change in attenuation of brine with inclusion of cesium chloride (CsCl). Single projections at 120kV of a square container filled with salt solutions at room temperature. The darker the color the higher the X-ray adsorption or attenuation. Air and pure water are added as comparison.*

UiO - Department of Physics

Jonathan Kings

Department of Physics, University of Oslo

GPU-based Numerical Simulation & Analysis of Constrained Folding Dynamics

Fall 2021 / Spring 2023
Supervisors: Eirik G. Flekkøy, Xing Cai (Simula / Dept. of Informatics)

Labyrinthine patterns can be seen emerging from frictional fingering in confined granular fluid systems [1], confined magnetic fluid systems [2], and polar seal maxilloturbinate cross-sections [3]. The striking similarities in patterns between these three systems gives rise to an interesting question; can a unified model be established to reflect these geometrical similarities?

A numerical model for these folding dynamics based on the time-evolution of nodes connected in a chain (representing the fluid-grain/fluid-fluid/fluid-solid boundary in the 2D case) or a triangulated surface (3D case) is set up, with two distinct stages: tessellation (i.e. growth of the system by addition of new nodes) and propagation (i.e. inter-node dynamics to preserve topology and evolve the system's geometry). The propagation step itself is modelled as one-to-one interactions between the nodes, and as such is trivially parallelizable on a GPU.

Numerical results are compared geometrically to experimental results from [1], [2], and [3], in particular in terms of fractal & backbone dimensions, curvature ratios, branch lengths, and density.

References:

[1] Olsen, K. S., Flekkøy, E. G., Angheluta, L., Campbell, J. M. (2019) *Geometric universality and anomalous diffusion in frictional fingers*, doi: 10.1088/1367-2630/ab25bf.

[2] Dickstein, A. J., Erramilli, S., Goldstein, R. E., Jackson, D. P., Langer, S. A. (1993) *Labyrinthine Pattern Formation in Magnetic Fluids*, doi: 10.1126/science.261.5124.1012.

[3] Mason, M. J., Wenger, L. M. D., Hammer, Ø., Blix, A. S. (2020) *Structure and function of respiratory turbinates in phocid seals*, doi: 10.1007/s00300-019-02618-w.

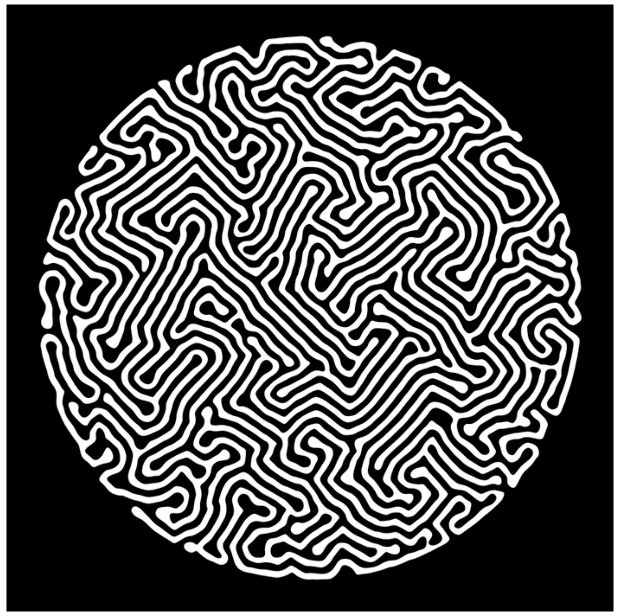


Figure 1. *two-dimensional numerical result from a simulation with high surface tension and volume conservation factors*

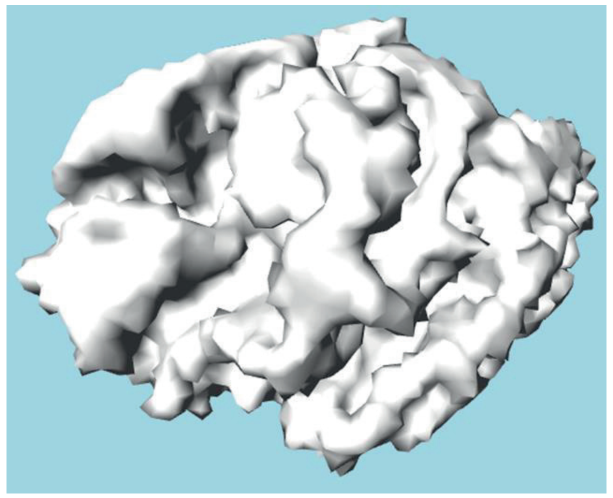


Figure 2. *three-dimensional numerical result from a simulation within a soft cylindrical boundary*

International Collaboration

Mark Willemsz

Department of Mechanical Engineering, Eindhoven University of Technology
In collaboration with the Department of Geoscience and Petroleum, NTNU

A Micro-Computed Tomography-Study on the Use of Xenon as a Pressure Indicator in Porous Media

Internship period: March-June 2022
Supervisors: Maja Rücker (TU/e) and Antje van der Net (NTNU)

Subsurface carbon-dioxide (CO_2) and hydrogen (H_2) storage are considered a promising approach to reduce the emissions of large polluters like the steel, chemical and cement industries. In order to develop gas storage techniques in geological formations it is crucial that we can describe and monitor these multiphase flows, which often also include water and oil. Micro computed tomography (Micro CT, X-ray technology) has opened up new opportunities to analyze the behavior of gases and fluids inside the medium at high resolutions reaching sub-pore level. However, measuring in-situ (local) pore pressures is still particularly challenging.

This research started the development of a method to determine in-situ pore pressures using Xenon gas. Such a method would enable us to describe pressures in static and dynamic multiphase flow in porous media. Xenon is a heavy, non-radioactive, inert, ideal gas that is already used as a tracer in research involving micro-CT due to its high atomic number. As well, its potential to function as a pressure indicator has been confirmed by van der Net in 2005.

We derived the energy level dependent (linear) relation between Xenon pressure and attenuation in micro-CT at different scales from static, single gas phase experiments in a Bentheimer sandstone core.

By analyzing images at the pore level in a Xe-pressurized core between 0-25 bar Xe, with 5 μm resolution, we were provided with new, highly relevant insights. For instance, material and geometry dependent artifacts as pseudo-enhancement were observed. They prevent for this moment the universal use of the obtained calibration curves, though specified to the used material and set-up curves prove great potential. As well, they mark the starting point and proof of concept of the method.

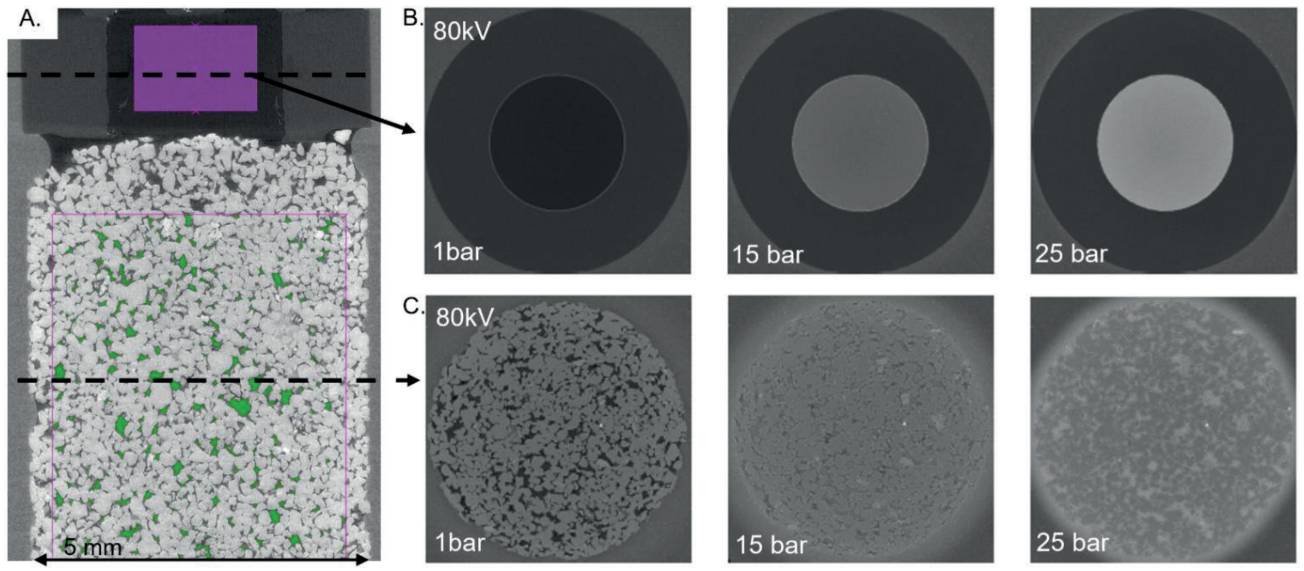


Figure: *The pressure dependence of Xenon visualized by micro CT scanning of a void space in a plastic ring and a cylindrical Bentheimer sandstone core, both seen in A. The resulting cross sections of the void space and the Bentheimer core at pressure levels of 1, 15 and 25 bar are presented in B. and C. respectively. At 15 and 25 bar the Xenon in the pores even has a higher (brighter) signal than the sand grains around, opposite to the image at 1 bar.*

International Collaboration

Marlo Kunzner

Clausthal University of Technology, Germany
In collaboration with the Department of Physics, NTNU

Aging of Nanoclay dispersions analyzed with Optical Tweezers

Internship period: February – August 2022
Supervisors: D. Johannsmann (TU Clausthal) and E. Eiser (NTNU)

Background:

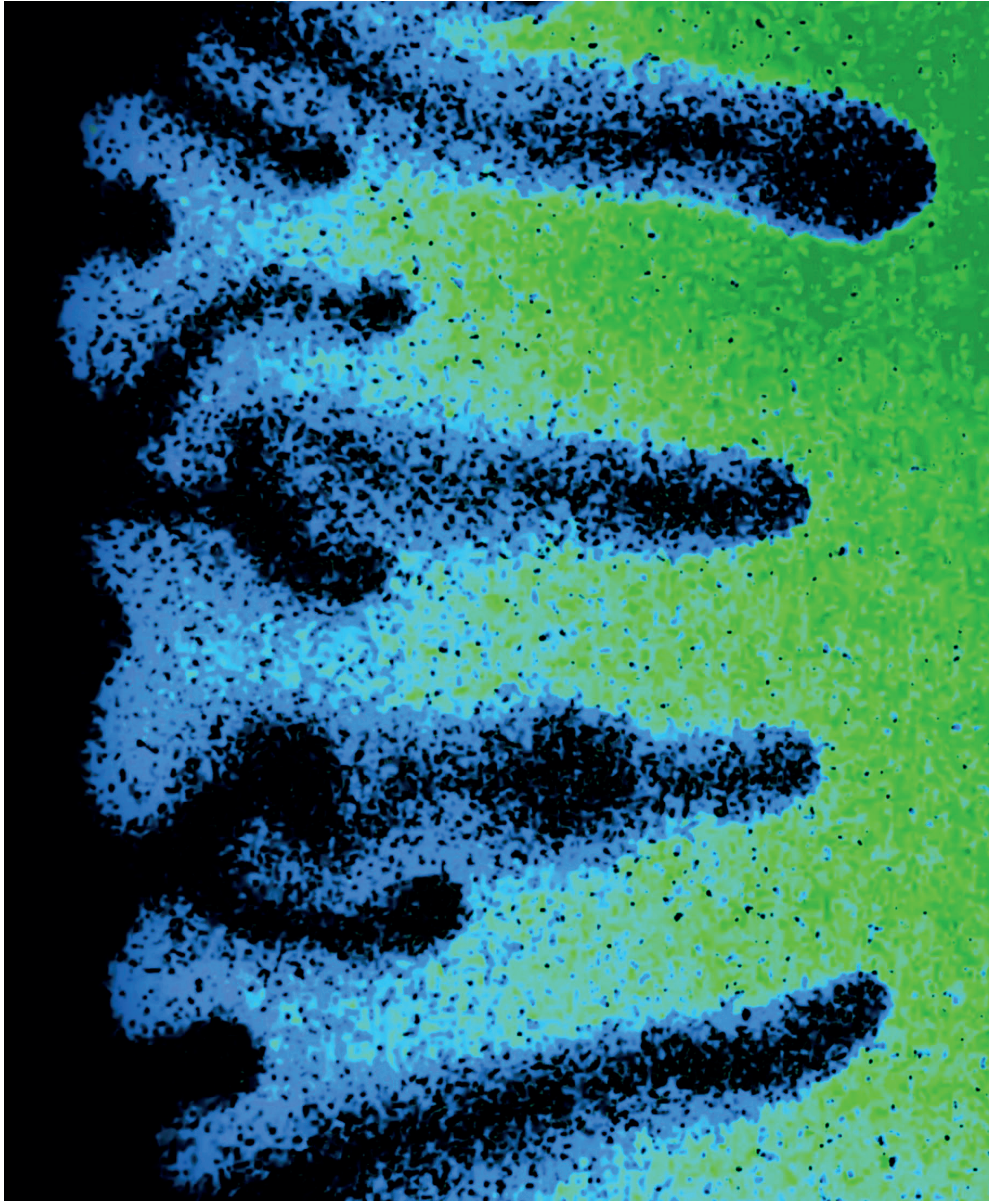
This work describes the use of optical tweezers for nanoscale-research on percolating networks and other complex fluids.

The fluids analyzed are water, Laponite solutions and F127 solutions. Water is used as a reference to validate the approach. Laponite is used due to its aging behavior and resulting "house of cards" structure. This makes Laponite a good starting point for analysis of percolated systems. F127 is used, due to its wide range of applications, from household products to pharmacy respectively. Furthermore, it does not age and is, like water, a stark contrast to Laponite.

Results:

This work shows that the tweezers can analyze all kind of transparent samples, and even detect aging processes in Laponite solutions. The probe's diffusivity and the viscosity of the solution, along with complex shear moduli have been experimentally determined. A clear change in viscosity was observed over time for 2.5% Laponite solutions. The complex shear modulus indicated percolation behavior.

This supports the thought of a "house of cards" structure forming locally around the probe. Water had an experimentally determined viscosity of $\eta_{exp} = 0.9355 \pm 0.0539$ mPa*s at 19°C, which is slightly below the literature value of $\eta_{lit} = 1.03$ mPa*s. The measurements of F127 confirmed the influence optical tweezers have on Newtonian liquids, for example the change in MSD if the laser power differs. Different laser powers also had a notable influence on the fluid's viscosity, due to heating. The trap's apparent elastic modulus was visible in different liquids measurements and aligned with the predicted value.



Laboratory experiment showing a granular fingering pattern that results when a liquid containing a granular mixture moves close to a solid wall. Picture by Antoine Dop, PoreLab UiO and ENS Lyon

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 (department of Physics)

Onsager symmetry in immiscible two-phase flow in porous media

Contact: Alex Hansen (Alex.Hansen@ntnu.no)

We have recently proposed a new approach to steady-state immiscible two-phase flow in porous media based on equilibrium statistical mechanics [1]. Here, "steady state" refers to the macroscopic parameters describing the flow fluctuating around well-defined and constant averages. The central idea behind the new approach is to consider the statistics of fluid configurations in cuts orthogonal to the flow direction and the flow direction as a pseudo time axis. Under steady-state flow, the statistics of the fluid configurations in the cuts will be in equilibrium.

We are now attempting to go beyond steady-state flow. If this is to succeed, it is necessary to verify whether Onsager symmetry - i.e., time reversal symmetry - applies to the extensive variables that appear in the theory.

This MSc project consists of using a dynamic pore network model to check whether the symmetry is obeyed or not.

[1] A. Hansen, E. G. Flekkøy, S. Sinha and P. A. Slotte, *A statistical mechanics framework for immiscible and incompressible two-phase flow in porous media*, Adv. Water Res. 171, 104336 (2023); https://doi.org/10.1016/j.advwatres.2022.104336.

Proposed Master Project at PoreLab NTNU (department of Physics)

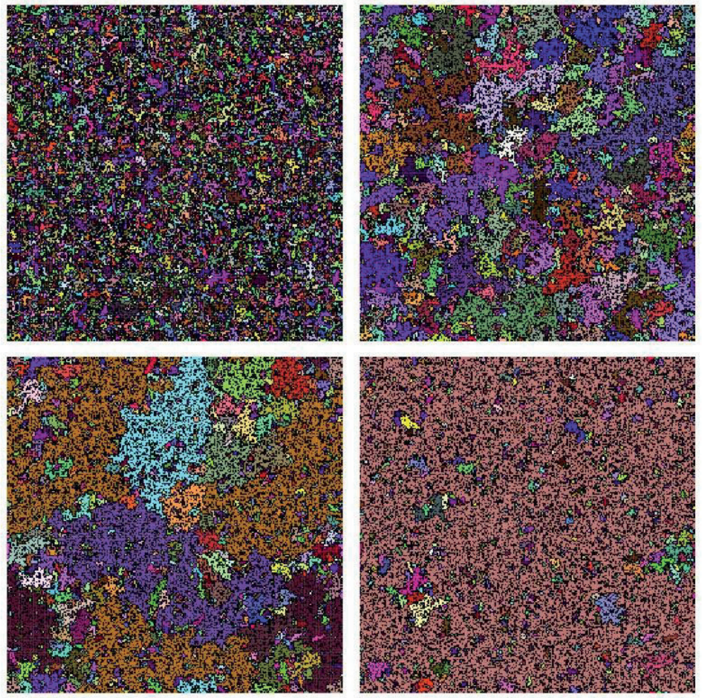
Role of system disorder and thermal noise in fracture growth

Contact: Santanu Sinha (Santanu.Sinha@ntnu.no), Alex Hansen (Alex.Hansen@ntnu.no)

Material stability is of key importance in industrial applications. Appearance of fractures and their growth in a material depend on the competition between the disorder in the material strength and the local stress concentration. The heterogeneities delocalize the fracture growth and offset the failure point at which a crack becomes unstable. With a bundle of linear elastic fibers, called as a fiber bundle model, it was shown that the transition from a sparse to a localized fracture growth can be of first or second order depending on the type of the disorder distribution [1].

There is another type of fracture process that can cause a material to fail over time even if the applied stress is below the failure point. This is called creep failure which is influenced by external factors such as temperature. Presence of thermal noise can delocalize a localized fracture growth and can make it a percolation-like process [2]. One such growth simulated with a local load sharing fiber bundle model is shown in the figure where the black and colored pixels correspond the intact and broken fibers respectively.

A fiber-bindle model consists of a set of elastic fibers placed in between two clamps under an external force. Each fiber has an elongation threshold beyond which it fails and the load it was carrying is distributed to all (equal load sharing) or nearby (local load sharing) intact fibers. The aim of this MSc project will be to use a fiber bundle model to study the creep failure for different types of threshold distributions and to find out how the two types of disorders, one related to the thermal noise and the other related to the thresholds, control the fracture growth.



References

[1] S. Sinha, S. Roy and A. Hansen, Physica A **569**, 125782 (2021).

[2] S. Sinha, S. Roy and A. Hansen, Phys. Rev. Res. **2**, 043108 (2020).

Proposed Master Project at PoreLab NTNU (department of Physics)

Shape of Clusters in Immiscible Two-Phase Flow in Porous Media

Contact: Alex Hansen (Alex.Hansen@ntnu.no) and Santanu Sinha (Santanu.Sinha@ntnu.no)

When two immiscible fluids flow simultaneously through a porous medium, they will self-organize into complex pattern that are describable using the language of critical phenomena. This has profound consequences for the properties of the flow.

Underlying this self-organization is a competition between the viscous forces, i.e. the usual hydrodynamic forces and the capillary forces coming from the interfacial tension between the fluids and the wetting properties between the fluids and the pore walls.

The self-organization manifests itself through how the fluids distribute themselves into clusters, which – when they move – are called ganglia. Ganglia dynamics is very rich and still rather poorly understood despite a huge effort to study these experimentally.

It is the aim of this MSc project to use a dynamic network model (i.e. a numerical model) to characterize the shape of trapped clusters and ganglia geometrically. We know, e.g. that there are length scales associated with the two types of forces involved, viscous and capillary. How do these length scales influence the shapes? To answer these questions, we will use the machinery developed in connection with percolation theory – the quintessential example of a non-thermal critical system. We will then go on to correlate the shape of the ganglia with their speed. Is there a typical shape? How does speed correlate with their size?

The findings in this project will open for later experimental studies.

Proposed Master Project at PoreLab NTNU (department of Physics)

Renormalization Group Technique for Local Load Sharing Fiber Bundle Model

Contact: Alex Hansen (Alex.Hansen@ntnu.no)

Ken Wilson won the 1982 Nobel Prize in physics for devising the renormalization group technique. Here is the essence of the idea behind it: We have a system that consists of many interacting parts. We wish to find a description of the macroscopic variables that reflects the underlying behavior of the interacting parts. The renormalization group technique consists of finding a way to replace the original system by another coarse-grained one – one that consists of fewer interacting parts, but which leads to the same behavior of the macroscopic variables. By making the coarse-graining incremental, we keep track of how the relation between the coarse-grained interacting parts and the macroscopic variables changes. We repeat the coarse graining over and over and a pattern of change emerges. This pattern tells us how the macroscopic variables behave.

The fiber bundle model consists of elastic fibers placed between two clamps. Each fiber has a maximum load it can take before it fails. The question is what the force on the clamps versus elongation of the distance between the clamps looks like. In 2018, we constructed a renormalization group procedure for this problem [1], which combining fibers pairwise into "super"-fibers.

There is a version of the fiber bundle model which is much more complex than the one I just described: The local load sharing fiber bundle. When a fiber fails in this model, the force it was carrying is given to the nearest surviving fibers. This makes the model much more complex. The aim of this project is to construct a renormalization group for this problem. This is a hard but not impossible problem.

[1] S. Pradhan, A. Hansen and P. Roy, Front. Phys. https://doi.org/10.3389/fphy.2018.00065.

Proposed Master Project at PoreLab NTNU (department of Physics)

Permafrost – Heat Transport in Porous Media

Contact: Erika Eiser (erika.eiser@ntnu.no) and Alex Hansen (alex.hansen@ntnu.no)

© AWI | Georg Schwamborn | ce wedges (Yedoma) on the Bol'shoy Lyakhovsky, the most southern Island of the New Siberian Archipelago[1]

Motivation

Permafrost is a combination of soil, rocks and sand, held together by ice. Most of it is below freezing throughout the year. However, the top layer, called the active layer, undergoes a thawing-freezing transition during Earth's winter-summer cycle[2].The soil in this layer is a densely packed, nanoporous network composed of silica-rich grains and clays, with a large size distribution of pores that are filled or partially filled with water. When below freezing, water in pores typically smaller than 10nm will remain liquid while the water in larger pores will freeze, which is known as Gibbs-Thomson effect. Recent theory by Flekkøy and Hansen (unpublished) finds ***super-diffusive propagation*** of a melting front in a frozen, nanoporous networks[3].

Your Project

To test the theory of super-diffusive propagation in a porous medium experimentally the student will build a nano-porous network in terms of a Hele-Shaw cell, which is a thin cell with flat walls. This will be densely packed with micron-sized silica beads and varying degrees of humidity. Using fluorescent microscopy and heating provided by a focused laser we will study how heat is propagating in such a controlled environment. The experiments will be conducted in a cold room, kept at -10°C.

Requirements

The applicant should have a very good understanding of thermodynamics and be keen on setting up the cell, including the optics and sample preparation.

Other aspects

The experimental study will be supervised by the Professor Eiser, an experimental physicist, and Alex Hansen a theoretician, PoreLab (www.porelab.no).

References

[1] https://www.sonnenseite.com/en/science/thawing-permafrost-is-shaping-the-globalclimate/

[2] J. Obu, "How Much of the Earth's Surface is Underlain by Permafrost?" J. Geophysical Research: Earth Surface, 126, e2021JF006123 (2021)

[3] E. G. Flekkøy, A. Hansen, B. Baldelli, "Hyperballistic Superdiffusion and Explosive Solutions to the Non-Linear Diffusion Equation" Frontiers in Physics 9, 640560 (2021)

Proposed Master Project at PoreLab NTNU (department of Physics)

The Flow of Nano-Crystals – Into the Woods

Contact: Erika Eiser (erika.eiser@ntnu.no) and Kristin Syverud (kristin.syverud@ntnu.no)

Motivation

In the past years, Nano Cellulose Fibrils (NCFs) and Crystals (NCCs) have become sustainable alternatives to synthetic polymers in applications such as membranes in water purification and flow-modifiers for 3D printing amongst many others[1]. NCFs and NCCs are extracted from wood, bushes and even from specialized bacteria through various chemical processes. The underlying molecular structure is that of poly-saccharide chains that, after extraction, self-assemble into fibrils of a hundred of nanometer thickness and many lengths in the range of millimeter. This very large aspect ratio gives rise to them acting as very strong gel-former and flow-modifier. However, the precise physical behaviour leading to their unusual effect on the flow of simple liquids is still largely unexplored.

Your Project

In this project the student will explore the rheology of aqueous suspensions of NCFs and NCCs as function of their charging state at different pH and the overall ionic strength of the solutions. The systems temperature dependence will be investigated as well, as they often display temperature-sensitive aggregation. The student will learn about mechanical, macroscopic rheology (study of how fluids flow) and light scattering based micro-rheology[2]. In the extended project the student will also explore the production of bacterial NCFs.

Requirements

would like an applicant who is keen on experimental work and understanding the background theory in polymer physics.

Other aspects

The experimental study will be supervised by Professor Eiser, an expert in the rheology of self-assembling DNA systems. Professor Kristin Syverud is an expert on Nano Cellulose Research for sustainable materials at the Chemical Engineering Department and Research Manager of RISE/PFI.

References

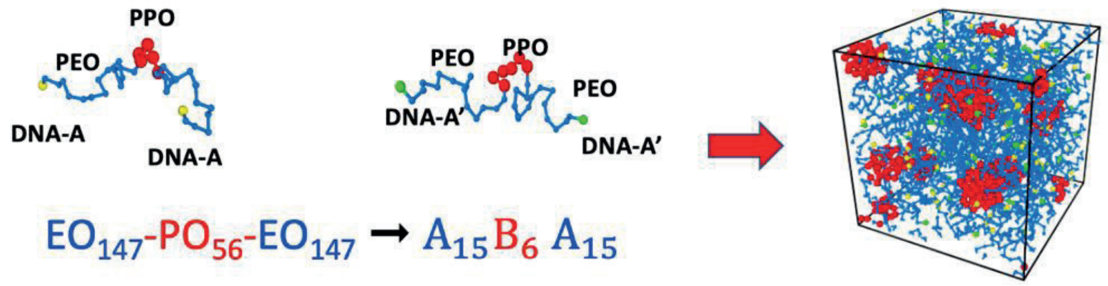
[1] M. Kobayashi, Y. Sato, T. Sugimoto 'Effect of pH and electrolyte concentration on sol–gel state of semi-dilute aqueous cellulose nanofiber suspension: an interpretation based on angle-dependent DLVO theory' *Colloid and Polymer Sci.* **300**, 953 (2022)

[2] Z. Xing, A.Caciagli, T. Cao, I. Stoev, M. Zupkauskas, T. O'Neill, T. Wenzel, R. Lamboll, D. Liu, E. Eiser 'Microrheology of DNA-Hydrogels' *PNAS* **115** (32), 8137 (2018)

Proposed Master Project at PoreLab NTNU (department of Physics)

Active Hydrogels - Simulations

Contact: Erika Eiser (erika.eiser@ntnu.no) and Raffaella Cabriolu (raffaela.cabriolu@ntnu.no)



Motivation

Hydrogels are solid materials predominantly made of water and a small fraction of self-assembled polymers. In everyday live we encounter hydrogels in form of foods, cosmetics and care products. But they are also essential in applications such as PCR tests, we had to go through in the past 3 years and DNA testing, pharmaceutics and diagnostic tools. Here we are interested in the study of hydrogels made of symmetric, non-ionic triblock copolymers, which are known as Pluronics®. At low temperatures their aqueous solutions are liquid. However, upon heating water becomes a less good solvent for the middle block and the chains start to aggregate to form micelles as shown in the simulation snapshot above[1]. At sufficiently high concentrations the micelles form a soft, gel-like crystal. By adding smart overhands, for instance short, single-stranded DNA, such systems can be made 'active', meaning they will react to an external stimulus.

Your Project

In this project the students will familiarize themselves with a Molecular Dynamics model of these triblock copolymers, previously mapped onto the real system[1], in LAMMPS[2]. As first task the students will perform some tests like, checking the self-assembling behaviour and reproduce a few points in the systems phase diagram[3].

The challenge will be to model the appropriate interactions between the free chain ends in terms of sticky patches with appropriate interaction potentials that will lead to the systems gelation in prescribed parameter settings. If time permits the structure and assembling dynamics will be explored.

Requirements

Background in Soft Matter physics would be advantageous. We would like an applicant who is interested in numerical model.

Other aspects

The project will be supervised by Professor Eiser, an expert in the rheology of self-assembling DNA systems. Associate Professor Cabriolu is an expert in simulation studies of soft matter systems. If interested the student can do both simulations and experiments.

References

[1] Jiaming Yu - PhD thesis: https://www.repository.cam.ac.uk/handle/1810/345675 (2023)

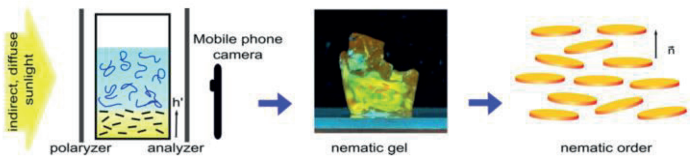
[2] LAMMPS Molecular Dynamics Simulator: https://www.lammps.org/#gsc.tab=0

[3] R. Liu, A. Caciagli, J. Yu, X. Tang, R. Ghosh, E. Eiser 'Dynamic Light Scattering based microrheology of End-functionalised triblock copolymer solutions' *Polymers* **15**, 481 (2023)

Proposed Master Project at PoreLab NTNU (department of Physics)

Aging in Nematic Gels

Contact: Erika Eiser (erika.eiser@ntnu.no)



Motivation
Many computer and TV screens use liquid crystal (LC) display technology. LCs are pure solutions of anisotropic molecules. They are known as thermotropic LCs because their phase transition from an isotropic to nematic order is driven by temperature. Similar phase transitions are observed in solutions containing anisotropic particles that are smaller than a few micrometer. These systems are called lyotropic LCs, and their phase transition is driven by increasing the particles' concentrations. While it is easy to synthesize either rod- or disk-shaped molecules with thermotropic LC behaviour, it is almost impossible to synthesize disk-shaped particles. Therefore, many researchers have focused on natural clays, which are 2D-crystals of 1 nm thickness and a diameter of 30-500 nm. A clay example is kaolinite that makes porcelain. Because of their large thickness-to-diameter ratio they should be excellent liquid crystal formers. However, their complex charging state leads to strong aging and gelation rather than LC formation when suspended in water. Recently we were able to overcome the aging dynamics by compressing a dilute clay suspension through osmotic pressure, exerted by a polymer solution (Figure above) [1].

Your Project
We will study the transition of the osmotically compressed clay layer under a light microscope using a video-microscopy tool called Differential Dynamic Microscopy (DDM) [2]. For this the student will build a suitable measuring cell and incorporate colloidal probe particles which we will follow in time. Their thermal fluctuations measured in terms of time-dependent scattering intensities will allow us to probe the transition of the clay suspension from an isotropic liquid to an anisotropic gel. Once established we can then test this transition & aging as function of various properties.

Requirements
Background in thermal & statistical physics would be advantageous. The applicant should be interested in experimental research and video microscopy.

Other aspects
The experimental study will be supervised by the Prof. Eiser, an experienced Soft Matter Physicist. Prof. D. Breiby's group will collaborate in terms of microscopy.

Contact person: Eiser Erika (erika.eiser@ntnu.no)

References
[1] P. Xu, A.F. Yazici, T. Erdem, H.N.W. Lekkerkerker, E. Mutlugun, E. Eiser; *J. Phys. Chem. B* **124**, 9475-9481 (2020)
[2] M Zupkauskas, Y Lan, D Joshi, Z Ruff, E Eiser; *Chemical Science* **8**, 5559 (2017)

Proposed Master Project at PoreLab NTNU (department of Physics)

Stabilizing Quicksand - Simulations

Contact: Raffaella Cabriolu (raffaela.cabriolu@ntnu.no), Erika Eiser (erika.eiser@ntnu.no) and Astrid de Wijn (astrid.dewijn@ntnu.no)

Motivation
The ground in Norway is rich in clay, a natural sheet-like crystalline mineral that is held together via ionic bonds. Thousands of years ago the land was under saline sea water stabilizing this clay-rich ground mainly via a combination of electrostatic and van der Waals forces. Today, when exposed to rain or an earthquake the force balance is disturbed, causing massive landslides or the 'drowning' of buildings like the Tasmanian devil in the figure above[1]. Build roads and constructions in a safe way require the use of large quantities of cements which is bad for the environment. We want to explore new, sustainable ways to achieve the stability of ground.

Your Project
In this project the student will first develop a Molecular Dynamics model of two clay surfaces interacting with each other across an aqueous layer[2,3], using the software package LAMMPS. The challenge will be finding the appropriate force fields to realistically reflect the interactions between the particles. In a second step we will explore how these interactions can be modified by the presence of various salts or other natural materials such as plant or bacterial based bio-polymers[4].

Requirements
Background in Soft Matter physics would be advantageous. We would like an applicant who is interested in numerical modeling.

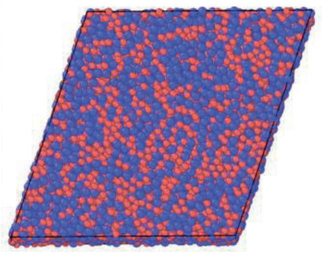
Other aspects
The main supervisor will be the Associate Professor Cabriolu, expert in molecular simulation studies of condensed, soft matter and yield-stress fluids. The project is in collaboration with Prof. Eiser, who is an experimental expert in the rheology of self-assembling DNA systems and soft matter, and with Prof. de Wijn, who is an expert in theory and modelling analytical of tribology and surface science.

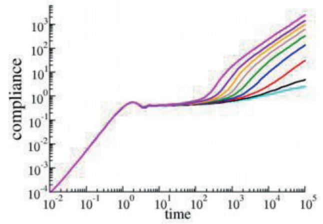
References
[1] A. Khaldoun, E. Eiser, G. Wegdam, D. Bonn, 'Liquefaction of qssssssssuicksand under stress' *Nature* **437**, 635 (2005)
[2] B. Ruzicka et al. 'Observation of empty liquids and equilibrium gels in a colloidal clay' Nature Materials 10, 56 (2011)
[3] P. Bacle et al., 'Modeling the transport of water and ionic tracers in a micrometric clay sample' *Applied Clay Science* **123**, 18 (2016)
[4] P. Xu, T. Erdem, E. Eiser, 'A Facile Approach to Prepare Self Assembled, Nacre-Inspired Clay/Polymer Nano-Composites', *Soft Matter* **16**, 3385 (2020)

Proposed Master Project at PoreLab NTNU (department of Physics)

Understanding non-Newtonian materials

Contact: Raffaella 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 behave 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.

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]. 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.

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 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. Eiser, whose expertise includes colloidal physics, and in particular on corn-starch [3].

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[1] D. Bonn and M. M. Denn , *Science*, **324** , 1401 —1402 (2009).
[2] R. Cabriolu, J. Horbach, P. Chaudhuri and K. Martens, Soft Matter, **15**, 415-423, (2019).
[3] C. Ness, Z. Xing, E. Eiser, Soft Matter **13**, 3664 – 3674 (2017).

Four Proposed Master Projects at PoreLab NTNU (department of Physics and department of Chemistry)

Ultrasound-mediated drug delivery to tumours and brain

Contact: Catharina Davies, Catharina.davies@ntnu.no

Web page https://www.ntnu.edu/physics/biophysmedtech/drugdel

Background: Ultrasound mediated delivery of drugs and nanoparticles in tumour tissue

Chemotherapy given alone or combined with radiotherapy or surgery is a common cancer therapy. A prerequisite for successful chemotherapy is that the drugs reach all cancer cells, and toxicity towards healthy tissue is limited. However, upon systemic injection of drugs, it is typically found that less than 1 % accumulates in tumors. Toxic effects on healthy tissue restrict the doses that can be applied and severely limit clinical outcome. A promising strategy for enhancing the accumulation of drugs to tumors, is to encapsulate drugs into nanoparticle carriers (NPs) and take advantage of the enhanced permeability and retention effect (EPR), permitting NPs to cross the leaky tumour capillary walls, but not capillaries in normal tissue. Although the NPs might extravasate across the capillary wall rather easily, the NPs do not to travel far away from the blood vessels and only a small population of cancer cells located close to the blood vessels will be exposed to the cytotoxic drugs as shown in Figure 1. The delivery of free drugs or drugs encapsulated into drugs and NPs depends on the vasculature, the transport across the capillary wall, through the extracellular matrix (ECM), and if the final target is intracellularly, the NPs/drugs have to cross the cell membrane (Figure 2). In order to improve the distribution of NPs/drugs, the delivery should be combined with a treatment facilitating the delivery.

Ultrasound (US) focused toward the tumour or brain has been reported to improve drug delivery by different mechanical mechanisms such as acoustic radiation force or acoustic streaming and cavitation.

Ultrasound in combination with gas filled microbubbles causes cavitation. Cavitation is the oscillation microbubbles in the acoustic field. Such oscillations can be stable and generate mechanical shear stress on the capillary wall thereby increasing the vascular permeability or the microbubbles can collapse in a violent process generating jet streams and shock waves that increase the vascular permeability, improve the transport through the ECM and increase the cellular uptake of NP. The overall aim of our project is to study to what extent US and microbubbles can improve the delivery of distribution of NPs/drugs in tumour tissue and across the BBB, and to understand the underlying mechanism.

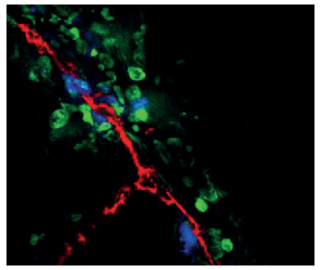


Figure 1: Nanoparticles (blue) do not travel far from the blood vessels (red).The encapsulated drug is taken up by cells (green) close to blood vessels

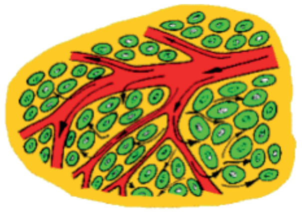


Figure 2: The delivery of nanoparticles/drugs depends on
1) The blood vessel network
2) Transport across the capillary wall
3) Penetration through the ECM.
4) Cellular uptake

1.Distribution of drugs in tumor tissue exposed to ultrasound and microbubbles

Contact: Catharina de Lange Davies (catharina.davies@ntnu.no), Veronica Nordlund (veronica.nordlund@ntnu.no), Sofie Snipstad (Sofie.snipstad@ntnu.no)

We have previously imaged the distribution of fluorescently labelled NPs in tumor tissue and compared the distance the NPs move from the vascular wall after ultrasound and microbubble exposure. Now we want to perform similar experiments using a small drug/fluorescent molecule. The background for studying the effect of ultrasound and microbubbles on uptake and distribution of small drugs is that at St.Olavs Hospital, we have two clinical studies treating cancer patients with standard chemotherapy in combination with focused ultrasound and microbubbles. We need to understand how ultrasound and microbubbles improve the distribution of small drugs in tumor tissue. Tumors with different degrees of vascularization and different amounts of collagen will be compared.

2.Multicellular spheroids as a model for drug delivery studies

Contact: Catharina de Lange Davies (catharina.davies@ntnu.no), Caroline Einen (caroline.einen@ntnu.no).

Multicellular spheroids consist of cells hold together by ECM and can be a good model to study transport of drugs and nanoparticles. Currently a master student is establishing and characterizing spheroids from various cancer cell line and studying the infiltration of NPs. Next we want to study the effect of ultrasound on penetration of NPs into spheroids.

3.Simulation of transport of nanoparticles in tissue

Contact: Signe Kjelstrup (signe.kjelstrup@ntnu.no), Magnus Aashammer Gjennestad (Magnus.Gjennestad@sintef.no), Sebastian Everard Nordby Price (sebastian.n.price@ntnu.no)

We are using various models to simulate the transport and distribution of nanoparticles in tissue. Various ultrasound parameters (frequency, pulse length, pules repetition frequency), properties of nanoparticles (size, charge, shape) and properties of the tissue (stiffness, permeability) can be modelled and give new insight in how the various parameters influences the transport of nanoparticles in tissue.

4.Simulation of biomolecule adsorption and the effect of nanoparticle coating

Contact: Anders Lervik (anders.lervik@ntnu.no), Signe Kjelstrup (signe.kjelstrup@ntnu.no), Sebastian Everard Nordby Price (sebastian.n.price@ntnu.no)

The blood circulation time of the nanoparticles is substantially reduced by protein adsorption. This can be avoided by coating the nanoparticle with surfactants, for instance, polyethylene glycol. The effectiveness of the coating will depend on the type of surfactant used and its characteristics (e.g. length). We will perform atomistic simulations (e.g. molecular dynamics) to investigate and understand the interactions between coated nanoparticles and biomolecules such as proteins on an atomistic scale. We aim to investigate how the interactions change, depending on the characteristics of the surfactant and nanoparticle, how this influences the transport, and to understand how more efficient coatings can be made. This is a theoretical project involving computer simulations and modelling.

Proposed Master Project at PoreLab NTNU (department of Chemistry)

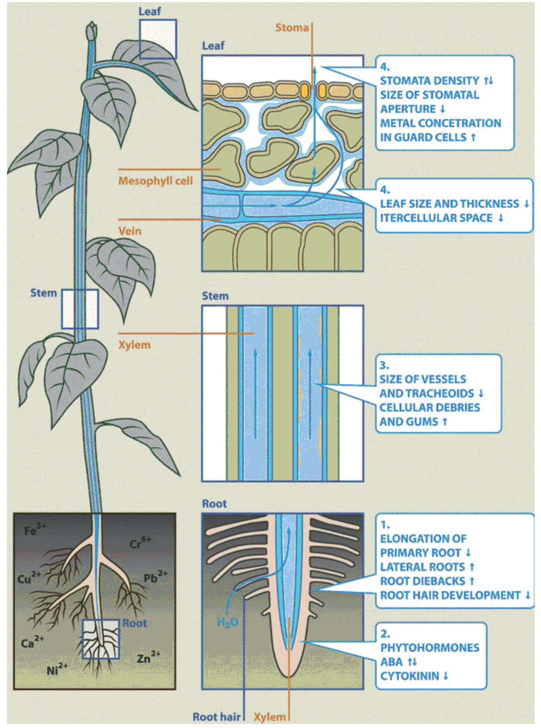
Transport of fluids and entropy generation in plant leaves

Contacts: Natalya Kizilova (natalya.kizilova@ntnu.no), Bjørn Hafskjold (bjorn.hafskjold@ntnu.no) and Signe Kjelstrup (signe.kjelstrup@ntnu.no)

Plant leaves are open thermodynamic systems that exchange water, nutrition, O_2 and CO_2 with environment and other parts of the plant (roots, shoots, branches, flowers and fruits). The mechanisms of the heat and mass exchange in plants are still unclear. It is known, water and nutritions come into a leaf through a bunch of porous vessels in its petiole due to active water suction by roots. The leaves have high evaporating area that creates very low (and even negative) hydrostatic pressure (additional top pump). The conducting system of leaf is composed by a network of veins while the short-range cell-to-cell transport is provided by microflows through the porous cell walls and diffusion. Since the leaf shapes and vein systems are proposed for different engineered systems (solar panels, absorbers of CO_2 and pollutants, etc.) understanding of the nonequilibrium thermodynamics of the transport and its optimization is essential.
Based on the balance equations for liquid and solid components with biochemical reactions in the leaf due to sun radiation (photosynthesis), the expressions for driving forces for the xylem and phloem transport can be derived and analyzed at different ambient conditions (soil, air, sun radiation) with non-equilibrium thermodynamics approach.

In this project, the student will familiarize with irreversible thermodynamics in the fluid dynamics problems at the microscale, balance equations and the linear force-flux relations, and learn how the short-range water delivery problem is solved in plants based on the thermodynamics laws. The project will be carried out according to the following steps:

1. Analysis of the balance equations for the plant sap flow in the leaves of different types.
2. Derivation and analysis of the entropy generation expression accounting for osmotic factors and chemical reactions.
3. Numerical computations of water transport in a model system at different ambient conditions (atmospheric pressure, temperature, humidity).
4. Elaboration of nature-inspired engineered units based on the principles studied



Proposed Master Project at PoreLab NTNU (department of Chemistry)

Remotely-activated nanobombs for selective destroy of cancer tissues

Contacts: Natalya Kizilova (natalya.kizilova@ntnu.no) and Signe Kjelstrup (signe.kjelstrup@ntnu.no)

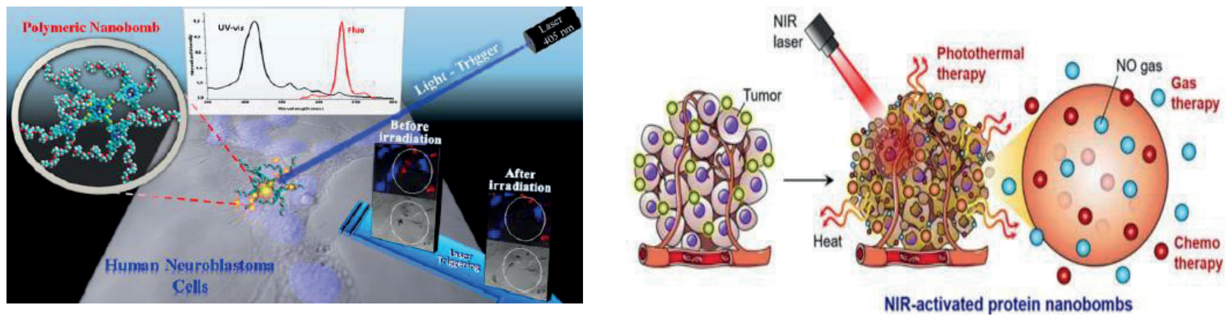
Cancer and other undesirable new-grown tissues can be selectively disrupt by the shock waves generated by nanobombs (photoacoustic, light-triggered polymeric, chemical or other types). The nanobombs can be delivered into the tissue and attached to the target cells by the receptor-mediated mechanism. Then the bomb can be activated by external laser or ultrasound irradiation or by fast chemical reaction inside the bomb. As a result, a strong point heat source appears and the heat wave accompanied by the pressure and flow waves propagates towards the cell membranes and disrupt them by both thermal and mechanical mechanisms. The force applied to the membrane must be estimated for more detailed calculations of the size and composition of the bomb(s) needed for guaranteed disruption of a tumor (or other undesirable tissues) without any significant influence on healthy tissues. Thermodynamics of the heat transfer, shock wave propagation at the nanoscale with high curvatures must be accounted for.

In this project, the student will familiarize with irreversible thermodynamics at the microscale and learn how the heat front and pressure shock wave propagates. The project will be carried out according to the following steps:

1. Classification of the nanobombes (composition, mechanism of activation, physical parameters, measured effects)
2. Problem formulation: wave equation for the heat/pressure propagation at nanoscale
3. Computations of the total entropy production across the front of the shock wave
4. Computations of the mechanical impact on the viscoelastic membrane
5. Biophysical applications of the results: numerical estimations of the mechanical and thermal damage for the cells/cellular structures of given geometry and material parameters.

Literature:

1. Feng X., Wang X. Nanodomain shock wave in near-field laser–material interaction. Physics Letters A 369 (2007) 323–327.
2. Park K. Smart nanobombs for inducing traumatic death of cancer cells. Journal of Controlled Release 135 (2009) 1.
3. Li D., Hallack A., Cleveland R.O., Jerusalem A. 3D multicellular model of shock wave-cell interaction. Acta Biomateriala 77 (2018) 282-291.



Proposed Master Project at PoreLab NTNU (department of Chemistry)

Counter-current transport of fluids and entropy generation in tree trunks

Contacts: Natalya Kizilova (natalya.kizilova@ntnu.no), Bjørn Hafskjold (bjorn.hafskjold@ntnu.no) and Signe Kjelstrup (signe.kjelstrup@ntnu.no)

Trees are ably to pump water and mineral components from soil to the leaves along their trunks which could be of 1-110 m height (giant sequoia). The mechanisms of the heat and mass exchange in plants are still unclear. The accepted mechanisms are active water suction by the root hairs via osmotic mechanism (bottom pump) and water evaporation in the leaves heated by the sun (top pump). Some additional mechanisms as direct water leakage from leaf veins could be added for the upward flow enhancing. The downward motion of the concentrated solution of sugars and other assimilated produced in the leaves (photosynthesis)

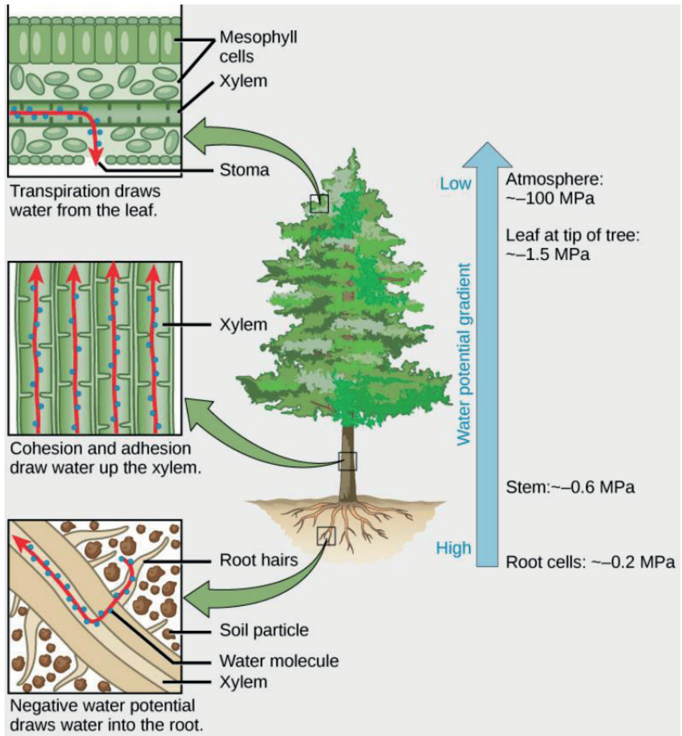
$$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6H_2O$$

is governed by osmosis-driven flow (Münh hypothesis).

The upward and downward transports are coupled and based on the mass and heat balance equations. In the experimental conditions the roots compartment can be substituted by a water vessel, while the tree crown can be substituted by a porous volume of any polymer material or gypsum. Such constructions are used for air moistening at home and office.

In this project, the student will familiarize with long-range fluid transportation in plants and irreversible thermodynamics in the mass transfer due to hydrostatic and osmotic pressure drops. The project will be carried out according to the following steps:

1. Analysis of balance equations for the long-distance fluid flow in a bunch of capillary tubes of the tree trunk.
2. Derivation of the expression for entropy generation accounted for the pressure-driven fluid flow, osmosis and water evaporation and its analysis.
3. Numerical computations of fluid transport along the tree trunks of different height and ambient conditions (atmospheric pressure, temperature, humidity).
4. Understanding nonequilibrium thermodynamics of the long-range fluid transport in trees.



Proposed Master Project at PoreLab NTNU (department of Chemistry)

Nature-inspired water and ice-repelling nanostructured surfaces

Contacts: Natalya Kizilova (natalya.kizilova@ntnu.no) and Signe Kjelstrup (signe.kjelstrup@ntnu.no)

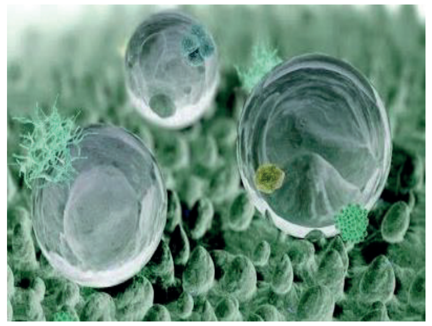
Recently, many nanofabricated surfaces with unique physical and chemical properties like super sticky, self-cleaning, hydrophilic, hydrophobic, ice-phobic, anti-fouling properties and with their combinations (multi-purpose smart surfaces) have been elaborated. Many important physical and geometric principles of their structure and function can be taken from nature, for instance self-cleaning lotus leaf, super sticky glue from mussels, super-hydrophobic surfaces of insects, air-accumulating surfaces of some leaves and water insects, ice-phobic insect eyes and many others. Modern water and ice-repelling surfaces must sustain different ambient conditions (temperature, pressure, humidity, wind), that needs elaboration of smart nanostructures of different materials.

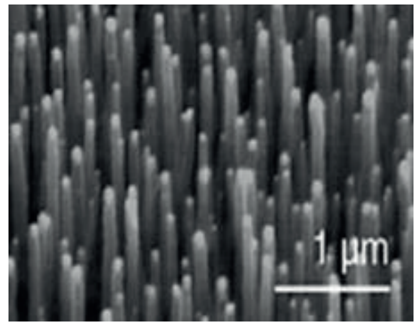
In this project, the student will familiarize with irreversible thermodynamics at the microscale and learn how the surface geometry and physical parameters influence its water- and ice-repelling abilities. The project will be carried out according to the following steps:

1. Classification of the nanostructured natural surfaces discovered in plants and animals and studied in literature.
2. Discussion of the physical and chemical mechanisms of the "smartness".
3. Elaboration of simplifies models of the nanostructured natural surfaces and computations of their surface energy.
4. Comparative analysis of their smart properties and propositions for experimental verification of theoretical results and discussion of possible application.

Literature

1. Jeevahan J., M. Chandrasekaran, G. Britto Joseph, R.B. Durairaj,G. Mageshwaran, Superhydrophobic surfaces: a review on fundamentals,applications, and challenges, J. Coat. Technol. Res. 15 (2018) 231–250.
2. Nguyen-Tri P., H.N. Tran, C.O. Plamondon, L. Tuduri, D.-V.N. Vo, S. Nanda,A. Mishra, H.-P. Chao, A.K. Bajpai, Recent progress in the preparation, propertiesand applications of superhydrophobic nano-based coatings and surfaces: areview, Prog. Org. Coat. 132 (2019) 235–256.
3. Yancheshme A.A., G. Momen, R. Jafari Aminabadi, Mechanisms of ice formation and propagation on superhydrophobic surfaces: a review, Adv. Colloid Interface Sci. 279 (2020) 102155.





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

Modelling extremely low friction of quasicrystals

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

In this project, you will focus on a particular class of crystalline materials that have an unusual structure: quasicrystals. The discovery of quasicrystals was awarded the Nobel Prize in chemistry in 2011. The project is concerned with how the quasi-crystal structure will affect the friction of these surfaces, through structural superlubricity. This is a dramatic effect by which friction is reduced enormously due to structural incompatibility between two surfaces at the atomic level. You will write a simple numerical simulation to compute interactions of contacts with quasi-crystalline surfaces, and whenever possible do analytical calculations to accompany them.

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

Supervisor
Astrid S. de Wijn <astrid.dewijn@ntnu.no>
Research environment: http://syonax.net/science/research.html.

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

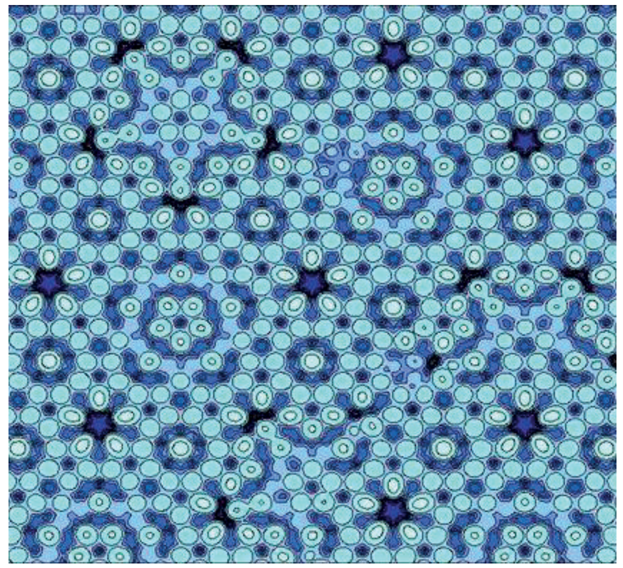


Figure: Example of a quasicrystal surface, atomic model of fivefold icosahedral-Al-Pd-Mn. (Picture from Wikimedia Commons)

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

Modelling mechanical properties of 2d materials

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no) and Melisa Gianetti (melisa.m.gianetti@ntnu.no)

In this project, we will investigate the mechanisms of solid lubrication using Molecular-Dynamics simulations. In lubrication with a solid powder, small, nm-thin flakes of the solid slide easily past each other. While we have some understanding of the behavior of single sliding flakes, we are only beginning to explore the effects of having multiple flakes that can act collectively, or how multiple layers interact with each other [1].
This project will focus on possible effects of tearing of layers, as well as the interactions between layers. Another possible line of inquiry is the interactions between flakes. 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.

[1] *Understanding the friction of atomically thin layered materials*, David Andersson and Astrid S. de Wijn, Nature Communications **11**, 420 (2020).

Recommended background
A basic programming course and an interest in modelling or programming. Tribology, basic statistical mechanics, or classical mechanics.

Supervisors
Astrid S. de Wijn astrid.dewijn@ntnu.no
Melisa Gianetti melisa.m.gianetti@ntnu.no
Research environment: http://syonax.net/science/research.html.

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.

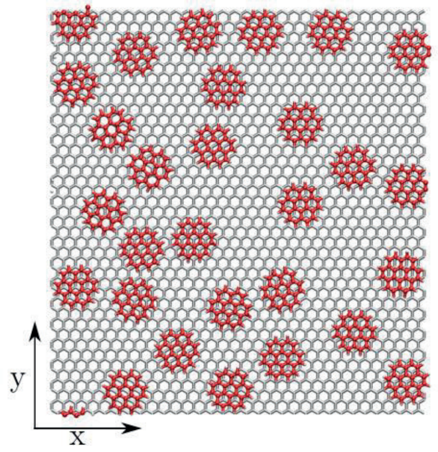


Figure : A top view of a simulation of a single layer of graphene flakes acting as a solid lubrican

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

Multi-contact superlubricity

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no), Melisa Gianetti (melisa.m.gianetti@ntnu.no) and Bjørn Haugen <bjorn.haugen@ntnu.no>

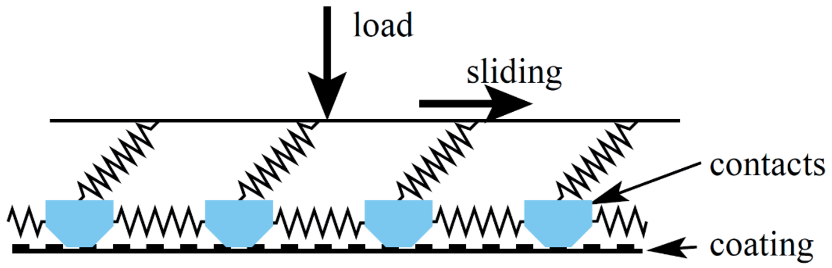
This project is concerned with structural superlubricity. This is a dramatic effect by which friction is reduced enormously due to structural incompatibility between two surfaces at the atomic level. Macroscopic surfaces in contact in the real-world, however, do not have one large flat contact, but consist 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, we will modify an existing model for multi-contact friction to take into account superlubric contacts. You will write and perform simulations of this model, and investigate its behaviour. If necessary, you will run simulations on high-performance computing facilities.

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

Supervisors
Astrid S. de Wijn <astrid.dewijn@ntnu.no>
Bjørn Haugen <bjorn.haugen@ntnu.no>
Melisa Gianetti <melisa.m.gianetti@ntnu.no>
Research environment: http://syonax.net/science/research.html.

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)

Simulating growth of cancer and the immune system

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no) and Rian Friedman (ran.friedman@lnu.se)

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.

Recommended 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 environment: http://syonax.net/science/research.html.

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 Mechanical and Industrial Engineering)

Simulating and measuring the contact mechanics of low-friction patterned surfaces

Contact: Astrid de Wijn (astrid.dewijn@ntnu.no), Bjørn Haugen (bjorn.haugen@ntnu.no), Melisa Gianetti (melisa.m.gianetti@ntnu.no) and Viet Hung Ho (viet.h.ho@ntnu.no)

This project is suitable for two students working together, one experimental and one computational. It is also suitable for individual students working alone or together with students from other departments, or at our collaborators at Trinity College Dublin.
In this project, we will investigate the contact mechanics of patterned surfaces with low-friction coatings. This project is related to 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 this project is to explore different designs for patterning of surfaces that lead to arrays of contacts with specific properties, that will reduce the problematic consequences of surface roughness.

Computational. In the computational part of this project, you will perform numerical calculations of nearly perfect arrays of spherical particles and possibly other structures in contact with each other. You will set up calculations for the deformation in the material using Hertz contact mechanics and other approaches. You will write and perform simulations, and investigate the behaviour of the system. If necessary, you will run simulations on high-performance computing facilities.

Experimental. In the experimental part of this project, you will construct or fabricate macroscopic patterned surfaces using assemblies of ball-bearings and other methods, depending on the shape and materials selection. It will be important to select materials that are suitable for functionalisation of superlubricious coatings using pencilling and other techniques developed by our collaborators at
Trinity College Dublin and École Central Lyon. You will design and build an apparatus for performing sliding experiments to measure friction in these systems.

Figure: A homemade set of patterned surfaces with low friction due to macroscale structural mismatch between the arrays of ball bearings. This device was built by second year undegraduate students in Dublin.

Recommended background
Tribology, basic statistical mechanics, or classical mechanics.
Computational: A basic programming course and an interest in modelling or programming.
Experimental: The experimental student should come from an engineering background and have an interest in material science.

Supervisors
Astrid S. de Wijn <astrid.dewijn@ntnu.no>
Bjørn Haugen <bjorn.haugen@ntnu.no>
Melisa Gianetti <melisa.m.gianetti@ntnu.no>
Viet Hung Ho <viet.h.ho@ntnu.no>
Research environment: http://syonax.net/science/research.html.

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 Geoscience and Petroleum)

Oil mobilization with reduced interfacial tension, a study using computational fluid dynamics and micromodels

Contact: Tomislav Vukovic (tomislav.vukovic@ntnu.no), Antje van der Net (antje.van.der.net@ntnu.no)

Cleaning processes and mobilization of trapped oil in confined systems can be improved by reducing interfacial tension (IFT). The full understanding of the mechanism behind the phase mobilization in different porous geometries is still unclear and with a better understanding, improvements to the flow processes in porous media can be made, e.g. for trapping CO_2 as well as for optimization of oil production.

In this project the importance of IFT, wettability and flow geometry is to be studied in micromodels using biosurfactants combined with computational fluid dynamics modelling for the design of the models and explanation of the effect. As part of the study low interfacial tension solutions are to be found by phase behavior testing with surfactants.

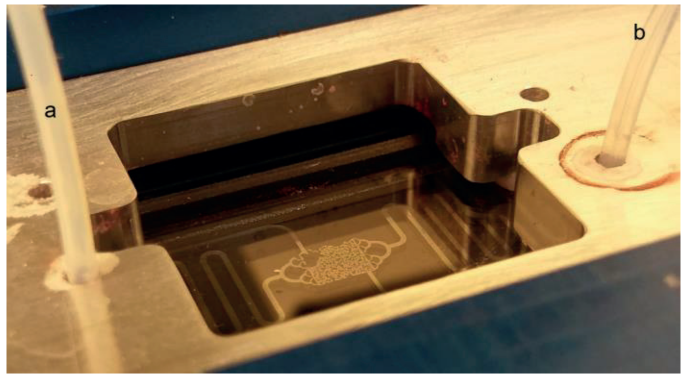


Figure: Example of a 2D micromodel representing a porous media, connected with an inlet and outlet flow line (a,b)

Proposed Master Project at PoreLab NTNU (department of Geoscience and Petroleum)

Pore-scale investigation of low salinity waterflooding in Sandstones

Contact: Tomislav Vukovic (tomislav.vukovic@ntnu.no) and Antje van der Net (antje.van.der.net@ntnu.no)

For research on understanding multiphase flow description in porous media wettability is one of the important parameters studied. New methods are considered for a better description of wettability changes in multiphase flow, of interest for example for low salinity flooding where wettability change is one of the underlying mechanisms. The measurement of zeta potential is one of these new methods. Zeta potential statically characterizes the transition zone between rock and liquid regarding the surface charge and fluid interaction.

In this project, the objective is to proof whether the zeta-potential measurements of rock-brine system can be used to predict the surface characteristics behavior during low salinity waterflooding and consequently additional oil recovery. Detectable with zeta-potential measurements are double-layer expansion and surface force modification, parameters recognized as important mechanisms of low salinity waterflooding.

The zeta-potential measurements of glass beads/crushed sandstone are used to investigate the sandstone-brine surface properties at different salinities and pH. Afterwards, the optimum chemical condition of the injection brine is examined in two-phase displacement micromodel experiments for a better understanding of pore-scale mechanisms of low salinity waterflooding EOR method.

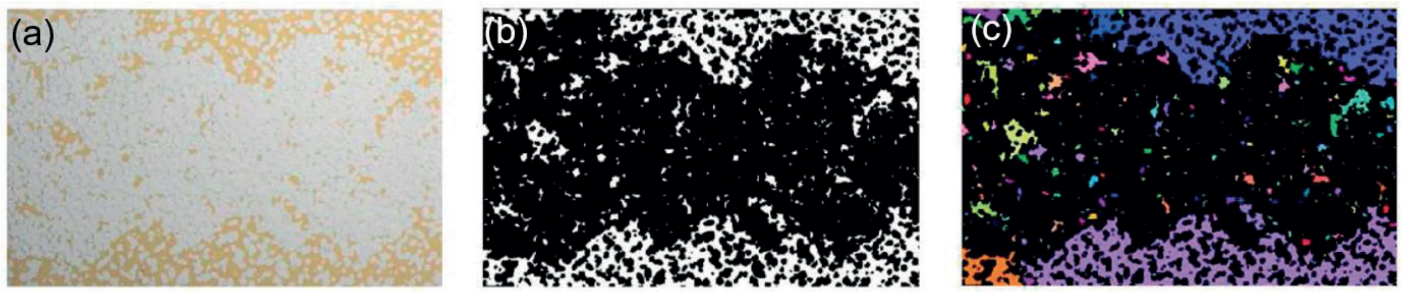


Figure (a) Pre-processing image of a microchip after water flooding (oil = gold, glass and brine transparent). (b) Segmented, binary image to enable quantitative analysis (oil in white). (c) Oil clusters colored individually for qualitative analysis. [from Aadland et al. Nanomaterials ***2020****, 10, 1296]*

Proposed Master Project at PoreLab NTNU (department of Geoscience and Petroleum)

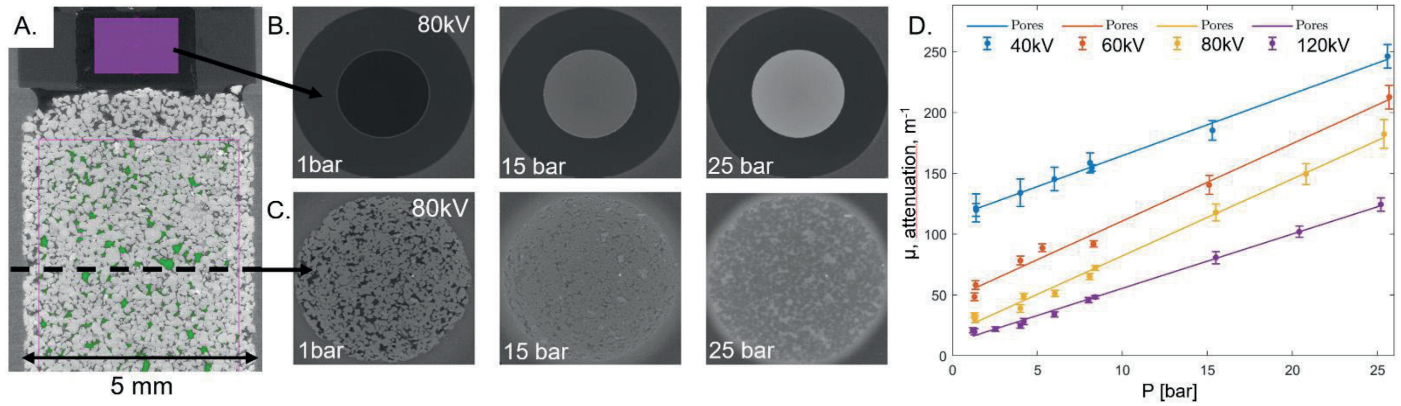
Pore scale imaging of CO_2 storage mechanisms using Xenon in a micro-CT scanner

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

Multiple storage mechanisms occur 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 storage potential of the reservoir, but not well understood and described 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 using Xenon, currently not feasible using CO_2 directly. 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:

1. Pore scale visualization of convective flow in 1, 2 and 3 D models
2. Pore scale monitoring of capillary trapping and Ostwald ripening
3. Local gas pressure measurements during capillary trapping and Ostwald ripening (see Figure below)



Figure; 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. Though hardly visible, the measured Xenon signal in the pores of the core differs from the void signal at the same pressure as a consequence of pseudo-enhancement. At 15 and 25 bar the Xenon in the pores has a higher (brighter) signal than the sand grains around, opposite to the image at 1 bar. 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 micro CT 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 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.

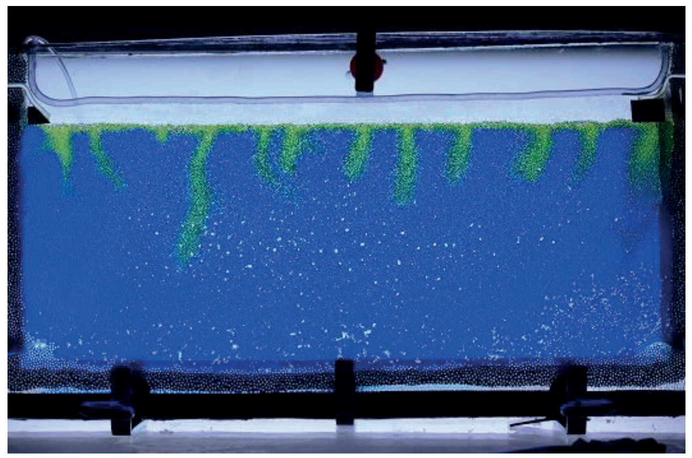


Figure: A layer of CO_2 above a water-saturated porous medium consisting of glass beads. An indicator acid has been added to the water carbonic acid to turn it blue. Where the CO_2 has been absorbed by the water, carbonic acid forms which turns the color to green. The acid has larger density than water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

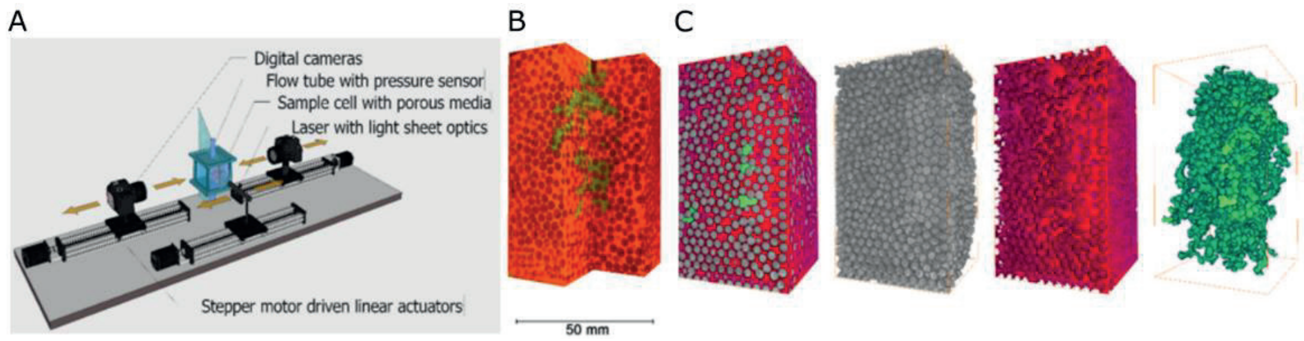


Figure: A The 3D scanner is based on optical index matching and fluorescence. A random packing of 3 mm glass beads forms the porous medium, index matched with two immiscible fluids. The fluids contain different fluorescent dyes that are excited with a 2D laser sheet that is driven through the sample 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.

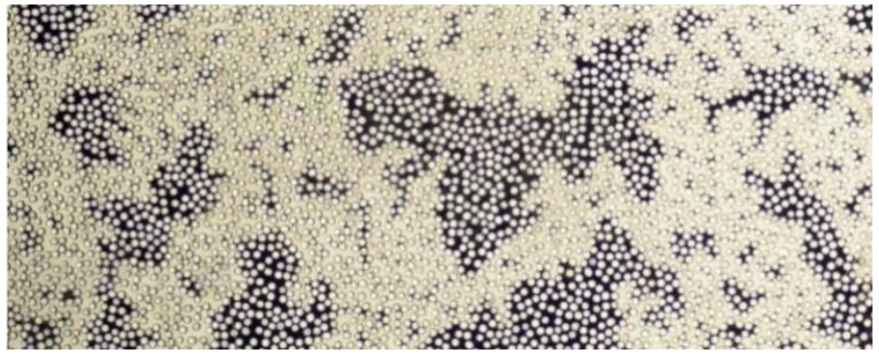


Figure: Detail of the trapped liquid clusters (blue) left behind after air (white) is slowly injected from the left in a quasi-2D porous network previously saturated with the liquid

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.

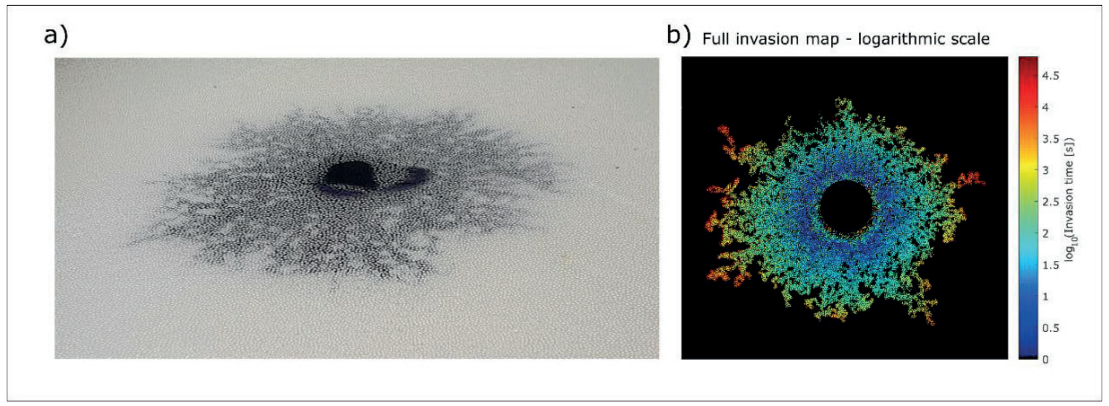


Figure: a) Experiment illustrating how a source of pollution (central dark blob) spreads through a partially wet porous network (here made of glass beads). Water films covering the internal surfaces of the porous medium can act as a fast pathway for the spreading of pollution. b) Spatiotemporal invasion 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 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 experiments 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.

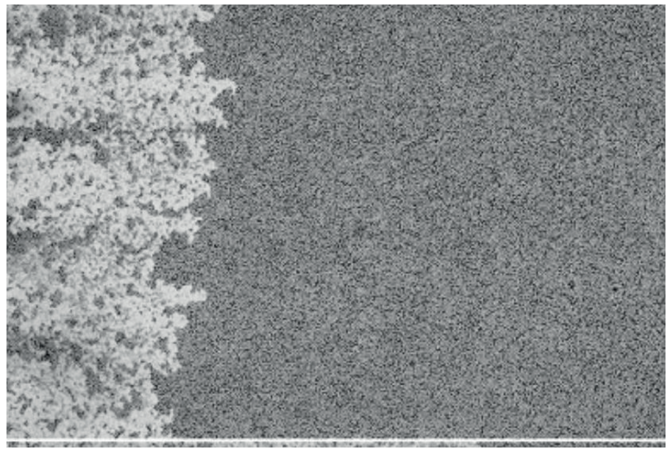


Figure: Steady state flow in a quasi 2D model system. Simultaneous injection of a glycerol/water (black) solution and rapeseed oil (white)

Proposed Master Project at PoreLab UiO (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 economical 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 is affected by speed of the flow.

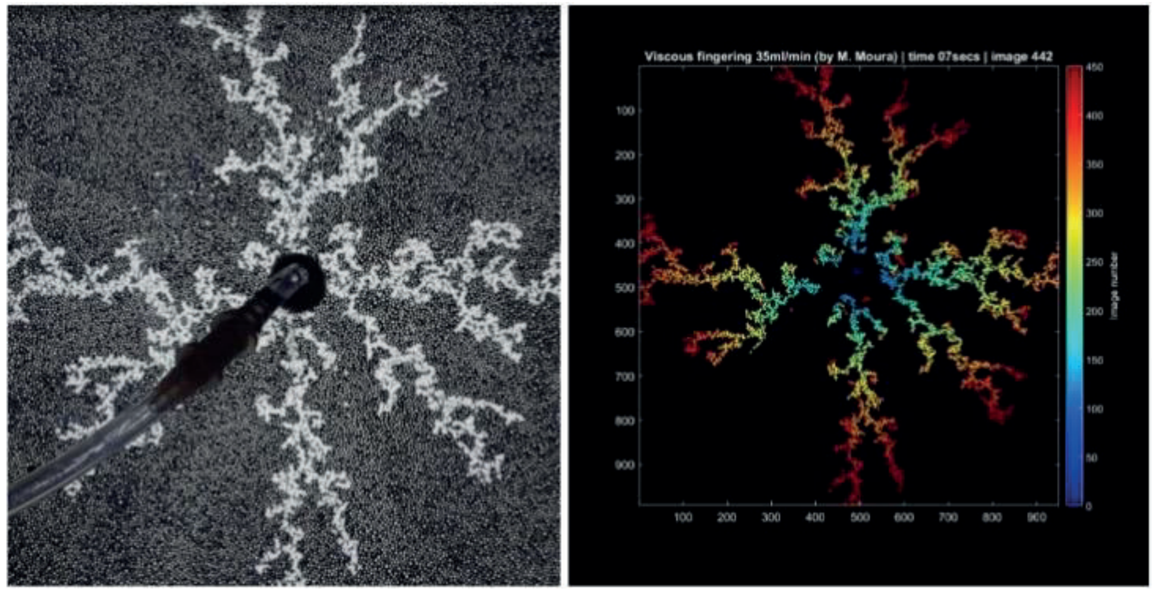


Figure: Viscous fingering pattern (left) observed when air is injected fast in a porous medium previously filled with a viscous liquid (blue). The image analysis (right) shows the time (image number) of injection of each pore

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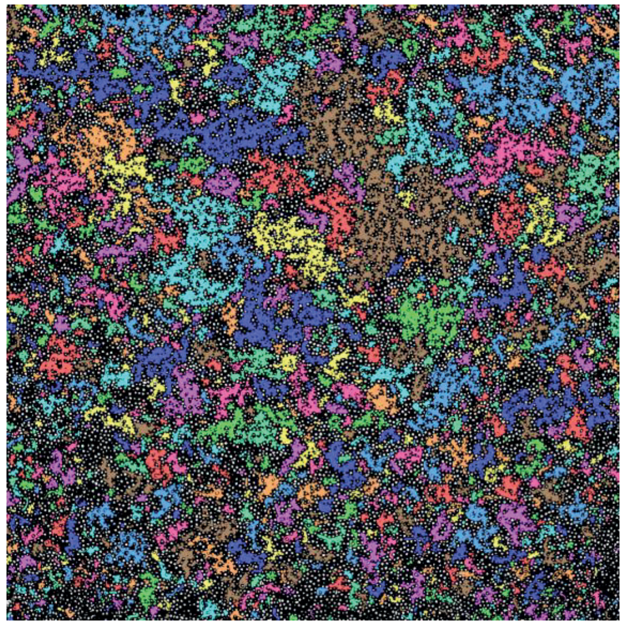
Proposed Master Project at PoreLab UiO (department of Physics)

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 (Njord center, department of Physics)

The role of pore fluid phase transition during earthquake ruptures: insights from an idealized numerical model

Contacts: Fabian Barras (fabian.barras@mn.uio.no), Gaute Linga (gaute.linga@mn.uio.no), Eirik G. Flekkøy (e.g.flekkoy@fys.uio.no)

Motivation

Earthquakes lead to large and fast changes in porosity along the fault and in the surrounding rock. Under water-saturated conditions, this rapid expansion of fluid-filled cavities and fractures could lead to transient phenomena such as vaporisation due to the resulting large pressure drop, impacting the propagating earthquake rupture. However, a proper quantification of the conditions leading to such events and their resulting stresses is needed.

Project description

In this project we propose to investigate the physics of a rapidly expanding fluid-filled cavity. The student will employ and develop a numerical model that fully couples solid and fluid dynamics at the tip of a rapidly growing tensile fracture. We will initially consider a single fluid-filled crack propagating between two semi-infinite solid blocks (see Figure). The compressible fluid dynamics within the expanding cavity will be simulated using a finite element method formulated on a moving mesh. The implementation of the fluid dynamic model will be validated against theoretical predictions. Next, the model will be used to identify the conditions leading to phase transition of the pore fluid and its impact on the surrounding solid, i.e. the formation and eventual collapse of cavitation bubbles. Throughout the project, the candidate will benefit from direct comparison with ongoing experiments at PoreLab UiO investigating cavitation in an analogue setup.

Resources

The candidate will learn how to use High-Performance Computing (HPC) infrastructure and will have access to the computing clusters of the Norwegian HPC infrastructure (Sigma2) as well as the local cluster of PoreLab UiO.

Required background

Basic programming skills (C++, Python) and basic background in fluid mechanics. Some knowledge of solid mechanics and thermodynamics is an advantage.

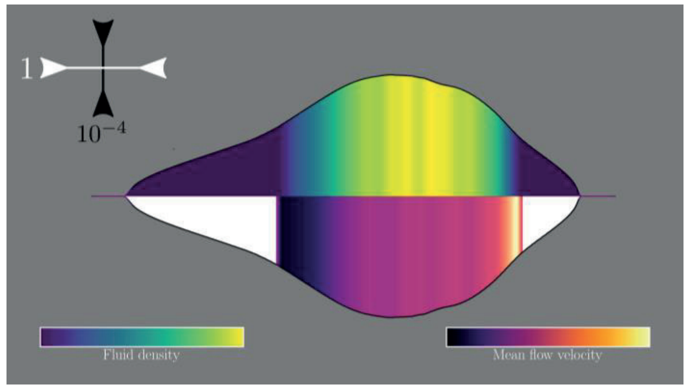


Figure: Snapshot of dynamic fluid flow simulation (i.e. density and mean fluid velocity) within a rapidly expanding crack cavity. The white area highlights the formation of a fluid-depleted cavity.

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

Experimental imaging of mixing in porous media

Contacts : Gaute Linga (gaute.linga@mn.uio.no), Marcel Moura (Marcel.Moura@fys.uio.no), Knut Jørgen Måløy (K.J.Maloy@fys.uio.no)

Motivation:

Mixing is the operation of bringing a system from a state of segregation to uniformity, like when you use a spoon to speed up the dissolution of sugar in your coffee. Solute mixing has broad implications for how chemicals and pollutants spread and react in the soil or other porous environments, where the complex flow paths act as the spoon. Since porous media (such as rock) are generally opaque, it is hard – but nevertheless highly desirable – to image the mixing dynamics within this confinement, especially when the flow field is time-dependent like in two-phase flow.

Project description:

We will employ state-of-the-art stereolithography 3D printing techniques to study the dynamics of mixing in porous media. Our setup allows for the full visualisation of how blobs and strips of dye (i.e. solute) deform in time. Image analysis techniques will be developed to track the spreading in real time, and we will assess how different boundary and flow conditions affect the dynamics. The experiments will be compared to numerical simulations performed under similar conditions (see other project) and could support the development of more energy-efficient micromixers.

Resources:

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

Required background:

Interest in fluid dynamics, experimental methods, data analysis.

Figure: Experimental visualization of chaotic mixing patterns during time dependent flow through a 3D printed porous medium.

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

Numerical simulation of mixing in microscale multiphase flow

Contacts: Gaute Linga (gaute.linga@mn.uio.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.

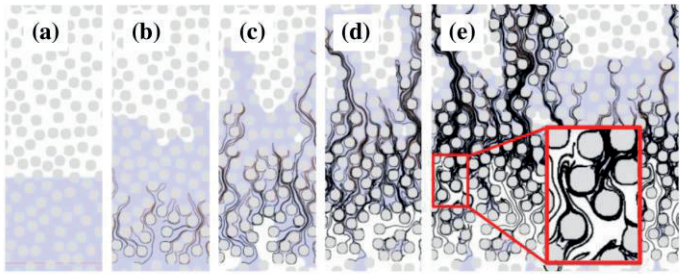
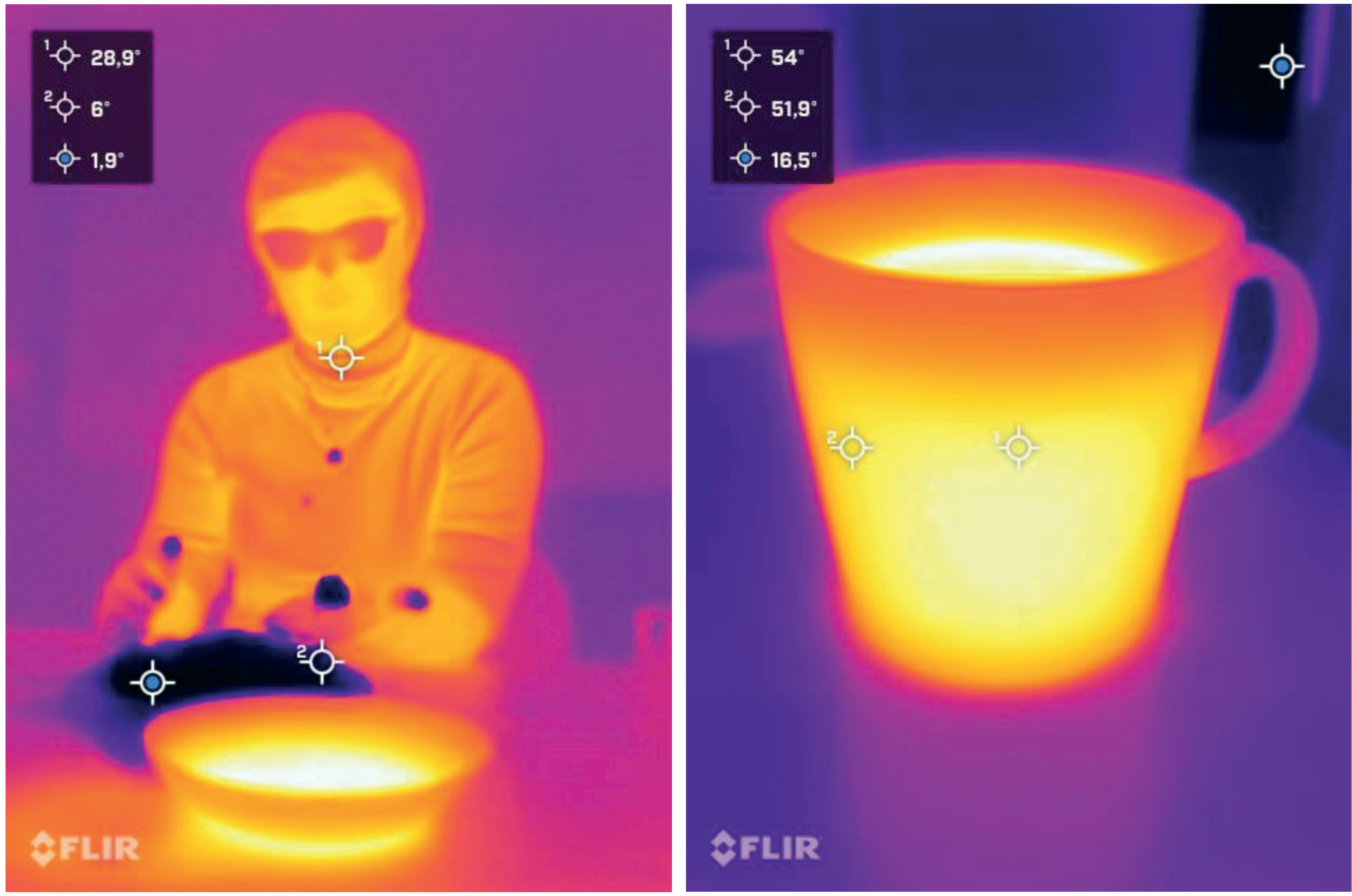


Figure: Simulations of chaotic mixing in two-phase flow in a 2D porous medium. (a)–(e) show a strip of solute at various instances of time as it is exponentially elongated by a net upward flow.



(left) Infrared image showing the temperature contrast between a human body, a bowl of warm water and a plate filled with snow
(right) Infrared image of a coffee mug from the Oslo PoreLab, filled with hot water
Pictures by Erika Eiser

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 at PoreLab in which the students apply techniques on realistic problems.

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. You have experience with how the temperature in a system can be controlled.
- knows the theory of dynamic light scattering and have experience in using light scattering to study diffusing particles and particles in a convective velocity field. You have 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 you are able to perform image analysis to characterize the structure and the dynamics. You know 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 the NTNU PoreLab node.
- 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.

Mass and Heat 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 will be individual adapted to the actual students taking the course.

Applied Heterogeneous Catalysis
KP8132, NTNU

The course is given every second year. Lessons are not given in the academic year 2022/2023. 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 into the mode of different types of instrumentation that is important for studies of biological macromolecules, cells and other soft materials. The course aims at providing an understanding of the mode of function of the components that the instrumentation consists of as well as a theoretical and practical understanding of how to operate the instrument, including i.e. calibration procedures and maintenance. Professor Erika Eiser, Pi at PoreLab is the coordinator and 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 petroleum resources.

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, relative permeability and applications in earth sciences and petroleum engineering.

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, significance of rock mechanics in reservoir control and 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 petroleum reservoirs. 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 of oil and gas and will be able to do derivation of equations for flow in porous media, and numerical solution of these by using finite difference methods.

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 are as follow: Summary of rock 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 methods; 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 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 is the coordinator for this course.

Numerical Methods in reservoir Simulation
PG8607, NTNU

The course gives an introduction to the various numerical formulations applied in reservoir simulators. The course contains:
- Difference methods,
- Control-volume method.
- Time integration.
- 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. Time integration.
4. Linear equation solvers.
5. Stability and numerical dispersion.
6. Streamline methods.
7. Up-scaling methods.

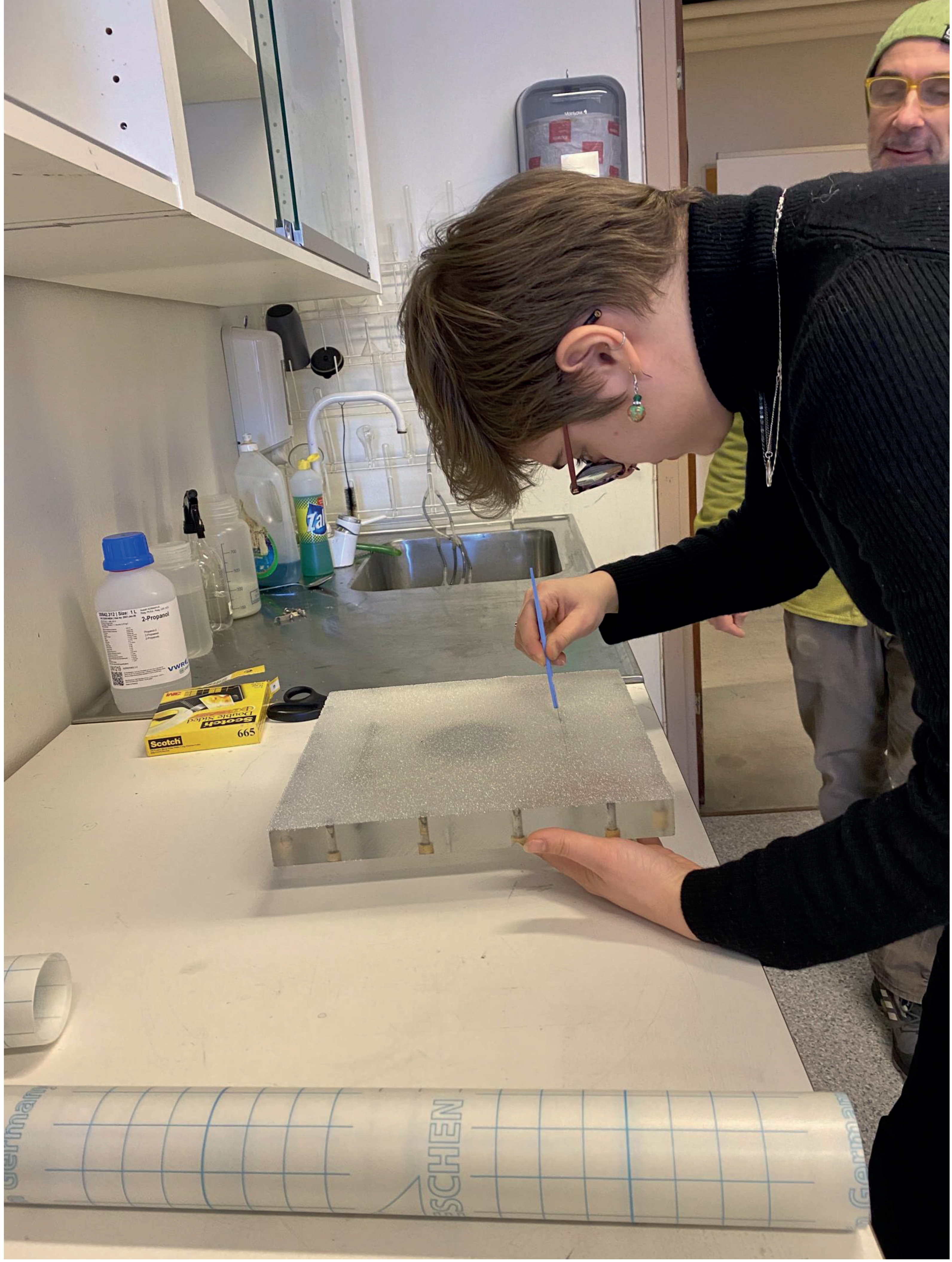
By completing the course, the candidate will have a deeper understanding of the mathematical building blocks that goes into various reservoir simulators, different numerical representations and solution methods. Professor Carl Fredrik Berg, PI at PoreLab, is the course's coordinator.

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. S(he) 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. S(he) will be able to deduce the master equation and use it to construct various Monte Carlo algorithms.



PhD candidate, Ilaria Beechey-Newman, learning how to prepare a thin Hele-Shaw cell under the watchful eyes of senior engineer Mihailo Jankov in the laboratories at PoreLab UiO
Picture by Erika Eiser

Porous Media Laboratory
NTNU, UiO

VISITING ADRESSES:

Trondheim:
S.P. Andersens vei 15B
PTS2
7031 Trondheim

Oslo:
The Physics building
Sem Sælands vei 24
0316 Oslo

POSTAL ADDRESSES:

Trondheim:
Department of Physics, NTNU
PoreLab
7491 Trondheim

Oslo:
Department of Physics, UiO
Postboks 1048
Blindern
0316 Oslo

CONTACT:

Professor Alex Hansen, Center Director
Phone: +47 73 59 36 49
E-mail: Alex.Hansen@ntnu.no

Professor Knut Jørgen Måløy, Deputy Director
Phone: +47 22 85 65 24
E-mail: K.J.Maloy@fys.uio.no

Dr. Marie-Laure Olivier, Administrative leader
Phone: +47 73 41 30 98
E-mail : Marie-Laure.Olivier@ntnu.no

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