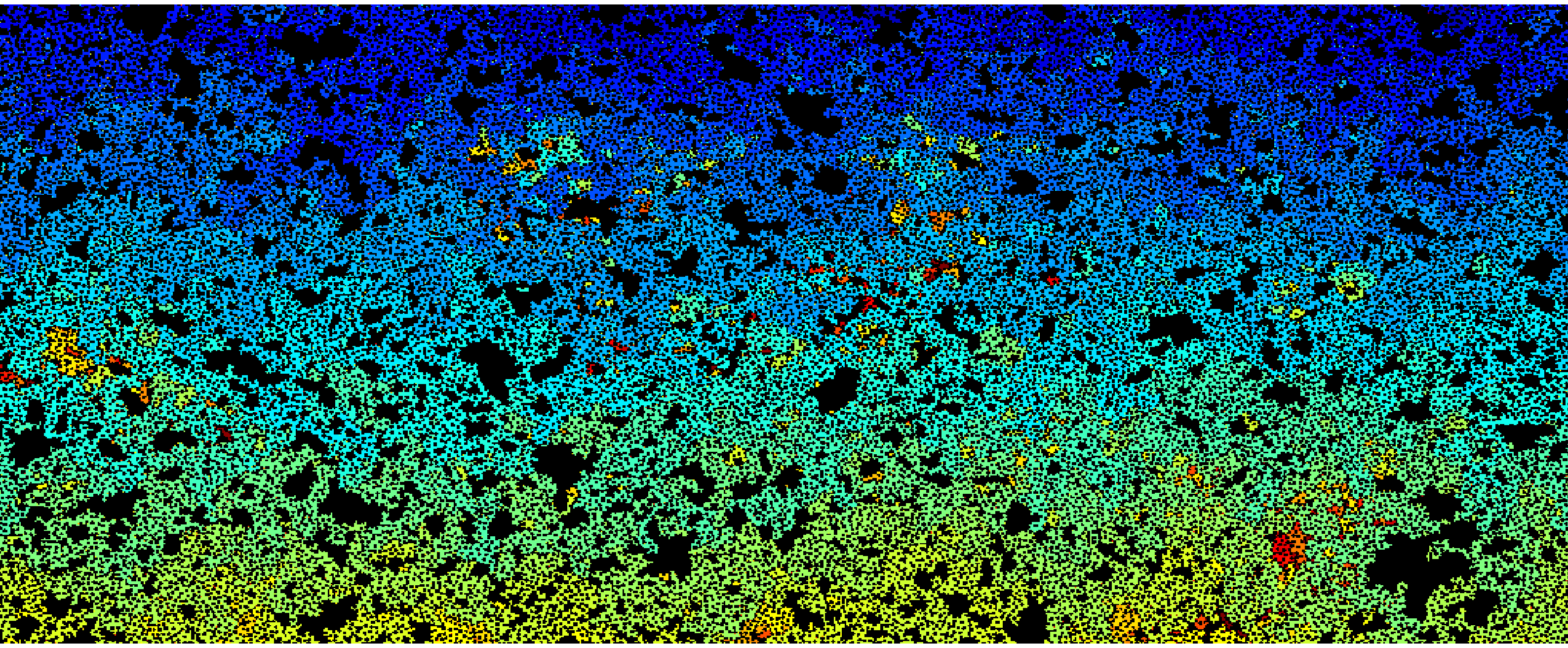
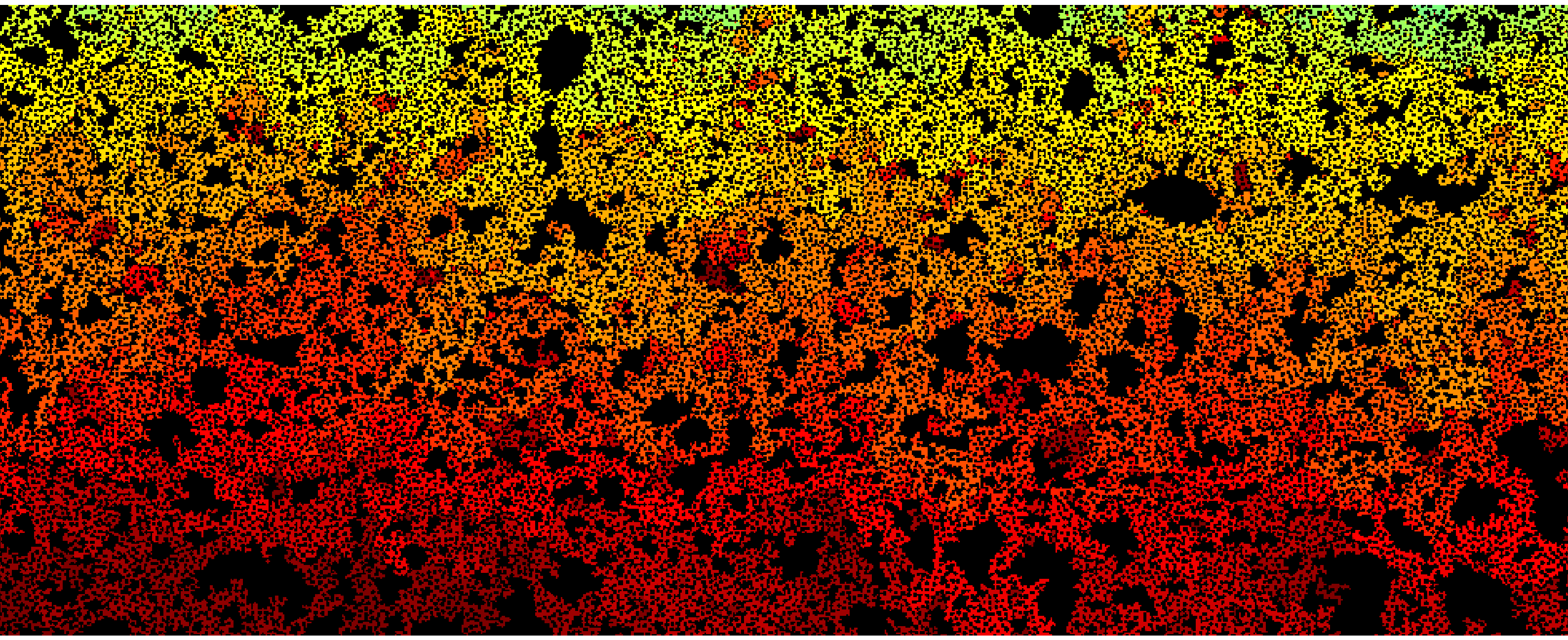
PoreLab
NTNU-UiO Porous Media Laboratory

Norwegian Centre of Excellence
The Research Council of Norway



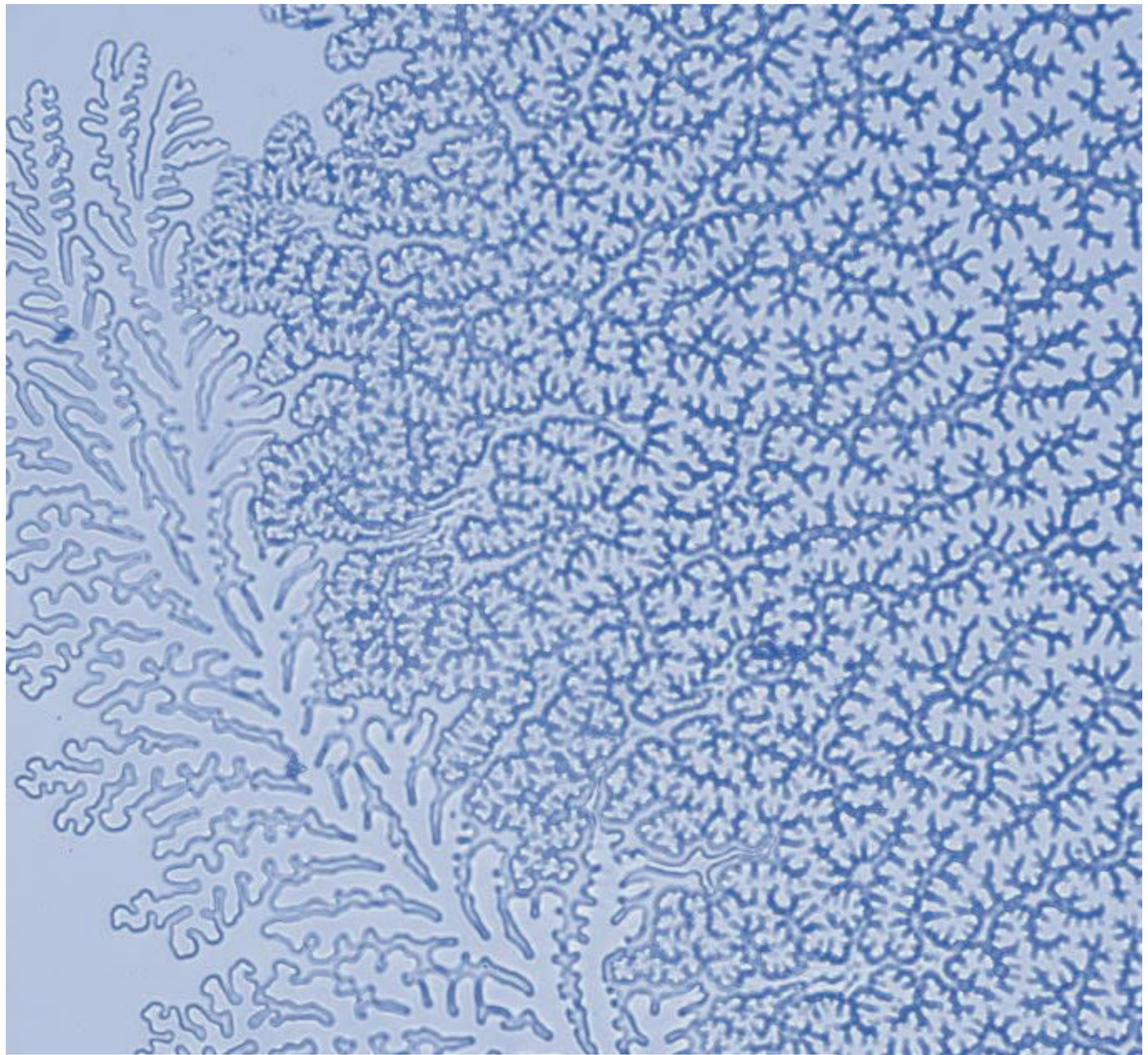
MSc at PoreLab 2019

Opportunities in 2020



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 recently established cross-disciplinary geoscience-physics center.

Table of Contents

Cover page: Slow drainage experiment in a gravitational field. The color code denotes the time for a given pore to be invaded, ranging from blue (early invasion events) to red (late invasion events). Picture by Marcel Moura

OVERVIEW – 2019 MSC STUDENTS

NAME	TITLE MASTER THESIS	SUPERVISORS
Stig-Martin Liavåg	Modeling nanoparticle transport in a pore network model	Ruth Catharina de Lange Davies, Magnus Aa. Gjennestad and Signe Kjelstrup
Simon Birger Byremo Solberg	Energy-efficient designs of systems: From nature to industry	Signe Kjelstrup and Elisa Magnanelli
Salem Akarri	Pore-scale investigation of the impact of silica-based nanofluid on residual oil	Ole Torsæter
Christina Rong Anfinsen	Identification of two-phase flow regimes	Carl Fredrik Berg
Patience Ankah	Experimental study of porosity, permeability and wettability and the effect of mineralogy on these properties	Ole Torsæter
Muhammad Iffan Hannanu	Lattice Boltzmann modeling for two-phase flow in a microfluidic chip with realistic pore structure	Carl Fredrik Berg and Thomas Ramstad
Marie B. Løvereide And Ilgar Azizov	Low-salinity EOR in carbonates	Carl Fredrik Berg and Ole Torsæter
Mohamed A. F. A. Omran	Experimental investigation on oil recovery from water flood and polymer-coated silica nanoparticles base nanofluids using the same pore structure	Ole Torsæter
Beatrice Baldelli	Simulations and means of characterization of gravity-stabilized flow on a self-affine surface	Eirik Grude Flekkøy and Knut Jørgen Måløy
Hilmar Yngvi Birgisson	Density driven CO_2 advection diffusion	Knut Jørgen Måløy and Eirik Grude Flekkøy
Joachim Falck Brodin	A new vision for 3D experiments on flow in porous media	Knut Jørgen Måløy and Marcel Moura
Ivar Svalheim Haugerud	Symmetry and reversibility in hydrodynamic dispersion	Eirik Grude Flekkøy, Knut Jørgen Måløy and Gaute Linga
Cristian Camilo Garcia Castaño	Micromodel investigation of spontaneous emulsification in low salinity water flooding	Ole Torsæter
Giulio Fossati	Computing coupling coefficient effects in a proton exchange membrane fuel cell using non-equilibrium thermodynamics	Signe Kjelstrup and Andrea Casalegno
Francis Mujica	A digital investigation into the impact of diagenesis above and below the oil-water contact	Lesley A. James, Carl Fredrik Berg, Derek Wilton
Mao Qiangqiang	Relationship between grain packing and single phase transport properties	Carl Fredrik Berg
Edgar Javier Rueda Rueda	A pore-scale study to evaluate the efficiency of nanoparticle-assisted polymer flooding	Ole Torsæter and Rosângela Barros Zanoni Lopes Moreno

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 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 2019 and inspire new students to join the team. We show as well that

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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.

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 Journal Club and the PoreLab lecture series. We host both types of events simultaneously in Oslo and Trondheim, and they are open to all. The PoreLab Journal Club meets every week to discuss scientific literature, where a PoreLab member chooses and presents either brand new or classical papers. The presented papers are then peer-reviewed by the group, and the junior members can experience the review process. In the lecture series, our own and visiting researchers give talks on a weekly basis. They present their work, share their ideas and get feedbacks from the audience

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. Srutarshi Pradhan, researcher at the Physics department, NTNU, provides a good summary: "*It is easy to meet seniors and discuss and express our doubts, in scientific matters or in any other issues. This has even been encouraged and assured by our senior members*", before adding: "*The wishes and constant efforts by the directors and the PIs have created a healthy and warm research atmosphere, with a family feeling among the group members*".

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 postdoctoral fellow, 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 recently became one of the most popular playgrounds for all at PoreLab NTNU.


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A glimpse of students' activities at PoreLab: 1. Pore Buzz in October 2019, a gathering for the juniors with the hottest research topics and pizza. 2. Srutarshi, Hossein, Giulio and Michael take a break. 3. PoreLab Journal Club: Is this paper any good? 4. Jonas, Louison, Kristian and Beatrice playing Pictionary

Stig-Martin Liavåg

Department of Physics, NTNU

Modeling nanoparticle transport in a pore network model

Spring 2019
Supervisors: Ruth Catharina de Lange Davies, Magnus Aashammer Gjennestad and Signe Kjelstrup

Background

A major problem in chemotherapy treatment of cancer is the low tumor uptake of therapeutic drugs. A promising strategy for enhancing the accumulation of drugs into tumors is the combination of focused ultrasound and gas filled microbubbles, which facilitates the transport of nanoparticles in tissue and improves the delivery of therapeutic molecules. Successful delivery of the drugs depends on many variables related to the pathology, structure and composition of the diseased tissue, the various ultrasound exposure parameters and physico-chemical properties of the drug carrier. Not all mechanisms of the transport behavior are well understood, and mathematical modeling and computer simulations can assist in the understanding and evaluation of such complex systems.

The aim of the thesis is to investigate how properties of the tissue and ultrasound parameters affect transport of the nanoparticles in tissue. By approximating the tumor tissue as a porous medium, a 2D pore network model has been set up to model fluid flow between a matrix of cells and how particles, subjected to advection and diffusion, move within the network. Preliminary results from these simulations can be used to gain a further understanding of the transport mechanics, which is a small step in the improvement of cancer therapy.

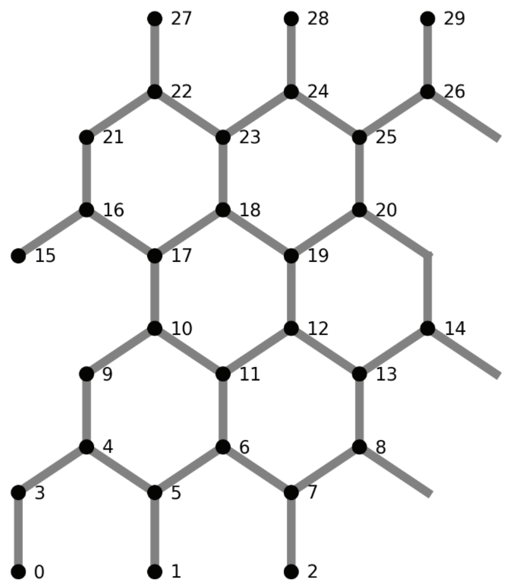


Figure 1: Illustration of a small pore network

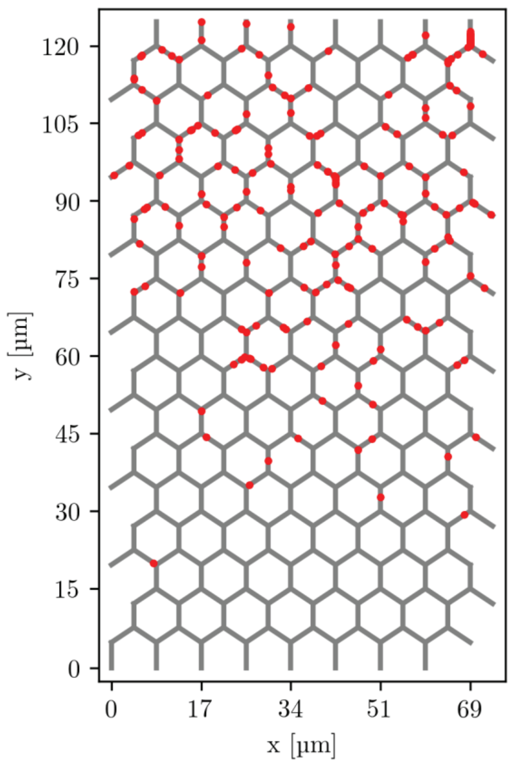
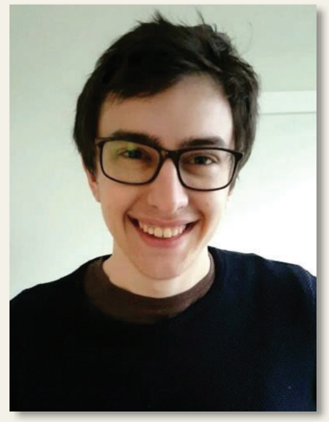


Figure 2: Nanoparticles situated in the network after a given time

Simon Birger Byremo Solberg

Department of Chemistry, NTNU



Energy-Efficient Designs of Systems: From Nature To Industry

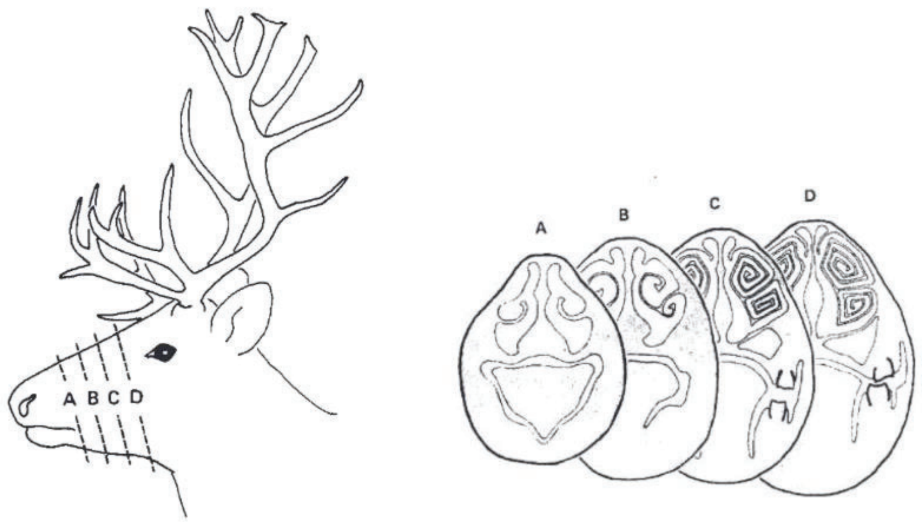
Spring 2019
Supervisors: Signe Kjelstrup and Elisa Magnanelli

Animals native to arctic regions show remarkable adaptations to the cold climate. An especially interesting feature is how their nasal anatomies have evolved, seemingly for better control of thermodynamic driving forces during respiration. The thesis aims to simulate respiration for a physically mature reindeer and for a calf, to evaluate the importance of their nasal geometries and quantify the entropy production (EP). The effect of different physiological parameters is also studied. The nasal geometry serves as inspiration for the idea of optimizing the geometry of a plug-flow reactor. For this, optimal control theory is used in order to find a diameter profile for the reactor which reduces the EP.

Results suggest that at low ambient temperatures, the nasal geometry gives the physically mature individual an advantage in terms of EP over a reference nose with a simple cylindrical shape. This is not the case for the reindeer calf at low ambient temperatures. It appears energy-efficient respiration from birth is not crucial for the survival of the calf. For the chemical reactor it is possible to construct a diameter profile which reduces the EP by up to 16%, however the reactor size may not be practical. Other cross-section geometries should be investigated in future works.

Overall, the different geometries in this thesis provide new results. They will lead to journal publications in physiology and chemical engineering.

Figure shows cross-sections of a reindeer's nose at four depth levels [1].



[1] H. K. Johnsen, Nasal heat exchange: An experimental study of effector mechanisms associated with respiratory heat loss in Norwegian reindeer (Rangifer tarandus tarandus), (1988)

Salem Akarri

Department of Geoscience and Petroleum, NTNU

Pore-Scale Investigation of the Impact of Silica-Based Nanofluid on Residual Oil

Spring 2019
Supervisor: Ole Torsæter

Background

The employment of X-ray computed microtomography has been an excellent 3D imaging technique to explore subsurface multiphase flow and trapping at pore-scale, which is important for petroleum-engineering processes [1]. Nanotechnology applications have received significant attention in the oil industry, particularly, because of its significant potential for enhanced oil recovery as a new method [2].

Objective

This study evaluated the effect of a Silica-based nanofluid on the remaining oil saturation at pore-scale employing X-ray microtomography. It investigated the connectivity of the residual oil phase after nanofluid flooding under different capillary numbers.

Experimental approach

A core-flooding setup integrated with a micro-CT scanner was used to perform the experiments in this study. Five miniature samples were drilled from a Bentheimer sandstone plug. Crude oil from Heidrun field was used for the primary drainage, as the non-wetting phase. A nanofluid (7 wt.% cesium chloride (CsCl) + 0.1 wt.% nanosilica) was injected to recover the oil.

Results

The silica nanoparticles effectively reduced the trapping efficiency, internal connectivity, and size of the remaining oil clusters.

Recommended reading

[1] Herring, A.L., et al., *Effect of fluid topology on residual nonwetting phase trapping: Implications for geologic CO2 sequestration.* Advances in Water Resources, 2013. **62**: p. 47-58

[2] Cheraghian, G. and L. Hendraningrat, A review on applications of nanotechnology in the enhanced oil recovery part B: effects of nanoparticles on flooding. International Nano Letters, 2016. 6(1): p. 1-10

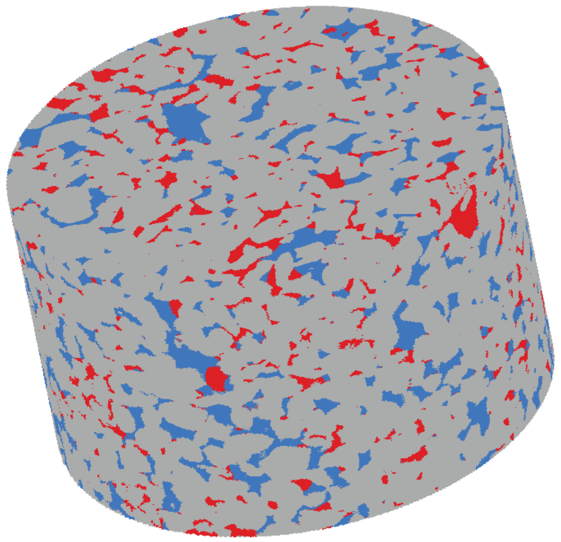


Figure: *Segmented 3-dimensional micro-CT image (grain: gray, oil: red, and brine: blue).*

Christina Rong Anfinsen

Department of Geoscience and Petroleum, NTNU

Identification of Two-Phase Flow Regimes

Spring 2019
Supervisor: Carl Fredrik Berg

Background

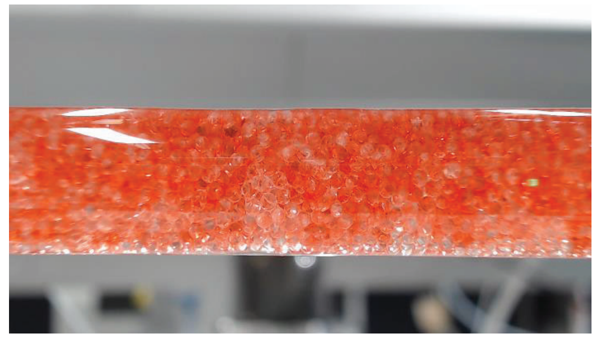
Up until today the vast majority of work on immiscible multiphase fluid flow in porous media has focused on invasion processes, while the steady state case has received far less attention.

There is very little pore scale experimental data available for steady state problems. Despite the importance of multiphase flow in porous media, fundamental questions about the underlying mechanism of multiphase fluid flow in porous media are still not adequately understood.

Objective

This thesis is an experimental study of two phase steady state flow in a porous medium. The objective is to find the relationship between the volumetric flow rate and the corresponding pressure drop. This is done by pumping oil and water simultaneously through a tube filled with glass beads, and measuring the corresponding steady state pressure drop.

The main focus of this thesis is on the scaling relationship between flow rate and pressure drop for very low flow rates, where we hope to identify a lower flow regime and investigate how capillary forces impact this regime.



Picture*: Glass bead pack flooded with oil and water*

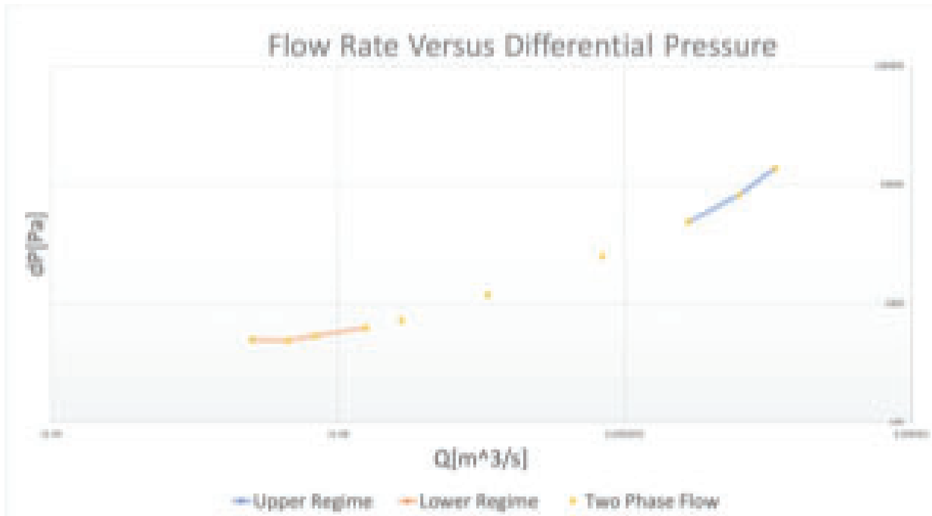


Figure*: Plot of results indicating two different flow regimes.*

Patience Ankah

Department of Geoscience and Petroleum, NTNU

Experimental study of Porosity, Permeability and Wettability and the Effect of mineralogy on these Properties

Spring 2019
Supervisor: Ole Torsæter

Background
Prediction of porosity and permeability is very important in the reservoir quality analysis in the oil and gas industry. In addition, the preferential tendency of one fluid in the presence of another to adhere to a solid surface is of great interest. The mineral composition, packing of the grains, grain size and grain size distribution affect the storage capacity of the rock (porosity), transport capacity (permeability) and the relative flow of one fluid in a multiphase system (relative permeability). The relative permeability is dependent on the wettability of the rock.

Objective
The main objective of the experimental work is to determine the wettability of different core samples using the combined Amott/USBM test. Standard microscopy and Scanning Electron Microscope (SEM) studies were performed to determine the various mineral compositions and their influence on the reservoir parameters.

Methodology
Evaluation of porosity, permeability, lithology and texture as well as wettability is information derived from routine/conventional and special core analysis. Porosity is calculated using Helium Porosimeter, permeability is measured from Constant Head Permeameter and combined Amott/USBM test was used for the wettability investigation. The identification of minerals in the rock samples were done by observing images of thin sections viewed under a polarizing microscope. By studying the samples under SEM detailed information about the unknown samples was obtained. Backscattered electron images (BEI) in combination with Energy Dispersive Spectrometer (EDS) were used to calculate the elemental composition and identification of the minerals.

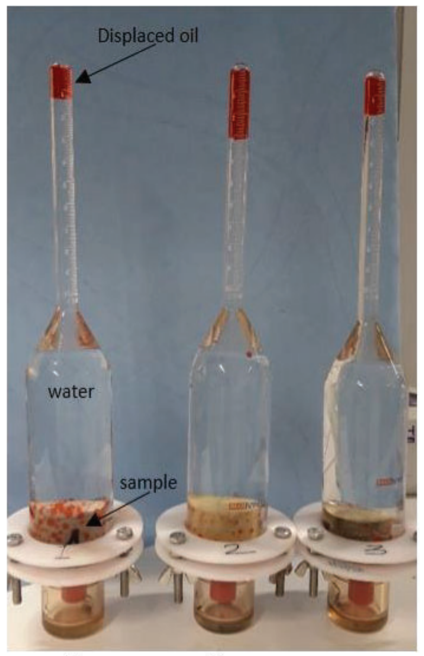
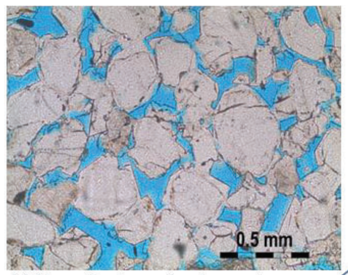
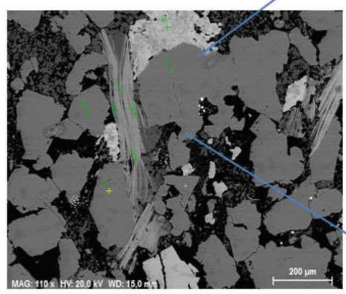


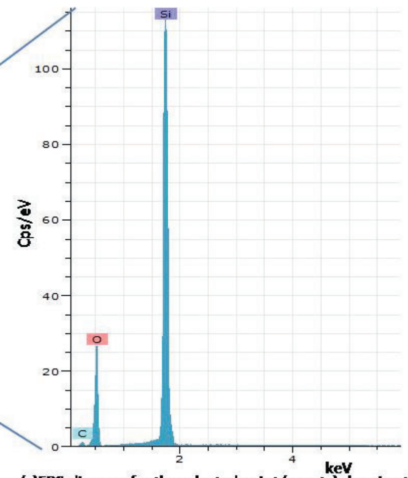
Figure showing Amott Cell: Spontaneous imbibition process.



(a)Thin section image showing quartz minerals.

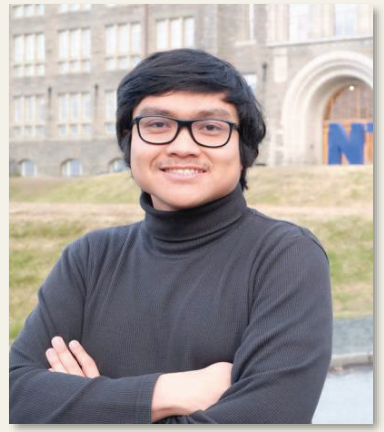


(b)BE-image of a sample



(c)EDS-diagram for the selected point (quartz) showing the elemental composition.

Muhammad Iffan Hannanu



Department of Geoscience and Petroleum, NTNU

Lattice Boltzmann Modeling for two-phase Flow in a Microfluidic Chip with Realistic Pore Structure

Spring 2019
Supervisor: Carl Fredrik Berg and Thomas Ramstad

Background

Nowadays, high-resolution image of a pore structure and high-performance computing become more available. Therefore, pore-scale simulation is emerging as a powerful tool to predict the flow properties in a porous media. In this thesis, Lattice Boltzmann Modeling (LBM) is used as the tool to model primary drainage and imbibition in a pore structure extracted from a microfluidic chip.

Methodology

For our simulation we are using the open-source software LBPM. The software uses D3Q19 lattice system and boundary conditions as described by McClure et.al (2018). The method is extended with colour gradient method to model immiscible two-phase flow. We are interested in seeing the first-order effect of the LBM parameters to the fluid distribution and flow properties, and how they are correlated with experimental studies.

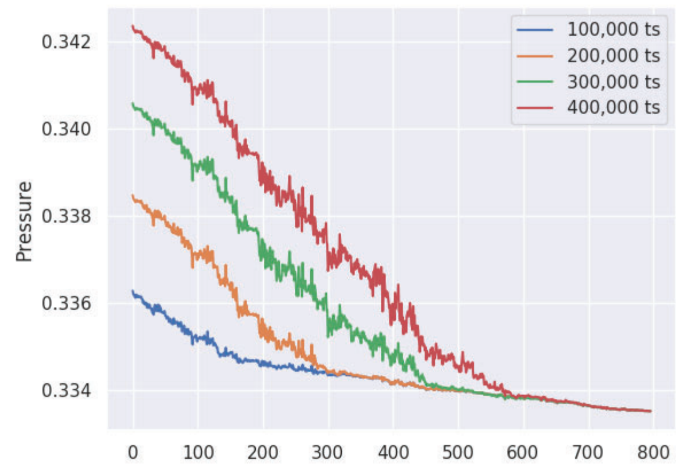


Figure 1. Average pressure at different time steps along the micromodel simulated using LBM

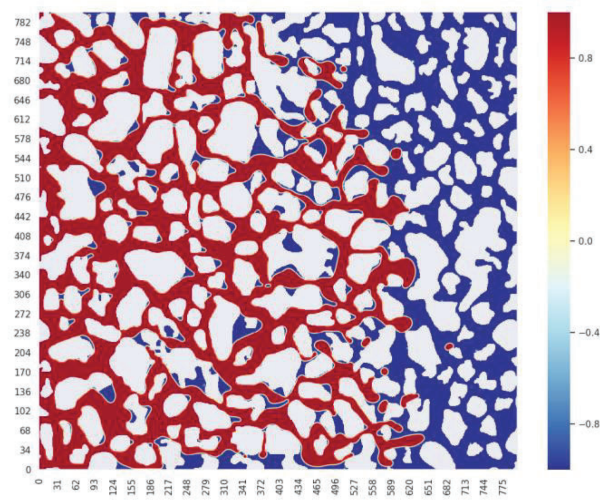


Figure 2. A snapshot of fluid distribution in a micromodel simulated using LBM

Marie B. Løvereide
Ilgar Azizov


Department of Geoscience and Petroleum, NTNU

Low-salinity EOR in Carbonates

Spring 2019
Supervisor: Carl Fredrik Berg and Ole Torsæter

Background

Around 60 % of the proved remaining global oil reserves are found in carbonate reservoirs. Carbonate fields are typically mixed/oil-wet, which can lead to reduced oil recovery. Recent studies indicate that wettability of carbonate rock can be altered to more water wet by tuning composition and/or reducing salinity of the injected brine. Therefore, injection of engineered brine (Low-Salinity EOR) has the potential of increasing recovery in carbonate fields. However, the underlying mechanism of Low-Salinity EOR is not well understood and its effect on specific reservoirs cannot be predicted without performing experiments in core scale.

The spontaneous imbibition (SI) is the most commonly used method for Low-Salinity EOR study on a core scale. The method allows to test several imbibing fluids on a core plug sequentially. However, experimental protocol used in recent papers involve potentially compromising core handling and might affect the results, e.g. a core plug is removed from a SI cell to replace the imbibing fluid.

Objective and methodology

The first objective of the thesis is to minimize influence of core handling on the results of SI experiments. In an effort to achieve this, a new setup for experiments at high temperatures has been designed. The setup allows to replace imbibing fluid in the SI cell without interruption of the experiment and keep a core plug under the same condition throughout the test.

The second objective of the thesis is to provide recommendation for Low-Salinity EOR for a field in Brazil, operated by Equinor. Within the scope of the task, a literature review on the wettability alteration mechanism in carbonates was performed. Based on the obtained knowledge, several wettability modifying brines were proposed for the SI test. The designed setup will be used to test these brines using outcrop rock material representing the reservoir

Mohamed A. F. A. Omran

Department of Geoscience and Petroleum, NTNU

Experimental Investigation on oil recovery from water flood and polymer-coated silica nanoparticles base nanofluids using the same pore structure

Fall 2019/Spring 2020
Supervisor: Ole Torsæter

NTNU - Department of Geoscience and Petroleum

Background

Polymer-coated silica nanoparticles (PSiNP) have been proposed for enhanced oil recovery (EOR) owing to their improved properties (stability, stabilization of emulsion, low retention on porous media, etc.) over bare nanoparticles. The underlying oil recovery mechanism of nanoparticles are not well understood. Under some circumstances, EOR fluids can be applied as secondary recovery agents. The ultimate recovery factor must be better than for traditional water flooding to ensure economic attractiveness of secondary EOR fluids.

Objective

This research unleashes the potential application of four types of PSiNPs for EOR in water-wet Berea sandstone reservoirs. The PSiNPs were mixed with synthetic seawater at 0.1 wt % concentration. The nanofluid oil recoveries were then compared with traditional water flood obtained with similar core pore structures.

Experimental approach

For this purpose, the following experiments were performed: First, four water flood tests were carried out until there was no oil production. Then, the cores were cleaned and dried. Second, each core was injected with designed nanofluid type in secondary recovery mode. To investigate the conservation of the pore structure after water flood process, porosity and permeability were measured. Supplementary studies of interfacial tension contact angle and an analysis of differential pressure across the cores were performed to reveal possible recovery mechanisms of PSiNPs.

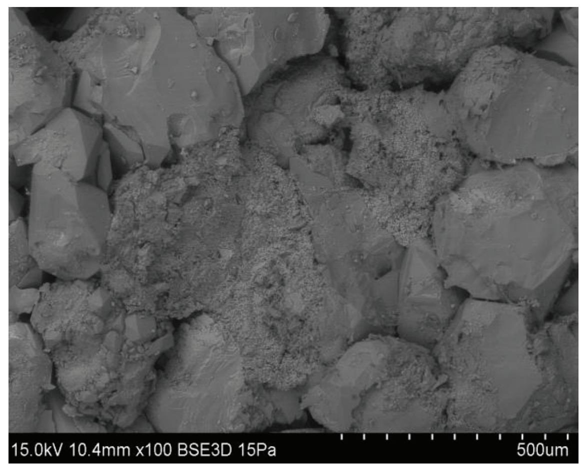
***Picture**: SEM image of nanoparticles →*

Results

The experimental results showed that oil recovery is increased with PSiNP based nanofluids. The nanofluids increased oil recovery by 14.1 % points compared with water flood. That is from 52.2% to 66.3% of water flood. Interfacial tension decreased with added PSiNPs from 10.6 to 4.12 mN/m. The contact angle 55 to 22 degrees. Emulsions were generated with increasing flowrate. Differential pressure increased with nanofluid injection, indicating a significant contribution of log-jamming effect on oil recovery.

Recommended reading

- Bera, A., & Belhaj, H. (2016). Application of nanotechnology by means of nanoparticles and nanodispersions in oil recovery - A comprehensive review. *Journal of Natural Gas Science and Engineering*, *34* , 1284–1309.
- Li, S., & Torsaeter,O. (2013). IOR by hydrophilic Silica Nanoparticles suspension: 2-phase flow experimental study. Paper IPTC 16707 presented at the IPTC held in Beijing, China, 26-28 March 2013.



Beatrice Baldelli

Department of Physics, University of Oslo

Simulations and means of characterization of Gravity-stabilized flow on a self-affine surface

Spring 2019
Supervisors: Eirik Grude Flekkøy and Knut Jørgen Måløy

UiO - Department of Physics

Background

Many naturally occurring surfaces on the planet, from landscapes such as mountain ranges and flatlands to underground fractures, are self-affine surfaces. Studies have been conducted on the flow of fluids over such surfaces. In particular, the flow of heavier (due to lower temperature or the presence of solute) fluid injected in a system initially filled with lighter fluid, has been examined.

The aim of this project is to simulate the inverse process, lighter fluid being introduced in a system filled with heavier fluid, and explore the effect of gravity, which traps the heavier fluid in the valleys of the self-affine surface. A code is developed, implementing the coupled Lattice Boltzmann Method, to simulate such a system.

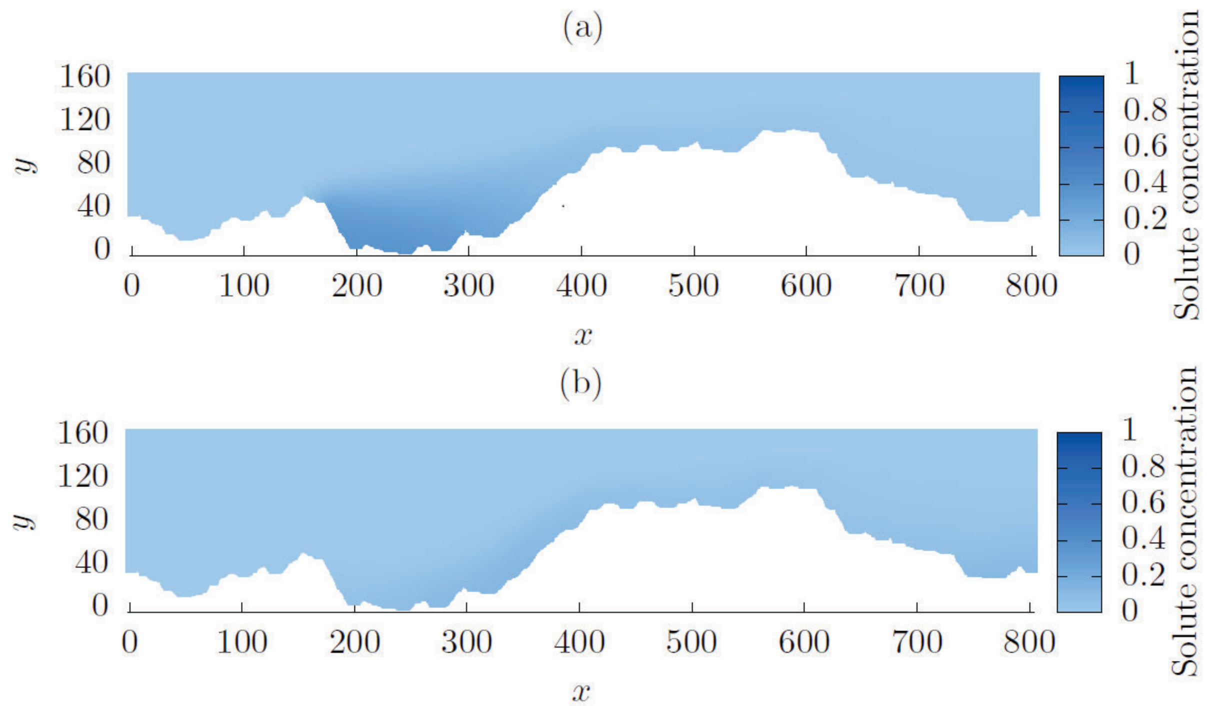


Figure: When gravity is switched on (a), the solute is held in the valleys for much longer than when gravity is absent (b).

Hilmar Yngvi Birgisson

Department of Physics, University of Oslo

Density driven CO_2 Advection Diffusion

Fall 2019 / Spring 2020
Supervisors: Knut Jørgen Måløy and Eirik Grude Flekkøy

Background

In general, advection diffusion is a highly complicated mechanism, where a dissolved species is transported both due to the solvent fluid flow and diffusion due to some concentration gradient. This thesis aims to investigate this mechanism in experimentally realized CO_2 porous media aquifers.

When gaseous CO_2 is introduced above the liquid surface, it will start to diffuse into the water and form carbonic acid. This increases the density of the liquid, and the densest liquid regions will start to sink due to gravity. These sinking regions, called plumes then forces new low-density water back up to the surface where it can absorb even more CO_2.

This effect greatly increases the rate of CO_2 dissolution compared to normal diffusion. Due to the plume dynamics, the density driven advection diffusion causes a fingering pattern, which can be realized experimentally and analyzed.

Understanding the dynamics of CO_2 advection diffusion is of great importance especially to environmental and geophysical applications. CO_2 aquifers have already been proposed as a possible candidate for long term carbon storage, so understanding their dynamics is highly relevant to today's climate battle.

UiO - Department of Physics

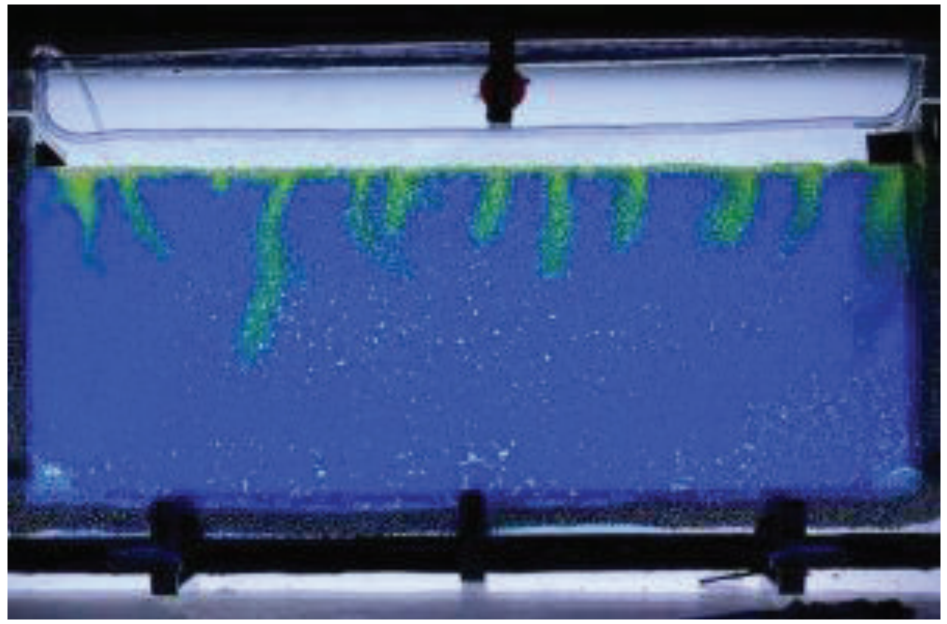


Photo: layer of CO_2 above a water-saturated porous medium consisting of glass beads (PoreLab UiO)

Joachim Falck Brodin

Department of Physics, University of Oslo

A new Vision for 3D Experiments on Flow in Porous Media

Spring 2019
Supervisors: Knut Jørgen Måløy and Marcel Moura

Background

The thesis concerns experimental work in the context of flow in porous media, a multi-disciplinary field coupling such topics as fluid dynamics, emergence, statistical mechanics and percolation theory. For reasons of both theoretical and practical appeal, the bulk of the studies in this field have been done on two-dimensional systems. Although this is deemed far from exhausted as an approach, the accumulated insight urges confrontation with the impact of scaling up to three dimensions.
The development of a fully functioning 3D-optical-scanner for experiments on flow in porous media is detailed. The image processing, segmentation-, visual rendering- and data analysis-protocols are also presented, with high-resolution images and qualitative and quantitative system assessments. The thesis also offers a very promising trial experiment, producing novel results that are comparable, both with studies conducted in 2D and 3D, as well as the theoretical framework. Invasion in the direction of gravitational acceleration, of a denser more viscous fluid, into a synthetic porous medium, displacing a less dense, less viscous fluid, displays dynamic behavior ranging from unstable displacement and fingering, for slow injection rates, to stable displacement and a narrow front, for high flow rates. Calculated fractal dimensions and dimensionless scaling numbers, put these results into an established framework, with links to experimental studies and values derived from simulations with invasion percolation- and diffusion-limited aggregation- algorithms.

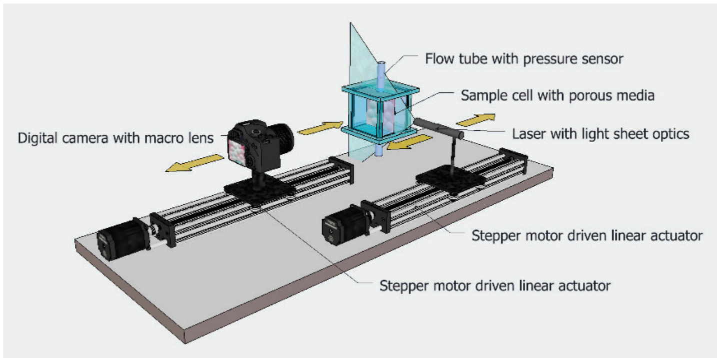


***Figure**: 3D set-up*

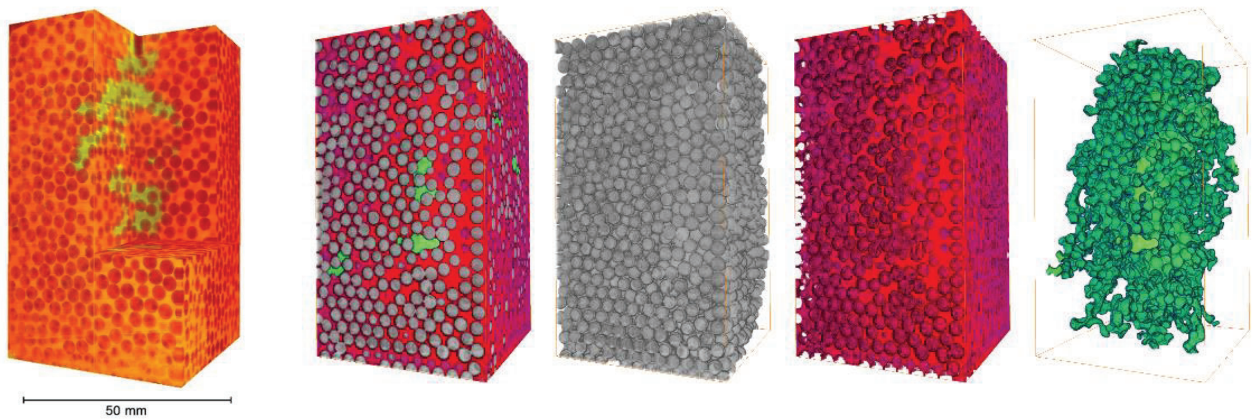
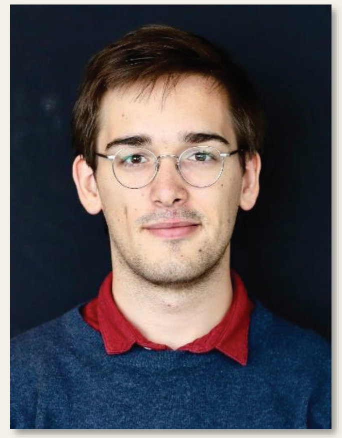


***Figure**: Results from the two-phase flow 3D scanner experiment. The bead packing (3 mm glass beads) is shown in grey. The pore fluids, canola oil (red) and glycerol (green), are shown in the two panes on the right. The experimental results show that the optical technique can clearly distinguish the porous media and pore fluids in a 3-dimensional flow cell.*

Ivar Svalheim Haugerud



Department of Physics, University of Oslo

Symmetry and Reversibility in Hydrodynamic Dispersion

Fall 2020/Spring 2021
Supervisors: Eirik Grude Flekkøy, Knut Jørgen Måløy and Gaute Linga

Background

Hydrodynamic dispersion is the irreversible spreading of a passive tracer by the combined effect of advection and diffusion. Low Reynolds numbers allows for reversible velocity fields, which combined with diffusion makes it possible to introduce a notion of reversibility for the movement of the diffusing particles in the fluid flow. The concentration measured at one point in the flow in response to a concentration pulse at another point will be the same if the two points are interchanged while simultaneously reversing the direction of the velocity field. This reversibility takes the form of a reciprocity relation and holds true regardless of the magnitude of molecular diffusion.

The reciprocity relation technique may have interesting medical, biological and industrial applications, as it allows for prediction and placement of a tracer inside an otherwise inaccessible region.
In medicine this can be the placement of a medical preparation within some tissue of the body. For example, within the lymph system, or any closed cavity where a slow elastic expansion and contraction would drive a reversible flow.

The conditions, limitations and applications of the reciprocity relation will be investigated analytically and numerically. Analytically the advection–diffusion equation will be studied, and numerically the Lattice-Boltzmann algorithm will be used.

Cristian Camilo Garcia Castaño

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In collaboration with the department of Geoscience and Petroleum, NTNU

Micromodel Investigation of Spontaneous Emulsification In Low Salinity Water Flooding

Fall 2019
Supervisors: Ole Torsæter

Background

The injection of low-salinity water (LSW) has been found to enhance oil recovery compared to high-salinity water injection. One of the mechanisms during LSW injection is emulsification.

Forced or spontaneous imbibition of low salinity brine introduces an osmotic pressure imbalance between the initial and the imbibed aqueous phases that are separated by the oil phase. The salinity/concentration gradient drives water into the oil phase. The transport of water through the oil phase at the pore level in the presence of a salinity gradient was previously demonstrated experimentally with respect to oil swelling, mobilization and emulsification (Fredriksen et al.)

Objective

The objectives of the experiment were to examine the conditions under which emulsions form and the frequency of emulsion in the oil phase. In this experiment, low salinity fluid was NaCl + water (500 ppm) in order to observe the impact of very low salinity. The low salinity water was injected in a low flow rate to avoid emulsion formation by shearing.

Experimental approach

Pore-scale visualization of spontaneous emulsification was achieved using a two-dimensional microfluidic device replicating the pore network structure found in sandstone. Micromodels imitate many aspects of pore structure of real porous media in order to allow direct visualization of single and multiphase flows at the pore scale. The experimental apparatus is shown in Figure 1. A microfluidics setup integrated with high resolution camera was used to accomplish the experiments. Four experiments were carried out using two types of salts, NaCl (30000ppm and 500ppm) and CaCl (500 ppm and 2000ppm) that were injected at $(50\ \frac{\mu l}{min})$ to recover the oil and then the LSW were injected at low rate.

Results

Figure 2 shows our pore-scale visualization experiments. It displayed water-in-oil emulsions that formed once the crude oil and the LSW brine came into contact. The dynamics of emulsification are rapid and difficult to capture in our experimental setup. It was also observed that regions not contacted by injection brine do not exhibit any emulsions. Clearly in the pictures the formation of micro-dispersion in the oil phase can be observed.

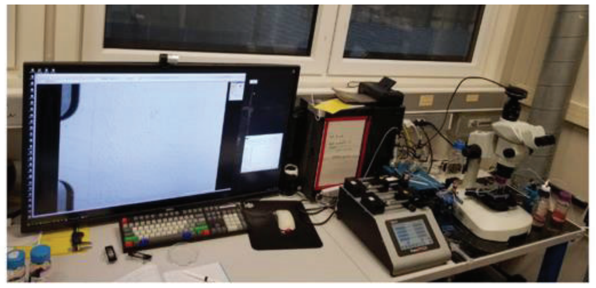

Figure 1: Micromodel apparatus used for this experiment

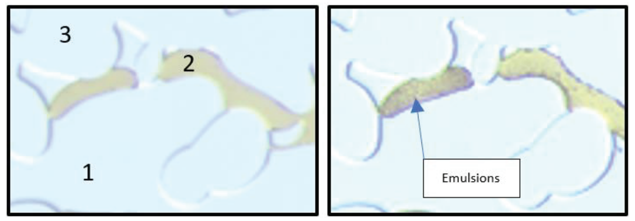

Figure 2: Micromodel experiments of Low salinity injection (Left picture shows the water (1), oil (2) and solid (3); the right picture illustrates the generated reverse water-in-oil emulsions by black spots in the oil phase)

Recommended reading

Fredriksen, Sunniva B., et al. "Pore-Scale Mechanisms During Low Salinity Waterflooding: Water Diffusion and Osmosis for Oil Mobilization." *SPE Bergen One Day Seminar*, Society of Petroleum Engineers, 2016, doi:10.2118/180060-MS

Giulio Fossati

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Computing coupling coefficient effects in a proton exchange membrane fuel cell using non-equilibrium thermodynamics

Spring 2019
Supervisors: Signe Kjelstrup and Andrea Casalegno

Background

Fuel cells are a promising technology to heal the problem of intermittent offer of energy, typical for renewable sources. Despite many years of development there are still crucial issues regarding degradation of the materials and dissipation of heat, heavily affecting the efficiency. Non-equilibrium Thermodynamics can be a powerful tool to predict the performance of the fuel cell, thus helping for the latter problem.

Goals

The first step of the project is to develop a numerical model of the Proton Exchange Membrane Fuel Cell, derived from Non-Equilibrium Thermodynamics theory. This will provide the profiles of temperature, electrical potential and concentration of chemical species along the distinct parts of the cell.

This model is then computed under different working conditions, to study the trend of the profiles, especially varying thermal load, aiming to minimize dissipation.

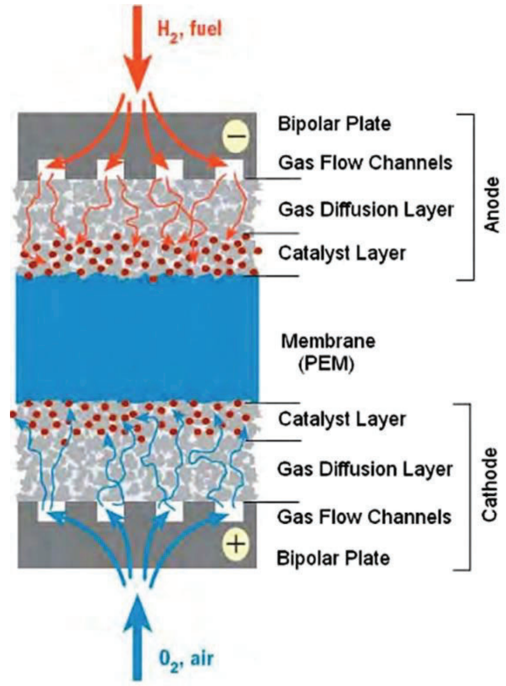

*Figure 1: Schematic of PEMFC (*Kahraman H., Orhan M.F. *Flow field bipolar plates in a proton exchange membrane fuel cell: Analysis & modeling.* Energy Conversion and Management 133 (2017) 363–384*)*

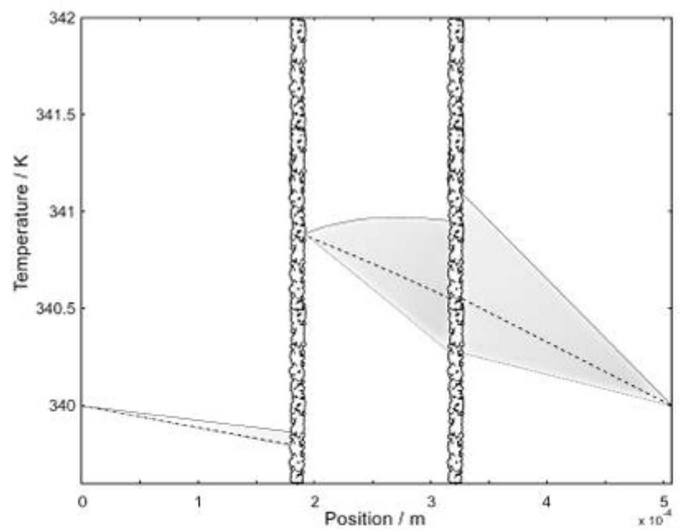

Figure 2: Temperature profile of the PEMFC with different current density (Kjelstrup S., Bedeaux D. *Non-Equilibrium Thermodynamics of Heterogeneous Systems*, World Scientific Publishing Co, 2008)

Francis Mujica

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In collaboration with the department of Geoscience and Petroleum, NTNU

A digital investigation into the impact of diagenesis above and below the oil-water contact

Spring 2019
Supervisors: Lesley A. James, Carl Fredrik Berg, Derek Wilton

Background

The Ben Nevis formation in the Hebron field is the newest producing reservoir offshore Newfoundland, Canada. It has a very distinctive Oil-water contact (OWC) that has been cored and preserved. The abrupt OWC and the rock similarities provide an excellent opportunity to evaluate possible differences caused by the oil emplacement.

Objective

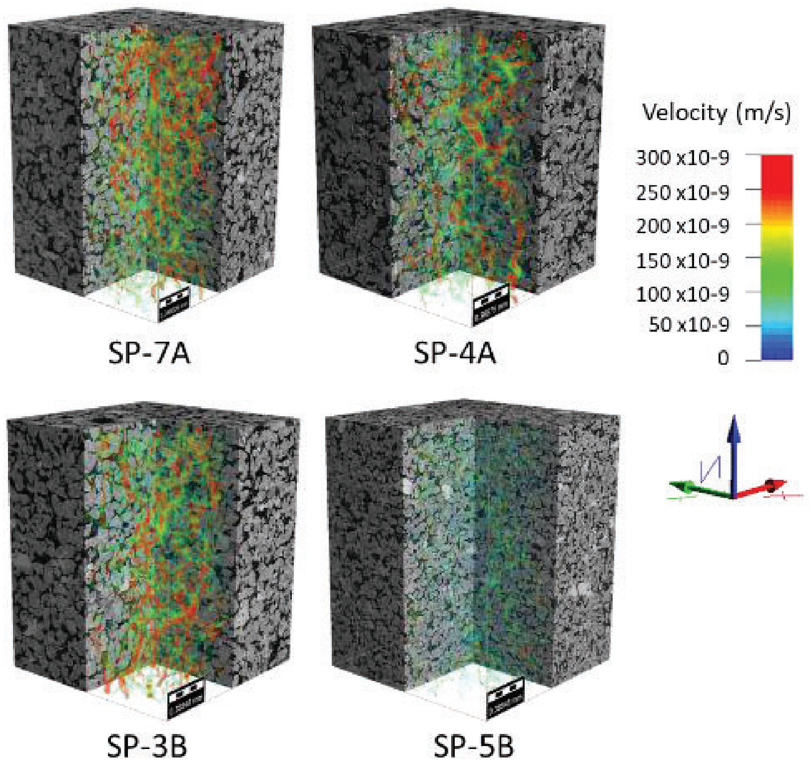
Quartz cementation was found to be more abundant in the water zone. The purpose of this project is to investigate and compare the transport properties of water and oil-bearing rocks using digital rock analysis.

We created a 3D representation of the rock based on μ-CT scans, images reconstruction, and segmentation. On the segmented volumes, we simulated mercury injection by a quasi-static morphological method, electrical conductivity by solving the Laplace equation, and single-phase flow by solving the Stokes equation.

Results

The results obtained are in good agreement with the expected values, even though the diagenetic differences apparently have only a small influence on pore structure and transport properties in the study area.

Figure: Flow velocity for absolute permeability estimation



Mao Qiangqiang

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Relationship between grain packing and Single Phase Transport Properties

Spring 2019
Supervisor: Carl Fredrik Berg

Background

It has long been recognized that grain size as well as grain size distribution exerts significant effect on porosity and permeability. Hence, a considerable amount of scientific work has been conducted focusing on qualifying and even quantifying such relationships.

The porosity appears to be independent of grain size, and only a function of the grain size distribution (sorting coefficient). The permeability is on the other hand highly dependent on grain size.

Objective

In this project we have created a Python script to simulate a two-dimensional grain packing process. The sedimentation process is purely geometrical based. Further, we have analyzed a high number of simulated grain packs to investigate the relationship between grain size distribution and porosity. Our results indicate that larger standard deviation leads to higher porosity, as smaller spheres are unable to pack closely around the larger spheres.

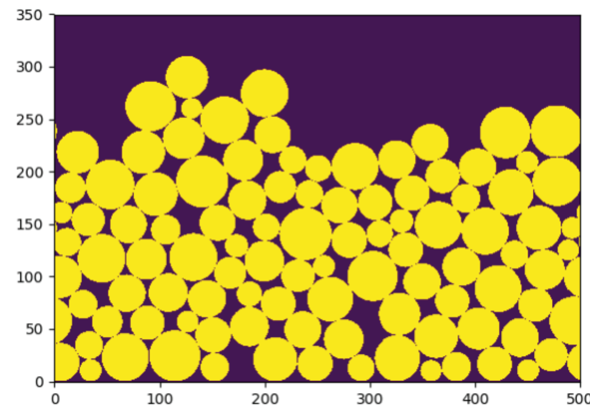
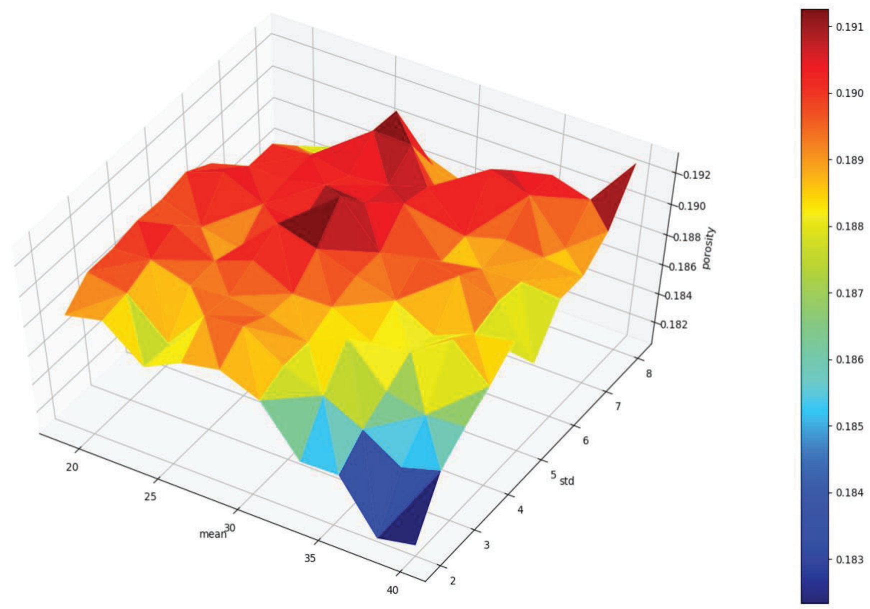


Figure 1: *A 2D grain pack simulated using the newly developed Python script.*

Figure 2: *A 3D plot of porosity versus the mean and standard deviation of the grain size distribution*



Edgar Javier Rueda Rueda

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In collaboration with the Department of Geoscience and Petroleum, NTNU

A Pore-Scale Study to Evaluate the Efficiency of Nanoparticle-Assisted Polymer Flooding

Autumn 2019
Supervisor: Ole Torsæter and Rosângela Barros Zanoni Lopes Moreno

Background

The polymer flooding is an EOR process designed to improve the mobility ratio between the oil to be displaced and the displacing solution. This technique improves the sweep efficiency and delays the water breakthrough **(fig. 1)**. On the other hand, recent studies have shown the potential of hydrophilic nanoparticles (NPs) in enhancing oil recovery. A minimum amount suspended in the injection fluid can reduce the interfacial tension and the contact angle between the oleic phase and the recovery agent, doing the surface more water wet **(fig. 2)**.

Objective

This pore-scale experimental work evaluates the efficiency of NPs-assisted polymer flooding via monitoring the changes in the displacement efficiency in glass microchips.

Experimental approach

A microfluidic setup is used to acquire images of a high spatial and temporal resolution to capture the dynamic changes inside the microchips during the flooding process. By means of image processing and analysis, valuable pore-scale parameters are extracted, which are coupled by data from pressure and volume sensors. In addition, fluid properties were determined to explain the results.

Results

This work shows that the proposed recovery agent NPs-assisted polymer flooding induced positive changes with the porous media, resulting in the best ultimate oil recovery. This fluid showed better clusterization and mobilization of the oleic phase. This finding was drawn from a comparison with nanofluid flooding, polymer flooding, and brine flooding. In addition, the study finds that the success of adding nanoparticles to a polymer flood significantly depends on the polymer type.

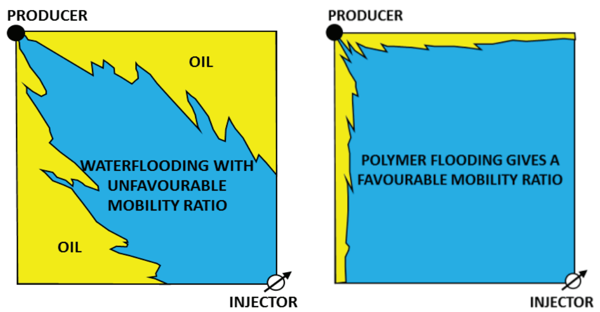


Figure 1. Sweep efficiency improved by polymers injection. Sorbie, K., 1991. Polymer Improved Oil Recovery. In: *Polymer Improved Oil Recovery.* Boca Raton: CRC Press, Inc., pp. 246 - 287.

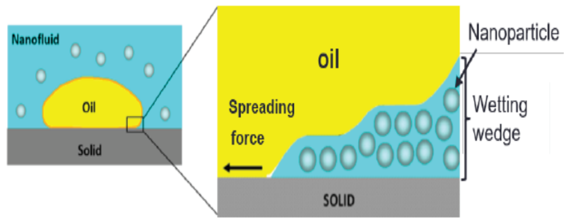
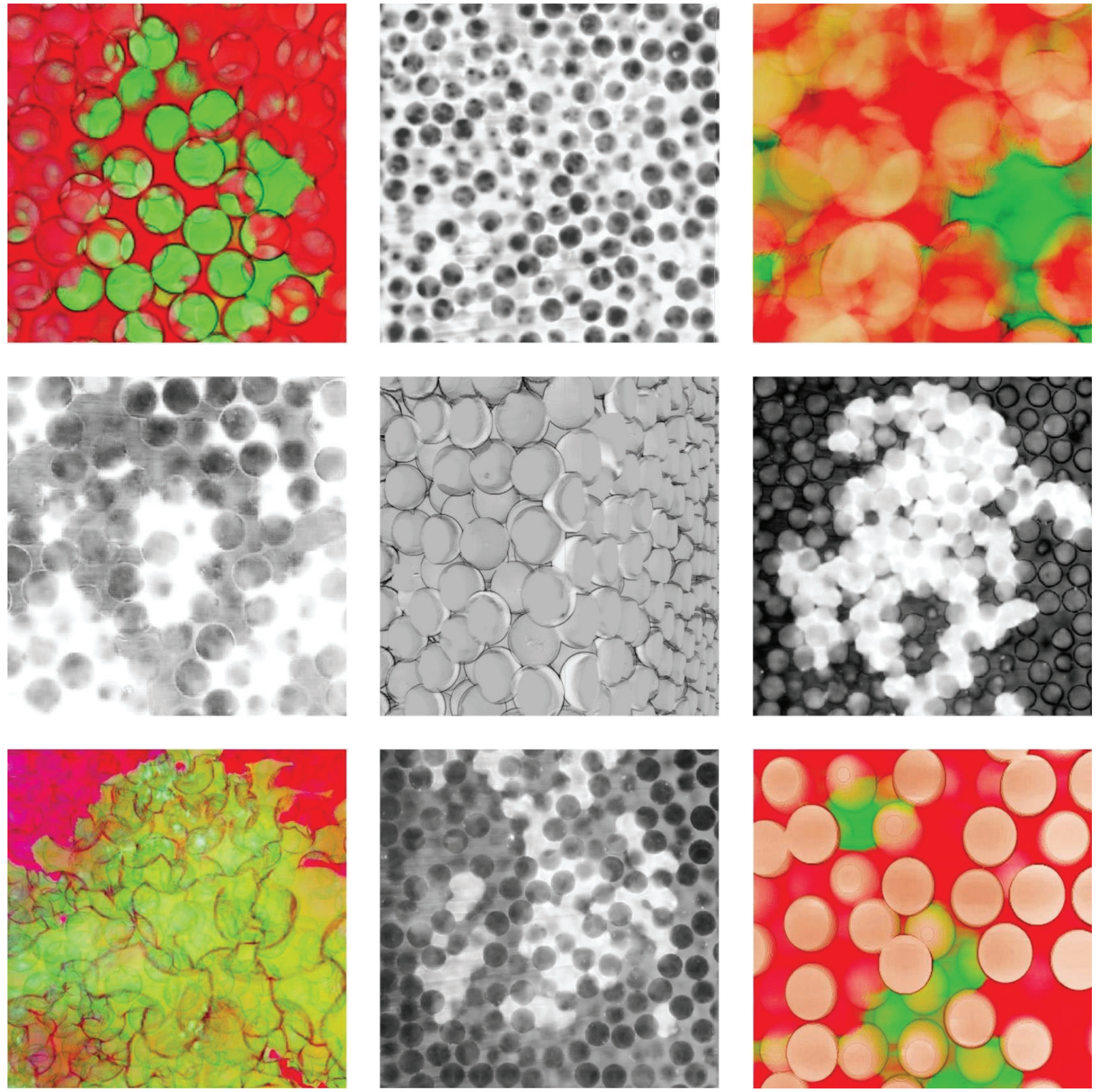


Figure 2. Nanoparticles acting in the oil/solid surface. (Wasan, D. & Nikolov, A., 2003. Spreading of nanofluids on solids doi:10.1038/nature01591. Nature, pp. 156 - 159).



***Figures**: Examples of 2D cross-sections in a 3D-scanned porous media, where one can identify the two liquid phases and the porous matrix (glass beads)*

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 UiO (department of Physics)

Pressure fluctuations in porous media flows

Contact: Knut Jørgen Måløy (K.J.Maloy@fys.uio.no)

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

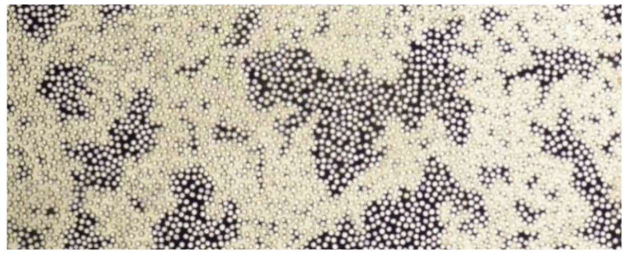


Figure: Detail of the trapped liquid clusters (blue) left behind after air (white) is slowly injected from the left in a quasi-2D porous network previously saturated with the liquid.

Proposed Master Project at PoreLab UiO (department of Physics)

Influence of the flow speed on the pore invasion dynamics

Contact: 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.

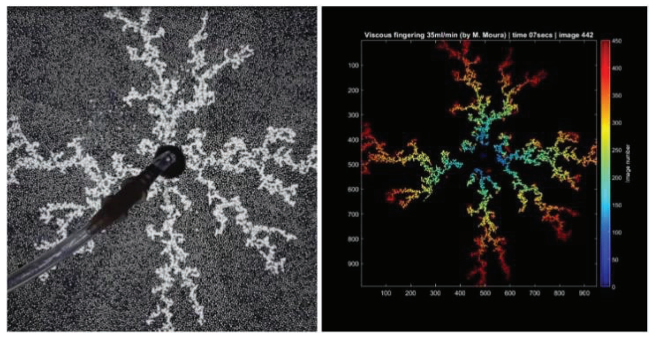


Figure : Viscous fingering pattern (left) observed when air is injected fast in a porous medium previously filled with a viscous liquid (blue). The image analysis (left) shows the time (image number) of injection of each pore

Proposed Master Project at PoreLab NTNU (department of Physics)

Monte Carlo Simulation of Immiscible Two-Phase Flow in Porous Media

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

Finding a set of equations describing the simultaneous flow of two immiscible fluids in a porous medium is an outstanding problem in theoretical physics. Today, it is possible to follow the fluids in detail at the pore level using e.g. micro-CT or other such techniques. However, to translate this visualization into a mathematical description at a coarse-grained level where the porous medium may be viewed as a continuum is a step that is still lacking. Finding such a description is a central theme for the Center of Excellence Porelab. Our approach is to emulate the approach of statistical mechanics leading to thermodynamics as the final continuum theory.

As part of this effort, we published in 2017 a paper presenting a Markov Chain Monte Carlo algorithm based on the Metropolis algorithm for simulation of the flow of two immiscible fluids in a porous medium under macroscopic steady-state conditions using a dynamical pore network model that tracks the motion of the fluid interfaces [1,2]. This method rests on our ideas using statistical mechanics to describe the flow problem being not only correct but also implementable.

The method as it stands has a major weakness: it requires that the underlying porous medium may be mapped onto a regular lattice. It is very important that we overcome this constraint and here is the central theme of the proposed MSc project: How to reconstruct the Monte Carlo method based on a generalized statistical mechanics so that it may be implemented on any pore network.

The project will involve extensive numerical calculations based on programs that are already in existence. It is necessary with a good understanding of statistical mechanics and a knowledge of fluid mechanics.

The PoreLab environment is highly interdisciplinary, international and dynamic.

1] I. Savani, S. Sinha, A. Hansen, D. Bedeaux, S. Kjelstrup and M. Vassvik, A Monte Carlo Algorithm for Immiscible Two-Phase Flow in Porous Media. *Transp Porous Med* 116, 869–888 (2017). https://doi.org/10.1007/s11242-016-0804-x.

[2] I. Savani, Non-Equilibrium Statistical Mechanics of Two-Phase Flow in Porous Media, PhD Thesis, NTNU (2016), http://hdl.handle.net/11250/2432735

Proposed Master Project at PoreLab NTNU (department of Physics)

Are Fluid Clusters Lattice Animals?

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

When two immiscible fluids simultaneously flow in a porous medium, they break up into clusters. What shape do these clusters have? So far no-one has delved deep into this question, which is essential for understanding how the fluids interact – or more precisely, how to characterize their interaction. A lot of research was done in the eighties on so-called lattice animals, which essentially are connected clusters in percolation theory. This theory will become useful in this work, but also ideas from integral geometry, more specifically Minkowski functionals that characterize the geometry of shapes, will be essential.

This MSc project is a part of a larger project, namely finding a set of equations describing the simultaneous flow of two immiscible fluids in a porous medium is an outstanding problem in theoretical physics. Today, it is possible to follow the fluids in detail at the pore level using e.g. micro-CT or other such techniques. However, to translate this visualization into a mathematical description at a coarse-grained level where the porous medium may be viewed as a continuum is a step that is still lacking. Finding such a description is a central theme for the Center of Excellence Porelab. Our approach is to emulate the approach of statistical mechanics leading to thermodynamics as the final continuum theory.

The project will involve extensive numerical calculations based on programs that are already in existence. It is necessary with a good understanding of statistical mechanics and a knowledge of fluid mechanics.

The PoreLab environment is highly interdisciplinary, international and dynamic.

Proposed Master Project at PoreLab NTNU (department of Physics)

Energy Variation in LLS Fiber Bundle Model

Contact: Srutarshi Pradhan (Srutarshi.Pradhan@ntnu.no) and Alex Hansen (Alex.Hansen@ntnu.no)

Background: Fiber bundle model (FBM) is a simple and efficient model to describe the fracture-failure in composite materials under stress. NTNU physics department is involved in FBM studies since 1992. Extensive research works have been done at NTNU on equal-load-sharing (ELS) and local load-sharing (LLS) versions of FBM -both theoretically and through numerical simulations [1,2]. The NTNU fracture group has been recognized as one of the leading groups on this topic and currently this group is a part of the editorial team for a Research Topic "*The Fiber Bundle*" in the Frontiers in Physics.

Problem formation: It is obvious that if we increase stress or load on a composite material, at some point the system will collapse i.e., the material cannot bear the load and breaks into pieces. But when does this collapse point come? Is there any prior signature? Can we somehow predict this collapse point? These are some long-standing questions in the field of fracture-failure of materials. In a very recent work [3] it has been observed that in equal load-sharing (ELS) Fiber bundle model the elastic energy variation can tell us exactly when the bundle will collapse.

The aim of this Master project is to extend and explore the energy concept (developed in [3]) to a more realistic load-sharing scheme -the LLS model. The elastic energy and damage energy will be measured numerically as a function of external stress (stretch of the bundle) in 1-D and 2-D systems. The simulation codes have been developed (in C, C++) in-house and are available for re-use and further improvement.

Other aspects: Strength estimation and prediction of collapse point is a central issue for **sustainability** of composite materials and structures including buildings, bridges etc. While better understanding of the fracture-failure process can help better designing of materials and structures, new knowledge on the prior signatures of upcoming collapse will surely help mitigation plans to avoid accidents and save human lives.

References:

[1] S. Pradhan, A. Hansen and Bikas K. Chakrabarti, "*Failure processes in elastic fiber bundles*'', Rev. Mod. Phys. Vol. 82, No 1, 499-555 (2010). [2] A. Hansen, P. C. Hemmer and S. Pradhan, "*The Fiber Bundle Model: Modeling Failure in Materials*", Wiley-VCH, Berlin (September 2015). [3] S. Pradhan, J. T. Kjellstadli and A. Hansen, "*Variation of elastic energy shows reliable signal of upcoming catastrophic failure*", Front. Phys. Vol. 7 106 (2019).

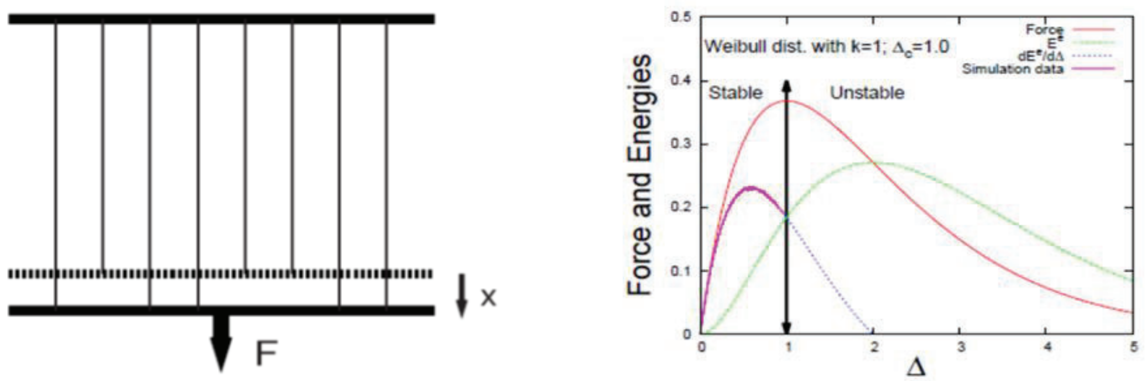


Fig: The ELS fiber bundle model (left) and the energy variations with stretch (right) for Weibull fiber strength distributions

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Proposed Master Project at PoreLab NTNU (department of Physics)

Swelling of Clay/Shale: A numerical investigation

Contact: Srutarshi Pradhan (Srutarshi.Pradhan@ntnu.no) and Alex Hansen (Alex.Hansen@ntnu.no)

Background: Swelling of Shale-rocks create several problems [1] during underground drilling operations, such as stuck-pipe/drill-bit. However, swelling of shale-rocks can close the gaps between rock (wellbore) and casing –therefore no cementing is needed – which can save a lot of time and money and such a "natural" closing ensures "no-leakage" during further drilling and production phases. The field experience reveals that some shale-rocks are good candidate for swelling and some are not. There are several parameters that can influence the swelling behavior, such as- porosity, clay-quartz contents, stress difference between field and drilling zone etc. Therefore, to plan a safe and efficient drilling through shale-rocks, we should understand the swelling mechanism of shale/clay.

Problem formation: To investigate swelling problem we have introduced a discrete element model (DEM), based on Monte-Carlo technique. We define a probability of swelling for all the clay grains in the shale-rock sample that includes the effect of stress-difference, porosity, temperature etc. The time evolution of grain swelling results in bulk swelling behavior of the sample and the simulation result qualitatively matches [2] with the observations of shale/clay swelling experiments [3,4].

The aim of this Master project is to study the Monte-Carlo based DEM for the entire parameter space by varying several important inputs like porosity, clay-quartz contents, stress difference etc. The DEM simulation codes are developed in-house and are available for re-use and further improvement.

Other aspects: As this problem is linked to practical field operations, we would like to develop a KPN proposal for NFR this year. Results from the Master project will be used in the proposal as important ground works and the Master student will be encouraged to join the KPN project if he/she wishes to pursue a ***research career*** on this topic. We (PoreLab) have applied (to NWO) for a joint research project with University of Delft on the topic "*Deformable Clay*". The Master student will get a chance to interact with the team members (both from NTNU and Delft) if the project gets funding.

References:

1.E. Fjær, R. M. Holt, P. Horsrud, A. M. Raaen and R. Risnes, *Petrolum Related Rock Mechanics* (Elsevier, 2008). 2.S. Pradhan, *Swelling behavior of shale/clay: Discrete element modeling, based on Monte-Carlo technique*, Interpore 2019, Valencia, Spain. 3. M. Deriszadeh and R.C.K. Wong, Transp Porous Med (2014) 101:35–52 DOI 10.1007/s11242-013-0229-8. 4. E. Rybacki, J. Herrmann, R. Wirth and G. Dresen, Rock Mech Rock Eng (2017) 50:3121–3140.

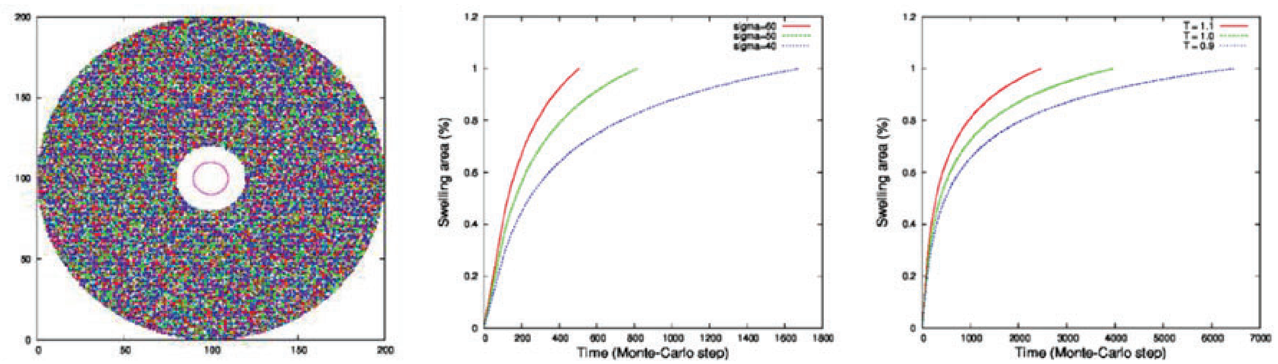


Fig: The DEM model for Shale rock sample with clay and quartz grains (left). Swelling amount with time for different stress levels (middle) and temperature levels (right).

Proposed Master Project at PoreLab NTNU (department of Physics)

Fracture Propagation During Fluid-Injection

Contact: Srutarshi Pradhan (Srutarshi.Pradhan@ntnu.no) and Alex Hansen (Alex.Hansen@ntnu.no)

Background: Fluid injection operations [1] are regularly done in several field case scenarios like petroleum production, geothermal installation, ground-water exploration and underground CO_2 storage. Normally fluids with high pressure are injected inside porous rocks through the injection wells and sometimes fractures open-up at the well-boundaries. We need better understanding of physical processes that guide fracture propagation in porous media and we also need to develop tools for monitoring fracture propagation. Several lab experiments [2,3] have explored the stress-induced fracturing behavior of number of reservoir rocks during fluid injection scenarios.

Problem formation: We have developed a discrete element model (DEM) simulation code based on invasion percolation and distance dependent stress intensity factor (K) to mimic the stress-induced fracturing of porous rocks. Our simulation code can handle the presence of pre-existing fractures inside the sample. The simulation results agree qualitatively [4] with the experimental observations.

In this Master project, the student will study the stress-induced fracturing with several important inputs like tensile strength distribution, breaking criteria, porosity, sample size, pressure etc. The DEM simulation codes are developed in-house and are available for re-use and further improvement.

Other aspects: Although fractures are mostly seen as "disturbing elements" for the stability of wells and well-operations, in some cases fractures are "intended" -for example, in hydraulic fracturing scenario people create fractures to increase permeability (flow channels) in the porous rocks. Creation of optimal flow channels is also the main goal for geothermal projects to enhance power production and thereby to contribute in the *Green-energy-sphere*. PoreLab is now developing a research proposal together with Institute of Geophysics, Warsaw on "*Fracturing in ice*". The Master student can be included in this project if he/she likes to pursue a ***research career*** on this topic.

References:
1. E. Fjær, R. M. Holt, P. Horsrud, A. M. Raaen and R. Risnes, *Petrolum Related Rock Mechanics* (Elsevier, 2008). 2. S. Pradhan, A. Stroisz, E. Fjær, J. Stenebråten, H.K. Lund and E. F. Sønstebø, "Stress-induced fracturing of reservoir rocks: Acoustic monitoring and mCT image analysis", Int. J. of Rock Mechanics and Rock Engineering, DOI 10.1007/s00603-015-0853-4 (2015).
3. S. Pradhan, A. Stroisz, E. Fjær, J. Stenebråten, H.K. Lund, E. F. Sønstebø and S. Roy, "Fracturing tests on reservoir rocks: Analysis of AE events and radial strain evolution", ARMA (2014).
4. Invited presentation on *Fracture propagation during fluid injection: Experiment, modeling and monitoring towards field scale applications* at "Fracmeet Conference", IMSc, Chennai, India in March 2019.

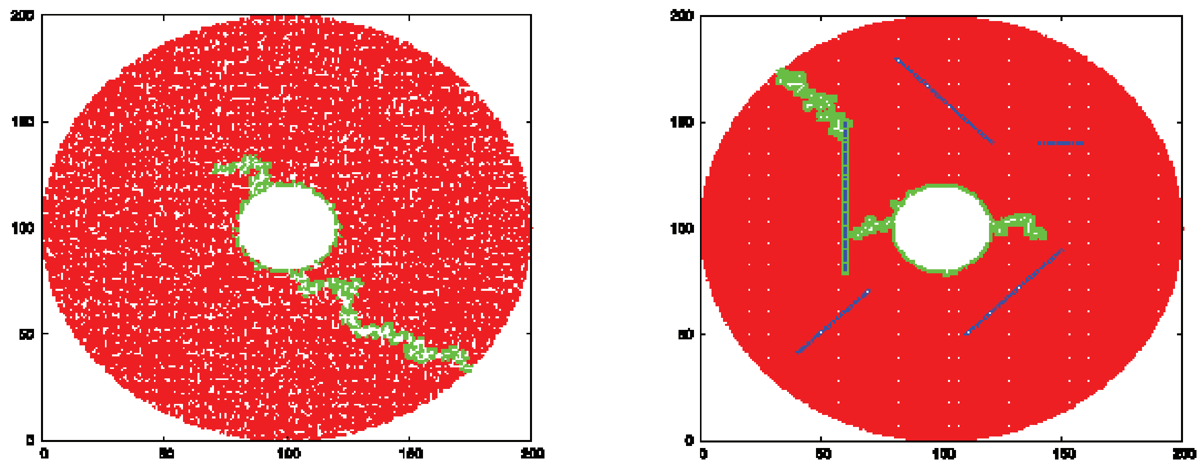


Fig: Fracture propagation in a DEM with no pre-existing fractures (left) and in a DEM with 5 pre-existing fractures (right)

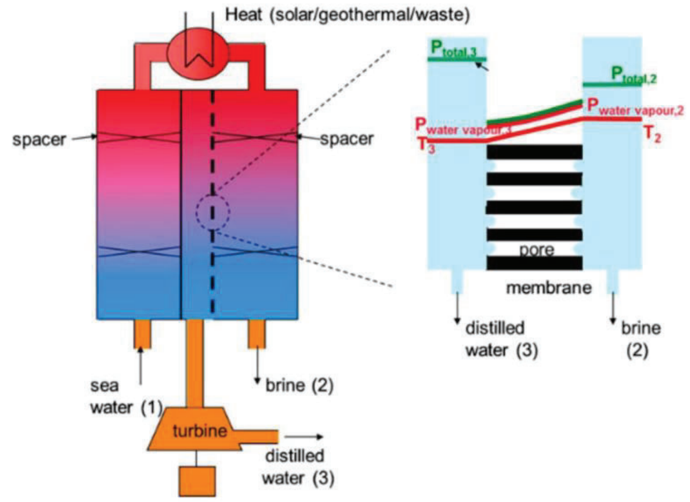
Proposed Master Project at PoreLab NTNU (department of Chemistry)

Thermal Osmosis

Contact: Professor Signe Kjelstrup (Signe.Kjelstrup@ntnu.no)

It has recently been found that hydrophobic membranes with pores of nanometer size will not transport water in the liquid state, but rather in the vapor state, when surrounded by water solutions at different temperatures. This opens up for a very interesting way to clean contaminated water by means of industrial waste heat. The figure illustrates an invention that puts this into practice. Water is transported against a pressure gradient by means of a temperature gradient. This is what we understand as thermal osmosis.

Problem formulation: The mechanism for water transport in the membrane that is used in the invention is little understood. The aim of the project is to help us understand how exactly (with what speed) water is passing the membrane. By understanding the transport better, we hope to improve conditions for it. The work will consist of setting up a NEMD model for water transport across a narrow pore, and study of the wall and pore shape affects the transport under relevant temperatures and pressures.



Other aspects: This study will benefit from similar simulation studies. The project will also benefit from experimental activities in our group (one Master student and partner in Spain).

References: 1. Keulen et al. J. Membr, Sci. 524 (2017) 151 2. Lee et al. Nature Nanotechnology 9 (2014) 317

Proposed Master Project at PoreLab NTNU (department of Chemistry)

Molecular dynamics simulations of Li in porous media battery electrodes

Contact: Professor Signe Kjelstrup (Signe.Kjelstrup@ntnu.no) and Sondre K. Schnell (Sondre.K.Schnell@ntnu.no)

The Seebeck effect can be used to convert thermal energy to electrical energy. This project is an extension of the work of master student Didrik Roest (2016) on molecular dynamics simulations of salts between two electrode walls. In the present project, there is a lithium salt in the electrolyte, and lithium metal in the porous electrodes. A thermal gradient is applied. In order to model the electric potential, we need the entropy of Li in the porous electrodes. The aim of the project is to find this entropy by simulations.

Other aspects: The master project is connected to the PhD work of Gunnarshaug, who is measuring Seebeck coefficients for Li-Battery components. This project will support her studies and vice versa.

International contact is Thijs Vlugt, TU Delft

Proposed Master Project at PoreLab NTNU (department of Chemistry)

Soret effects in porous media for Li-batteries

Contact: Professor Signe Kjelstrup (Signe.Kjelstrup@ntnu.no)

Background. The heat evolution in Li batteries need to be controlled to understand why the battery sometimes overheat and catch fire in the surroundings. During the course TKJ4200, the Soret effect was investigated in an electrolyte mixture of components, LiPF6, ethylene carbonate and di-methyl carbonate. The investigation was done with LAMMPS software. The study showed that it was likely that all components were moving in a thermal field. The results were not conclusive, however, and we would like to verify them.

Problem formulation. In order to reach valid conclusions, it is an advantage to build the system gradually and introduce new variables in a stepwise manner. It thus is interesting to study the single components, before a mixture, and a mixture before a ternary mixture. We will study all 4 cases in equilibrium in order to characterize the equilibrium state. When that is known, we apply the temperature gradient, and find the Soret coefficient for each of the systems.

Other aspects. The student will benefit from similar studies going on in the group, from experimental as well as computational activities on ionic systems (one Master student, Gunnarshaug, and students working on Seebeck coefficient problems).

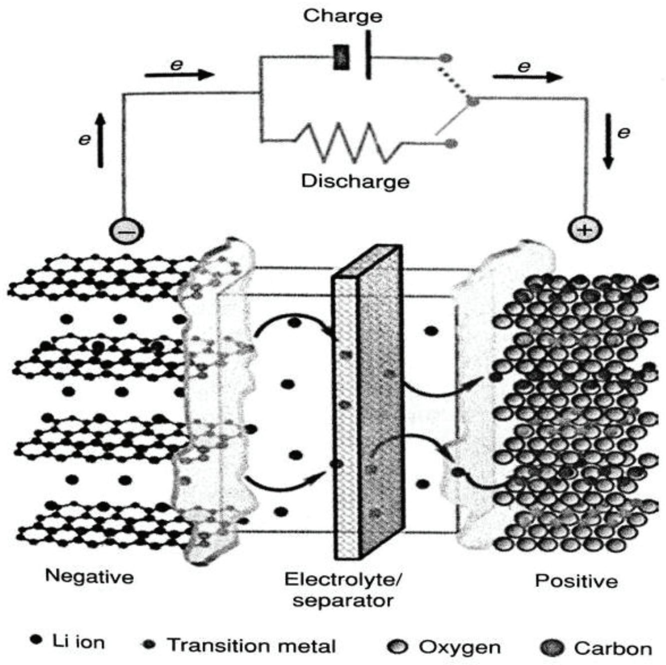


Fig.1 The electrolyte and electrodes in a Li battery.
Scrosati et al: Li-Batteries, 2013

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

Fluid-redistribution in micromodels

Contact: Haili Long-Sanouiller (Haili.Long-Sanouiller@ntnu.no)

The specialization project and master will conduct micro-model flooding to investigate the effect of ageing on fluid redistribution. The specialization project will be a literature review on ageing, together with initial testing of the micro-model setup. In the master project the candidate halts a drainage of a water-filled micro-model. During such prolonged halts, the candidate will investigate changes in contact angles and redistribution of oil.

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

The effect of water quality on imbibition

Contact: Carl Fredrik Berg (carl.f.berg@ntnu.no) and Ole Torsæter (ole.torsater@ntnu.no)

Running Amott-tests on a larger set of (carbonate-)core samples to evaluate the effect of different water composition on imbibition at elevated temperatures. This project will be a continuation of a previous experimental program. The specialization project will be to upgrade the current experimental setup. The master thesis would be a continuation of the specialization project: The candidate should measure the spontaneous imbibition from core samples at irreducible water saturation, by placing the core samples in Amott cells containing water with different composition and at high temperature. A possible second master student will investigate the field scale effect of injection water quality through reservoir simulations.

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

Molecular dynamics simulation of Haines jumps

Contact: Carl Fredrik Berg (carl.f.berg@ntnu.no) and Bjørn Hafskjold (bjorn.hafskjold@ntnu.no)

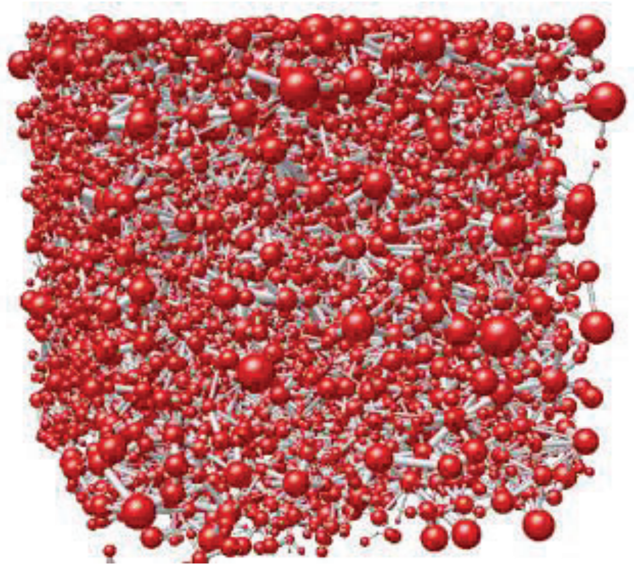
The aim of this project is to combine molecular dynamics simulations with analyses based on irreversible thermodynamics in order to determine the entropy production in Haines Jumps in a model system. The candidate will conduct molecular dynamics simulations of a single Haines jump through a pore throat. The model will consist of a two-component system of Lennard-Jones particles to simulate two immiscible fluid phases with different wetting properties with respect to the pore. The simulation will be conducted so that the non-wetting phase will advance through the pore. From such simulations the student should estimate the pressure and velocity profile at different time steps, and thereby estimate the amount of energy dissipated from viscous flow induced by the Haines jump. The energy dissipation from individual Haines jumps should be compared to the energy dissipation in macroscopic two-phase flow. These simulations will be conducted by modifying an existing code base written in Fortran.

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

Segmentation of phases in experimental images of fluid flow using machine learning

Contact: Hamid Hosseinzade Khanamiri (hamid.hosseinzade@ntnu.no)

Natural porous media has a complex geometry at which fine features like small channels coexist beside larger features like ordinary pores. The geometry becomes further complicated when two fluids occupy the pore space. The traditional segmentation methods may suffer uncertainty in resolving the small channels and fluid-fluid interfaces. These features could be averaged out by the surrounding larger features. In this project, the possible improvement in segmentation by machine learning will be investigated. The work can be started by introducing different types of noise (salt and pepper, streaks, rings etc. or convolution of these) in synthetic images and attempting to recover the original images using traditional methods and machine learning techniques. The project can be developed by applying the experience in the first step in segmentation of pore or fluids in experimental 2D micro-model images and further on in 3D X-ray tomography images. The student should be familiar with Python where there are modules and libraries for machine learning.



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

Thermodynamical based primary drainage

Contact: Carl Fredrik Berg (carl.f.berg@ntnu.no)

In this project the candidate should develop scripts for simulating primary drainage based on thermodynamics, either in grid models or in network models of porous media. For the network model, the candidate should extend existing Python codes for pore scale network modeling already developed by other students. For the grid model, the candidate should extend a prototype. The first step is to conduct primary drainage on an altered version of the which simplifies the thermodynamic based drainage process. One research question for the project is to reveal how energy dissipation during primary drainage is dependent on sample size.

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

Characterization of wetting through electrokinetics

Contact: Carl Fredrik Berg (carl.f.berg@ntnu.no) and Per Arne Slotte (per.slotte@ntnu.no)

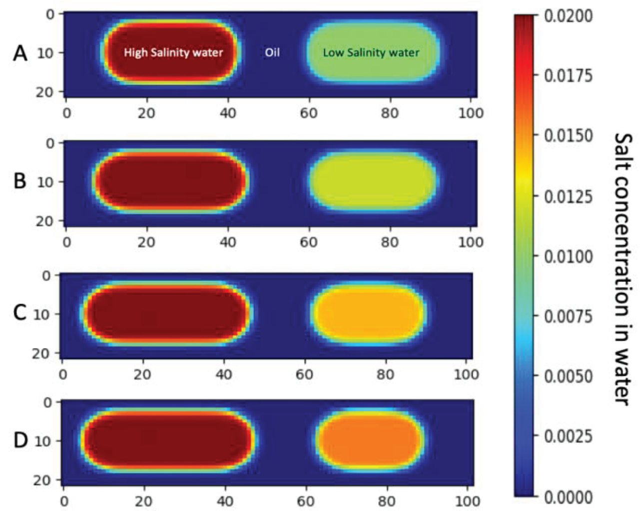
The aim of this project is to develop an experimental procedure for measuring all three interfacial tensions in the Young contact angle equation through electrokinetics. The candidate will extend the existing contact angle measurement equipment to obtain an electrical potential difference (voltage difference) between the fluid and the substrate (the solid). According to electrokinetic theory the contact angle is related to the potential difference, and this relationship can be used to estimate all three interfacial tensions; fluid-gas, solid-fluid and solid gas.

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

Microfluidic investigation of osmosis mechanism in low-salinity enhanced oil recovery

Contact: Mohammad Hossein Golestan (mohammad.h.golestan@ntnu.no)

This specialization project and consecutive master project will be the literature review and experimental investigation of osmosis mechanism during low-salinity water injections as an enhanced oil recovery method. The specialization project will focus on the literature review and preparing the experimental set-up for conducting 1D and 2D microfluidic experiments. In the master project, the student will focus on conducting the experiments in different water salinities and oil properties for characterizing the water-oil interaction in low-salinity water injection. The main purpose of the project is to conduct benchmark experiments and consider the membrane behavior of oil separating low-salinity and high-salinity water.



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

The course 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 2 - Experimental techniques in condensed matter physics

FYS4420/FYS9420 (Experimental techniques in condensed matter physics) at UiO or PG8605/TPG4565 (Dual porosity reservoirs / Petroleum Engineering) at NTNU

The course contains four projects that will give students introduction to important experimental techniques in the field of condensed matter physics. The course provides fundamental understanding of the physical and mathematical basis for different models describing double porosity media and fluid flow in such media.

Additional courses offered at either NTNU or UiO are relevant for porous media. Please notice that the list below is not exhaustive, we are still working setting up the program.

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.

Irreversible Thermodynamics

TKJ4200, NTNU

The course focuses on the construction of entropy production 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. Applications to problems such as fuel cells, chemical processes, thermoelectric effects or salt power plants are covered. The underlying molecular mechanisms for coupled transport processes are discussed. The energy efficiency of the mentioned processes is in focus.

Mass Transfer

MT8108, NTNU

The course gives a rigorous treatment of mass transfer theory with relevant applications. The students shall be able to read theoretical and modeling literature in the area without difficulty at the end of the course. They will be able to perform mathematical modeling of mass transfer processes in chemical, metallurgical and electrochemical systems; learn to simplify the models to obtain unambiguous analytical and numerical solutions; learn how to obtain results needed for correlation of experimental results involving mass transfer; use such background for the purposes of design of research tools as well as industrial process equipment.

Mass and Heat Transfer in Porous Media

EP8208, NTNU

This course covers the following topics: physical and chemical effects of fluid-pore wall contact, heat and mass transport with and without chemical reaction and radiation in the pores, analogy between heat and mass transport, diffusion and convective heat and mass transport, diffusivity, transient and stable mass transport in different phases, adsorption and desorption, energy conversion, capillary pressure, capillary flow, radiation exchange inside pores, phenomenological consideration, side effects such as shrinkage / swelling, deformation, stress state. Practical examples from technical processes are given. The curse focuses as well on the mathematical modeling of transport processes.

Applied Heterogeneous Catalysis

KP8132, NTNU

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 chosen from the following list: Environmental catalysis, Heterogeneous catalysis (advanced course), Industrial colloid chemistry, Reactor modelling and Chemical engineering (special topics). Modules from other specializations can be chosen given the approval of the coordinator.

Chemical Engineering Thermodynamics

TKP4107, NTNU

Chemical engineering thermodynamics is a basis for understanding chemical processes. The course is based on international book and will teach the students to calculate thermodynamic properties of pure components and mixtures. Both ideal and non-ideal cases will be covered. At the same time the student will improve their skills on energy, entropy and exergy balances helping the students to calculate and simulate chemical engineering processes and apply the knowledge to both traditional industrial processes as well as new more sustainable processes.

Energy and Process Engineering, Specialization Project

TEP4550, NTNU

The topics are closely linked to ongoing research activities and can be chosen among the following subjects: thermal energy, industrial process technology, fluids engineering and energy and indoor environment.

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.

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.

Applied Computer Methods in Petroleum Science

TPG4155, NTNU

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. 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.

Statistical Mechanics

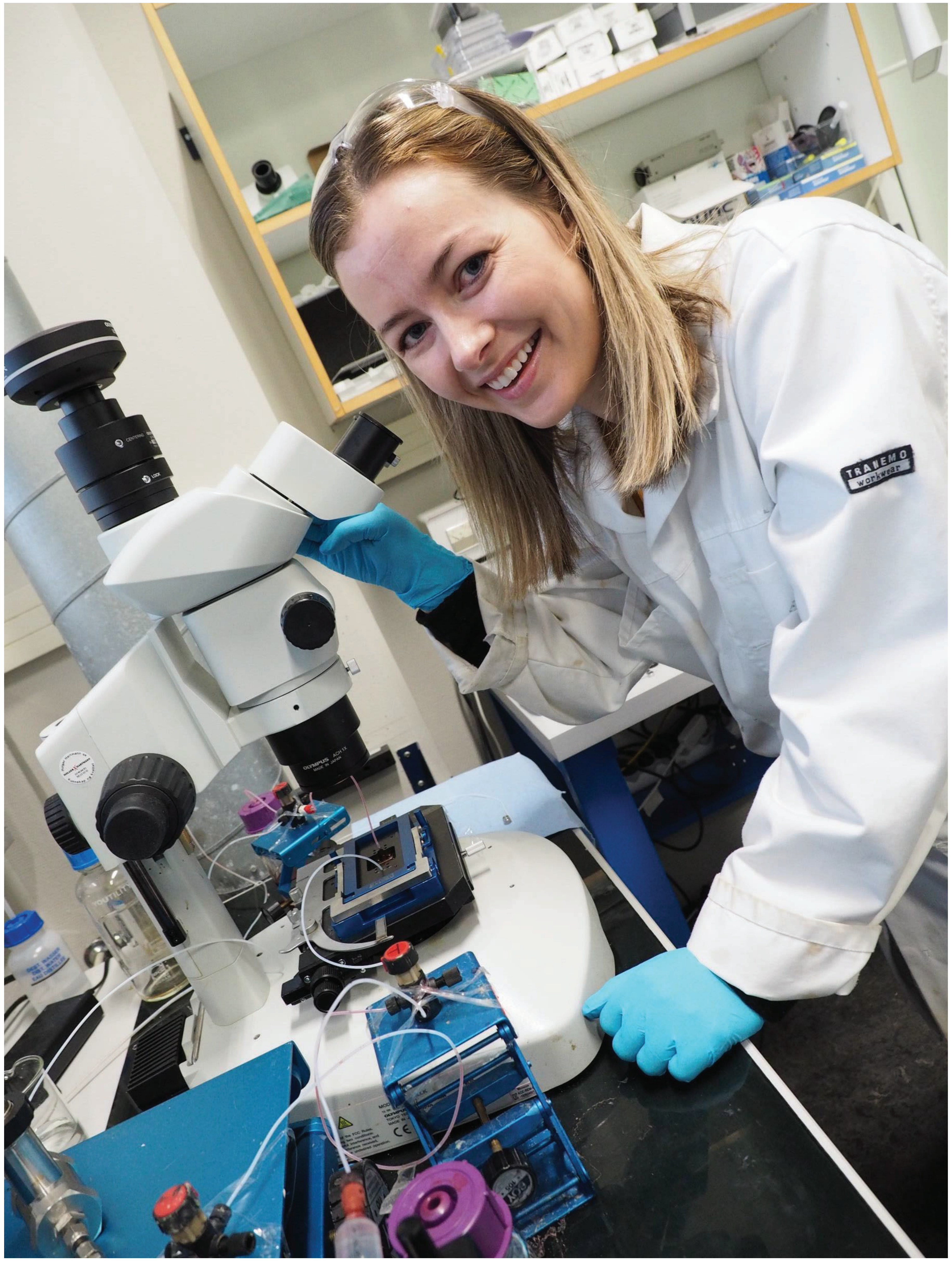
FYS4130, UiO

The students will obtain a general background in thermodynamics and statistical physics. In particular, they will be able to understand the fundamental properties of gases, liquids and solids. In addition they will obtain a theoretical foundation for further studies of systems with many particles or degrees of freedom.

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.

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.

__Photo on the right__: PhD candidate Reidun Cecilie Aadland and her micromodel set-up in the laboratory at the Department of Geoscience and Petroleum, NTNU (Photo: Per Henning)



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