PoreLab
NTNU-UiO Porous Media Laboratory

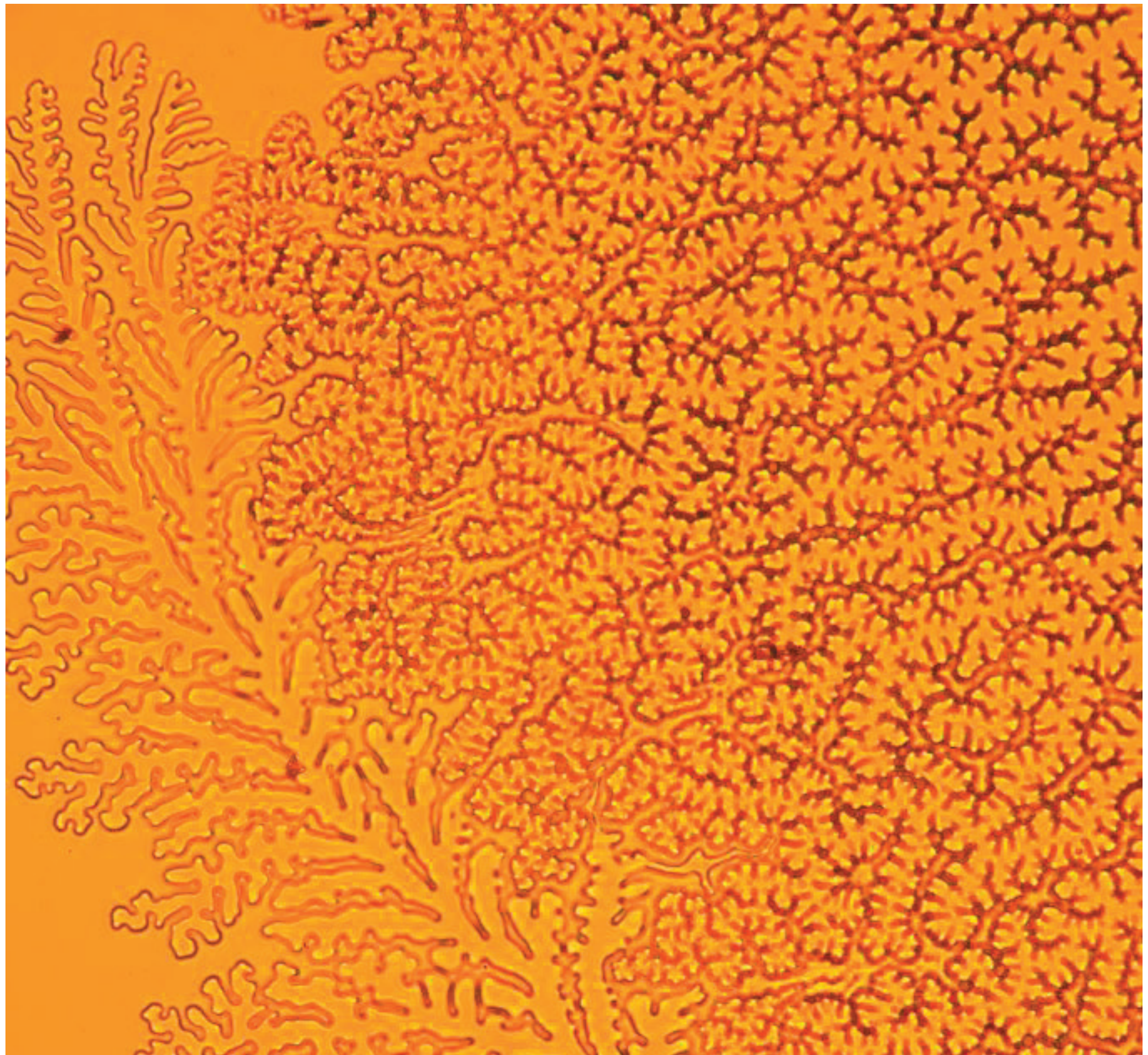
Norwegian Centre of Excellence
The Research Council of Norway

MSc at PoreLab 2021

Opportunities in 2022

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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Labyrinth pattern emerging when air invades a granular/fluid mixture in a 2D cell, in a process known as frictional fingering. Color represents the time of invasion, showing the regions invaded earlier in a brighter color to highlight the history of the invasion process. Picture by Antoine Dop, PoreLab UiO

OVERVIEW – 2021 MSc STUDENTS

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Henrik Haugerud Carlsen	Dynamics of Quantum Vortices in Different Confinements	Luiza Angheluta-Bauer and Jonas Rønning
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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 2021 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, puzzles, and table soccer became popular playgrounds for all at PoreLab NTNU.

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. Jonas, Louison, Kristian and Beatrice playing Pictionary

Michelle Louise Grung Angell

Department of Physics, NTNU

Phase Diagram of Mixed Wetting

Fall 2021 / Spring 2022
Supervisors: Santanu Sinha and Alex Hansen

To better understand and predict how fluids move through porous media it can be helpful to create models that focus on specific conditions regarding the solids of the system.

One example of such a condition is mixed wetting properties, meaning that the fluid that is in contact with the solid either has a wetting angle below or above 90 degrees, depending on the solid. A system consisting of two immiscible fluids with mixed wetting angles will display a flow through the pore throats where positive and negative solids meet, due to the loss of capillary forces. A simplified version of the system is shown in figure 1.

The objective of this thesis is to examine the wetting angle ratio at which a system will exhibit percolation, as seen in figure 2, using numerical simulations with periodic boundary conditions.

This is done by creating a matrix consisting of pores, links and solids, where the pores are considered open at all times, while the status of the links depend on the solids surrounding them. Using a searching algorithm called Hoshen-Kopelman and checking for percolation by open links, it is possible to find this ratio and thereby the phase diagram of the system.

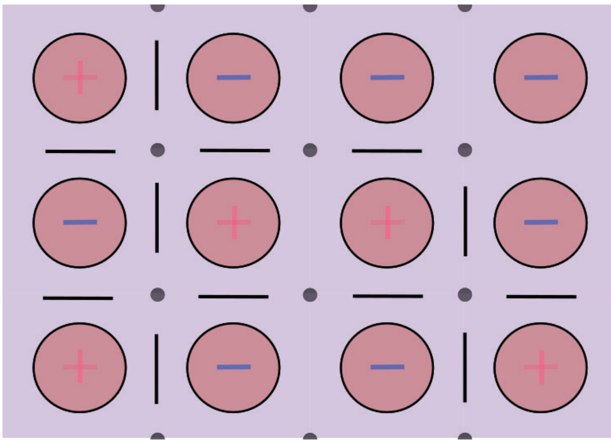


Figure 1: A simplified illustration of the mixed wetting system. The brown circles represent solids of different wetting, shown by positive or negative signs. The small black dots represent the pores, while the lines are open pore throats.

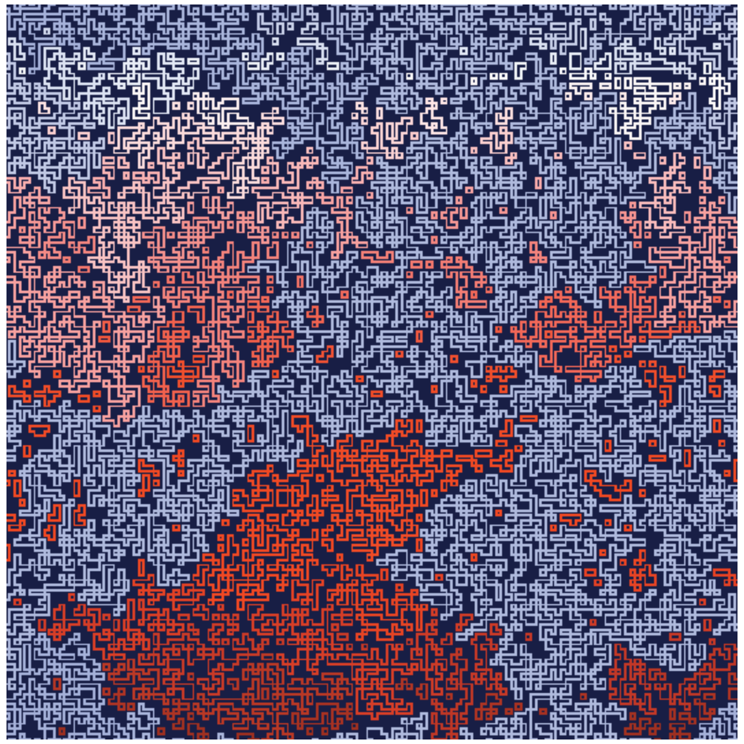
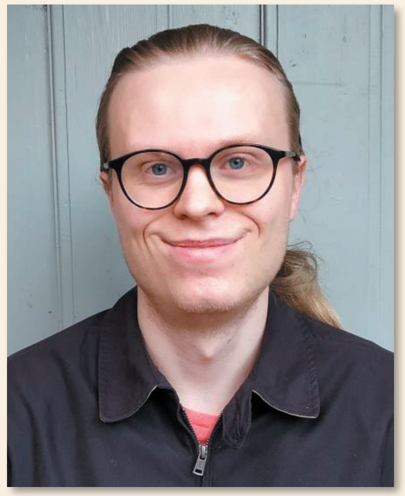


Figure 2: An example of percolation in the mixed wetting model. Different colors correspond to different clusters of open links. The light purple shows the percolating cluster, which spans the entire lattice.

Jonas Bueie



Department of Physics and Department of Mechanical and Industrial Engineering, NTNU

Viscosity of Complex Fluids in Molecular Dynamics

Fall 2021 / Spring 2022
Supervisor: Raffaela Cabriolu, Astrid de Wijn and Christopher Devik Fjeldstad

Viscosity and friction heavily impact energy consumption in a wide variety of technological applications. Understanding the viscosity of fluids is important to understand the behavior of, for example, lubricants. This master's project concerns complex fluids, such as mixtures of distinct types of fluids, or fluids consisting of particles that interact at long range.

Viscosity, and other transport properties, are difficult to describe theoretically in complex fluids. However, numerical approaches are possible. Using non-equilibrium molecular dynamics (NEMD), and with a basis in the kinetic theory of fluids, this master's thesis studies the viscosity of certain types of complex fluids. This could contribute to a better understanding of viscosity as a transport property.

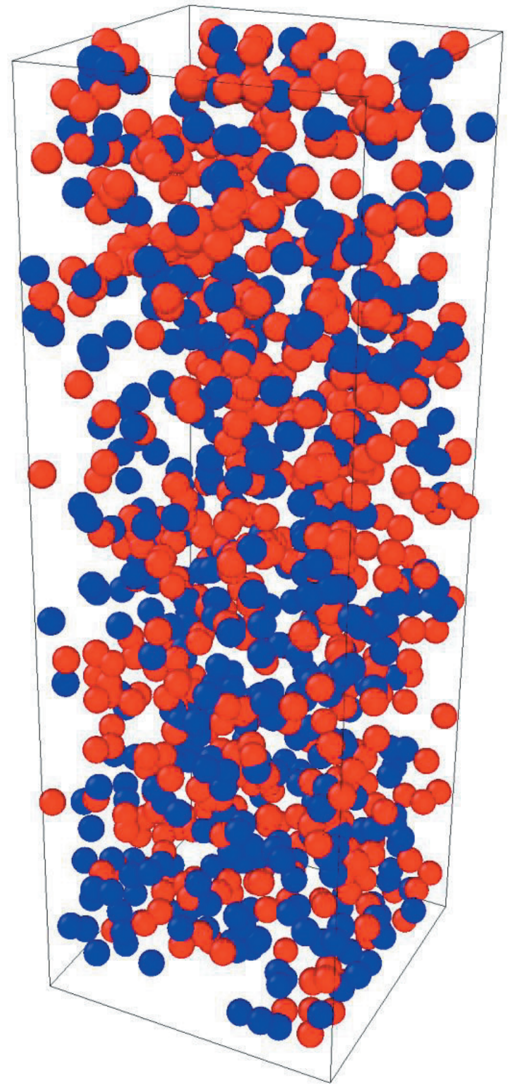


Figure: A snapshot from a simulation of a fluid mixture, which consists of a large collection of two different particle types. The viscosity of such fluids can be estimated numerically in NEMD.

Trygve Scheline Urdahl

Department of Physics, NTNU

CT Image Denoising with Generative Adversarial Networks

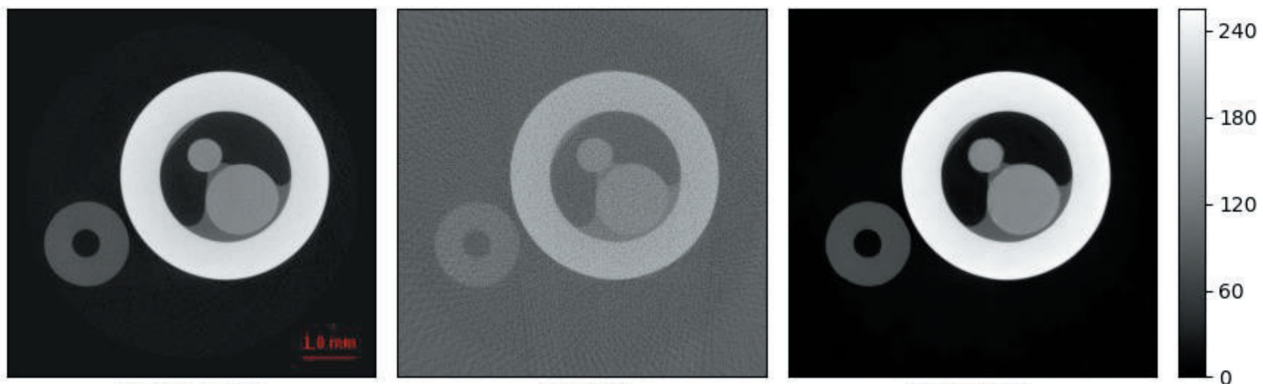
Spring 2021
Supervisor: Basab Chattopadhyay

Background

X-ray Computed Tomography (CT) allows for non-destructive imaging of internal structures of materials in many disciplines including material science, medical imaging, and geological studies. The process involves recording X-ray projection images of the entire sample as it is rotated about a common axis and then these images are reconstructed computationally to provide a 3-dimensional image of the sample. Such experiments and reconstruction can be a lengthy process depending on the sample complexity. Moreover, long exposure to X-ray can cause radiation damage. In order to image a dynamic process or to facilitate low dosage imaging, it is necessary to collect CT images with low exposure times and fewer projections. However, such an imaging protocol will introduce a large amount of noise in the final images and much research has been done to investigate how this noise can be reduced, e.g. through iterative reconstruction algorithms.

This thesis aims to use a type of neural networks known as Generative Adversarial Networks (GAN) to reduce the noise in CT images. Reconstruction is done with a dataset containing:
i) sufficiently large number of projections to create high-quality images, and
ii) with a low number of projections to create low-quality images.
The GAN is then trained to recreate the high-quality images from the low-quality images, and the goal is to map noisy reconstructions to approximations of the ideal noiseless reconstructions.

The figure below shows:
a) a high-quality reconstruction of a CT image of a glass capillary containing glass spheres and a fluid,
b) the same image reconstructed with a subsample of the projections, and
c) the corresponding denoised image executed with a GAN.



a) High-quality b) Noisy c) Denoised

Halvor Herlyng

Department of Energy and Process Engineering, NTNU

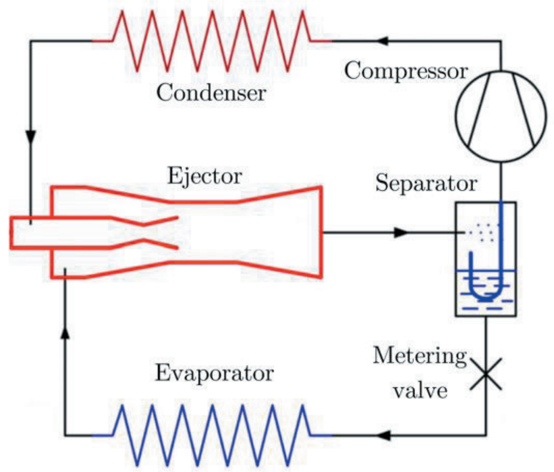
Geometric Optimization of Ejectors

Fall 2021/Spring 2022
Supervisors:
Øivind Wilhelmsen, Ailo Aasen and Krzysztof Banasiak

Background

Ejectors are versatile mechanical devices used in various industrial processes. In an ejector, two fluids of different pressures flow coaxially and mix together, exiting the ejector at an intermediate pressure. When operating at so-called design conditions, the flow in ejectors is often supersonic and multiphase, making the analysis and modeling of the physics of the process challenging.

In our mission to limit climate impact, ejector technology proves useful, with ejectors being good candidates for increasing energy efficiency of several industrial processes. Furthermore, they can operate with climate-friendly fluids. Ejector technology is widely used in refrigeration cycles, where they can be utilized to recover expansion work. See the below figure, which is adapted from [1], for an example of such an application. The major drawback of ejectors is their low efficiency, often due to exergy destruction during the intense mixing process taking place inside the ejector.



Thesis Work: Goals and Methodology

Increasing the ejector efficiency through optimization of the ejector geometry is the main goal of this thesis work. A numerical simulation tool written in Python for modeling the flow in ejectors will be further developed, with the goal of contributing to practice and theory regarding accurate modeling of ejector flow and transport phenomena. The numerical results are validated with experiments conducted with a two-phase CO_2 ejector.

In a second part of the thesis, an optimization problem for the ejector geometry will be formulated by use of Optimal Control Theory and Non-Equilibrium Thermodynamics. We wish to optimize the ejector efficiency by minimizing the entropy production of the flow. The governing equations of the flow are used as constraints, with flow variables as state variables. Our control variable will be the radius of the cross section.

The aforementioned modeling tool will be used to perform simulations of the flow with these optimal ejector geometries to assess the efficiency, with the hope that improved ejector geometries and design criteria can be determined. This can furthermore help improve our general understanding of thermodynamic driving forces and transport mechanisms in energy processes, which would help us gain more understanding and further improve the energy efficiency of other industrial processes, such as fuel cells.

Reference:

[1] S. Elbel, “Historical and present developments of ejector refrigeration systems with emphasis on transcritical carbon dioxide air-conditioning applications”, *International Journal of Refrigeration*, vol. 34, no. 7, pp. 1545–1561, 2011.

NTNU - Department of Materials Science and Engineering

Vegard Gjeldvik Jervell

Department of Materials Science and Engineering, NTNU

Thermodynamic and Kinetic Modelling of Thermal Diffusion in Mie-fluids

Fall 2021/Spring 2022
Supervisor: Øivind Wilhelmsen

Background: Thermal diffusion is a transport phenomenon in which a thermal gradient drives a mass flux. As of today, there is no consistently reliable model for prediction of the coupling coefficient, known as the Soret coefficient, that describes this effect. The ability to predict the Soret coefficient would introduce the possibility of more accurate modelling of material and fluid behaviour in high thermal gradient environments. This in turn, could open for design of alloys, coatings, membranes, cathode materials, electrolytes etc. that utilize the thermal gradient to which they are exposed for improved performance. To contribute to this development, the long-term goal of this project is to develop a reliable model for thermal diffusion in porous media.

Methodology: A model proposed by Kempers[1] has been investigated in detail. The model uses the results of revised Enskog theory to predict the Soret coefficient in a reference state, and an equation of state to predict the deviation of the true coefficient from that in the reference state. The model has been tested in its ability to replicate results from MD simulations of Mie-fluids.

[1] Kempers, J. Chem. Phys. **115,** 6330 (2001)
[2] Lafitte et al., J. Chem. Phys. **139**, 154504 (2013)

Results: There are clear inconsistencies between the model and MD simulations. The employed equation of state has been confirmed to accurately describe the phase behaviour of Mie-fluids in most phase points. A closer look at the description of the reference state used by the model is warranted and will be part of the continuation of this work.

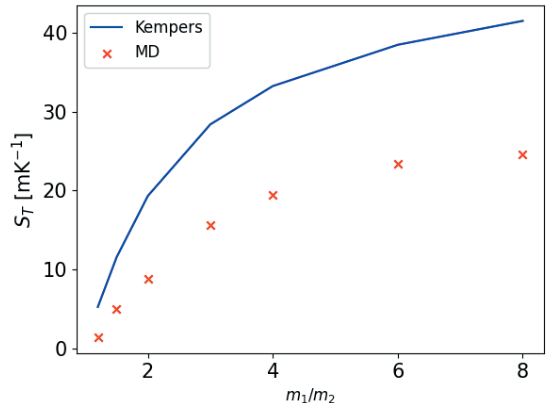


Figure 1: Soret coefficient in Mie-fluid mixtures with varying mass ratio of the constituents

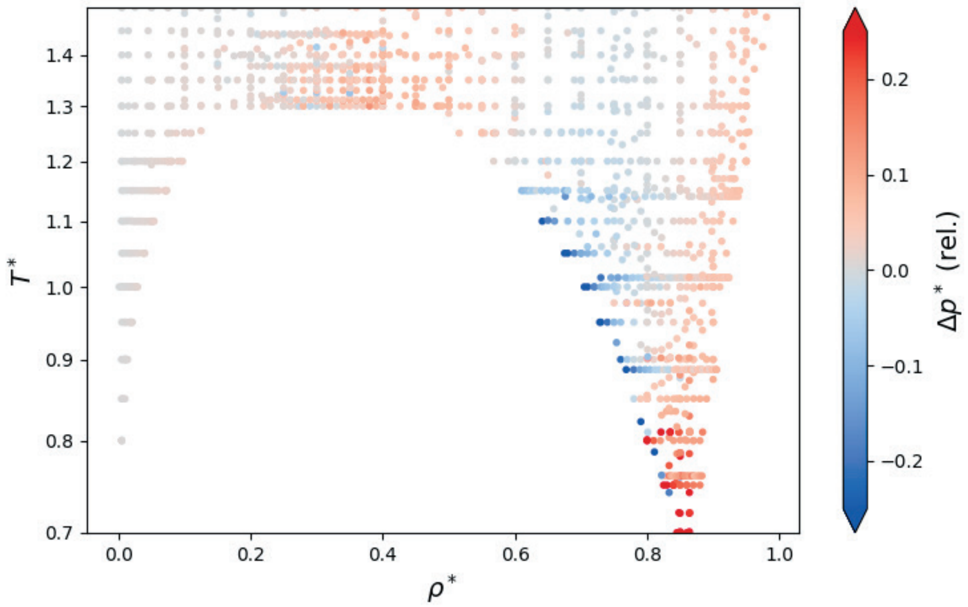


Figure 2: Discrepancy between SAFT-VR-Mie [2], and MD predicted phase behaviour of the Lennard-Jones fluid

Tage Maltby

Department of Chemistry, NTNU

A Study of the Entropy Production in Liquid Phase Shock Waves

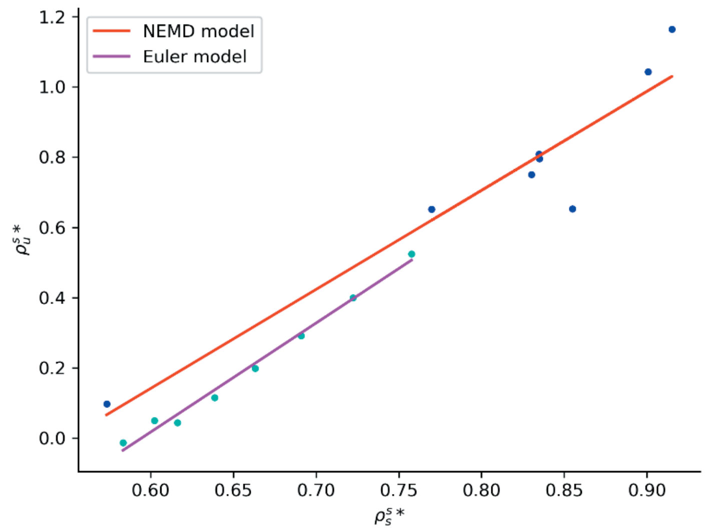
Fall 2021
Supervisor: Øivind Wilhelmsen

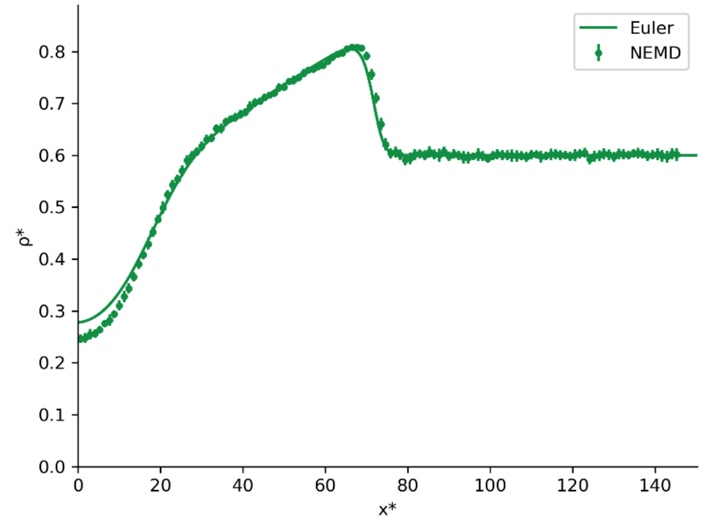
A shock wave is a sudden, almost discontinuous change in temperature, pressure, and density which travels at supersonic speed. Shock waves occur in a variety of settings, including porous media, and have been an area of interest in many fields, such as aerodynamics, medicine and, in the Processing industry.

Recently, work has been published by Hafskjold and coworkers, where they've studied the thermodynamic properties of shock waves in the gas phase, such as the entropy production, by use of Non-Equilibrium Molecular Dynamic simulations (NEMD).

In this Msc. work, previous efforts by Hafskjold have been extended to shock waves in the liquid-phase by use of NEMD and by solving the hydrodynamic equations with an equation of state adapted for the Lennard-Jones Spline fluid.

The two methodologies have been compared, and different methodologies to study the surface temperature, speed, and entropy production of a liquid shock wave have been investigated. The modelling of the hydrodynamic equations has shown promising results, having similar characteristics and behavior to their respective NEMD simulations.





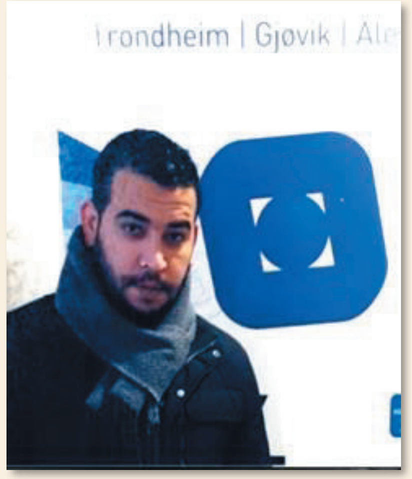
NTNU - Department of Chemistry

Tareq Aljamou

Department of Geoscience and Petroleum, NTNU

Multi-phase Segmentation of Imaged Fluid Distribution in Porous Media using Deep Learning

Fall 2021 / Spring 2022
Supervisor: Carl Fredrik Berg



Background

The derivation of rock and fluid properties from high-resolution images may lead to a better understanding of the rock properties, pore structure and the physical processes that control the transport and flow of fluids in porous media. The segmentation of three-dimensional CT images is a cornerstone in creating precise digital rock models. Traditional segmentation workflows have been prone to operator bias. Using deep learning-based segmentation can reduce unwanted bias and manual tuning required in conventional segmentation methods. [1]

Objectives

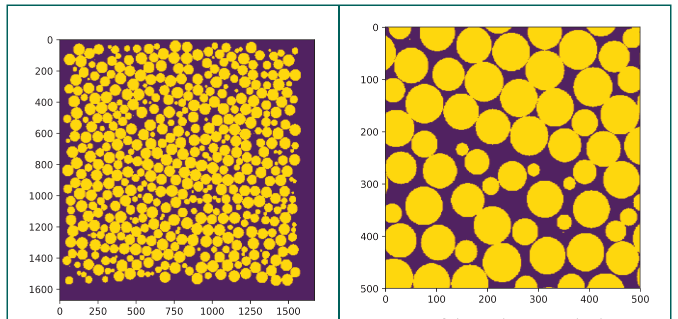
This thesis studies and develops neural networks for segmenting micro-CT images, including fluid distribution in these images. The work automates the segmentation process, thereby eliminating operator bias. The main task for this thesis is to generate training data for the neural networks.

Methodology

Training data for the neural network is generated by a two-step process. The first step is to generate sphere packs representing porous media, while the second step is to simulate fluid displacement inside the generated sphere packs.

The sphere pack is generated by hard-sphere packing software developed by Baranau and Tallarek. [2]. It generates monodisperse sphere packs. An example of a cross section of a sphere pack with 10000 spheres generated by this software is shown in Figure 1.

The fluid invasion is simulated using a morphological method as shown in Figure 2.



Cross section of a sphere pack with 10000 spheres.

A crop of the sphere pack above prepared as a grid for fluid displacement simulation.

Figure 1: Cross section of a sphere pack with 10000 spheres generated by the software developed by Baranau and Tallarek [2]

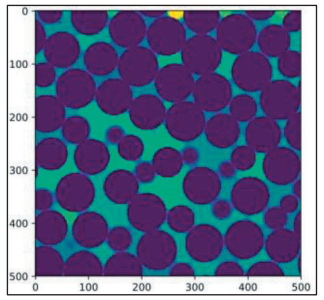
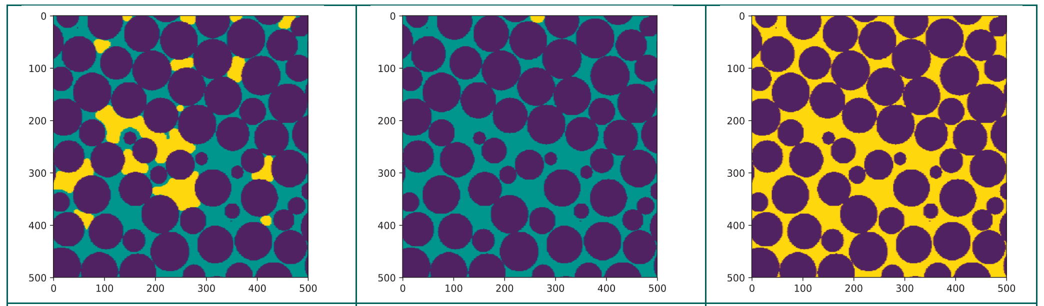


Figure 2: Morphological invasion

This creates maps of water-oil distribution at different pressures. Examples of fluid distributions at different pressures are shown in the Figure 3 below.



pressure=0,13 | pressure =0,08 | pressure =0,05

Figure 3: Fluid Distribution at different pressures

[1] https://doi.org/10.1016/j.asoc.2021.107185
[2] https://github.com/VasiliBaranov/packing-generation/wiki/Compilation

Victor de Souza Leão Barros

Department of Geoscience and Petroleum, NTNU

CFD Simulation of the Clogging Process in a Porous Medium

Fall 2021 / Spring 2022
Supervisors: Carl Fredrik Berg and Hamidreza Erfani Gahrooei

Background

During the drilling process, the drilling fluid might escape from the well annulus into the formation at an uncontrolled rate, such phenomenon is known as lost circulation. A potential solution to tackle lost circulation is adding solid particles (i.e., known as lost-circulation materials, LCM) to the drilling fluid to seal fractures and highly permeable fluid pathways into the formation.

Objectives

The main aim of the project is to analyze the effectiveness of the injection of solid particles, as LCMs, with the drilling fluid. We use computational fluid dynamics (CFD) and a discrete particle model using the Ansys Fluent software to model the pore space blockage by added particles, which reduces the lost circulation.

Methodology

The porous rock formation is simplified to the packing of uniform-sized spheres, as seen in Figure 1. The liquid-solid flow is modeled in an Euler-Lagrange perspective, enabling us to track individual particles as the separated discrete phase from the continuous fluid phase. The equations for the liquid-solid flow are solved using the Dense Discrete Phase Method (DDPM), while the Discrete Elements Method (DEM) is used to calculate the forces and torques due to the particle collisions with the wall or other adjacent particles. The clogging of the porous medium is illustrated in Figure 2.

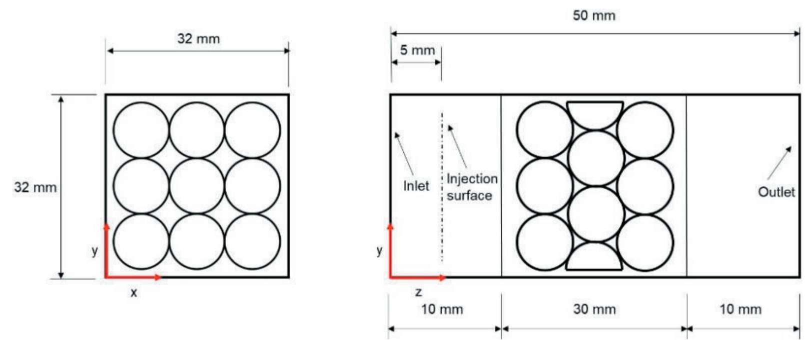


Figure 1. Simplification of the porous media

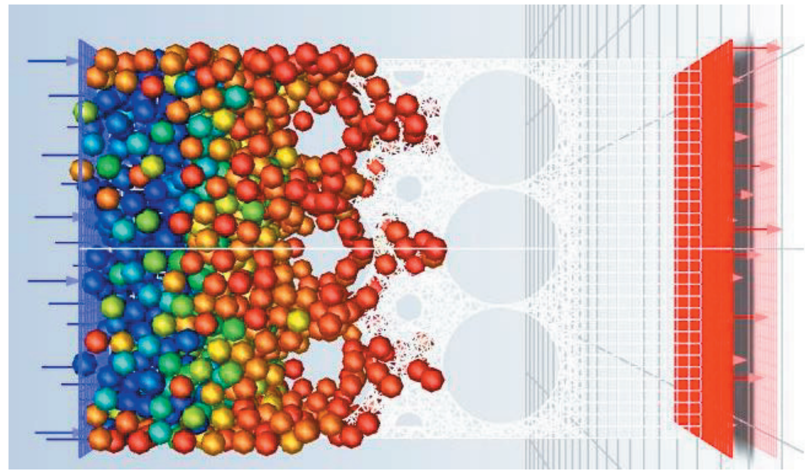


Figure 2. Clogging process of the porous medium.

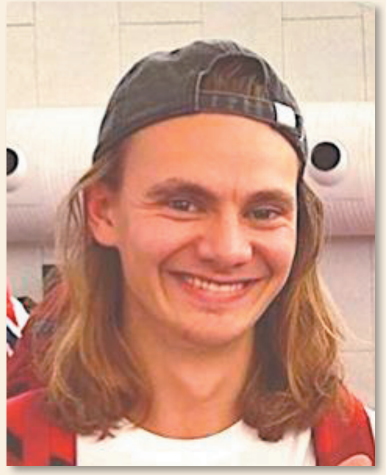
NTNU - Department of Geoscience and Petroleum

Tormod Kårstad

Department of Geoscience and Petroleum, NTNU

Predicting Local Pore Scale Transport Properties using CNN

Fall 2021 / Spring 2022
Supervisors: Carl Fredrik Berg



The derivation of rock properties from high-resolution images is a disruptive technology in the way that it can fundamentally alter how the industry measures basic rock properties that are used to characterize reservoirs and help predict their performance. The technology is based on the use of high-resolution 3D images to derive digital models of reservoir rocks. These models in combination with the right simulation tools can be used to derive macroscopic rock properties. The goal of this project is to develop new hybrid simulation tools, where traditional simulation tools such as Pore Network Models are integrated with AI tools to get more efficient and accurate predictions of physical properties.

The first sub-goal is to train a CNN-model to be able to predict the local hydraulic conductivity between two pore bodies connected by a pore throat. Machine learning models are as good as the data they are trained on, and high-quality training data is important. The training data is a set of images generated from the sub volume between two pore bodies connected by a pore throat labeled with a corresponding hydraulic conductivity, obtained through traditional pore network modelling.

An example image of a set of cross-sections between two connected pore bodies is seen in the figure below.

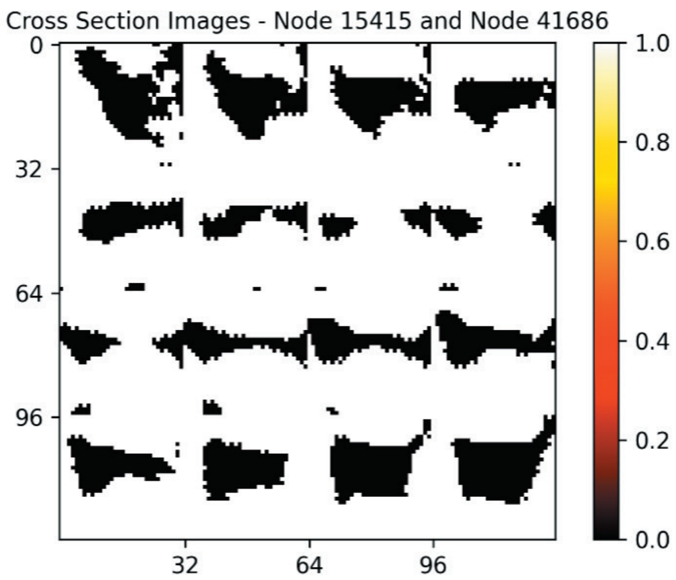


Figure: *Example of cross section images from the subvolume between connected pore bodies*

Fatemeh Dibaei Moghaddam

Department of Geoscience and Petroleum, NTNU

Automated Permeability Estimation using CT-scans of Extracted Core Data

Fall 2021 / Spring 2022
Supervisors: Carl Fredrik Berg and Kurdistan Chawshin

Background

X-ray computerized tomography is a non-destructive technique widely applied to investigate materials in earth sciences, including petroleum geoscience. Whole core CT-scan images can provide up to millimeter scaled information about the composition and internal structure of the reservoir rocks.

Objectives

This project evaluates the possibility of automated permeability estimation using the information of whole core CT-scan images of wells on the Norwegian continental shelf. In order to evaluate this possibility, this project aims to develop a workflow to custom the possibilities in whole core CT-scan images in combination with core analysis data.

To be more specific, the project has twofold objective: 1) to investigate whether core CT-scan images provide enough information content to estimate permeability, and 2) to develop a workflow for automated permeability estimation based on the information content of CT images and core analysis data.

Methodology

The applied workflow employs a supervised learning algorithm, where a Convolutional Neural Network model (figure 1) is trained to predict permeability from whole core CT-scan images, using permeability derived from routine core analysis measurements as the training data.

Results

The results indicate that, after we apply a post processing procedure, there is a relatively good correlation between the predicted permeability values using the proposed method and the core plug permeability measurements (figure 2). This indicates that the model is able to learn the relation between the distribution of grey-level attenuations of the images, with the permeability measurements.

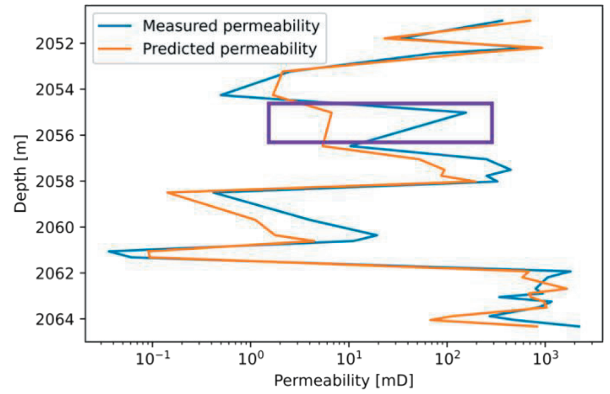


Figure 2*. Permeability prediction, and the actual measured permeability plotted versus depth. The purple rectangle is representing the fragment where predicted permeability and the permeability measurements are not correlating. This discrepancy is considered to be caused by the presence of possible outliers*

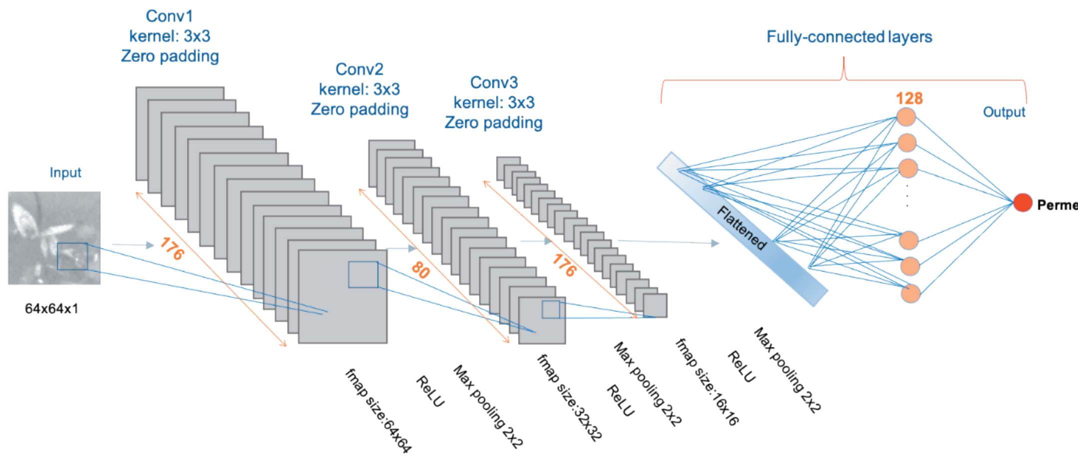


Figure 1*. The optimal CNN architecture for permeability estimation using two-dimensional grayscale CT images*

Henrik Haugerud Carlsen

Department of Physics, University of Oslo

Dynamics of Quantum Vortices in Different Confinements

Fall 2021/Spring 2023
Supervisors: Luiza Angheluta-Bauer and Jonas Rønning

The goal of my master thesis is to get a better understanding of the dynamics of stirred or rotating superfluid Bose gases, in terms of the formation and motion of quantized vortices. The project focuses on a theoretical and computational study of the Gross-Pitaevskii dynamics applied to weakly-interacting Bose gases in two- and three- dimensions.

The theoretical aim is to analytically study the Gross-Pitaevskii equation for a vortex solution and derive analytical expressions of the velocity of point vortices in 2D condensate and line vortices in 3D condensate. We do this using the Halperin-Mazenko method. The basic idea of this method is to identify vortices as zeros in the amplitude of the wavefunction, i.e. vortices are located by the "holes" in the superfluid density. I will study how the general formulas for the velocity and positions of the defects depends on the details of the trapping and stirring potentials. Previous studies suggest that rotating BEC might be a good playground for studying and predicting the vortex mass. A possible study is to see if the Halperin-Mazenko method can be used to derive the vortex mass.

Computationally, the aim is to develop a numerical implementation of the Gross-Pitaenskii equation using spectral methods. The idea is to study numerically different dynamical regimes of stirred superfluids in both 3D and 2D confining traps. Furthermore, the aim is to implement numerically the Halperin-Mazenko method for tracking vortices and test the analytical predictions of the vortex velocity. The overarching goal is to extend the formalism to 3D superfluids and study more "hard-wall" confining potentials beyond the soft quadratic trapping

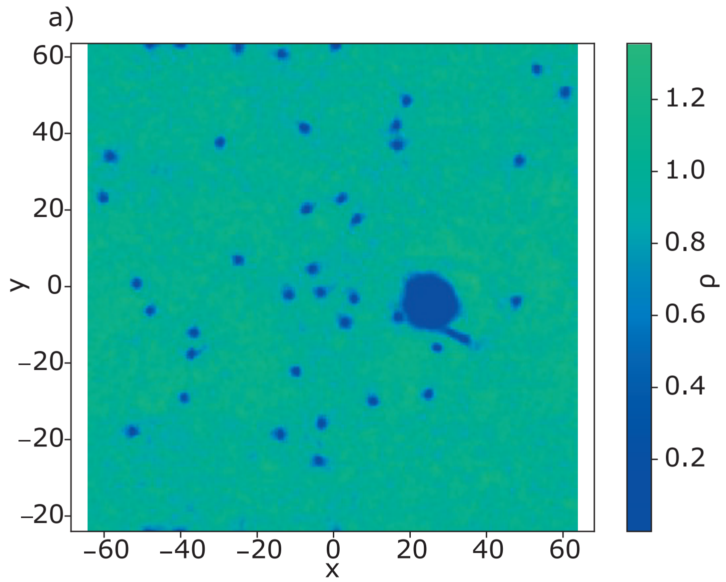


Figure: A snapshot of condensate density which vanishes at the vortex core and stirring potential.

Emily Q. Z. Moen

Department of Physics, University of Oslo

Active Matter in Confinement

Fall 2020/Spring 2022
Supervisors: Luiza Angheluta-Bauer and Kristian S. Olsen

The physics of active matter pertains to understanding the emergent states of matter from the coordinated dynamics of self-propelled entities. There are abundant examples of active matter across diverse biological systems from macroscopic scales, i.e. flocks of birds, school of fish, herd of sheep, etc) down to microscopic scales, i.e. bacteria colonies, tissue cells, etc. At the individual level, each self-propelled entity has the ability to consume chemical energy from the environment and convert it into motion. This gives them the property of being active and out-of-equilibrium with the environment.

In most realistic scenarios, active particles move in complex media. This complexity may range from geometric obstacles or disorder, to complete confinement. In recent studies, both of experimental and numerical nature, it has been shown that non-trivial interactions between the active particles or interactions between particles and walls give rise to interesting behaviors like particles accumulating at walls, due to inherent persistence in the particle's direction of motion.

The aim of this project is to use simple theoretical models of active particles to study how the microscopic dynamics of the particles affect the time spent trapped at a wall. The project uses analytical methods from statistical physics, like Fokker-Planck equations and first-passage formalism, as well as numerical simulations of Langevin equations.

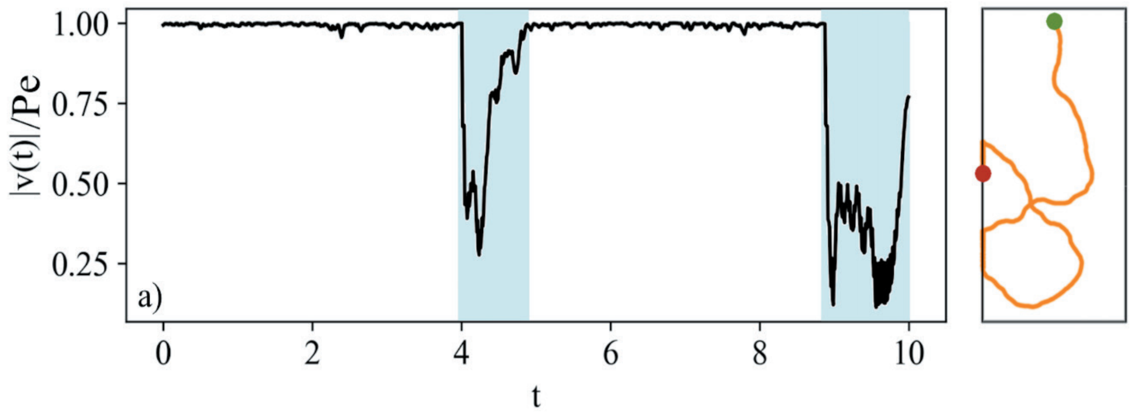


Figure: Time-series of a particles speed shows trapping events as the particle collides with a boundary. Right panel shows the corresponding particle trajectory initialized at the green dot.

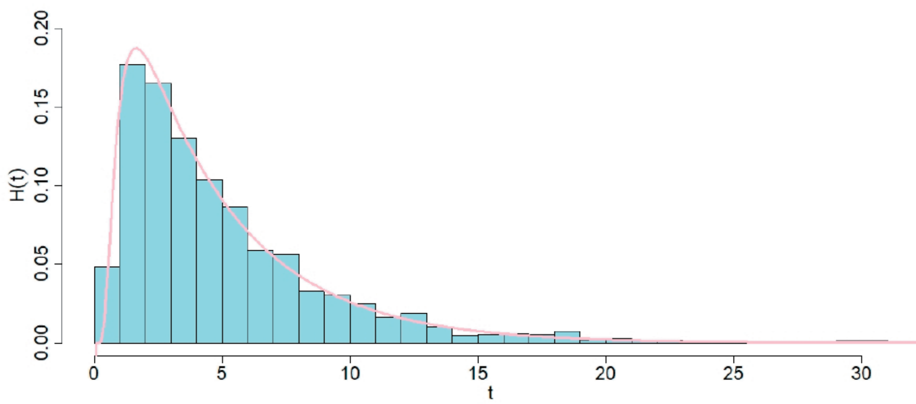


Figure: First passage time distribution H(t). The histogram is from the simulation, and the pink solid line is the analytical result.

Inspiration for Master Projects

You find in the following pages a few suggestions for master projects to be performed at PoreLab

Proposed Master Project at PoreLab NTNU (department of Physics)

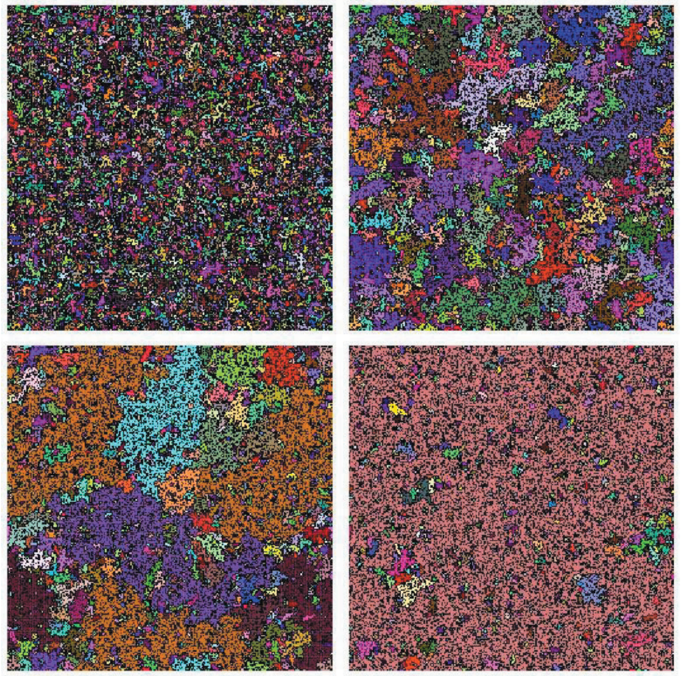
Role of system disorder and thermal noise in fracture growth

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.



[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.

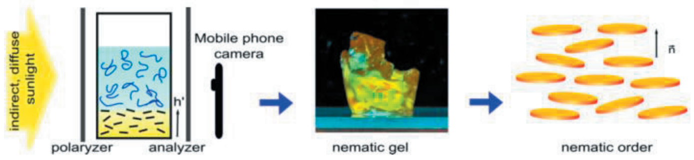
There is a version of the fiber bundle model which is much more complex than the one I just described: The local load sharing fiber bundle. When a fiber fails in this model, the force it was carrying is given to the nearest surviving fibers. This makes the model much more complex. The aim of this project 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)

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.

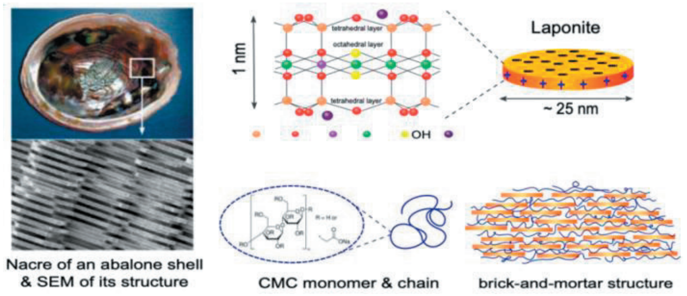
Contact person: Eiser Erika (erika.eiser@ntnu.no)

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)

Nature-inspired Sustainable Materials

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



Motivation

The growing environmental pollution of the world with synthetic, non-compostable plastics poses an ever-growing problem. Hence, it is desirable to replace these by natural polymers such as plant-based cellulose or alginate. However, they make no mechanically strong materials, which we need in packaging and coatings. Recently the Eiser group developed bioinspired, nanostructured composite materials with a microscopic architecture that resembles the brick-and-mortar structure of the mechanically tough, iridescent nacre in seashells as possible substitutes for synthetic polymers (Figure above) [1].

Your Project

We will explore the possibility to use different natural clays (2D-crystals; example is Laponite in the Figure above) and biopolymers to further develop such recyclable nanocoposite materials as transparent coatings. In particular, we want to integrate transparent active materials such as graphene or MOFs (Metal Organic Frameworks) rendering these smart plastic-replacements.

Requirements

Background in thermal & statistical physics would be advantageous. The applicant should be interested in experimental research, microscopy and scattering methods.

Other aspects

The experimental study will be supervised by the Prof. Eiser, an experienced Soft Matter Science researcher. Prof. D. Breiby and Prof. R.Cabriolu will collaborate with their groups in terms of x-ray scattering and simulation work, respectively.

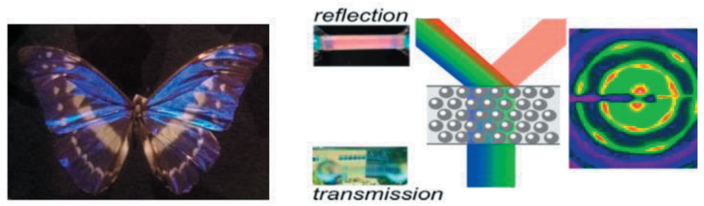
Contact person: Eiser Erika (erika.eiser@ntnu.no)

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)

Proposed Master Project at PoreLab NTNU (department of Physics)

Nature-inspired Sustainable Materials

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



Motivation

In nature we find butterflies, beetles, flowers but also bird wings and opals with intense coloration. Such strong, pure colours do not arise from pigment molecules that adsorb a fraction of the wavelengths in the visible region but from the highly ordered structure of the underlying building blocks [1]. An example are opals, which are semi-precious stones: their colour stems from the periodic arrangements of sub-micronsized silica colloids. When large there are simply transparent glass, but it is the periodicity of high to low refractive index in the crystalline arrangement of these beads that will reflect only a narrow band of wavelengths (see the red in the Figure above [2]) while the rest is being transmitted. Although it is very difficult to make large colloidal crystals with such structural colours, researchers and in particular industry are highly interested in developing new materials with such optical properties.

Your Project

In this project we will extend recent studies on 200 nm large, fluorinated particles that form charge stabilized, face-centred cubic crystals in aqueous solutions. By changing the colloidal concentration, the reflected colour of such suspensions can be tuned continuously from blue to green to red. The aim will be twofold: synthesizing these colloids and dope them with various and playing with the background fluid to improve the materials reflectivity and to solidify the samples such that they can be made mechanically stable for applications such as waveguides or for light harvesting purposes.

Requirements

Background in statistical physics and optics would be advantageous. The applicant should not be afraid of doing a bit of chemistry.

Other aspects

The experimental study will be supervised by the Prof. Eiser, an experienced Soft Matter Physicist. We will also interact with Prof. Yang Lan from University College London, who is an experienced colloid synthesist.

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

References

[1] H.S. Lee, T.S. Shim, H. Hwang, S.-M. Yang, S.-H. Kim 'Colloidal Photonic Crystals toward Structural Color Palettes for Security Materials.' *Chem. Mater.* 25, 2684 (2013)

[2] T. Erdem, T. O'Neill, M. Zupkauskas, A. Caciagli, P. Xu, Y. Lan, P. Bösecke, E. Eiser 'Transparent Colloidal Crystals With Structural Colours' *Front. Phys.* 10:847142 (2022)

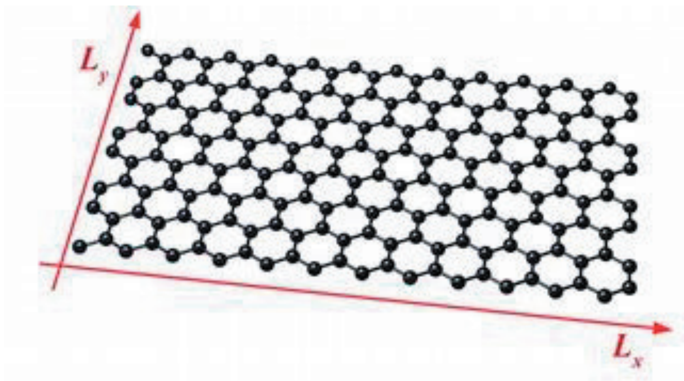
Proposed Master Project at PoreLab NTNU (department of Physics)

Dimensionality Effect on Thermal Conductivity

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

Motivation

The physical quantity that expresses the ability of a material to conduct or transport heat, by diffusion or conduction, is the intensive material property called thermal conductivity. Despite the enormous implications in fundamental science and engineering applications, thermal transport is not fully understood, also because of the difficulties associated with the experimental and theoretical estimation of thermal conductivity [1]. Furthermore, many theoretical and experimental works [2,3,4] reported an anomalous strong dependence of the thermal conductivity on the system size in quasi 1-D objects, breaking the intensive character of the thermal conductivity.



Your Project

In this project, we will study the effect that removing systematically "rows" from a 2D graphite layer has on its thermal conductivity. The student will use Molecular Dynamics simulations with a non-equilibrium method to estimate the effect of the aspect-ratio, L=Lx/Ly, on the thermal conductivity.

Requirements

Background in thermal physics and thermodynamics are desirable. We would like a person interested in modeling, simulation and programming.

Other aspects

This project will be supervised by the associate Prof. Cabriolu in physics at NTNU in collaboration with Prof. Berend Smit at EPFL in Switzerland.

Contact Person

Raffaela Cabriolu (raffaela.cabriolu@ntnu.no)

References

[1] McGaughey A.J.H. et al., *Adv. In Heat Transf.*, 39, (2006)

[2] Crnjr A. et al., *Phys. Rev. Mat.* 2, 015603 (2018)

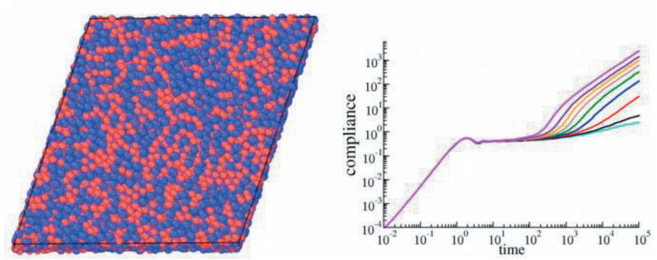
[3] Cwang C. W. et al., *Phys. Rev. Lett.* 101, 075903 (2008)

[4] Hsiao H.K. et al., *Nat. Nanotechnology* 8, 534 (2013)

Proposed Master Project at PoreLab NTNU (department of Physics)

Understanding non-Newtonian materials

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

References

[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).

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 quasicrystalline surfaces, and whenever possible do analytical calculations to accompany them.

Required 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.

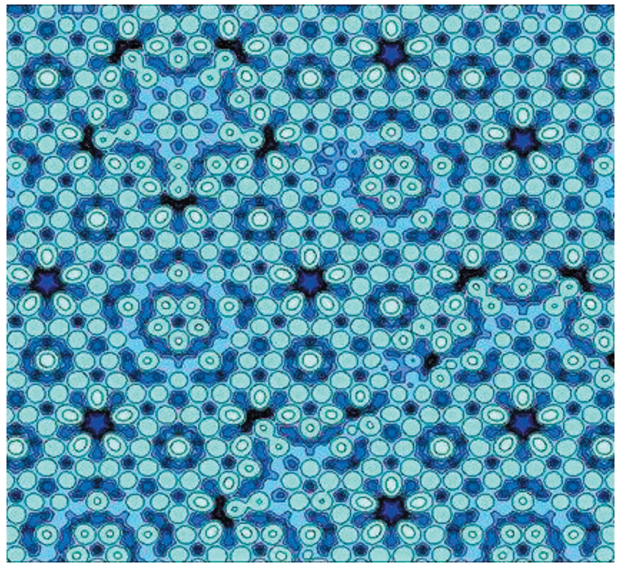


Figure: Example of a quasicrystal surface, atomic model of fivefold icosahedral-Al-Pd-Mn. (Picture from Wikimedia Commons)

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)

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).

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

Supervisor
Astrid S. de Wijn <astrid.dewijn@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.

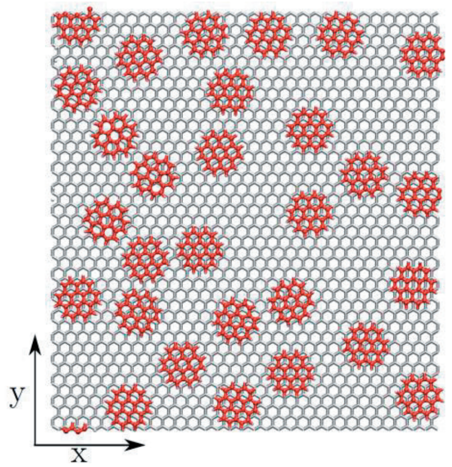


Figure 2: A top view of a simulation of a single layer of graphene flakes acting as a solid lubricant

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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)

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.

Required 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>
Research environment: http://syonax.net/science/research.html.

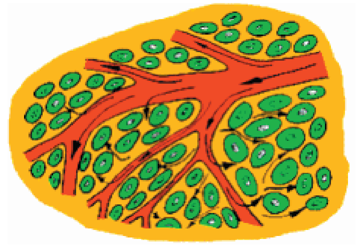
Work load
This project is intended for a combined specialization project thesis and master thesis, i.e. 45 or 60 ECTS in total.

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

Transport of therapeutic molecules in tissue – Simulation of transport of nanoparticles in tissue

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

A major problem in cancer therapy based on chemotherapy is the low uptake of drugs in tissue. Thus, there is a need to understand the mechanism for transport and how to improve it. We have an ongoing project studying how ultrasound focused on the tumour can improve the transport of nanoparticles.



Delivery of drugs depends on 1) The blood vessel network 2) Transport across the capillary wall 3) Penetration through the extracellular matrix 4) cellular uptake

In this proposed project, 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 influence the transport of nanoparticles in tissue.

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

Transport of therapeutic molecules in tissue – Simulation of biomolecule adsorption and the effect of nanoparticle coating

Contact: Catharina de Lange Davies (catharina.davies@ntnu.no), Anders Lervik (anders.lervik@ntnu.no), Sebastian Everard Nordby Price (sebastian.n.price@ntnu.no)

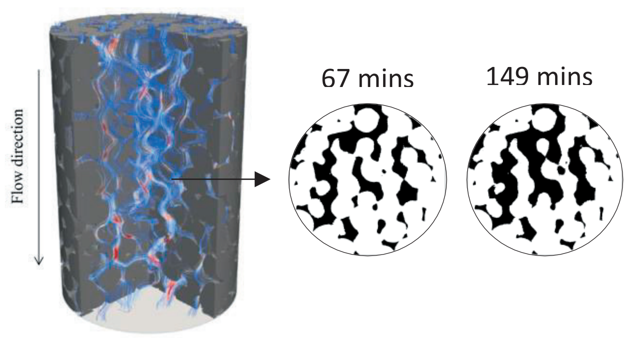
A major problem in cancer therapy based on chemotherapy is the low uptake of drugs in tissue. Thus, there is a need to understand the mechanism for transport and how to improve it. We have an ongoing project studying how ultrasound focused on the tumour can improve the transport of nanoparticles.

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 Geoscience and Petroleum)
Pore-scale imaging of rock dissolution in carbonate samples

Contact: Hamidreza Erfani Gahrooei (hamidreza.erfani@ntnu.no), Haili Long-Sanouiller (haili.long-sanouiller@ntnu.no) and Carl Fredrik Berg (carl.f.berg@ntnu.no)

Underground CO_2 storage is a practical technique to mitigate global warming and to reach carbon neutrality. Quantifying rock dissolution and pore space morphological change during CO_2 storage has a great importance for simulation of carbon storage in saline aquifers, as well as oil and gas reservoirs. In this project, we utilize novel imaging techniques (tomography X-ray imaging) to visualize the carbonate rock dissolution during single-phase flow in porous media. We will study the effects of some parameters such as injection flow rate and pH in pore space evolution, porosity, and permeability variation in the sample during fluid injection.



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. 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.

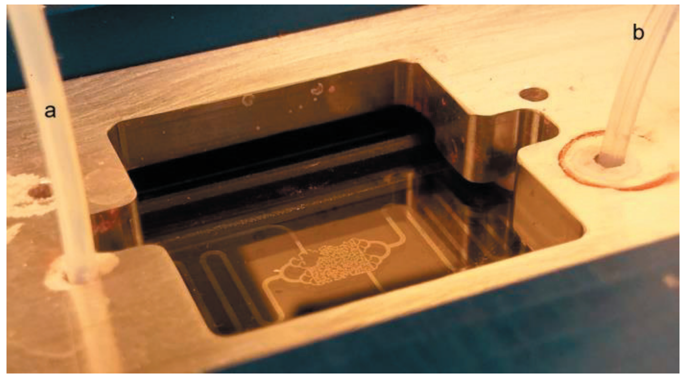


Figure: Example of a 2D micromodel representing a porous media, connected with an inlet and outlet flow line (a,b)

Proposed Master Project at PoreLab NTNU (department of Geoscience and Petroleum)
Characterization of capillary desaturation curve-structure dependency in water wet porous media

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

For flow optimization in porous media an understanding of trapping in the porous media is crucial. This can be relevant for reduction of trapping of oil but for also stimulation of gas trapping in CO_2 flooding. For hydrocarbon flooding the concept of the capillary desaturation (CDC) curve correlates how the residual oil saturation depends on the capillary number (ratio of viscous and capillary forces), mainly for water wet systems. This concept is in simulation tools used to adapt the end point saturations of the relative permeability curves, dependent on how either viscous or capillary force are changing. The CDC curves are measured in the lab, determining residual oil saturation as a function of flow rate. The question is when this concept of CDC curves is applicable. How to use this concept if the wettability changes? Can variations in CDC curve tell anything about the wettability distribution within the core?

To start answering these questions, a literature study shall collect knowledge available. The study shall explore the use and dependencies of CDC curves measured, e.g. dependencies on wettability. Micromodels and core flooding will be used to further explore the effect of wettability on the CDC curve.

Proposed Master Project at PoreLab NTNU (department of Geoscience and Petroleum)
Pore-scale investigation of low salinity waterflooding in Sandstones

Contact: Tomislav Vukovic (tomislav.vukovic@ntnu.no), Hamidreza Erfani Gahrooei (hamidreza.erfani@ntnu.no), 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.

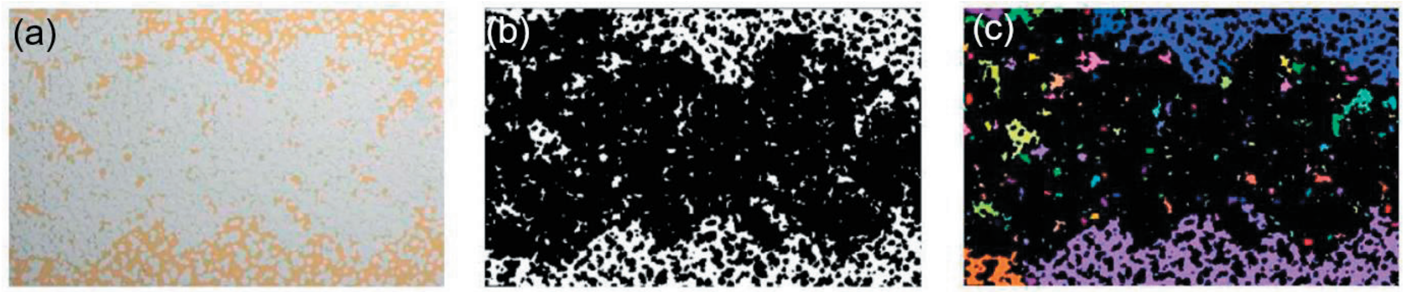


*Figure (a) Pre-processing image of a microchip after water flooding (oil = gold, glass and brine transparent). (b) Segmented, binary image to enable quantitative analysis (oil in white). (c) Oil clusters colored individually for qualitative analysis. [from Aadland et al. Nanomaterials **2020**, 10,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

Proposed Master Project at PoreLab NTNU (department of Geoscience and Petroleum)
Improvement of unsteady state relative permeability measurements by the use of partitioning tracers, in collaboration with Resman

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

For the description of two-phase immiscible flow in porous media, the concept of relative phase permeabilities was introduced. This concept describes on a macroscopic scale (core scale) the ability of two immiscible phases to flow in the porous media relative to each other. This can be directly related to the phase saturations in the porous medium. Relative permeability curves can be determined by performing unsteady state relative permeability measurements. The determination of the phase saturations is hereby critical. However, the production monitoring of core flooding experiments often comes with a large uncertainty.

The use of partitioning and none partitioning tracers can potentially be used as a second additional method for saturation determination. The idea is that by monitoring the arrival of the different tracers and the use of tracer modelling more accurate in-situ saturations can be derived.

Simulations in CMG stars or a similar modelling tool shall verify the possibility of use of partitioning tracers in core flooding. Experiments with modelling of unsteady state flooding experiments shall show the proof of concept in the lab. The project will be in collaboration with tracer technology company Resman.

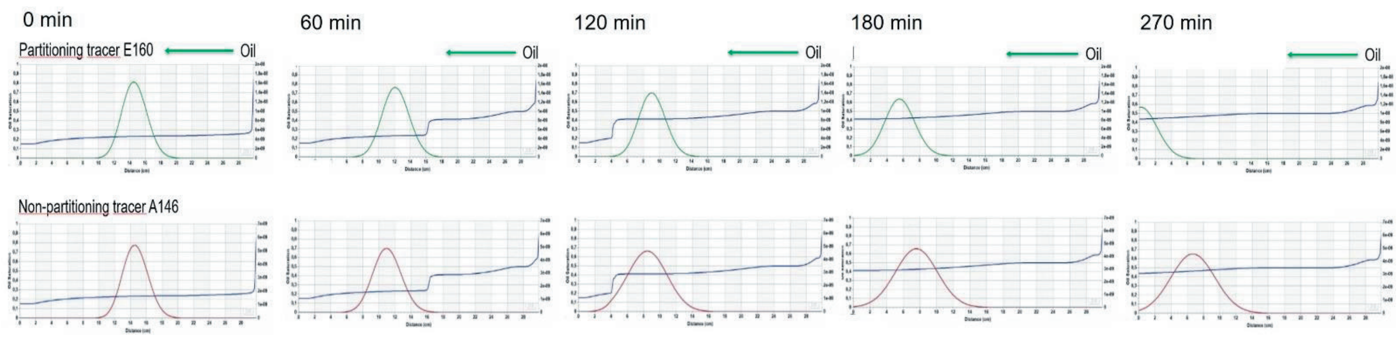


Figure: Simulation of the movement of a non partitioning tracer (red) and in oil partitioning tracer (green) during back production to the well (left), with oil drainage from the right side (blue curve= oil saturation). At low oil saturations the non-partitioning tracer moves quicker. Once the oil front passes, increasing the oil saturation, the partitioning tracer velocity increases and overtakes the non-partitioning tracer, leading to an earlier breakthrough.

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.

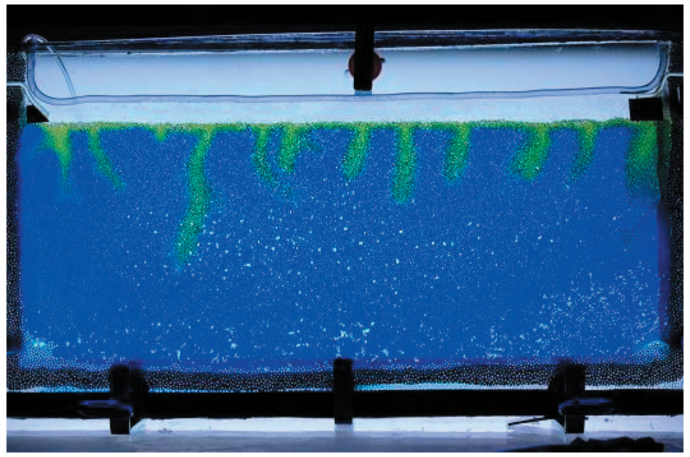


Figure: A layer of CO_2 above a water-saturated porous medium consisting of glass beads. An indicator acid has been added to the water carbonic acid to turn it blue. Where the CO_2 has been absorbed by the water, carbonic acid forms which turns the color to green. The acid has larger density than water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

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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.

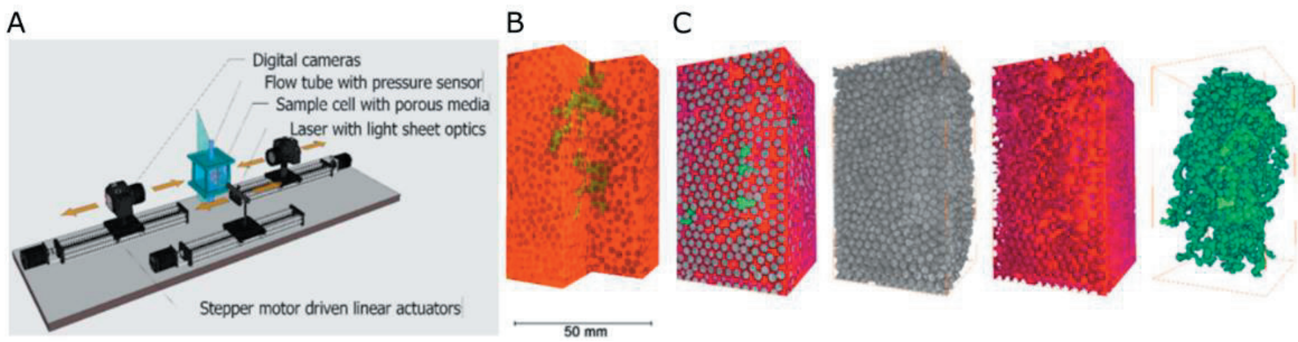

Figure: A The 3D scanner is based on optical index matching and fluorescence. A random packing of 3 mm glass beads forms the porous medium, index matched with two immiscible fluids. The fluids contain different fluorescent dyes that are excited with a 2D laser sheet that is driven through the sample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

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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.

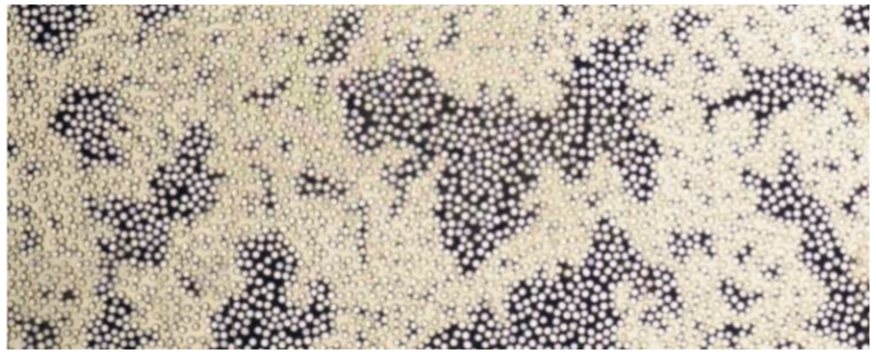

Figure: Detail of the trapped liquid clusters (blue) left behind after air (white) is slowly injected from the left in a quasi-2D porous network previously saturated with the liquid

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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.

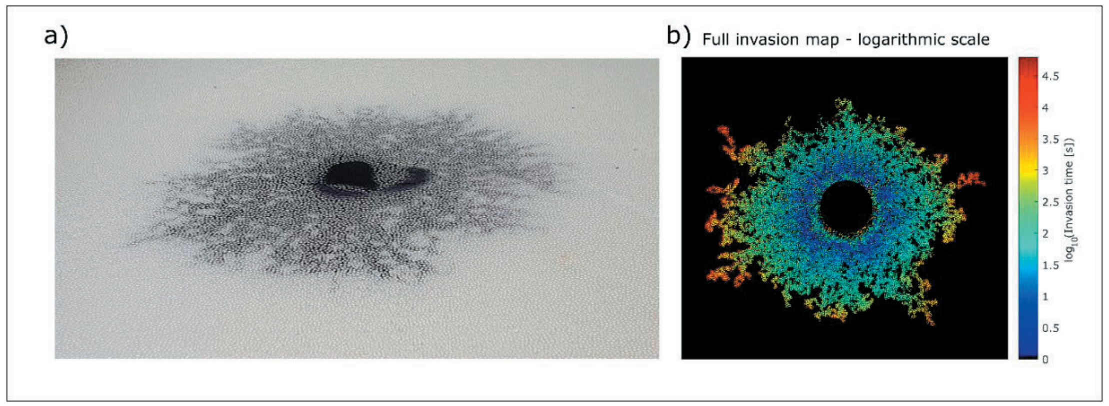

Figure: a) Experiment illustrating how a source of pollution (central dark blob) spreads through a partially wet porous network (here made of glass beads). Water films covering the internal surfaces of the porous medium can act as a fast pathway for the spreading of pollution. b) Spatiotemporal invasion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

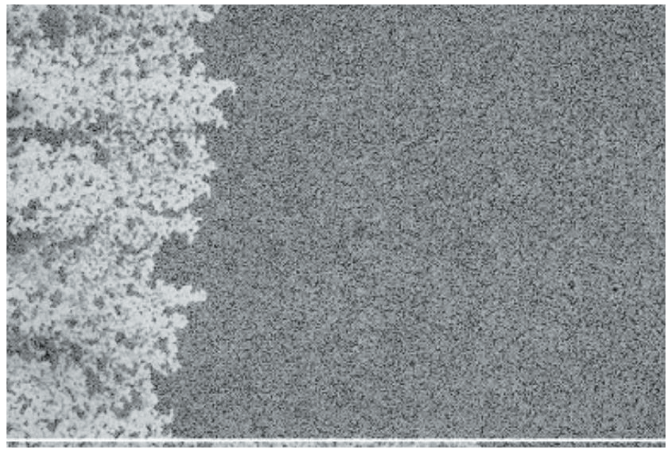

Figure: Steady state flow in a quasi 2D model system. Simultaneous injection of a glycerol/water (black) solution and rapeseed oil (white)

Proposed Master Project at PoreLab UiO (department of Physics)

Influence of the flow speed on the pore invasion dynamics

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.

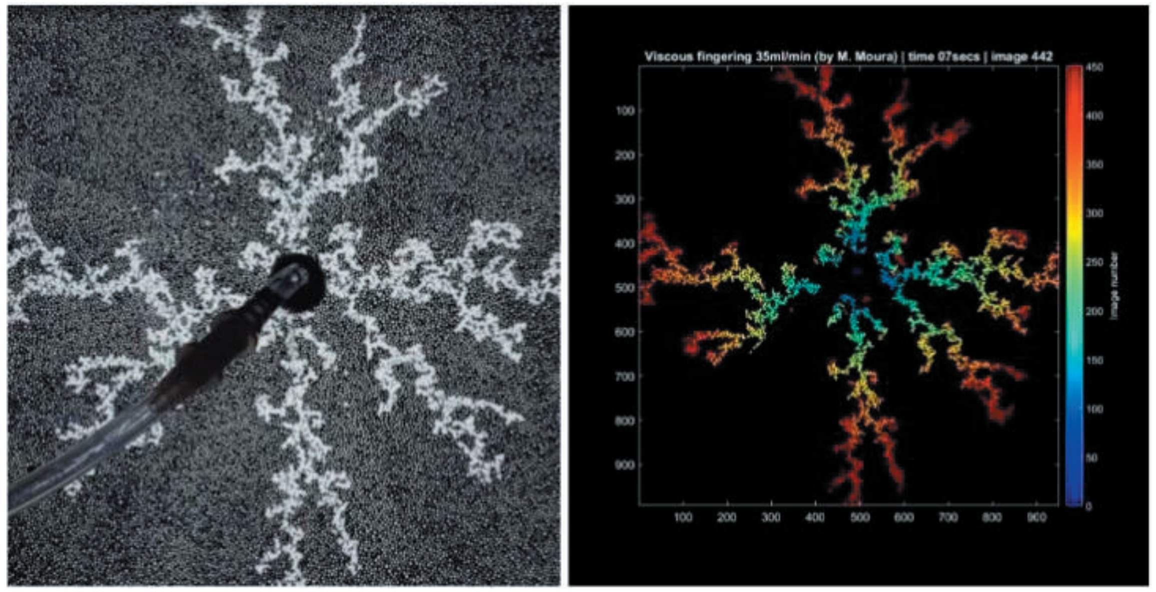

Figure: Viscous fingering pattern (left) observed when air is injected fast in a porous medium previously filled with a viscous liquid (blue). The image analysis (right) shows the time (image number) of injection of each pore

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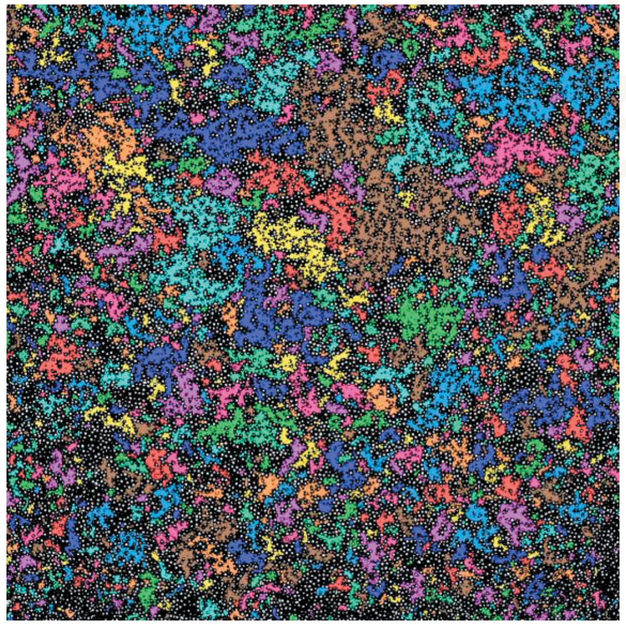
Proposed Master Project at PoreLab UiO (department of Physics)

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

Contact: 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

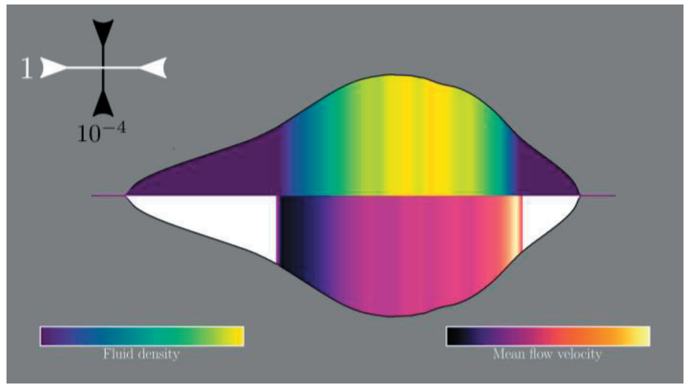
In this project we propose to investigate the physics of a rapidly expanding fluid-filled cavity. The student will employ and develop a numerical model that fully couples solid and fluid dynamics at the tip of a rapidly growing tensile fracture. We will initially consider a single fluid-filled crack 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.



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

Contact : 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.

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

Contact: 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:

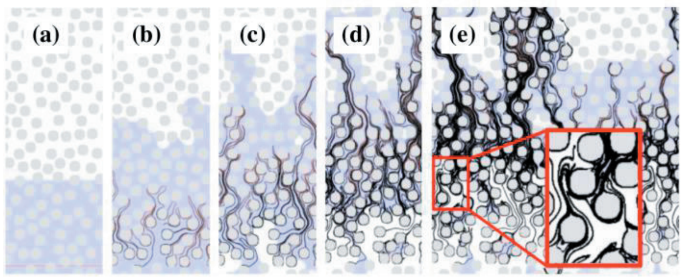
- Implementing and comparing different discretization schemes for the 3D fluid flow model. This will allow us to answer under which conditions (fully or partially) implicit schemes, with fewer but larger time steps, are advantageous over more explicit schemes, with more but smaller time steps.
- Investigate 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

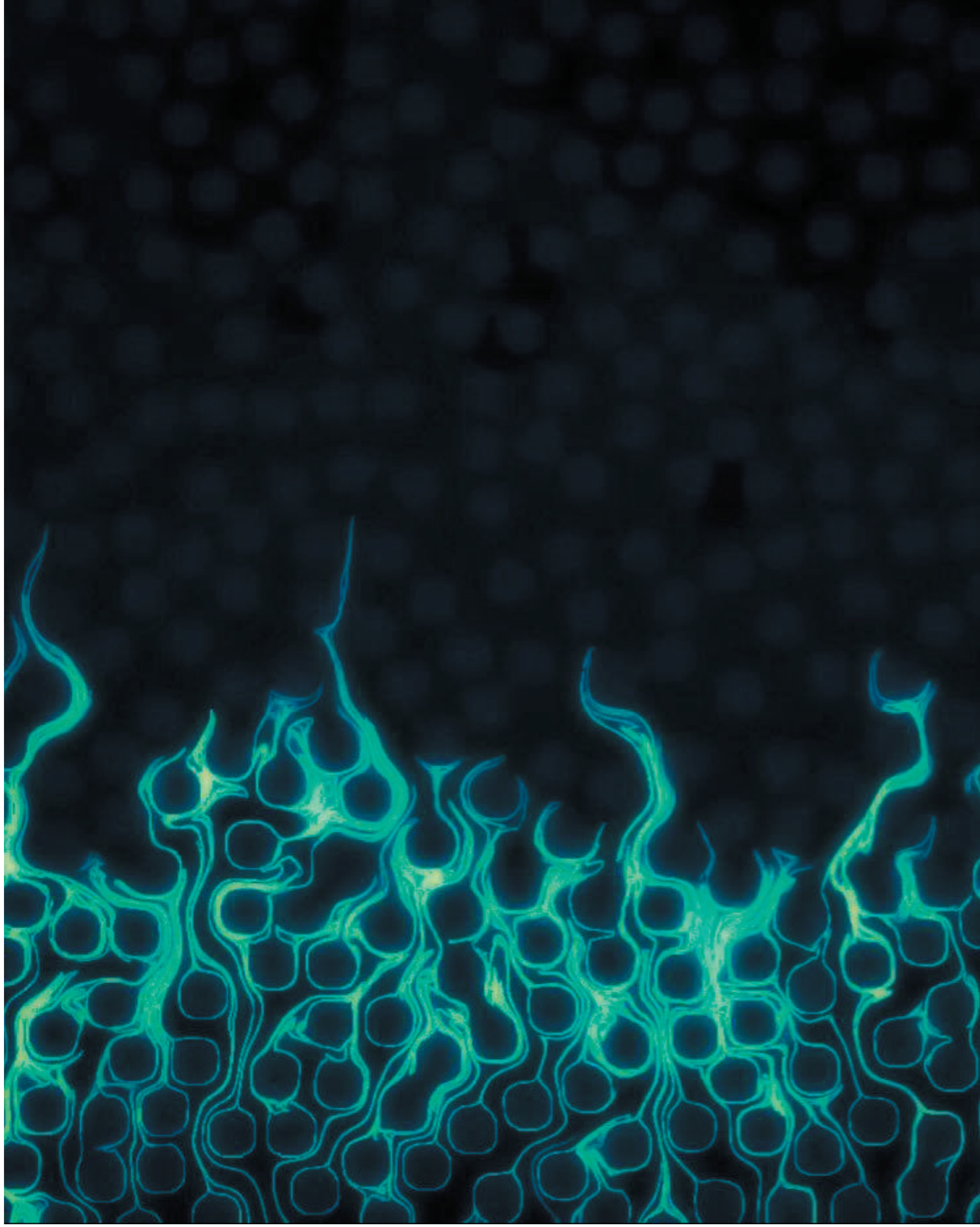
The student will learn how to use HPC infrastructure and have access to Sigma2 and the PoreLab UiO cluster. The project will benefit from comparison to experiments carried out under similar conditions (see other project).

Required background

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



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.



The figure above shows evidence of chaotic mixing in a simulated two-phase flow through a porous medium consisting of randomly arranged cylindrical obstacles: a strip of solute (light colour) is elongated exponentially in time by a net upward flow. The two fluid phases can be distinguished as the two dark shades filling the space between the obstacles. Picture by Gaute Linga, PoreLab UiO

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 it 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. The course content is motivated in terms of ground water flows, biological tissue, hydrocarbon management, fuel cells, electrophoresis, building materials and the quest for the governing equations. PoreLab course 1 is open for students from both NTNU and UiO. Professor Eirik Flekkøy 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 physic) at UiO or PG8605/TPG4565 (Dual porosity reservoirs/Petroleum engineering) at NTNU

PoreLab course 2 covers experimental techniques related to porous media and is open for students from both NTNU and UiO. The course is adapted to PoreLab with a special focus on porous media physics. It contains projects that will give students introduction to important experimental techniques in the field porous media and complex systems. The teaching consists of 4 projects and approximately 4 hours of lectures for each project. The lab part of each project will take a total of 1-2 full days. Finally, a research report will be written on each of the projects. PoreLab course 2 is offered on both Ph.D. and Master level and is open for domestic and visiting students. Contacts are: Professor Knut Jørgen Måløy, UiO, and Professor Ole Torsæter, NTNU.

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

Irreversible Thermodynamics

TKJ4200, NTNU

In this course we learn to describe energy conversion and the efficiency of this conversion using irreversible thermodynamics. The entropy production (the energy dissipation) will be constructed for systems with transport of heat, mass and charge. It covers as well: concentration cells, liquid junctions, membrane transport, electrokinetic effects, Soret, Duffour, Peltier and Seebeck effects. The fundamental properties will be connected to renewable energy technologies, like thermoelectric effects, salt power plants, batteries, thermal osmosis or fuel cells. The underlying molecular mechanisms for coupled transport processes are discussed. The energy efficiency of the mentioned processes is in focus. The students take part in a project, theoretical or experimental, formulated in collaboration with the teacher. The purpose is to obtain hands-on experience to use irreversible thermodynamics with the purpose of contributing to the UN goals of sustainability. The purpose is also to train collaboration skills and presentation techniques

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: Fick´s, Navier-Stokes, Euler´s, Bernoulli's and Newton's second equations and conservation laws in transport processes. The Chapman-Enskogs, two-film, Eyrings, hydrodynamical, penetration, and varying interface renewal theories. The models and concepts of Dufour, Soret, Onsager, Kingery, Luikov and Stamm. The analogy of micro and macro transport processes. Criteria of similarity, model and object equations. Equations for steady state and transient convective and molecular diffusion in gases, liquids (ionic or not), concentrated solutions and porous solids. The gradients of concentration, moisture, temperature, pressure and phase change. Dimensionless groups and experiments on internal and external transport in laminar and turbulent flows. Transport properties in multicomponent mixtures. Transport in bubbles, droplets, cellular, capillary and porous solids. Quasi-steady method and mass transport in equally accessible surfaces. The development of transport rates in with chemical reaction, diffusion and convection. Sorption isotherms and spacial polytherms equations with effect of temperature. Sorption inflection points and distribution of micro and macropores and related equations. Experimental application of transport equations and correlations.

Applied Heterogeneous Catalysis

KP8132, NTNU

The course is given every second year, next time in the fall term 2021. 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.

The students will be able to understand and apply basic thermodynamic concepts, select and apply suitable thermodynamic models, calculate thermodynamic properties of components and mixtures, in ideal and non-ideal systems, use standard chemical potential, fugacity and activity in practical calculations, explain the limitations and assumptions in presented thermodynamic models, calculate simple phase equilibria and phase equilibria in multi-component systems.

Energy and Process Engineering, Specialization Project

TEP4550, NTNU

The topic will be closely linked to the ongoing research activities. The following subjects are offered:

1. Industrial heating and refrigeration processes in all parts of society. 2. Processing, transport and utilization of natural gas and hydrogen. Multiphase flow. Thermal power production. gas-fired power plants, fuel cells. Safety, environment, economy and management. 3. Combustion processes, industrial burners, boilers and gas turbines, emissions of polluted materials from combustion. Exhaust cleaning. Safety regarding fire and explosion. 4. Turbines for water and wind power. Transport of liquid and gas in pipe systems. Pumps and compressors. Aerodynamics of buildings, transport vessels and sports. Hydraulics, hydraulic control systems for control of various machinery. Energy and Indoor Environment. District heating and other hydronic processes. Energy conservation and energy monitoring. Solar heat utilization. 5. Components, processes and plants regarding refrigeration and food processing. Cooling / freezing, dewatering / drying, heat pumps and environmentally secure working fluids.

The specialization topic consists of two subjects (tema), each 3,75 study points. Choice of themes is done in consultation with the responsible teacher of the chosen project work. Further info regarding the subjects and teachers is given by the specialization topic at one of the 4 department groups.

Reservoir Property Determination by Core Analysis and well testing

TPG4115, NTNU

The objective of the course is to teach fundamental techniques as an aid for further studies in reservoir engineering and related subjects. The students learn basic theory to determine reservoir properties by well testing and core analysis. They study the influence of reservoir properties on one- and two-phase flow in subsurface reservoirs and will be able to do well test interpretation and conduct basic measurements in a core lab.

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

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 content is as follow: partial differential equations 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.

Applied Computer Methods in Petroleum Science

TPG4155, NTNU

The course addresses methods for numerical differentiation and integration, numerical solution of ordinary differential equations, numerical solution of sets of linear equations, numerical solution of partial differential equations, and numerical optimization useful for petroleum engineering and geoscience.

The course aims at giving the students experience in use of computers to solve numerical problems in petroleum engineering and geoscience.

The students will acquire knowledge about basic numerical techniques applied to problems from petroleum engineering and geoscience. They will be capable of writing programming routines for the numerical solution of problems in petroleum engineering and geoscience.

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

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.

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 you 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.

Condensed Matter Physics II
FYS9430, UiO

The course presents an overview of some functional materials and their properties, mainly seen from an experimental viewpoint. Some central theories, which describes the properties of the materials and their response to external impact, will be discussed. Topics that will be covered include dielectric materials, magnetic materials, superconductors as well as selected topics within micro- and nanostructured materials. The subject will be useful for gaining an understanding of the interplay between classical and quantum mechanical phenomena and clarify how microscopic/atomic processes give rise to the typical properties of different materials.

By completing the course the student will have a broad knowledge of the core areas of condensed matter physics and materials science, as well as a good understanding of the physical basic principles behind the properties of different types of functional materials and some micro/nanostructured materials

Photo on the right: PoreLab PhD candidates Olav Galteland and Astrid Fagertun Gunnarshaug at the Department of Chemistry, NTNU, are looking at how molecular simulations can be used to calculate transport coefficients of seawater in vapor-gap membranes

Porous Media Laboratory
NTNU, UiO

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