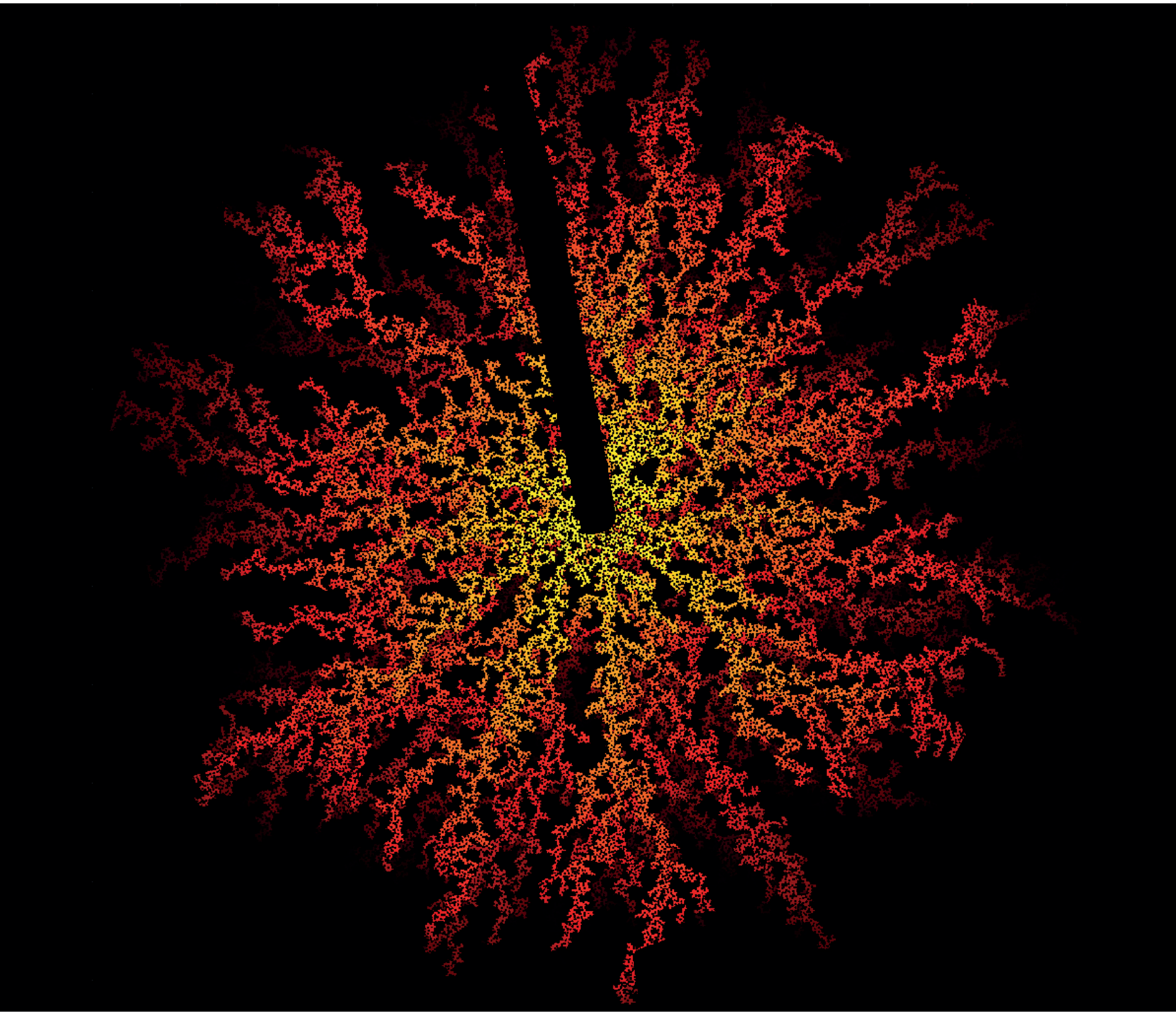
PoreLab
NTNU-UiO Porous Media Laboratory

Annual Report 2022

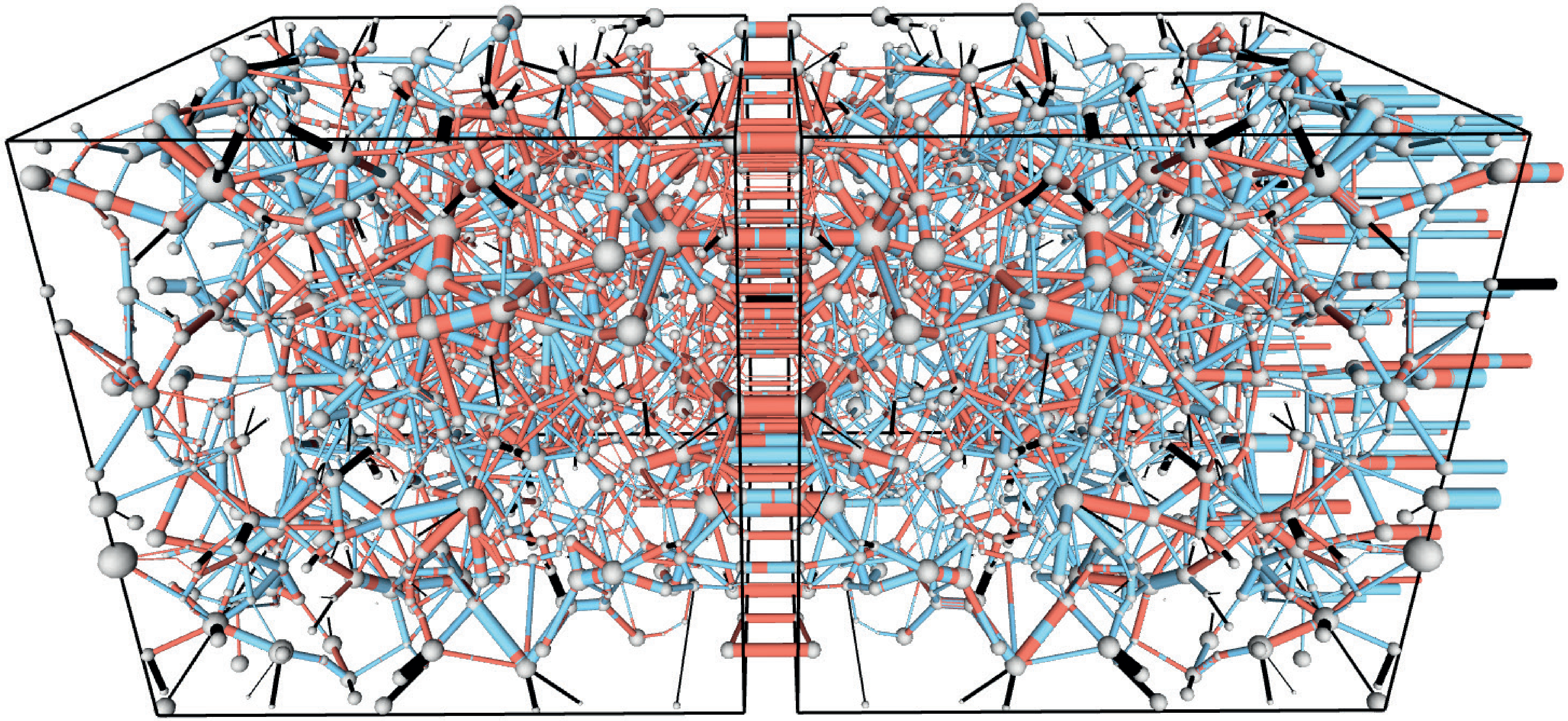


NTNU
Norwegian University of Science and Technology

UiO : University of Oslo

Norwegian Centre of Excellence
The Research Council of Norway

To unify and advance understanding of porous media



Simulation of two-phase flow in a reconstructed network of Berea sandstone using dynamic pore-network model. The flow velocities are calculated by solving equations for fully developed flow in the pores that take viscous and capillary forces into account. The wetting (blue) and the non-wetting (red) fluids are displaced by moving the interfaces between them. The two cuboids are the mirror images of each other which allow the system to evolve to a steady state. Figure by Santanu Sinha, PoreLab NTNU

COVER PAGE:
Invasion pattern resulting from the injection of pressurized air at the center of a circular cell containing a porous medium that is initially saturated with a viscous liquid. The color is added digitally and signifies the time a given pore is first reached by air, going from bright yellow to dark red. More information about this experiment on page 28

WHAT IS PORELAB?

The Research Council of Norway describes their Centre of Excellence (CoE) program as follows: *The CoE scheme gives Norway's best researchers the opportunity to organize their research activities in centres that seek to achieve ambitious scientific objectives through collaboration and with long-term basic funding.*

After an application process that started in 2015, we were awarded CoE status in August 2017 by the Research Council of Norway. PoreLab, acronym for Porous Media Laboratory, was born!

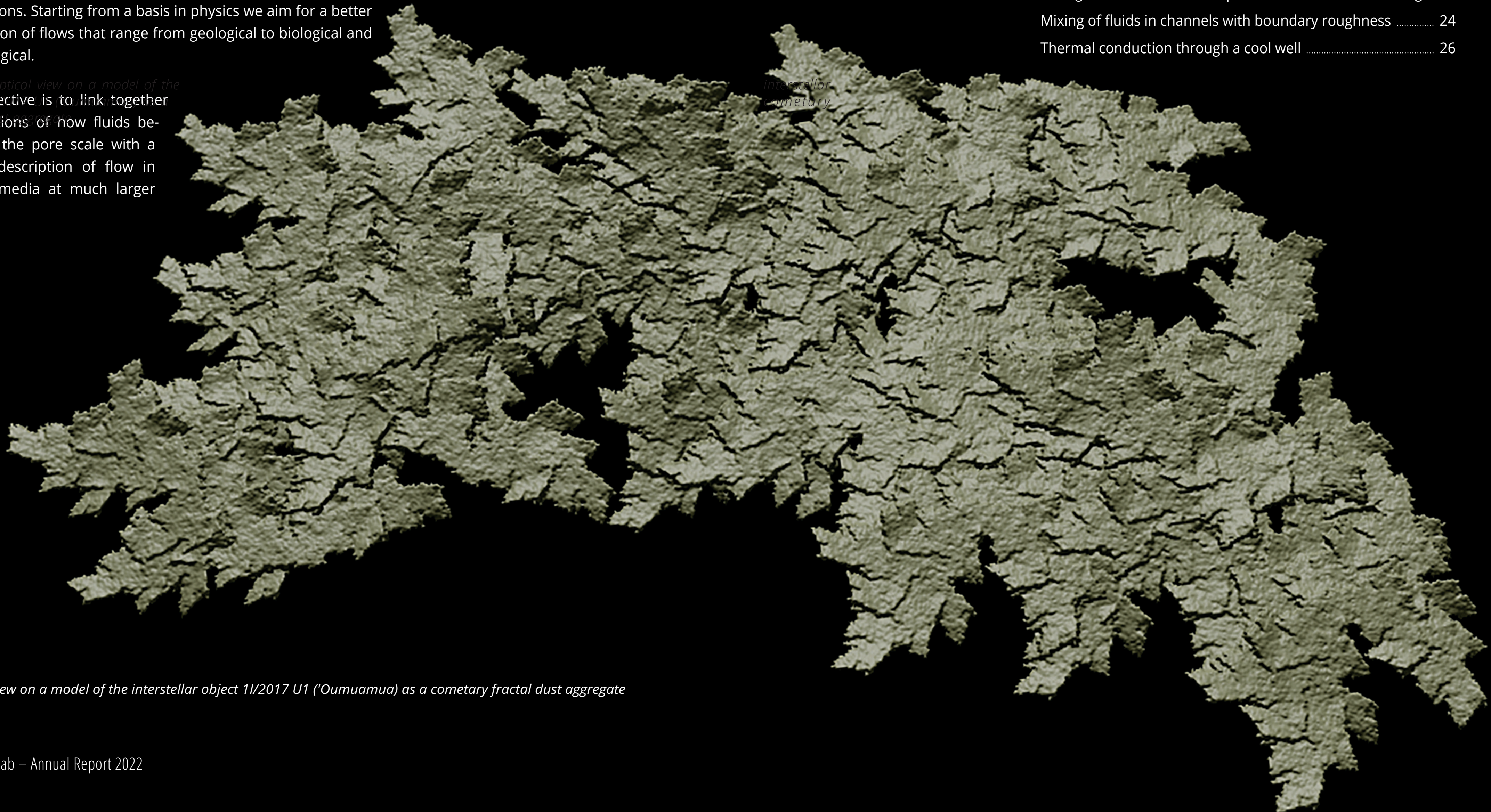
PoreLab has two nodes, at the Norwegian University of Science and Technology (NTNU) in Trondheim and at the University of Oslo (UiO). It is led by seven principal scientists from physics, chemistry, and reservoir engineering. At UiO, PoreLab is part of the Njord Center which is a cross-disciplinary geoscience-physics center.

The mission of PoreLab is to advance the understanding of flow in porous media, both at a fundamental level and in applications. Starting from a basis in physics we aim for a better description of flows that range from geological to biological and technological.

Our objective is to link together observations of how fluids behave at the pore scale with a proper description of flow in porous media at much larger scales – the scales that typically are relevant for applications. In other words, our aim is to construct a large-scale theory for flow in porous media based on the detailed physics at the pore level. To achieve this, we combine hydrodynamics, non-equilibrium thermodynamics and statistical physics using theoretical, computational, and experimental methods. But we also consider other problems such as the interactions between fluids and grains in unconsolidated porous media.

Our strength is to combine knowledge in physics, chemistry and geoscience using all three ways of approaching a problem: experimental, theoretical and computational.

PoreLab receives an annual funding from the Norwegian Research Council of about 15 MNOK. NTNU and UiO contribute with the same financial support. In December 2022, we received the information from the Research Council of Norway that the mid-term evaluation planned originally during the spring 2023 was cancelled. PoreLab will therefore continue until the date of completion, i.e., August 2027.



Optical view on a model of the interstellar object 1I/2017 U1 ('Oumuamua) as a cometary fractal dust aggregate

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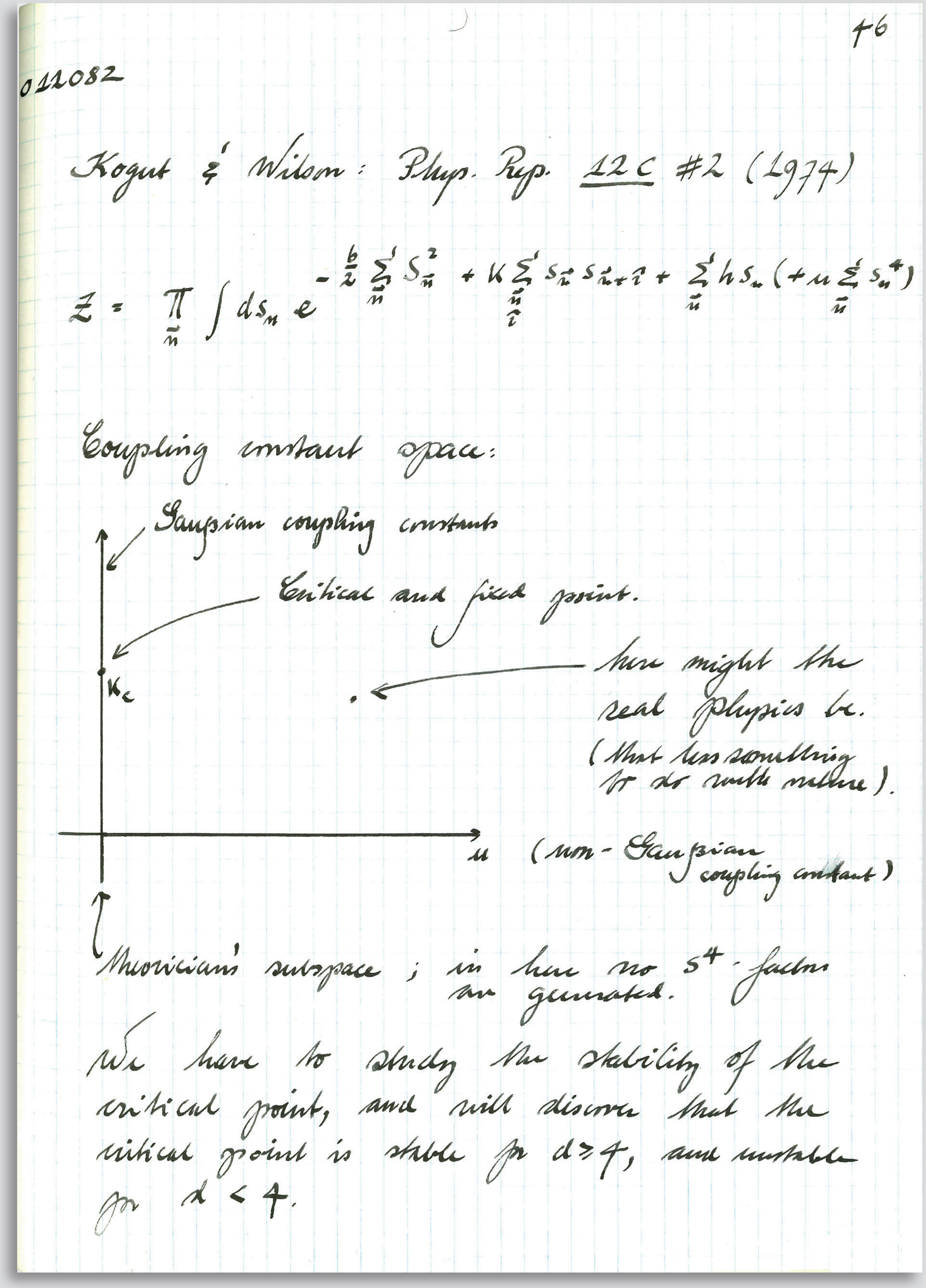

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Kogut & Wilson: Phys. Rep. 12C #2 (1974)

$$Z = \prod_{\vec{n}} \int ds_{\vec{n}}\, e^{-\frac{b}{2}\sum'_{\vec{n}} s_{\vec{n}}^2 + K \sum'_{\vec{n},\vec{\rho}} s_{\vec{n}} s_{\vec{n}+\vec{\rho}} + \sum'_{\vec{n}} h s_{\vec{n}} \left(+ u \sum_{\vec{n}} s_{\vec{n}}^4\right)}$$

Coupling constant space:

Gaussian coupling constants

Critical and fixed point.

K_c

here might the real physics be. (That has something to do with nature).

u (non-Gaussian coupling constant)

Theoreticians' subspace; in here no s^4-factors are generated.

We have to study the stability of the critical point, and will discover that the critical point is stable for $d > 4$, and unstable for $d < 4$.

Page 46 of my lecture notes from Kenneth G. Wilson's course on the renormalization group given at Cornell in the fall of 1982. The lecture is dated October 1, 1982, which was less than ten days before the Swedish Academy announced that he had won the Nobel Prize in physics for the renormalization group. – Alex Hansen

ACROSS THE SCALES REDUX

Alex Hansen

I wrote a short essay in the Annual Report of 2020 called *Across the Scales* (see page 7). It was centered around a celebrated essay written by Philip W. Anderson in 1972: *More is Different*[1]. 2022 was the fiftieth anniversary of this text. In this connection, Nature Physics Reviews published a celebratory viewpoint article on it. [2] This was the ingress:

August 1972 saw the publication of Philip Anderson's essay 'More is different'. In it, he crystallized the idea of emergence, arguing that "at each level of complexity entirely new properties appear" — that is, although, for example, chemistry is subject to the laws of physics, we cannot infer the field of chemistry from our knowledge of physics. Fifty years on from this landmark publication, eight scientists describe the most interesting phenomena that emerge in their fields.

I read for the first time Anderson's text in the early nineties, and it made a profound impression on me. The first lesson was that smaller does not mean more fundamental. The second lesson was that different scales demand different descriptions. The first point was Anderson's reaction to the hierarchy existing in physics: particle physicists regard themselves as studying more fundamental physics than condensed matter physicists (and even more so than the primitive life forms (in the eyes of particle physicists) that study porous media). The second point he made is, of course, that of emergence as pointed out in the 2022 ingress quoted above: New and different behavior is seen as one moves across scales and this demands different descriptions.

The main message I had concerning porous media in my little 2020 essay was the following: Concepts that function on the pore scale do not work on scales where the porous medium may be viewed as a continuum. A completely different description is necessary with variables that are different. Let me take this further in this follow-up essay.

There are two main trends in the field of porous media regarding upscaling: That which focuses on momentum transfer and that which focuses on energy transfer. In the first case, one starts with the hydrodynamic equations on the pore scale, and in the second case, one sets up a thermodynamic description on the pore scale. Then comes the coarse-graining, i.e., the homogenization, which is the scaling-up step. This means in practice spatial averaging.[3] There are several ways of doing this, perhaps that of Whitaker[4] is the most well-known. It is based on connecting the averages of gradients of pore-scale variables to gradients of the averages over the variables plus an integral over the surface area of the pores. The problem with porous media is that the surface area is extensive in the volume, so that this integral does not vanish to zero as one goes up in scale. We split the variables in the surface integral into an average part and a fluctuating part. This leaves us with having the averages, and gradients of the averages expressed in terms of the fluctuations of the original variables. The last step is to make an independent assumption on how the fluctuating variables are related to the averages – a closure assumption. With this, the equations we had between the original, pore-scale variables have been turned into equations between spatial averages of these variables. Hence, scale up is achieved.

Here is the problem with this approach. One cannot produce new types of variables, only averages over already existing variables. One may liken it to defocusing a camera. The picture gets blurred, but no new features appear. *No new variable types nor phenomena emerge.*

Now, there exists in physics already an upscaling procedure that does pick up emergent properties in the form of new variable types: Equilibrium statistical mechanics. Used e.g., to describe a gas or a liquid, it takes us from a mechanical description on the molecular scale to a continuum scale description, which in this case is thermodynamics. Here, temperature, pressure, chemical potential etc. are emergent variables.

In practice, statistical mechanics turns the original scale-up problem into that of calculating an integral, the partition function. I had the good fortune of doing my PhD at Cornell during the early eighties, when people like Ben Widom, Michael E. Fisher and Kenneth G. Wilson were doing their work on critical phenomena there. There are certain points in thermodynamic phase diagrams where the thermodynamic variables are singular. These singularities are described by critical exponents. Very different systems, e.g., magnets and gases can have critical exponents with the same numerical values. How is this possible as gases and magnets are completely different systems? Wilson and Fisher devised a method for calculating the partition function answering this question: the renormalization group. This method, which won Wilson the Nobel prize in 1982, constitutes the most successful upscaling program ever. It fully accounted for the emergent critical exponents, where earlier attempts using homogenization techniques had failed.

The problem in implementing a variant of statistical mechanics to describe immiscible two-phase flow in porous media is that it is an *equilibrium* theory. Flow in porous media represent, on the other hand, driven systems, which are far from equilibrium. Is there a way around this obstacle? My claim is, *yes there is*.[5]

A successful implementation of a variant of statistical mechanics to the flow in porous media will deliver a scaling up from the pore scale to the continuum scale in that it turns the problem into that of calculating an integral. There will be emergent variables, such as *agiture*,[6] *flow derivative*, and *flow pressure*, variables that have no equivalents on the pore scale – and there will be relations between them that follow from the upscaling, which have no meaning on the pore scale. These come from concepts that are meaningless on the pore scale, such as scale invariance, but which become central on large scales. Emergent properties in other words, in the full sense that Anderson crystallized the concept.

1 P. W. Anderson, More is different, Science, 177, 393 (1972).
2 S. Strogatz et al., Fifty years of 'More is different,' Nature Reviews Physics, 4, 508 (2022).
3 McClure et al. has recently pointed out that fluctuations in time are also important and should be averaged over to produce a complete coarse graining, see Phys. Fluids, 34, 092011 (2022).
4 S. Whitaker, Flow in porous media I: A theoretical derivation of Darcy's law, Transp. Porous Media, 1, 3 (1986).
5 See page 20 in this annual report.
6 See footnote 5.

DIRECTOR'S COMMENTS

The year 2022 was the year that saw the end of Covid. Well, a lot of us got it but it was no longer a threat thanks to the vaccines that had been invented. We could return to work for real. Conferences were no longer virtual, and we could visit colleagues again. But not everything was as before. Everybody had learned to use communication tools such as Zoom and therefore we could, e.g., have great speakers from all over the world for our weekly seminar series. We did not use such possibilities as actively before Covid, because we did not realize their potential, and the quality of these tools were not as developed.

We started for real in August to prepare for the *midway evaluation* that all RCN-funded[1] centers of excellence (CoE) go through, by organizing a two-day PI meeting in Oslo where we went through in detail the evaluation program that the previous generation of centers had gone through, assessing all aspects of PoreLab in the process. Huge was our surprise when we received an email from the RCN on December 13 stating that the Midway Evaluation was canceled, and all centers were recommended for continuation[2]. There was a sigh of relief, but also some regret. A midway evaluation is a lot of work, but it is also an opportunity to really stop and think about where we are and to have an independent and serious evaluation of our work.

As part of the midway evaluation, we were asked to provide a plan for what would happen after 2027 when the CoE funding would run out. By the end of the year, we had a complete sketch for a continuation plan which essentially emulates the way the Njord Center in Oslo[3] has been set up. But there is still a long way to go before there are contracts to sign.

Among the Principal Investigators (PI), there were at the end of 2022 three at the Department of Physics at the University of Oslo, one at the Department of Chemistry at NTNU, one at the Department of Geoscience and Petroleum, NTNU, and two at the Department of Physics, NTNU. In 2022 we were given an Onsager Fellowship under the NTNU Department of Physics. This is a tenure track position equivalent to an Assistant Professorship. It was announced worldwide in late 2022 in *computational porous media physics*. Hence, the PoreLab Trondheim's physics PIs will therefore cover all three "pillars of physics": experiment (Eiser), theory (Hansen), and computation (Onsager fellow).

We welcome Professor Douglas Durian, University of Pennsylvania, and Dr. Steffen Berg, Shell Research as new members of the Scientific Advisory Board (SAB). They represent experimental physics (Durian) and theoretical physics (Berg). Professor Anne Korre of Imperial College leaves the SAB. We look forward to continuing to have the SAB as a critical sounding board for our work, and even more so in that the midway evaluation was canceled.

We created a new eighth work package, "Steady-state experiments and coarse-grained modeling" to complement Work Package 1, "Thermodynamics of flow in porous media" and Work Package 5, "Thermodynamic driving forces." It has taken time to develop the theory under Work Packages 1 and 5, so it is only now that this new work package makes sense. *Marcel Moura* at the University of Oslo is the Principal Investigator for Work Package 8.

We saw a dip in the number of published papers in 2022, as compared to 2021: 57 vs. 76. The explanation for this is that 2022 is the fifth year of PoreLab. Our PhD students normally use four years to get their degree. When we started in 2017, many PhD students started, and they graduated in 2021. They have been replaced by a new generation. This generation was in their first year of studies in 2022, and hence had not started producing papers. In other words, the dip in the number of published papers is part of a natural and expected oscillation.

Here are some highlights of what we have published in 2022:

- Roy et al. investigated the co-moving velocity, a velocity parameter that does not transport anything, but which makes it

1 RCN: Research Council of Norway.
2 Why? Long story starting from somewhere deep inside the current Minister of Research.
3 https://www.mn.uio.no/njord/english/

Alex Hansen, visiting the Grand Prismatic Hot Spring at Yellowstone National Park, Wyoming, USA in October 2022. Photo by Quirine Krol possible to decompose a constitutive equation for the average flow velocity in immiscible two-phase flow in porous media into constitutive equations for each of the two immiscible fluids. In the paper, Roy et al. reconstructed the co-moving velocity by reverse engineering relative permeability data from the literature. It turns out that the co-moving velocity has a very simple form expressed in the right variables. A consequence of this is that Roy et al. found a simple relation between the wetting and non-wetting relative permeabilities which had never been seen – or even anticipated – before in the 86 years relative permeability theory has existed. One does not have to measure two independent relative permeabilities. It is enough to measure one and then use the relation between them that Roy et al. found (Transport in Porous Media **143**, 69 (2022)).

- There are three theories for what makes the oblate visitor from outer space ʻOumuamua deviate from its track around the sun that gravitation dictates: 1. Outgassing due to heating which acts the same way as rocket propulsion would, 2. that the object is a sail using light pressure as propulsion made by an alien civilization, and 3. a cosmic dust bunny (fractal) which is light enough to be driven out of course by the forces generated by radiation from the sun. Theory number 3 is the one that Flekkøy et al. (PoreLab) have proposed. But how do we distinguish between the three theories? Flekkøy and Brodin have calculated what the observational signature would be for each of them (Astrophys. J. Lett. **902**, L11 (2022)). Using this work, the James Webb telescope will be able to determine which of the three theories are correct.

- When flow in porous media was recognized as being an interesting problem in physics in the eighties, it was because injection of one fluid into a porous medium already containing another fluid immiscible with the first could lead to fractal structures under a wide set of parameters. Anything fractal was of great interest at that time. The problem which nobody discussed at that time was that the density of fractals would tend to zero as the length scales considered increased: When dealing with reservoirs that are measured in kilometers, the fractals would not be relevant. What is relevant on such scales is a measurable saturation of the injected fluid, and this demands underlying compact structures, and not fractals. Eriksen et al. have studied experimentally and theoretically compactification of viscous fingers, identifying the relevant mechanisms behind (Phys. Rev. Fluids **7**, 013901 (2022)).

- Vincent-Dospital et al. demonstrate experimentally and theoretically that gravity and gradients in grain size in granular porous media have the same impact on viscous and capillary fingers during drainage (Nature Com. Physics **5**, 306 (2022)). This simplifies considerably the theoretical understanding of such processes.

- Dichroism is a phenomenon seen in some nano-structured translucent materials, namely that the material has one color when the light source is behind it and a different color when the light source is in front of it. This is not a surface effect, but a bulk effect. The Romans discovered by accident this phenomenon almost two thousand years ago and demonstrated by the famed Lycurgus Cup in the British Museum (look it up on the net). Only in the seventies it was understood that the effect, in this case, is due to gold and silver nanoparticles and the difference in the color and direction they re-emit light which they receive. Erdem et al. use suspended non-metallic colloids forming Wigner crystal-like structures to produce dichroism (Front. Phys. **10**, 847142 (2022)).

- Bråten et al. have worked out a new framework for calculating the equation of state for fluids confined in small spaces – such as in porous media. It works for a wide range of geometries, sizes, interparticle interactions and wall-particle interactions. Molecular dynamics simulations match very well the theoretical predictions (J. Chem. Phys. **156**, 244504 (2022)).

- Berg et al. (Geophysical Prospecting **70**, 400 (2022)) have looked at the conductivity of partially saturated porous media. They are able to pick the conductivity apart into geometric concepts describing the porous medium: tortuosity and constriction. This is remarkable as conductivity is a transport property and not a geometric property.

We present further projects – and some of those above – in much more detail on pages 20 to 49.

AMBITIONS FOR 2022: DID WE DO WHAT WE SET OUT TO DO?

We allocated considerable time to the RCN midway evaluation during the fall of 2022. Then it was canceled. Never mind, it gave us an excellent opportunity to stop for a moment and reflect on where we are. And to consider the future, not the least beyond 2027, the year the CoE funds run out.

We started but have not finished writing the lead article on upscaling of porous media for *Frontiers in Science*.

Slowly but surely, we are edging towards a more equal gender balance.

And lastly, we are very satisfied with our scientific work. Rereading our proposal for PoreLab written in 2015 is interesting. There are not that many tasks that have not been touched at this point.

AMBITIONS FOR 2023

Our main ambition for 2023 is to continue our scientific work. A challenge is that the number of open questions that should be investigated is multiplying too rapidly. This is a sign that we are in new unexplored territory, and – you know what – this is a great place to be. As we cannot pursue all open ends, we need to better our ability to say no and to prioritize. In earlier annual reports, I have expressed a worry about integration between the different fields represented in PoreLab. I am no longer worried. It simply takes time to integrate a trans-disciplinary team. People from different fields have different understanding and knowledge and this needs to be overcome, and this is a learning process. I think we are there now.

We will continue to work on planning the continuation of PoreLab after 2027. We now have a pretty clear idea on how to proceed, and what is needed now is to bring this to the involved departments. Now, 2023 will be a year of politics in this sense.

The Language Council of Norway (Språkrådet) is worried about the overuse of English in the universities. I guess worrying about such matters is part of their job description. Nevertheless, we could be better at using Norwegian in discussions when appropriate. It is a fact that Norwegian scientific terminology is quite underdeveloped compared to English in fields that are rapidly advancing.

And we will continue striving for a more equal gender balance.

Alex Hansen

PoreLab: ADVANCING OUR FUNDAMENTAL UNDERSTANDING OF POROUS MEDIA PHYSICS FOR THE ENERGY TRANSITION AND BEYOND

The Ebers papyrus of about 1500 BCE describes the use of porous charcoal to treat indigestion in ancient Egypt.[1] Since then, we have come a long way in developing experimental and modeling workflows for porous media research. Historically, this was born of necessity, as porous materials are almost everywhere, influence our everyday lives, and are essential to our most basic requirements such as food, water, health, and energy. But, in reality, how effective are we at characterizing porous media and utilizing them to meet the needs of the future?

By **Steffen Berg**,
Shell Global Solutions International B.V.

As the energy transition becomes more pressing, technology improvements and breakthroughs in all areas of engineering and material science will need to happen more rapidly—especially in areas critical to decarbonization. Porous media research will have a critical role in imminent developments in technology areas such as batteries, smart materials, and refining. These applications will benefit from a combined perspective between multiphase fluid flow and thermodynamics, one of the many strengths of PoreLab.

PoreLab addresses the challenges for the future from an already very strong starting position. It has key capabilities in a range of relevant domains—for example, a strong foundation in theory development combined with expertise in experimentation. Porous media behavior presents some of the toughest problems in soft condensed matter physics. These non-linear, non-equilibrium, potentially non-ergodic, and complex-confinement problems have resisted, so far successfully, the most common approaches. However, as porous media are such a broad class of materials, views on the level of rigor to use to describe porous media processes naturally diverge.

For many engineering applications, simple-to-use pragmatic formulations have evolved that serve their purpose—up to a point. But, in the spirit of Karl Popper's philosophy of science,[2] such pragmatic descriptions are never the final word, and are often insufficient for taking the next step. Despite decades of research, many fundamental questions have not been satisfactorily answered: Are the common flow equations we use for multiphase flow really correct? What are the state variables? Can we derive the flow equations from first principles? Is there additional, unaccounted for, dissipation? And what about the energy balance? Therefore, what could be more important in the energy transition than aiming for a description level more consistent with a thermodynamic picture. It is clear that there is much more to porous media research for the energy transition than just repeating what has been largely already done before, only now for CO_2 and hydrogen. PoreLab therefore aims to raise the level of conceptual understanding. Could there be processes for harvesting energy from porous media in so far unimagined ways?

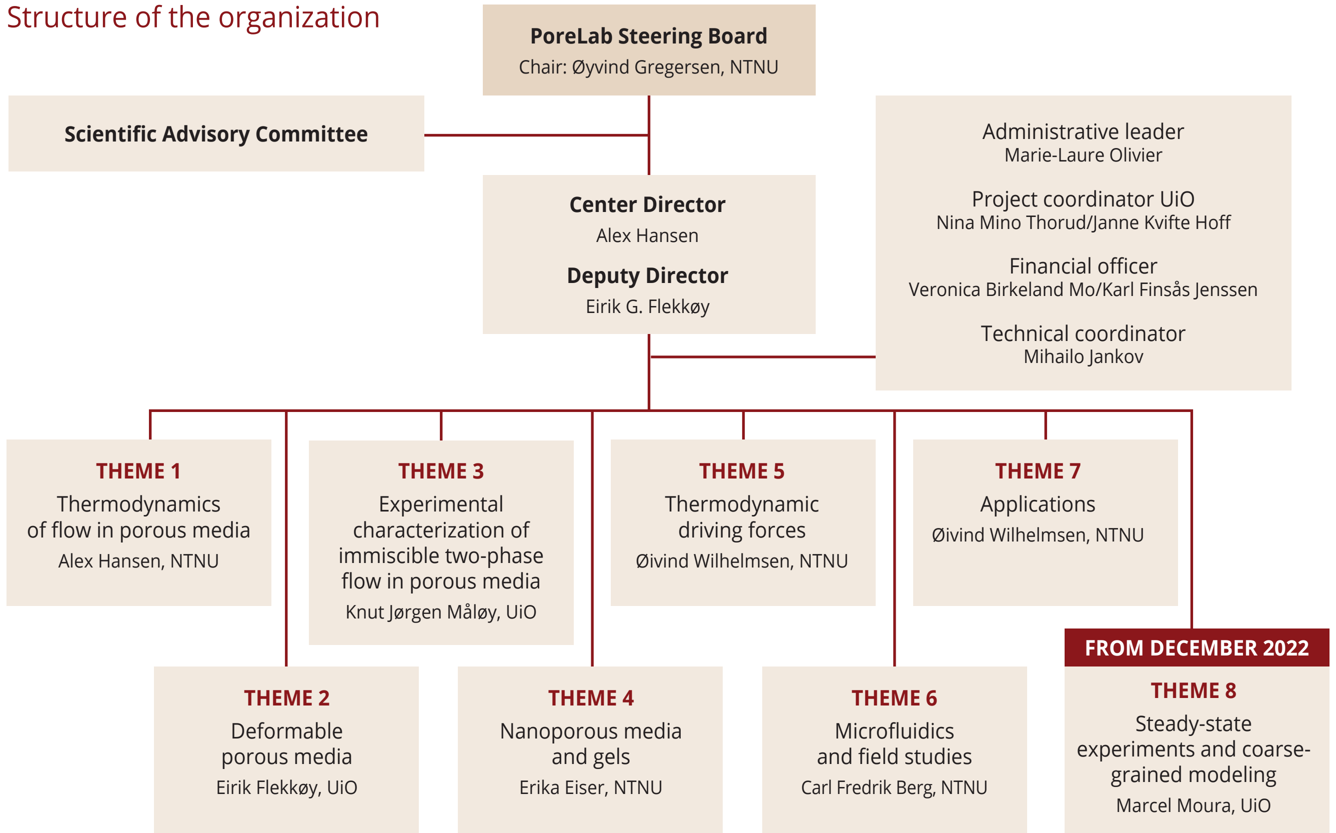
As a new member of the scientific advisory board, I find myself, as a scientist, in the right place. I know that PoreLab, with its rich mix of scientists of diverse scientific backgrounds, nationalities, and aspirations, is an open-minded and welcoming place. Furthermore, PoreLab addresses a very important gap in the porous media research landscape by combining experimental observation and theory development that follows classical natural science,[3] but transformed to a modern, interdisciplinary, and collaborative setting. In the coming years I expect to witness the major impact of PoreLab on porous media research and application. Watch this space!

Steffen Berg *is a Principal Science Expert at Shell Global Solutions International B.V. in the Netherlands. His main research interests range from the fundamental aspects of multiphase flow in porous media to gas dynamics at pore scale, which includes applications such as* CO_2 *sequestration and underground storage of hydrogen. He pioneered in-situ 3D real-time imaging by fast X-ray computed tomography to gain insights into structures at the pore scale. He is currently also a visiting reader in the Earth Science and Engineering and Chemical Engineering departments at Imperial College London, and the Chair of the Board of Directors of the InterPore Foundation.*

1 Bryan, C. P., *Ancient Egyptian Medicine: The Papyrus Ebers* (Chicago: Ares, 1974).
2 Popper, K. R., *The Logic of Scientific Discovery* (New York: Basic Books, 1959).
3 Bacon, Francis, *Novum Organum: With Other Parts of the Great Instauration*, trans. and ed. Peter Urbach and John Gibson (Chicago and La Salle: Open Court, [1620] 1994)

ORGANIZATIONAL CHART
OF PORELAB

Structure of the organization



PoreLab gathers scientists from 5 departments at NTNU and UiO. The Department of Physics is the host. Partners are the Departments of Chemistry, Geoscience and Petroleum, Civil and Environmental Engineering, all at NTNU, and Department of Physics at UiO. SINTEF Industry is our external research partner.

The Center is managed by the Director, Alex Hansen (NTNU) jointly with the Deputy Center Director, Eirik Flekkøy (UiO) and the Center Administrative Leader, Marie-Laure Olivier (NTNU).

PoreLab's research has been organized in eight Research Themes lead by the Principal Investigators (PIs). During PoreLab's strategy meeting in October 2021, the Leader Group decided to merge Themes 3 and 4, becoming Theme 3 on *"Experimental characterization of immiscible two-phase flow in porous media"*. A new Theme 4 on *"Nanoporous media and gels"* is now led by Professor Erika Eiser who joined NTNU and PoreLab in July 2021. PoreLab welcomed Professor Øivind Wilhelmsen as well who, from August 2021, replaced Professor Signe Kjelstrup now retired. Professor Wilhelmsen is now leading both Themes 5, *"Thermodynamic Driving Forces"*, and 7, *"Applications"*. In December 2022, we created a new Research Theme, number 8, entitled *"Steady-State Experiments and Coarse-Grained Modeling"* and led by Dr. Marcel Moura. Dr. Moura joined PoreLab in its early days, first as postdoctoral fellow, then as researcher. A description of both new Themes, 4 and 8, is given in the following page of this report. The organizational structure of the Center is flat. The team of now eight Principal Investigators and the Administrative Leader forms the Leader Group and has bi-weekly meetings to discuss administrative and scientific issues and update each other on developments and progress. The system for immediate updates ensures interdisciplinary progress.

The PoreLab Executive Board includes members from the faculties involved at NTNU and UiO. The board is responsible for overseeing that the activity takes place according to the contract with the funder, the Research Council of Norway. A central task of the Executive Board is to enhance the collaboration among participating Departments at NTNU and UiO.

The Scientific Advisory Committee of international experts aids in the development of a strategy for the scientific development of the center, thereby helping the leadership group to achieve the stated scientific aims.

NEW RESEARCH THEME 4

Nanoporous Media and Gels

In the fall 2021, we decided to merge the two Research Themes 3 and 4, *"Experimental Characterization of Steady-State properties of Flow in Porous Media"* and *"Experimental transient immiscible two-phase flow"* into a new Research Theme 3: *"Experimental Characterization of immiscible two-phase flow in porous media"* (read page 7 on the Annual Report 2021). In place of the old Research Theme 4, we created a new Research Theme 4 *"Nanoporous media and gels"* which is led by Professor Erika Eiser. Erika joined NTNU and PoreLab in July 2021, she is a soft matter physicist.

The objective of this new Research Theme 4 is to set up a *Soft Matter Group* that allows us to design and create nanoporous materials with well-defined pore-size distributions to study flow of complex fluids and gases through them. We employ various video-microscopy and micro-rheology techniques combined with simulation studies to study primarily dense colloidal suspensions and polymer gels that serve as biomimetic model systems. Our findings will be used to develop upscaling models that relate nano to bulk behaviours.

Understanding the flow of binary fluids through media with completely random pore-size distributions remains challenging, because it is both difficult to design such systems in the laboratory and often 3D porous systems are opaque. Examples of nano-porous media are for instance bioengineered membranes mimicking natural filtration systems to provide smart, implantable drug-delivery systems, bioartificial organs, and other medical devices, but they also constitute the cathode material in rechargeable lithium-ion batteries, membranes for desalination or even in the development of random lasers.

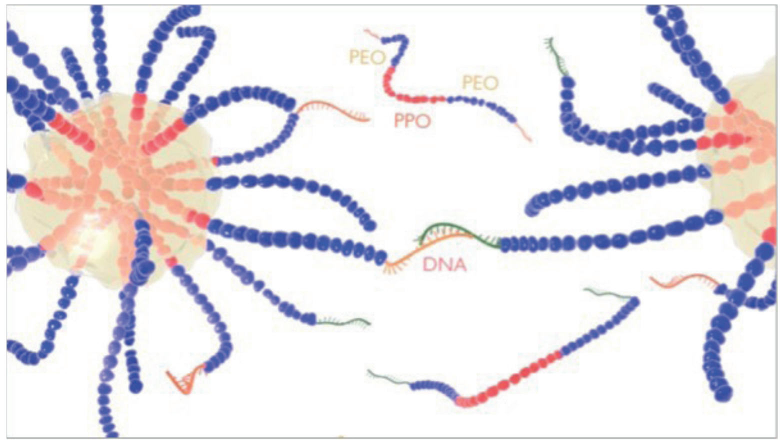
The Eiser group focuses on four main topics:

1. **Building colloidal networks with well-defined pore-size distribution:** Using our experience using short strands of DNA attached to colloids as highly selective, thermo-reversive glue to build transparent, model-porous networks embedded in a microfluidic channel and employing confocal microscopy to study binary flow through them as function of pore-size distribution, wettability, flow pressure and other properties.

2. **Sustainable stabilization of clay-rich ground:** Clay suspensions/gels as nanoporous colloidal systems will be further developed to study transport through them when exposed to freeze-thaw cycles mimicking for instance thawing in permafrost. In particular, we will use the interactions and results from mechanical measurements (e.g. microrheology) relating to the nanoscale to develop up-scaling models to understand the large-scale behaviour of clay-rich soils.

3. **Sustainable nanocomposite-films and coatings:** Transparent films made of natural clays and biopolymers have proven to have excellent mechanical and other physical properties. We will develop these systems into protective coatings, e.g. for solar cells, in particular studying the transport properties of gases through them, experimentally and developing a coarse-grained model for the nanocomposite.

4. **Highly selective bio-sensors:** We use our DNA-functionalized colloidal systems to develop highly sensitive and selective diagnostic tools for easy pathogen-DNA detection.



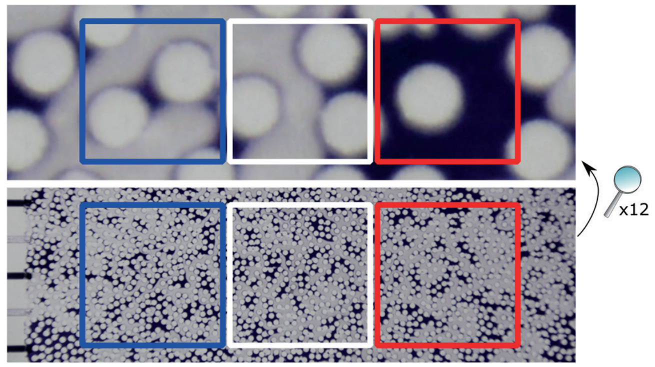
One model gel-system we explore are aqueous suspensions of Pluronics$^{\grave{O}}$. These commercially available, symmetric triblock-copolymers are made of two outer polyethyleneoxide (PEO) chains that are water soluble at all temperatures between zero and around 100 °C, and a polypropyleneoxide (PPO) middle block that is water soluble only at low temperatures. Hence, above a critical micelle temperature these polymeric surfactants form non-interacting spherical micelles. By functionalizing the free PEO chain ends with short, single-stranded DNA oligomers, we induce a competing self-assembling force that leads to the formation of a rich phase diagram showing liquids and viscoelastic, transient gels with complex relaxation behaviours. The structural properties and the corresponding rheological response of pure Pluronics$^{\grave{O}}$ systems have been studied in detail, the influence of the addition of DNA is still largely unexplored as it is costly in terms of DNA quantities needed. The Eiser group has mapped their experimental findings onto a course-grained simulation model mimicking both DNA-binding and attraction due to hydrophobic interactions between the PPO chains to explore a wide parameter range that can be accessed through the variability of the attached DNA strands. The image was created by Jiaming Yu based on his coarse-grained simulations using Blender: It represents self-assembled F108-micelles interacting with each other via complementary DNA strand.

NEW RESEARCH THEME 8

Steady-State Experiments and Coarse-Grained Modeling

In December 2022, we created the new Research Theme 8 entitled *"Steady-state experiments and coarse-grained modeling"* led by Dr. Marcel Moura. Marcel joined PoreLab in its early days, first as postdoctoral fellow, then as researcher. This new Research Theme is designed as an experimental counterpart to the theoretical approach put forward in Research Theme 1. The objective of this Research Theme is to design and execute experiments tailored to test the validity of the coarse-grained models that act as a bridge between the pore-scale physics and the continuum scale.

The experimental techniques employed to visualize and understand the dynamics of fluids moving through a porous network have experienced a fast development in recent years. The advance in computer power has had an immediate impact on the field either by simply allowing for larger data sets (necessary when dealing with larger samples) or by allowing for more powerful filtering routines (more data means also more noise). In spite of these undeniable experimental advances, many fundamental questions in the field remain unanswered, particularly around the task of establishing a theoretical level of description of multiphasic flows that is both **physically sound** and **applicable in practical settings**. By **physically sound**, we mean that the pore-scale physics must be fully satisfied. By **applicable in practical settings**, we mean that one must be able to use this theory to make predictions of quantities of relevance for large-scale systems, such as phase saturations and average currents. Research Theme 1 is devoted to the task of developing such a theory, a statistical mechanics description for immiscible and incompressible two-phase flow in porous media. This new theoretical framework necessitates new experimental designs to test its predictions. We will not only need to be able to produce high-speed and high-resolution images of the flows, but we will also need to tune properties of the porous networks in a controlled manner, something that typically is not done in most of the currently employed techniques. In order to fulfill that goal, we will work with artificial porous networks produced via a modern 3D printing technique called stereolithography. This technique allows for the construction of transparent networks of controlled geometrical properties with high resolution at the pore scale while still allowing for samples large enough to yield statistical relevance.



Two different levels of magnification of an experiment in which two immiscible fluids (lighter and darker colors) are simultaneously injected in a porous medium formed by a 3D printed array of circular cylinders. In the top image, the colored squares represent the typical pore scale and we see a very heterogeneous picture: the distributions of fluid phases inside the squares look very different. In the bottom image, the squares represent an intermediate scale of the experiment for which one can have well defined average quantities: the fluid configurations inside the colored squares are statistically similar.

Here are some examples of typical questions the experiments in this Research Theme will target:

1. Considering a given set of boundary conditions (fixed flow rates or pressures), fluid properties (ex. viscosities, densities and surface tension) and network properties (porosity and single-phase permeability), what is the steady-state saturation of each fluid phase?

2. What is the characteristic signature of the fluctuations in the phase saturation inside a given REV (representative elementary volume) and how do these fluctuations relate to the experimental conditions such as average flow rates and permeability?

3. If a steady-state configuration is perturbed (for instance by a pulse in pressure in the system), how does the system relaxes again to the steady-state?

4. What happens when two systems, each in a steady-state configuration are put in contact with each other? One could imagine this scenario for instance with a porous medium with two sections of different permeabilities. Will a new steady-state be reached for the combined system? If so, how does this new steady-state relates to the previous ones? This situation is somewhat analogous to putting two thermal systems at different temperatures in contact with each other. As they exchange heat, a new final state with intermediate temperature is reached. But what are the analogs of temperature, heat, and Fourier's law of heat conduction in the context of multiphasic flows?

DELIVERABLES ARE EXPECTED TO BE:

- A characterization of how the steady-state in immiscible two-phase flow in porous media is reached, its dependence on fluid properties, network properties and boundary conditions and its relaxation dynamics upon perturbations.

- A robust experimental protocol for testing the applicability of the coarse-grained models developed in Research Theme 1, its variables and the relations between them.

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HIGHLIGHTS

2022
4 new PoreLab related projects get funding in 2022: 2 from the RCN, 1 from the Arts Council Norway and 1 from EU (Horizon MSCA)

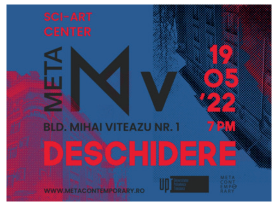
17 January 2022
Professor Emerita Signe Kjelstrup receives the InterPore Honorary Lifetime Membership Award

14 March 2022
PoreLab publication selected to be Editors Pick and on the cover of the Journal of Chemical Physics

29 March 2022
Professor Emerita Signe Kjelstrup receives the 2022 EFCE Michel L. Michelsen Award

8 April 2022
PoreLab - TUDelft - TU/e Seminar on Computational Methods in Nanothermodynamics

13 May 2022
PoreLab publication in Nature Communication by Professor Ursula Gibson



19 May 2022
Opening of the MV SCI-ART CENTER – Cultural Center for Contemporary Art and Science in Timisoara, Romania, with Marcel Moura, PI at PoreLab

15-16 June 2022
EarthFlows Meeting at the University of Oslo

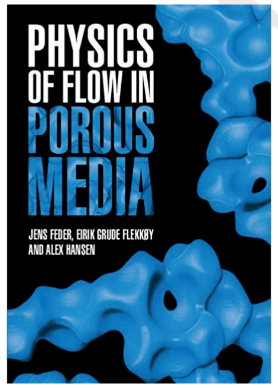
28 June 2022
Article *"Equation of state for confined fluids"* from Vilde Bråten and al. chosen as featured article and as science highlight by AIP

28-30 June 2022
Workshop on *Non-Newtonian Flow in Porous Media*, Hotel Gran Marquise, Fortaleza, Brazil

1 July 2022
Symposium in honor of José Soares Andrade Jr.'s 60th birthday

9 July 2022
Publication in Nature Communication by Seunghan Song, PhD candidate at PoreLab together with Professor Ursula Gibson

17-22 July 2022
Researchers Paula Reis and Gaute Linga had their poster presentations awarded during the 2022 *Gordon Research Conference on Flow and Transport in Permeable Media* in Les Diablerets, Switzerland



September 2022
Release of the book *"Physics of flow in Porous Media"* by Feder, Flekkøy and Hansen

September 2022
Professor Carl Fredrik Berg, PI at PoreLab, is the new president of the board for the SCA (The Society of Core Analysts)

10 November 2022
Former PoreLab Scientific Advisory Board member and long-term visitor at PoreLab, Daan Frenkel, Emeritus Professor at the University of Cambridge, receives the Lorentz Medal Award 2022 from the Royal Netherland Academy of Arts and Sciences

EQUILIBRIUM STATISTICAL MECHANICS FOR DRIVEN FLOW IN POROUS MEDIA?

Alex Hansen[1], Eirik G. Flekkøy[2], Santanu Sinha[2] and Per Arne Slotte[3]

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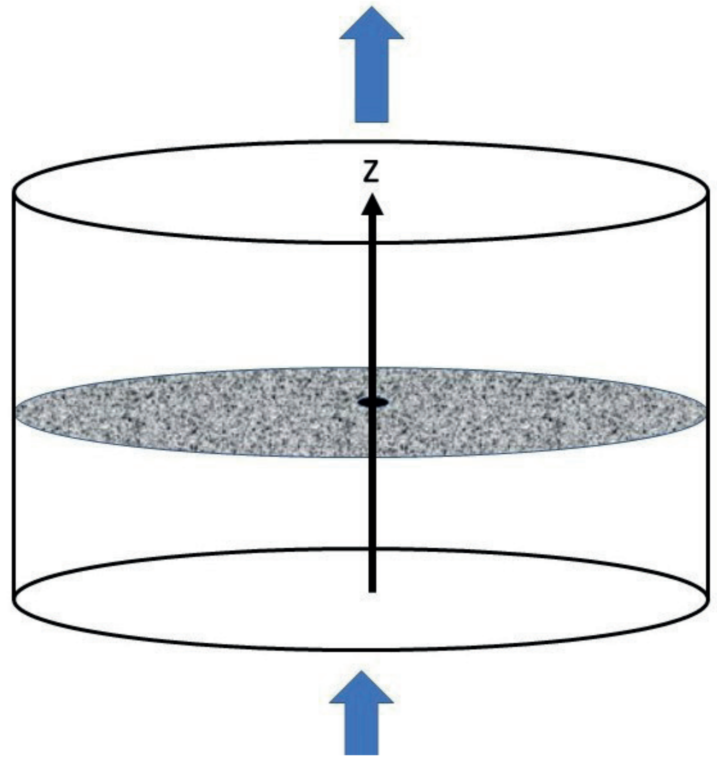
Equilibrium statistical mechanics is a method for scaling up from a small-scale description of a system to a large-scale description. For example, take a gas. On small scales, the gas is a collection of molecules flying around and bouncing into each other. On the human scale, the gas will be something we characterize by using a thermometer and a pressure gauge. Statistical mechanics is the method by which we get from the molecular description of the gas to the human description of the gas.

So, equilibrium statistical mechanics should be ideal for scaling up immiscible multiphase flow in porous media from the pore scale to the Darcy – continuum - scale. The problem is the term "equilibrium." Flow is dissipative and not in equilibrium. We must therefore forget the standard implementation of statistical mechanics for this problem. It will not work.

However, in the fifties, Edwin T. Jaynes generalized equilibrium statistical mechanics by changing its foundation from mechanics to information theory [1]. After Shannon had introduced the information entropy function [2] – a function that measures what we do *not* know about a system – among other criteria demanding that it has its maximum, when all possible configurations of the system we consider are equally probable. Jaynes built on the information entropy concept by turning the problem on its head. Given the information entropy of a system, can we work out what is the probability distribution for the different configurations of the system? Yes, by maximizing the entropy given what we know about the system.

We show in the figure a cylindrical block of porous material. The bottom and top edges are open whereas the sides are closed off. We imagine that a mixture of two immiscible fluids is steadily injected through the bottom and leaving through the top. Inside the porous medium, the flow is then in a steady state. This means that the macroscopic variables are constant or fluctuate around well-defined averages. We show an imaginary cut through the porous block. The cut will reveal a pattern of matrix material and void, and in the void, there will be patterns according to how the immiscible fluids are distributed. Lastly, the fluids will form a distribution of velocities in the cut. All this information made up by these patterns may be characterized by a *flow entropy* constructed from their statistics. As we move the cut in the z-direction, there will be no increase nor decrease of this entropy. There is no production or destruction of flow entropy along this axis as there is no way to determine where the cut was made along the cylinder (apart from close to the inlet and outlet edges). We may interpret the z axis as a "time" axis, and our porous medium problem becomes similar to those handled ordinarily by equilibrium statistical mechanics. Now, all the ingredients are in place to use the Jaynes approach: We have thus constructed an equilibrium statistical mechanics based on the flow entropy in this paper that was published online in 2022 [3].

This statistical-mechanics approach leads to a thermodynamics-like formalism in the continuum limit. There are emergent variables such as *agiture* – short for "agitation temperature," which is the conjugate of the flow entropy, the *flow derivative* – a relative of the chemical potential in ordinary thermodynamics, which is the conjugate of the saturation, and the *flow pressure* – which has no equivalent in ordinary thermodynamics, which is the conjugate of the porosity. This thermodynamics-like formalism makes contact with our 2018 paper [4] based on the Euler homogeneous function theorem. There we speculated whether there was complete pseudo-thermodynamics hiding behind this approach. Now we know, we have seen the entire iceberg.



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[1] E. T. Jaynes, *Information theory and statistical mechanics*, Phys. Rev. **106**, 620 (1957).

[2] C. Shannon, *A mathematical model of information*, Bell Systems Technical Journal, **27**, 379 (1948).

[3] A. Hansen, E. G. Flekkøy, S. Sinha, and P. A. Slotte, *A statistical mechanics for immiscible and incompressible two-phase flow in porous media*, Adv. Water Res.,**171**, 104336 (2023).

[4] A. Hansen, S. Sinha, D. Bedeaux, S. Kjelstrup, M. Aa. Gjennestad and M. Vassvik, *Relations between seepage velocities in two-phase flow in homogeneous porous media*, Transp. Porous Med. **125**, 565 (2018).

RESEARCH PROJECTS

COLLECTIVE STATES OF ACTIVE MATTER WITH STOCHASTIC REVERSALS: EMERGENT CHIRAL STATES AND SPONTANEOUS CURRENT SWITCHING

Kristian S. Olsen [1], Eirik G. Flekkøy[2], Luiza Angheluta[2]

[1] Nordita, Royal Institute of Technology and Stockholm University, Sweden
[2] PoreLab, The Njord Centre, University of Oslo, Norway

Collective behaviour is ubiquitous in biological systems, ranging from collective migration of cells and bacteria to flocks of birds and other animals [1]. Multistability is often present in realistic swarming behaviour, where the system undergoes a series of transitions between different collective states, that are triggered by perturbations. Often such perturbations are external, e.g., in the form of disordered media, obstacles or externally applied fields. In biological systems however, perturbations may be internal in the sense that agents represented as particle occasionally perform make individual choices. For example, several species of bacteria are known to suddenly reverse their direction of motion, while their normal dynamics only includes smooth slow reorientations. It is the goal of this project to unveil which collective states may be produced when such reversals are combined with inter-particle interactions.

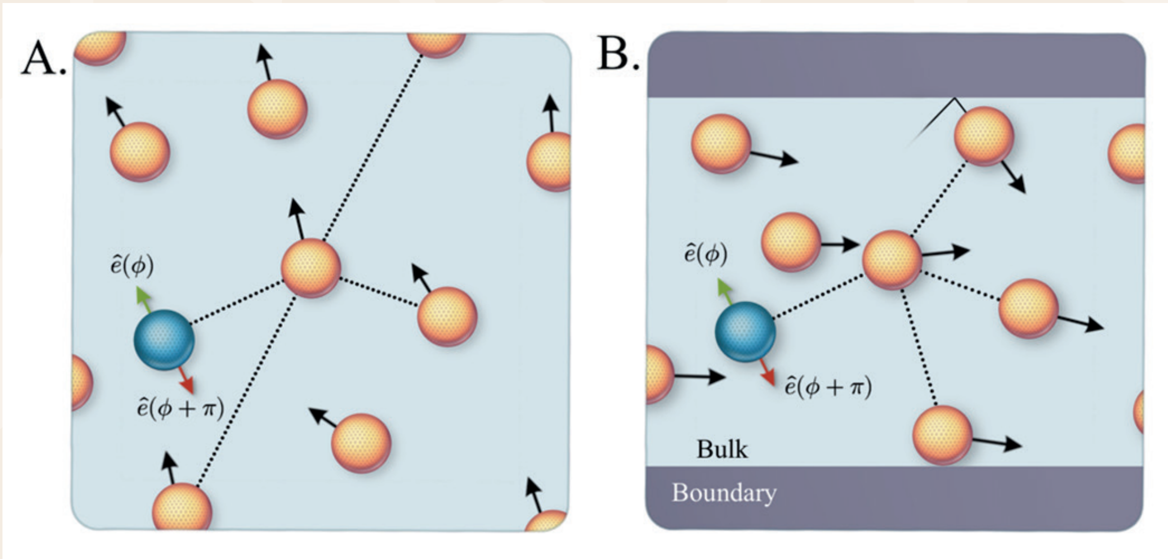
In particular, we consider active particles that move with a constant self-propulsion speed in two dimensions [2]. Particles interact with a random selection of other particles and tries to align their direction of motion with their neighbours. Randomly, but at constant rate, the particles reverse their direction of motion. See figure for sketch of the dynamics.

When the particles move in open unconfined space (part A in figure), surprising collective states appears. At weak interaction strengths the flock of particles performs seemingly random motion. As the interaction strength increases the flock becomes chiral as the mean direction of motion picks up an angular velocity. At intermediate interaction strengths this angular velocity randomly switches signs, while at strong interactions it is constant. Similar effects are found when the particles are put in a channel (part B in figure); in this instance the flock can collectively move either to the right or to the left in the channel, and the collective states undergo transitions between these two possible states.

RECOMMENDED READING

[1] M. C. Marchetti, J.-F. Joanny, S. Ramaswamy, T. B. Liverpool, J. Prost, M. Rao, and R. A. Simha, Hydrodynamics of soft active matter, Rev. Mod. Phys. **85**, 1143 (2013).

[2] Olsen, K. S., Angelutha, L., Flekkøy, E. G., (2022). Collective states of active matter with stochastic reversals: Emergent chiral states and spontaneous current switching. Physical Review Research **4**, 043017.



Sketch of the system under consideration. Self-propelled particles align through continuous-time alignment interactions and undergo stochastic reversals of their direction of motion at random times (see e.g., blue particle). Particles interact with a fixed number of other particles irrespective of their physical separation. Both collective dynamics in open space (fig. A) and confined to a 2D channel (fig. B) is considered.

MIXING OF FLUIDS IN CHANNELS WITH BOUNDARY ROUGHNESS

Ivar S. Haugerud[1], Gaute Linga[2], Eirik G. Flekkøy[2], Luiza Angheluta[2]

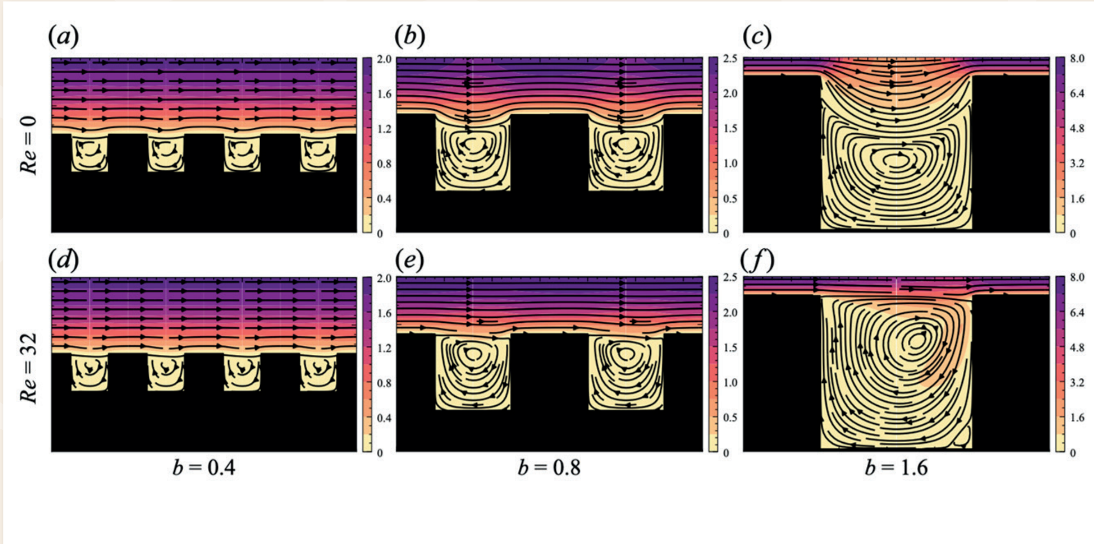
[1] Institute of Physics, University of Augsburg, Germany
[2] PoreLab, The Njord Centre, University of Oslo, Norway

Transport of solutes through channels with rough boundaries is abundant in natural and engineered settings. However, it is not known currently what the consequences of an abruptly alternating boundary are for the solute dispersion, in particular when advected by inertial fluid flow. To investigate this, we compute numerically the spreading of a passive solute advected by fluid flow through a two-dimensional channel with square boundary roughness. This showed how the effective diffusion coefficient depends on the boundary amplitude, and the parameters that describe the flow and mixing. These parameters include the fluid velocity, the fluid viscosity and the molecular diffusion coefficient. For creeping flow, the effective diffusion coefficient is found to be enhanced significantly through the recirculation zones. Such flows are characterized by a small ratio of velocity to viscosity, which is typical for flows at small Reynolds numbers. Decreasing the fluid viscosity, however, reduces the effective diffusion coefficient by up to a factor of two. This counter-intuitive effect, that mixing is reduced with decreasing fluid viscosity, is due to the change in the shape of the streamlines which is seen by comparing the upper and lower panels of the figure. By analyzing the time spent in the recirculation zones by particles that diffuse and follow the flow, this effect may be understood as follows: At smaller viscosities more particles are trapped in recirculation zones, depleting the population of particles on open streamlines where the contribution to the overall spreading is stronger.

The effect that flow fields with small viscosities or high velocities cause a weaker mixing than flow fields of high viscosity or low velocity is surprising and also holds for the spreading of heat. It is therefore relevant for thermal exchange processes that take place in geological or engineering contexts.

RECOMMENDED READING

Haugerud I.S., Linga G., Flekkøy E.G. (2022). Solute dispersion in channels with periodic square boundary roughness. J. Fluid Mech., **944**, A53, *doi:10.1017/jfm.2022.522*



Visualization of the velocity fields at different roughnesses b and Reynolds numbers. For each panel, the spatial axes are scaled equally, and the color bar denotes the fluid speed in factors of the unit cell average value. (a–c) Reynolds number 0, and roughness b = 0.4, 0.8 and 1.6, respectively. (d–f) Reynolds number 32, and roughness b = 0.4, 0.8 and 1.6, respectively.

THERMAL CONDUCTION THROUGH A COOL WELL

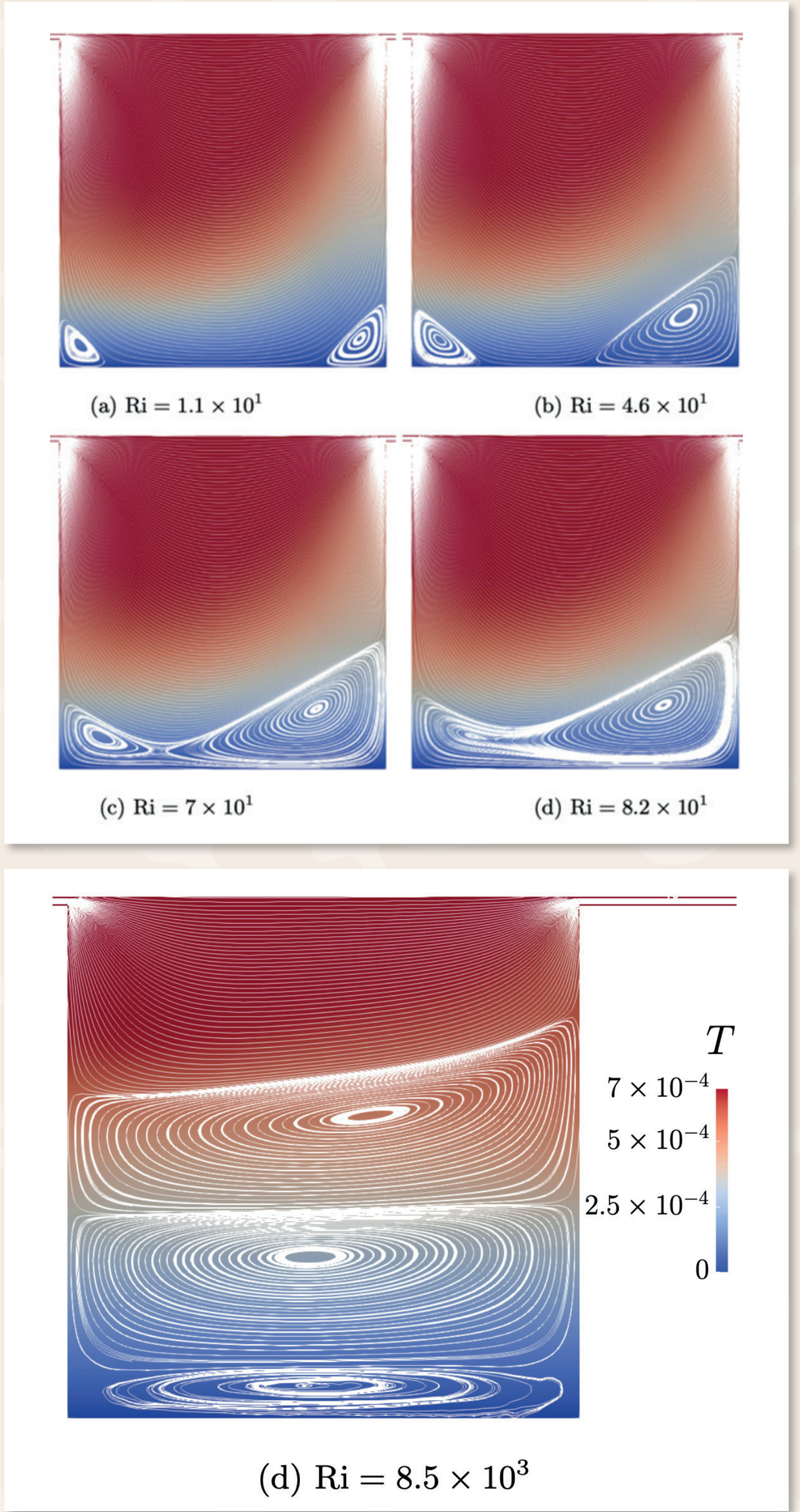
Beatrice Baldelli[1], Gaute Linga[1] and Eirik G. Flekkøy[1]

[1] PoreLab, The Njord Center, University of Oslo, Norway

Understanding the heat exchange between a moving fluid and solid walls is of interest in contexts that range from those of biology to engineering and geology. This heat is generally affected by the surface roughness. In this study the surface roughness is represented by a single square well over which the fluid is flowing between two narrow channel openings. When there is a temperature difference between the top and the bottom of the well, the resulting flow field in the well is governed both by fluid inertia and buoyancy forces. The ratio of the latter to the former is known as the Richardson number Ri. Contrary to most studies of thermal convection, where the buoyancy enhances the flow (for instance, when solar heating forms cumulus clouds) this study focuses on the case where the flow is suppressed by buoyancy as the bottom of the well is colder than the top. This reduces the vertical transport of thermal energy and hence has an insulating effect as the advective part of the transport is reduced with increasing temperature differences: As the value of Ri increases the cavity becomes filled by vortices that grow out of the bottom corners, see Fig. A. As this happens the average fluid velocity decreases, so that the fluid in the cavity approaches the state where diffusion becomes the dominant factor in the heat transport, as is the case in Fig. B where the slow system spanning vortices hardly advects any energy at all, leaving the energy transport to thermal diffusion. The main result of the study is the measurement of the effective thermal conductivity through the well, which changes by a factor 3 or more as Ri and Reynolds number is varied.

RECOMMENDED READING

Baldelli, B., Linga G., Flekkøy, E.G., (2022). *Thermal conduction through a cool well*. Physical Review Fluids **7**, 103503.



The streamlines and temperature field (red is warm, blue is cold) at different values of the top-to-bottom temperature difference. The dimensionless Ri is the ratio of buoyancy forces to inertial forces in the fluid.

THE TRANSITION FROM VISCOUS FINGERS TO COMPACT DISPLACEMENT DURING UNSTABLE DRAINAGE IN POROUS MEDIA

Fredrik Kvalheim Eriksen[1], Marcel Moura[1], Mihailo Jankov[1], Antoine Turquet[1,2], Knut Jørgen Måløy[1], Eirik Grude Flekkøy[1]

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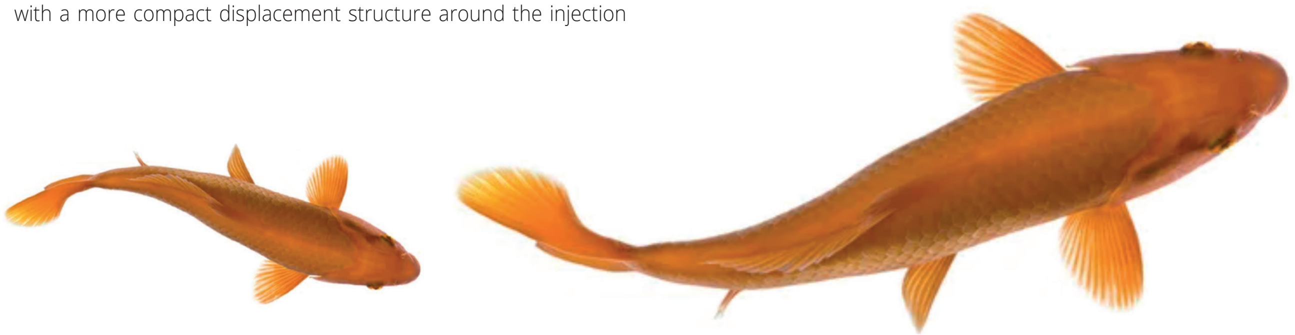
The displacement of one fluid by another in a porous medium is a rather common thing. It's what happens when rain falls down on the ground invading the pore-space and displacing the air that was previously there, a process called imbibition. The opposite scenario, say for instance when air displaces water from the soil during evaporation, is called drainage. Previous studies have shown that the typical invasion patterns that result from these processes (i.e., which pores get invaded when one fluid displaces another) are strongly dependent on properties of the fluids (like their viscosity, density and interfacial tension) and of the experimental conditions (for instance, how fast the fluids flow). A particularly interesting invasion scenario occurs when a less viscous fluid rapidly displaces a more viscous one from a porous medium. The resulting invading pattern is called viscous fingering, and it is characterized by a very branched structure that could somewhat resemble a lightning bolt or a branching tree, see Figure 1. This curious invasion structure has been extensively studied in the past and in particular it has been shown that the mass distribution of the invading phase is fractal with a fractal dimension of D = 1.62 [1].

In a recent investigation [2] we have analyzed what happens when the ratio M between the viscosities of the invading and defending fluids is changed. Interestingly, we have found that when M exceeds a given threshold, a notably different invasion pattern is observed with a more compact displacement structure around the injection point followed by viscous fingers around its perimeter, see Figure 2. This project aims to characterize and explain the processes leading to the cross-over from the previously studied viscous fingers to the more stable and dense compact displacement patterns. In our experimental work, we have employed a radial cell filled with a single layer of glass beads as a model for the porous network. Using this setup (called a modified Hele-Shaw cell), we have run a series of experiments in which we systematically vary the viscosity ratio M (by varying the composition of the fluid filling the cell, a glycerol-water mixture) and the overpressure at which the air phase is injected. We show that above a critical value of the viscosity ratio M and of the air overpressure, the compact displacement patterns become dominant.

These compact displacement structures with fingers around the perimeter present some additional interesting geometrical features. For example, we have observed that this system presents proportional growth, i.e., the ratio between the size of the fingers to the size of the whole structure remains constant during the growth process (just like it happens sometimes in biological systems, if we look at a small fish and a big fish, one looks like a scaled up version of the other). We have also observed that contrary to what is seen in the standard viscous fingering case, the pores inside the compact zone closer to the inlet present very strong ganglion dynamics, their state being intermittently filled by one fluid phase and then the other in fast secession. Another feature of this compact displacement regime, which is also in opposition to what has been observed in standard viscous fingering, is that the pressure in the space between the fingers does not reach a nearly constant value but presents instead strong gradients. This observation helps us to explain the intense ganglion dynamics that was observed. We are now working on a theoretical model to explain these finds and in particular the origin of the observed proportionate growth of the patterns.



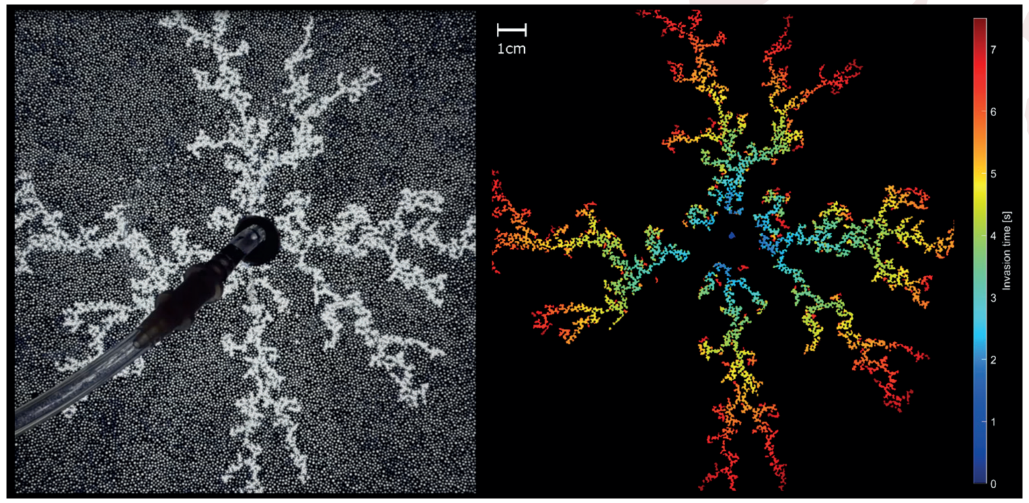


Figure 1: (left) Viscous fingering pattern that emerges when a lower viscosity fluid (in this case air, light color) is rapidly injected into a porous medium saturated with a higher viscosity fluid (a glycerol-water mixture, darker color). The porous network is formed by 1mm glass beads in a quasi-2D geometry. (right) Image analysis of the invasion pattern where the color is used to indicate the time of invasion.

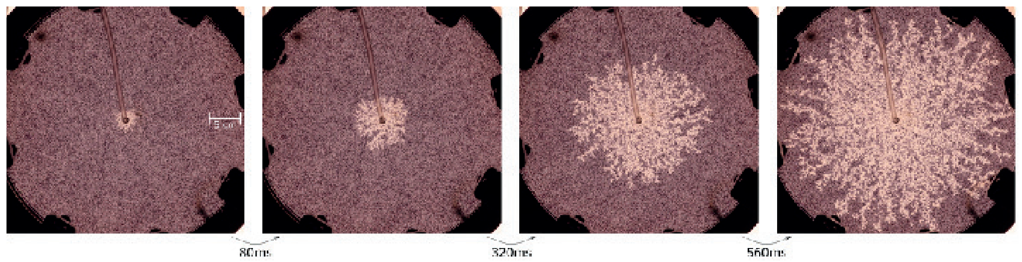


Figure 2: When the ratio between the viscosities of the invading and defending fluids exceeds a given threshold, an interesting invasion pattern is seen with a compact dense zone around the inlet followed by branching fingering structures around its perimeter. The four snapshots illustrate the temporal evolution of a typical experiment in which the defending fluid (darker color) was a glycerol-water mixture with glycerol concentration Cg = 20 % (by mass) and the pressure of the invading air (lighter color) was 50 cmH_2O. The time delay between consecutive snapshots is shown in the figure.

RECOMMENDED READING

[1] Knut Jørgen Måløy, Jens Feder, and Torstein Jøssang. Viscous Fingering Fractals in Porous Media. *Phys. Rev. Lett.* **55**, 2688 (1985).

[2] Fredrik Kvalheim Eriksen, Marcel Moura, Mihailo Jankov, Antoine Leo Turquet, and Knut Jørgen Måløy. The transition from viscous fingers to compact displacement during unstable drainage in porous media. *Phys. Rev. Fluids* **7**, 013901 (2022).

DRAINAGE PATTERNS IN POROUS MEDIA WITH A GRADIENT IN GRAIN SIZE

Tom Vincent-Dospital[1], Marcel Moura[1], Renaud Toussaint[1,2], and Knut Jørgen Måløy[1]

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[2] University of Strasbourg, France

Porous media that display a gradient in the structure of their networks are common in nature, but the understanding of the flow patterns in such media is still limited. In most experimental investigations, the porous media geometry does not include any large-scale heterogeneities, i.e., porosity and permeability do not vary in accordance to any pre-defined trend but are instead taken as constant values characterizing the whole network. It is understandable why this is so: when trying to study something complicated, one often needs to make simplifications and build knowledge step-by-step. From the theoretical point of view, the description of homogeneous and isotropic systems is simpler, involving scalar fixed quantities instead of varying tensorial quantities in the laws governing fluid flows. Experimentally, it is challenging to tune parameters of the porous matrix in a controlled manner, due to technical limitations either in the resolution with which samples can be produced or in the total size of such samples. However, in recent years, the rise of modern 3D printing techniques has opened a new window of investigation for the experiments: we can now produce porous samples with controlled geometry that are large enough to include enough pores to be statistically relevant while still keeping sufficient resolution at the pore-level (see page 59 of the PoreLab Annual Report 2021 for a description of the 3D printing methodology).

In this work [1] we employ modern stereographic 3D printing techniques to present an investigation of drainage in porous media with a gradient in the grain size (and hence in pore invasion thresholds), in an external gravitational field. Previous studies have shown how gravity can stabilize an invasion front [2]. Intuitively we can understand that: if a lighter fluid is invading a heavier one from the top, the front between them is flattened out by gravity. We have now shown, both theoretically and experimentally, how a structural gradient in the average pore size can have a similar effect as gravity in the stabilization of the front (or in its destabilization, depending on the direction of the gradient). This is a surprising find, as in principle there is no obvious connection between a body force like gravity and geometrical features of the porous sample.

In Figure 1 we show snapshots from experiments in which we used a quasi-2D porous structure produced by stereographic 3D printing. The porous matrix is initially saturated with a darker liquid (a mixture of glycerol and water) and air enters the medium from a width-spanning channel in one of the sides. In a), the average pore size decreases in the direction of the flow, which leads to a stabilized front. In b), the opposite happens, i.e., the average pore size increases in the direction of the flow, thus destabilizing the invasion and leading to the air phase fingering through the medium. In c) and d) we show how tilting the model (thus adding a gravitational component opposite or along the flow direction respectively) can revert the stability of the experiment. We also present invasion percolation simulations of the same phenomena, see Figure 2. Those simulations are in line with our theoretical and experimental results showing that gravity and gradients in pore sizes have a similar effect and can be used to stabilize or destabilize the invasion (Figure 2 a) and b) respectively). Our experimental and numerical finds have led us to propose a theoretical framework that allows us to better quantify these patterns. In particular, we can now predict precisely how the width η of a stable invasion front (see Fig. 2 a) scales with gravity, the spatial gradient of the average pore invasion threshold and with the local distribution of this (disordered) threshold.

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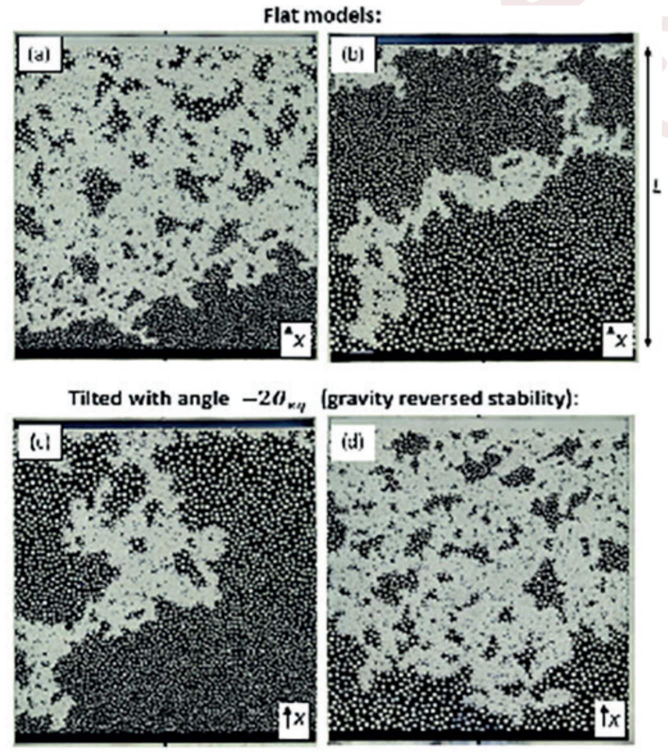
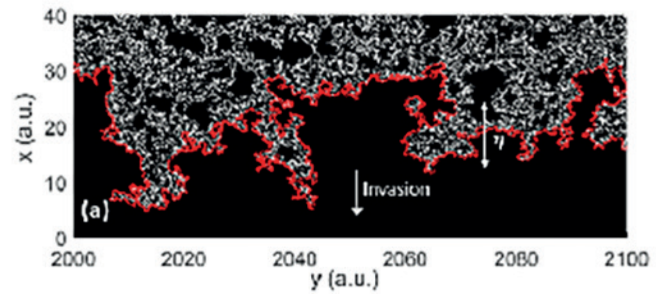


Figure 1: Drainage experiments in a 3D printed quasi two-dimensional model. Air invaded from the top of the pictures into a water-glycerol solution coloured with nigrosin. (a) A decrease in 'permeability' as the flow progresses (the air invades from the big pores to the small ones) leads to a stable invasion. (b) An increase in 'permeability' with the flow progression and an unstable process. In both cases, the model is horizontal, which means we have no contribution from gravity. (c) and (d) show the same experiments in a chosen destabilising or stabilising gravity field (respectively) with tilt angle −2θeq. The stability of the flow is thus reversed by gravity.



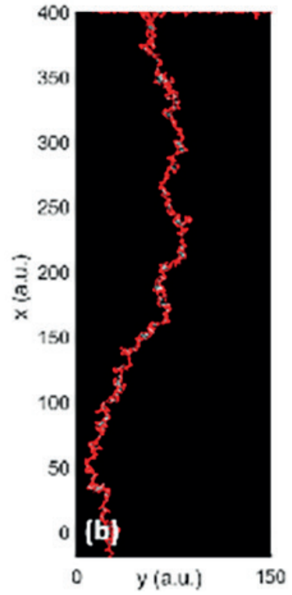


Figure 2.:
a) Invasion percolation simulations with a stabilizing gradient in invasion threshold.
b) Invasion percolation simulations with a destabilizing gradient in invasion threshold.

RESEARCH PROJECTS

SUSTAINABLE, STABLE GROUND

SUSTAINABLE STABLE GROUND

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Sustainable, Stable Ground is a new project within Theme 4 "*Nanoporous media and gels*" and is part of the equally named RCN proposal (Bærekraftig Grunn). This project started mid 2022 providing 3 PhD students and 3 postdoctoral fellows, who will be involved via experiments and simulations at different length scales.

The ground in Norway is rich in illite clay, a natural sheet-like crystalline mineral that is held together via ionic bonds. Due to this particular crystalline structure illite is the main cause of massive landslides. Hence, building roads and constructions require the use of large quantities of cements for stabilization. Environmentally, cement is a major contributor to the world production of CO_2, making up around 8% of the annual emission.

In this project **we aim at exploring the question** of how possible ground stabilization solutions may quantitatively work at the fundamental scales and how they connect to macro-scale properties. Furthermore, we want to develop smart solutions that may utilize solid waste products to contribute to a sustainable stabilization of ground. To address these questions successfully, our team of PIs, postdocs and PhD students, needs to first develop coarse grained simulation methods, starting at the atomistic scale and going up to the macroscale. A first step is to explore the Norwegian illite clay composition such that the group around Ida-Marie and Astrid can start constructing atomistic models of the clay's crystalline unit cell to find the correct force fields describing the interactions between clay particles across the aqueous background and as function of its ionic strength. The Eiser group recently hired a PhD student, René Tammen, who will extract the native illite from bore-cores taken around Trondheim using standard purification methods. While many clays around the world have a similar base composition as most 2:1 Phyllosilicates, it is the partial substitution with different elements of the Si atoms and the presence of the characteristic counterions that make each single clay behave differently.

Hence, we need to obtain the ratio of different elements present. Further, we will determine the average particle charges to obtain further insight into the DLVO forces (summing Coulomb and van der Waals interactions). Building on the knowledge gained we can start exploring larger scale experiments such as stability against shear stresses for several solvent conditions.

In collaboration with all team members, we will then gradually upscale our experiments and feed our findings into the course graining of the modeling part. The most important aspect will then be to explore different, sustainable option to stabilize illite-rich soils.

Building on the experience of the Eiser group on assessing and quantifying the aging process of suspensions of the synthetic clay Laponite we also explore the use of bio-polymers such as chemically modified cellulose, agarose and other polysaccharides as additives to those Laponite solutions. We have shown that mixtures of Laponite and Cetylmethyle Cellulose form nanocomposite films with excellent mechanical, thermal and optical properties. Under the right conditions these films of coatings can even become water-insoluble and therefore represent ideal coatings made of sustainable materials. This work is pursued in a Masters project in collaboration with Professor Kristin Syverud from the RISE-PFI Institute.

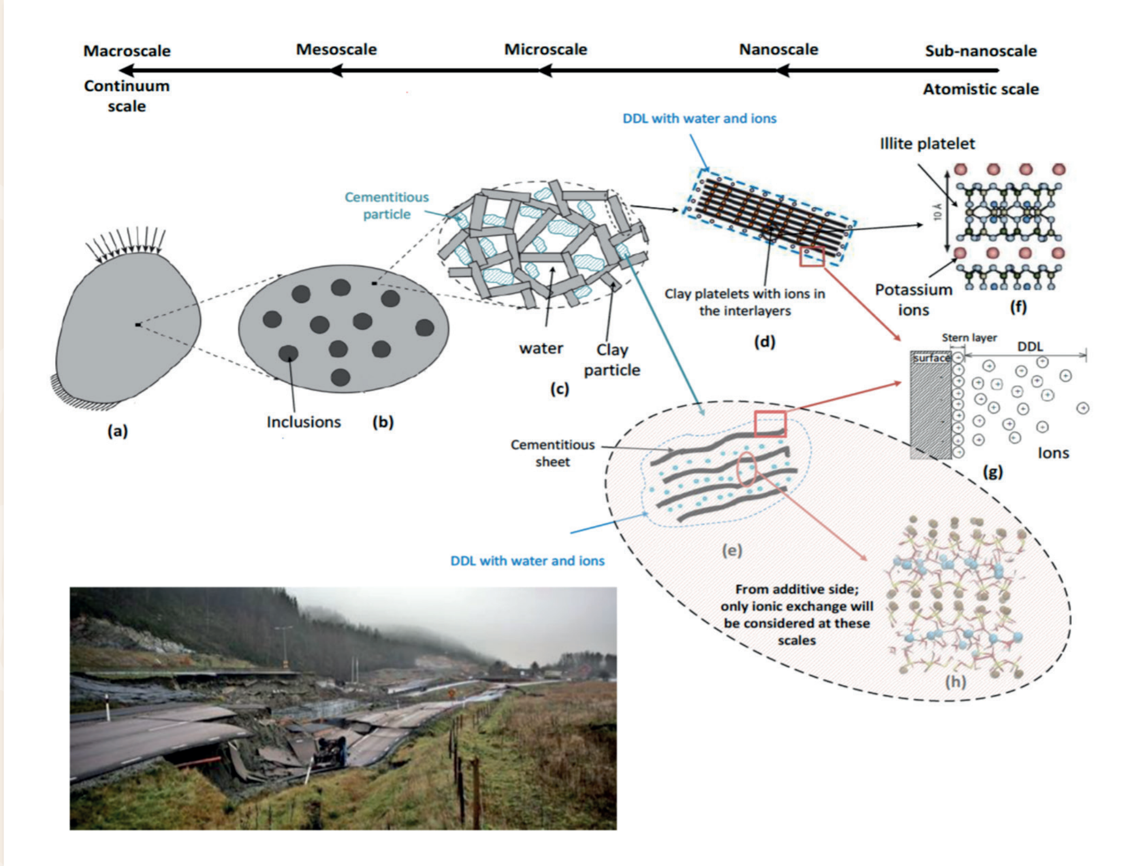

Figure: Cartoon detailing the many length-scales involved in understanding the relation between the macroscopic failure of clay-rich ground and the interparticle interactions on nano-scale. The natural clay illite is a phyllosilicate with a sheet-like crystalline structure made of covalently bonded, octahedral layers, which are sandwiched by two tetrahedral silicon oxide layers (f). Several of these 1nm thick platelets are glued together via ionic bonds to form clay particles (d). In the presence of water the platelets will interact via a Diffuse Double Layer, caused by the charges on their different faces: The flat faces are negatively and he rims are positively charged leading to a complex interaction potential between them. Depending on the ionic strength of the aqueous background the thickness of the DDL can vary, leading to swelling in low salt condition. This leads to dramatic lowering of friction between the platelets and eventually to dramatic failure in the soil as illustrated in the photograph that depicts the Småröd slid; photo Wenche Marie Jacobsen.

NANOTHERMODYNAMICS AND TWO-PHASE FLOW IN POROUS MEDIA

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We present the essential steps of a new upscaling procedure for porous media science using nanothermodynamics[1].

A long-standing problem in porous media science is the thermodynamic description of two-phase flow. In Darcy's law, the volume velocity of either phase, J, is proportional to the pressure gradient $\partial p/\partial x$ across the medium with as proportionality constant, the one-phase flow permeability, K, times the relative permeability k divided by the fluid viscosity η of the phase:

$$J = -(k\frac{k}{\eta})\frac{\partial p}{\partial x} \tag{1}$$

Nonequilibrium thermodynamics (NET) has since long been used to describe one-phase flow through porous media[5], see Box 1 for the essential steps of NET. The fluid may interact with the porous medium and is then included in Gibbs' equation. The assumption of local equilibrium for his interaction, the Scatchard assumption[6], has been shown to apply for a broad range of chemical, thermal and mechanical driving forces. A continuous path through the membrane can then be defined. For two-phase flow, however, this procedure does not work, as Gibbs' equation originally applies to one homogeneous phase. Another problem is the pressure difference between two immiscible phases. The capillary equation relates the hydrostatic pressures of the two phases in Fig.1, through the liquid-liquid surface tension and the radius of curvature of the interface between them, but what is the driving force of transport? Can a NET formulation be constructed also here? The answer is yes, provided that we can construct system variables that obey a particular Gibbs type-equation, and which are in local equilibrium in the sense that this equation applies also in the presence of driving forces. We have seen that such constructions become possible in nanothermodynamics[1,4,7-9], and this has enabled us to apply the *systematic procedures* of NET of Box 1 to give a thermodynamic basis to Eq.1.

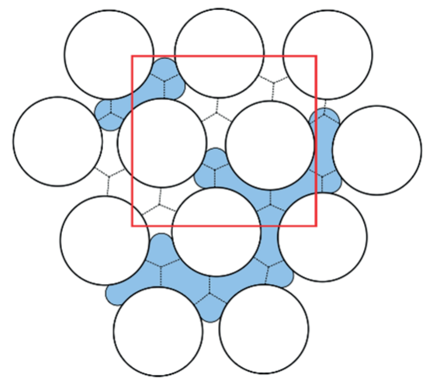

Fig.1. Illustration of two liquid phases (blue and white) in a porous medium of spheres (white). A representative elementary volume REV is indicated by a red line.

Dealing with a variable geometry

Box 1. The five steps of standard NET

1. Construct the Gibbs equation for the variables
2. Introduce balance equations into the Gibbs equation and find the entropy flux and production
3. Write flux-force relations predicted by the entropy production
4. Write fluctuation-dissipation theorems for fluxes of the REV

In order to embed the capillary equation in the thermodynamic description, the thermodynamic method must also be able to deal with shape and size as variables. The classical Gibbs equation is then not sufficient, as it is no longer extensive in system variables. We have been looking for a way to include immiscible phases, size- and shape as variables in a systematic, not ad hoc, manner. Hill's theory of small systems[4] offers such a possibility. He introduced size-and shape dependent system variables, restoring extensivity with an ensemble of systems. Ordinary statistical mechanics will then apply, but to the ensemble. Hill's extension of thermodynamics which has been applied to porous media[1] was called nanothermodynamics. It applies to any system which has geometry-dependent thermodynamic variables. The Gibbs equation will appear for the single system including the immiscible phases, but the variables are ensemble averages. The REV of a medium is a volume where all relevant microstates are present, cf.Fig.1. The environment is furthermore critical. The variables of the environment specify the ensemble of small systems (the REVs) and control the single REV. They must therefore always be defined.

Constructing REV variables using nanothermodynamics

In order to be representative, the REV must not be too small, but also not to large. In a porous medium it is always open and has the temperature and chemical potentials controlled by reservoirs. The REV has a fixed volume, V. In addition, there are REV-specific variables, which are averages over the REV volume (mass-, internal energy- and entropy densities). The size of the REV needs to be large enough to give good average properties, but not substantially larger. The REV variables fluctuate[7], but in the system of interest, their averages do not vary significantly across the REV. In a crystalline lattice, the unit cell is frequently the smallest possible REV[2]. Irregular porous media have a larger REV. We examine an ensemble of REVs.

We are looking for a REV, composed of miscible and immiscible phases put together in the volume V. There is a distribution over micro-states, characteristic of the set of control variables. This is now used to define REV thermodynamic properties. Coarse-grained densities are obtained by dividing REV additive properties by its volume. Consider, as an example, three immiscible phases in a REV, two fluid phases and one solid at equilibrium. In order to find the total entropy, S, we add all bulk-, surface-, and line-contributions

$$S = S^n + S^w + S^r + S^{nr} + S^{wr} + S^{nw} + S^{nwr} \tag{2}$$

Superscripts n,w,r refer to the least wetting, more wetting fluids and the solid respectively. Double superscripts refer to the interfaces between two phases, and three superscripts refer to the three-phase contact line. Energy- and mass densities are constructed similarly. Areas, lines, points, or radii of curvature enter these variables. The ensemble of REVs makes them well defined. And the additivity property gives us reason to assume that the Gibbs equation applies on the coarse-grained level. The assumption can be justified when there is weak coupling between REV subsystems, see Bedeaux and Kjelstrup[7] for a statistical mechanical argument. The seven contributions from the bulk phases, surfaces, and three-phase contact lines, combine in this manner to one REV variable. This constitutes the coarse-graining procedure.

Gibbs' equation and local equilibrium in the REV. Gibbs' equation plays a central role in NET because it is the starting point for the derivation of the entropy production, see Box 1. The variables of the REV are the additive variables described above, see also[1,7-9]. The big, but necessary, assumption is now that we can write the Gibbs equation for the REV coarse-grained densities to give:

$$du = Tds + \mu^n d\rho^n + \mu^w d\rho^w + \mu^r d\rho^r \tag{3}$$

where u is the internal energy density of the REV, T the temperature, μ and ρ the chemical potentials and mass densities of the three phases of the REV. The assumption of local equilibrium concerns *the state* of the REV during transport. When a series of REVs is exposed to an external field, the system responds by creating gradients of all sorts. These lead to time-dependent changes in the REVs. We consider REVs that are small enough to remain in the same equilibrium state when the changes take place. This is yet a formulation of the assumption of local equilibrium in the REV: The equations take the same form as in global equilibrium. This assumption is, in fact, standardly used in the field of fluid dynamics, whenever thermodynamic equations are used in a control volume.

Balance equations and the entropy production

Box.2. NET for porous media

I. Find a REV consisting of weakly coupled parts
II. Construct an ensemble of REVs with environmental control variables
III. Write the coarse-grained variables for the fixed volume
IV. Write the Gibbs equation for the coarse-grained variables
V. Continue w/ standard steps Box 1

The next step is to introduce the balance equations into the Gibbs equation (cf. Box 1). Doing this we can identify the entropy flux and the production σ in the normal way: *The only difference between the standard procedure and that of porous media*, is that now the coarse-grained variables are used, cf. Box 2. Typically, there is always a certain degree of freedom in the choice of variables. But the entropy production is independent of the choice of variables. The choice can be motivated by what is practical. We choose here a measurable heat flux to be conjugate to the gradient in the inverse temperature. The negative chemical potential gradients must then be taken at constant temperature. We refer to Kjelstrup and Bedeaux[5] for nomenclature, symbols, and other variable choices.

$$\sigma = J_q'\frac{\partial(1/T)}{\partial x} - J_n\frac{\partial\mu_T^n}{T\partial x} - J_w\frac{\partial\mu_T^w}{T\partial x} \tag{4}$$

Mass fluxes are used rather than flows (mass fluxes times the cross section) *because the fluctuation-dissipation theorem (see below) is expressed in terms of these fluxes.* The porous medium serves as the frame of reference for the fluxes, J_r=0. The gradient in the chemical potential taken at constant temperature contains the pressure gradient.

Flux-force relations. The flux-force relations are defined from the entropy production of the REV:

$$\begin{aligned} J_q' &= L_{qq}\frac{\partial(1/T)}{\partial x} - J_{qn}\frac{\partial\mu_T^n}{T\partial x} - J_{qw}\frac{\partial\mu_T^w}{T\partial x} \\ J_n &= L_{nq}\frac{\partial(1/T)}{\partial x} - J_{nn}\frac{\partial\mu_T^n}{T\partial x} - J_{nw}\frac{\partial\mu_T^w}{T\partial x} \\ J_w &= L_{wq}\frac{\partial(1/T)}{\partial x} - J_{wn}\frac{\partial\mu_T^n}{T\partial x} - J_{ww}\frac{\partial\mu_T^w}{T\partial x} \end{aligned} \tag{5}$$

The fluxes are linearly related to the forces and the conductivity matrix of Onsager coefficients is symmetric, $L_{ij}=L_{ji}$. The coefficients can be determined at steady state. The flux-force relations allow a generalization of the relative permeability theory to systems with non-uniform composition. Fluxes of two incompressible immiscible fluids confined to an isothermal porous medium are related through their confinement. One component cannot move without the other moving in the space left behind. This linear dependence leads to a zero determinant. A basis to Darcy's law of a two-phase fluid emerges by these steps. The form opens up for addition of other forces. *Special for the nanoporous medium* is that the gradient in the pressure refers to the integral pressure, or an effective pressure. Galteland et al.[9] found the local permeability for a single-phase fluid using this equation. A large variation in the permeability with porosity was observed for a regular crystal-like lattice.

Fluctuation-dissipation theorems for REV variables. Permeabilities can also be obtained from flux-correlation studies, similar to the situation for homogeneous fluids. Each flux is written as composed of a dissipative and a fluctuating contribution, $J_{j,tot}=J_j+J_{j,R}$, where j equals q, n or w. The averages of the fluctuating contribution are zero. Their second moments are given by fluctuation-dissipation theorems:[7]

$$< J_{i,R}(\mathbf{r},t)J_{j,R}(\mathbf{r'},t') > = 2k_B L_{ij}\,\delta(\mathbf{r}-\mathbf{r'})\delta(t-t') \tag{6}$$

This gives a second route to the permeabilities. We can find them via the flux-force relations or via the fluctuation-dissipation theorems. The Onsager symmetry are in both cases a consequence of microscopic reversibility. Winkler et al.[10] showed that the Onsager relations hold within the accuracy of the simulations.

Concluding remarks. We have proposed a way to set up a non-equilibrium thermodynamic theory for porous media transport of multi-phase flow. The procedure was inspired by standard nonequilibrium thermodynamics, with the additional essential assumption that geometry dependent variables be handled with the method of Hill (Box 2). Using this, we have explained how Darcy's law can be recovered. This happens under isothermal conditions, when the composition is uniform, and when the only contribution to the chemical potential is from the pressure gradient. This provides Darcy's law with a new thermodynamic basis.

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THERMAL MARANGONI EFFECTS, THERMODIFFUSION, AND THERMO-OSMOSIS IN SLIT PORES

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The Marangoni effect is fluid creep flow along a surface caused by a gradient in the surface tension. The effect can be seen on a contaminated water surface when a drop of surfactant is added to the surface, or in a glass of wine when wine appears to creep up along the glass, known as "tears of wine". In these cases, the gradient in surface tension is caused by concentration gradients. The effect may also be a result of a temperature gradient, in which case the effect is called a thermal Marangoni effect or thermo-capillary convection.

The components of a fluid mixture in a temperature gradient will to some extent separate. This is the Ludwig-Soret effect also known as thermodiffusion. Thermodiffusion occurs in both bulk fluids and in porous media, such as hydrocarbon mixtures in reservoirs with a geothermal gradient. In porous media with low permeability, another effect known as thermo-osmosis may also occur, both in mixtures and pure fluids. The result of thermo-osmosis is a pressure difference between hot and cold regions of the fluid. This effect is not found in bulk fluids or porous media with high permeability due to low resistance to fluid flow. Combinations of type of fluid, type of porous medium, and the possible effects of a temperature gradient are shown in Table 1.

Table 1. Effects driven by a temperature gradient in different systems

Fluid / Medium	One component	Mixture
Low permeability	Thermo-osmosis	Thermo-osmosis Thermodiffusion
High permeability, bulk fluid	No effect	Thermodiffusion

The Soret coefficient is used to quantify the effect of thermodiffusion. For a binary mixture, it is defined as

$$S = \left(\frac{1}{x_1 x_2}\frac{\Delta x_i}{\Delta T}\right)_{J_1=J_2=0}$$

where x_i is the mole fraction of component *i* and *T* is the temperature. The Δ means the difference between the hot and cold bulk fluid properties. The condition $J_1 = J_2 = 0$ means no net flow through any cross section of the pore. This is achieved by restricting the flow through the boundaries of the system and establish a stationary state.

The thermo-osmotic coefficient quantifies the thermo-osmotic effect. It is defined as

$$D_p = \left(\frac{\Delta P}{\Delta T}\right)_{J_1=J_2=0}$$

where *P* is the pressure.

Thermodiffusion and thermo-osmosis can be studied by non-equilibrium molecular dynamics simulations in combination with non-equilibrium thermodynamics. We have so far studied a binary fluid mixture in a porous medium consisting of a lattice of matrix particles [1]. We found that both *S* and D_p depend strongly on the porosity of the matrix and Figure 1 shows some key results from this work. The units used here are reduced molecular units, but the data can be converted to SI units for components with known molecular interaction potentials. For instance, *S* = 0.5 for a binary mixture of methane and decane corresponds to 3.4×10^{-3} K^{-1} in SI units. Likewise, $D_p = 0.2$ corresponds to 6×10^4 Pa K^{-1}.

In a new project, we use a collection of slit pores instead of the matrix so that we can vary porosity and permeability independently. An illustration of one wide pore is shown in Figure 2. A gradient in interfacial tension along the pore wall due to the temperature gradient generates a thermal Marangoni effect and sets up a creep flow along the walls. The aim is to investigate how the resulting convection will change thermodiffusion and thermo-osmosis in a porous medium as compared with bulk fluid.

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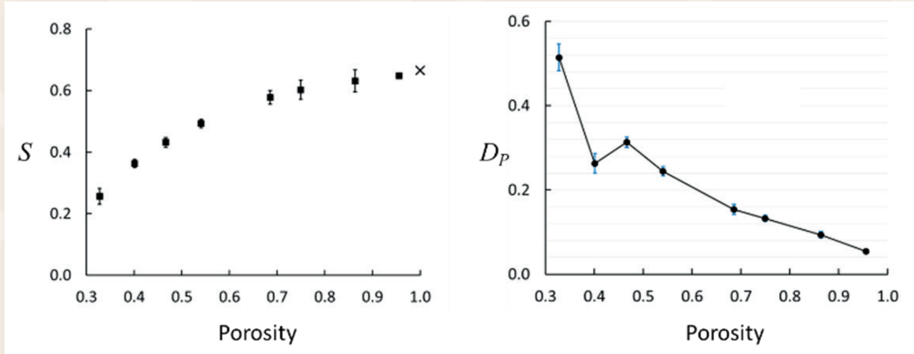

Figure 1. Soret coefficient (left) and thermo-osmotic coefficient (right) in a two-component fluid mixture in a porous matrix. See text for the units of S *and* D_p.

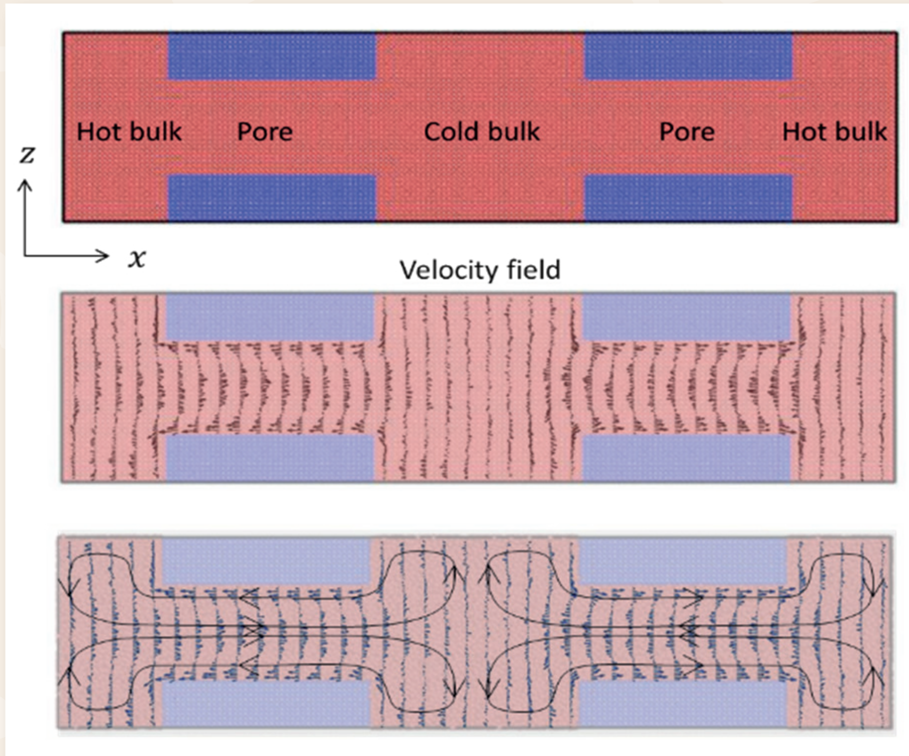

Figure 2. Side view of a slit pore. The blue regions are pore walls of Lennard-Jones/spline particles in a solid state. The red region contains the same type of particles in a liquid state. A temperature gradient is set up in the fluid between the hot and cold bulk compartments, which sets up a convective flow field as illustrated by the velocity vectors in the middle panel and exaggerated in the lower panel.

ION COMPOSITION EFFECT ON SPONTANEOUS IMBIBITION IN LIMESTONE CORES

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Over the past two decades, numerous studies have been performed on the effect of injection water ion composition and salinity on the wettability alteration in carbonates [1-6], which is usually referred to as low salinity enhanced oil recovery (EOR). Low salinity flooding is considered favorably due to the availability and small environmental impact of low salinity water, making the technique practically and feasibly implementable. There is however an ongoing debate on the underlying mechanisms occurring during low salinity flooding in carbonates [7-8].

The main aim of our study was to tune the ionic composition of imbibing brine to maximize the oil recovery from spontaneous experiments on limestone outcrop cores, as analogue for an offshore Brazilian carbonate reservoir.

Improved spontaneous imbibition experiments were performed, exposing an oil saturated core to three brines sequentially, where the brine exchange between primary, secondary and tertiary fluid imbibition cycles at high temperatures was accomplished smoothly with a newly developed high temperature set-up, reducing systematic errors in the recovery data. See Figure 1 for the schematic. Contact angle, zeta potential and interfacial tension measurements completed the data set.

It was observed through improved oil recovery from tertiary imbibition that complete dilution of synthetic seawater based on the North Sea composition (SSW) (10 times) had limited impact on improved oil recovery on our limestone cores. However, selective dilution of SSW with respect to the sodium chloride (NaCl) content resulted in significant improved oil recovery. In line with this observation, brines depleted in NaCl and enriched in magnesium (Mg) and sulfate (SO_4^{2-}) ions were tested and resulted in improved oil recovery in tertiary modes. A positive test on the role played by the sulfate ion was recorded when SSW was enriched 2 and 4 times in sulfate ion concentration, however, substantial recovery increases required increased magnesium content (See Figure 2, with 2x enrichment of sulfate and 4x and 8x Mg^{2+} enrichment; LS2S4Mg, LA2S8Mg). Contact angle measurements on polished rock chips, cut and shaped from the same rock material, and aged in brines at 96° C, confirmed the observed results, where zeta potential measurements at both 25° C and 70° C showed inconclusive results.

These results show that not only by salinity reduction but also brine composition tuning, oil recovery from carbonates at high temperature can be optimized further.

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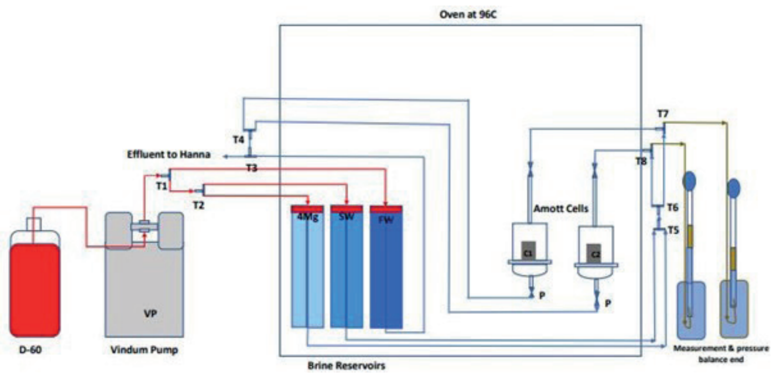

Figure 1: The schematic of the high temperature (up to 96°C) spontaneous imbibition experiments, applying up to 3 different kind of brines (4Mg, SW, FW in this case). It is to be operated with a closed heating chamber during the entire experiment. Fluid flow into and out of the heating chamber (oven), using the oil Exxsoll D-60 as driving fluid, was externally controlled with a network of T-valves. 'Hanna' is the conductivity/salinity measurement tool. This procedure limits temperature changes and pressure pulses when changing imbibition brines in Amott cells minimizing its effect on the recovery data and additionally it increases the safety.

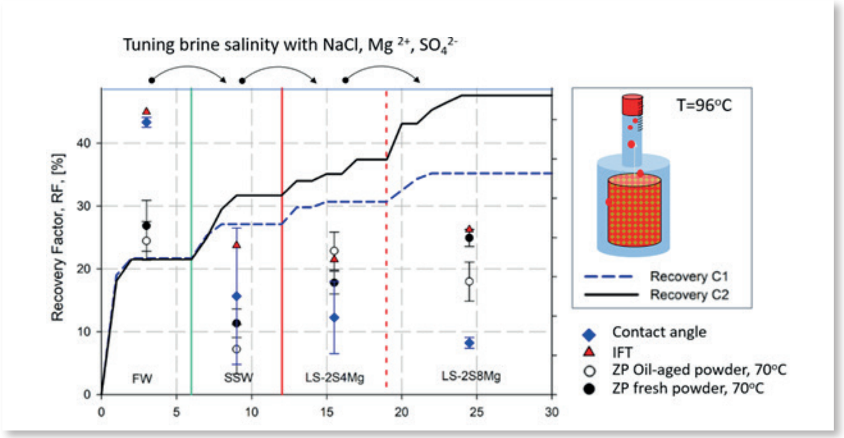

Figure 2: The development of the recovery factor of a spontaneous imbibition test using an Angola limestone core, exposed sequentially to different brine compositions, monitored for a month. Initial formation water was followed by synthetic seawater (SSW) after which the core was exposed to 10 times NaCl reduced SSW with [SO_4^{2-}] twice enriched (2S) and [Mg^{2+}] 4 and 8 times higher than in SSW respectively (LS-2S4Mg), (LS-2S8Mg). Additionally, the contact angle, interfacial tension (IFT) and zetapotential (ZP) of fresh and aged to powder grinded Angola core were measured.

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WATER TRANSPORT THROUGH OIL FILMS: EXPERIMENTAL OBSERVATIONS AND NUMERICAL SIMULATION

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Several controlling mechanisms have been proposed to explain the mobilization of oil when a porous medium is flooded with low-salinity water. Among them, osmosis and water-in-oil emulsions are two potential mechanisms. However, these two potential mechanisms are not fully understood. We have therefore conducted a series of experiments in oil-wet micro-models. Additionally, we have also conducted numerical simulations of the proposed processes.

For our studies we used three aqueous solutions and two alkanes in a series of micro-fluidic experiments with glass micro-chips. The micro-chips were coated by a siliconizing fluid to render them wetting to the alkanes. This wettability state is needed to develop oil films encapsulating disconnected water. The micro-model was placed on a movable stage under a Olympus SZX7 microscope with a digital camera connected to a computer for continuous imaging of the micro-chip. The micro-model had a 10 x 20 mm domain with an etched pore structure of depth 20 micrometer resembling a geological porous material. A dual-drive system syringe pump, Harvard Apparatus Pump 33 DDS, was used for fluid injection into the micro-model.

To obtain fluid distributions with high-salinity water disconnected and separated from low-salinity water by oil films, we conducted the following flooding routine: We first vacuumed the micro-model, and then fully saturated it with a high salinity water. Then we injected the alkane phase to displace most of the high-salinity water. The alkane phase was injected at a high flow rate to ensure that a significant amount of high-salinity water remained in the model. Last, we injected low-salinity water until breakthrough of water. To ensure that the fluid distribution was stable, we waited 30 minutes before starting to record the development of the fluid-fluid interfaces. The oil phase was marked in red and the low salinity water was died blue to distinguish the three different phases when imaging the micro-model.

As shown in Figure 1, disconnected high-salinity water then expands. We tested different salinity contrasts, and observed a clear relationship between salinity contrast and high-salinity water expansion. The expansion rate also depends on the width of the oil film which separates the two different waters. We also conducted baseline experiments without any salinity contrast, where the fluid-interfaces remained stagnant.

We observed that ionic strength and the hydrocarbon chain length both play important roles in water diffusion. Heptane and dodecane both were found to be diffusive to water, and this property could be significantly affected by the salinity contrast at two sides of alkanes.

Molecular dynamic simulations, see Figure 2, were conducted to explore the effect of water salinity on water transport through oil films. Through the conducted molecular simulations, we observed water molecules transported through the heptane phase. Based on the calculated profiles of ions, almost no ions appear at the oil-water interface and inside the heptane phase. By investigating the interfacial tension changes and mean square displacement calculations, we conclude that higher salinity leads to a lower diffusion coefficient of water molecules, i.e., slower water movement. Moreover, high salinity reduces the probability of water diffusion through the interface into the oil phase. This leads to lower solubility of water in oil near the interface between oil and high-salinity water, and thus verifies the experimental result that the direction of net water movement is towards high salinity water.

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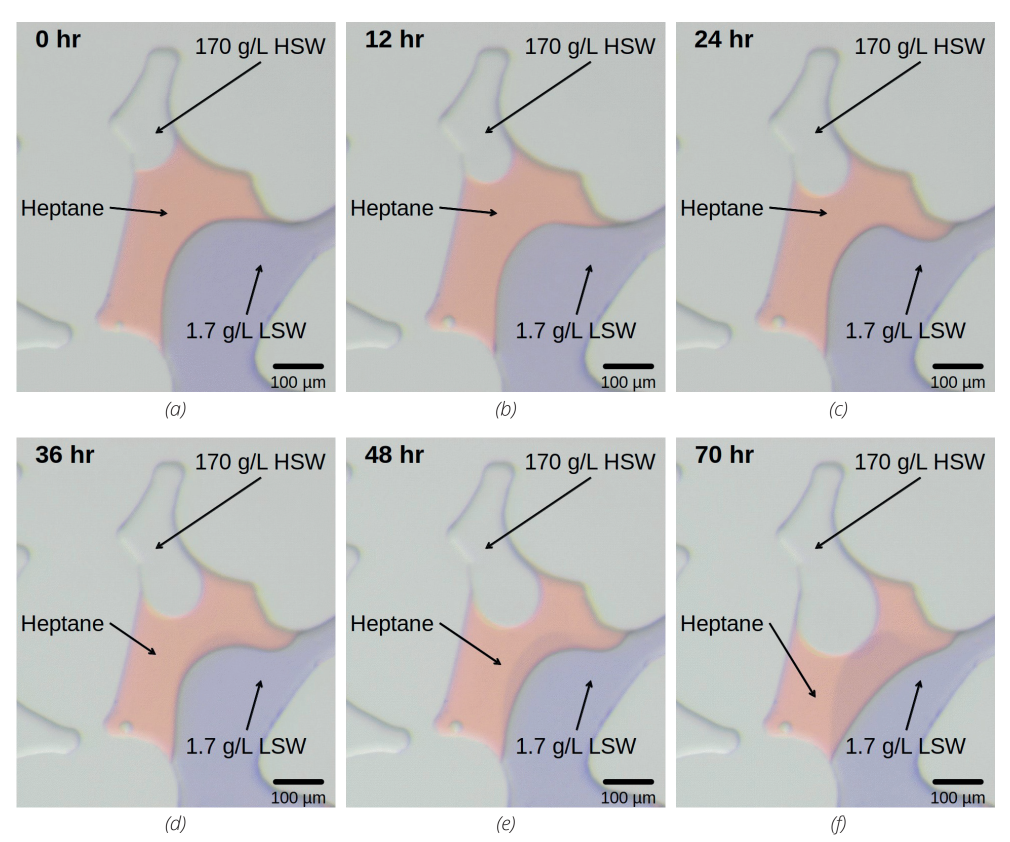

Figure 1: Images showing the expansion of high-salinity water disconnected from the low-salinity water by an oil film. Both matrix and high-salinity water is in gray, heptane is in orange, and low-salinity water is in purple.

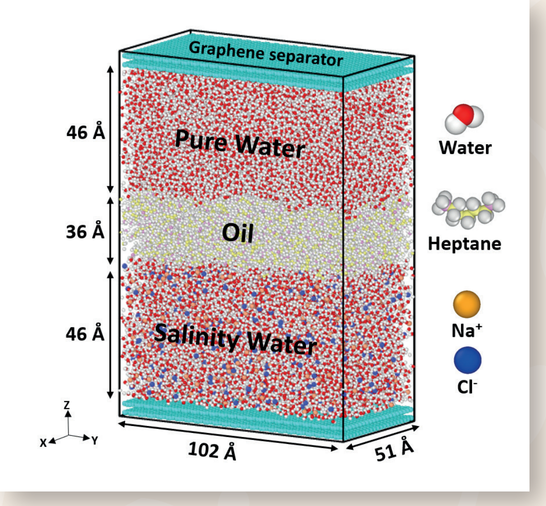

Figure 2: A schematic of the setup for molecular dynamic simulations, with an oil film separating water with different salt concentration.

RESEARCH PROJECTS

MECHANISTIC ASPECTS OF CHEMICAL ENHANCED OIL RECOVERY IN VISCOUS OIL SYSTEMS

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Chemical enhanced oil recovery techniques have been suggested as efficient alternatives to thermal methods in many viscous oil reservoirs. Such acidic oil reservoirs are good candidates for alkaline (A) and surfactant (S) floods. In this study, pore-scale microfluidic tests were designed to give some new insights on the mechanisms of AS floods augmented with polymer (P) solutions in viscous oil systems. Viscous oil (14,850 mPa s at 25°C) samples from a field in Alberta, Canada, was used in all the experiments.

In the ASP experiments an aqueous phase loaded with 0.1weight% anionic surfactant (sodium alkane sulfonate) and 0.3 weight% sodium carbonate (Na_2CO_3) was used since this mixture gave ultralow interfacial tension, 0.002 mN/m and produced low viscosity type II (+) emulsion (740 mPa s, which is much lower than the viscosity of originating oil). The polymer was a high molecular weight polyacrylamide at a concentration of 0.1 wt.%. The results from two pore volumes injection of this cocktail into sand-packs resulted in around 20% OOIP incremental oil recovery, which is almost doubled after injecting two pore volumes of extended water. The fluid effluents from these experiments were all low viscosity oil in water emulsions, consistent with observations in batch mixing experiments. Sand-pack experiments also showed that incremental oil recovery to ASP flood was almost twice the recovery obtained in the polymer flood with nearly 4.5 times larger pressure build-up across the sample. *These observations suggest that the main mechanism is emulsification and oil entrainment rather than improvement in sweep efficiency*. The main objective of the present study was to investigate the speculated mechanisms from the core scale observations by performing microfluidics experiments. The emulsification and oil entrainment mechanism are well documented by the results from seven displacement experiments in sand-pack, and the results from batch mixing experiments. In addition to the abovementioned experiments viscosity and interfacial tension measurements were performed. The entire project is documented in reference [1] and only a brief presentation of the microfluidics experiments is given here.

The microfluidic experiments were performed in the apparatus shown in Figure 1. Borosilicate microfluidic chips with dimensions of 45 × 15 × 1.8 mm and a physical rock network (edging depth 20μm) were applied and the experimental procedure was as follows: a) chip was fully saturated with deionized water (DIW) b) heavy oil was injected from right to left, c) heavy oil uniformly displaces DIW d) heavy oil injection was stopped to assure oil does not enter the capillaries e) final fluid distribution in the analyzing window was recorded before starting water flood. As shown in Figure 1, a syringe pump was used to inject fluids into the microfluidic chip, which was placed under the microscope equipped with a digital camera to capture images during flooding. The porosity, permeability, and pore volume of the microfluidic chips are 57%, 2.5 D, and 2.3 μL, respectively.

The microfluidics experiments followed the same flooding protocol as the sand-pack core flooding experiments. The chip at irreducible water saturation was water flooded for 5 pore volumes (PV). Then the chip was flooded with ASP, AS, and P solutions in three different runs. Finally, each experiment was concluded with extended water injection. Injection velocity in all the runs were the same as velocity applied in the sand-pack flooding experiment, 2.5 × 10^{-6} m/s. In the end, water injection velocity in the extended water flood was increased by a factor of 30 to investigate the effect of increasing viscous forces to displace residual ganglia.

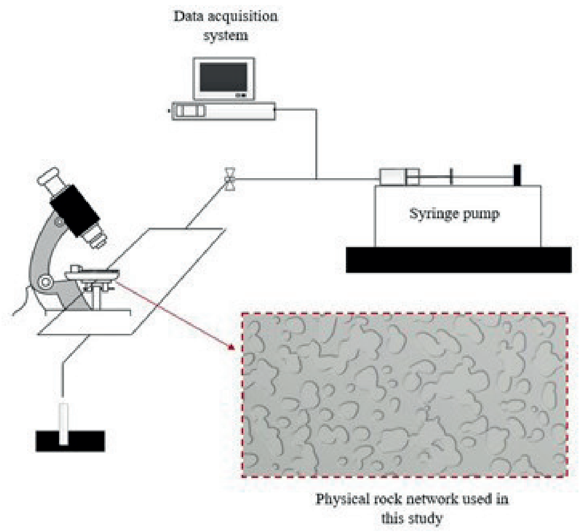

Figure 1. Schematic of microfluidic apparatus. From reference [2].

The results of the three experiments with ASP, AS and P are shown in Figures 2. The injected ASP efficiently emulsifies the residual ganglia, as shown in Figure 2c. In this case, the low viscosity emulsions with droplet diameters smaller than the pore throats, depicted in the zoomed images enclosed in Figure 2, are entrained. Also, the injected ASP efficiently entrained viscous oil from the edge of the main channel, which was left behind after the primary water flooding. In the extended water flood, increasing viscous forces through increasing injection velocity facilitates the flow of oil in water emulsion droplets, as depicted in the magnified images of the same pore space flooded at different velocities (see Figures 2d and e). In this case, the droplets of the double (water in oil in water) emulsions, have been efficiently entrained in the extended water floods. These pore-scale observations explain the notable incremental oil recovery in sand pack that was obtained in the extended water flood just after ASP flood. The significant emulsification observed due to the ASP flood was not observed in the AS flood. Given the same surfactant and alkaline concentrations as in the ASP flood, these observations emphasize the effect of polymer on emulsification. Polymer is required to provide the sufficient driving force required for AS solution to contact the residual ganglia in the swept area or efficiently strip the oil from the channel edge. In the absence of polymer, the AS can slightly penetrate through the ganglia/channel leading to the small oil stripping from the edge. Therefore, the residual ganglia cannot be efficiently mobilized even after increasing the velocity in the extended water flood. However, in the presence of polymer, the ASP can efficiently penetrate the ganglia/channel's edge to enhance emulsification, making the process much more efficient than just stripping from the ganglia edge (see Fig. 2c, d and 2e). Although the presence of polymer is proved to play a critical role in ASP flood to mobilize oil, it is the least efficient chemical solution if applied alone.

This study showed that ASP solution can efficiently penetrate the residual ganglia or the edge of the water channels from which oil can be efficiently stripped. This oil is easily entrained in the form of low viscosity oil in water emulsions. These results emphasize the critical role of polymer in the cocktail. In the absence of polymer, AS cannot efficiently penetrate the residual viscous oil leading to only a minuscule improvement in oil recovery. This result could be of great interest in field applications where injectivity problems reduce recovery. The ASP-injection has the potential to give high recovery without injectivity problems.

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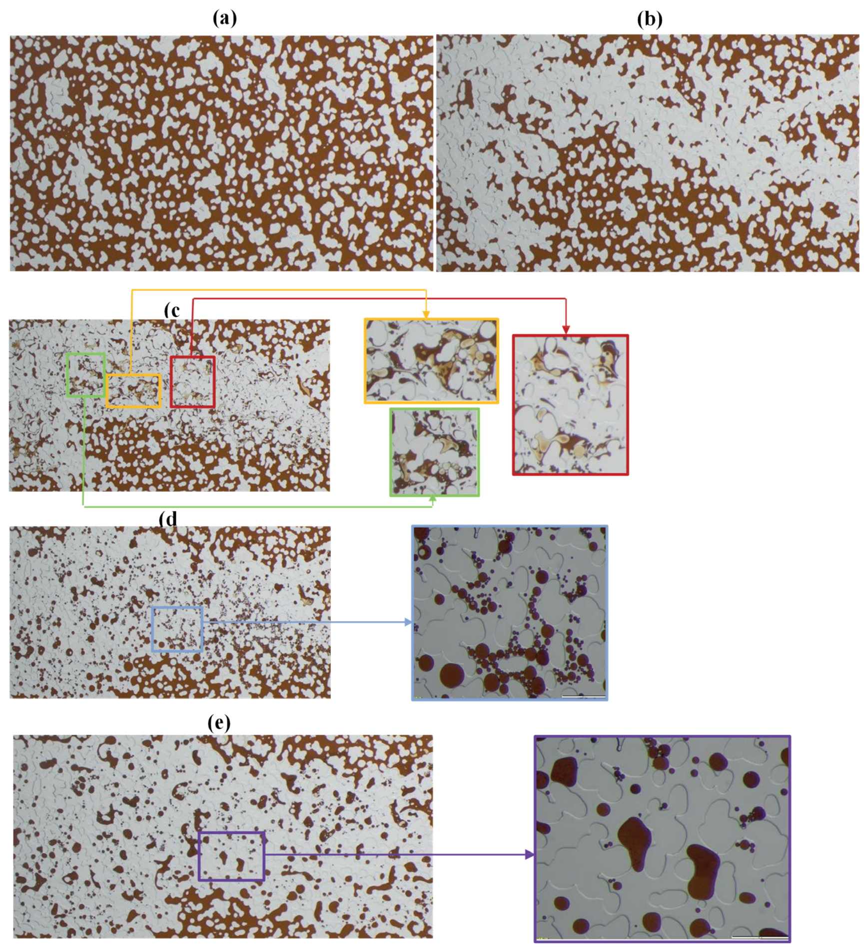

Figure 2. Initial conditions and various floods: a) initial condition at connate water saturation b) water flood c) ASP flood d) extended water flood conducted at the same velocity as the ASP flood e) extended water flood at high velocity. In all images, brown represents oil, while water and grains are colorless. From reference [1]

POLYMER-COATED SILICA NANOPARTICLES FOR ENHANCED OIL RECOVERY IN WATER-WET SANDSTONE

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This work evaluates the potential of polymer-coated silica nanoparticles (PSiNPs) as additives to the injection water for enhanced oil recovery (EOR) applications. The main advantages of these nanomaterials compared to unmodified silica nanoparticles are improved stability in brine and low retention on the rock surface. Therefore, their role in the oil recovery process is addressed to make the nanoparticle technology more robust for field applications.

Four types of PSiNPs were used in this work and they were supplied as AERODISP®, which is AEROSIL® particles in liquid solution. The PSiNPs size was 32 to 218 nm. The PSiNPs were mixed with synthetic seawater (38.318 ppm) to 0.1 wt. % concentration. The density and viscosity of the nanofluids were 1.023-1.028 g/cm^3 and 1.022-1.057 mPas, respectively, at 22 °C. A light crude oil with density 0.887g/cm^3 and viscosity 34 mPas, at 22°C obtained from a field in the North Sea was used in the flooding experiments and n-decane was used for wettability experiments.

Two-phase flow experiments were conducted at ambient conditions by injecting PSiNPs as secondary and tertiary recovery agents in water-wet sandstone rocks. A standard core flooding apparatus was used and is described in reference [1]. A total of sixteen flooding tests were conducted with water-wet Berea sandstone rocks denoted M1 to M8 with diameter 3.75cm and length ranging from 4.5 to 6 cm. The core porosity and permeability ranged from 16.7-18.5 % and 0.277-0.400 µm^2, respectively. The drainage was conducted by injecting oil at 0.5, 1.0 and 3 cm^3/min to establish initial water saturation (S_{wi}) and original oil in place (OOIP). Then, nanofluid was injected directly to displace oil. This is called secondary mode injection. The nanofluids are denoted NF-1 to NF-4 and the main difference between them is particle size. In tertiary mode, water flood (WF) started at S_{wi} until there was no oil production. Then the injection was switched to nanofluid, and some additional oil was produced. In both injection schemes, a constant flowrate of 0.2 cm^3/min was used. The oil production was collected every ¼ PV.

The core flooding experiments revealed improved oil recovery with PSiNPs injection. In the secondary mode the oil recovery reached as high as 54.5% for NF-3, giving an increased recovery of 14.8% points compared to the recovery of 39.7% of OOIP from "pure" water flood (Figure 1). In tertiary mode, the PSiNPs increased the oil recovery up to 9.77% of OOIP. The resulting recoveries from tertiary nano flooding are summarized in Table 1.

Drop shape analyzer was used to measure the interfacial tension (IFT) between the fluids at ambient conditions. The IFT between seawater and oil was 10.6 mN/m, and it was decreased slightly to 4.1 mN/m with added PSiNPs. The IFT reduction is therefore considered to have minor contribution to the increase in recovery.

The wetting effect on post- nanofluid flooded cores was evaluated by conducting imbibition tests. It was observed slightly more water-wet properties in nanofluid flooded cores compared with the original cores. However, it was concluded that the rock surface was moderately affected with PSiNPs, as expected since the PSiNPs and Berea sandstone have similar surface charge.

The differential pressure was recorded during the flood tests and differential pressure increase was observed during nano flooding. PSiNPs have the tendency to accumulate at the pore entrances (the so-called log jamming effect). The flow diversion due to PSiNPs blocking the pores could affect the oil recovery positively.

This study shows that polymer-coated silica nano particles increase the oil recovery during flooding in water wet core plugs. Most likely the increase in recovery is a synergistic effect of interfacial tension reduction, slight alteration of wetting properties, and pore blockage. More work is needed to quantify the relative contribution of each of these mechanisms. Knowledge of relative contributions will help designing the optimal nanoparticles for specific reservoir rock and fluid systems.

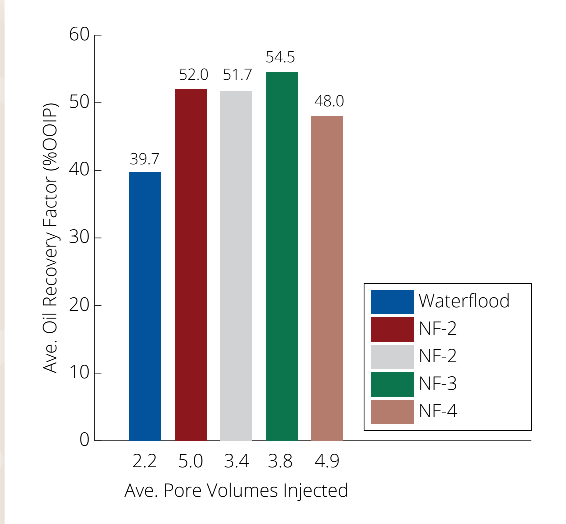

Figure 1. Oil recovery factors for waterflooding and waterflooding with added PSiNPs, so called secondary mode nano flooding (NF). The numbers on the x-axis are number of pore volumes injected. The recovery numbers are the average of eight experiments for waterflooding (WF) and two experiments for each of the nano floodings. From reference [2].

Core #	Nanofluid 0.1 wt.%	Waterflood (WF) recovery	Recovery due to nano flood	Total recovery after WF and tertiary nano flood
M1	NF-1	43.07	4.61	47.69
M2		38.91	7.25	46.15
M3	NF-2	41.70	7.39	49.09
M4		39.42	7.01	46.43
M5	NF-3	40.72	8.67	49.39
M6		37.91	9.77	47.68
M7	NF-4	35.08	9.51	44.59
M8		40.58	6.62	47.20
Average;		39.7	7.6	47.3

Table 1. Oil recoveries expressed as % of OOIP. Pure waterflooding (column 3) and tertiary flooding with PSiNPs (nano flooding after waterflooding). From reference [2].

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THE COMPLEX ELECTROLYTE OF THE LITHIUM BATTERY: KNOWLEDGE FOR BETTER BATTERY MODELLING

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Batteries are in increasing demand in the world today, to help realize the overdue transition to greener technologies. Among batteries, the lithium battery with its high voltage, is since long used in iphones and has become common in cars. The chemical reaction inside this battery is accompanied by local changes in temperature and composition. Clearly, knowledge about the state of the battery during charging or discharging is needed to understand how to best predict the battery performance or handle used batteries for recycling.

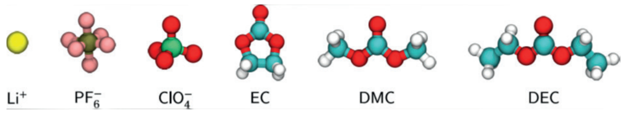

Fig. 1. Ions and molecules typical of the lithium battery electrolyte: From left to right are pictured ions of typical lithium salts, lithiumhexofluoride, or lithiumchlorate. Solvents are ethylene carbonate (EC), dimethyl carbonate (DMC) and diethyl carbonate (DEC).

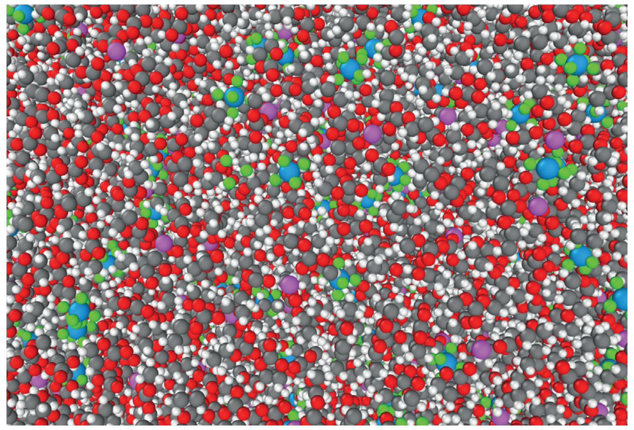

Fig. 2. Snapshot of lithium battery electrolyte (separator not shown). Solvent atoms C, H, O are grey, red and white. The atoms in the salt are parse (Li^+) and blue-green (PF_6^-). Structure ordering takes place, clustering can be observed.

The electrolyte of a lithium battery is a complex liquid mixture held in place between two electrodes by a porous separator. Figure 1 shows typical components. A lithium salt of high concentration dissociates and its ions carry charge across the electrolyte. Hexafluoride- or tetrachloride compounds are harmful when released, while the solvent compounds EC, DMC, and DEC are not harmful when released after use.

The Nernst-Planck equation is frequently used in a physical chemical description of the processes in the battery during charge transfer. The assumption, that each ion moves independently of the other ions in the electrolyte, is also frequently used. While this assumption may be good for dilute electrolytes, it may not apply for concentrated electrolytes. A snapshot of the mixture that contains the components of Fig. 1 is shown in Fig. 2. In the case of a concentrated electrolyte, ion-ion and ion-solvent interactions are probably non-negligible. We need a systematic way to deal with this situation. Such a systematic theory is offered by nonequilibrium thermodynamics, and we are now making efforts to apply this theory to batteries and to porous media [1].

One of the basic assumptions of nonequilibrium thermodynamics is the regression hypothesis. This assumes that fluctuations on the molecular level decay to the state of equilibrium according to the same laws of transport that we find on the continuum level. The hypothesis provides two ways to find the transport coefficients that we need in a battery. We can 1) find them from simulations of *boundary driven transport* like is often done in nonequilibrium molecular dynamics simulations. And we can 2) find them as expressed by the fluctuation-dissipation theorems that apply to *equilibrium states* (the Green-Kubo relations, see [2]). All information about transport, one may thus say, is contained in the equilibrium fluctuations of the system. The hypothesis contains a symmetry law of Nature: The symmetry that we observe in the macroscopic world in terms of the Onsager relations, is a reflection of the symmetry of the interactions in the microscopic world.

The Green-Kubo relations of nonequilibrium thermodynamics offer a general, systematic extension of simpler coefficient models. The relations have been used extensively to produce diffusion coefficients in multicomponent mixtures, see Liu et al. [3] for a review. We have recently used them to extend common expressions for batteries [4]. We have applied entropy production invariance [4] to find new relations of the transport coefficients of the components pictured in the mixture of Fig.2.

To obtain sufficient experimental data is sometimes an obstacle, as experiments are time-consuming. But such data can now be obtained with good precision and in a less time-consuming manner, via computer simulations. Computer simulations are essential in the exploit of Green-Kubo formulas. With present day's force fields of better and better quality, realistic results can be expected for the Onsager coefficients. We have obtained several sets of coefficient data, working first with isothermal systems. The electric conductivity of the electrolyte, the transference coefficients of the salt in solution, and the electro-osmotic drag coefficient of the solvent molecules have been predicted. We can now provide a complete set of coupling coefficients.

The following conclusions can be drawn. The simple model, with independent transport of ions, captures only half the value of the electric conductivity. The real electrolyte Joule heat may accordingly be much smaller than expected from old results. This is good news for a possible overheating problem in the battery. But it is also clear that the new coefficients overestimate the participation of the lithium ion in the charge transfer process. This can lead to a rate-limiting step in the charge/discharge process which may severely alter the conditions at the boundaries where the electrode reactions take place. This means also that local changes in composition can be more cumbersome than previously thought of. A salt gradient at the electrode will certainly cause overvoltage phenomena, maybe also produce fractal forms upon metal depletion, a likely cause for local overheating and fire risk.

Our advice to those who need to charge lithium batteries is to go for the slower, more controllable charging situation. Less of local accumulation or depletion of components will then occur inside the battery.

To apply a more sophisticated theory means an extra effort, but the gain is deeper insight into the electrolyte processes of the electrochemical cell under operation. The principles used in the derivations are perfectly general, and formulas can be applied to other batteries or electrolytic cells once the procedures have been found to work

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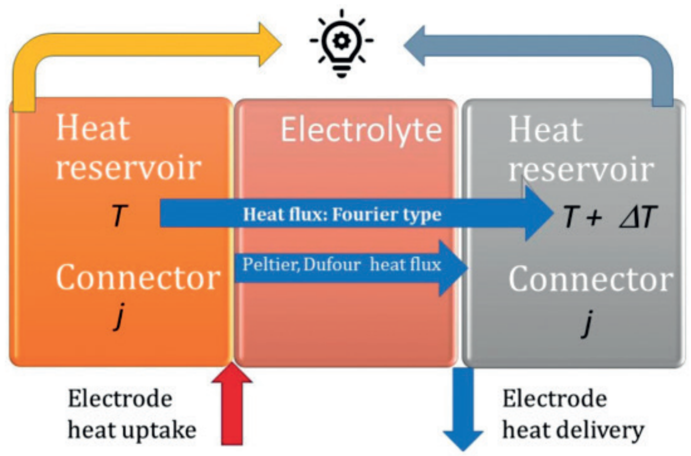

SHOCK WAVE IN LIQUIDS

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A shock wave is a wave of liquid or gas travelling at supersonic speed. It is a highly irreversible process which has been utilized to disintegrate kidney stones [1], in explosive welding [2], to design supersonic aircrafts, and in basic studies of supersonic flows. A key question is: despite the fact that the shock wave is not in *global non-equilibrium*, can one still assume *local equilibrium*? If so, we can use analytic tools from non-equilibrium thermodynamics (NET) and the entropy balance equation to map the coupled transport processes and find new constitutive flux-force relations. This opens a new route to understanding processes far from equilibrium, including transport phenomena in porous media.

The aim of this work is to find a more detailed description of energy conversion and coupling between heat and mass transport in shock waves based on computer simulations and NET. We believe that this approach can add significant insight and understanding of shock waves. A better understanding of the behavior and properties of shock waves will benefit several areas of science.

We have assessed the assumption of local thermodynamic equilibrium in a shock wave by comparing local thermodynamic data generated with non-equilibrium molecular dynamics (NEMD) simulations with results from corresponding equilibrium simulations. For a shock with Mach number approximately equal to 2 in a liquid-state Lennard-Jones/spline model system, we compared the shock data with equilibrium simulation data and found that the local equilibrium assumption holds perfectly well behind the wave front and that it is a very good approximation in the front itself.

In addition to the NEMD simulations, we have solved Navier-Stokes (N-S) equations numerically for the same conditions. Thermodynamic properties given by the equation of state are inherent in the N-S equations, and therefore local equilibrium are assumed in the N-S results. Two snapshots of the pressure- and entropy waves are shown in Figure 1.

The shock front is clearly seen in the pressure profile. The entropy density has a distinct peak at the shock front, which shows that the front has entropy in excess of the adjacent fluid. The shock is therefore amenable to an analysis based on non-equilibrium thermodynamics of surfaces [3] and that we can treat the shock front as a surface.

Each point in the NEMD plots represent a local control volume with 80 - 400 particles, depending on the volume's position relative to the shock front. The N-S and NEMD results agree quite well in the shock front, which is another good indication of local equilibrium in the front.

The excess entropy production in the shock front was computed with four different methods from the NEMD and N-S data. In two of the methods, we treated the shock as an interface in Gibbs' sense. The other two methods were based on the local equilibrium assumption in a continuous description of the shock front. We show for the shock studied in this work that all four methods give excess entropy productions that are in excellent agreement, with an average variation of 3.5% for the NEMD simulations.

Further information of this work can be found in ref. [4].

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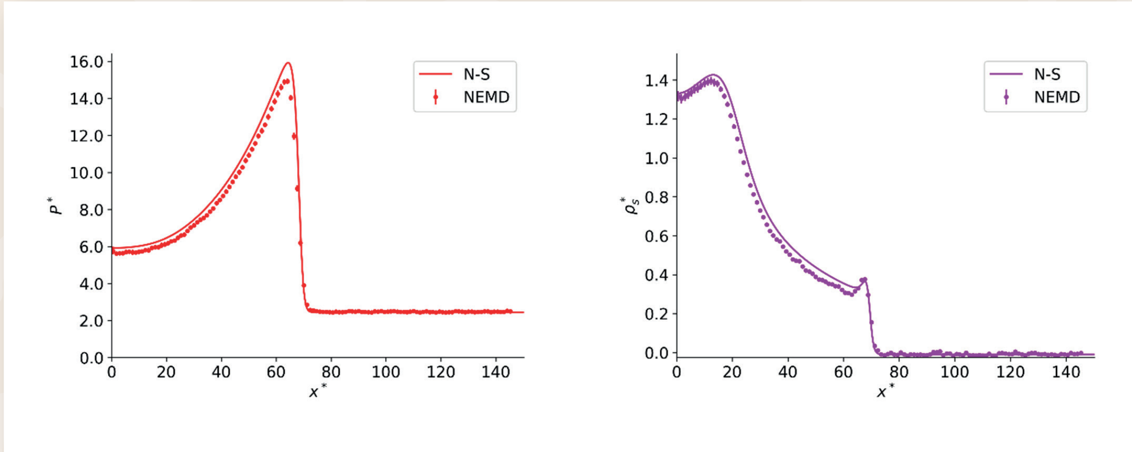


Figure 1. Left: pressure (trace of the pressure tensor) as function of distance from the wave origin (x) at some time after the blast. Right: entropy density as function of x* at the same time.*

SOCIAL WELLNESS …

We thrive at PoreLab to shape an environment that empowers research collaboration and creativity. Social engagement forms an integral part of PoreLab's culture and opportunities for social gatherings are various as shown on the pictures below. For more 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. Quizzes and treasure hunts are organized during the Christmas parties. An ever-present thousand-pieces puzzle as well as a ping-pong table and a table soccer became popular playgrounds for all at PoreLab NTNU.

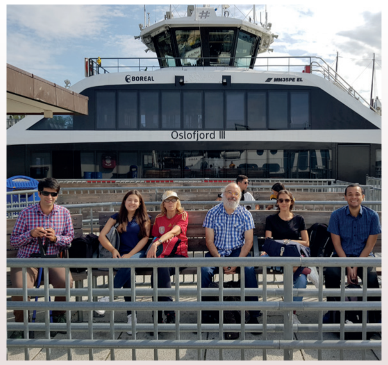










… AND SUSTAINABLE FURNISHING

PoreLab falls within two of the four Strategic Research Areas of the NTNU, *Sustainability* and *Energy*. Our research activities within hydrogen fuel cells, storage of captured CO_2 and ground stabilization are just a few examples reflecting our ambition at PoreLab to develop sustainable solutions. But sustainability is not just at the core of our research activities. Do you know that most of the furniture used at PoreLab is recycled?

The European Environmental Bureau in its report on circular economy opportunities in the furniture sector reports that 10 million tons of furniture are discarded by businesses and consumers in EU members states each year, the majority of which is destined for either landfill or incineration (*https://circulareconomy.europa.eu/*). Our friends on the other side of the Atlantic do not do much better. EPA, the US Environmental Protection Agency, estimates that 9 million tons of furniture and furnishings have been tossed every year since 2010 in USA (*www.epa.gov*). As a comparison, the waste represented 2 million tons in 1960.

It is time to save on resources and environment!

The trend to use and reuse recycled furniture is in the air and PoreLab, as modest as we are, have sought to be a valuable contributor in this respect. As soon as PoreLab was established and premises allocated to our center, the idea was to use furniture left on the campus, and "shop" the rest through an intensive use of NTNU's "Gjenbruktorget" that could be translated by "Recycling Market" in English. In addition, some of the PoreLab members gave old furniture from home. New furniture was only purchased when it became an absolute necessity.

Our most beautiful and centerpiece of recycled furniture is definitively the large table located at PoreLab NTNU in the common area: a massive single-piece oak table, 140 cm wide and 415 cm long (see picture 1). It was quite a challenge for NTNU's caretakers to move it down from its storage room at the Science Building and up to PoreLab premises located at the second floor of the Petroleum Technical Center (PTS2) building. But it was worth it! This table is not just gorgeous and immensely practical, its history is epic. Alex Hansen, who is quite knowledgeable on antiques, evaluates the table to be from 1910-1920 and it could very well be the board room table for the University back in the old days. He says: *"I wouldn't be surprised if it was made by the local but nationally well-known cabinetmaker Edvard Røhmen"*. The table was the centerpiece of the old villa that housed the Department of Theoretical Physics on the northern fringe of the Gløshaugen campus. It was then moved to the Science Building when the various branches of the Physics Department were gathered under one roof in 2000. Stored and unused during seventeen years, it was in danger to be chopped up, but we saved it, claiming it for our premises at PoreLab. Sixteen Mart Stam chairs from the thirties or forties came with it. Alex Hansen has heard from somewhere that both Lars Onsager (Nobel Prize in Chemistry in 1968) and Werner Heisenberg (Nobel Prize in Physics in 1932) have sat at this table when visiting Trondheim. Professor Eivind Hiis Hauge, NTNU's Rector between 2002 and 2005, told us that the double Nobel Prize winner, Linus Carl Pauling (Chemistry in 1954 and Peace in 1962), made an indelible impression. He tells: *"A tall and powerful American, Pauling, took the round of greetings around the table. The new fellow Hauge carefully muttered his name, and the Big Man's response was "What was your name again?" The next attempt at presentation was more successful. This was before my US stays, so I hadn't yet learned that Americans are generally very good at picking up names."*. If this table could talk, so many exciting tales it could tell!


Picture 1: Common area at PoreLab NTNU

Most of the furniture at NTNU PoreLab premises are recycled

POSTDOC

KHOBAIB KHOBAIB

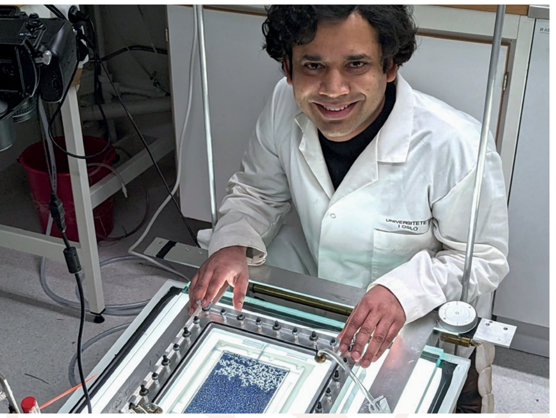
Department of Physics, UiO

Who are you? What is your background?

My name is Khobaib, and I am a postdoctoral researcher at PoreLab – University of Oslo. I grew up in Delhi, India. I am an experimental physicist, with a Bachelor of Science in Physical Science and a Master of Technology in Nanoscience and Nanotechnology from Delhi University, India. I completed one year of my master studies in an exchange program at Joseph Fourier University in Grenoble, France. I obtained my PhD in soft matter physics from Adam Mickiewicz University in Poznań, Poland.

So what area of physics was your PhD about?

My PhD topic was *"Experimental studies of particle-covered droplets in an electric field: Mechanical and rheological properties of droplets and interfacial particle organization."* The objective of my thesis was to study the droplet's deformation, relaxation, electro-rotation, and arrested coalescence, as well as the mechanics of a particle shell formed on the fluid-fluid interface. I applied tailored electric fields to form particle-laden droplets and investigate their mechanical and rheological properties. These electric phenomena include electrohydrodynamic circulation flows, electrocoalescence, and dielectrophoretic and electrophoretic interactions. I studied primarily single particle-covered droplets subjected to uniform and non-uniform DC and AC electric fields.



How did you come being interested in physics?

My interest in physics started during school. I used to talk with my older brother about physics, and he always gave me lessons with a fun approach and interesting examples. I enjoyed studying chemistry equally. In my bachelor's degree, I studied both physics and chemistry as the main subject. In 2012, I moved to France in an exchange program and completed my master's degree in nanophysics.

My master thesis topic was "Fabrication and electrical characterization of diamond power devices." During my thesis, I found physics research fascinating, so I decided to pursue my PhD in physics.

What made you decide to come to Oslo, Norway?

During my PhD studies, I had a chance to visit PoreLab at the University of Oslo. I found the working environment at PoreLab extremely friendly, and the research was impressive. After finishing my PhD, I saw that a postdoctoral position was open at PoreLab, so I snatched the opportunity to apply. So far, I am incredibly happy with my decision, and I can imagine staying longer in Norway.

What are you doing now in your research?

My post-doctoral research evaluates the slow drainage of liquid in porous media. In our experiments, we construct transparent model 3D random porous media using 3D printers. We sandwich these printed models between two Plexiglass sheets. Initially, we inject a glycerol water solution into the porous model, and afterward, we slowly drain the liquid using a syringe pump. During drainage, we image the pattern of the liquid displacement in a porous medium with a camera. We do image analysis to reconstruct the pattern of the fluid invasion front and relate its evolution to the geometry of the porous medium. This work helps us better understand how the pore-scale disorder flow impacts multiphase flow phenomena within the porous medium.

How is the working environment at PoreLab?

The working environment at PoreLab is incredible and working at PoreLab is one of my most satisfying experiences so far. In PoreLab, researchers are friendly and always ready to help in solving problems. Being an experimentalist, this is the best place for me to gain knowledge, both theoretical and experimental. PoreLab is interdisciplinary, and researchers come from many different fields. Researchers have expertise which spans experiments, theory, as well as simulations, and these different bodies of knowledge often come together and complement one other. PoreLab provides a stable platform for scientists to produce cutting edge research in porous media, and I'm excited to be a part of it.

POSTDOC

PAULA K.P. REIS

Department of Physics, UiO

Who are you? What is your background?

My name is Paula Reis, and I came from Brazil. I lived most of my life in Rio de Janeiro, where I got my bachelor's, master's, and doctor's degrees in different branches of Engineering. My scientific background revolves around numerical modeling and, before joining PoreLab, I was involved in the development of a pore-network model for condensing flows. In April 2022 I moved to Oslo to be a Postdoc in Physics at UiO, so that I could have a shift in perspective on how to investigate flow through porous media.

What made you decide to come to *Norway?*

In 2020 I had the opportunity to live in Trondheim for 6 months for family reasons and really enjoyed the city. The close proximity to nature mixed with the local culture that promotes outdoor activities left a great impression on me. Then, after I finished my PhD in May 2021 in Rio, I started looking for research positions in Norway and came across with an open postdoctoral position in PoreLab/Oslo. The position was related to a project investigating flow through thin liquid films in porous media and could align really well my personal and professional aspirations, making me even more enthusiastic about moving to the country.

Tell us more about your project

Currently I am part of the FlowConn project, which investigates connectivity enhancement due to thin films in porous media flows via experimental, numerical and theoretical methods. The project goal is to understand the role of wetting-phase connectivity along paths of connected corners and capillary bridges in multiphase transport through porous media. The existence of such paths for film flow can be identified in a variety of important natural and industrial processes, such as geological CO_2 sequestration, water management in soils and water removal from PEM cells. Still, the extent to which these processes are affected by the flow through films is not well defined in the literature.

My role in this project is to define and implement an effective way to model gas-liquid drainage flows in porous media taking into account the effects of film flow, at the pore-scale.

What is your favorite activity in your research?

I really enjoy mathematical modeling. I often find myself impelled to carefully observe natural phenomena and try to understand why certain systems and materials behave the way they do. Therefore, I feel very lucky to be able to work with the conceptualization of a model to represent a recently identified transport mechanism in porous media. The group in PoreLab managed to gather experimentally a rich set of data regarding drainage through film flow, and that puts me in a particularly privileged position to correctly reproduce its key aspects computationally.

What about the future, where do you see yourself in 5 years?

As of now, I can't picture myself outside academia. One thing that I would really like to get into in the near future is the supervision of students, which could be an important step in my path to eventually becoming a professor. Applying for funding for my own research is also a top priority for the next years, so that I get more in touch with the less exciting, but necessary, part of what it is to have an academic career. Finally, it would also be interesting to become part of some initiative to attract more women to pursue scientific careers. I find it really sad that still in 2023 we are so underrepresented in this field.

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

PHD

KIM ROGER KRISTIANSEN

Department of Chemistry, NTNU

Tell us about yourself. What is your background?

I am Kim Kristiansen. I grew up in the north of Norway, in Alta. I started my working life as an electrician in a local firm but realized quickly that I did not want to do that for 40 years. Then I thought about becoming an electrical engineer considering my background as electrician. But along the way I simply fell in love with natural sciences. I had trouble to decide between physics, biology, and chemistry. I ended up with chemistry because it was somehow the 'middle thing'.

What made you decide to start a PhD?

I have always been drawn towards the fundamentals. I like to reason my way to how things work and understand the mechanisms behind what I see. My aim from the very beginning was therefore to obtain a PhD which is why I choose to start with a Bachelor, then a Master and finally a PhD, all at NTNU. I felt that this path gave me more freedom to shape my own degree.

What is the idea behind your PhD project?

The idea behind my project is to make use of industrial waste thermal energy. Ten years ago, ENOVA performed an investigation and discovered a vast amount of low-grade waste heat in Norway. There have been also international reports that aim to map the extent of this waste. We need new methods to exploit this untapped energy source. Membrane distillation is when you distill water through a porous and hydrophobic membrane using a temperature difference across the membrane. Because the driving force is the temperature difference, one does not depend on the absolute temperature, therefore you can perform membrane distillation at room temperature. During my PhD, I have been developing further a Dutch concept that was developed almost a decade ago. It is known as mempower and the idea behind it is to use the pressure difference. One purifies water and generates mechanical power simultaneously. During my PhD, I have been working on the theory and performed more accurate experiments to demonstrate the concept.

Can you tell us more about these experiments?

There was a lot of planning involved in order to make sure that the apparatus could take everything into account. We are dealing with quite small effects in the present commercial membranes. There is a high sensitivity to noise. In addition, the apparatus must handle the conditions. Some of the challenges were for example corrosion due to hot salt water. Stainless steel can withstand high pressure but would be eaten away by hot salt water. Plastic materials would not be able to withstand the pressure. I ended up working with relatively exotic materials for some parts of the apparatus. Some of these parts had to be ordered right when the pandemic started. This is when the problems began with really long delays. I ended up with a rather expensive apparatus that took a long time to set up, but the end results were promising.

How did you manage to fulfill your work in the laboratory in the middle of Covid's restrictions?

I set up the apparatus in a way that all the crucial control and measurement components were monitored by a computer. So, it was all gathered in a customed program assigned specifically for this apparatus. If you control everything from a computer and you manage to access this computer remotely then you have a remote-control system. I spent some extra time designing this remote control streamlined because of the pandemic. It would have been unpractical for me to rely on the laboratory being open at all times, and also, I live quite far away from Trondheim. So, it was a good and practical solution. From home and at any time in the day, I would just need to log on into the computer and press a couple of keys to control the experiments remotely.

What are you doing now?

I have been working as a Chemical Engineering Specialist at Ocean GeoLoop AS in Verdal commune since October 2022. I have responsibility for running a carbon capture pilot plant at Norske Skog at Skogn, and for doing the necessary experiments to further develop our technology. Actually, I have taken the principle of this remote-control system developed during my PhD to my new job. I am controlling the entire carbon capture pilot plant from home in Verdal now.

How is it to be a PhD at PoreLab?

I really enjoyed my time at PoreLab, always enjoyed coming to the office. There is a nice collection of people there, both competence wise and personality wise. People have different types of background and I thrive in this culture. This multidisciplinary working environment has been good for productivity. I realize that two of my papers started at the lunch table. Because we get all together at the common lunch table, you start discussing with people who have a slightly different perspective than you and that gets you thinking. Then you get the ball rolling and suddenly you are writing a paper. This lunch table culture is a healthy aspect of PoreLab. Overall, my time at PoreLab has been a truly nice experience.

PHD

CAROLINE EINEN

Department of Physics, NTNU

Who are you? What is your background?

My name is Caroline Einen and I come from Mandal, the southernmost city in Norway. In 2013 I moved up to Trondheim to do my masters in Nanotechnology at NTNU and have not left the city since. After graduating from NTNU in 2018 I worked as a researcher in SINTEF Energy Research for a couple of years before starting my PhD in Biophysics at NTNU.

Tell us more about your project

In my project we are attempting to understand the mechanisms behind ultrasound and microbubble mediated delivery of nanoparticles for cancer therapy. This is a promising strategy for more targeted delivery of chemotherapy to cancer tumors, but how the system works is not yet fully understood. Specifically, we are working both experimentally and through simulations to understand how ultrasound and microbubbles can enhance the transport of nanoparticles through cancerous tissue, which essentially is a porous medium comprised of protein networks, water-holding sugar gels, cells and more.

How are you performing your research?

My role in the project is to investigate ultrasound and microbubble enhanced nanoparticle transport experimentally in different models of biological tissue to feed into a predictive model of nanoparticle transport being developed. I am working both *in vitro* using hydrogels to model the porous structure of tissue, and *in vivo* using various tumor models growing in mice for a more relevant biological system.

Why is your research important?

Cancer is one of the deadliest diseases in the world today, and we need to continuously develop and invent new tools to improve cancer therapy. We should also be able to understand fully how and why a certain therapy works, not only to optimize the treatment to be effective and safe, but also to know where an alternate approach might be the better choice. Using ultrasound, microbubbles and nanoparticles to deliver chemotherapy is just one of many promising new cancer therapies, and identifying the cases where it works best is important. There is no one-size-fits-all.

What is your motivation to be part of PoreLab?

I like the idea of combining fundamental principles and theory of transport in porous media with the complexity we see in biological systems. We are also able to combine our own experimental data with modelling, both for model validation and to say something more general about the system we are working with. It is also very exciting and challenging to be a part of the interdisciplinary environment in PoreLab. People come from many different backgrounds and with many different perspectives. There is always something to learn from each other!

PhD candidate Caroline Einen at the PoreLab's stand during the Researchers Night on September 30th, 2022. Photo by Per Henning

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

PHD

JOACHIM BRODIN

Department of Physics, UiO

Who are you? What is your background?

I suppose I have a bit of an unusual background for a PhD-candidate in physics. I only started studying in earnest when I was 38 years old, and even then, my idea was just to study for a year. During most of my adult life I have been trying to write fiction, while traveling the world, doing odd jobs, and starting various companies and other ventures. When my first child was coming along, I realized that writing made me miserable, and I did not want to drag a whole family into that. I started to work full time as a carpenter and built up a company together with another guy. Five years we were building houses all over the greater Oslo area. It started to go from something casual that I was doing to feed the family for a while, to something that was becoming my life. It felt like it was time to make a shift again. It was my wife that pushed me to study. I figured I was too old to really take it anywhere, and it certainly was a surprise that I was good enough at it to get the bachelor in two years and be able to compete for a PhD after the master.

How did you come being interested in flow in porous media?

I was drawn to PoreLab by the fact that it was one of the most active research centers at the physics departments in Oslo. As I was bound to Oslo by my family and my wife's dedication to her job, I figured that I might as well pursue something that has an active, thriving environment here. I also prefer more tangible problems, rather than overly abstract ones. A great deal of the experimental work we do at PoreLab is tabletop experiments, where the studied phenomena often can be seen with the naked eye. It was also an opportunity to exploit my practical background as a craftsman. We have a very collaborative work environment, which is very much in line with my preference. I both appreciate the social environment, and the access to fellow minds, to speed up the thought process and increase the creative flux.

What are you doing now in your research?

My research focus is on the study of two-phase fluid flow in porous media, which also encompasses related areas such as optics and computer science. The work builds on a framework that has been studied at UiO for several decades, but primarily using 2D systems. I have been working on developing a 3D model for these types of experiments using an approach of index-matching porous media and immiscible fluid phases, which are scanned using fluorescent dyes and a 2D laser-sheet. Currently, I am working on two main areas of research: (1) Examining the fundamentals of two-phase flow in 3D and building on the findings of previous 2D studies, and (2) Investigating the spread of pollutants within a complex network through secondary transport mechanisms such as capillary pumping and diffusion.

PHD

KIM R.B. TEKSETH

Department of Physics, NTNU

Tell us about yourself

My name is Kim Robert Tekseth, and I am from Trondheim. I studied applied physics and mathematics at NTNU with a specialization in applied physics. During my master thesis I worked in the X-ray physics group of Dag Werner Breiby at the Department of Physics on methods to optimize image quality in computed tomography (CT) scans through CT simulations. This work provided a solid background for my PhD project within the same research group, and I am currently in my final year of my PhD.

Tell us more about your research project

My main research project can generally be described as computational imaging applied to various flow phenomena at the pore-scale. Early on in my PhD I worked extensively on implementing an efficient algorithm for improving temporal resolutions in CT, allowing dynamic phenomena to be imaged in 4D. By combining this CT reconstruction algorithm with state-of-the-art synchrotron facilities, we have been able to study the interfacial dynamics of quasi-repeatable Haines jumps, a phenomenon that lasts just a few milliseconds, in 3D + time. The fundamental assumption of the technique was that the flow pattern and Haines jumps could be made quasi-repeatable by cycling a liquid back and forth, an assumption that we showed could be fulfilled for a model consolidated porous medium, shedding new light on this fascinating phenomenon.

A secondary part of my research has been on developing a Fourier Ptychographic microscope for the identification and characterization of surface flaws on float glass. Our results provide key input parameters for strength prediction models for predicting fracture origin and cracking in glass such as windows in buildings and windshields in cars.

What is your favorite activity in your research?

One of my favorite activities is preparing for complex experiments. I have been so lucky as to have conducted several experiments at synchrotrons in the course of my PhD, and every time I have appreciated the whole process preparing for these, including developing new ideas and experimental designs, realizing such designs and solving all the problems that occur unexpectedly during testing. While such experiments can at times feel overwhelming as one often only has a single shot of getting it right, it is very rewarding when the experiment is conducted successfully.

Do you have any notion of what your research can mean for the industry?

There has been a growing interest in the development of efficient reconstruction algorithms, enabled by computer hardware advances, for improving temporal resolutions in CT. Improving time-resolution in CT scans can allow dynamic phenomena in opaque samples to be probed in 3D + time and can thus be applicable in many scientific disciplines including fluid flow in porous media and mechanical sample loading. My work in this field has piqued an interest from Equinor and has materialized into a new project continuing the development within this exciting field.

Who is involved in your research?

There are several collaborators, both academic and industrial partners, that has played an important role in my PhD work. The core of my PhD work lies on several experiments conducted through beamtimes at the European Synchrotron Research Facility in France. Furthermore, the project I am hired on have a close collaboration with Muhammad Nadeem Akram and his group at the University of South-East Norway, whose expertise in optical imaging has been fundamental for the work I did in optical imaging. I would also like to mention Tore Børvik and his group at SFI CASA, and their collaborator BMW, for providing the challenging task of identifying surface flaws on glass. All these collaborations have made my PhD work very fulfilling and rewarding.

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

PHD

DAVOOD DADRASAJIRLOU

Department of Civil and Environmental Engineering, NTNU

Davood Dadrasajirlou, during his thesis defence on October 31st, 2022.

Who are you? What is your background?

I am a Civil Engineer with a specialised background in Geotechnical Engineering. I am originally from Ardabil in the northwest of Iran, where I have had my undergraduate and graduate education. I enjoy applied maths and theoretical soil mechanics, particularly mathematical modelling of the mechanical behaviour of geomaterials. As my master's thesis at Tabriz University, I have worked on the effects of decay of bonding between soil particles and stiffness degradation of soil foundation on embankment behaviour. I have recently completed my PhD at PoreLab and Geotechnical Division, Department of Civil and Environmental Engineering, Norwegian University of Science and Technology (NTNU). Before starting my PhD journey, I had the privilege to experience working in large-scale geotechnical projects like the design and construction of a ship lock and the rehabilitation of a rockfill dam.

What made you decide to come to Norway and NTNU?

During my graduate study, I gained a decent knowledge in plasticity theory and the inviscid mechanical behaviour of soil. Later, in practice, I have come across the design and construction of geosystems on soft soils and was astounded by their significant viscous behaviour. To expand my knowledge in this area, I decided to come to Norway, one of the leading countries with a long history of developing knowledge in geotechnical engineering, particularly on challenging soft soils.

Tell us more about your project

The constitutive relation of soil is the core of soil mechanics. It is a mathematical idealisation of the real mechanical response of soil that plays a vital role in solving geotechnical engineering problems.

The mechanical behaviour of soils is governed by their history, like the rate and direction of deposition or erosion, exposure to chemical bonding agents, weathering, leaching, etc. The perplexing features of soil's behaviour as a particulate material include friction, dilatancy, anisotropy, softening and instability, and rate dependency, which are affected by the aforementioned natural processes. Considering these intertwining complex features, it is a formidable challenge to construct a physically representative yet practical constitutive model with a minimum number of efficiently measurable parameters.

My PhD project, under the supervision of Prof. Gustav Grimstad and Dr Seyed Ali Ghoreishian Amiri, specialises in the constitutive modelling of mechanical behaviour of soft natural clays considering thermodynamics laws. The approach used in this research project is based on so-called generalised thermodynamics with a strong emphasis on the use of internal variables to describe the history of the material. The First and Second Laws of Thermodynamics are enforced directly in this formulation so that any model defined within this framework will unconditionally obey these important laws. In this approach, all elements of a constitutive model in plasticity theory such as yield and plastic potential surfaces, hardening rules and elasticity are defined through the specification of two potentials: the free energy potential and the dissipation function (or force potential). This importance of the use of potential functions provides possibilities to decrease the number of material parameters with some amount of rigorous mathematics using extremum principles, leading to computational robustness and practical confidence.

Since you just finished your PhD, what do you do now?

I just started a postdoctoral position at Geotechnical Division, Department of Civil and Environmental Engineering at NTNU, to, fortunately, continue my academic career. I am excited about this phase in my career since I have the privilege to be involved in an industry-academic collaboration, including the Norwegian Public Roads Administration (Statens vegvesen), the Norwegian Water Resources and Energy Directorate (NVE), and Bane NOR, to be able to develop further my PhD work and employ them in practical engineering problem. In this project, we are working in a team to revisit and boost competence in the current practice regarding the safety assessment of natural slopes. Natural soft clays exhibit large compressibility and poor mechanical strength, and thus, present unique problems for engineers to assess the safety of slopes and infrastructures built upon them. The situation is dramatically worse in the case of extremely sensitive soils like quick clay.

PHD

VILDE BRÅTEN

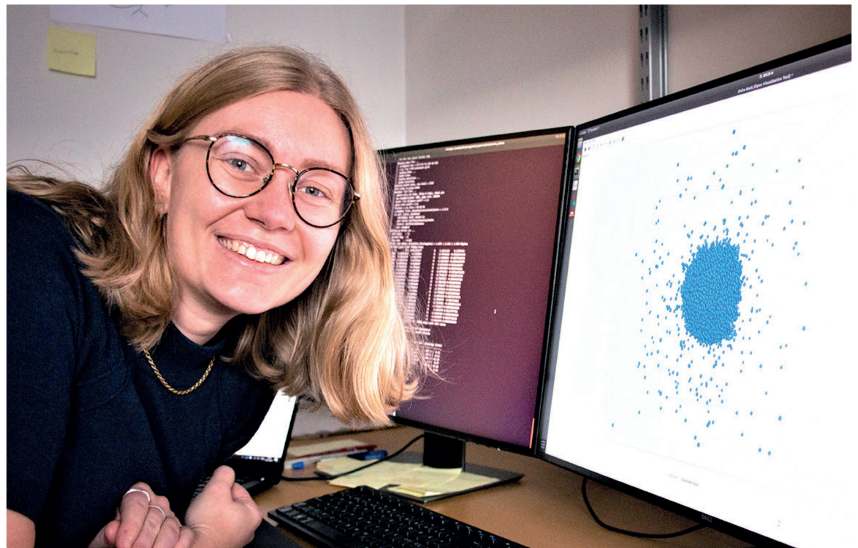
Department of Materials Science and Engineering, NTNU

Who are you? What is your background?

My name is Vilde Bråten, and I am from Lillehammer in Norway. Until October 2022 I worked with my PhD in Nanothermodynamics at Department of Materials Science and Engineering at NTNU and PoreLab. Before starting the PhD work, I studied Chemical Engineering and Biotechnology at NTNU for a combined Bachelor's and Master's degree, where I specialized in Physical Chemistry. During the work with my Master's thesis, I compared methods for computation of partial molar enthalpies and Kirkwood-Buff integrals using molecular dynamics simulations. I found the work super interesting, and I enjoyed the working environment at NTNU. I realized quite early that I wanted to do a PhD within the same field. In my free time, I like to go hiking or bouldering, or travel to different countries to experience new cultures, in particular the food and wine! I also love going to music concerts and festivals.

What did your PhD project entail?

My PhD work consisted of several projects with the same overall goal: to bring new insight on the thermodynamics of nanosystems. Nanosystems are interesting because their behavior is very different from what we expect for macroscopic systems. Nanotechnology utilizes this change in behavior to design systems with specific properties. For instance, gold nanoparticles can be used as catalysts in chemical reactions, while macroscopic gold has no catalytic properties. Nanoparticles can also be used as vehicles for drug delivery in the human body, because they have a unique ability to cross biological barriers. Another category of nanosystems is fluids confined in small spaces. When the size of the confinement is sufficiently small, the behavior of the fluid differs from bulk behavior. This can lead to changes in both dynamic behavior and in phase transitions. Understanding this change is particularly important in porous media science.



What is your favorite activity in your research?

My favorite part about working in research is actually being able to work with so many different activities, and that every day will be different. I enjoy programming, analyzing data, discussing with my colleagues, but I am also very happy when I can spend a few days reading literature and getting up to date on the newest findings in the field.

How is the working environment at PoreLab?

Working at PoreLab these last years has been amazing! I have really enjoyed the casual atmosphere with daily coffee breaks and lunches where PhD candidates, postdocs and professors all participate together. I believe it makes it easier to collaborate and to learn from each other when everyone knows each other a little on a personal level. One of the greatest privileges has also been having colleagues from different departments and research groups, which creates a great synergy

Since you just finished your PhD, what do you do now?

After nine years in Trondheim, it was time for me to check out a new place. I therefore recently moved to Germany, where I now work as a postdoc at Lehrstuhl für Thermodynamik, which is a research group at Technische Universität Kaiserslautern. Currently I am studying mass transfer through vapor-liquid interfaces of mixtures, with specific focus on enrichment of one components in the interfacial region. The central hypothesis in the present research is that the enrichment can lead to a mass transfer resistance at the interface. This resistance is important to account for in techniques used for separation of fluids, such as distillation and adsorption. The findings of this work are therefore relevant in industries that utilize such separation techniques, such as the chemical and pharmaceutical industry.

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

WHERE ARE THEY NOW?

PoreLab is 5 years old, and the first group of graduates have left. Discover on this page what our graduates have been getting up to since leaving PoreLab. They moved on to fascinating and diverse careers in academy, industry, research, start-up, and beyond!

A PoreLab-Alumni group has thus been created this last year. Its mission is to develop a network which offers a welcoming atmosphere for future and existing alumni. It creates a link between old and new members of PoreLab. One purpose is to facilitate recruitment of PoreLab PhD students. Another is to disseminate recent research from PoreLab. PoreLab Alumni members can take an active role in our international alumni network. They can keep up to date in PoreLab's field and continue to develop their network and collaboration through PoreLab's lectures and seminars, receiving research news from PoreLab. We expect that they can become bridge builders in particular between PoreLab and the industrial sector. The first PoreLab-Alumni meeting was organized on March 18th, 2022, with a presentation from former PhD candidate, Jonas Kjellstadli.

Reidun Cecilie Aadland

After 2019
Full-time parenting, Stavanger, Norway

Ailo Aasen

After 2019
Research Scientist
SINTEF Energy Research, Trondheim, Norway

Olav Aursjø

After 2020
Senior Researcher
NORCE Stavanger, Norway

Beatrice Baldelli

After2022
Software Engineer
Vizrt, Bergen, Norway

Eivind Bering

After 2021
Machine Learning Software Developer, Giant Leap Tech. AS, Oslo, Norway

Alberto Luis Bila

After 2020
University lecturer, Eduardo Mondlane University, Maputo, Mozambique

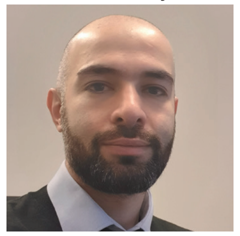
Vilde Bråten

After 2022
Postdoc, Technische Universität Kaiserslautern-Landau, Germany

James Campbell

After 2020
Data scientist
Ministry of Justice, UK

Davood Dadrasajirlou



After 2022
Postdoc, Dept. of Civil and Environmental Engineering, NTNU, Norway

Guillaume Dumazer

After 2018
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Fredrik Kvalheim Eriksen

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Olav Galteland

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Hao Gao

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IKM Ocean Design AS
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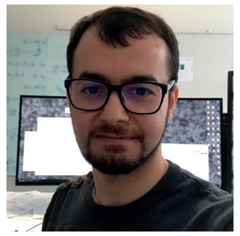
SLB, Oslo, Norway

Hamid Khanamiri



After 2020
Software Developer
SAP, Trondheim, Norway

Jonas Kjellstadli

After 2019
Data Scientist
VitalThings
Trondheim, Norway

Kim Roger Kristiansen

After 2022
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Verdal, Norwa

Haili Long-Sanouiller

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Chuangxin Lyu

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Fredrik Kristoffer Mürer

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Kristian Olsen

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Srutarshi Pradhan

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Michael T. Rauter

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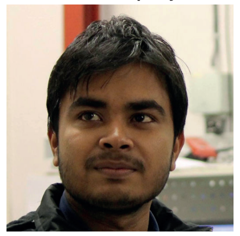
Scientist ZEROe project,
Airbus
Hamburg, Germany

Subhadeep Roy



After 2021
Assistant Professor, Birla Institute of Technology and Science, Hyderabad, India

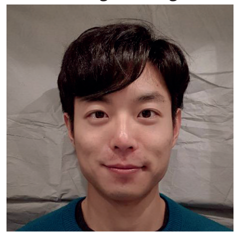
Marco Sauermoser

After 2021
Stack Specialist Flying Fuel Cell, MTU Aero Engines, München, Bayern, Germany

Per Arne Slotte

After 2022
Retired
Trondheim, Norway

Seunghan Song



After 2021
Staff Engineer
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Seoul, South Korea

Louison Thorens

After 2021
Postdoc
Tufts University,
Massachusetts, USA

Antoine Leo Turquet

After 2020
Researcher
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Robin Sam Vacher

After 2022
Research scientist,
SINTEF Industry,
Trondheim, Norway

Morten Vassvik

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JangaFX, Egersund, Norway

Tom Vincent-Dospital

After 2022
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Oslo, Norway

Mathias Winkler

After 2021
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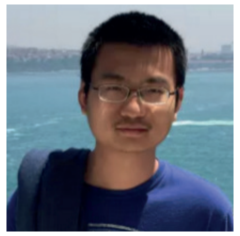
Sopra Steria, Trondheim, Norway

Le Xu



After 2019
Lecturer, Changzhou Institute of Technology, Changzhou China

PoreLab-Alumni meeting on March 18th, 2022, with a presentation from Jonas Kjellstadli (PhD / 2019): How is life after leaving the sacred chambers?

HEADING FOR THE FUTURE:

OUR NEW EXTERNALLY FUNDED PROJECTS

PoreLab researchers developed 4 new external funding projects in 2022, either as project leader or in collaboration with our partners. Two of them are financed by the Research Council of Norway, the third one is financed by the Arts Council Norway through the EEA agreement with the EU and the fourth one is a Marie Sklodowska-Curie Postdoctoral fellowships from the EU commission. These four projects come in addition to our 5 projects granted in 2021 and 8 projects granted in 2020 and 2019. Let us specify that previous granted projects become part of the research projects of our annual reports.

SnowMagnet

Project leader: Quirine Krol, NTNU

Duration: 2022 – 2025

This project involves 2 partners: PoreLab at NTNU and the Montana State University in Bozeman, USA. The awardee for the EU MSCA (Marie Sklodowska-Curie Actions) Postdoctoral fellowship, Quirine Krol, holds a PhD in Civil and Environmental Engineering from EPFL, Switzerland, and a MSc in Theoretical Physics from Utrecht University, The Netherlands.

She summarizes her project as follow:

"The effective hydraulic conductivity of snow is highly impacted by its microstructure, introducing a variability of at least three orders of magnitude, impacting seasonal flooding and glacier hydrology. Yet, the mechanisms of unsaturated flow and the impact of local phase transitions have never been investigated at the pore scale. This inhibits improving on the constitutive laws for larger scale models of snow hydrology using upscaling methods. Micro-computer tomography is a very effective method for dry snow metamorphism but fails for wet snow because the transient flow and the accelerated change in microstructure cannot be resolved. We propose nuclear magnetic resonance (NMR) methods in combination with Lattice-Boltzmann simulations and Pore-Network models to characterize water flow in snow. Applying these methods on unsaturated flow in snow, we can resolve local saturation, liquid water displacement probabilities and diffusion measures, quantitatively measuring mechanisms of water transport. These are essential for gauging modelling approaches of transport phenomena. Whilst NMR methods have been used extensively on saturated flow, it has found limited application in unsaturated media and is poised for significant advances. To target melt and percolation phenomena in snow, we start with 3D printed porous media (single pores and fully resolved snow geometries) to refine the experimental setup and provide novel data for unsaturated flow in porous media. Assisted by Lattice-Boltzmann simulations we can link pore-scale mechanisms to the NMR data. The action will produce unique data sets on unsaturated flow as a function of capillary number in model porous media and snow. This data will be used to calibrate dynamic pore network models aiming at quantifying the transient flow in snow. This leads to a parameterization of effective hydraulic conductivity for a wide range of snow microstructures providing a new standard for models resolving water transport in snow."

Figure: 3D printed micro-CT of coarsened snow

The 2 first years of the project are planned at the Montana State University, USA, and supervised by Professors Sarah Codd and Joe Seymour. The third year will be spent at PoreLab, NTNU, Norway with Professor Alex Hansen as supervisor for the researcher.

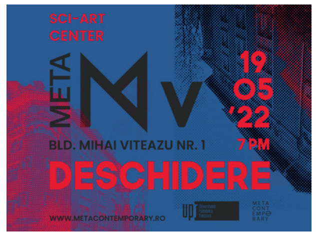
POROUS MATTER. Void fractions in materials, ideas and society

Project leaders: Mirela Vlăduți, Asociația META Spațiu, Romania and Alex Hansen for PoreLab, NTNU

Duration: 2023

This project is a collaboration between the META Spațiu contemporary art gallery in Timișoara, Romania, the Polytechnic University in Timișoara and PoreLab. It is financed by the Arts Council Norway through the EEA agreement with the EU.

The Polytechnic University of Timișoara and the artistic organization META Spațiu have joined forces in creating a flagship cultural center, MV Sci&Art, that opened its doors to the public on May 19, 2022.



Marcel Moura, researcher at PoreLab, attended the opening of the centre and gave an interview on Radio România Cultural for the occasion.

The center has three main directions: a contemporary art gallery, a Sci&Art incubator, and a multi-media dynamic cultural events program. PoreLab, through a bilateral initiative, is part of the Sci&Art incubator.

The main idea is to build a program of transdisciplinary cooperation between artists (student level or established) and scientists, and to integrate art and science into a strong developed program that can contribute to innovation.

The main objective of this initiative is to create a new type of sustainable interaction between art, science, and technology, focused on the way in which artistic and scientific experiments can give birth to different ideas and attitudes and can contribute to the configuration of future societies – or future realities – on various levels (communication, new experiences, societal debates, interventions in scientific processes and supporting the individuals' personal development). The contribution of art and science collaborations can prove themselves essential for the development of the future cultural reality of Timișoara 2023 European Capital of Culture – Connections territory, Reflections stations, Horizons of knowledge route (bid-book), and the consolidation of cultural and creative sectors. This initiative is meant as well to foster the contemporary creation, production and transdisciplinary collaborations between science and art.

The project plans exchange visits between PoreLab and MV Sci&Art, an exchange program between artists and scientists, mentoring courses and producing a bilateral exhibition by the end of the project.

FME HYDROGENi

Project leader: Nils Røkke, SINTEF and Øivind Wilhelmsen for PoreLab, NTNU

Duration: 2022 - 2030

PoreLab is a research partner for the center HYDROGENi and participates to the center in securing a high academic tenure. HYDROGENi is financed by the Norwegian government and the industry through the Norwegian Research Council's Center for Environment-Friendly Energy Research (FME) program. The center's work to build a sustainable hydrogen economy is focusing on four main research areas:

1. Cost-efficient and scalable production
2. Transport and storage in Norway and Europe
3. End-use technologies
4. Safety and material integrity

HYDROGENi

PoreLab participates in the research activities of HYDROGENi through a PhD position under the Research Area 2 (RA2). RA2 aims to enable efficient transport and storage of H_2 and H_2 carriers.

Tage Maltby was recruited as PhD candidate in November 2022. His supervisors are Professor Øivind Wilhelmsen, PI at PoreLab, Postdoctoral researcher at PoreLab Morten Hammer and Associate Professor Anders Lervik.

Tage introduces his project as follow:

"During my Ph.D. I will investigate Novel quantum refrigerant mixtures for energy efficient hydrogen liquefaction. The main goal will be to develop new, accurate molecular based thermodynamic models for quantum mixed refrigerants.

Large-scale transport across long distances requires that hydrogen is in a dense phase. A promising candidate, both from a cost and energy point-of-view is liquid hydrogen (LH_2), as it gives superior flexibility in the receiving end with respect to purity, pressurization, distribution, and usage. The energy requirement for this process is large, but a key enabler for reducing this energy requirement is the utilization of quantum refrigerants, consisting of H_2, neon, and helium.

Several areas will need to be addressed during the project to learn more about these refrigerants. The topics of research will be to map the risk of solid-formation of neon at the lowest temperatures, improve upon the "SAFT-VRQ Mie" equation of state (EOS) for lower temperatures, apply square gradient theory to refrigerants to determine the surface tensions of these fluid mixtures, and to perform molecular simulations of refrigerants using quantum path integral sampling. My research is also part of Research Theme 7 in PoreLab, where Objective 4 is to study hydrogen in porous materials."

Dual-Functional Anti-Gas Hydrate Surfaces (D'andra): Ice Growth Confined in Porous Media

Project leader : Zhiliang Zhang, NTNU

Duration : 2022 – 2023

This project is directly connected to the NANO2021 project, Dual Function Anti-Gas Hydrate Surfaces (D'andra).

It is funded through the Coordination and Support Activity for Researcher mobility from the RCN and intends to support the research stay for Professor Natalya Kizilova of the V.N. Karazin Kharkov National University, Kharkiv, Ukraine, as guest researcher for 1 year at the NTNU Nanomechanical Laboratory in collaboration with PoreLab in Trondheim. Professor Kizilova has been the head of the Department of Theoretical and Applied Mechanics in Kharkov National University. Her university has been bombed out of operation in March 2022 after Russia invaded Ukraine. The project is therefore also in solidarity with the victims.

Professor Natalya Kizilova, V.N. Karazin Kharkov National University, Kharkiv, Ukraine

The idea of D'andra is to develop a model that describe flow of subcooled water in nanoconfined pores. Supercomputers are being used in the project to build algorithms and solve the hydrodynamic flow in pores of various dimensions, to understand and prevent ice-formation. The D'andra project is educating two PhDs, and their work will be extended and supported by including Prof. Kizilova. The aim of the research stay for Prof. Kizilova is to investigate aspects of the governing equations that describe transport of subcooled water to and from ice-growing regions in porous media, to support the modelling of equilibrium, as well as describe non-equilibrium in partially frozen networks of pores. The D'andra project has the appealing strategy to *allow hydrates to form, when minimizing their tendency to deposit on / facilitate their detachment from solid surfaces.* Without deposition and agglomeration, the hydrate slurry can be transported away from the critical sections by the hydrodynamic shear force until it exits in a thermodynamically stable region without impeding production. There are presently no commercial anti-hydrate surfaces available in the market and the research on anti-hydrate surfaces has just begun. The present project for Prof. Kizilova will add to the existing leader team's competence by increasing their scientific capacity for student supervision and facilitate student exchange to N.V. Karazin Kharkov National University.

ERIKA EISER'S RESEARCH LABORATORY

In 2022 Professor Erika Eiser set up her experimental lab dedicated to the development and study of bio-inspired, sustainable materials.
Studying the structure of nanoporous networks and transport/flow through them experimentally requires both a wet lab for the preparation of those and a dry lab equipped with appropriate instruments such as microscopes with fast cameras and micro-rheology tools.

THE WET LAB

was established to synthesize and functionalize various colloids. Amongst those are fluorinated latex particles that form colloidal crystals with tunable structural colors[1]. The Eiser Group also studies DNA-functionalized colloidal networks with well-defined pore-size distribution. Here, a dense brush of short single-stranded DNA attached to the colloidal surfaces acts as a temperature induced ON-OFF switch for very strong, short-ranged attraction. The selectivity of DNA-binding enables the formation of two intertwined, percolating networks called bigels [2,3] (Fig. **Wet Lab**). Moreover, our colloids can be used to induce out-of-equilibrium crystallization at liquid-liquid interfaces[4].

Further, we use a bio-mimetic approach to develop clay-biopolymer nanocomposite films and coatings made from Laponite, a synthetic clay, and cetylmethyl cellulose[5].

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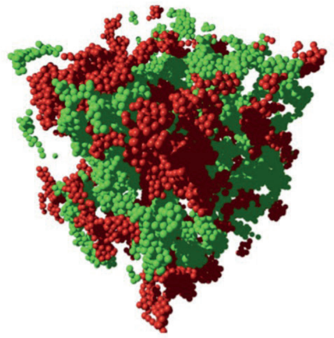

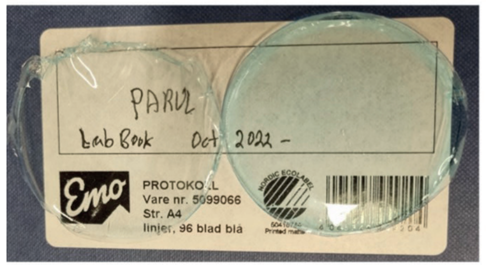

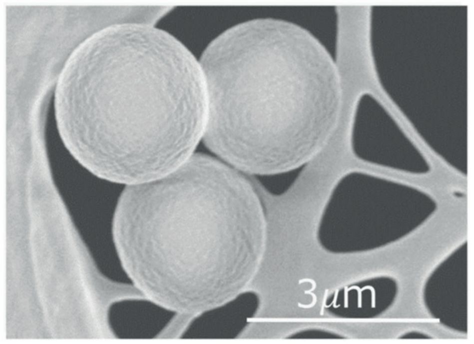

Wet Lab *Photograph of our sample preparation room, equipped with fume hood and tools to prepare soft matter samples and determine their phase diagram. Bottom left: clay-polymer nanocomposite films. Bottom right: SEM image of polystyrene colloids synthesized by Thomas O´Neill (taken from his PhD thesis, Cambridge 2019). Top right: Snapshot of a simulation of a bigel, provided by Francesco Varrato[2].*

THE DRY LAB

was developed to focus on the study of the rheology of complex fluids and eventually two-phase flow in porous media. Over the past 15 years the Eiser group has explored various light scattering based particle sizing and micro-rheology techniques to probe the viscoelastic equilibrium properties of complex systems. Amongst those techniques are Differential Dynamic Microscopy (DDM)[6] that allows the determination of particle sizes between 50 nm and several micrometer using simple video-microscopy. This technique proved particularly useful to study the diffusivity of colloids in confining porous networks[7].

When working with precious samples such as protein solutions or DNA hydrogels, it is imperative to use micro-rheology rather than classical bulk rheology. We use Dynamic Light Scattering (DLS)[8] and Diffuse Wave Spectroscopy (DWS) based micro-rheology[9] as well as a dual Optical Tweezers setup (Fig. **Dry Lab**). In all three cases we measure the thermal fluctuations of the inserted probe colloids to obtain their mean-squared displacement $\langle \Delta X(\omega)^2 \rangle$, which is directly related to the elastic and loss modulus, G'(ω) and G"(ω), of the background fluid. The advantage of these methods is that we can measure the local and bulk viscoelastic response of highly complex fluids, which cannot be achieved with conventional methods. Moreover, they allow us to explore the systems response over a large temperature range. Both DWS and DLS measurements are fast, allowing also for time-resolved experiments.

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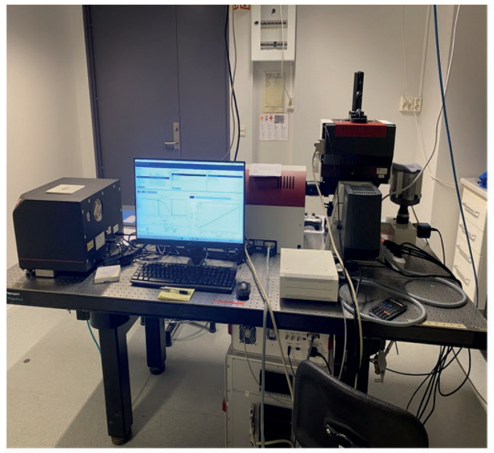
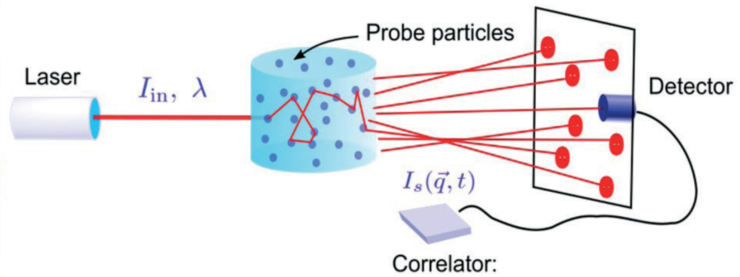
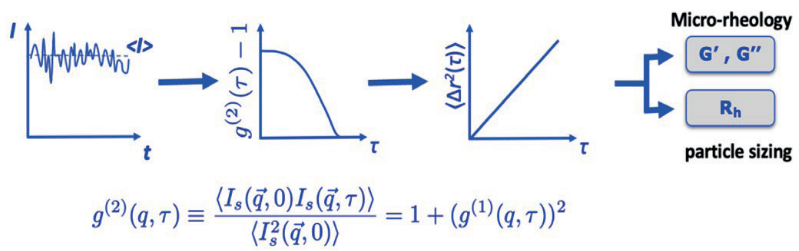
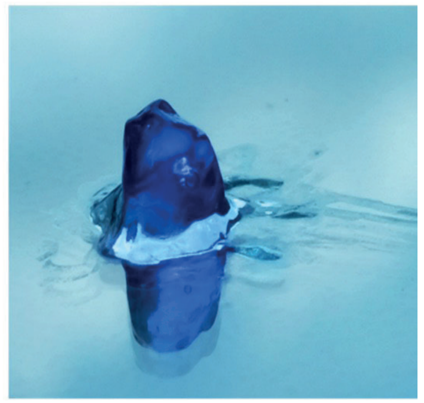
Dry Lab *Top left: Photograph of optical table holding a DWS setup from LS Instruments (Fribourg, CH) and a dual optical tweezers setup (JPK NanoTracker™ 2). The cartoons illustrate the setup and functioning of DWS micro-rheology. Bottom right: Photograph of a drop of a DNA hydrogel made of Y-shaped DNA nanostars.*









PORELAB GRADUATE SCHOOL

TRAINING THE NEXT GENERATION OF RESEARCH LEADERS

In 2022, the pandemic was far from over. Nevertheless, most actions taken by the authorities have focused on vaccinations and a large number of measures intended to limit the spread of the disease, such as campus closure, mandatory online courses, limited gatherings, remote work, and travel restrictions, were lifted gradually allowing students and employees to return on the campus and travel again. It was easier as well for our guests to come back to Norway since only a COVID-19 certificate was mandatory to enter the country. This is positive. But it will come as no surprise, also we have observed that our working habits have changed irrevocably. During the pandemic, we adopted quickly and effectively technologies for videoconferencing and other forms of digital collaboration. The tools have improved, and our working habits changed, but the PoreLab ambition remains the same: to create a scientifically stimulating and inclusive workday, and an interdisciplinary and international training ground for our juniors.

Two PoreLab courses

Two courses are offered by PoreLab scientists, open to both PhD and master students, at our host institutions. The courses have a special focus on porous media physics.

The PoreLab course *"Experimental Techniques in Porous and Complex Systems"* (FYS4420/FYS9240) is organized every year during the fall semester by UiO. The course contains four projects that give students an introduction to important experimental techniques in the field of condensed matter physics. The teaching is based on four projects in which the students apply techniques on realistic problems in condensed matter physics. Despite the pandemic, students from NTNU travelled to UiO to attend the laboratory courses. The course lecturer is Professor Knut Jørgen Måløy, PI at PoreLab.

The PoreLab course on theory and simulation of flows in complex media is offered in a digital format in order to welcome students at both UiO and NTNU. The course has a double title and code: *"Dynamics of complex media"* (FYS4465/FYS9465) at UiO and *"Flows in porous media"* (KJ8210) 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 by the needs to describe ground water flows, biological tissue, hydrocarbon management, fuel cells, electrophoresis, building materials and the quest for governing equations. The course lecturer is Professor Eirik G. Flekkøy, PI at PoreLab.

PoreLab Junior Forum

The PoreLab Junior Forum was established by and is run by the juniors themselves. The main goal of the PoreLab junior forum is to bring together the group of PhDs, postdocs and early career researchers of PoreLab, new and old, with the objective of allowing them to better know each other and share their respective work and scientific interests. The PoreLab junior forum is particularly important to PoreLab, also because it serves to bind the two hubs in Oslo and Trondheim together. The center has two physical locations but is indeed a single center. The forum extends possibilities for collaborations and networking. The Junior forum meets usually twice a year. Because of the restrictions under the pandemic, the gatherings have been somehow disrupted in 2020, 2021 and 2022: the 5th junior forum was organized online in November 2020, the 6th junior forum was held at UiO in November 2021 and the 7th junior forum took place in October 2022 in Trondheim.

The program started with a presentation from the senior members, followed by an introduction of new members. Ingrid Heggland, senior research librarian at NTNU and expert on open Access gave a presentation on: *"Open Science – what, why and how?"* Some time were reserved for a discussion among the juniors on *"What happens after PoreLab?"* Social activities were organized by the end of the day with a dinner at the restaurant Bror Bar in Trondheim followed by a gathering at a minigolf.

Both nodes, PoreLab NTNU and PoreLab UiO, have their Junior Forum spokespersons. Her/his main task is to coordinate the organization of the PoreLab junior forum. She/he acts as a bridge and contact person between the leadership at PoreLab and the juniors. The spokesperson represents the members of their campus in issues that concern the operation of the center that need be addressed by the PoreLab leaders.

Master, PhD and Postdoctoral training

Each student and fellow follow her/his regular institutional training program, with specified demands for scientific work, supported by course work and other activities.

The scientific work is organized in clusters around each PhD candidate. Two supervisors are natural members of the cluster in addition to master students, postdocs or guests that are working on the same problem or takes an interest in it. This organization helps ensure the inter-disciplinary nature of our work, network creation and mentoring.

Courses on ethics, rhetoric's, dissemination, and communication are for instance available at both NTNU and UiO. The course on *"Doing science: methods, Ethics and Dissemination"* (MN 8000), includes an introduction to the history of science, the principles and challenges of scientific enquiry, central and controversial issues on the interface between science and society, scientific writing, dissemination of science through media, and the ethics of proper scientific conduct. This course is mandatory for all PhD candidates at PoreLab NTNU.

Postdocs are offered a variety of courses and workshops suitable for their career plan at the host institutions, NTNU and UiO. Examples are courses on PhD supervision, or workshops on publishing practice in international journals. Pedagogical courses, offered by UNIPED (NTNUs Educational Development Unit) may be relevant. As far as possible and when suitable for the projects, the postdocs will co-supervise PhDs and master students. To teach at the BSc an MSc-level is encouraged for all postdocs. All PoreLab postdocs need to work out a suitable career development plan in close collaboration with their supervisor. This plan comes in addition to the usual and annual appraisal interview that all employees need to complete with their manager.

National and international collaborations are highly encouraged and therefore supported within the group of students and young researchers. The center offers some funds that allow foreign master students to spend time with us, as well as to send our own students abroad. The same offer is available for master students between NTNU and UiO. As an example, master student, Zehra Saleh, spent one month during the fall 2022 with Professors José Soares de Andrade Junior and Hans Herrmann at the department of Physics at Universidade Federal do Ceara in Brazil, working on her thesis related to percolation in N-particle systems.

Similarly, all homely-recruited PhD candidates and postdocs are invited to spend some time at one of our collaborating institutions. As an example, postdoc. Morten Hammer, spent three months during the spring 2022 at the University of Stuttgart in Germany, visiting the research group of Professor Joachim Gross at the Institute of Technical Thermodynamics and Thermal Process Engineering. The purpose of his stay was to learn from Gross expertise on classical density functional theory (DFT), a method to efficiently describe gas-liquid interfaces and to study fluids confined in pores. This joint work led to a publication.

All at PoreLab, including master students, PhD candidates and postdocs, are invited to attend and contribute to all PoreLab events, such as the PoreLab lecture series and the Thursday's talks. All junior members are encouraged to submit abstracts and present posters or lectures at national and international conferences. Expenses are covered by the Center.

The center receives every year many visitors, some renowned national and international researchers, and the junior researchers obtain opportunity to meet and interact with world leading scientists. A list of visitors is given page 78.

Master Students 2022

Similar to the three previous years, a dedicated catalogue presents our suite of excellent master students. Coming from physics, chemistry, chemical engineering, mechanical engineering, and geosciences, they represent the interdisciplinarity of PoreLab. In 2019 we had the great pleasure to welcome five international master students at PoreLab's premises. This was a result of international collaboration. Unfortunately, restrictions on travel and entry to Norway due to the pandemic put a halt on this fruitful exchange in both 2020 and 2021. It is then with great pleasure that we saw a timid come-back in 2022 with two master students choosing to accomplish a part of their master with us.

The catalogue provides an overview of projects performed by our master students in 2022. Students can also find suggestions for new master projects in this catalogue. Hopefully, this can inspire new students to join the team.

PoreLab Lecture series, Porous Media Tea Time Talk and Thursday Talks

The use of video conferencing has intensified since the beginning of the pandemic. It allowed us to broaden our pool of lecturers and we noticed a boost in attendance. This trend continued in 2022 with no less than 31 lectures (see page 79 for the list). As a comparison, we had 27 lectures in 2021 and 29 in 2020. The PoreLab lecture series are now almost always given by external lecturers.

The PoreLab lecture series are organized alternating with the Porous Media Tea Time Talks (#PorousMediaTTT), a webinar series, sent via YouTube and organized by a team of young porous media researchers, including PoreLab members. Thirteen sessions of the Porous Media TTT with at least 2 talks each were organized in 2022.

Porous Media Tea Time Talks

The Thursday's talks aim to promote internal speakers who are given the possibility to present their own activities or give a lecture. They are meant for PoreLab members to present and receive feedback on their own problems. Both PoreLab lecture series and Thursday's talks are administered and organized by dedicated PoreLab juniors.

MEETINGS AND WORKSHOPS

Researchers at PoreLab have numerous opportunities to present their scientific activities and research results to both internal and external events. We list in this double page the meetings and specialized workshops organized by PoreLab members alongside other experts in their field in 2022.

COMPUTATIONAL METHODS IN NANOTHERMODYNAMICS – CASE STUDIES OF POROUS MEDIA, SMALL SYSTEMS AND IONIC LIQUIDS

Together with the chair of engineering thermodynamics in TU Delft, the thermodynamics group at NTNU have already since the beginning of PoreLab, developed computational methods, aimed to study confined fluids in porous media. The textbook *Nanothermodynamics. General theory* by Dick Bedeaux, Signe Kjelstrup and Sondre Schnell serves as one theoretical basis for the effort. The joint effort is now branching out into numerous applications. A central joint topic with the group in Delft, led by Professor Thijs Vlugt, is the study of two-phase equilibria of fluids confined to slit and cylindrical pores. Several PhD students from PoreLab (Olav Galteland, Vilde Bråten, Michael Rauter) have made considerable progress on this topic. The workshop brings together simulators positioned in both countries to exchange ideas, methods, discuss problems and possible ways out of these. In 2022, the workshop entitled *"Computational Methods in Nanothermodynamics - Case studies of porous media, small systems and ionic liquids"* was organized on April 8th by Vilde Bråten together with Signe Kjelstrup. Our long-term partners from the section for Engineering Thermodynamics at Delft University, the Applied Physics group at the Eindhoven University and the Thermodynamics group at the department of chemistry and PoreLab gathered in Trondheim. The day started with presentations from the different groups. The traditional free discussion in small and big groups at the end of the seminar was appreciated in particular, and the round-off with delicious food at Troll restaurant is beginning to get famous.

Welcome next time!

5TH NATIONAL INTERPORE NORWAY WORKSHOP ON POROUS MEDIA

The mission of the Norwegian Chapter of InterPore is to create a platform for scientists and engineers involved in porous media studies in Norway or with connection to Norway. The Norwegian Chapter of InterPore focuses on interdisciplinary and fundamental studies of porous media in connection with applications and national and international technological demands. It aims to advance and disseminate knowledge for the understanding, description, and modelling of natural and engineered porous media systems.

The Norwegian Chapter of InterPore (InterPore Norway) was founded in September 2016 with a kick-off workshop in Bergen. The annual workshop was conducted from 2017 in Trondheim, Oslo, Stavanger and Bergen, except in 2021, which was cancelled due to the COVID-19 pandemic.

During the workshop, lectures in different disciplines of porous media were given by national and international invited speakers, followed by a poster session.

2022 National Interpore Norway workshop was organized on December 1st, 2022, at NTNU, Trondheim. The workshop was organized by Professor Alex Hansen, Professor Carl Fredrik Berg and Dr. Seyed Ali Ghoreishian Amiri, all PoreLab members.

Norway InterPore Chapter

WORKSHOP ON NON-NEWTONIAN FLOW IN POROUS MEDIA IN FORTALEZA, BRAZIL, AND SYMPOSIUM IN HONOR OF JOSÉ SOARES ANDRADE JR.'S 60TH BIRTHDAY

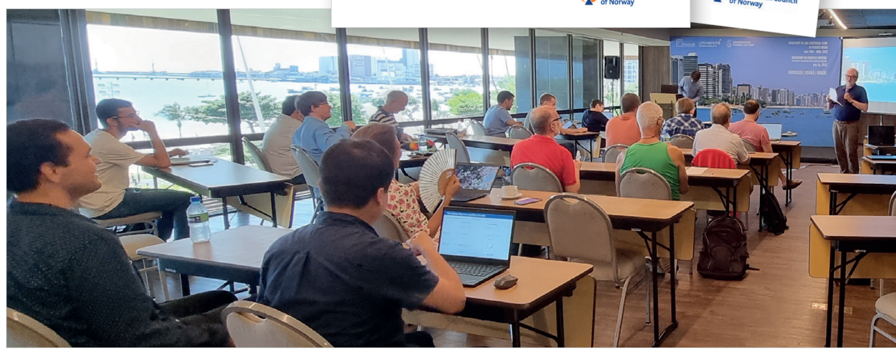
In 2020, an INTPART project on non-Newtonian Flow in Porous Media was allocated to PoreLab by the Research Council of Norway (RCN). The INTPART funding scheme is for creating an international partnership for excellent education, research and innovation. It supports the creation of an international research environment resulting in strong and lasting networks between the researchers.

The INTPART project on *Non-Newtonian Flow in Porous Media* was developed as a collaboration between Alex Hansen from PoreLab in Norway, Laurent Talon from the FAST laboratory and Alberto Rosso at the LPTMS, both at the University of Paris-Saclay in France, and José Soares Andrade Junior and Hans Herrmann from the Complex Systems Group at the Universidade Federal do Ceará in Brazil. The project aims at scaling up the description of flow of non-Newtonian fluids in porous media from pore scale to the continuum scale.

In addition to the exchange of Master students, PhDs, postdocs and researchers between the three laboratories, the project supports the organization of two main international workshops, the first one being planned in 2022 and the second one by the end of the project in 2024. The objective of these workshops is to bring together experts in different fields, complex fluids mechanics, porous media, statistical physics to share their different approaches and advances.

The first comprehensive workshop was organized on 28-30 June 2022 at the Hotel Gran Marquise in Fortaleza, Brazil immediately followed by a Symposium in Honor of José Soares Andrade Jr.'s 60th Birthday on July 1st, 2022. The workshop gathered experts invited by the organizing committee to give a lecture. They were coming not only from PoreLab (well represented with 10 researchers), the University of Paris-Saclay and UFC, but as well from ESPCI, Ecole Normale Supérieure and Ecole Polytechnique in France, ETH Zürich, the Universities of Barcelona in Spain, Lisboa in Portugal, Southern California in USA and British Colombia in Canada. Each lecturer was given 40 minutes which allowed plenty of time for questions and discussions.

The second workshop, larger, is planned on 14-19 July 2024 at the Banff International Research Station in Alberta, Canada. The lead organizer is Professor Ian Frigaard from the University of British Columbia who attended the workshop in Fortaleza. The workshop is supported by the three INTPART partners together with Purdue University and Princeton University.



EARTHFLOWS JUNE MEETING 2022

EARTH FLOWS

The EarthFlows Meeting is an annual event on its 8th edition, and part of a strategic research initiative for cross-disciplinary research at the University of Oslo, Norway. This year's seminar was held in Oslo between 15 and 16 June 2022. The EarthFlows meeting is a two-day international conference, with the intention of bringing together top researchers from various disciplines (geoscience, mathematics, material science, theoretical and experimental physics), who have different perspectives on interface dynamics, flows and deformations during solid and fluid earth processes.

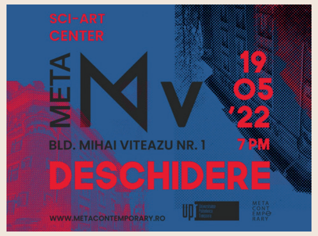
The seminar is funded by the Research Council of Norway (project COLOSSAL), the University of Oslo (project EarthFLows), and Equinor through the Akademia agreement (project MODIFLOW).

OUTREACHS

An important goal of PoreLab is to communicate its research and findings, as well as to increase the appreciation and understanding of science in general. Bringing scientific culture and research closer to pre-university educational levels and promoting research vocation is of great importance to PoreLab. We have received several times school students in these recent years. In 2022, we participated again to the Researcher's night. Marcel Moura gave several interviews in his home country, Brazil. This year he was interviewed on Radio Romania Cultural.

19 May 2022:
Researcher Marcel Moura participated to the opening of the SCI-ART center in Timisoara, Romania.

"POROUS MATTER. Void fractions in materials, ideas and society" is a collaboration between the META Spaţiu contemporary art gallery in Timişoara, Romania, the Polytechnic University in Timişoara and PoreLab (see page 62). The Polytechnic University of Timişoara and the artistic organization META Spaţiu have joined forces in creating a flagship cultural center, MV Sci&Art, that opened its doors to the public on May 19, 2022. The MV Sci&Art center is a cultural center and contemporary art gallery that will focus on the promotion and integration between scientists and artists. It has three main directions: a contemporary art gallery, a Sci&Art incubator, and a multi-media dynamic cultural events program. This center is a premier, not only for Timisoara but also for Romania, by its aims to support collaborations between science and art at the university level and bring together professionals from both spheres.

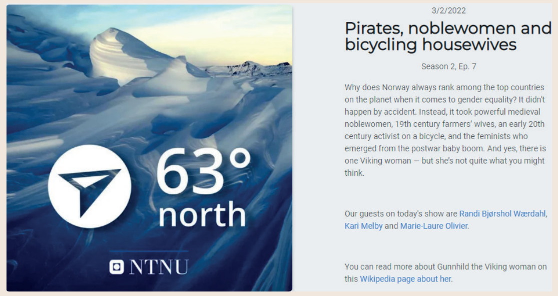


Marcel Moura, researcher at PoreLab, attended the opening of the centre and gave an interview for the occasion. He was interviewed by Mihaela Ghiță from Radio Romania Cultural.

2 March 2022:
Marie-Laure Olivier, administrative leader for PoreLab was invited to the podcast 63° North, hosted by NTNU.
The topic was about gender equality.

About the episode:

Why does Norway always rank among the top countries on the planet when it comes to gender equality? It didn't happen by accident. Instead, it took powerful medieval noblewomen, 19th century farmers' wives, an early 20th century activist on a bicycle, and the feminists who emerged from the postwar baby boom. And yes, there is one Viking woman — but she's not quite what you might think.



SOCIAL MEDIA

Visit our website **www.porelab.no** where you find daily updated information on our researchers, scientific findings, happenings, studies and many more. Follow us on Twitter as well, and YouTube!

30 September: PoreLab at Researcher's nights, NTNU

The Researcher's night was launched at the European level under the initiative *"Researchers in Europe 2005"*. The European Research's Night takes place every year, on the last Friday of September. It is meant to increase awareness of the impact of science on everyday life, boost public recognition of research's work and spark interests of young people in science and research. This year's theme was the ocean.

PoreLab participated in Researcher's night 2022 with Caroline Einen, Hyejeong Cheon, Sebastian Price and Tage Maltby, PhD candidates, together with Professor Erika Eiser. They presented concepts relevant to porous media research by showing various experimental demonstrations and simulation results. High school students could discover how is make a bio-porous materials and how insulation porous materials used in building interact with water. The group also presented simulation results related to the self-agglomeration of collagen, shock waves, and the turbinate structure of seal noses in arctic and subtropical regions. Hyejeong says about the event: *"The students showed great interest in the demonstrations and the simulation results. They enjoyed as well some Stratos, which is a typical porous chocolate. We had fun discussing with them, and we hope that our activities stimulate their passion for science."*

25 November 2022: School visit at PoreLab UiO

A first-year high school class from Hartvig Nissen came for a visit during what they call "fagdag". We had a discussion and brief presentation of PoreLabs activities, followed by experimental demonstrations and a lab tour.

AWARDS and prestigious nominations in 2022

Congratulations to Professor Emerita **Signe Kjelstrup** with the 2022 *InterPore Honorary Lifetime Membership Award*

The InterPore Honorary Lifetime Membership Award is reserved for individuals who have made extraordinary contributions to porous media science and technology, who are world-renowned in the porous media community, and whose contributions are consistent with the aims and ideals of InterPore.

The committee wrote about Signe:
She has made extraordinary contributions in applying the methods of non-equilibrium thermodynamics based on energy conservation, entropy production and local thermal equilibrium to describe multiphase flow in porous media. Her outstanding work in equilibrium and non-equilibrium thermodynamics is widely known, not only from her many scientific papers, but also from a series of books, including a book for engineering students, "Non-Equilibrium Thermodynamics for Engineers". Prof. Kjelstrup has widely applied novel scientific ideas in porous media science, from hydrogen-based fuel cell technology to the transport of nano-sized medication particles in the blood stream and the minimization of heat loss of reindeer and seal noses in winter. She is a principal investigator in PoreLab Center of Excellence at the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway, where she has overseen graduate education and delivered a generation of researchers and engineers within the fields of equilibrium and non-equilibrium thermodynamics and porous media.

Postdoctoral researchers **Paula Reis** and **Gaute Linga** had their poster presentations awarded during the 2022 *Gordon Research Conference on Flow and Transport in Permeable Media*

Postdoctoral researchers Paula Reis and Gaute Linga had their poster presentations awarded during the 2022 *Gordon Research Conference on Flow and Transport in Permeable Media*. The conference happened on July 17-22, 2022, in Les Diablerets, Switzerland, and is one of the most important events worldwide for the porous media community.

The posters were entitled *"Pore-scale modeling of film flow effects during gas-liquid drainage"* and *"Chaotic mixing in intermittent two-phase porous media flows"*. Both Paula and Gaute are working in connection with two projects funded by the Research Council of Norway under the Researcher Project for Young Talents funding scheme.

Congratulations to our young researchers!

Professor **Carl Fredrik Berg** is appointed President of *The Society of Core Analysts*

Professor Carl Fredrik Berg, Principal Investigator at PoreLab, has been appointed President of the Society of Core Analysts, a Chapter of the SPWLA, in 2022. This organization is a Chapter-at-Large of the Society of Petrophysicists and Well Log Analysts (SPWLA).

Its objectives are to promote the aims, purpose, and membership of the SPWLA which is a non-profit scientific organization, as well as to serve the interests of all persons who use or obtain reservoir evaluation information from rock and core samples. SCA was founded in 1986.

Congratulations, Carl Fredrik, for this nomination!

Professor Emeritus **Daan Frenkel**, receives the *Lorentz Medal Award 2022*

Former PoreLab Scientific Advisory Board member and long-term visitor at PoreLab, Daan Frenkel, Emeritus Professor at the University of Cambridge, received the Lorentz Medal Award 2022 from the Royal Netherland Academy of Arts and Sciences (KNAW) for his pioneering and innovative work in theoretical physics. The Lorentz Medal 2022 award ceremony took place in Leiden, on November 10th, 2022. The Lorentz Medal in physics is awarded every four years to a researcher who has made groundbreaking contributions to theoretical physics.

The Academy commented as follow: *The use of computer simulations to map molecular systems may be a no-brainer today, but it was not self-evident a few decades ago. One of the driving forces behind a 'quiet revolution', Frenkel pioneered the use of creative computer simulations to mimic chemical and physical processes. Frenkel's research forms the basis of a large number of theoretical and experimental studies on the behavior of suspensions: liquids containing insoluble spherical, rod-shaped and plate-shaped particles.*
Frenkel is considered one of the most creative and versatile computer physicists in the world, preferring to simplify rather than complicate his models. In many of his scientific breakthroughs, Frenkel used surprisingly simple code, according to his peers. Frenkel's research is not limited to theoretical physics. It has also resulted in innovative insights in related fields including chemistry, biology and crystallography. Frenkel was recently involved in a publication that – based on his earlier work – proposes a new method for detecting the DNA of different pathogens.

Professor Emerita **Signe Kjelstrup** receives the 2022 *EFCE Michael L. Michelsen Award*

The European Federation of Chemical Engineering (EFCE) has named Signe Kjelstrup, Professor Emerita of physical chemistry as the laureate of the 2022 EFCE Michael L. Michelsen Award. The honor, previously called the Distinguished Lecture on Thermodynamics and Transport Properties, is conferred every two years by the EFCE Working Party on Thermodynamics and Transport Properties.
In choosing her for the award, the judges cited her internationally renowned research in the area of non-equilibrium thermodynamics, with emphasis on entropy production minimization, electrochemical cell modelling, heterogeneous systems and nanothermodynamics. They also highlighted her contribution to the development of novel important research in the field and her strong commitment to education and training, in her country and internationally.

The 2022 Michael L. Michelsen Awardee is supported by Elsevier and its journal Fluid Phase Equilibria.

Signe gave a keynote lecture on the opening day of the ESAT 2022 meeting on March 29th in Graz, Austria, and got her award during the ceremony.

The 2022 *Interpore-PoreLab award*: Dr. **Senyou An**

The 2022 winner of the Interpore-PoreLab award for young researchers is Dr. Senyou An, Research Associate at the Department of Earth Science & Engineering at Imperial College of London, UK.

Senyou received his PhD degree from the University of Manchester in 2021. Areas of Senyou's expertise cover advanced computational and experimental methods for fluid dynamics, such as multiscale multiphase flow, reactive transport, heat transfer, fluid-fluid interfaces, complex fluids (rheology), and non-classical theories of flow through porous materials to address fundamental problems in engineering and natural applications. The close cooperation between Interpore and PoreLab has led to the creation of the Interpore-PoreLab award for young researchers. The award, allocated for the first time in 2018 is given in recognition of outstanding contributions to fundamental research in the field of porous media.

Award winners receive a grant of 1000 euros and is offered to spend up to 60 days at PoreLab either in Trondheim or in Oslo, supported with a daily stipend.

We had the pleasure to receive Senyou at PoreLab Trondheim for a month during the fall 2022.

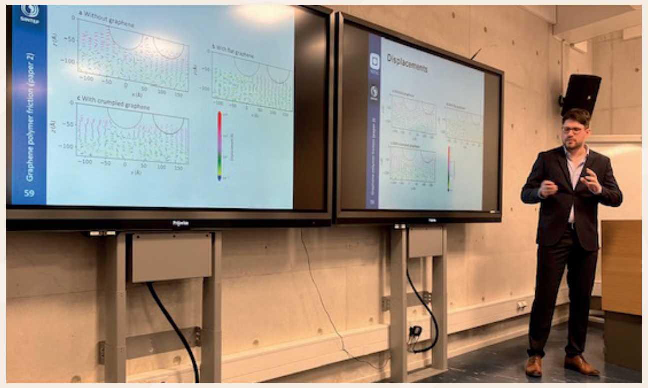
COMPLETED PHDs IN 2022

NAME	DEPARTMENT	DATE	THESIS	SUPERVISORS
Robin Sam Vacher	Dept. of Mechanical and Industrial Engineering, NTNU	30.03.2022	*Nanoscale Trobological Simulations of a semi-crystalline Polymer*	Astrid de Wijn, Sergio Armada Nieto
Olav Galteland	Dept. of Chemistry, NTNU	10.05.2022	*Nanothermodynamics and Molecular Simulations of Fluids in Porous Media*	Signe Kjelstrup, Bjørn Hafskjold, Dick Bedeaux
Vilde Bråten	Dept. of Materials Science and Engineering, NTNU	30.09.2022	*Fundamental Aspects of Thermodynamics of Small Systems Investigated Through Molecular Simulations and Theoretical Descriptions*	Sondre K. Schnell, Øivind Wilhelmsen
Michael Tobias Rauter	Dept. of Chemistry, NTNU	05.10.2022	*Fluid Transport through Nanoporous Media in the Presence of Phase Transitions*	Signe Kjelstrup, Sondre K. Schnell, Øivind Wilhelmsen
Davood Dadrasajirlou	Dept. of Civil and Environ-mental Engineering, NTNU	31.10.2022	*Hyper-Viscoplastic Modelling of Clay Behaviour*	Gustav Grimstad, Seyed Ali Ghoreishian Amiri

*Defense of thesis for **Olav Galteland***
From left to right: Prof. Guillaume Galliero, Dr. Olav Galteland and Prof. Ignacio Pagonabarraga

*Defense of thesis for **Vilde Bråten***
From left to right: Prof. Astrid de Wijn, Associate Prof. Sondre Kvalvåg Schnell, Prof. Øivind Wilhelmsen, Dr. Ivan Latella, Dr. Vilde Bråten and Associate Prof. Christelle Miqueu (on the screen)

*Defense of thesis for **Davood Dadrasajirlou***
From left to right: Dr. Seyed Ali Ghoreishian Amiri, Prof. Gudmund R. Eiksund, Dr. Christelle Abadie, Dr. Davood Dadrasajirlou, Prof. Philip J. Vardon, Associate Prof. Yutao Pan and Prof. Gustav Grimstad



*Defense of thesis for **Robin Sam Vacher***
On March, 30th, 2022

*Defense of thesis for **Michael Tobias Rauter***
From left to right: Prof. Amparo Galindo, Prof. Ingve Simonsen, Dr. Michael T. Rauter, Prof. Øivind Wilhelmsen, Prof. Emerita Signe Kjelstrup, Associate Prof. Sondre Kvalvåg Schnell, and Prof. Rainer Helmig

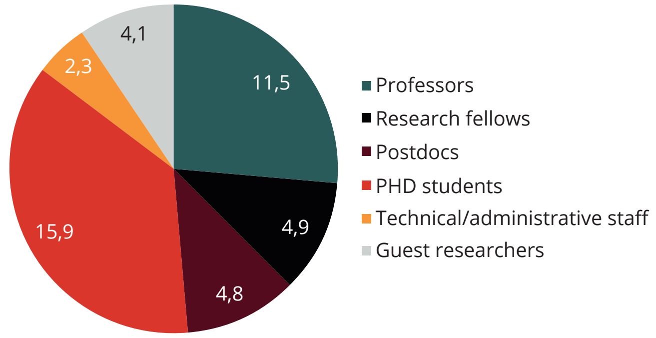
FUNDING IN 2022

FUNDING (1000 NOK)	AMOUNT	PERCENTAGE
The Research Council	15 247	66.7 %
NTNU	2 905	12.7 %
University of Oslo	4 709	20.6 %
TOTAL	22 861	100 %

FACTS AND FIGURES

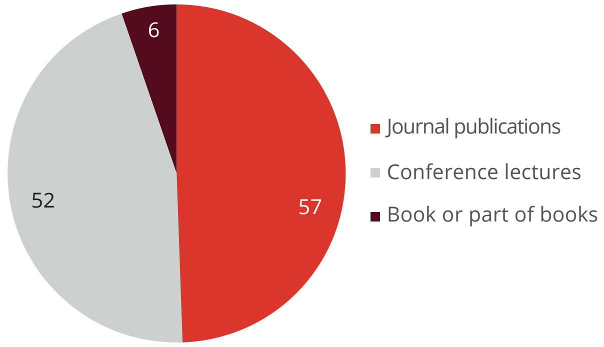
PORELAB STAFF categorized by position

PoreLab equals 43,4 man-years in 2022
The pie chart on the right shows the categorization of our staff by position



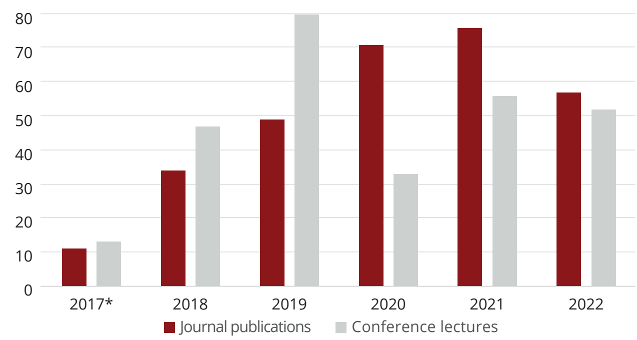
PUBLICATIONS in 2022

- 57 Journal publications
- 52 Conference lectures and academic presentations
- 6 books, part of book and reports



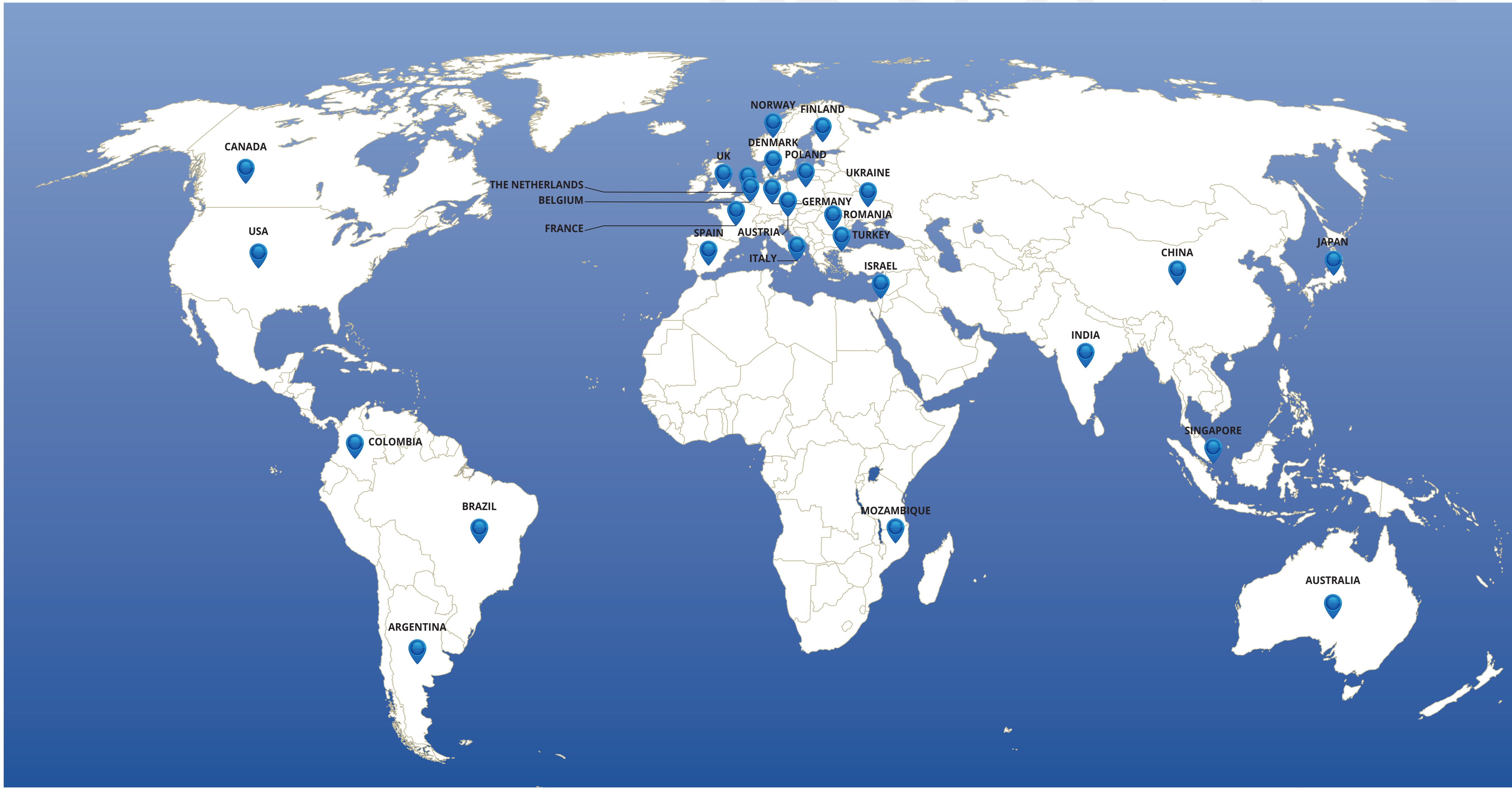
The regular augmentation of the number of publications we observe from 2017 to 2021 reflects the production of the *first generation* of PoreLab young researchers (PhD, postdocs, and researchers) represented by those who joined PoreLab at its start and those who were recruited during the first months of PoreLab existence. Employment periods varying from 3 to 4 years, the productivity culminated in 2021. The *second generation* of PoreLab young researchers joined us around 2020. It will take a few years for the new juniors to produce the results of their research activities. The interval between the 2 *generations* explains the reduction in the number of publications we observe in 2022.

The decrease in our contribution to conferences between 2019 and 2020 is a direct consequence of events being cancelled or postponed, and restrictions on travel. With the reorganization of many conferences as digital or hybrid events, and the restrictions on travel being gradually lifted, we observe an increase of the conference lectures both in 2021 and 2022.



*Publications over 4,5 months since PoreLab started on 15.08.2017

NATIONAL AND INTERNATIONAL COLLABORATION



USA
Sarah L. Codd, Joseph Seymour, *College of Engineering, Montana State University, Bozeman*
James McClure, *Virginia Tech*
Peter Kang, *University of Minnesota*
Saman Aryana, *University of Wyoming*

CANADA
Steven Bryant, Danial Arab, Apostolos Kantzas: *University of Calgary*

COLOMBIA
Daniel Barragán, Andrés Arango-Restrepo: *School of Chemistry, Faculty of Sciences, National University of Colombia*

ARGENTINA
Diego Kingston: *University of Buenos Aires*

BRAZIL
Jose Soares Andrade Jr., Hans J. Herrmann: *Universidade Federal do Ceara*

NORWAY
Jan Øystein Haavig Bakke: *Schlumberger Stavanger*
Magnus Aa. Gjennestad, Rune Hansen, Ailo Aasen, Asbjørn Solheim, Vegard Brøtan, Pierre Cerasi: *SINTEF*
Preben Vie, Geir Helgesen, Kenneth Knudsen: *Institute for Energy Technology, IFE*
Lars Folkow: *The Arctic University of Norway*
Bernt O. Hilmo: *Asplan Viak AS*
Marianne Øksnes Dalheim, Kristin Syverud: *RISE PFI AS*
Harald Berland, Olav Aursjø: *NORCE Norwegian Research center AS*
Thomas Ramstad: *Equinor Research Center, Trondheim*
Bjørn Karlsen: *Jotun, Sandefjord*

DENMARK
Joachim Mathiesen: *Niels Bohr Institute, University of Copenhagen*

FINLAND
L. Laurson, Mikko Alava: *Department of Applied Physics, Aalto University, Espoo*

GERMANY
Rainer Helmig and Joachim Gross: *University of Stuttgart*
Andrzej Gorak: *TU Dort*
Steffen Schlüter: *Helmholtz Center for Environmental Research, Leipzig*

THE NETHERLANDS
Thijs J.H. Vlugt, Claire Chassagne, Othon Moultos: *Delft University of Technology*
Majid Hassanizadeh: *Multiscale Porous Media Laboratory, Utrecht University*
Edgar M. Blokhuis: *University of Leiden*
Steffen Berg: *Shell Research, Amsterdam*
Maja Rücker: *Eindhoven University of Technology*

BELGIUM
Tom Bultreys, Veerle Cnudde: *Gent University, Department of Geology, Gent*

AUSTRIA
Sofia Kantorovich: *University of Vienna*

UK
Bjørnar Sandnes: *Energy Safety Research Institute, College of Engineering, Swansea University*
Fernando Bresme, Erich A. Müller: *Imperial College London*
Daan Frenkel, Matthew Mason: *University of Cambridge, UK*
Robin Cleveland, *Oxford University*

FRANCE
Sunniva Indrehus: *Pierre and Marie Curie University, Paris VI*
Alberto Rosso: *Laboratoire Physique Théorique et Modèles Statistiques (LPTMS), Université Paris-Saclay, Orsay*
Laurent Talon: *Laboratoire FAST, Université de Paris-Saclay, Orsay*
Renaud Toussaint, Monem Ayaz: *Institut Terre et Environnement de Strasbourg, CNRS, Université de Strasbourg*
Tanguy Le Borgne: *University of Rennes*
Jean-Marc Simon: *University of Bourgogne, CNRS*
Stéphane Santucci, Michael Bourgoin: *Ecole Normale Supérieure de Lyon, UMR CNRS, Lyon*
Wei Dong: *CNRS, Lyon*
Osvanny Ramos: *Department of Physics, Claude Bernard University, Lyon*
Jean-Noël Jaubert, Silvia Lasala: *Université de Lorraine*

SPAIN
Miguel Rubi, David Reguera: *University of Barcelona*
Riccardo Rurali: *Theory and Simulation Department, Materials Science Institute of Barcelona (ICMAB–CSIC)*
María Barragán Garciá: *Department of Applied Physics, Complutense University of Madrid*

ITALY
Luciano Colombo: *University of Cagliari*

MOZAMBIQUE
Alberto Bila: *Eduardo Mondlane University (EMU). Maputo*

POLAND
Wojciech Debski: *Department of Theoretical Geophysics, Institute of Geophysics Polish Academy of Sciences, Warszawa*

ROMANIA
Mirela-Nicoleta Stoeac-Vladuti: *Art space director, META Spatiu, Timisoara*
Cosmin Haias, automation engineer and artist, *Timisoara*

UKRAINA
Natalya Kizilova: *Department of Theoretical and Applied Mechanics, Kharkov National university*

TURKEY
Talha Erdem: *Abdullah Gul University, Kayseri*
Levent Akyalçin: *Eskişehir Technical University, Eskişehir*

ISRAEL
Ran Holtzman: *Hebrew University of Jerusalem*

INDIA
Purusattam Ray: *Institute of Mathematical Sciences, Chennai*
S. B. Santra: *Indian Institute of technology, Guwahati*

CHINA
Ye Xu: *School of Mechanical Engineering and Automation, Beihang University, Beijing*
Xin Wang: *Institute of Oceanography Instrumentation, Shandong Academy of Sciences, Qingdao*

JAPAN
Pieter Krüger: *Graduate School of Science and Engineering, Molecular Chirality Research Center, Chiba University, Chiba*
Koji Amezawa: *Institute of Multidisciplinary Research for advanced materials, Tohoku University*
Hironori Nakajima: *Department of Mechanical Engineering, Faculty of Engineering, Kyushu University*
Satoshi Nishimura: *Faculty of Engineering, Field Engineering for the Environment, Hokkaido University*
Yasuhiro Fukunaka: *Research Organization for Nano and Life Innovation, Waseda University, Shinjuku, Tokyo*

SINGAPORE
Shidong Li, Nanji Hadia, Yeap Hung Ng, Ludger Stubbs, Qi Hua Ng: *Institute of Chemical and Engineering Sciences (ICES), Agency for Science, Technology and Research*
Hon Chung Lau: *National university of Singapore*

AUSTRALIA
Peter Daivis: *RMIT, Royal Melbourne Institute of Technology, Melbourne*
Benjy Marks: *University of Sydney*
Ryan Armstrong: *University of New South Wales*
Mark Knackstedt: *Australian National University, Department of Applied Mathematics, Canberra*

GUEST RESEARCHERS AT PORELAB

The COVID-19 outbreak and following restrictions on travels led to a drastic drop in the number of visitors both in 2020 and 2021. We had 64 visitors in 2019, 14 in 2020 and only 7 in 2021. As the pandemic's effects further reduce and restrictions are gradually lifted, it was a great pleasure to welcome again our guests at PoreLab. The number bounced back in 2022 with 46 guests visiting both PoreLab NTNU and PoreLab UiO.

NAME	POSITION	AFFILIATION	PERIOD
Per Arne Rikvold	Professor	Department of Physics, Florida State University, USA	06.08.20 – current
Khobaib Khobaib	PhD candidate	Adam Mickiewicz University (UAM), Poznań, Poland	08.11.21 - 31.08.22
Peyman Mianji	PhD candidate	Ruhr University of Bochum, Germany	10.02.22 - 06.05.22
Marlo Kunzner	MSc student	Technische Universität Clausthal, Germany	01.02.22 - 12.08.22
Ren Liu	PhD candidate	Cavendish Laboratory, University of Cambridge, UK	13.02.22 - 01.03.22
Grace (Xiaoying) Tang	PhD candidate	Cavendish Laboratory, University of Cambridge, UK	13.06.22 - 06.03.22
Jiaming Yu	PhD candidate	Cavendish Laboratory, University of Cambridge, UK	13.02.22 - 06.03.22
Mark Willemsz	MSc student	Eindhoven University of Technology, the Netherlands	25.02.22 - 30.06.22
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	28.02.22 - 18.03.22
Alain Gibaud	Professor	Université du Maine, Le Mans France	10.03.22 - 19.03.22
Claire Chassagne	Associate Professor	Department of Hydraulic Engineering, TU Delft, The Netherlands	28.03.22 - 02.04.22
Natalya Kizilova	Professor	Kharkov National University, Ukraine	01.04.22 – current
Thijs Vlugt	Professor	TU Delft, The Netherlands	07.04.22 – 09.04.22
Othon Moultos	Assistant Professor	TU Delft, The Netherlands	07.04.22 – 09.04.22
Shrinjay Sharma	PhD candidate	TU Delft, The Netherlands	07.04.22 – 09.04.22
Mert Polat	PhD candidate	TU Delft, The Netherlands	07.04.22 – 09.04.22
Parsa Habibi	PhD candidate	TU Delft, The Netherlands	07.04.22 – 09.04.22
Mahinder Ramdin	Assistant professor	TU Delft, The Netherlands	07.04.22 – 09.04.22
Sofia Calero	Professor	Eindhoven University of Technology, The Netherlands	07.04.22 – 09.04.22
Dominika Wasik	PhD candidate	Eindhoven University of Technology, The Netherlands	07.04.22 – 09.04.22
Estaban Acuna Yeomans	PhD candidate	Eindhoven University of Technology, The Netherlands	07.04.22 – 09.04.22
Mike Pols	PhD candidate	Eindhoven University of Technology, The Netherlands	07.04.22 – 09.04.22
Bin Fang	Scientist	National Center for International Research on Deep Earth Drilling and Resource Development, China	07.04.22 – 09.04.22
Wei Dong	Directeur de recherche	CNRS, Ecole Normale Supérieure de Lyon, France	25.04.22 – 29.04.22
Luca Giomi	Associate Professor	Leiden University & Lorentz Institute of Theoretical Physics, The Netherlands	25.04.22 – 29.04.22
Ignacio Pagonabarraga	Professor	Department of Fundamental Physics, University of Barcelona, Spain	08.05.22 – 11.05.22
Guillaume Galliero	Professor	Université de Pau et des pays de l'Adour, France	09.05.22 – 11.05.22
Sabina Schwarz	Student	HLUW (Höhere Lehranstalt für Umwelt und Wirtschaft) Ypsertal, Austria	07.06.22 – 30.06.22
Aaron Hammerl	Student	HLUW (Höhere Lehranstalt für Umwelt und Wirtschaft) Ypsertal, Austria	07.06.22 – 30.06.22
Klara Lechner	Student	HLUW (Höhere Lehranstalt für Umwelt und Wirtschaft) Ypsertal, Austria	07.06.22 – 30.06.22
Saman Aryana	Associate Professor	University of Wyoming, USA	13.06.22 - 18.06.22
Maja Rücker	Assistant professor	Eindhoven University of Technology, the Netherlands	20.06.22 - 24.06.22
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	03.08.22 - 19.08.22
Gloria Buendia	Professor	Universidade Simón Bolivár, Venezuela	09.08.22 - 16.09.22
Hans Herrmann	Professor	Ecole Supérieure de Physique et de Chimie Industrielles, Paris, France, and Universidade Federal do Ceará, Fortaleza, Brazil	21.08.22 - 24.08.22
Sauro Succi	Senior research executive and PI	Center for Life Nano Science at la Sapienza, Roma, Instituto Italiano di Tecnologia, Italy	28.08.22 - 05.09.22
Mirela Vlăduti	Art Space Manager	META Spatiu, Timisoara, Romania	02.09.22 – 07.09.22
Cosmin Haias	Artist and engineer	Automation engineer, Timisoara, Romania	02.09.22 – 07.09.22
Senyou An	Research associate	Dept. of Earth Science and Engineering, Imperial College, London, UK	30.09.22 - 12.10.22
Berend Smit	Professor	School of Basic Sciences, EPFL, Lausanne, Switzerland	10.10.22 – 14.10.22
Alain Gibaud	Professor	Université du Maine, Le Mans, France	12.10.22 – 17.10.22
Senyou An	Research associate	Dept. of Earth Science and Engineering, Imperial College, London, UK	26.10.22 - 05.11.22
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	03.10.22 - 14.10.22
Quirine Krol	Researcher	University of Montana, Bozeman, USA	08.11.22 - 18.12.22
Steffen Berg	Principal science expert	Shell Global Solutions, Amsterdam, The Netherlands	30.11.22 - 01.12.22
Aksel Hiorth	Professor	University of Stavanger and Chief Scientist at IRIS, Norway	01.12.22

PORELAB LECTURE SERIES LIST OF LECTURES

The use of video conferencing has intensified since the beginning of the pandemic. It allowed us to broaden our pool of lecturers and we noticed a boost in attendance. This trend continued in 2022 with no less than 31 lectures. As a comparison, we had 27 lectures in 2021 and 29 in 2020. The PoreLab lecture series are now almost always given by external lecturers

DATE	NAME, AFFILIATION	TITLE
Jan. 26	Osvanny Ramos, associate professor, Institut Lumière Matiére, CNRS, Université de Lyon, France	*The LabQuakes project – from a granular fault to earthquake statistics*
Feb. 9	Renaud Toussaint, Directeur de recherche CNRS, U. of Strasbourg, France, and adj. Professor at PoreLab, University of Oslo, Norway	*Bubble cavitation during underwater contact between solids*
Feb. 23	Dr. Paul Grassia, School of Chemical and Process engineering, University of Strathclyde, UK	*All foams in porous media great and small*
Feb. 25	Ren Liu, Xiaoying Tang, Jiaming Yu, PhD candidates, Cavendish Laboratory, Cambridge University, UK	*DNA-functionalized triblock copolymer solutions: experiments and molecular dynamics simulations*
March 2	Maja Rücker, assistant professor at the Eindhoven University of Technology in the Netherlands	*Wetting – from molecular interactions to fluid dynamics in porous media*
March 4	Ren Liu, Xiaoying Tang, Jiaming Yu, PhD candidates, Cavendish Laboratory, Cambridge University, UK	*Light-Induced Self-Assembly of Colloidal System*
March 11	Peyman Mianji, PhD candidate, Ruhr-Universität Bochum, Germany	*The impact of bentonite-slurry-infiltration on the hydro-mechanical parameters of granular soil in the context of hydroshield tunnelling*
March 23	Sverre Holm, Dep. of physics, University of Oslo, Norway	*Wave equations for porous media described by the Biot model*
March 29	Claire Chassagne, Associate Professor, department of hydraulic Engineering, TU Delft, The Netherlands	*Characterization of suspensions, sludges and soils*
April 4	Wei Dong, laboratoire de chimie, ENS Lyon, France	*Disjoining chemical potential: A twin concept of disjoining pressure*
April 28	Associate Professor Luca Giomi, Leiden University & Lorentz Institute of Theoretical Physics, The Netherlands	*Hydrodynamics and multiscale order in confluent epithelia*
May 4	Professor Rudy Valette, MINES ParisTech, France	*Non-Newtonian fluids flow instabilities in confined geometries. Application to extrusion flows*
May 11	Ignacio Pagonabarraga, Professor in Condensed Matter Physics at the University of Barcelona, Spain	*Activity-induced interactions and collective response in model active matter*
May 11	Professor Guillaume Galliero, Université de Pau et des pays de l'Adour, France	*From nanofluidics to geological reservoir simulations: a molecular simulation perspective*
May 16	Dr. Hans Kåre Flø from Tekna and Norwegian Academy of Technological Sciences (NTVA), Norway	*Sustainability as a challenge for PoreLab*
May 18	Antoni Forner Cuenca, Assistant Professor, Department of Chemical Engineering and Chemistry at Eindhoven University of Technology, NL	*Gas Diffusion Layers with Patterned Wettability for Next-generation Polymer Electrolyte Fuel Cells*
May 20	Ruby Fu, Assistant Professor of Mechanical and Civil Engineering, Caltech, Pasadena, CA, USA	*Solidification Flows in Porous Media: Stories from Gas Hydrate and Snow*
May 25	Himangsu Bhaumik, Post Doc, Technion, Israel Institute of Technology, Israel	*Yielding, avalanche and structural change of different glasses under a thermal cyclic shear*
June 16	Associate Professor Saman Aryana, U. of Wyoming, USA	*Transport and Phase Behavior in Multiscale Disordered Media.*
June 24	Mark Willemsz, Master student at TU Eindhoven, The Netherlands, doing an internship at PoreLab NTNU	*A micro computed tomography-study on the use of Xenon as a pressure indicator in porous media, Static pressure-attenuation calibration relations*
Aug. 23	Professor Hans Herrmann, PMMH, ESPCI Paris, France and UFC, Fortaleza, Brazil	*Frustrated Bearings*
Aug. 29	Professor Sauro Succi, IIT-CLNS, Harvard University and University College London, UK	*From Softmat to Dropmat: computer explorations of droplet-based states of flowing matter*
Sept. 14	Prof. Gloria M. Buendia, U. Simon Bolivar, Venezuela	*Monte Carlo Simulations of Out of Equilibrium Systems: Surface reactions*
Oct. 3	Dr. Marcel Moura, PoreLab Researcher at the physics department, UiO, Norway	*Complexity "More is Different" also in porous media flows*
Oct. 5	Professor Douglas Durian, University of Pennsylvania, USA	*Statistical Mechanics of Granular Clogging*
Oct. 6	Professor Rainer Helmig, U. of Stuttgart, Germany	*Porous media free-flow coupling model concepts -from pore to Darcy-scale*
Oct. 10	Dr. Senyou An, Department of Earth Science and Engineering, Imperial College London, UK	*Multi-scale flow and transport dynamics in porous media*
Nov. 2	Associate Professor James McClure, Virginia Tech National Institute, USA	*Non-equilibrium theory for non-ergodic systems based on time-and-space averaging*
Nov. 16	Nicholas Heier, Biomimicry Center, Arizona State University, USA	*Evolve to Survive: How emulating nature's adaptive strategies can help researchers and innovators*
Nov. 30	Dr. Pål-Erik Øren, Petricore Norway AS	*Multiscale Digital Rock Analysis of Complex Rocks*
Dec. 2	Professor Aksel Hiorth, Reservoir Technology at the University of Stavanger	*Perspectives on the importance of pore scale input for upscaling of reactive flows*

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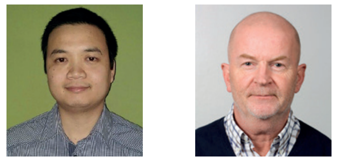

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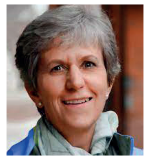
Ursula Gibson
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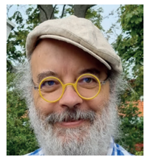
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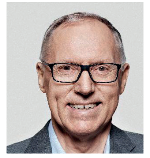
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Catharina de Lange Davies,
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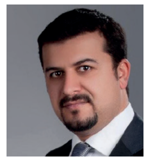
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Signe Kjelstrup
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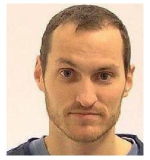
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PUBLICATIONS

The following lists journal publications, books, reports, conference lectures and academic presentations generated in 2022.

JOURNAL PUBLICATIONS

Alonso-Llanes, L.; Martinez Roman, Etien; Batista-Leyva, A. J; Toussaint, Renaud; Altshuler, E.
Continuous to intermittent flows in growing granular heaps. *Physical review*. E 2022; Volum 106.(1) NTNU UiO

Alonso-Llanes, L.; Sánchez-Colina, G.; Batista-Leyva, A.J.; Clément, C.; Altshuler, E.; Toussaint, Renaud.
Sink versus tilt penetration into shaken dry granular matter: The role of the foundation. *Physical review*. E 2022; Volum 105.(2) UiO

Arab, Danial; Bryant, Steven L.; Torsæter, Ole; Englezos, Peter; Gopaluni, Bhushan; Kantzas, Apostolos.
Elucidation of the mechanistic aspects of chemical EOR in viscous oil systems. *Journal of Petroleum Science and Engineering* 2022; Volum 216.(110846) NTNU

Arab, Danial; Bryant, Steven L.; Torsæter, Ole; Kantzas, Apostolos.
Water flooding of sandstone oil reservoirs: Underlying mechanisms in imbibition vs. drainage displacement. *Journal of Petroleum Science and Engineering* 2022; Volum 213. s.1-16 NTNU

Baldelli, Beatrice; Linga, Gaute; Flekkøy, Eirik Grude.
Thermal conduction through a cool well. *Physical Review Fluids* 2022; Volum 7.(10) UiO

Bedeaux, Dick; Kjelstrup, Signe.
Fluctuation-Dissipation Theorems for Multiphase Flow in Porous Media. *Entropy* 2022; Volum 24.(46) NTNU

Bering, Eivind; Torstensen, Jonathan Økland; Lervik, Anders; de Wijn, Astrid S.
Computational study of the dissolution of cellulose into single chains: the role of the solvent and agitation. *Cellulose* 2022 NTNU HVL

Bila, Alberto Luis; Stensen, Jan Åge; Torsæter, Ole.
Polymer-Coated Silica Nanoparticles for Enhanced Oil Recovery in Water-Wet Berea Sandstone Core Plugs. *Advances in Science, Technology & Innovation (ASTI)* 2022 s.409-412 NTNU SINTEF

Bozkurt, Kerem; Akyalçn, Levent; Kjelstrup, Signe.
The thermal diffusion coefficient of membrane-electrode assemblies relevant to polymer electrolyte membrane fuel cells. *International Journal of Hydrogen Energy* 2022 NTNU

Brodin, Joachim Falck; Moura, Marcel; Toussaint, Renaud; Måløy, Knut Jørgen; Rikvold, Per Arne.
Visualization by optical fluorescence of two-phase flow in a three-dimensional porous medium. *Journal of Physics: Conference Series (JPCS)* 2022; Volum 2241. UiO

Brodin, Joachim Falck; Rikvold, Per Arne; Moura, Marcel; Toussaint, Renaud; Måløy, Knut Jørgen.
Competing Gravitational and Viscous Effects in 3D Two-Phase Flow Investigated With a Table-Top Optical Scanner. *Frontiers in Physics* 2022; Volum 10. NTNU UiO

Bråten, Vilde; Zhang, Daniel Tianhou; Hammer, Morten; Aasen, Ailo; Schnell, Sondre Kvalvåg; Wilhelmsen, Øivind.
Equation of state for confined fluids. *Journal of Chemical Physics* 2022; Volum 156.(24) ENERGISINT NTNU

Campbell, James; Sandnes, Bjørnar; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
Dynamics of Dendritic Ice Freezing in Confinement. *Crystal Growth & Design* 2022; Volum 22.(4) s.2433-2440 UiO

Chawshin, Kurdistan; Berg, Carl Fredrik; Varagnolo, Damiano; Lopez, Olivier.
Automated porosity estimation using CT-scans of extracted core data. *Computational Geosciences* 2022; Volum 26. s.595-612 NTNU

Dadrasajirlou, Davood; Grimstad, Gustav; Ghoreishian Amiri, Seyed Ali.
On the isotache viscous modelling of clay behaviour using the hyperplasticity approach. *Géotechnique* 2022 NTNU

Erdem, Talha; Zupkauskas, Mykolas; O´Neill, Thomas; Caciagli, Alessio; Xu, Peicheng; Altintas, Yemliha; Mutlugun, Evren; Eiser, Erika.
Magnetically controlled anisotropic light emission of DNA-functionalized supraparticles. *MRS bulletin* 2022; Volum 47. s.1-8 NTNU

Eriksen, Fredrik Kvalheim; Moura, Marcel; Jankov, Mihailo; Turquet, Antoine Leo; Måløy, Knut Jørgen.
Transition from viscous fingers to compact displacement during unstable drainage in porous media. *Physical Review Fluids* 2022; Volum 7.(1) UiO NORSAR NTNU

Flekkøy, Eirik Grude; Brodin, Joachim Falck.
Discerning between Different 'Oumuamua Models by Optical and Infrared Observations. *Astrophysical Journal Letters* 2022; Volum 925.(2) UiO

Gahrooei, Hamidreza Erfani; Babaei, Masoud; Berg, Carl Fredrik; Joekar-Niasar, Vahid.
Scaling CO_2 convection in confined aquifers: Effects of dispersion, permeability anisotropy and geochemistry. *Advances in Water Resources* 2022; Volum 164. NTNU

Galteland, Olav; Bering, Eivind; Kristiansen, Kim; Bedeaux, Dick; Kjelstrup, Signe.
Legendre-Fenchel transforms capture layering transitions in porous media. *Nanoscale Advances* 2022; Volum 4.(12) s.2660-2670 NTNU

Galteland, Olav; Rauter, Michael Tobias; Bratvold, Mina S.; Trinh, Thuat; Bedeaux, Dick; Kjelstrup, Signe.
Local Thermodynamic Description of Isothermal Single-Phase Flow in Simple Porous Media. *Transport in Porous Media* 2022; Volum 145.(1) s.153-173NTNU

Galteland, Olav; Rauter, Michael Tobias; Varughese, Kevin K; Bedeaux, Dick; Kjelstrup, Signe Helene.
Defining the pressures of a fluid in a nanoporous, heterogeneous medium. *Frontiers in Physics* 2022; Volum 10. s.866577 NTNU

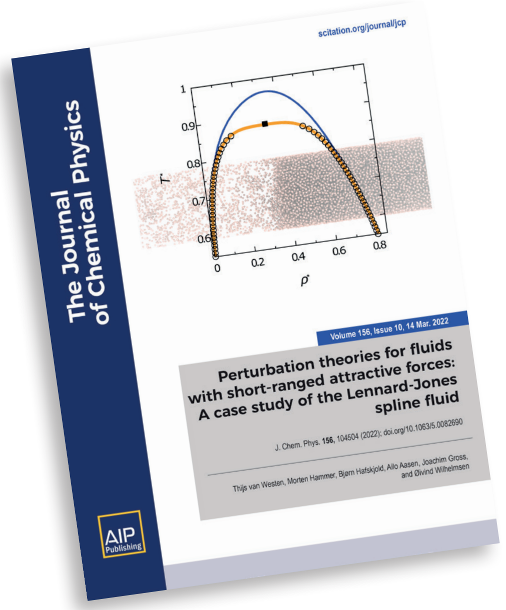
Gao, Hao; Ghoreishian Amiri, Seyed Ali; Kjelstrup, Signe; Grimstad, Gustav; Loranger, Benoit; Scibilia, Elena.
Formation and growth of multiple, distinct ice lenses in frost heave. *International journal for numerical and analytical methods in geomechanics* (Print) 2022; Volum 47. s.82-105 NTNU

Hafskjold, Bjørn; Bedeaux, Dick; Kjelstrup, Signe; Wilhelmsen, Øivind.
Soret separation and thermo-osmosis in porous media. *The European Physical Journal E : Soft matter* 2022; Volum 45.(5) NTNU

Hansen, Alex; Flekkøy, Eirik Grude; Sinha, Santanu; Slotte, Per Arne.
A statistical mechanics framework for immiscible and incompressible two-phase flow in porous media. *Advances in Water Resources* 2022; Volum 171. UiO NTNU

Haugerud, Ivar Svalheim; Linga, Gaute; Flekkøy, Eirik Grude.
Solute dispersion in channels with periodic square boundary roughness. *Journal of Fluid Mechanics* 2022; Volum 944. UiO

Hutt, Axel; Grüning, André; Hansen, Alex; Hartung, Thomas; Robeva, Raina.
Editorial: Machine Learning in Natural Complex Systems. *Frontiers in Applied Mathematics and Statistics* 2022; Volum 8. NTNU



PoreLab publication, from van Westen, Hammer, Hafskjold, Aasen, Gross and Wilhelmsen selected to be Editors Pick and on the cover of the Journal of ***Chemical Physics*** *on March 14th, 2022*

Khobaib, Khobaib; Rozynek, Zbigniew Jerzy; Hornowski, Tomasz.
Mechanical properties of particle-covered droplets probed by nonuniform electric field. *Journal of Molecular Liquids* 2022; Volum 354. s.1-10 UiO

Köehn, D.; Köehler, S.; Toussaint, Renaud; Ghani, I.; Stollhofen, H.
Scaling analysis, correlation length and compaction estimates of natural and simulated stylolites. *Journal of Structural Geology* 2022; Volum 161. UiO

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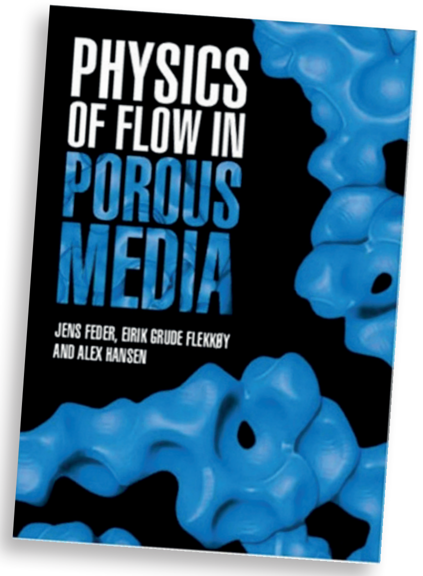

Release of the book *"Physics of flow in Porous Media"* by Feder, Flekkøy and Hansen in September 2022

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