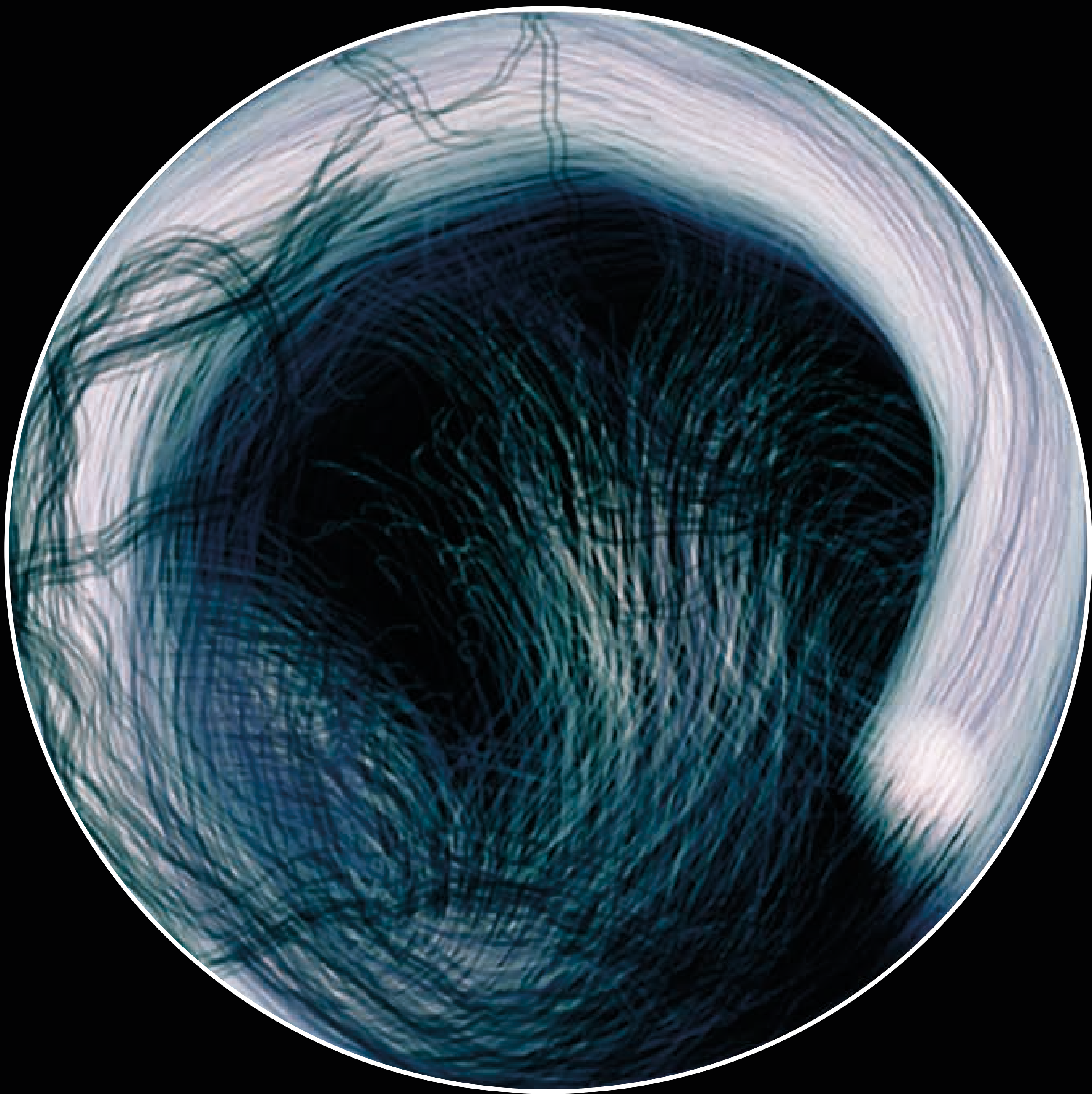
PoreLab
NTNU-UiO Porous Media Laboratory

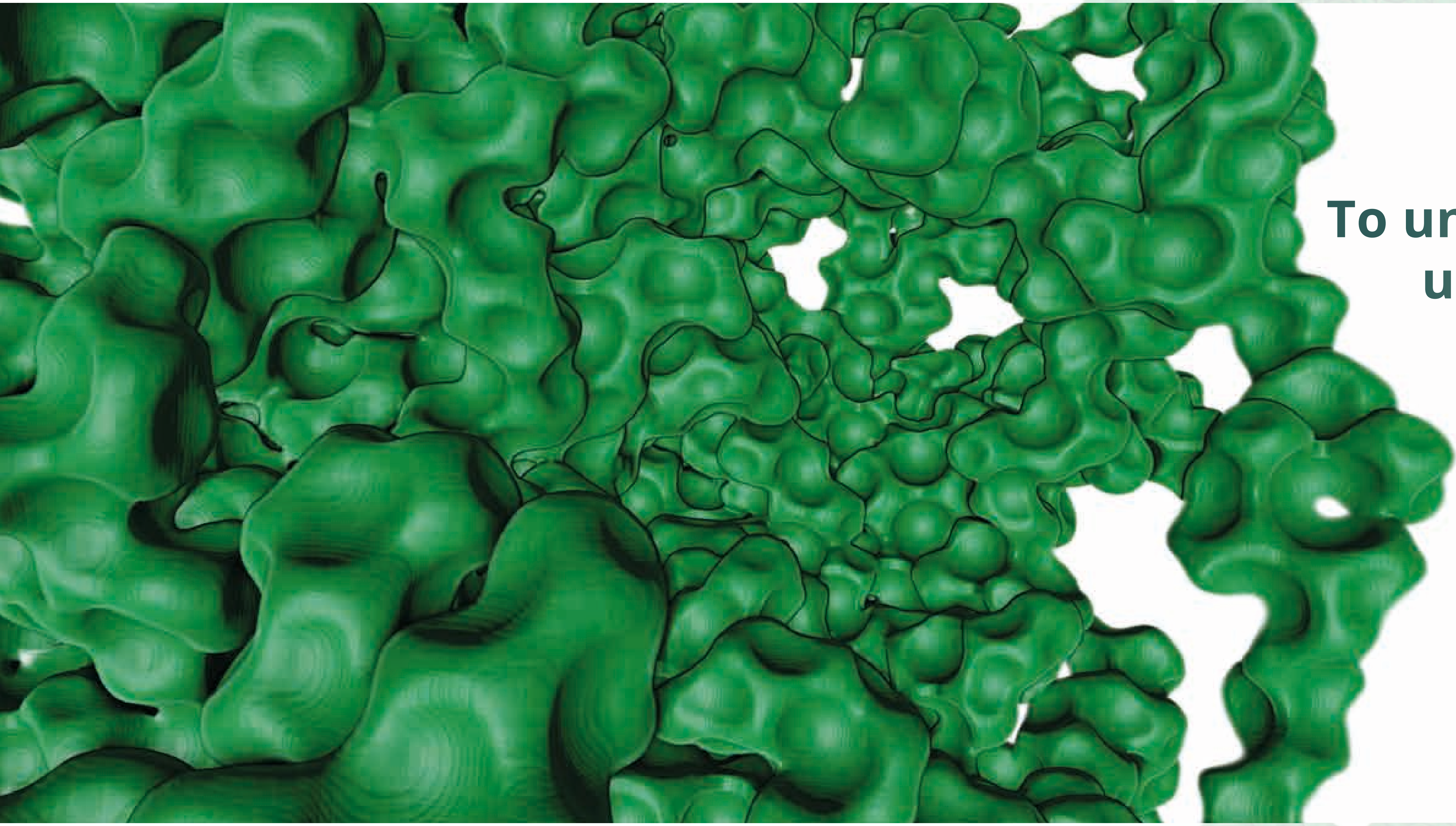
Annual Report 2020



NTNU
Norwegian University of Science and Technology

UiO : University of Oslo

Norwegian Centre of Excellence
The Research Council of Norway



Our Mission

To unify and advance understanding of porous media

Picture by Joachim Falck Brodin, UiO, 2020: *Experimental result – 3D-scanner, based on index matching. Here we see a 3D rendering of the segmented invading fluid phase. The porous medium and the defending fluid have been removed, leaving the invading structure suspended alone.*

COVER PAGE:
Picture by Kristian Stølevik Olsen, UiO, 2020: *Active matter consists of particles trying to overcome the noise in the system to move in the same direction. Inside confinements like a disc, the particles will for low noise form a cluster that moves along the system boundary.*

WHAT IS PORELAB?

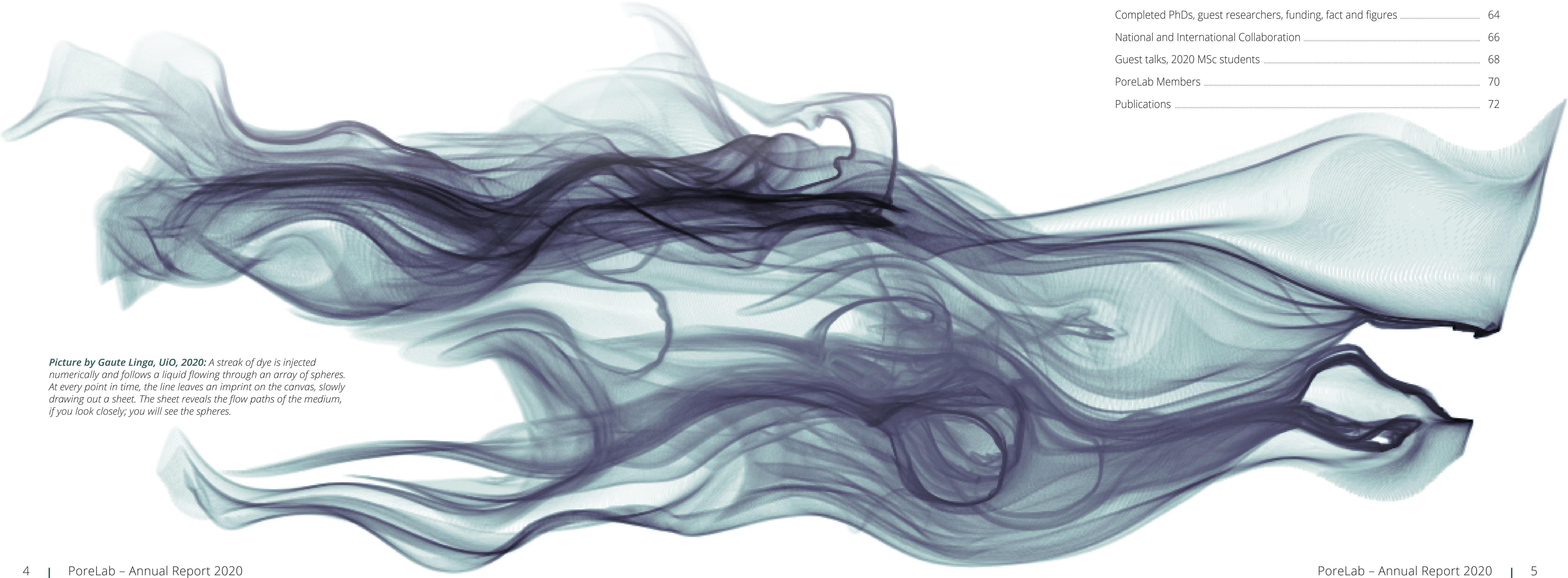
Our internationally recognized work was awarded Norwegian Centre Of Excellence (CoE) in August 2017 from the Norwegian Research Council. PoreLab, acronym for Porous Media Laboratory, was born!

A CoE is a funding scheme administered by the Norwegian Research Council. The goal of the CoE program is to give Norway's best scientists the opportunity to establish larger units focusing on frontier research at a high international level and to contribute to raising the quality of Norwegian research.

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 five principal scientists from physics, chemistry and reservoir engineering. At UiO, PoreLab is organized under the auspices 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. Starting from a sound 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 scales that are much larger than the pore scale. 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.

PoreLab receives an annual funding from the Norwegian Research Council of about 15 MNOK for an initial six years period. NTNU and UiO contribute with the same financial support. Conditional to a positive outcome of a mid-term evaluation, an additional four years will be granted. If so, the date of completion will be August 2027.



Picture by Gaute Linga, UiO, 2020: *A streak of dye is injected numerically and follows a liquid flowing through an array of spheres. At every point in time, the line leaves an imprint on the canvas, slowly drawing out a sheet. The sheet reveals the flow paths of the medium, if you look closely; you will see the spheres.*

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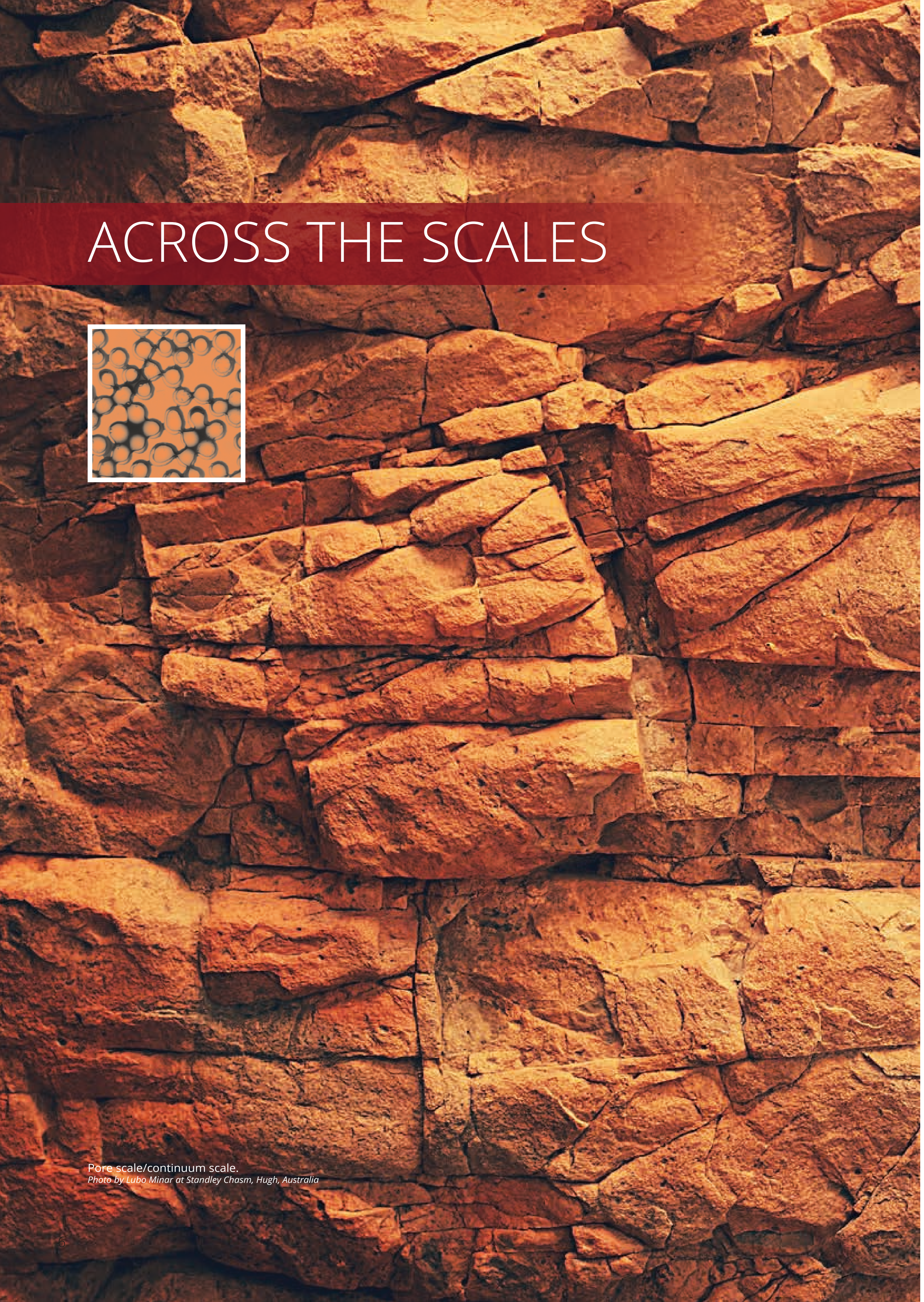
ACROSS THE SCALES



Pore scale/continuum scale.
Photo by Lubo Minar at Standley Chasm, Hugh, Australia

Big things are more complex than little things. Right? Right. This is obvious since we may dismantle bigger things into smaller things. Hence, the bigger things must be at least as complex as the smaller things they consist of.

Smaller then means more fundamental. Elementary particle physics is more fundamental than atomic physics which in turn is more fundamental than chemistry.

And what do we mean by "fundamental"? If we understand the more fundamental fully, we automatically also understand the less fundamental since the less fundamental consists of the more fundamental. For example, atoms and molecules do consist of elementary particles.

This little piece of philosophy is still permeating much of the thinking around how the natural sciences are organized. We divide them into basic – fundamental – sciences and applied sciences.

But it is a flawed way of thinking. Elementary particle physics has more blank areas than atomic physics. We are far away from finding a "theory of everything," the holy grail of elementary particle physics that would explain the four forces, quantum gravity, dark matter, dark energy, ... The list of known unknowns is immense. Who knows what the list of unknown unknowns would look like? Atomic physics, on the other hand, also has its unsolved problems, but they are small in comparison. Hence, the idea that bigger things – atoms – are more complex than little things – elementary particles – is not a universal truth.

And there are more flaws. The idea that a full understanding of the more fundamental – read smaller – will lead to an understanding of the less fundamental – read bigger - is also quite absurd. Psychology, for example, is the science of the mind. The mind is the product of the chemistry of the brain. Chemistry is the science of how atoms and molecules interact, and they consist of elementary particles. So, will a full understanding of elementary particle physics lead to a revolution in psychology?

Phillip W. Anderson staked out this route of thinking in his famous essay *More is Different* in the journal Science in 1972. After having pointed out what I have paraphrased above, he then goes on to draw the conclusion that organizing science in a hierarchy from more fundamental to less fundamental is counterproductive. There is a hierarchy in terms of scale, however, and the different branches of science offer different levels of description based on the scale on which they focus. Elementary particle physics, atomic physics, chemistry, and psychology operate on different scales. They sit inside each other like Russian dolls, but there is no hierarchy. Elementary particle physics is useless at the level of scale at which chemistry operates.

So, what does this have to do with porous media? In an oil reservoir or in an aquifer, there might easily be some seven orders of magnitude in length scales between the pore scale and the scale of the reservoir itself. At the pore scale, the physics of how immiscible fluids compete when they flow is a problem that has made enormous strides in the direction of better understanding over the last couple of decades. At the scales of the reservoir itself, the description being used is still the old relative permeability theory from 1936.

Just as Anderson points out that different branches of science in reality are different levels of description, so is the situation in the physics of porous media. The pore level description with its moving interfaces, contact lines, wetting angles and appropriate thermodynamics and hydrodynamics, is appropriate at small scales. It is not appropriate on large scales where the porous medium appears continuous. The language used in relative permeability theory, such as the capillary pressure field, is appropriate at these scales, but not at the pore scale. A new theory to replace (rather than repair) relative permeability theory, needs to be cast in a language appropriate for the large scales at which it is to function, but not at the pore scales.

Will we then end up in a situation where we have two completely independent descriptions of porous media, one on the pore scale and one on the continuum scale? No, one needs to be able to go from one to the other and see how the concepts change into each other. But it is necessary to understand that concepts that are fruitful on one scale may have no meaning on the other scale. To make a controversial statement – thus proving that we are not kicking in open doors – defining two pressures, one in the more wetting fluid and another in the less wetting fluid makes sense at the pore scale. However, at the continuum scale where the immiscible fluids behave as a single fluid controlled by the parameter saturation, this makes no sense. Yet, it is an integral and fundamental part of relative permeability theory.

To solve the scale-up problem, i.e. bridging the gap between the pore scale description and the continuum level description, it is therefore necessary to have understood what Anderson says in his essay: we are dealing with two different descriptions where the concepts are different. Don't mix them. Rather, figure out how they may work together.

Alex Hansen

DIRECTOR'S COMMENTS

2020 was a tough year. As most other organizations in Norway, PoreLab screeched to a halt on March 12. From that day onwards, we were to do our work from home. For those of us who do our research with pen, paper, and a computer, this was in principle not the end of the world. However, the experimentalists were in a sorry state: what to do when the laboratories had to be closed?

We learned quickly to use virtual meetings based e.g. on Zoom or similar software. The scientific discussion did not die out in any way. The loss was the spontaneous meeting – that which occurs around the copying machine. But we rapidly instituted the virtual coffee break on Tuesday and Thursday morning, and this was very useful. Here we could have spontaneous scientific discussion, and these discussions would be as good as any such discussion sitting around a table. And there was one huge benefit here. As PoreLab is divided between Oslo and Trondheim, the difference with business as usual would be that we would *all be present*, no matter where we were physically. We would be on an equal footing, each occupying a little square on the Zoom screen. Earlier, when we would have our PI meetings, the Trondheim group would sit around a table in one room, and the Oslo group around a different table in a different room (and town). This would divide us up into two clear groups. Only after starting to have Zoom meetings where all are equal, could we see how far from ideal the old way of doing meetings were. In this context Covid-19 has erased the distance between Oslo and Trondheim.

Travel stopped. It was not possible – or at least very difficult – to cross borders. Some of our visitors having planned to return home in early spring, suddenly found themselves stuck here. Whereas we had 64 visitors in 2019, this number dropped to 14 in 2020. Most of these 14 visitors were doctoral students and postdocs. Due to their extended stays, the visitor expenses for 2020 only dropped by 30 % compared to 2019.

Essentially all conferences became virtual. This is going to be a disaster we all thought, but – amazingly enough – they worked well in conveying science. What was lost, however, was the network building part. And the human contact at conferences. We are social beings and it is in situations like this that one realizes that this is not a theoretical statement.

The first Covid-19 wave retreated in June, but the summer and early fall was not normal, but compared to spring, it was nearly so. And then it started again. We left 2020 in the same state as we entered three months into it. At home.

But enough about Covid-19 here – see *Staying Creative in Covid Times* on page **42** for more.

Was 2020 a good year scientifically for PoreLab? We published 69 papers in refereed journals. Here are some highlights:

- Moura et al. measured experimentally Haines jumps, rapid movements of the fluid interfaces during slow drainage, i.e. when a non-wetting fluid displaces a wetting fluid in a porous medium. What is new in this work is that two types of boundary conditions have been used: Controlled Withdrawal Rate and Controlled Injection Pressure. The first type of boundary condition is by far the easiest to implement experimentally – so earlier experiments studying Haines jumps have been performed using these boundary conditions. On the other hand, the second type of boundary condition is the easiest to study theoretically, so that is what has been done. Now, through this work, we may compare them. It is a fundamental challenge in our efforts to understand upscaling that we sort out the difference between these two boundary conditions – and this is a first step in this direction. (Frontiers in Physics **7**, 217)

- Onsager worked out his reciprocity relations more than 90 years ago. These relations, which laid the foundation for non-equilibrium thermodynamics hinge on there being a time-reversal symmetry in the correlations between the fluxes in the system. Winkler et al. pose the question, is there such a time-reversal symmetry in immiscible two-phase flow in porous media? Imagine taking snapshots of how the fluids distribute themselves in the porous medium at regular time intervals. Scramble the order of the sequence. Can you reorder the snapshots in the original time sequence? If no, we have time-reversal symmetry. And this is what Winkler et al. found using a deterministic network model – quite an astonishing result which lays the foundation for our scale-up work. (Frontiers in Physics **8**, 60)

- In 2018, Hansen et al. (TiPM, **125**, 565) presented a generalization of relative permeability theory to non-linear flux-pressure gradient relations. This generalized theory was derived from symmetries at the macroscopic (continuum) level. Roy et al. derive a way to relate the earlier macroscopic results to the distribution of velocities at the pore level, thus making a connection between the pore scale and the continuum scale, a recipe for upscaling. (Frontiers in Physics **8**, 4)

- The larger a system, the more variables are needed to describe it fully. But, and this is the whole point, we normally do not need to describe our system fully. The trick is then to reduce the number of variables necessary to as few as possible. This, in a nutshell, is upscaling. The permeability is a single parameter describing single-fluid flow in porous media. Differential geometry tells us that we only need five parameters to describe the geometry of a body, the Minkowski functionals. Is this enough to fully characterize the permeability? The Hadwiger theorem says yes. But the numerical work of Slotte et al. says no. It is not enough. More is needed. But what? (Transport in Porous Media, **131**, 705)

- Immiscible fluids trying to occupy the same pore space lead to the formation of droplets. Under what conditions do what kind of droplets, or bubbles, form? Gjennestad and Wilhelmsen analyze this problem using thermodynamics and deliver a complete solution in this article which has attracted considerable attention. (Langmuir **36**, 7879)

- Lastly, I highlight one of a series of papers on hydrogen fuel cells, i.e. a more applied project. The fuel cell contains a membrane sandwiched between porous catalytic layers where protons and oxygen from air meet to form water. The two gases need to be fed into the membrane by a system of channels. Traditionally, these channels are laid out in a serpentine pattern that facilitates water transport out, but delays oxygen supply from the air. Sauermoser et al. rectifies this by looking to Nature: lungs are highly optimized branching structures that supply the blood with air of the same composition and pressure everywhere. They used entropy production minimization to demonstrate the efficiency of their geometrical layouts. (Chemical Physics Physical Chemistry **22**, 6993).

We present further projects – and some of those above – described in much more detail on pages 18 to 41.

And then there is art. Science is to make sense of our environment; art is to make sense of ourselves. PoreLab Oslo has put together a series of photos depicting various scientific processes that they have explored, not based on their contents but based on their esthetics. In one of his books, the great contrarian Christopher Hitchens describes how his teachers in elementary school tells the children that god filled Nature with the color green to please us with such a beautiful color. Hitchens, as a child, thinks to himself that the teacher gets it completely inverted. We find the color green pleasing *because* Nature is filled with it. Is the same mechanism behind the success of the Oslo pictures depicting Nature at work - because they really *are* beautiful?

AMBITIONS FOR 2020:
DID WE DO WHAT WE SET OUT TO DO?

We are now three and a half years into our funding period. Despite Covid-19 turning everything on its head, it is legitimate to ask how status now compares to the ambitions we had when anticipating 2020 in the 2019 Annual Report.

Our priority number one was integration of our research projects. It still is. We are not there yet, but we are a lot closer now than we were in 2019. The three-pronged approach - 1. Using thermodynamics to identify the proper variables and constitutive equations at a coarse-grained scale; 2. Using Euler theory for homogeneous functions to find relations between the flow rates of each of the immiscible fluids; 3. Expressing the thermodynamic functions at the coarse-grained level in terms of the Minkowski functionals – are no longer three separate approaches. Zoom works very well for discussing these problems and that is what we do.

In 2019, we pointed out the necessity to ensure that our network of collaborators would not distract us to go in all sorts of directions. We have heeded that, perhaps helped by the fact that Covid-19 has grounded us all. External collaborations are extremely important, but we keep in mind what is our main area of focus. The Scientific Advisory Board has reminded us of this, and we have listened.

We got 8 proposals through in 2020. It seems that we have been able to fulfill our ambition to write successful proposals. We will see in 2021 whether we are able to keep up this trend.

As for gender balance, well, it is better. To see the actual status, look at the Zoom photos on pages 42 to 43 – some 20% of those shown are female. We have recruited several female doctoral students. As for faculty, one more will join us in 2021 as full professor.

The junior Forum continues to be a very good instrument for making sure that ideas on how to improve PoreLab generated outside the PI group actually reach us. This, we got right. Surveys among the junior PoreLab members indicate that they are quite happy with their workplace.

The last and most important ambition on our wish list for 2020 was to turn PoreLab into "an important hub for porous media research in Trondheim and Oslo in that it is becoming a meeting place for people who work on porous media but coming from different disciplines." Now, this is on hold thanks to Covid-19.

AMBITIONS FOR 2021

First, get back to normal, or rather the New Normal. We have learned that Zoom meetings are highly effective. We have learned that talks given by someone giving a talk sitting in Rio de Janeiro to an audience here works just as well as having the speaker physically here. So, less travel – even when Covid-19 is gone.

Professor Erika Eiser from the University of Cambridge will join us as Professor of Experimental Mesoscopic Physics from August. We are now preparing the ground for her to set up her laboratories. She will be an immensely important member of PoreLab.

Our efforts to integrate our research will continue. We will continue to strengthen the use of double advisors for our doctoral students. This is an excellent way to accomplish this.

After a year of focusing on internal integration, i.e. getting the internal machinery of PoreLab tuned, we also need to look outwards. We need to continue our branding efforts. PoreLab has the potential to become a hub nationally but also internationally. For this to happen, we need to be visible.

We will further strive towards gender balance.

PORELAB: UNRAVELING THE EXTRA-ORDINARY PHYSICS OF POROUS MEDIA BY PROFESSOR RUBEN JUANES, MIT, USA

Porous media are central to our environment, economy and society. Water flow through the porous subsurface is a key component of the hydrologic cycle. (Vitruvius, who probably wrote in the time of Augustus, devotes a chapter of his *Architectura Libri Decem*[1] to the study of water, including a lucid interpretation of the hydrologic cycle involving the infiltration of rainwater or snowmelt through soils and rocks; unfortunately, his theories on subsurface water flow were largely forgotten for many centuries).

Fossil fuels extracted from deep geologic reservoirs still account for over 80% of global primary energy. Geologic carbon storage is a key technology in our transition to a low-carbon energy future, and is necessary in all negative-emissions technologies, such as blue hydrogen, green hydrogen or direct air capture, all of which rely on disposing of enormous amounts of CO_2. Porous media also make up many man-made materials (wood, concrete, textiles) and biological structures (bone, skin, termite nests). When scientists look for evidence of life on Mars, they look at its soil. And in this day and age, marked by the all-encompassing impact of the COVID-19 pandemic, our health and safety rely to some extent on the effectiveness of porous face coverings

Ruben Juanes is a professor in the Department of Civil and Environmental Engineering and Director of the Henry L. Pierce Laboratory at the Massachusetts Institute of Technology. His research focuses on multiple fluids flow simultaneously in porous geological media. Professor Juanes initiated in 2018 a benchmark study of the different numerical models used for simulating immiscible two-phase flow in porous media. The challenge was to replicate a set of drainage and imbibition patterns his group had generated in their laboratory. PoreLab participated in this study.

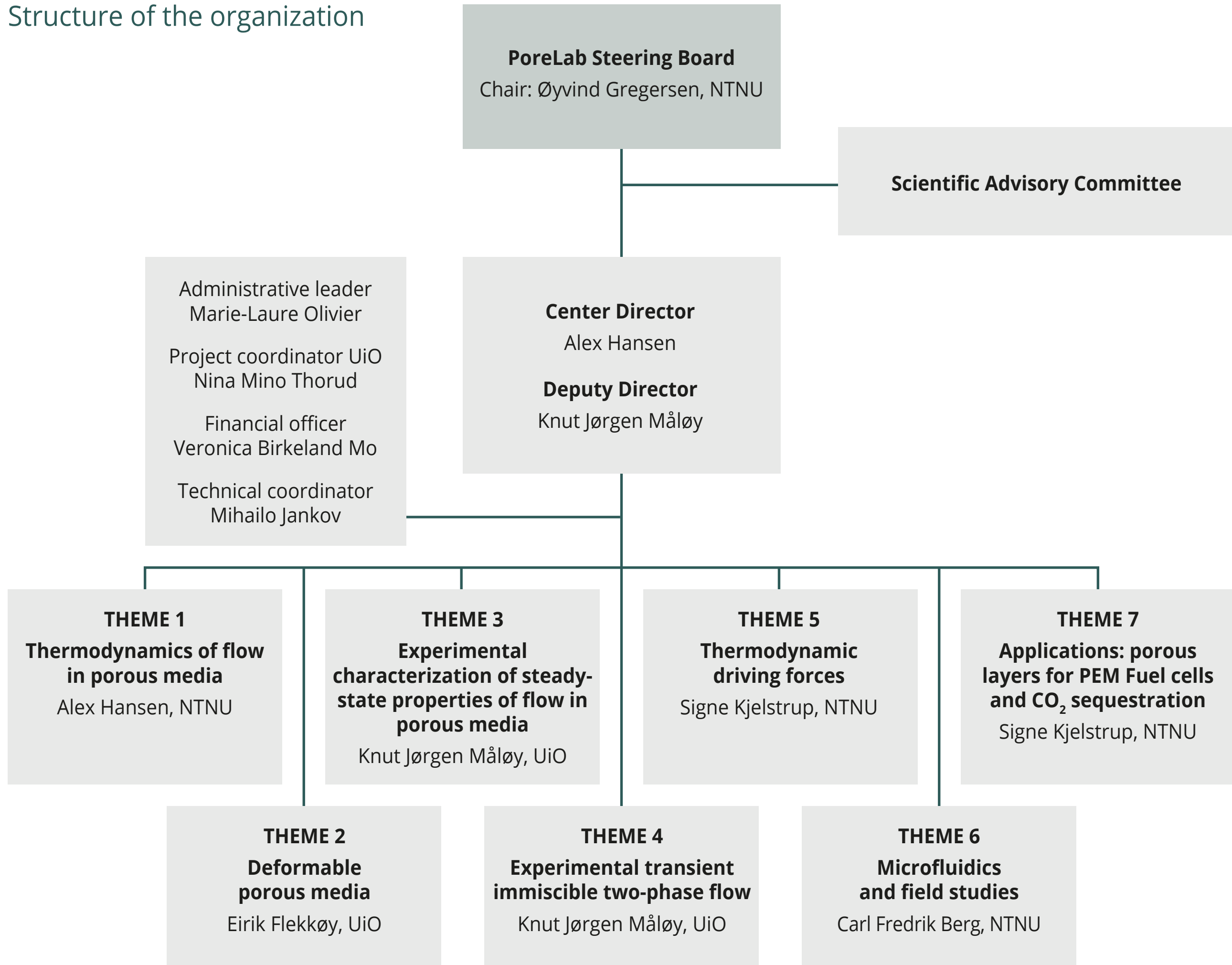
Porous media are notoriously difficult to study. They are disordered and often rough, highly heterogeneous, and usually opaque. And at the same time, few systems offer such a rich playground to uncover new physics. Dry granular media continue to challenge macroscopic descriptions of the onset of flow and the scaling of avalanches. Wet granular media, in which the mechanics of grain contacts are coupled with the hydrodynamics of fluid interfaces, exhibit a wide range of fascinating behaviors, from the structural integrity of sandcastles to the development of "craquelure" in paintings and desiccation cracks in soils. Although the characteristic scale of these morphologies is typically sub-centimeter, they can control natural processes at much larger scales, as with methane venting from the seafloor, expulsion of volatile gases during volcanic eruptions, and giant landslides on land and on the sea floor.

At the heart of these complex phenomena is the powerful coupling among viscous, capillary, and frictional forces within a porous medium—what we could call "porous-media physics". Our current understanding of porous-media physics has been shaped by the string of discoveries made by Norwegian research groups over the past four decades. PoreLab is, in some ways, the culmination of this long-term quest, where NTNU and University of Oslo have inspired generations of researchers and students in Norway and worldwide with their exquisite experiments and insightful theories. But the creation of PoreLab is also a starting point: it has elevated this long tradition to an even more prominent standing, simultaneously reaffirming the importance of porous-media physics as a scientific discipline and sending the unequivocal message that Norway will continue to lead this field for decades to come.

1 Vitruvius, Architectura Libri Decem [The Ten Books on Architecture] (Harvard University Press, Cambridge, Mass.) translated by M. H. Morgan, 1914.

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 and WesternGeco are external research partners.

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

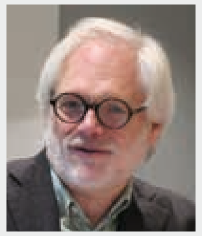
The organizational structure of the Center is flat. PoreLab's research has been organized in seven Research Themes lead by the Principal Investigators (PIs). The team of five Principal Investigators and the Administrative Leader forms the Leader Group and has bi-weekly meetings to discuss administrative 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.

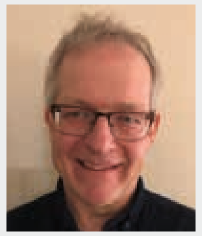
MANAGEMENT AND ADMINISTRATION

THE LEADER GROUP



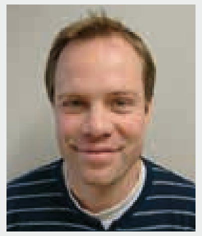
Alex Hansen
Director
Professor, PI Theme 1

Eirik Flekkøy
Professor
PI Theme 2

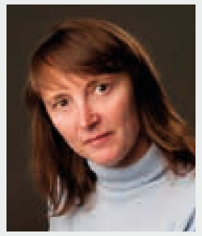


Knut Jørgen Måløy
Deputy Director
Professor, PI Themes 3 and 4

Signe Kjelstrup
Professor
PI Themes 5 and 7



Carl Fredrik Berg
Associate Professor
PI Theme 6



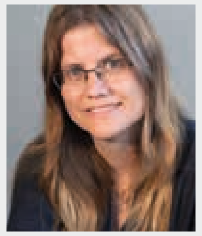
Marie-Laure Olivier
Administrative leader

PORELAB EXECUTIVE BOARD

Øyvind Gregersen
Dean
NV faculty, NTNU

Erik Wahlström
Head of Department
Department of Physics
NTNU

Sveinung Løset
Professor, Department of Civil and Environmental Engineering, NTNU
Vice Dean Research and Innovation
Faculty of Engineering, NTNU



Heidi Sandaker
Head of department
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(until April 2020)

Susanne Viefers
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(from May 2020)

Brit Lisa Skjelkvåle
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Department of Geosciences
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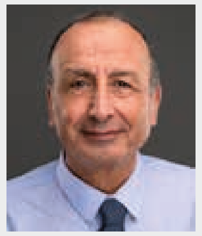
SCIENTIFIC ADVISORY BOARD



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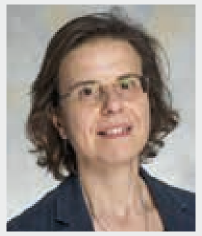
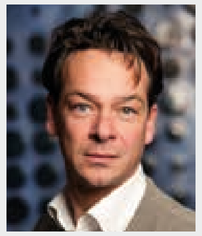


Anna Korre
Professor of Environmental Engineering
Co-director of Energy Futures Lab
Imperial College London
United Kingdom



Daniel Bonn
Professor
Van der Waals-Zeeman Instituut
University of Amsterdam
The Netherlands

S. Majid Hassanizadeh
Professor
Department of Earth Sciences
University of Utrecht
The Netherlands

Pål-Eric Øren
Chief Technology Officer
Digital Rock Services
Petricore, Trondheim
Norway

PARTNERS

NTNU

UiO : University of Oslo

SINTEF

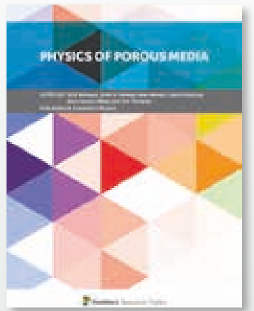
WesternGeco

HIGHLIGHTS

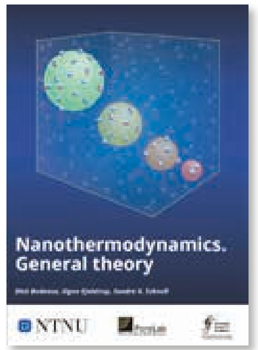
January 2020
Anders Lervik
new Ass. Prof. at PoreLab
within non-equilibrium thermodynamics
and molecular dynamics

January 2020
3 additional Porelab related projects,
in addition to the 5 granted in Dec. 2019,
get funding, for a total of 8 projects
to start in 2020

January 27-30, 2020
Celebrating the 60-year anniversary
of Knut Jørgen Måløy with a three day
seminar on porous media
in Courmayeur

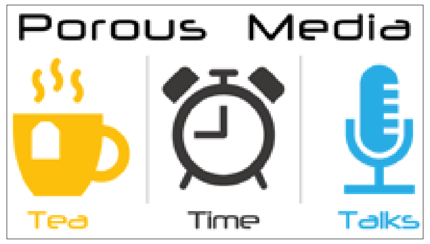


March 2020
The Principal Investigators
at PoreLab gather to release
"Physics of Porous Media"
The publisher is
Frontiers in Physics

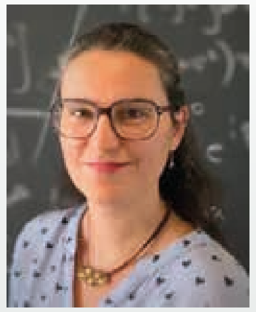


May 2020
New release from Signe Kjelstrup,
Dick Bedeaux and Sondre K.Schnell
PoreLab is the Publisher

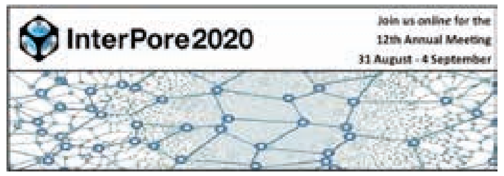
June 11-12, 2020
5th Earthflow seminar
at the University of Oslo



June 30, 2020
Starting the webinar series
Porous Media Tea Time Talks
#PorousMediaTTT



August 2020
Luiza Angheluta-Bauer
gets the title of Professor



September 1, 2020
Keynote lecture from
Prof. Signe Kjelstrup at
InterPore 2020, 12th annual meeting

September 21, 2020
"The art of Porous Media"
Opening of the PoreLab Virtual Gallery exhibition

September 24, 2020
PhD candidate Vilde Bråten,
ranked second in the national final in
Researchers Grand Prix

PHYSICS-INSPIRED PANDEMIC MODELLING

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Traditional models of disease spreading have the major shortcoming that they ignore both spatial and temporal heterogeneity, and instead model the global, coarse-grained behavior through so-called compartmental models. Although such models date back almost a hundred years, they are still the prevailing models used in the scientific community for epidemic modelling, including for the Covid-19 pandemic. Much like how a macroscopic description of fluids in terms of coarse-grained quantities like density and velocity fields are averaged quantities where microscopic information is lost, the compartmental models ignore the network of contacts between potentially disease-carrying individuals, which is where the disease spreads in reality. As it turns out, concepts from statistical mechanics have a lot to offer to improve upon the state of the art in epidemic modelling.

In disease spreading processes, the extremes can be more important than averages, as manifested in the key role of superspreading events. Many forms of individual heterogeneity are important: extroversion, infectiousness, mobility, age, etc. Instead of lumping these together into effective parameters fitted to macroscopic data, individual-based models give full, bottom-up direct control of all such parameters. This is analogous to how Lattice Boltzmann or molecular dynamics can correctly reproduce the macroscopic behavior of a fluid flow only by specifying the particle-particle interactions.

The spatiotemporal contact networks where disease spreads can be mapped using phone-based proximity data [1] or modelled by particles colliding on a lattice (see figures) [2]. These modelling approaches allow us to directly evaluate strategies for contact tracing, which consist in cutting links in the contact network before they are formed, i.e. focusing interventions where they are most effective. Our modelling confirmed what has been observed repeatedly during the pandemic: interventions are non-additive and highly non-linear, and this cannot be qualitatively captured correctly in compartmental models. Methods in statistical mechanics that are constructed to deal with complex systems are likely to yield new and important insights into disease spreading processes, and may provide decision makers with better tools to make informed decisions.

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[2] Vejen til frihed, Weekendavisen, Bjarke Frost Nielsen, Gaute Linga, Kristian S. Olsen, 2020. (https://www.weekendavisen.dk/2020-19/ideer/vejen-til-frihed)

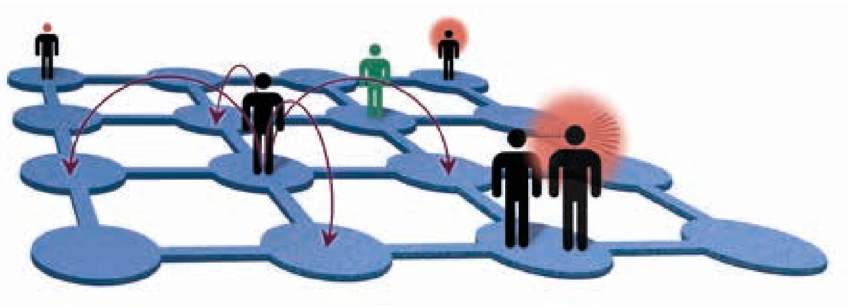

Figure 1: In a simplified model where both heterogeneity and non-stationary networks are present, the particles move on a two dimensional lattice and are redirected randomly upon collisions. Collisions between a susceptible and infected particle results in a transmission of the disease with a certain probability.

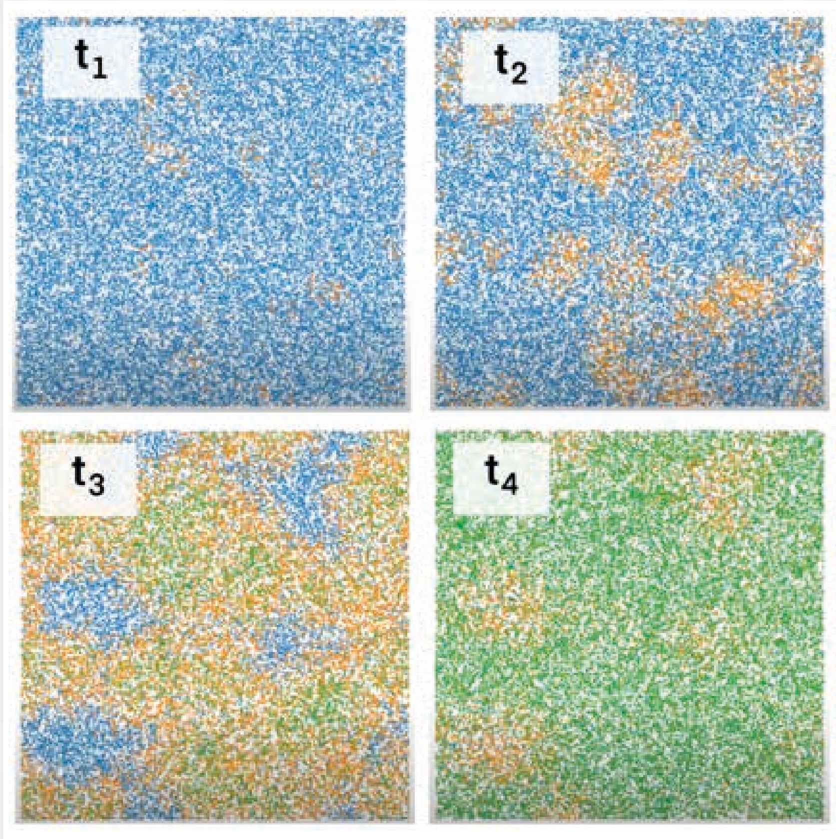

Figure 2: Snapshots from a simulation of the model described in Fig. 1 where 30 000 particles move randomly on a two dimensional lattice. In contrast to traditional disease spreading models, this system captures both spatial dynamics and temporal complexity of the contact networks. Initially (t1) a low number of infected particles (orange) are present. At intermediate time scales, (t2 and t3) the infection spreads diffusively, taking over the susceptible particles (blue). At late times (t4) all particles will recover (green).

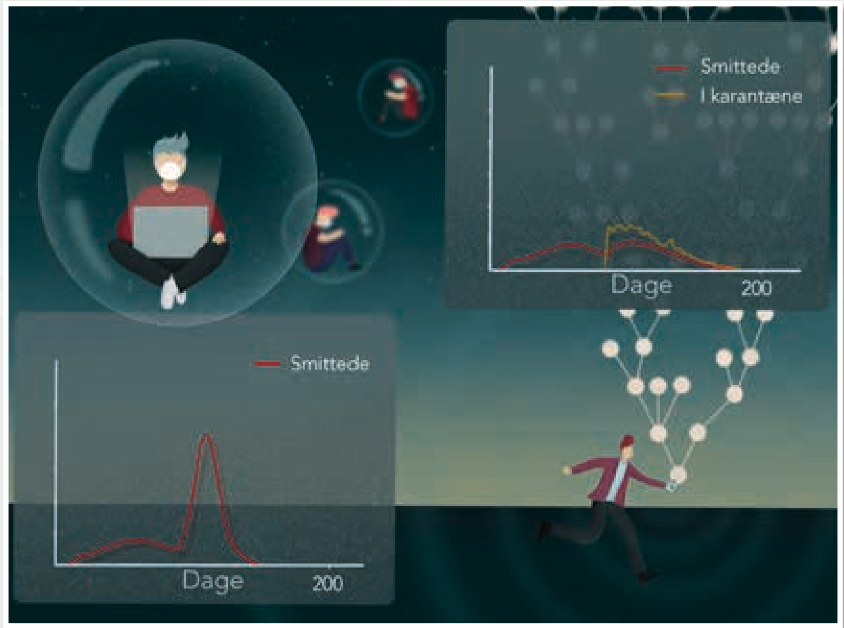

Figure 3: Covid-19 is (as other pathogens) spread by contact between individuals. Accordingly, non-pharmaceutical interventions operate by cutting links in these spatiotemporal contact networks. To ensure maximally limited spread and minimal disruption to society, decision makers must be supplied with models that correctly take these features into account. Illustration taken from [2].

BEYOND DARCY

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This started 12 years ago in the laboratory of Knut Jørgen Måløy, see [1]. The device in Figure 1 is a Hele-Shaw cell seen from above. It consists of two parallel plexiglass plates placed some hundreds of micrometers apart. The space between the plates is filled with glass beads that are glued in place. This creates a two-dimensional porous medium. Two immiscible fluids are then injected from one side. The fluids leave the system at the opposite side. The remaining two sides, orthogonal to the sides at which the fluids are injected and extracted, are sealed. The immiscible fluids are injected as shown in the figure through a series of syringes placed in series. This creates a steady-state flow in the Hele-Shaw cell where the fluids are well mixed, forming clusters of different sizes.

Among several other questions posed in Tallakstad et al. [1], one really stood out: What is the pressure difference across the system as a function of flow rate. The remarkable result of measuring this relationship was that *the pressure difference follows a power law in the flow rate with exponent close to ½*.

This result is quite unexpected. Henry Darcy measured the relationship between pressure and flow rate for single fluid flow through porous media already in 1856, finding *a linear relationship between them*. In retrospect, Darcy's result is not surprising. It is an example of linear response. The Ohm law, stating that electrical current is proportional to the voltage drop is another example. There are plenty of such examples – and they are not difficult to explain.

The leading theory for immiscible two-phase flow in porous media, *relative permeability theory*, also assumes linear response.

But this is not right. Tallakstad et al. [1] demonstrated that there is a non-trivial power law dependency. Here is what is happening. There are capillary forces between the two fluids. These try to keep the interfaces between the fluids in place. As the overall flow rate is increased, more and more interfaces held in place start to move, opening more and more flow channels. It is this gradual increase in active flow channels that produce the power law.

As a logical consequence of this explanation, there must be two additional relations between the flow rate and pressure difference apart from the power law regime. When the flow is very slow, both the immiscible fluids flow through open channels already present in the porous medium as we assume that both fluids form percolating channels through the porous medium. As the overall flow rate is increased, the system then enters the non-linear power law regime. The third regime occurs when the overall flow rate is so large that all interfaces that may move do so (some, e.g. associated with dead ends, never move). The relationship between the pressure drop and flow rate is again linear in this regime.

So, as we move from very small flow rate to very high flow rate, the relation between pressure drop and flow rate moves from first being linear, then being a power law, and lastly becoming linear again.

The power law is right in the regime where viscous and capillary forces compete. This is also the regime where relative permeability theory is supposed to work. Hence, this result may be very important. It requires new thinking on how to model immiscible two-phase flow far beyond the traditional. Monitoring the literature on this problem, it is clear that there is a rapidly increasing interest in it.

Now, these results have been obtained in the laboratory on fairly small systems – small compared to e.g. the size of reservoirs or aquifers. Is the power law regime present also in these much larger structures? We have studied this question using numerical methods. We find that *the power law regime goes away as the dimensions of the system is increased* [2]. But, this result hinges on our numerical model being able to capture all the subtleties of the real problem. We are therefore cautious about this result. It is imperative that it is tested in the laboratory.

Life would be simpler if the power law regime goes away with increasing system size. But, less challenging and therefore fun. Hopefully our conclusion is wrong.

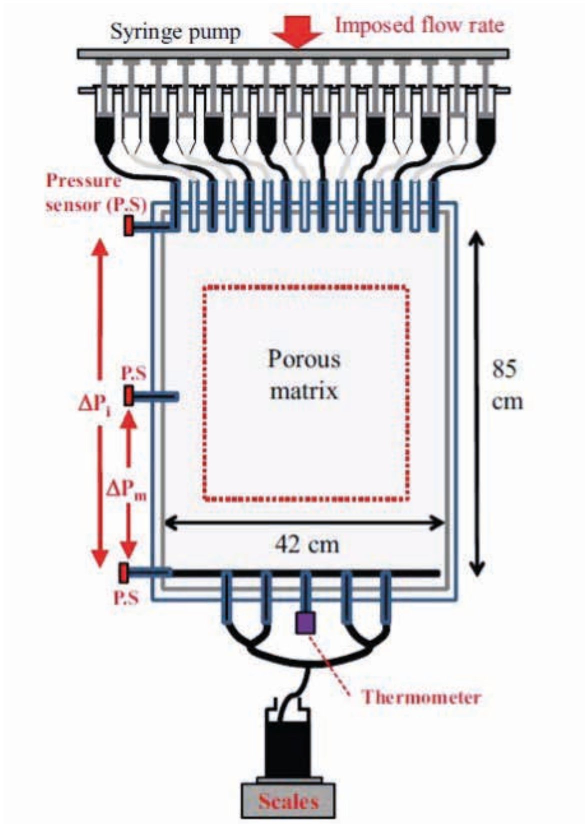

Figure 1: The Hele-Shaw cell, a two-dimensional model porous medium, used in Reference [1].

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[2] S. Roy, S. Sinha and A. Hansen, Immiscible two-phase flow: Effective rheology in the continuum limit, arXiv:1912.05248.

GRAVITATIONAL STABILIZED INVASION FRONTS

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When a non-wetting fluid displaces a wetting fluid in a gravitational field, the gravity will stabilize the fluid front and pockets of trapped fluid will be left behind the front. It is of particular interest to know how the saturation behind the advancing front depends on the fluid properties like surface tension, densities and viscosities, and the local geometry of the porous medium. It is further important to know if the trapped fluid behind the front is stable or if it will be drained on large time scales. Can we understand the dependence between the measured pressure in the fluid and the fluid saturations?

We have experimentally and numerically studied the influence of gravity on the pressure-saturation relationship in a given porous medium during slow drainage. The effect of gravity was systematically varied by tilting the system relative to the horizontal configuration. The use of a quasi two-dimensional porous medium allowed for direct spatial monitoring of the saturation. Exploiting the fractal nature of the invasion structure, we obtained a relationship between the final saturation and the strength of the gravity using percolation theory. Moreover, the saturation, pressure, and gravity field were functionally related, allowing for pressure-saturation curves to collapse onto a single master curve. This allows to upscale the pressure-saturation curves measured in a laboratory to large representative elementary volumes used in reservoir simulations. The large-scale behavior of these curves follows a simple relationship, depending on the density difference, the gravity field, and on the flow direction. The size distribution of trapped defending fluid clusters is also shown to contain information on past fluid flow and can be used as a marker of past flow speed and direction.

We have further studied the effects of connectivity enhancement due to film flow phenomena on the drainage and the relative influence of gravity for such effects. Our setup allows us to directly visualize the dynamics of the flow and, in particular, to pinpoint which pore invasion events are due to film flow phenomena. We have observed the formation of an active zone behind the liquid-air interface, inside which film flow drainage events are more likely to occur.

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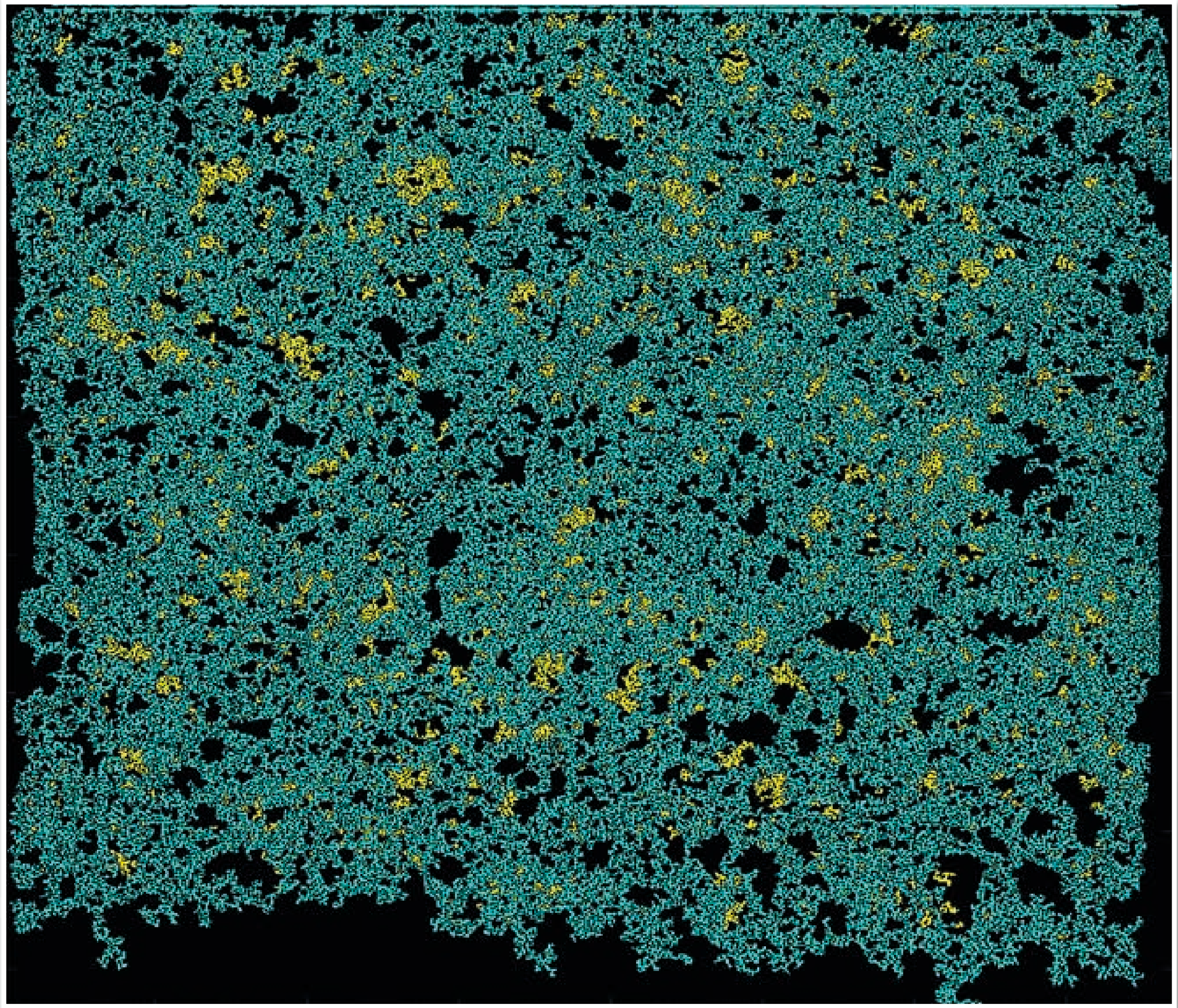
Moura M., Flekkøy E.G., Måløy K.J., Schäfer G. and Toussaint R., Connectivity enhancement due to film flow in porous media, *Phys. Rev. Fluids* **4**, 094102 (2019).



The picture shows a gravity stabilized front where air (in green) invades a glycerin/water solution (in black). The cluster left behind invaded by film flow at large times are seen in yellow.

SLOW DRAINAGE EXPERIMENTS IN POROUS MEDIA: WHAT HAPPENS IN YOUR FACEMASK WHILE YOU SLEEP

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You arrive home after another day of socially distanced interactions with your fellow colleagues. Had this been another year, you could grab some snack, open a beer and jump on the sofa straight away. But this is 2020, so the first thing you do is remove and wash your facemask, this life-saving, COVID-blocking porous medium. After a thorough wash, you decide to hang it on a string, to let it dry overnight, such that tomorrow this porous medium can go back to its heroic mission of preserving life on Earth as we know it. But what is really happening inside that mask while you sleep (or drink your beer)?

The drying mask is nothing but the most common 2020 realization of a porous medium slow drainage experiment. As gravity and evaporation work their ways, the water in the mask gives room for the surrounding air, which creeps into the mask, filling in the voids between the fibers of the tissue. This process, which seems rather smooth and continuous, is actually far from that. It occurs as an interesting succession of fast invasion events, some very small, with just one pore getting dry, others much larger, with air invading and drying several pores at once. This interesting intermittent dynamics is not exclusive to drying facemasks. It occurs in many natural and engineered settings and porous media scientists have kept a close eye on it over the years. By using artificially designed transparent porous networks, we can see very well the evolution of the air invasion dynamics. We show the result of one of those experiments on the right side of the figure. In this experiment, air invaded a porous network that was initially filled with a liquid (much like the process of the drying of a facemask on a string, as shown on the left of the figure). The different colors were randomly placed to help us see the different air invasion bursts, i.e., different portions of the medium that get dry. We have found that this drying occurs in an intermittent manner, with a wide distribution of invasion events, some small and some very large. It is interesting to notice how even such an apparently simple phenomenon, the drying of a piece of tissue, can present very interesting dynamics if we look close enough.

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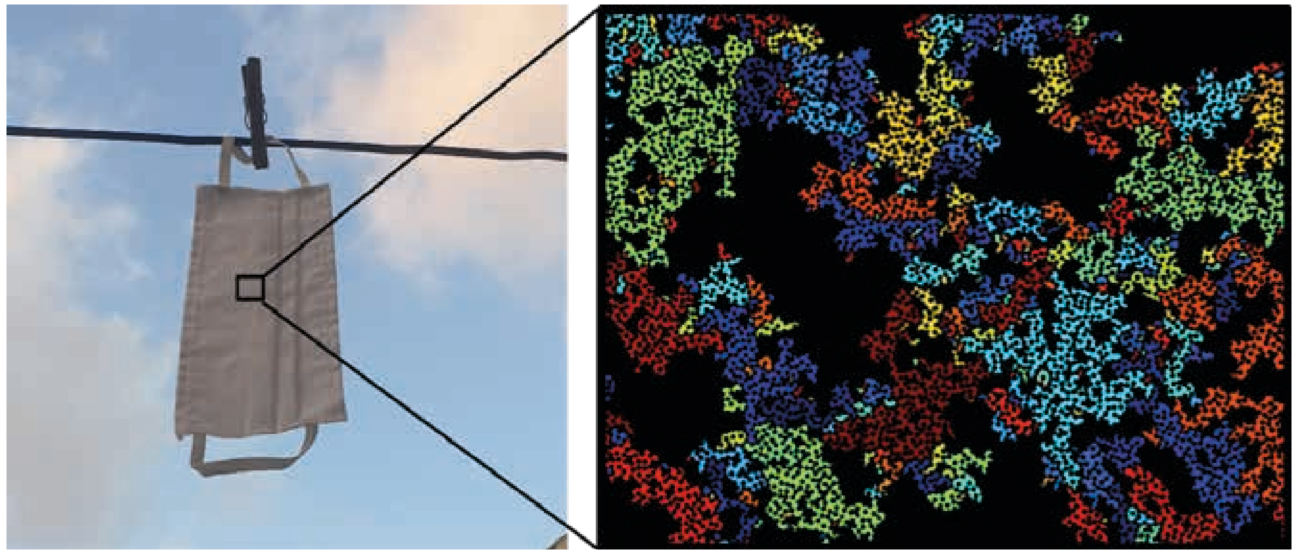
Marcel Moura, Knut Jørgen Måløy, Eirik Grude Flekkøy, and Renaud Toussaint, "Intermittent dynamics of slow drainage experiments in porous media: characterization under different boundary conditions", *Front. Phys*. **7**, 217 (2020).



A drying facemask (left) is an example of a slow drainage experiment in a porous medium. Although the process of drying seems very slow and continuous, it actually presents an interesting intermittent invasion dynamic, in which portions of the wet porous medium are successively invaded by the surrounding air. The invasion bursts can be well seen in our experiments, using artificial transparent porous network. In the experiment shown on the right, a viscous liquid is removed from the right side while air enters from the left. The different invasion bursts are colored randomly, to aid visualization. We see a wide distribution of air invasion events, some very small and some very large. The circular black dots are the porous matrix, in this case a monolayer of glass beads.

THE EFFECT OF WETTABILITY ON NANO-PARTICLE ENHANCED OIL RECOVERY

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PoreLab has several ongoing experimental projects on effects of wettability on flow performance in porous media (glass models and rock samples) with application to enhanced oil recovery. Water flooding is a century old method for oil recovery, and the search for cost efficient and environmentally friendly additives to the injection water to increase the oil recovery rates has a long history. In the work presented here we study the effect of adding polymer-coated silica nano-particles (PSiNP), and how this effect is influenced by the wettability. A microfluidic approach was utilized, and we have studied the micro scale flow behavior and oil recovery at three wettability states (water-wet, intermediate-wet, and oil-wet). In addition, cluster mobilization is studied in detail in all experiments. The obtained results were used as a basis to understand the changes induced by the nano-particles while flooding at different wettability, and adds to the understanding of the behavior of polymer-coated silica nano-particles as a recovery agent.

MICROFLUIDIC MODEL

Borosilicate microfluidic chips with a physical rock network are used in this study. The dimension of the chips' porous medium is 20 x 10 x 0.02 mm and the porosity, permeability, and pore volume are 57 %, 2.5 D, and 2.3 µL, respectively. A digital camera was used to capture images during flooding, and a syringe pump was used to inject fluid.

WETTABILITY ALTERATION

It is well known that hydrocarbon-soluble siliconizing fluid (Surfasil TS-42800) modifies the wettability of porous media via dilution in a nonpolar organic solvent. In this work, Surfasil was diluted in heptane at a concentration of 0.05 and 1 v/v % to obtain an intermediate- and oil-wet state of microfluidics models, respectively. Detailed procedure is given in reference 1. The wetting states for the system of synthetic sea water (SSW) and oil used in this study were validated by contact angle measurement on glass substrates subjected to similar treatment.

EXPERIMENTS

Three experiments were performed to displace oil by SSW, using water-, intermediate- and oil-wet microfluidic chips with an injection rate of 0.1 µl/min. Figure 1 shows that the brine (displacing from left to right) has a better displacement pattern in the water wet model than in the intermediate and oil wet models.

Similar as the SSW-flooding, the microfluidics models were flooded with PSiNPs at an injection rate of 0.1 µl/min. Figure 2 shows the oil recovery (in percentage of initial oil in place, IOIP)) for the three wetting conditions. Here the recovery factor is the maximum recovery obtained at this injection rate. The number of pore volumes injected (PVI) needed to reach this recovery is also indicated in Figure 2. The nanoflooding reached the maximum recovery faster than SSW-injection and the recovery was significantly higher than for pure waterflooding.

RECOMMENDED READING

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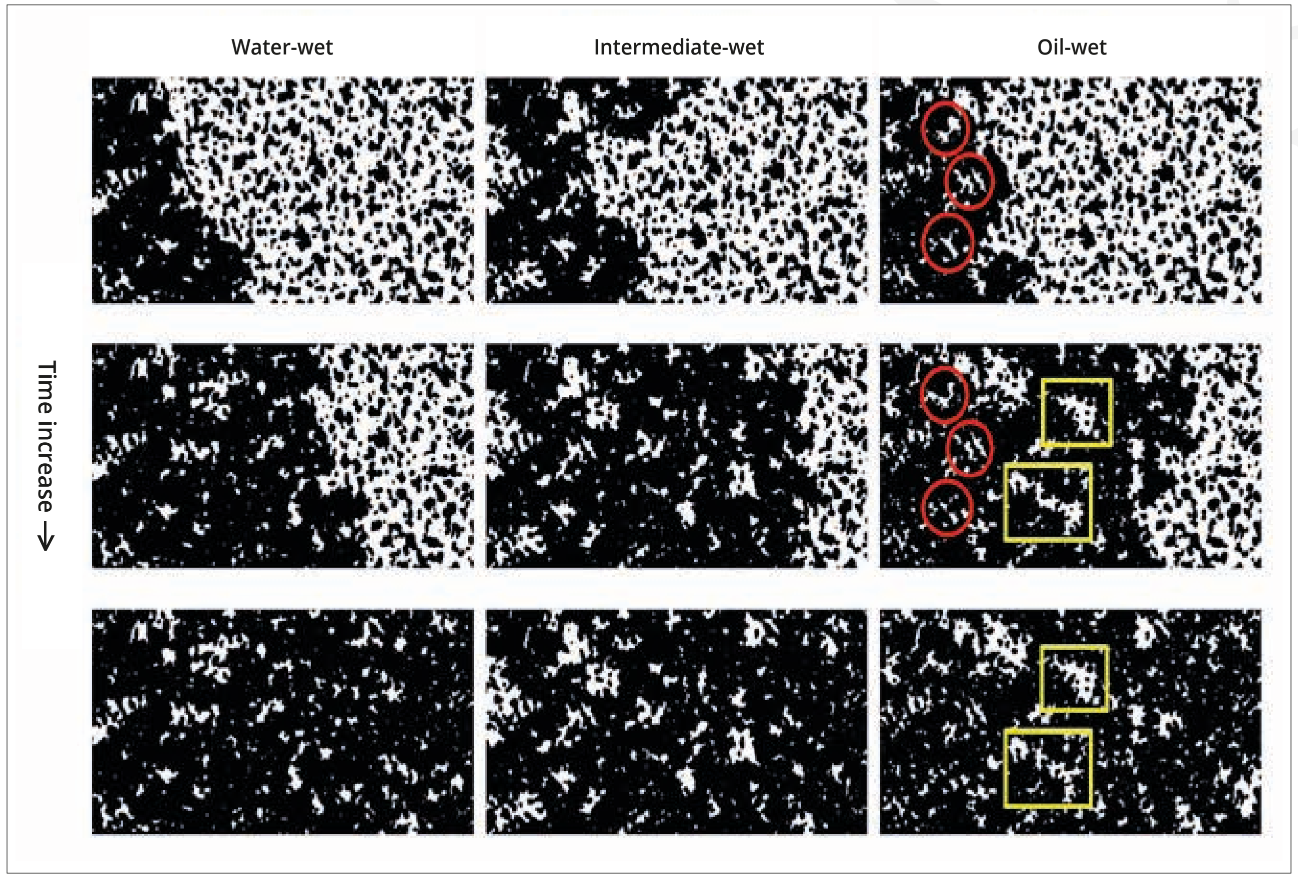

Figure 1: Displacement of the oil by the brine (oil: white; glass and water: black); red circles and yellow boxes show the changes in the oil due to invasion of the unswept areas behind the displacement front[1].

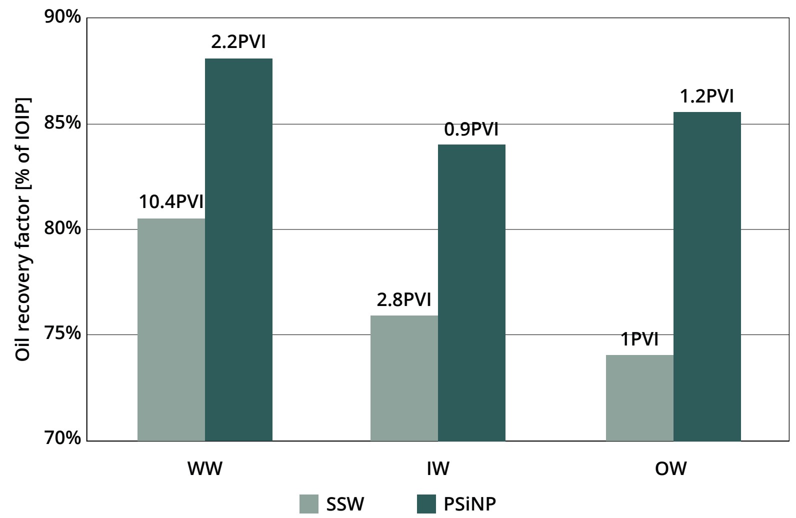

Figure 2: Oil recovery and corresponding injected pore volume (PVI) for SSW and PSiNP flooding at 0.1 µl/min[1].

CONTACT ANGLES IN TWO-PHASE FLOW IMAGES

Hamid Hosseinzade Khanamiri, Per Arne Slotte and Carl Fredrik Berg[1]

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In two phase flow, wettability, that is the relative affinity of the fluids towards the solid, has a strong influence on the microscopic fluid distribution in the porous medium, and thus on the macroscopic flow properties. The angle the interface of the two fluids with the solid, the contact angle, is a measure of wettability and is an important input parameter in pore scale simulations. It is well known that if the free energy associated with the solid–fluid and fluid–fluid interfaces depend only on interface areas, the equilibrium contact angle θ is given by Young's equation

$$\cos\theta = \frac{(\sigma_{2s}-\sigma_{1s})}{\sigma_{21}}, \qquad (1)$$

where σ_{21} is the fluid–fluid and σ_{ns} is the fluid–solid interfacial tensions. The effect of rough surfaces can be included in the effective fluid–solid interfacial tensions, with a resulting effective contact angle θ. Even though the surfaces of glass beads in synthetic media are smoother than surfaces in natural porous media, the angles measured by means of µ-CT in the micron scale should be categorized as the effective angles. However, we expect the effective interfacial tensions to be fairly constant throughout the medium. Accordingly, the contact angle is expected to be close to constant in a single material porous medium, such as sintered glass beads.

Several authors have reported in situ measurements of contact angles from µ-CT images. However, the measured contact angles tend to show a wide distribution rather than a single value. Mixed wetting, surface roughness, advancing/receding contact angles, and free energy contributions from three-phase contact lines or surface curvature contribute to a spread in contact angles. However, user-biased image segmentation, the limited image resolution, and artifacts imposed by surface smoothing will also contribute to contact a spread in the measured angles. In order to answer questions related to the relative importance of surface roughness, advancing/receding angles, and additional free energy contributions for the contact angle and curvature variations, it is important to minimize and quantify these errors.

In this work, we present a method for extracting contact angles by smoothing triangulated surface representations of the solid–fluid and fluid–fluid interfaces. High resolution experimental data of sintered glass beads and simple fluids were investigated to minimize the contact angle spread as a result of mixed wetting or other surface heterogeneities. Furthermore, we make no assumptions based on the current understanding of a physical equilibrium, or any assumptions on the possible variables influencing the contact angles.

MESH GENERATION AND MESH SMOOTHING

Our smoothing algorithm is based on "isotropic smoothing flow" by Meyer et al. (2003). This is similar to the work by AlRatrout et al. (2017), in the sense that vertices are displaced to minimize the curvatures. However, weights of displacements and the way we use the neighborhood of vertices are different. The vertices are displaced along their unit normal vectors with mean curvature as the weight. There is also an additional constraint on the maximum displacement based on imaging uncertainty. The vertices on the three-phase contact lines belong to both the solid–fluid and the fluid–fluid meshes and must be smoothed consistently through smoothing iterations.

CONTACT ANGLE VARIATIONS ALONG THE THREE-PHASE LINES

Fig. 1 shows examples of brine clusters where the contact angle is measured. The smallest clusters are taken out of the analysis since the smoothing algorithm tend to flatten these, resulting in contact angles close to zero. Also imperfections, with size close to the image resolution, in the sintered glass bead surfaces, in addition to segmentation artifacts, result in kinks in the 3-phase contact lines and locally high contact angles. Removal of these data points from the analysis would however involve manual inspection. The median contact angle in the analyzed image is around 70° and the spread is less than reported earlier.

Visual inspection of contact angle variations along selected smooth 3-phase lines revealed that the angle tends to be larger at the convex parts of the line and smaller at the concave parts (see Fig. 1). This behavior can be explained by the generalized Young's equation:

$$\cos\theta = \frac{(\sigma_{2s}-\sigma_{1s})}{\sigma_{21}} - \frac{\gamma}{\sigma_{21}}\kappa, \qquad (2)$$

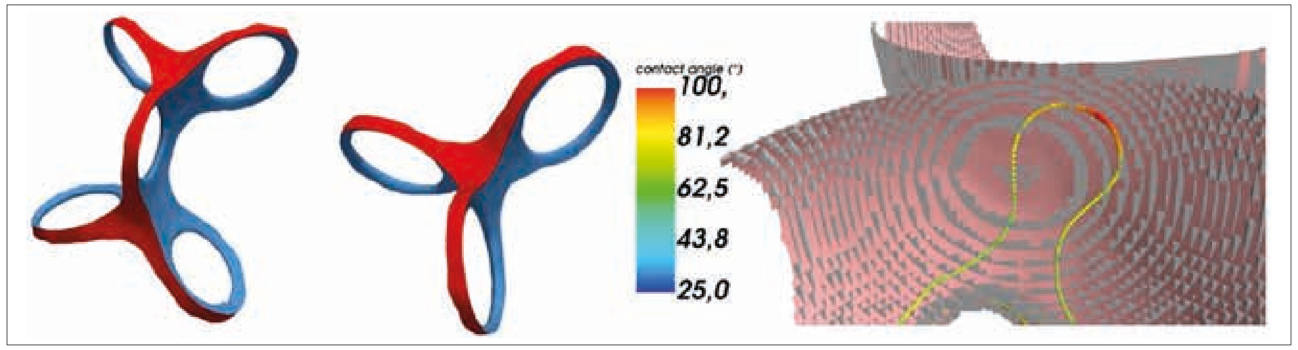

Figure 1: Left panel: Typical small brine clusters, with solid–fluid interface in blue and fluid–fluid interface in red. Right panel: Solid surface with three-phase contact line colored by contact angle.

where γ is the line tension (excess free energy per length of 3-phase line), and κ is the line curvature on the solid surface. Convex parts of the line with $\kappa > 0$ will have larger θ, whereas concave parts with $\kappa <$ 0 will have smaller θ.

More work is needed to show that the angle variation is not a result of the smoothing algorithm, but we have calculated the line tension γ using pairs of vertices with known θ and κ and Eq. (2). Using the known interfacial tension, the calculated line tension is $\gamma \approx 9 \times 10^{-7}$ *N*, which is in the high end of line tensions reported in the literature. It should be noted that γ in our micro scale measurements is an effective value possibly influenced by sub-resolution surface roughness and wetting variations. We have also estimated the total surface and line energies from individual clusters and find that the line energy is a significant part of the total the free energy of the two-fluid system in micro scale. The studied experimental system is composed of relatively large and smooth glass beads; thus, we can expect an even stronger effect in natural porous media such as sandstone rocks.

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[1] Hamid Hosseinzade Khanamiri, Per Arne Slotte, and Carl Fredrik Berg: Contact Angles in Two-Phase Flow Images. *Transport in Porous Media* (2020) **135**:535–553 https://doi.org/10.1007/s11242-020-01485-y

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EFFICIENCY OF SLOW DRAINAGE

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While wettability is widely recognized as having an important influence on multi-phase flow in porous media, there is a lack of measurement techniques for in-situ wettability in porous materials. Traditional measurement techniques are typically based on external measurements, such as the Amott-Harvey index based on displacement experiments or contact angle measurements on polished surfaces of similar materials.

When a non-wetting fluid displaces a wetting fluid over a solid surface, the fluid-solid interfacial tension will increase. Thus, this displacement will happen at a positive capillary pressure (the pressure of the displacing fluid minus the pressure of the displaced fluid). This increased internal energy requires external work, and the external work can be regarded as a proxy for the wettability. In essence, the Amott-Harvey index is based on such an assumption.

Except for simplified pore structures, the displacement process is non-reversible, with rapid internal redistribution of fluids due to snap-off and Haines jumps. This obscures a direct link between the externally applied work and the change in fluid-solid surface energies. In this work we show that for primary drainage processes the efficiency of the displacement process is closely linked to the pore scale geometry [1]. We can therefore calculate the efficiency based on images of the pore micro-structure. The local displacement efficiency for an imaged sandstone sample is displayed in Figure 1.

The pore structure description of the efficiency is linked to the pore body-throat aspect ratio, which again is connected to the constriction factor for electrical conductance [2]. We have shown a good correlation between the efficiency and the electrical conductance factor for a wide range of natural porous media. This open the possibility to calculate the displacement efficiency from electrical measurement, which are readily available for both core plugs and from down-whole well logs.

With the local efficiency we can also calculate the wettability from the externally applied work. This was done for the imaged displacement process in [3]. Using our local efficiency calculations, we obtained wetting values for the individual imaged displacement steps, reported as contact angles in Figure 2. This plot also contains the wetting values if assuming an efficiency of 1, i.e., a thermodynamicly reversible displacement process. Even for the simple pore structure of a bead pack there is an evident change in contact angles by including the displacement efficiency. The resulting wettability corresponds well with other measurements, including image analysis of the in-situ contact angles, as reported in [4].

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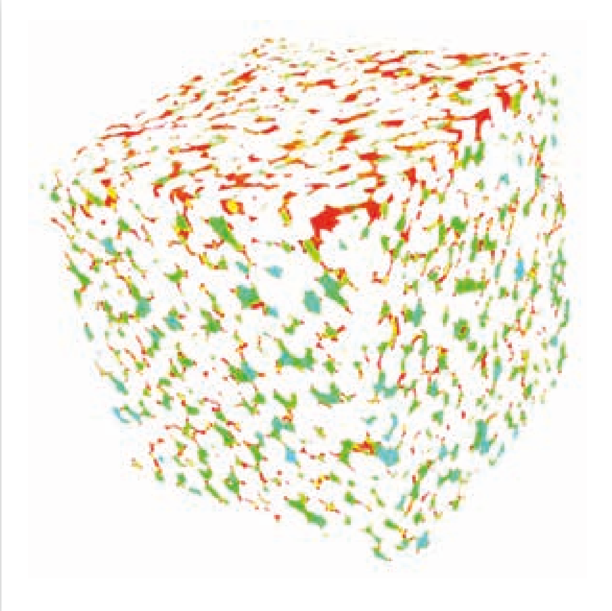

Figure 1: The local displacement efficiency in an imaged sandstone sample. The displacing fluid is entering the sample from the top. Note the higher efficiency in smaller pores and corners.

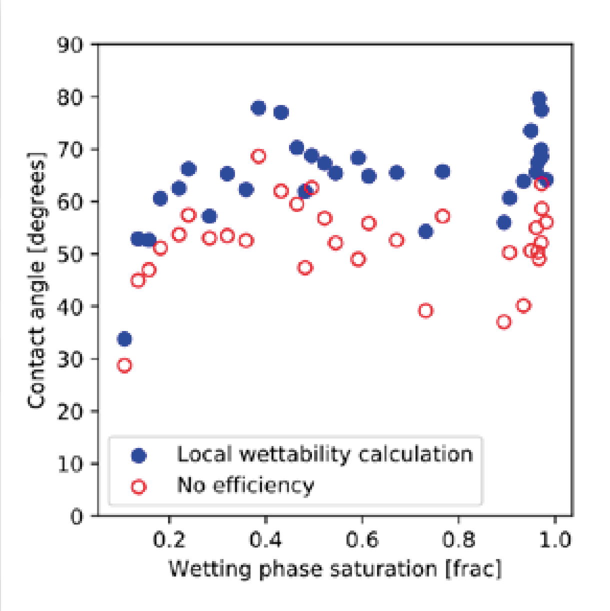

Figure 2: The calculated contact angle during an imaged displacement in a bead pack. The blue plot is using the local efficiency, while the red is not using the efficiency.

LEGENDRE–FENCHEL TRANSFORMS FOR SMALL AND LARGE THERMODYNAMIC SYSTEMS

THE CASE OF POLYMER STRETCHING

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As a system shrinks in size and the energy ceases to be extensive in the particle number, the thermodynamic theory as we know it from Gibbs, ceases to apply [1,2]. We have, for instance, shown [3] that new concepts of integral and differential pressures need be introduced to extend Gibbs thermodynamics for confined fluids in slit pores. A question is then: To which extent can we use other familiar equations to describe these small systems? We have investigated the applicability of central thermodynamic tools; namely the tools called Legendre and Legendre–Fenchel transforms [4]. We have found that systems which fail to obey the classical Lengendre transform, may still obey a Legendre-Fenchel transform. As a simple example to show this, we have taken the energies involved in the stretching of a single polymeric molecule.

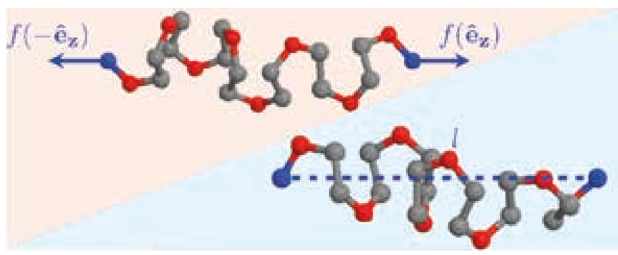

Figure 1. The polyethylene oxide polymer subject to isotensional and isometric stretching.

A SIMPLE MODEL

The polymer in this study is described by a united-atom model, which is a popular choice in the field of polymers [4]. The system is then investigated using molecular dynamics. As a case study, polyethylene oxide was chosen due to its relative simplicity combined with its wide range of applications [5]. In this particular model each bead, as shown in Fig. 1, represents either a methyl group (blue), a methylene group (grey) or an oxygen atom (red).

The model has all the standard contributions to the potential energy of a molecule, including bond stretching, - bending, and - torsion. The force- elongation curves for the two cases are illustrated in Fig. 2. For low forces, the molecule is all curled up, and almost no force is needed to stretch it. A regime follows, where bending and torsion dominate. In the end, the force needs to be relatively large to pull the beads apart. The temperature was controlled to 300 K in these cases. The average force for isometric stretching of a small molecule differs from that of isotensional stretching, see Fig. 2. In the long polymer limit they are the same. This has been verified experimentally, computationally, and theoretically, see Süzen et al. [6].

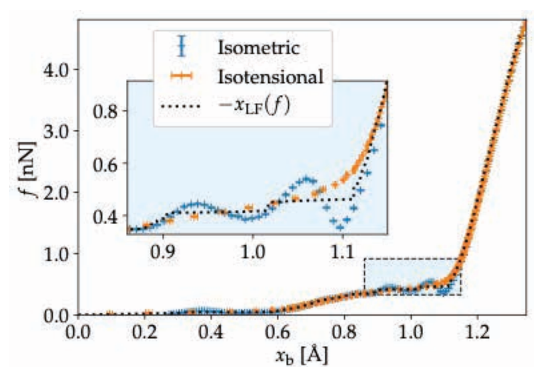

Figure 2. The isometric and isotensional stretching force (f) as a function of polymer fractional length (length per bond, x_b).

LEGENDRE TRANSFORMS

The energy of a system at constant volume and temperature, is the Helmholtz energy F, and the energy at constant pressure and temperature, is the Gibbs energy, G. It is useful to be able to transform from one type of energy into another. We know that two convex functions are Legendre transforms of each other when their first derivatives are inverse functions. But looking at the energies in Fig. 3, the Helmholtz energy is clearly not a convex function in this case. This has also been observed in experiments.

LEGENDRE-FENCHEL TRANSFORMS

However, there is hope. We have recently discovered that we are not without transformation possibilities. We have found using molecular dynamics simulations of polyethylene oxide, that the Helmholtz and Gibbs stretching energies of small, and large molecules as well, can be related by a Legendre–Fenchel transform. An important point is that we now can do the transform in both directions, from the isometric stretching regime to the isotensional one, and back!

This opens up the possibility, that also other systems, which fail to obey Legendre transform, could obey Lengendre–Fenchel transforms.

The Legendre–Fenchel transform [7] is a generalization of the usual Legendre transform, suited for energies that exhibit curvature anomalies. We have applied this transform and verified that it was reduced to the usual Legendre transform for large polymers. Next, we found that it worked for small systems.

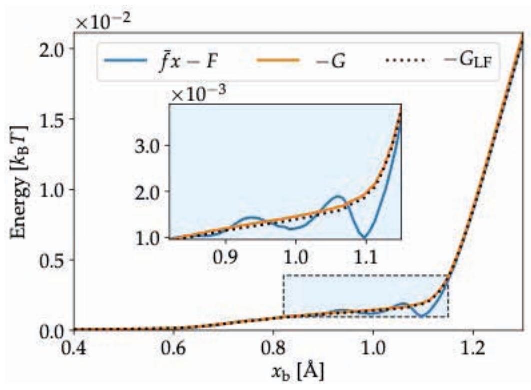

Fig. 3. The Helmholz (F) and Gibbs (G) energies are shown with the Legendre–Fenchel transform of the Helmholtz energy (G_{LF}), for a system of N= 12 beads.

In physical terms we can explain the success of the Legendre–Fenchel transform by the shape of the energy distributions of the relevant states. A classical system is well characterized by narrow peaks in the energy distributions. Also, the small systems that we considered, have highly peaked distributions, albeit different from those in the classical limit. When we use the Legendre–Fenchel technique, we select only a part of the peak to be used, whether it is of a classical system or of a small system. Evidently, the sharp distribution of states for small polymers is sufficient for the method to work.

This result is encouraging and opens up for a wider possibility to carry out energy transforms than hitherto has been available, for classical small systems.

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THE IMPACT OF ENTROPY BARRIERS ON TRANSPORT IN BIOLOGICAL MATERIALS

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To optimize the transport of nanoparticles (NPs) and therapeutic agents (TA) into cancerous tissue, it is essential to understand the underlying mechanisms and determine which parameters are most critical for successful delivery. The structure of the biological tissue, and the carcinogenic tissue in particular, is then essential. Successful delivery of NPs depends on many parameters such as the properties of the NPs (size, charge, shape, surface coating, material) and tissue properties (porosity, elasticity, viscosity). Experimentally, it is not possible to control all these parameters separately and determine their impact. Therefore, a physical-chemical model, in combination with experiments, is required to understand the behavior of penetrating therapeutic agents into the cellular medium under varying conditions.

We are addressing the important issue of finding optimal conditions for delivery of cancer-specific drug-loaded nanoparticles into tumor tissue. Spatial and temporal variations of the structure of the cancerous tissue, and therefore of the shape of the interstices through which nanoparticles may flow, gives place to entropic forces. We have proposed a model, in which the obstacles that nanoparticles encounter along their trajectories, hampering their motion, are described by means of entropic barriers. These barriers might well play a key role.

In our view it is important to consider the effect of the microstructure, its temporal and spatial variation and its impact on the chemical potential of the therapeutic agent (see Fig. 1).

This effect is captured in the entropic barrier (Fig. 2) and it accounts for the variation of the number of microstates related to the cross-sectional area. In an ideal system, the chemical potential is then:

$$\mu(r,t) = k_B T \ln x(r,t) + k_B T \ln \frac{(h(r,t) - R_{NP})^2}{l^2}$$

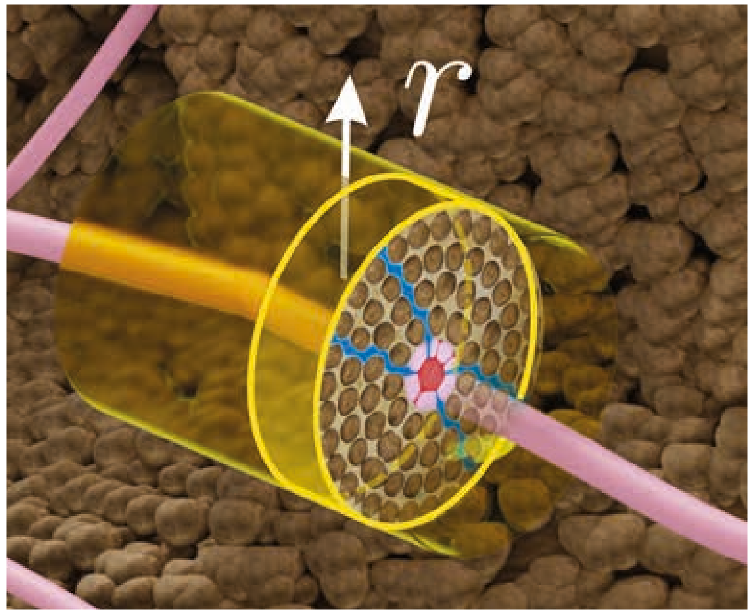

Figure 1: Illustration of a portion of a carcinogenic tissue composed of capillaries, mainly made of endothelial cells (pink), and cancer cells (brown) in the extracellular matrix. The movement of therapeutic agents (TA), drug-loaded-nanoparticles, takes place along the free space in the cells and among the cells (blue channels). The channels illustrate some possible trajectories in the radial direction in which entropic barriers affect the movement.

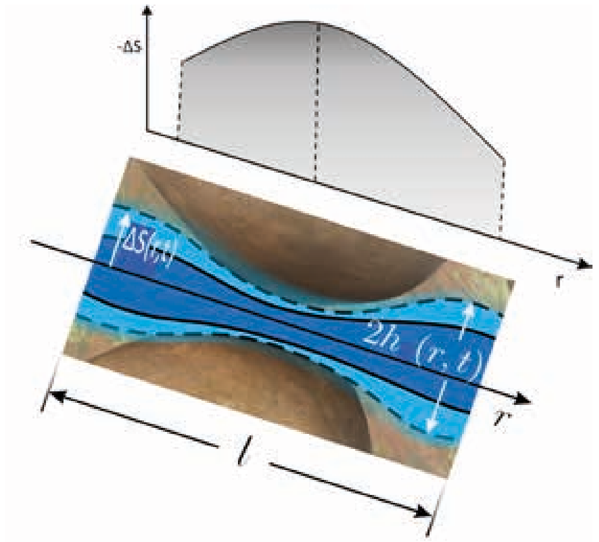

Figure 2: Entropic barrier defined from a channel corresponding to the free space between cells. Variation in ΔS comes from variations of the channel radius h and therefore the cross-sectional area. The entropy delta is defined as: $\Delta S = S(r) - S_{ref}$

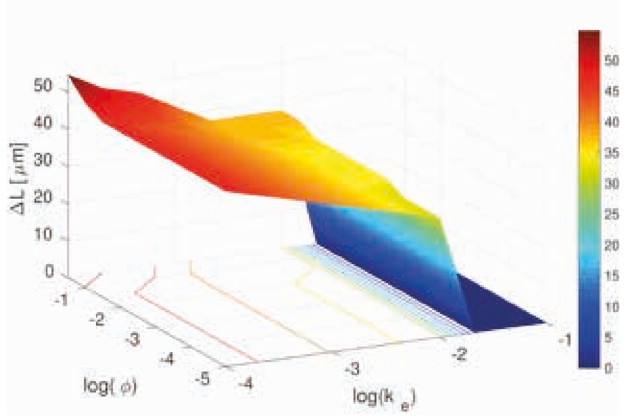

Figure 3: Penetration length ΔL as a function of the porosity Φ and elasticity of the medium k_e.

where the first term on the right-hand side corresponds to the ideal chemical potential, whereas the second one accounts for the effect of the entropic barrier (-ΔS) in which $\frac{(h(r,t) - R_{NP})^2}{l^2}$ is proportional to the number of microstates. Here ***x*** is the mole fraction of therapeutic agent, ***h*** is the radius of the channel (Fig. 2) which depends on the position and time, ***l*** is the length of the system and R_{NP} is the radius of the particle. From nonequilibrium thermodynamics we obtain the driving force for transport from the gradient of the chemical potential.

By considering the effect of the entropic force we can compute the efficacy of the drug transport in terms of the penetration length (*ΔL*), for instance. Here ***ΔL*** is the maximum distance, from the capillary wall (pink cells in Fig. 1), that the NPs reach into the cellular medium (brown cells in Fig. 1). This length can be computed for different channels' shape (blue channels Figs. 1 and 2) depending on characteristic parameters of the medium (porosity, elasticity, etc.) which vary among different types of cancers. In Fig. 3 we show the behavior of ***ΔL*** as a function of the porosity and elasticity of the medium when an external force is applied to the channels.

Fig. 3 is only one example of possible outcomes of the analysis that can be done with the model. It shows the penetration length as a function of porosity and medium elasticity. Further studies may be conducted to consider a variety of phenomena as thermophoresis, convection, electrophoresis as well as the energy dissipation as heat, and heat release to the surroundings. All in all, we want to ensure optimal conditions for drug delivery. This analysis can well be used as a starting point to consider the impact of micro-structure in the development of theoretical and experimental studies, for further improvement of cancer therapies for example.

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MIGRATION OF A GOLD LIQUID ALLOY THROUGH SOLID SILICON

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A curious observation was made by W. G. Pfann in 1955 [1]. In a paper on "Temperature Gradient Zone Melting", he described that a liquid droplet could be transported through a solid state material, if the system was exposed to a temperature gradient. When an alloy was exposed to a temperature gradient of the right magnitude, and the local temperature reached the melting point of the relevant alloy, droplets of the liquid alloy could be observed to form and start to flow down the temperature gradient. This curious migration of a liquid solution through a solid was further studied in the 1960s and 1970s. The aim was to find an effective method for doping of silicon, however, so a relatively small gradient was used, below a few hundred K/cm. The consequent migration rate was therefore also small, a few hundred nanometer per second [2]. The phenomenon has still not been satisfactorily explained with respect to the origin of the transport phenomenon and the mechanism involved.

We have therefore started new experiments using much larger temperature gradients, in the hope to gain a better understanding as to why and how this phenomenon occurs. Indeed, by applying a laser to create and control the temperature gradient in the silicon fiber, we have been able to observe again the curious droplet movement, here of a gold-silicon alloy in the pure silicon fiber. The system is illustrated in Fig.1, where A stands for silicon and B stands for gold, and the "droplet" is the rectangular liquid region in the model. The liquid is a mixture of Si and Au. There is a hot and a cold interface of solid silicon on each side of the droplet alloy. A movement of the droplet to the hot side can be measured.

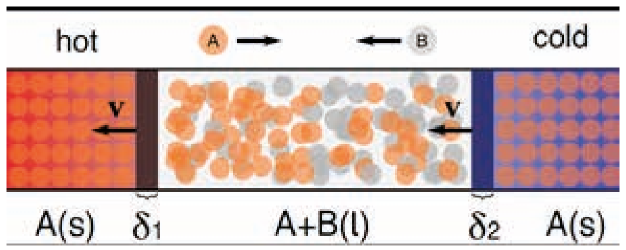

Figure 1. The liquid droplet of the alloy of Si and Au in a temperature gradient between two interfaces. The interface moves with velocity v with respect to the wall. While Si is transported from hot to cold, there is a circulation of Au between the interfaces, which keeps the net velocity of Au equal to zero, in the surface frame of reference.

A separation of components in a mixture exposed to a temperature gradient, e.g. the Soret effect, is widely studied and also well described in terms of interacting mass and heat fluxes. The Soret equilibrium can be understood as a balance of chemical and thermal forces. Movement of mass takes place as a response to the thermal driving force, until this balance is reached. The separation of components is a result, not a cause of transport, however.

We shall see that this is so also for our droplet moving in the solid phase. The only external driving force available to explain the droplet movement is the thermal driving force. In search for an explanation, it is not sufficient to look at the events in the liquid. The response of the system to the external force is primarily to transport heat, and this is most efficiently done by melting the solid material on the hot side and freezing out some of the same material on the cold side. The enthalpy of melting of silicon is large, 49 kJ/mol. As A is melted into the liquid on the warm side and is freezing out of the liquid on the cold side, heat is transferred and more effectively so, than by conduction alone. The overall gain gives an explanation for the phenomenon.

Clearly, a concentration gradient arises inside the droplet alloy, but this is not adequate to explain the droplet movement. It does explain the mechanism. A concentration gradient of Si would be created in response to the movement of the droplet. The concentration of Si in the droplet will increase where it melts and decrease where it freezes. This promotes transport of Si from hot to cold. For Au there are two options. It may not move at all in the reference frame of the drop (since Au cannot escape the droplet.) But Au may also move in the opposite direction to recover Soret equilibrium. In the interface frame of reference there must then be a circulation of Au in the alloy droplet, still keeping the net flux of Au equal to zero in the droplet frame of reference.

We have performed experiments and molecular simulations to find support for this theory. For the thermomigration experiment we used glass-encapsulated silicon fiber as a solid matrix. A liquid alloy was formed by introduction of gold into the silicon. A focused CO_2 laser of wavelength 10.6 µm (Synrad 48-2) was used to create a large temperature gradient (up to 104 K/cm). The silica cladding effectively absorbs the CO_2 laser radiation and converts it into heat. Movement was recorded in real time using the CCD camera. An image sequence of a single drop moving through silicon is shown in Fig 2

Experimentally as well as by simulations, we have seen that the droplet moves in a thermal field, with an interface velocity which is proportional to the temperature difference between the interfaces. Preliminary simulations seem to confirm possible circulation of Au inside the droplet.

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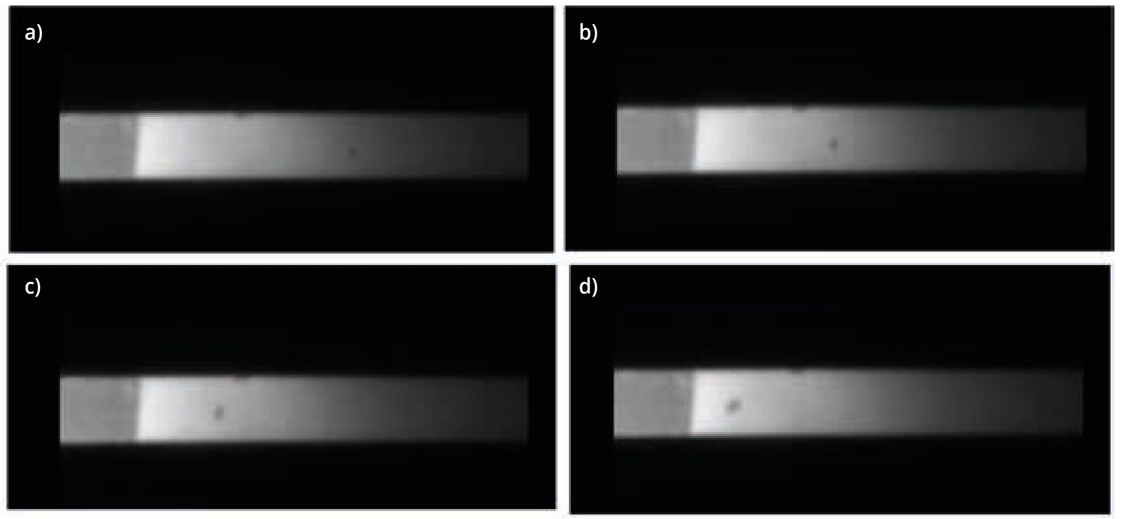

Figure 2. Time sequence of Au-Si drop moving through solid silicon. The dark region is the laser heated zone, with a temperature greater than the melting point of silicon; the distance traveled by the drop is ~0.5 mm and the time is approximately 4 seconds.

CAN PORTLAND CEMENT BE USED TO SECURELY PLUG UNDERGROUND CO_2 STORAGE RESERVOIRS?

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Storing CO_2 in depleted oil and gas reservoirs is considered the most promising mitigating measure for resolving the global CO_2 emission crisis.[1] The risk of CO_2 leakage is the main concern that has slowed down the implementation of this technology. Portland cement is the natural choice for sealing the reservoirs and it is crucial to assess the response of cement under subsurface conditions with high temperature, high pressure, and CO_2 in its supercritical state. Owing to its complexity, only few field studies have been undertaken to study the integrity of real CO_2 wells.[2] Understanding the dynamics of the cement carbonation processes based on ex-situ laboratory experiments is also difficult because the effects of carbonation must be decoupled from the effects of depressurization prior to observing the sample.[3]

When CO_2 saturated water is in contact with cement at reservoir conditions, a series of chemical reactions lead to cement carbonation, with the associated loss of structural and mechanical integrity.[2] Upon CO_2 saturated water exposure several distinct reaction zones form in cement and propagate into the cement bulk with time, involving dissolution of portlandite and other cement phases, followed by precipitation of calcium carbonate ($CaCO_3$), and subsequent dissolution of the same $CaCO_3$, rendering a weak porous silica phase.[3] The carbonation rate depends on the chemical composition and physical properties of cement, as well as the CO_2 brine flow, preparation and curing conditions. It has been reported that fractures in cement can either close, typically by calcium carbonate precipitate filling, or open wider upon carbonation.

To address this environmentally important problem, we have carried out a series of *in-situ* time-resolved X-ray computed tomography ("4D CT") studies of Portland cement carbonation under realistic reservoir conditions[4-6] using the unique X-ray tomography-compatible triaxial deformation apparatus *HADES*[7]. In one study,[4] a sample of cured Portland cement was prepared with a smooth cylindrical channel ("leakage path") of diameter 0.4 mm running through the sample (see Fig. 1). The cement was exposed to the high hydrostatic pressure (28 MPa) and temperature (80 °C) corresponding to ~2 km depth. The sample was exposed to alternating flow and hydrostatic (non-flow) conditions of CO_2 saturated water to delineate precipitation and dissolution-dominated regimes.

We observed directly cement reaction fronts propagating through the cement sample, as well as precipitation and dissolution of $CaCO_3$ in the leakage path present in the cement. The time-lapse 3D images allowed monitoring the progress of reaction fronts in the cement, including density changes, sample deformation, and mineral precipitation and -dissolution. The temporal evolution of the volumes of the carbonated and porous silica zones showed quantitatively how the growth rates of the carbonated and porous silica regions changed with the flow conditions. The experiments thus provided unique data for testing and calibrating numerical models, giving further insight into the dynamics of the cement-CO_2 system under storage conditions. The reaction zones could be clearly discerned in the CT images, including their propagation with time. $CaCO_3$ was seen to precipitate during stages with stagnant (non-flow) conditions, and to dissolve during stages with flowing brine.

Our results confirm by direct imaging that the rate of cement alteration depends on the CO_2 flow conditions, with rapid cement degradation under flow conditions, and slow degradation for hydrostatic conditions. The flow rate exerts a first order control on the pH in the channel and determines the rate of cement degradation because the diffusive transport of reactants into the cement is proportional to their concentration gradients. Pathways partially sealed by mineral precipitation can re-open if the fluid flow rate in the pathway is increased – establishing a strong history dependence on the cement response.

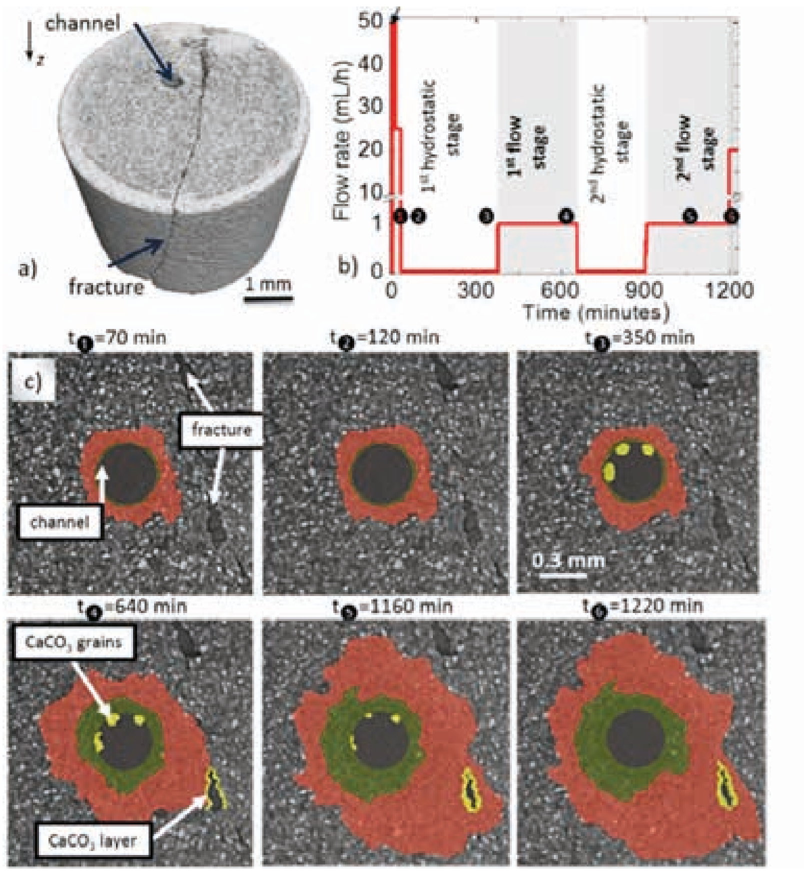

Figure 1. a) Perspective view of a cement sample. b) The flow history of CO_2 saturated brine during the experiment. c) Lateral μ-CT cross sections showing the region near the channel, obtained at the indicated times. The images show the evolution of the carbonated zone (colored red) and porous silica (green), and precipitation/dissolution of calcium carbonate (yellow). [Reproduced from Ref. 4 with permission].

We emphasize that such quantitative data (see Refs. 4-6 for details) about the reaction dynamics are in high demand and would be very difficult to achieve with other techniques, as the mineral chemistry is prone to change also during depressurization and subsequent sample handling. Our work provides direct experimental evidence that the local state of cement in cemented well bores is strongly impacted by the surrounding CO_2 water/brine. Finally, we have demonstrated that also the *history* of the fluid flow rate over time plays a key role for the behaviour of fractures, pointing to the need of careful planning of the entire reservoir filling and well plugging process, as the presence of CO_2 can contribute both to sealing and degradation of the cement.

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HYPER-BALLISTIC SUPERDIFFUSION IN POROUS MEDIA

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Diffusion is a process that may be found at work almost everywhere. It controls the spreading of heat in solid materials, nutrient transport in living cells as well as the spreading of pollutants in a soil. But it is a slow process, which is always characterized by a spreading speed that decays with time. The simplest example is that of particles that move in random steps with no preferred direction, so-called random walkers.

What happens if, for some reason, such spreading processes accelerate? This is the question we pose in the present project. It turns out that under some surprising conditions, this may indeed happen. An extreme example of this is known as hyper-ballistic diffusion.

Hyper-ballistic diffusion is the phenomenon where diffusion gives rise to a spreading process that is faster than ballistic, that is, faster than some constant speed. For a random walker that changes its direction at regular intervals, this would mean that on the average it would move further than a walker that never changes its direction. This appears almost a contradiction in terms, for, how could you get further if you constantly forget where you are going than if you head straight for a target. Yet, such behavior may exist when the step length increases with time sufficiently quickly. In order to study such processes, we have focused on the simplest possible case where the step length of the walkers increases rapidly as their local density decreases. This model allows for analytic solutions for the spreading process.

Real world examples of such behavior may include bacterial swimmers that compete for nutrition inside a porous media, or even the spreading of heat inside a porous media with a mix of frozen and melted water in the pores. As a conceptual starting point, we simulate a model system where the random walkers have a step length that goes as an inverse power of the local density. Such a model allows for an exact mathematical solution that indeed predicts hyper-ballistic behavior. The figure shows a snapshot of such random walks, which may be imagined to represent bacteria on the micron scale, or the propagation of heat on the meter scale. Understanding such bacterial processes may be relevant for the description of infection spreading, and the spreading of heat may be of relevance for questions on how heat propagates downwards in a tundra environment, or on the existence of water beneath the surface of Mars. Such heat propagation will cause melting at larger depths than what is predicted by normal diffusion.

RECOMMENDED READING

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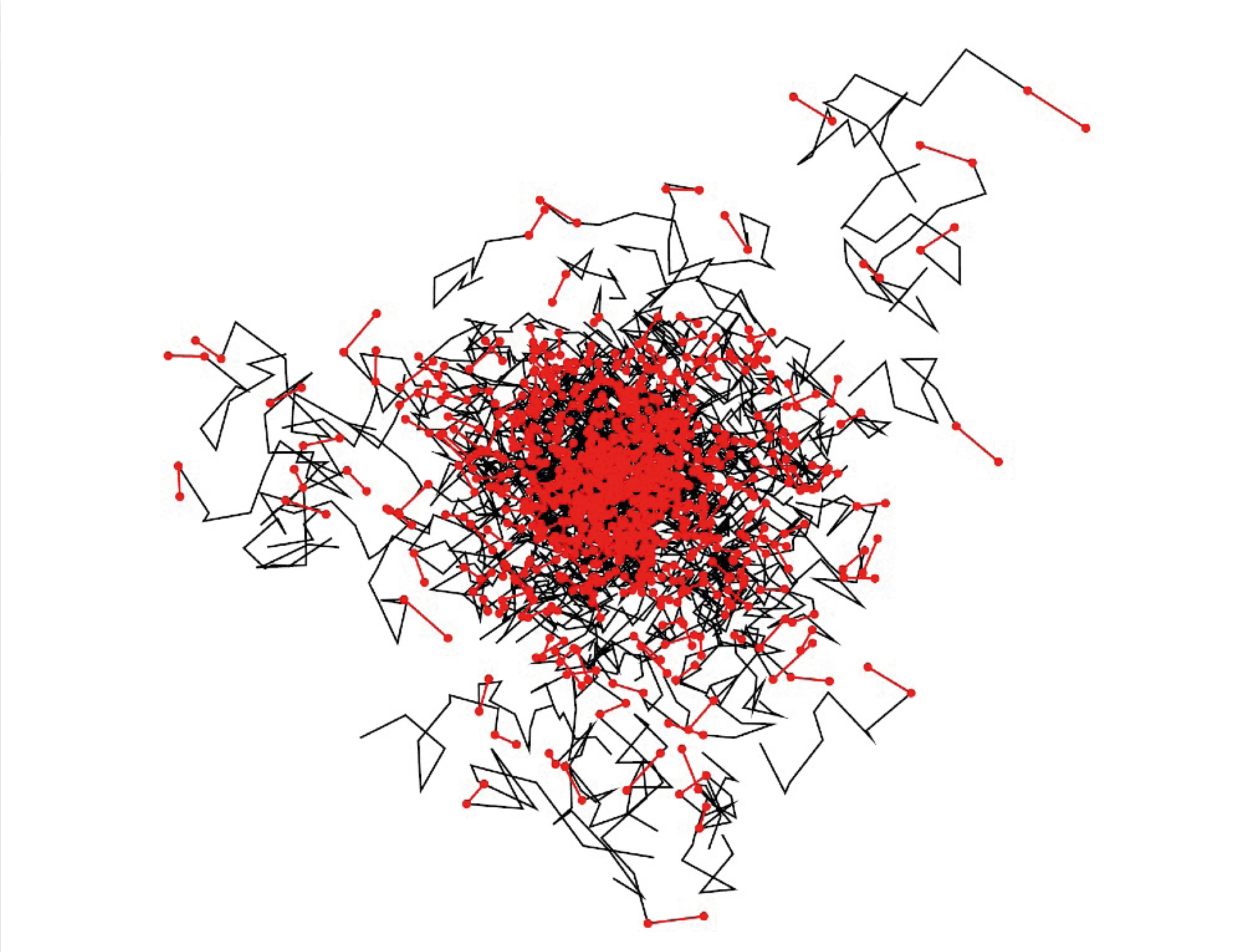

Figure: Random walkers that spread out with a step length that increases as their density decreases. Each line shows the trace of a random walk over the last 10 steps where the last step is colored red.

STAYING CREATIVE IN CORONA TIMES

Like many other research groups, PoreLab members were eager to use expertise to combat Covid-19, cf. our stories on pages 18 and 59. But the "corona-times" have also posed a challenge to the interdisciplinary nature of our work.

Interdisciplinarity is indeed at the core of PoreLab. At first, the center gathered scientists from five departments at NTNU and UiO: the department of Physics, Chemistry, Geoscience & Petroleum, Civil Environmental Engineering, all at NTNU, and the department of Physics at UiO. But over the last years, members from other departments joined us. They are associated members, researchers, PhD candidates, and all are here to work with PoreLab members. They are coming from the departments of Materials Science & Engineering, Energy & Process Engineering, Mechanical & Industrial Engineering at NTNU and the department of Geosciences at UiO. Creating and developing a shared culture, seamless blend across discipline, has been an essential objective for the center. Much effort was done these last years to create space and arenas where people can meet, create, exchange ideas and work together.

Then in early 2020, the COVID-19 virus reaches Europe and Norway. The virus outbreak and following containment measures has had in 2020 and will continue to have in 2021, long-lasting impact on the working lives. One of the first effects we experienced at PoreLab was a drop in the number of visitors, from 64 in 2019 to 14 in 2020 due to the restriction on travels. A second effect was a net decrease in our contribution to conferences as many events planned worldwide in 2020 were either cancelled or postponed. A 3-day PoreLab workshop planned around the Junior forum and a meeting with our Scientific Advisory Board, was first postponed from April to the fall 2020, before being postponed again to a later date in 2021. The reader will notice that this report stands out for its lack of group pictures! Unfortunately. In addition to restricting travel and canceling large events, most of the employees at both NTNU and UiO, and consequently PoreLab, have been encouraged or even mandated to work remotely.

For a center avid for international collaboration and interdisciplinary participation, the containment measures led to serious challenges. In order to continue working together and efficiently, and creating value under these new circumstances, we had to make rapid changes to how we operate. And members in turn, had to navigate new ways of working. Did we succeed to overcome the negative consequences of the containment measures? The use of video conferencing became more intensive in 2020, as illustrated by the picture on this page. As a result, we broadened our pool of lecturers and noticed a boost in attendance. Working from home and online meetings were introduced as the main rule. With a few exceptions, all teaching went online. Teams, Zoom and Skype became the regular tools to conduct interviews for the recruitment of new staff. A rotation in some laboratories was organized to allow experimentalists to carry on. When possible, experimental activities were redefined for master thesis students. Let us point out a few key numbers: we published 69 journal publications in 2020 against 49 in 2019 and 34 in 2018. Hiring plans went as scheduled in 2020. PoreLab developed or collaborated to 16 grant applications early in 2021, a number equivalent to the ones in 2020 and 2019.

But zoom-coffee is never going to taste as good as in a real face-to-face meeting. Despite all our efforts to mitigate the restrictions brought by the pandemic, we will return to the real meetings soon. In them lies the future.

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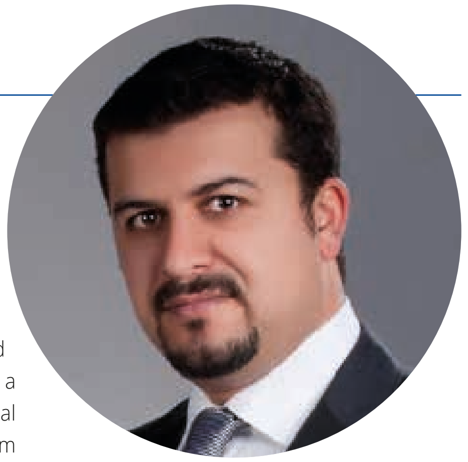


Who are you? What is your background?

My name is Seyed Ali Ghoreishian Amiri and I am from Iran. My academic background is geotechnical engineering. I completed my PhD in computational geomechanics in 2012 in Tehran, Iran. The research topic of my PhD was about developing a computational model for non-isothermal two-phase flow in deformable porous media. I continued my academic career as a researcher at Civil and Environmental Engineering Department, NTNU in 2014. I joined the PoreLab center of excellence in 2018.

How did you come being interested in geotechnics?

I enjoyed studying mechanics and mathematics when I was in high school. Indeed, I was always fascinated by big infrastructures and I knew that they are very much related to mechanics. Thus, I decided to study civil engineering. I found it even more interesting than my initial expectation, because it was very diverse, from material science to solid and fluid mechanics and applied mathematics. Among the different subjects in civil engineering, I felt in love with geotechnics. I saw the complexity of mechanical analysis in a multiphase porous system (a soil mass) in the introductory course of the subject. I became inspired by the professor of the course while he was discussing about contribution of different fields in the daily life of a geotechnical engineer.

What are your activities at PoreLab?

Together with Hao Gao, Davood Dadrasajirloo, Chuangxin Lyu, Gustav Grimstad and Signe Kjelstrup, we are working in a team to revisit some of our geotechnical models in the framework of nonequilibrium thermodynamics. Despite the advantages of the current soil models in geotechnical engineering, some of them do not really follow the basic laws of thermodynamics. This puts serious limitations on the applicability of the models and increases the number of parameters. Considering the geological and environmental conditions in Norway, the main efforts have been made on frozen soils (including the frost heave phenomenon) and soft clays.

In addition to the ongoing activities mentioned above, we are planning to define a new research project on ground stabilization technology. Natural soft clays exhibit a large compressibility and a poor mechanical strength, and thus, present unique problems to engineers in the construction of infrastructures like roads and railroads. The situation is dramatically worse in case of sensitive soils like quick clay. Soil stabilization by deep-mixing technology using a mixture of lime and cement is often used as a method to improve the strength and compressibility characteristic of soft soils. Although the lime-cement mixture is an efficient agent to improve the mechanical behavior of soft clays, their production is carbon intensive; about 1 ton of CO_2 per ton of lime or cement. Considering the soil condition in Norway, the contribution of ground stabilization with lime and cement to the carbon inventory of large infrastructure projects is very high. Many times, it is the largest single contributor. As an example, 7000-ton cement (equivalent) was used to stabilize (approximately) 1 km of quick clay deposit at Klett in the E6 Trondheim – Melhus project. Our plan is to radically change the deep-mixing technology to sustainable alternatives originating from solid wastes and make a circular economy around this technology. In order to achieve this goal, we need an interdisciplinary research with a bottom up modelling approach, across scales and disciplines.

How is the working environment at PoreLab?

The research environment at PoreLab is excellent. It is also unique as it gathers researchers from different disciplines in one place. Porous media is a very broad field of research that involves different disciplines and applications. However, these different disciplines follow their own research activities and rarely communicate to each other. PoreLab provides the opportunity to make this communication possible. Here, we sit together and discuss the problems from different points of view and share our experience in different aspects of the problem. This is extremely important since we will complete each other, and we don't need to reinvent the wheel.

PHD

HURSANAY FYHN

Department of Physics, NTNU

Who are you? What is your background?

My name is Hursanay Fyhn. I belong to the Uyghur ethnic group and spent my childhood in Urumqi, China. My teenage years and onwards have been in Norway. I obtained Master of Science Degree in Physics from NTNU in the summer of 2020. Through my studies at NTNU, I have gained a broad background within physics. This involves experiences within both theoretical, numerical and experimental physics. Currently, I am working as a PhD candidate in Physics at PoreLab, NTNU.

What are you doing now in your research?

My research consists of theoretical and numerical study of two-phase flow in porous media. Right now, I am working with two different topics. The first one is to examine the rheology of two-phase flow in mixed wet porous media. Secondly, I am working with the theoretical description of multiphase flow at the continuum scale.

How is it to be a PhD candidate at PoreLab?

For the longest time, I have had the goal of becoming a theoretical physicist. Professor Alex Hansen has given me the once in a lifetime opportunity to pursue my goal at a fantastic research group in PoreLab. Here I am doing what I desire and enjoy the most, which is to work with the intriguing and complex field of physics.

Surrounded by many great minds in PoreLab, I am constantly encountering new things to learn and making progress in my research. The seminars, presentations and lectures PoreLab organizes create wonderful opportunities to learn more about the porous media research in general and keep us up to date with the advances in the field.

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

I want to continue having a career within the academia. Within 5 years, I will have finished my PhD. Thereafter, with my increased amount of knowledge, experience and achievements, I will continue on a postdoc position. Becoming a professor in physics in the end will be a long journey, albeit a fruitful one. I will make sure to enjoy every step of the way.

SPOTLIGHT ON SIX YOUNG RESEARCHERS

PHD

KRISTIAN STØLEVIK OLSEN

Department of Physics, UiO

Tell us about yourself

I am a theoretical statistical physicist at PoreLab, where I am in the process of finishing my PhD. My research interests lie on the interface of statistical physics, non-equilibrium thermodynamics, soft matter and biology. Before my PhD studies I studied the renormalization group for the quantum Hall effect at the theoretical physics group at the University of Oslo.

How did you come being interested in statistical physics?

I was always intrigued and impressed by the flexibility and range of statistical physics. From a theoretical perspective, the methods used to describe phase transitions in magnetic systems are very similar to the methods used to describe collective animal motion and even how opinions spread through social networks. With such range and scope, one cannot help but wonder whether system that may seem disparate at first really share some underlying commonality. Such universal behavior is a large factor in my interest in statistical physics.

What are you doing now in your research?

My current research focuses on the physics of active matter. While passive systems, like granular media or diffusing particles, are typically driven out of equilibrium through externally imposed forces, active systems have the defining property that the microscopic constituents themselves are driving the system away from equilibrium. In particular, such systems exhibit a wide range of interesting non-equilibrium steady states that are of a self-sustained nature, originating in the fact that energy and angular momentum is supplied to the particles on the microscale. These properties, while simplified through physicist methodology, are central to almost all living matter. Active matter is therefore motivated both biologically and by the potential discovery of new insights into non-equilibrium statistical physics in general.

Why is your research important?

A particularly interesting sub-field of active matter is that of self-propelled particles in confinement. In addition to being important in order to understand a myriad of biological situations where confinement or porous media are ubiquitous, the development of methods for geometrically controlling active particles and making them perform certain tasks is also important for designing bio-inspired technology.

SPOTLIGHT ON SIX YOUNG RESEARCHERS

PHD

MARCO SAUERMOSER

Department of Chemistry, NTNU

Who are you? What is your background?

My name is Marco Sauermoser, and I am originally from Austria. I did my Bachelor of Science and Master of Science in Petroleum Engineering at the Montanuniversität in Leoben, Austria. After my studies, I worked as a project and sales engineer in Austria for one year. Currently, I am doing my PhD at PoreLab, where I am mainly working on two topics. The first one is the development of a non-equilibrium thermodynamics model for PEM fuel cells. The second one is the design of nature-inspired flow field patterns for the use in PEM fuel cells.

Tell us more about your project

PEM fuel cells will be an important energy source for the planned transition to renewable energy and the reduction of greenhouse gas emissions in the future. However, efficiencies are still below technological targets. In order to optimize them, it is crucial to understand what is happening inside a fuel cell. Therefore, I try to model different transport phenomena with so-called non-equilibrium thermo-dynamics. This allows us to plot the profiles for various variables in 1D to get a better understanding of the local effects in the various components. Another topic I am working on is the use of nature-inspired designs for the flow field plate of a PEM fuel cell to improve the performance. I developed new flow field plates, using tree-like flow channels which are inspired by the human lung, and experimentally compare them to an industry-standard

What is your favorite activity in your research?

My most favorite activity is definitely the development of new designs for the flow field plate in a PEM fuel cell. I love to think about how things can be machined or manufactured and applied in the real world, as my background is in engineering. Solving the problem of translating a theory into reality is a challenge I enjoy working on.

How is it to be a PhD at PoreLab?

Being a PhD at PoreLab is a fantastic experi-ence. PoreLab offers an excellent working environment where young researchers, such as myself, can thrive. The biggest advantage is the vast amount of international collabo-rations, but also the interdisciplinary work, allowing you to gain knowledge even outside of your area of expertise.

Annually organized events such as the PoreLab Junior forums help you to keep in touch with all the other junior researchers in Trondheim and Oslo. Additionally, they create the possibility for fruitful discussions with like-minded people.

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

This is always a difficult question to answer because so far, my career had some exciting changes in direction, such as going from Petroleum Engineering to fuel cell technology. One of my passions is to bring an idea based on a developed theory to life and use it in the real world. Therefore, I hope that one day I can apply the knowledge I gained in my PhD in research, either in academia or industry, where I can work both on the theory and experiments.

Rendered model of flow field plate with a tree-like flow pattern for the use in polymer electrolyte membrane fuel cells.

PHD

EIVIND BERING

Department of Physics, NTNU

What is your background?

I studied applied physics and mathematics at NTNU and specialized in applied physics with a focus on computational methods and idealized models for fracture propagation. These days I am in the process of completing my PhD in physics at PoreLab.

Tell us about your research project!

My main research focus has been on computer modeling of polymers under tensile loading, that is, we stretch polymers under various conditions. In my first article, we studied stretching and breaking of PEO (polyethylene oxide/glycol) nanofibres. During this work, it became clear that there were open questions also on the single molecular level. Using the same model as earlier, we estimated the entropy production associated with stretching in different ensembles and provided numerical evidence for previous theoretical work on the thermodynamics of small systems. One of the findings from this study was so interesting that we decided to make it into a separate publication, that was later selected for editor's choice in Nanomaterials. The curious reader is referred to the text "Legendre-Fenchel transforms for small and large thermodynamic systems. The case of polymer stretching" presented elsewhere in this report. The final project in my PhD is a computational study of the dissolution mechanism of cellulose.

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

Cellulose has an incredibly wide range of applications, and a major bottleneck for many of these is to break down the cellulose fibrils so that it can be converted into other useful products. One approach would be to dissolve the bundles into individual chains, which could then be processed more easily. In our molecular dynamic simulations, we agitate the bundles by imposing oscillatory tensile loading in the presence of various solvents. While further investigations are ongoing, we are starting to get a better understanding of the particular conditions that allows for dissolution to occur.

How is it to be a PhD student at PoreLab?

PoreLab is filled with wonderful people and has an atmosphere that really facilitates interaction and collaboration, while still providing a space where one can work uninterruptedly. On top of this you have all these scientific seminars and presentations, allowing you to completely derail from what you were supposed to be doing. It is great.

What are your plans after your PhD?

There are good chances that I will continue working with Astrid de Wijn for six more months after my PhD, this time shifting the focus more towards tribology, the study of friction, lubrication and wear. After this my plans are more open, I am on the lookout for interesting research-related positions either in academia or industry, preferably around Oslo, where I have my family. My biggest passions are sustainability and health, I am hoping to someday link my work with this.

PHD

AILO AASEN

Department of Energy and Process Engineering, NTNU

Who are you? What is your background?

I am Ailo Aasen, 29-year-old from Finmark in Norway. I took a master's degree in physics and mathematics at NTNU, and recently finished my PhD in thermodynamics.

Who is involved in you research?

I've been lucky to have a lot of excellent collaborators in my research. My previous PhD advisor, Øivind Wilhelmsen, continues to be a close collaborator. During my PhD I had successful research stays at Professor Edgar Blokhuis at Leiden University, Professor Erich Müller at Imperial College London, and Professor David Reguera at the University of Barcelona – all of whom were very welcoming. One thing I learned in my PhD was how research stays is an excellent way to expand your academic network.

What are the most important results so far?

A key result is accurate molecular force fields of quantum fluids, which are substances like helium, neon and hydrogen that are in the fluid state at temperatures below 50°K. With molecular force fields, almost any physical property of the fluid can be simulated on a computer. For these substances quantum corrections become crucial to capture their behavior at low temperatures.

We have also obtained some interesting results in nucleation theory, which is the theory of the mechanism underlying phase transitions, and the speed at which they happen.

Water at atmospheric pressure can actually be heated to 300°C without boiling, if it is sufficiently pure and is kept in a clean container. Predicting the onset of boiling is intimately connected to the surface tension of water, and particularly how it changes for the highly curved surfaces of nanoscopic droplets and bubbles. By calculating curvature corrections to this surface tension, we were able to obtain quantitative agreement with experiments for water-alcohol mixtures.

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

The molecular force fields can be used to, for example, study how hydrogen behaves in small pores. This might be interesting to study and optimize hydrogen storage in metal-organic frameworks.

Nucleation theory has several applications.

One example that I am actually working on now is predicting the maximum flow rate of liquid that you can pass through a nozzle, where nucleation theory enters in a decisive way. This is relevant to, for example, modeling safety valves or dimensioning equipment used in refrigeration systems in the process industry.

How is the working environment at PoreLab?

It is an open and social atmosphere with genuinely nice people. I especially like how there is so much interaction between the senior and junior researchers, for example by having a common lunch table with the master's student and PhDs. I also enjoy the table tennis room, which is a great way to take a break between the bouts of research.

HEADING FOR THE FUTURE:
OUR NEW PROJECTS

PoreLab researchers managed to develop not less than 8 new external funding projects by the end of 2019 and in 2020, either as project leader or in collaboration with our partners. We have been very busy this year in hiring new PhDs and PostDocs to manage the new scientific work and the hiring process will continue during the first part of 2021.

INTPART – Non-Newtonian Flow in Porous Media

Project leader: Alex Hansen (NTNU)
Duration: 2020 – 2023

This project aims at the description of the flow of non-Newtonian fluids in porous media, at length scales at which the medium may be viewed as a continuum. The project is particularly focused on the development of differential equations to explain such flows.

To achieve its objectives, this project will derive expertise from the network of international collaborators in Norway (led by Prof. Alex Hansen, PoreLab), in France (led by Dr. Laurent Talon, Laboratoire FAST, CNRS) and in Brazil (led by Prof. José Soares de Andrade Jr., Complex Systems Laboratory, Universidade Federal do Ceará).

INTPART is about creating an international research environment resulting in strong and lasting networks between the researchers. The project will allow MSc students, PhD-students, postdoctoral researchers and experts to have research stays at the different laboratories, in addition to organizing 2 main international workshops. INTPART allows us as well to develop a joint doctoral degree (Cotutelle) between NTNU and U. Paris-Saclay. Federico Lanza joined us in Nov. 2020.

INTPART – COLOSSAL: Collaboration on "Flow across Scales"

Project leader : François Renard (UiO)
Duration : 2020 – 2023

The COLOSSAL project is an interdisciplinary collaboration bringing together researchers from 8 different universities in 4 countries (Brazil, France, USA and Norway). The collaboration includes partners from diverse fields such as: Geosciences (geology, glaciology, geophysics, hydrogeology), Physics (condensed matter physics, fluid mechanics, statistical mechanics), and Civil Engineering (geomechanics). Common to all partners is the necessity to address the problem of flow and deformation in porous and fractured media across a wide range of length and time scales, and the plethora of complex phenomena that follow such flows.

Partners in the project will be stimulated to work across their own field of expertise, bringing the tools they know well to the analysis of problems they may be not too familiar with.

In addition to the organization of workshops and exchange of researchers, the collaboration also includes a series of geological field trips to study active faults in California, fossil faults in Norway and an aquifer near Rennes.

Ultrasound-Mediated Transport of Nanoparticles in Tissue: A Predictive Model

Project leader: Catharina Davies (NTNU)
Duration: 2020-2024

A prerequisite for successful cancer chemotherapy is that the drugs reach all tumor cells. However, less than 1% of injected drugs accumulate in tumors. Encapsulating drugs into nanoparticles (NPs) improves the accumulation of drugs in tumors and reduces the toxic effect, but the tumor uptake of NPs is low and heterogeneous.

The overall aim of this project is to reveal the transport mechanisms for NPs and

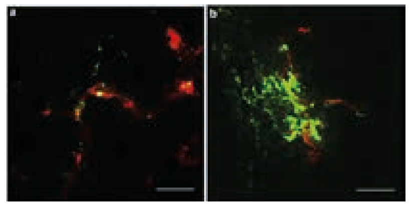


Figure: Distribution of NPs in tumour tissue with no FUS (a), with FUS in the presence of MBs (b). Red=Blood vessels, green= NPs.

drugs in tissues when applying focused ultrasound (FUS), and create a model predicting the FUS-induced distribution of NPs and drugs in tissue. The theoretical work and simulations are to be carried out at PoreLab. The results of the simulations will be continuously challenged and validated through experiments and advanced imaging of NPs in tissues. The project is fully financed by the Research Council of Norway and add two PhD students to our team, Sebastian Price and Caroline Einen, Sebastian being involved in the theory and simulations, and Caroline involved in the experimental work.

PoreFlow: Seeing Multiphase Flow in Porous Media with Neutron Imaging

Project leader: Dag W. Breiby (NTNU)
Duration: 2020 - 2023

PoreFlow is part of the program Nano2021 financed by the RCN and gathers a consortium of scientists in physics, geology/geophysics, neutron imaging, X-ray CT, and the life sciences. Three of Norway's universities are involved, with NTNU being the pivot (with Prof. Breiby and Prof. Mathiesen), together with UiO (Prof. Renard), and USN (Profs. Johannessen and Aasmundtveit). The main objective of the project is to develop neutron imaging as a tool for microscopy of multiphase flow in porous media. The aim is to be able to visualize multiphase flow in porous networks in 3D, and to extract reliable quantitative information about the flow properties. This ability would be a substantial step towards solving several imminent societal challenges, in particular in the geo- and life sciences. One PhD candidate, Fazel Mirzaei, has been hired in the project team.

EXCITE: Electron and X-ray microscopy Community for Structural and Chemical Imaging Techniques for Earth Materials

Project leader: U. of Utrecht, NL
Duration : 2021 - 2024

The X-ray Group at the Department of Physics, NTNU, is part of the EXCITE project that forms a consortium of 15 European Universities and research centers. The project is organized under the European program H2020-INFRAIA-2020. It is coordinated by the University of Utrecht, The Netherlands.

The objective of the EXCITE project is to establish a European research infrastructure with focus on earth-materials science and technology. The consortium consists of 15 European facilities specializing in electron and X-ray microscopy with a collective objective to develop correlative imaging technologies and provide access to world-class facilities, particularly to new and non-expert users. Contacts at NTNU are Dr. Chattopadhyay, Profs. Breiby and Mathiesen, all associated members of PoreLab.

PredictCUI: Prediction of water liquid and vapour migration for mitigating corrosion under insulation

Project leader: Åsmund Ervik (SINTEF)
Duration: 2020 - 2023

This competence building project received funding by the Norwegian Research Council. Here, Prof. Alex Hansen and Prof. Øivind Wilhelmsen from PoreLab will collaborate with researchers from SINTEF Energy Research and the industry to deal with one of the major challenges at the Norwegian Continental Shelf, Corrosion under insulation (CUI). The piping in process plants is frequently insulated. CUI occurs under externally clad or jacketed insulation due to the penetration of water. If not mitigated, CUI leads to structural failure with serious consequences, ranging from leakages to explosions.

The picture above shows how water can be adsorbed by a porous insulation material. In the project, one of the goals is to develop a predictive model for transport of water vapor and liquid through the highly porous insulation material in order to understand where the moisture migrates and where corrosion could potentially occur. One PhD, Hyejeong Cheon, will be educated on this topic. Hyejeong joined PoreLab in August 2020.

Pore Scale Simulations for Wettability Description

Project leader: Carl Fredrik Berg (NTNU)
Duration: 2020 - 2023

This project is part of the program Petromaks2 funded by the Norwegian Research Council.

Wettability has a first order effect on multiphase flow in porous media and is therefore essential for generating flow parameters needed for predictive reservoir modeling. Wettability knowledge is also important for a range of enhanced oil recovery techniques. The primary goal of this research program is to develop a workflow for wettability characterization through pore scale simulations directly on images of the fluid distribution. To achieve this goal, we will extend an existing open-source lattice Boltzmann (LBPM) simulation software with capabilities to model wettability during simulation of multiphase flow in a way that is physical sound and in line with experimental results. These capabilities should include options for modeling of wettability heterogeneities and dynamic wettability alterations.

Partners are: Queen Mary U. of London, UiO and Virginia Tech., USA.

This project will employ 1 PhD candidate and 1 postdoctoral fellow. Both will be joining PoreLab at the beginning of 2021.

ICONIC: Nature's way from molecule to crystal – 3D imaging with coherent X-rays

Project leader: Basab Chattopadhyay (NTNU)
Duration: 2020-2024

ICONIC project is funded by the FRINATEK program of the Norwegian Research Council and assembles an international team of scientists from NTNU (Norway), ULB (Belgium), ESRF (France), IMMM (France) and UiO (Norway). The project consortium includes experts from complementary fields of X-ray physics, imaging, and materials science.

ICONIC aims to use recent breakthroughs in state-of-the-art 3D Coherent X-ray Diffraction Imaging (CXDI) to directly image and understand the biomineralisation pathway from molecule to crystal. The development of dynamic CXDI proposed in ICONIC is implemented in combination with time-resolved Small- and Wide-Angle X-ray Scattering and tested by studying model biominerals. Key objectives of ICONIC involve the implementation of biomimetic crystallization protocols to regulate nucleation and growth using microfluidic sample environments and development of liquid phase CXDI to monitor dynamic processes. The proposed technique of dynamic CXDI is a hot research topic at synchrotron beamlines across the world and it is emerging as one of the flagship experimental methods.

The project will finance 2 PhD candidates and 1 postdoc, all hosted by the X-ray Physics group at NTNU.

LABORATORY FACILITIES

As technology evolves and technical staff increases, there has been significant upgrade in our laboratories. They all continue to offer excellent working conditions and are equipped with state-of-the art equipment and instrumentation.

LABORATORIES AT THE PHYSICS DEPARTMENT AT UIO

PoreLab has four specialized laboratories at UiO, all of which are equipped with a wide set of state-of-art techniques to study the dynamics and structure of flow in 2D and 3D porous media. The laboratories have a full range of high-resolution and high-speed imaging techniques, including two ultrafast *Photron Ultima (SA5 and APX)* cameras with 7000 fps. at a spatial resolution of 1024x1024 pixels and up to 1 million fps. at a reduced resolution.

In 2020, an important part of our activity has been 3D modeling. PoreLab has acquired a *Carbide Shapeoko XL CNC* milling machine and two *Formlabs Form 3 3D* printers that are based on a new Low Force Stereolithography (LFS) technology. This technology allows for 3D printing of very fine, high resolution models in a variety of resin types. The acquisition of these state-of-the-art printers gives us a unique opportunity to quickly design and 3D print synthetic porous materials. Apart of the foray into 3D modeling, we have also engaged in improving the imaging equipment in the labs. The latest addition to our wide array of different cameras are two new high-speed cameras, the *Photron WX100 mini*. These new cameras can take 4 MP images at 1000 fps (FullHD at 2000 fps) and all the way up to 80K fps for lower resolutions.

PoreLab has also a high-resolution *FLIR SC300* infrared camera used for real-time measurements of heat dissipation in fractures, hydro-fractures and porous media flows and a wide variety of *DSLR* cameras and accompanying optics.

Microscale experiments can be imaged via far field microscopy using a *Zeiss Stemi 2000-C* distortion-free stereomicroscope that couples to our high-speed and high-resolution cameras. This is currently in process of being upgraded for enhanced magnification. Flicker-free illumination sources tailored for the different applications (including high-speed microscopy) are also available. PoreLab has recently bought a *Krüss DSA25* drop shape analyzer to perform direct measurements of surface tension, wetting properties and surface free energy, as illustrated in Fig.1.

Additionally, the PoreLab laboratories include a large set of different optical equipment, such as lasers with different intensities and wavelengths, lenses and other optical components, cameras and microscopes for Particle Image Velocimetry. The labs are well equipped to perform homodyne correlation spectroscopy for the measurement of particle velocity fluctuations in fluids, diffusion constants and viscosities. PoreLab developed a 3D optical scanner which makes it possible to measure 3D fluid structures in refraction index matched porous media. This equipment can be used to study dispersion in mono-phase flow and two-phase flow studies.

In addition to this wide variety of state-of-art techniques, our laboratories are also fully equipped with standard fluid mechanics labware, such as capillary viscometers, high-precision scales, pressure and temperature sensors, surface treatment chemicals for the control of wetting properties and general laboratorial glassware. By focusing on both standard and state-of-art techniques in the same physical space, our laboratory benefits from a relatively high degree of independence.

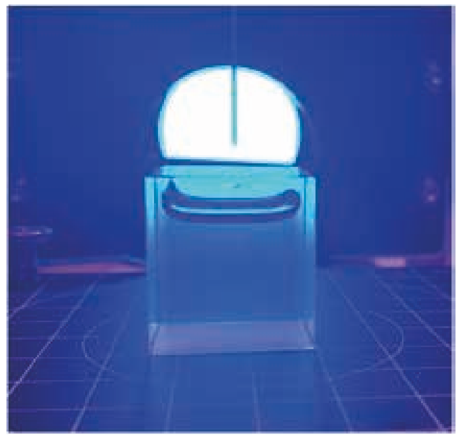


Figure 1: Detail of a drop shape analyzer, an optical tensiometer. This device tracks the shape of a liquid drop hanging from the needle to determine the surface tension between the liquid and the surrounding air.

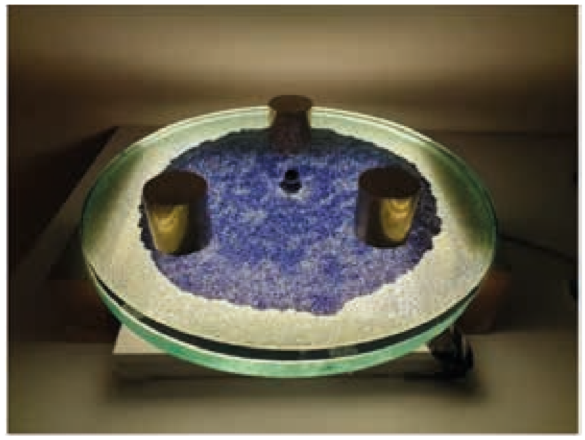


Figure 2: An underground lake. This model shows a portion of liquid trapped inside a transparent quasi-2D porous network. If the soil beneath our feet was transparent, this is somewhat representative of what an aquifer would look like.

SELECTED LABORATORY SETUPS OF THE X-RAY PHYSICS GROUP, DEPARTMENT OF PHYSICS, NTNU

Time-resolved computed tomography for flow in porous media

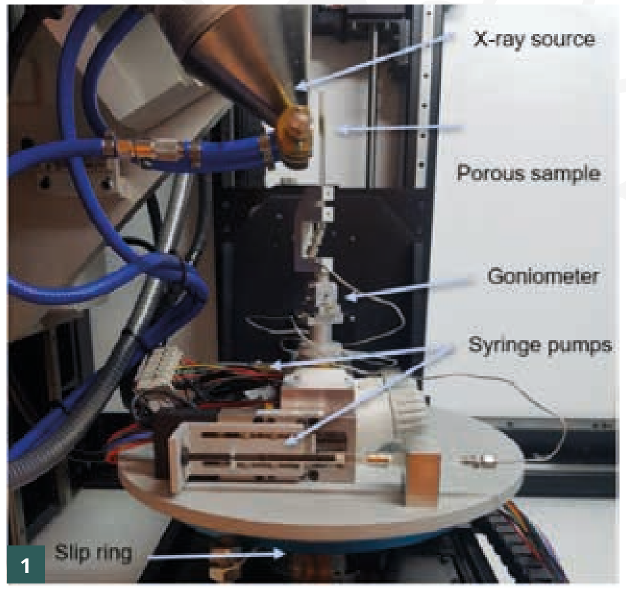
Time-resolved computed tomography (CT) allows studying single- or multiphase flow in porous media. By injecting fluids into a porous sample, while at the same time performing CT measurements, the flow dynamics can be resolved in 3D. To obtain time-resolved 3D images, reconstruction methods requiring only few measured projections are required. To this end, compressed sensing algorithms are used, which enable tomography with a time resolution as good as 30 seconds. The time-resolved 3D maps can be analyzed to provide a better understanding of multi-phase flow in porous media, which is important, for example, for improving carbon capture and storage (CCS) technology.

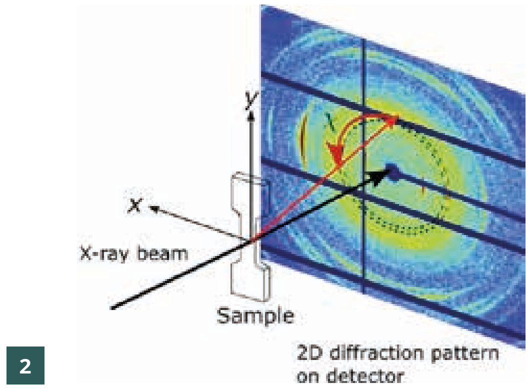
Small- and wide-angle X-ray scattering

X-ray scattering can be used to identify e.g. particle sizes, sample compositions and crystal lattice parameters. Our in-house equipment can be used for both small-angle X-ray scattering (SAXS) and wide-angle X-ray scattering (WAXS), allowing structural features of different sizes to be studied. SAXS/WAXS can be done on several sample types, ranging from particles dispersed in solutions, to centimeter-sized bulk samples. By translating the samples in x and y (see Fig. 2), spatially resolved maps can be obtained, and the two-dimensional (2D) detector, facilitates information about the structure orientation to be captured.

Fourier ptychography microscopy

Fourier ptychography microscopy (FPM) is a recent optical microscopy technique for quantitative imaging of samples with a large field of view. The recovered quantitative amplitude and phase maps can be used to study porous media and biological materials. Figure 3 shows the in-house FPM setup. The sample is sequentially illuminated by partially coherent light-emitting diodes (LEDs) in a 2D array, and the transmitted light is focused by an objective lens onto a camera. As each LED illuminates the sample from a unique direction, the recorded transmission images can be numerically combined to give high-resolution quantitative amplitude and phase images. The quantitative phase images are useful for studying weakly absorbing samples, such as biological tissue, or to study fractures in glass surfaces. Figure 4a shows the reconstructed quantitative phase image from a piglet cartilage histology sample. The quantitative phase information can be used to calculate scattering coefficients (Fig. 4b) giving information about the light transport through the sample.





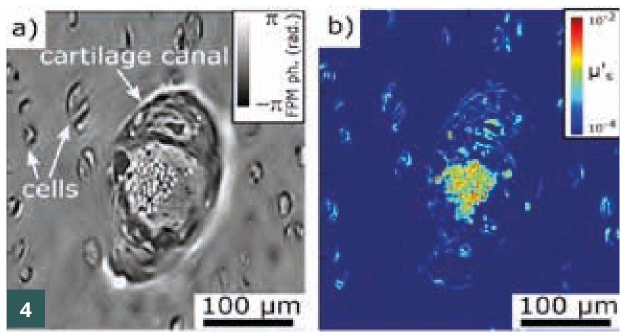


Figure 1 Sample stage for in-house CT-experiments of dynamic flow experiments
Figure 2 Schematic wide-angle diffraction setup for measurements of a polypropylene "dog bone" sample.
Figure 3 The Fourier ptychography setup
Figure 4 a) FPM quantitative phase-image of a growth cartilage sample from a pig. b) The reduced scattering coefficient calculated from the phase image in a).

PORELAB GRADUATE SCHOOL

TRAINING THE NEXT GENERATION OF RESEARCH LEADERS

The COVID-19 pandemic has profoundly disrupted the education system at both NTNU and UiO. Following the recommendations from the Norwegian authorities, the campuses have been partly closed several times during the year and most of the teaching remained digital. At PoreLab, following an uncertain period at the beginning of the year, we had to find a way to navigate through the crisis, and swiftly design responses, to maintain the high quality in the training of our Master and PhD students, as well as postdoctoral researchers. It is indeed our ambition at PoreLab, to maintain an interdisciplinary and international training ground for our juniors, and the ambition has remained even during these corona times.

PoreLab Lecture series and internal seminars

Most of the lectures and seminars at PoreLab were already webinars for Oslo and Trondheim before the virus struck. The use of video conferencing became more intensive in 2020 and led us to broaden our pool of lecturers. We noticed a boost as well in attendance.

Our Wednesday seminars - or PoreLab lecture series - are now almost always given by external lecturers (the list of our guests' lectures can be found in page 68 of this report).

2020 has seen a change in the structure of the PoreLab Journal Club. The Journal Club was an excellent instrument to keep up with the literature in research groups that do not span too widely. But PoreLab is now no longer a research group that does not span too widely. Hence, we decided that a common Journal Club for the entire PoreLab was no longer viable. The new format – called Thursday's talks – aims to promote internal speakers who are given the possibility to present their own activities or give a lecture. It is our goal that each PoreLab member should participate with at least one presentation during the course of the year. The Thursday's talks take place once every two weeks.

Courses at PoreLab

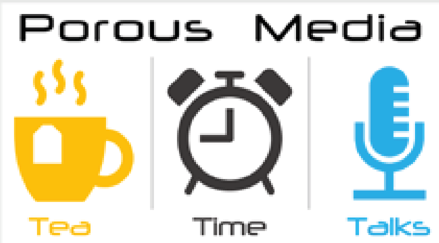
PoreLab offers a range of courses open to all students at our host universities. The lectures are held in PoreLab Oslo and PoreLab Trondheim

The PoreLab course on *"Experimental techniques in porous and complex systems"* (FYS4420/9240) is organized every year during the fall semester by UiO. The course is adapted to PoreLab with a special focus on porous media physics and is offered for both Ph.D. and master students. In 2020, the course contained three projects, including an extended one, that give students introduction to important experimental techniques in the field of condensed matter physics. Each project assignment amounts to 1-2 full working days in the laboratory. Students from NTNU travelled to UiO to attend the laboratory courses. The course lecturer is Prof. Knut Jørgen Måløy, PI at PoreLab.

The PoreLab course on theory and simulation of flows in complex media is offered both at UiO and NTNU with a double title and code: *"Dynamics of complex media"* (FYS4465/FYS9465) at UiO and *"Flows in porous media"* (KJ 8210) at NTNU. The course covers hydrodynamics where capillary and viscous forces play a role. It also covers simulation methods, thermodynamics and statistical physics relevant to porous media. The course content is motivated in terms of ground water flows, biological tissue, hydrocarbon management, fuel cells, electrophoresis, building materials and the quest for the governing equations. The course is adapted to PoreLab with a special focus on porous media physics and is offered for both Ph.D. and master students. The course lecturer is Prof. Eirik G. Flekkøy, PI at PoreLab.

Porous Media Tea Time Talks

The PoreLab lecture series are organized in alternance with the Porous Media Tea Time Talks. The Porous Media Tea Time Talks (#PorousMediaTTT) is a new webinar series, sent via YouTube, created and organized by a team of 5 young porous media researchers including Marcel Moura, researcher at PoreLab, University of Oslo. This event is meant to provide the worldwide porous media community with a practical outlet for the early career scientists to communicate and advertise their recent work and interact with the broader scientific community.

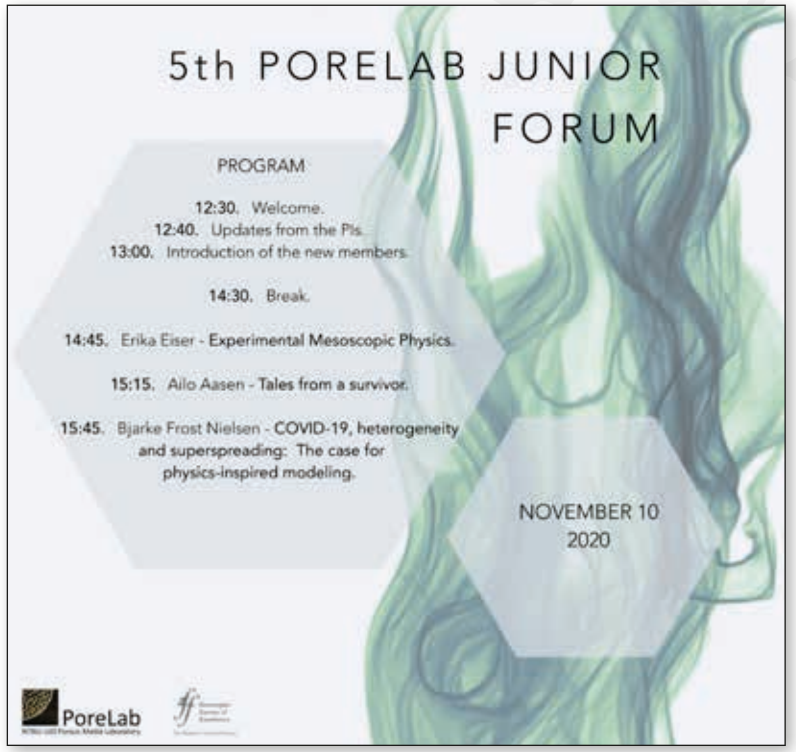


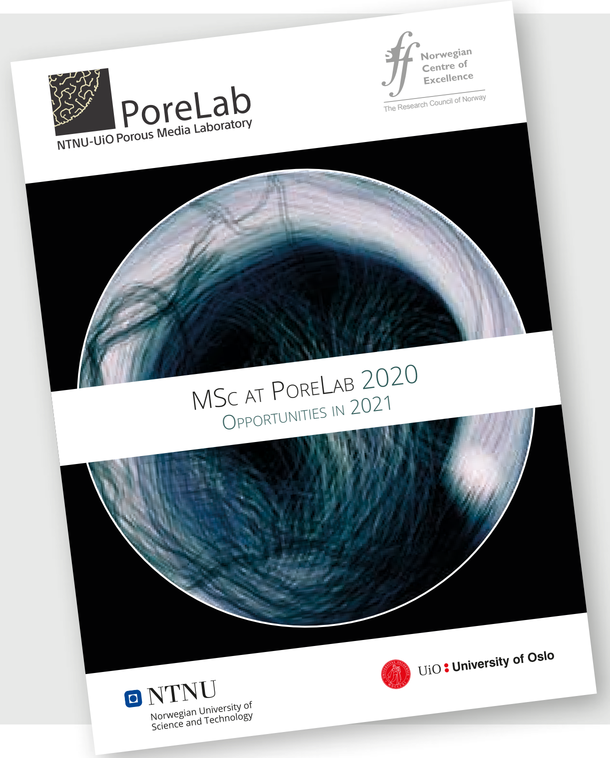
PoreLab Junior Forum

The PoreLab Junior Forum was established and is run by the Juniors themselves. The main goal of this forum is to bring together the group of PhDs, PostDocs and early career researchers of PoreLab with the objective of allowing them to better know each other and share their respective work/scientific interests.

The Junior Forum is particularly important to PoreLab, also because it serves to bind the two hubs in Oslo and Trondheim together. It is important to make it clear, particularly to the newest members, that the center has two physical locations but is indeed a single center. The forum extends possibilities for collaborations and networking.

The Junior Forum meets regularly and normally twice a year. Because a gathering was impossible during the spring 2020 due to the COVID-19 outbreak, the 5th PoreLab Junior Forum was postponed to later in the fall in the hope that the Juniors could meet physically then. But it turned out that need for physical distance was still the requirement and the 5th forum was then organized online, on November 10th, 2020.





PoreLab Master Students 2020

Similar to last year, a dedicated catalogue presents our suite of excellent Master Students. In 2019, we had the great pleasure to welcome at our PoreLab premises five international master students as a result of collaboration with international partners. Unfortunately, and due to the pandemic, this fruitful exchange could not happen in 2020. Nevertheless 24 students chose to work on their master project at PoreLab in 2020. Coming from physics, chemistry, petroleum engineering, structural engineering, civil and environmental engineering, they represent how highly cross-disciplinary is PoreLab. A list of our 2020 Master students and the title of their master thesis can be found page 69 of this report.

The aim of the catalogue is to provide an overview of the projects performed by our Master students in 2020 and inspire new students to join the team. Students can find suggestions for upcoming master projects in this catalogue.

PORELAB AND THE INTERPORE NETWORK

InterPore is the International Society for Porous Media where PoreLab is an institutional member. PoreLab has been a major contributor to InterPore and has added to the development of the central organization. The close cooperation between PoreLab and InterPore Norway led to the organization of annual national workshops in 2017, 2018 and 2019. Unfortunately, and due to the COVID-19 outbreak, the 2020 Norwegian national workshop was cancelled and the rendez-vous postponed to 2021. The close cooperation between PoreLab and InterPore has also led to the creation of the InterPore-PoreLab award for young researchers that is granted annually since 2018. PoreLab junior members are also active in the SAC, the InterPore Student Affairs Committee.

12TH ANNUAL MEETING INTERPORE, 2020

The Annual Meetings of the International Society for Porous Media are the focal events for the diverse porous media community worldwide, bringing together professionals and students to learn about new and exciting advances in porous media. The 12th Annual Meeting, which should have taken place in Qingdao, China, by the end of May 2020, was finally organized online between August 31st and September 3rd, 2020 due to the pandemic. It was InterPore's first virtual Annual Meeting. PoreLab was again this year largely represented at this event.

Professor Signe Kjelstrup, PI at PoreLab, and Professor at the department of Chemistry, NTNU, held a keynote lecture on «*Addressing the water scarcity problem with thermal osmosis*". In her contribution that is meant to help avert the problem of water scarcity, she showed that the theoretical basis of non-equilibrium thermodynamics can help understand the mechanism of thermal osmosis. An exact description can then follow and lend itself to experimental control and optimization.

Professor Signe Kjelstrup

The participation from PoreLab was large with presentations from Master Student Peder Holmqvist, PhD candidates Louison Thorens, Joachim Falck Brodin, Marco Sauermoser, Kim Robert Tekseth, Aldritt Scaria Madathiparambil, Hao Gao, and Astrid F. Gunnarshaug/Lena Spitthoff, researchers Srutarshi Pradhan, Marcel Moura and Santanu Sinha, and associated member to PoreLab Renaud Toussaint. All presentations were recorded before-hand.

INTERPORE-PORELAB AWARD FOR YOUNG RESEARCHERS

A major event during the InterPore annual meetings is the award ceremony that took place on the last day of the 12th Annual Meeting. The InterPore-PoreLab award for young researchers is given in recognition of outstanding contributions to fundamental research in the field of porous media. The research may be theoretical, computational or experimental.

The 3rd InterPore-PoreLab award was given in 2020 to **Dr. Hamed Aslannejad**. Dr. Aslannejad is a post-doc researcher at Utrecht University in the Netherlands. His current research concerns the interaction of water-based inks and paper in inkjet printing. Among other aspects, he investigates the motion of ink pigments into paper layers using pore-scale models. The research results are being used to develop a novel class of inks for high-quality inkjet printing. Dr. Aslannejad received his Ph.D. in January 2019, from Utrecht University with the distinction of cum laude (the highest distinction for a PhD degree in the Netherlands).

Hamed Aslannejad
2020 winner of the InterPore-PoreLab Award for Young Researchers

Award winners get a stipend of 1500 euros per month for up to three months stay at PoreLab, NTNU or UiO. The stipend, which also covers travel and accommodation expenses, is financed by PoreLab.

THE INTERPORE STUDENT AFFAIRS COMMITTEE, SAC

The *InterPore Student Affairs Committee*, or SAC, aims to attract, involve, and include more PhD students and postdoctoral fellows into the InterPore activities, by organizing educational, career and social oriented activities. The SAC activities are open to participants from all career stages, from the early student to the experienced researcher/professor. PoreLab PhD students and researchers are involved in several segments of the SAC. The committee consists exclusively of young researchers and four of them are coming from PoreLab: researcher Marcel Moura, PhD students Olav Galteland, Seunghan Song and Marco Sauermoser.

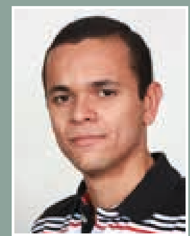
In response to the excellent participation in the previous years, the Student Affairs Committee organized a set of activities during the 2020 InterPore virtual meeting:

- A Career Development Event
  One of the most common struggles for a PhD student is to decide which career path to follow after graduate school. There are numerous opportunities that are potentially open to PhD students, which can take them on very different career paths. A good approach to making an informed decision is listening to experiences and personal views of established professionals. The SAC invited a set of speakers from varied background to share their professional journeys and the important choices they had to make along the way. The Career Development Event was organized on the second day of the 12th Annual Meeting, on September 1st, 2020.

- Scientific Writing Seminars
  This workshop is meant to teach the participants on how to write a successful research paper. Through several real cases, the attendants learnt the common mistakes made when submitting a manuscript for consideration to a specialized journal. This event was held twice during the 2020 InterPore Annual Meeting, on September 1st and 2nd, 2020.

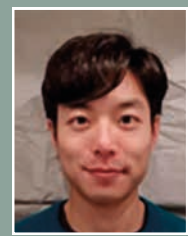
INTERPORE-SAC 2020 BOARD MEMBERS

Chair
Marcel Moura
University of Oslo
Norway

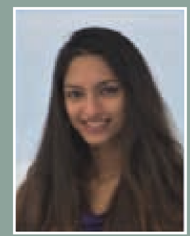


Vice-Chair
Olav Galteland
Norwegian University of Science and Technology
Norway

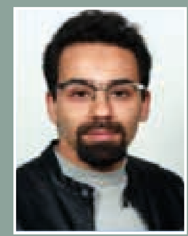
Secretary and Communication Advisor
Seunghan Song
Norwegian University of Science and Technology
Norway



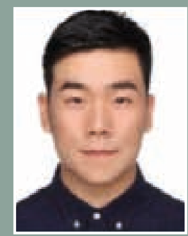
Events Manager and Financial Advisor
Neerja Zambare
Montana State University
USA



Communication Officer
Mohammad Nooraiepour
University of Oslo
Norway



Communication Officer
Cunqi Jia
University of Petroleum
China



Events Director
Marco Sauermoser
Norwegian University of Science and Technology
Norway

PROMOTING PORELAB's SCIENCE TO THE PUBLIC

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. You find in these 2 pages a few stories the PoreLab scientists have participated in during 2020.

26 September 2020 - Vilde Bråten, PhD candidate at PoreLab and at the department of Materials Science and Engineering at NTNU, presented nanothermodynamics on national television

Vilde was placed second in the national finale in the Norwegian Research Grand Prix, where researchers from universities all over the country presented their research in a way where it becomes possible to understand for the general population. Vilde did an amazing job in communicating in a simple manner a complex topic. The contest consisted of one regional finale in Trondheim, Norway, and one National finale. Researchers' Grand Prix is a passionate, fun, eventful competition focused on research communication. Researcher's Grand Prix puts the spotlight on research communication and helps to highlight the breadth of Norwegian research at the PhD level.

10 October 2020 – PoreLab goes pink!

PoreLab participated to the virtual Pink Ribbon Run 2020 both in Trondheim and Oslo. The Pink Ribbon is an international symbol of breast cancer awareness. At PoreLab we work on improving cancer therapy, therefore having a PoreLab-team at the Pink Ribbon Run is spot-on! We work on optimizing focused ultrasound to improve the delivery of drugs and nanoparticles carriers throughout the tumour interstitium. A video of the run is available on YouTube.

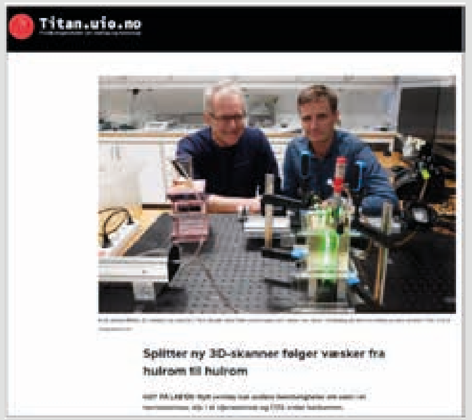
20 February 2020 – PoreLab at VIVO 2020

VIVO is a career day for students in chemistry, biology, and biotechnology at NTNU. PoreLab was represented by PhD candidate Kim Kristiansen and Master student Peder Holmqvist. *"Our purpose there was primarily to have the thermodynamics group visible as a possible choice for doing a master or a PhD with us. With our new direction towards biological systems through the biophysics department, I argue that PoreLab also becomes more relevant in the future for microbiologists and medicinal chemists"*, says Kim Kristiansen.

'Oumuamua – is the first known interstellar object detected passing through the solar system. Since its observation in 2017, 'Oumuamua's origin remains a subject of much debate. Eirik G. Flekkøy and Renaud Toussaint from PoreLab, and astronomer Jane Luu, developed a theory to explain how 'Oumuamua could have a porous structure that makes it so light that even sunbeams can push it around. PoreLab coined the nickname "cosmic dust bunny" for this unidentified object. The studies by Flekkøy et al. have so far been reported in around 100 popular science journals, both in Norway and around the globe, including Pour la Science, Aftenposten, Fox News, Popular Science and the Norwegian magazine Fra fysikkens verden.

18 May 2020 – PoreLab researcher Marcel Moura on live TV in Brazil. It was a special program about the anniversary of Marcel's hometown Caruaru. Marcel talked about PoreLab's activities and showed a video of the flying chain experiment. He explained as well why air flow through a facemask is indeed a problem of flow in porous medium.

8 May 2020 – Brand new 3D-scanner follows fluid from pore to pore – Prof. Knut Jørgen Måløy and PhD candidate Joachim Falck Brodin talk about the new 3D scanner, a tool that can reveal secrets about water in water reservoir, oil in oil reservoir and CO_2 under the seabed.



7 May 2020 – Exit-Strategy – Kristian S. Olsen and Gaute Linga, Ph candidate and postdoctoral fellow at PoreLab, published an article in the Danish newspaper Weekendavisen, "Vejen til Frihed" ("The Road to Freedom"), about possible strategies for Denmark to handle reopening of the community after the first lockdown.

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!

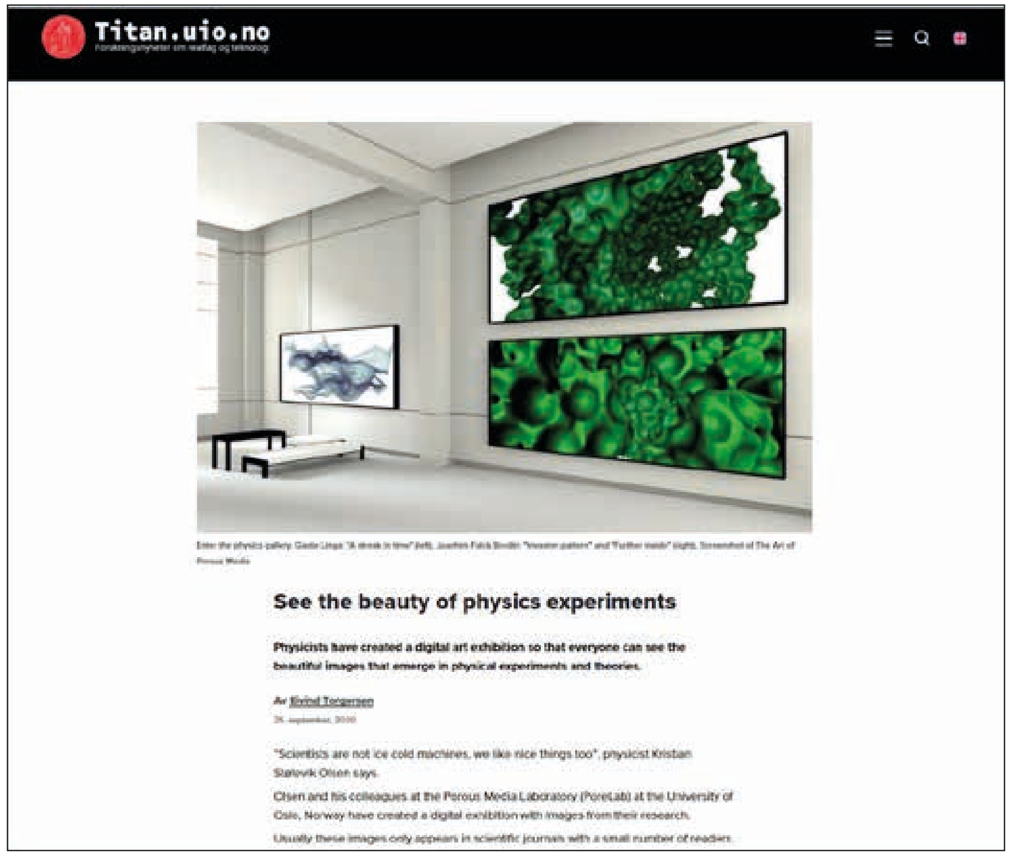
SCIENCE IS ART, ART IS SCIENCE

– A VIRTUAL ART EXHIBITION

Beauty can be found in the most ordinary of things. Some of the greatest scientists that ever lived endorse this viewpoint. Richard Feynman, in one of his many strokes of pure genius boldly spoke about the several layers of beauty that he – a curious observer of reality – could see in a flower. His "Ode to a Flower" is filled to the brim with the scientific and aesthetic joy. When scientists turn to art, they do not turn away from the study of reality. Albert Einstein himself once said "The greatest scientists are artists as well".

At PoreLab, the Porous Media Laboratory, we are lucky enough to work in a field in which one really does not need to look too much to find aesthetically pleasing images. Everything is beautiful if you look closely and carefully enough. Over the years we have in PoreLab come across a tremendous collection of striking visual patterns, stunning compositions of matter and motion brought to us by nature itself. So, it was with great pleasure that PoreLab in 2020 opened an exhibition with some of the most beautiful moments. The original plan was a physical exhibition, but the pandemic forced us to think differently, and the idea of a virtual gallery came to life. Each of the pieces in the virtual gallery is the result of the dedicated work of PoreLab's researchers in trying to better understand the world around us.

The virtual exhibition has been a success and been viewed by many so far. It has been reported in Titan, in InterPore's newsletter, and artists have even been contacted by people interested in buying their art! Even though the pictures carry a good amount of scientific information, they are presented in the gallery quite simply as beautiful collages of shape and color. And maybe are the most intriguing pieces of art also the most intriguing pieces of science?

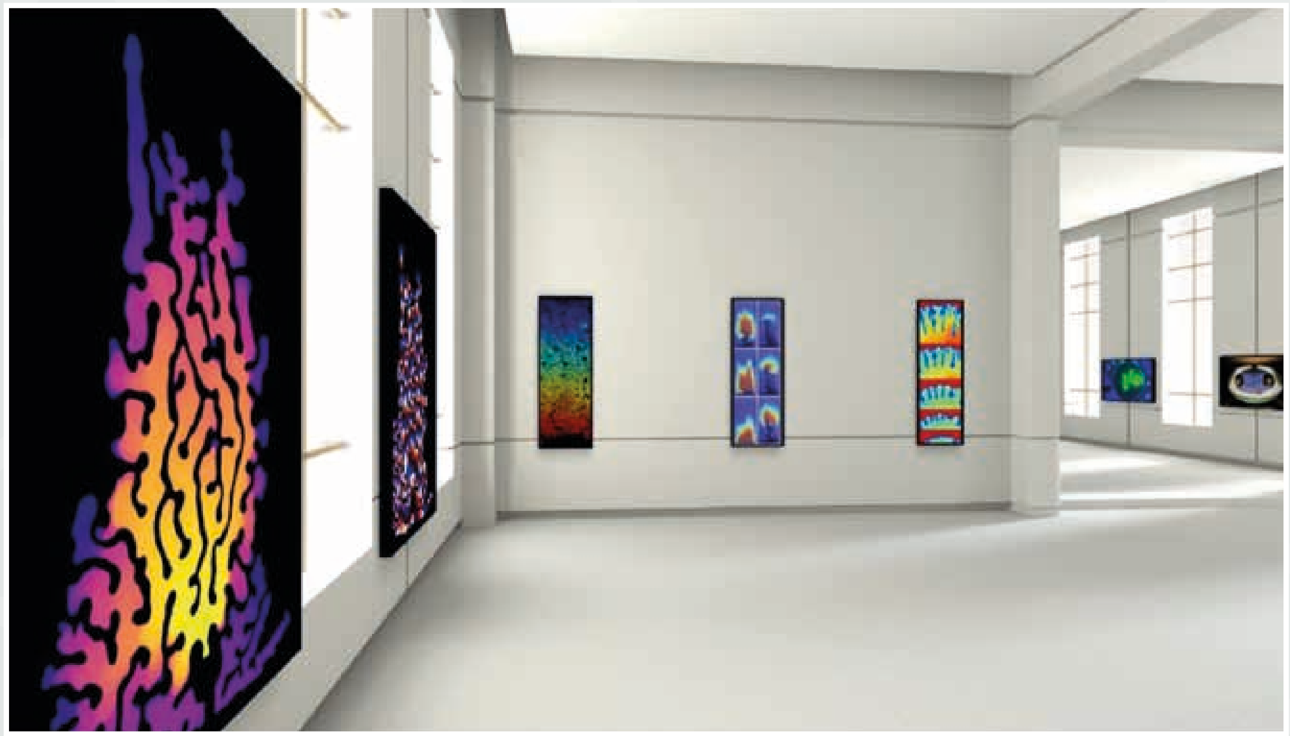

See the beauty of physics experiments

Physicists have created a digital art exhibition so that everyone can see the beautiful images that emerge in physical experiments and theories.

"Scientists are not ice cold machines, we like nice things too", physicist Kristian Stølevik Olsen says.

Olsen and his colleagues at the Porous Media Laboratory (PoreLab) at the University of Oslo, Norway have created a digital exhibition with images from their research.

Usually these images only appears in scientific journals with a small number of readers.



BOOKS AND NEW RELEASES

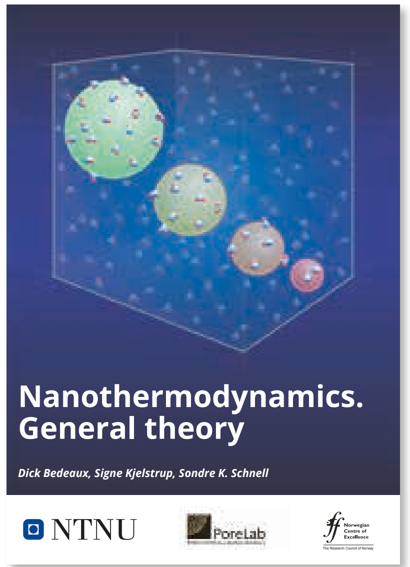
Publishing and co-authoring have been a priority at PoreLab since the start of the center.
We are happy to present below a selection of new releases.

This new release from Professors Signe Kjelstrup and Dick Bedeaux from PoreLab NTNU came out in August 2020.

Building on the success of the first edition, this expanded second edition features two new chapters on the effect of curvature on interface transfer coefficients and the catalyst surface temperature.

This book utilizes non-equilibrium thermodynamics to describe transport in complex, heterogeneous media. There are large coupling effects between transport of heat, mass, charge, and chemical reactions at surfaces, and it is important to know how one should properly integrate across systems where different phases are in contact. This book is the first to give a prescription of how to set up flux equations for transports across heterogeneous systems. Readership: Graduate students, researchers, lecturers and professionals in physics, nanoscience and surface science.

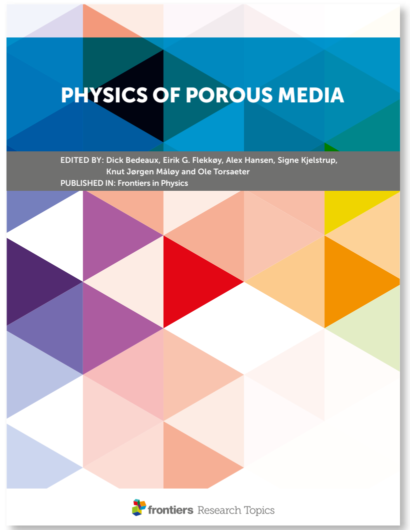
The publisher is World Scientific.



The world of small systems challenges standard knowledge. Can we use classical thermodynamics? The answer to that is no. The book discusses how Terrell Hill developed the field of nanothermodynamics, which applies perfectly well also to small systems, to address this problem. He introduced an ensemble of replicas of the small system and showed that the energy needed to add such a replica plays a crucial element in the description of the small system contribution.

This new book from Professor Signe Kjelstrup, Professor Dick Bedeaux and Associate Professor Sondre Kvalvåg Schnell from PoreLab NTNU was released in May 2020.

The publisher is PoreLab.

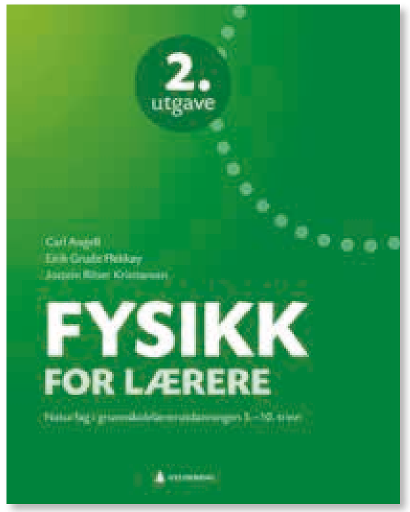


The Principal Investigators at PoreLab gathered to release **"Physics of Porous Media"** in March 2020.

The topic editors are: Professors Dick Bedeaux, Alex Hansen, Signe Kjelstrup, Ole Torsæter from NTNU, and Professors Eirik G. Flekkøy and Knut Jørgen Måløy from UiO.

This Research Topic aims to present a snapshot of the state of the art in some of the domains that constitute the physics of porous media. The physics of porous media is of course far too wide to make it possible to give a comprehensive picture of the field. However, the authors present the use of porous media in a number of contexts such as fuel cells, frost heave, etc. besides presenting fundamental theories and experimental results. Interdisciplinarity is a key word.

The publisher is Frontiers in Physics.

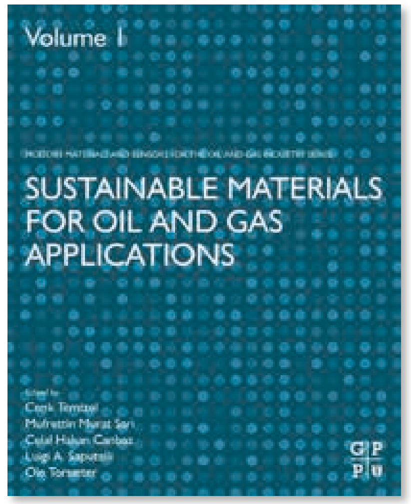


How far are the stars? Why can insects, but not us, walk on water? Are snow crystals exactly alike? Are there colors outside of those we see in the rainbow? Could the giants in Gulliver's journey rise on two legs and walk upright?

Children and even adults could ask the questions. In this book, the authors provide answers as concrete as possible, to arouse the joy of knowledge and increased curiosity among the readers. "Fysikk for Lærere" is written for primary and secondary school teachers from 5th to 10th grades.

The authors are Carl Angell, Eirik G. Flekkøy and Jostein R. Kristiansen. Eirik G. Flekkøy is professor at PoreLab UiO.

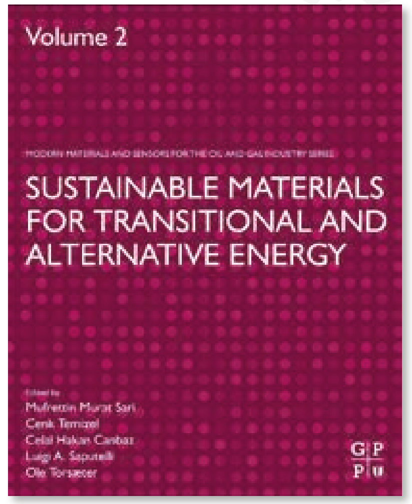
The book – in Norwegian – was released in January 2021 and the publisher is Gyldendal.



Congratulations to Ole Torsæter, Professor at PoreLab NTNU, and his colleagues for the release of two Advanced Materials books in February 2021:

1. ***Sustainable Materials for Oil and Gas Applications,***
2. ***Sustainable Materials for Transitional and Alternative Energy,***

Sustainable Materials for Oil and Gas Applications, a new release in the Advanced Materials and Sensors for the Oil and Gas Industry series, comprises a list of processes across the upstream and downstream sectors of the industry and the latest research on advanced nanomaterials. Topics include enhanced oil recovery mechanisms of nanofluids, health and safety features related to nanoparticle handling, and advanced materials for produced water treatments. Supplied from contributing experts in both academic and corporate backgrounds, the reference contains developments, applications, advantages and challenges. Located in one convenient resource, the book addresses real solutions as oil and gas companies try to lower emissions.



Sustainable Materials for Transitional and Alternative Energy, a new release in the Advanced Materials and Sensors for the Oil and Gas Industry series, comprises a list of processes across the energy industry coupled with the latest research involving advanced nanomaterials. Topics include green-based nanomaterials towards carbon capture, the importance of coal gasification in terms of fossil fuels and advanced materials utilized for fuel cells. Supplied from contributing experts in both academic and corporate backgrounds, the reference contains a precise balance on the developments, applications, advantages and challenges remaining.

The book addresses real solutions as energy companies continue to deliver energy needs while lowering emissions. The oil and gas industry are shifting and implementing innovative ways to produce energy in an environmentally friendly way. One approach involves solutions developed using advanced materials and nanotechnology. Nanomaterials are delivering new alternatives for engineers making this a timely product for today's market.

COMPLETED PHDs IN 2020

NAME	DEPARTMENT	DATE	THESIS	SUPERVISORS
Ailo Aasen	Department of Energy and Process Engineering, NTNU	27 March	*Bulk and interfacial thermodynamics of mixtures: From aqueous systems to ultracryogenic fluids*	Øivind Wilhelmsen and Morten Hammer
Alberto Bila	Department of Geoscience and Petroleum, NTNU	20 May	*Experimental investigation of surface-functionalized silica nanoparticles for enhanced oil recovery*	Ole Torsæter and Jan Åge Stensen
Magnus Aashammer Gjennestad	Department of Physics, NTNU	24 November	*Modelling of two-phase equilibrium, stability and steady-state flow in porous media*	Alex Hansen, Signe Kjelstrup and Øivind Wilhelmsen

GUEST RESEARCHERS AT PORELAB

The Covid-19 virus outbreak and following restrictions on travels led to a drop in the number of visitors, from 64 in 2019 to 14 in 2020.

NAME	POSITION	AFFILIATION	PERIOD
Danial Arab	PhD candidate	Department of chemical and petroleum engineering, U. of Calgary, Canada	02.09.19 – 31.01.20
Antoine Dop	Master student	Ecole Normale Supérieure de Lyon, France	01.10.19 – 30.06.20
Xidong Wang	PhD candidate	School of Geosciences, China University of Petroleum, Qingdao, China	28.10.19 – 30.10.20
Tom Bultreys	Researcher	Department of Geology, Ghent University, Belgium	12.01.20 -17.01.20
Santanu Sinha	Researcher	Beijing Computational Science Research Center, Beijing, China	15.02.20 – 15.02.21
Joachim Mathiesen	Professor	Niels Bohr Institute, Denmark	24.02.20 – 26.02.20
Tanguy Le Borgne	Professor	Université de Rennes, France	24.02.20 – 26.02.20
Jane Luu	Professor	Draper Laboratory, USA	29.02.20 – 07.03.20
Andrés Arango-Restrepo	PhD candidate	Department of Physics Condensed Matters, U. of Barcelona, Spain	02.03.20 – 29.07.20
Miguel Rubi	Professor	Department of Physics Condensed Matters, U. of Barcelona, Spain	04.03.20 – 02.07.20
Edgar Javier Rueda Rueda	Master student	LABORE/CEPETRO/UNICAMP Universidade Estadual de Campinas, São Paulo, Brazil	24.04.20 – 10.05.20
Farad Sagala	PhD candidate	Dept. of Chemical and Petroleum Engineering, University of Calgary, Canada	30.04.20 – 30.07.20
Zbigniew Rozynek	Researcher	Adam Mickiewicz University, Poland	01.09.20 -
Lifei Yan	PhD candidate	Department of Geosciences of Utrecht University, The Netherlands	01.11.20 – 19.12.20

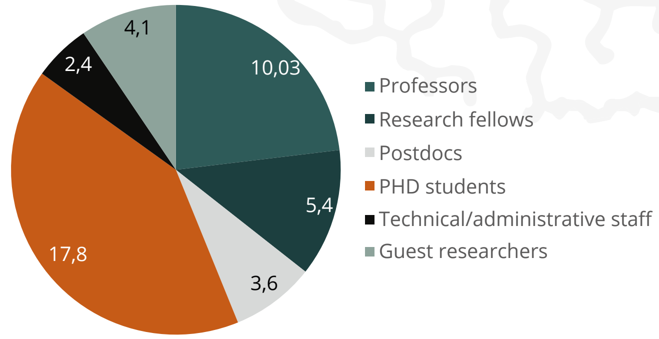
FUNDING IN 2020

FUNDING (1000 NOK)	AMOUNT	PERCENTAGE
The Research Council	15 347	45 %
NTNU	11 424	34 %
University of Oslo	7 317	21 %
TOTAL	34 088	100 %

FACTS AND FIGURES 2020

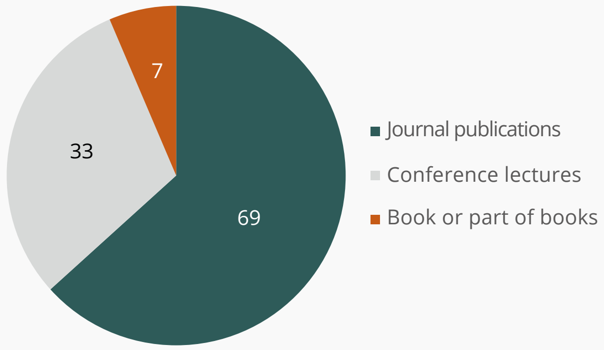
PORELAB STAFF categorized by position

PoreLab staff equals 43,4 man-years in 2020.
The pie chart on the right shows the categorization of our Staff by position.



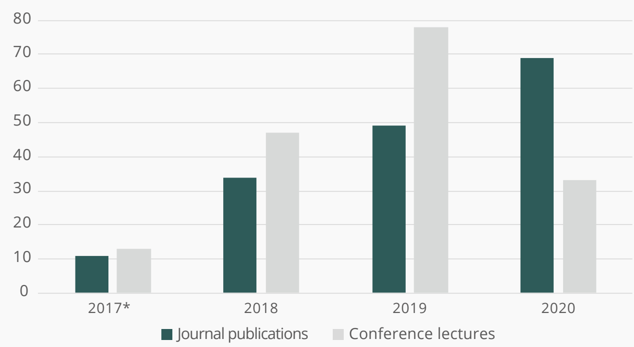
PUBLICATIONS in 2020

- 69 Journal publications
- 33 Conference lectures and academic presentations
- 7 book or part of book



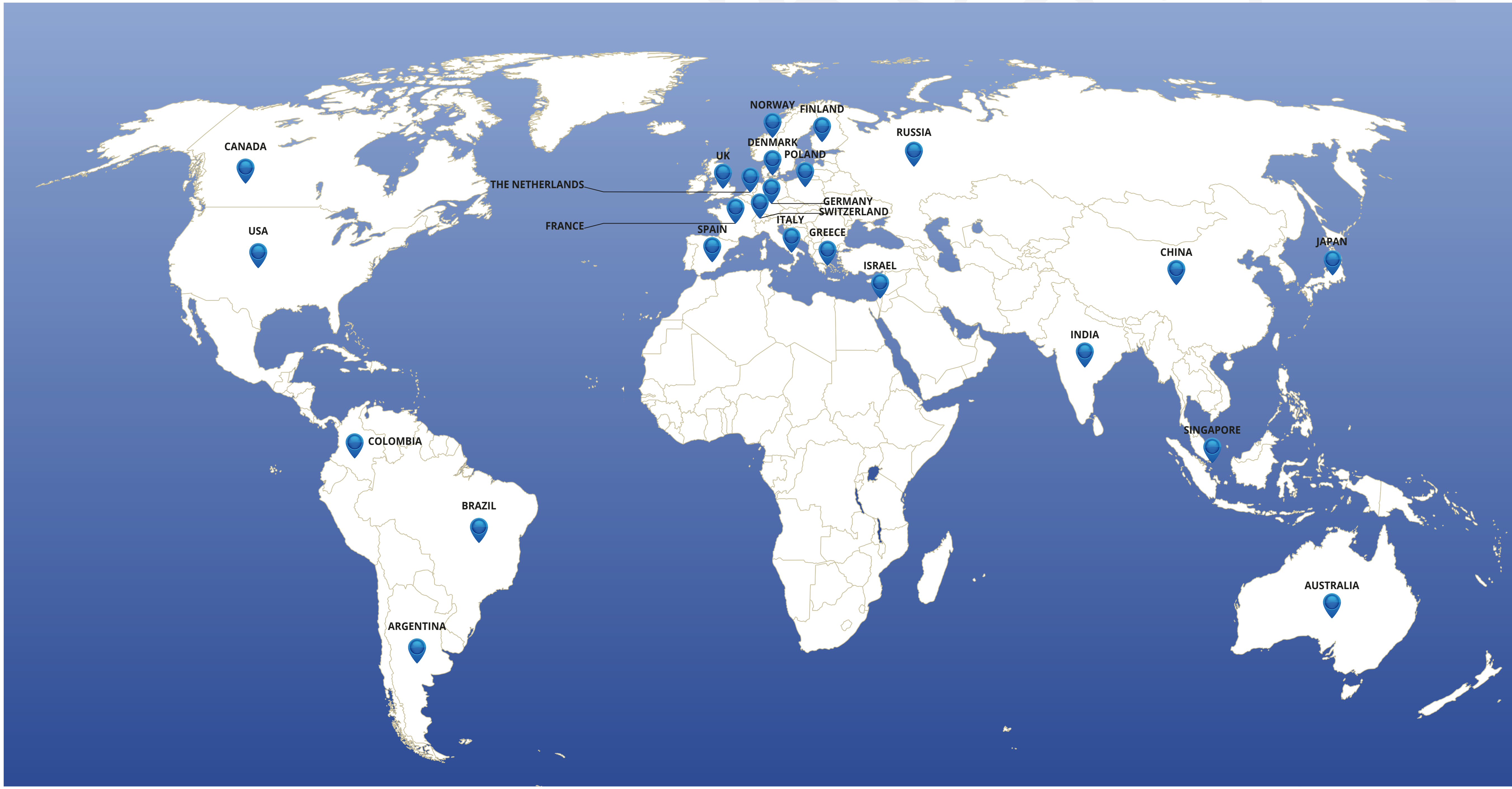
Research efforts have been increasing every year since the start of PoreLab as reflected in the graph for journal publications to the right.

Although 2020 has seen a decrease in our contribution to conferences compared to the previous years. This result was expected since many conferences planned in 2020 were either cancelled or postponed due to the virus outbreak and restrictions on travel. Some events such as InterPore 2020 managed to re-organize itself as a digital conference.



*Publications over 4,5 months since PoreLab started on 15.08.201

NATIONAL AND INTERNATIONAL COLLABORATION



USA
Sarah L. Codd: *College of Engineering, Montana State University, Bozeman*
Daniel H. Rothman: *Department of Earth, Atmospheric, and Planetary Sciences, Massachussets Institute of Technology*
Jane Luu: *Draper Laboratory, Massachusetts*
Steven Pride: *Energy Geosciences Division, Lawrence Berkeley National Lab, Berkeley, California*
James McClure: *Virginia Tech*
H. George E. Hentschel: *Department of Physics, Emory University, Atlanta*

CANADA
Steven Bryant, Marie Macquet, Somayeh Goodarzi, Ali Telmadarreie, Ellen Liu, Carter Jordan Dziuba, Ian Gates: *University of Calgary*
Francis Mujica Urbina: *Department of Earth Sciences, Memorial University of Newfoundland*

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.: *Universidade Federal do Ceara*

NORWAY
Jan Øystein Haavig Bakke: *Schlumberger Stavanger*
Øivind Wilhelmsen, Asbjørn Solheim, Olaf Trygve Berglihn, Torleif Holt, Erik Lindeberg, Dag Wessel-Berg, Vegard Brøtan: *SINTEF*
Preben Vie, Geir Helgesen, Kenneth Knudsen: *Institute for Energy Technology, IFE*
Mario Acquarone, Lars Folkow: *The Arctic University of Norway*
Bernt O. Hilmo: *Asplan Viak AS*
Ellinor B. Heggset, Kristin Syverud: *RISE PFI AS*
Harald Berland, Olav Aursjø: *NORCE Norwegian Research center AS*
Thomas Ramstad: *Equinor Research Center, Trondheim*

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

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

THE NETHERLANDS
Thijs J.H. Vlugt, Ger J.M. Koper, Claire Chassagne, Othon Moultos, Mate Erdos: *Delft University of Technology*
Majid Hassanizadeh: *Multiscale Porous Media Laboratory, Utrecht University*
Edgar M. Blokhuis: *University of Leiden*

UK
Bjørnar Sandnes: *Energy Safety Research Institute, College of Engineering, Swansea University*
Fernando Bresme: *Department of Chemistry, Imperial College London*
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Laurent Talon: *Laboratoire FAST, Université de Paris-Saclay, Orsay*
Renaud Toussaint, Monem Ayaz: *Institut de Physique du Globe 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*
Osvanny Ramos: *Department of Physics, Claude Bernard University, Lyon*
François Renard: *Institut de Physique du Globe de Strasbourg, CNRS/University of Strasbourg*

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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
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Gian Paolo Beretta: *Politecnico di Milano*

GREECE
Marios Valavanides: *Dept. of Civil Engineering, University of West Attica*

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K. Khobaib, R. Rozynek: I*nstitute of Acoustics, Faculty of Physics, Adam Mickiewicz University, Poznań*
Natalya Kizilova: *Institute of Aeronautics and applied Mechanics, Warsaw University of Technology*
Wojciech Debski: *Department of Theoretical Geophysics, Institute of Geophysics Polish Academy of Sciences, Warszawa*

FINLAND
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RUSSIA
Sergey Abaimov: *Skolkovo Institute of Science and Technology*

ISRAEL
Ran Holtzman: *Hebrew University of Jerusalem*
Itamar Procaccia: *Weizmann Institute, Rehovot*

INDIA
Purusattam Ray: *Institute of Mathematical Sciences, Chennai*
Chakrabarti Bikas K.: *Saha Institute of Nuclear Physics, Kolkata*

CHINA
Hai-Qing Lin: *Beijing Computational Science Research Center*
Jingya Zhang: *College of Geosciences, China University of Petroleum, Beijing*
Ye Xu: *School of Mechanical Engineering and Automation, Beihang University, Beijing*
Fulong Ning: *China University of Geosciences Wuhan*
Xin Wang: *Institute of Oceanography Instrumentation, Shandong Academy of Sciences, Qingdao*

JAPAN
Pieter Krüger: *Graduate School of Science Pieter Krüger: Graduate School of Science and Engineering, Molecular Chirality Research Center, Chiba University, Chiba*
Tamio Ikeshoji: National Institute of Advanced Industrial Science and Technology, AIST
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: I*nstitute 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: *UNSW, School of Petroleum Engineering, Sydney*

GUEST TALKS

Since PoreLab was born, we had the great privilege to host a number of guest researchers for shorter or extended periods. In 2019 we welcomed not less than 64 visitors at PoreLab Trondheim and Oslo. Unfortunately, and due to the COVID-19 outbreak, the number of visitors fell drastically in 2020. Nevertheless, it is important for us to maintain communication and the exchange of ideas under these restricted travel conditions. As a result, and after a somehow floppy first months, we caught up quickly, used video conferencing more intensively and broaden our pool of lecturers. Here is below the list of our guests' lectures for 2020.

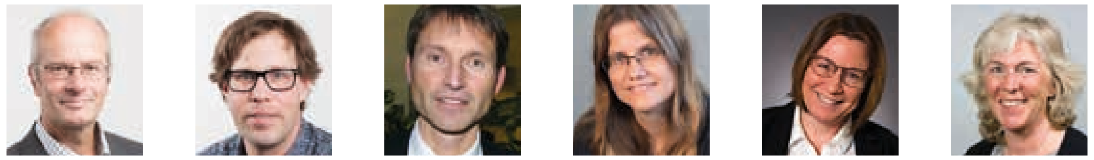
DATE	NAME, AFFILIATION	TITLE
Jan. 13	Tom Bultreys, winner of the InterPore-PoreLab award 2019, Department of Geology, Ghent University, Belgium	*Integrating pore-scale simulations and experiments of multi-phase flow in rocks*
April 1	Dhrubaditya Mitra, NORDITA, Stockholm U. and KTH, Stockholm, Sweden	*Hydrodynamics with balls : Rheology and transport*
April 7	Renaud Toussaint, directeur de recherche, Inst. de Physique du globe de Strasbourg, France	*#Stay home: How and why? R0 stories in SIR models, basics and confrontation to epidemiology statistics in the "Far-East" region (France)*
May 13	Fabian Barras, postdoctoral fellow at Njord Center, UiO, Norway	*There is a crack in everything, that's how the light gets in. But what about fluid?*
May 28	Ruben Juanes, Professor, Dep. of Civil and Environmental Engineering, MIT, USA	*Impact of wettability on multiphase flows and granular mechanics: experiments, modeling and theory*
June 17	Andrès Arango-Restrepo, PhD candidate, Dept. de Física de la Matéria Condensada, U. de Barcelona, Spain	*Entropic transport for the delivery of nanoparticles"*
June 25	Ann Muggeridge, Professor, Imperial College London, UK	*Viscous fingering – What is it and does it matter?*
Aug. 18	Daniel D. Jensen and Lars-Oliver Kautschor, TESCAN	*TESCAN DynaTOM – New opportunities in dynamic 3D X-ray imaging in the lab*
Sept. 9	Federico Municchi, Research fellow in Applied Mathematics, U. of Nottingham, UK	*Multiscale modelling of transport in heterogeneous reactive media: conjugate transfer and surface reactions*
Sept. 16	NIRS, NTNU International Researcher Support NTNU, Trondheim, Norway	*NIRS – what do we offer?*
Sept. 21	Ass. Prof. Jan Torgersen and Post-doc Robert Bock from the Department of Mechanical and Industrial Engineering, NTNU, Norway	*Parametric optimization and high-resolution fabrication of freeform Gas Diffusion Layers*
Sept. 23	Matthias Ihme, Professor, Center for Turbulence, Stanford U., USA	*Heterogeneous Combustion in Porous Media as Ultra-low Emission Combustion Concept"*
Sept. 30	Thomas Ramstad, Principal researcher at Equinor, Trondheim, Norway	*The LBPM software package for simulating multiphase flow on digital images of porous rocks*
Oct. 7	Martin Blunt, Professor, Dept. Earth Science & Engineering at Imperial College London, UK	*Flow in porous materials: a tale of X-rays, minimal surfaces and wettability*
Oct. 14	Joaquim Jimenez Martinez, Dept. Water Resources and Drinking Water, ETH Zurich, Switzerland	*Mixing control on fluid-fluid and fluid-solid chemical reactions in multiphase systems*
Oct. 21	Steffen Berg, Shell Global Solutions International B.V., Amsterdam, The Netherlands	*Upscaling Multiphase Flow from Pore to Darcy Scale – From a geometric state function of capillarity to a generalized description of wetting*
Oct. 28	Ravi A. Patel, Karlsruhe Institute of technology, Karlsruhe, Germany	*Modelling complex degradation processes in concrete structures across material scales*
Nov. 11	Hadi Hajibeygi, Associate Professor TU Delft, the Netherlands	*ADMIRE: a multiscale framework for subsurface energy storage in (fractured) geological formations*
Nov. 18	Sophie Roman, Ass. Professor, ISTO (Institut des Sciences de la Terre d'Orléans), France	*Multiphase Flow and Reactive Transport in Porous Media: an Experimental Microfluidic Approach*
Nov. 25	Behzad Ghanbarian, Ass. Professor of engineering geology, Kansas state U., USA	*Single- and two-phase rock typing*
Nov. 26	Kamaljit Singh, Professor at Heriot-Watt U., UK	*Imaging of flow in porous materials: from rocks to termite nests*
Dec. 2	Cyprien Soulaine, Associate scientist at CNRS, France	*A (real) multi-scale solver for two-phase flow: a micro-continuum approach*
Dec. 9	Nikolaos Prasianakis, Group leader, Paul Scherrer Institute, Switzerland	*Process coupling and upscaling of effective transport parameters in porous media: Towards Digital Twins*
Dec. 16	Cino Viggani, Professor of geomechanics, U. of Grenoble, France	*Recent developments in laboratory testing of geomaterials with emphasis on imaging processes*
Dec. 17	Professor Verónica Pérez-Simonsen, affiliated to the dep. of Physics, NTNU, Norway	*Non-parametric reconstruction of the statistical properties of penetrable, isotropic randomly rough surfaces from in-plane, co-polarized light scattering data*

2020 MSC STUDENTS – OVERVIEW

NAME	TITLE MASTER THESIS	SUPERVISORS
Yngve Nylund Arnestad	*Advanced CT Studies of Deformation Mechanics*	Ragnvald Mathiesen and Dag W. Breiby
Elias Hvideberg	*Molecular Dynamics Simulation of the Contact Mechanics of hydrogels*	Astrid de Wijn and Alex Hansen
Marthe Brevig	*Monte Carlo Simulation of Immiscible Two-Phase Flow in Porous Media*	Alex Hansen and Santanu Sinha
Carlos Martínez Mingo	*Ultrastructure Analysis of Gallbladder Stones using Computed Tomography*	Basab Chattopadhyay and Dag W. Breiby
Martin Alexander Toresen	*Swelling of Clay/Shale: A numerical investigation*	Srutarshi Pradhan
Fredrik Rosenberg	*2-D Image Analysis of Snow for Cross-Country Skiing*	Astrid de Wijn and Antonius Van Helvoort
Mina Sørensen Bratvold	*The Permeability Of Porous Media As Studied By Nemd*	Signe Kjelstrup, Michael Tobias Rauter and Olav Galteland
Peder Langsholt Holmqvist	*Non-Isothermal Transport In Cation-Exchange Membranes: The Seebeck Effect In Systems Of Ions Abundant In Seawater*	Signe Kjelstrup and Kim Roger Kristiansen
Sebastian Nordby Price	*Improving the Perturbation Theory for Mixtures Described by Lennard-Jones Potential with Large Differences in Well-Depths*	Anders Lervik and Øivind Wilhelmsen
Kevin Kottakkakathu Varughese	*Nanothermodynamics Of A Single-Phase Fluid Confined In Complex Porous Medium*	Signe Kjelstrup, Olav Galteland and Michael Tobias Rauter
Daniel Tianhou Zhan	*The First Steps Towards a Perturbation Theory for Small Systems*	Anders Lervik and Øivind Wilhelmsen
Gbadebo Nafiu Adejumo	*Experimental Study on the Effect of Low Salinity and Ionic Composition on Wettability Alteration in Carbonates*	Carl Fredrik Berg and Antje Van der Net
Fadhil Berylian	*Calculation and Visualization of Energy Dissipation and Energy Balance in Reservoir Models*	Carl Fredrik Berg
Anna Bjørke Kallestad	*Geochemical Modeling of Low Salinity Flooding*	Ashkan J. Ghahfarokhi
Raymond Mushabe	*Effect of water Quality on Spontaneous Imbibition into Carbonate Cores*	Carl Fredrik Berg and Antje Van der Net
Shirin Safar Zadeh	*Appraisal of Low-Salinity EOR on Micro-Scale: Effect of Brine Concentration on Interfacial Tension, Contact Angle, and pH*	Ole Torsæter
Ådne Årevik Vikdal	*Segmentation of Phases in Experimental Images of Fluid Flow using Machines Learning*	Carl Fredrik Berg
Wenyu Zhou	*Experimental Investigation of Osmosis and Spontaneous Emulsification Effect in the LSW Flooding*	Carl Fredrik Berg
Marvin Glissner	*Service Life Prediction Of Concrete In Cold Climate, Benchmarking Of Chloride Ingress Simulations*	Mette Rica Geiker, Alexander Michel and Victor Marcos Meson
Morten Hovind and Kjetil Lien	*Parametric Study of Mechanical Properties for Saline Frozen Clay*	Rao Martand Singh and Chuangxin Lyu
Tonje Roås Mikalsen	*Estimation of the Unfrozen Water Content Based on a Joint Electrical and Acoustic Method*	Ali Amiri
Hilmar Yngvi Birgisson	*Density driven CO_2 Advection Diffusion*	Knut Jørgen Måløy and Eirik G. Flekkøy
Ivar Svalheim Haugerud	*Effective Diffusion in Two Dimensional Channels*	Knut Jørgen Måløy, Eirik G. Flekkøy and Gaute Linga
Emily Q. Z. Moen	*Active Matter in Confinment*	Luiza Angheluta-Bauer and Kristian S. Olsen

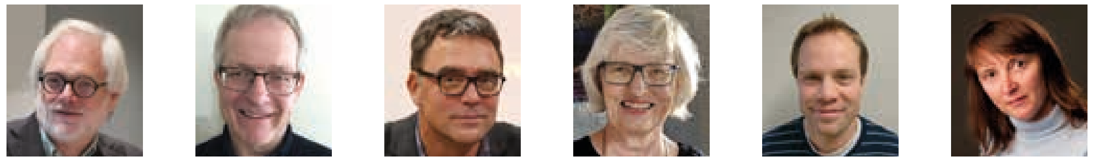
PORELAB MEMBERS

PoreLab Executive Board



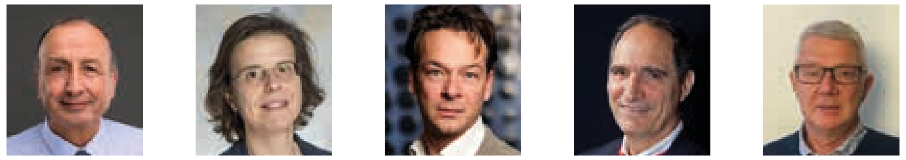
- **Øyvind Gregersen** – Dean, NV faculty, NTNU
- **Erik Wahlström** – Head of Department, Department of Physics, NTNU
- **Sveinung Løset** – Professor, Department of Civil and Environmental Engineering, NTNU; Vice Dean Research and Innovation, Faculty of Engineering, NTNU
- **Heidi Sandaker** – Head of department, Department of Physics, University of Oslo (until April 2020)
- **Susanne Viefers** – Head of department, Department of Physics, University of Oslo (from May 2020)
- **Brit Lisa Skjelkvåle** – Head of Department, Department of Geosciences, UiO

The Leader Group



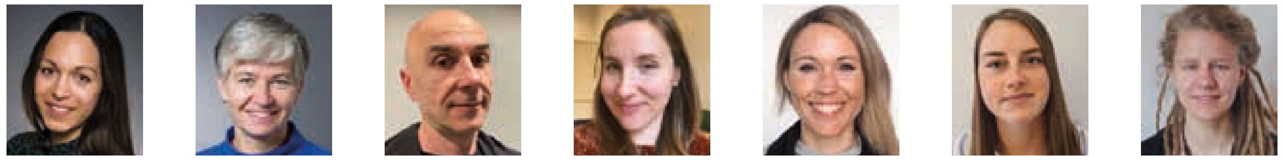
- **Alex Hansen** – Director, Professor, Department of Physics, NTNU
- **Knut Jørgen Måløy** – Deputy Director, Professor, Department of Physics, UiO
- **Eirik Flekkøy** – Professor, Department of Physics, UiO
- **Signe Kjelstrup** – Professor, Department of Chemistry, NTNU
- **Carl Fredrik Berg** – Associate Professor, Department of Geoscience and Petroleum, NTNU
- **Marie-Laure Olivier** – Administrative leader, Department of Physics, NTNU

Scientific Advisory Board



- **Dani Or** – Professor, Soil and Terrestrial Environmental Physics, ETH, Zurich, Switzerland
- **Anna Korre** – Professor of Environmental Engineering, Co-director of Energy Futures Lab, Imperial College London, UK
- **Daniel Bonn** – Professor, Van der Waals-Zeeman Instituut, University of Amsterdam, The Netherlands
- **S. Majid Hassanizadeh** – Professor, Department of Earth Sciences, University of Utrecht, The Netherlands
- **Pål-Eric Øren** – Chief Technology Officer, Digital Rock Services, Petricore, Trondheim, Norway

Administrative and Technical Staff

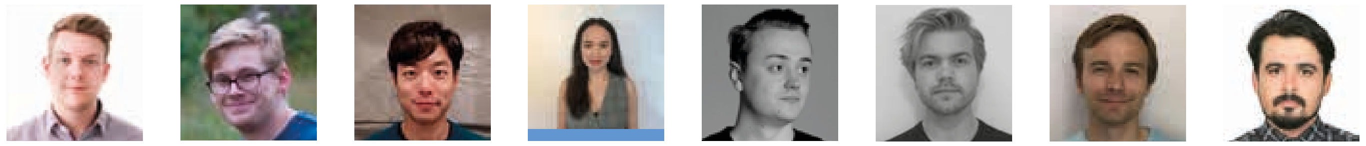


- **Nina Mino Thorud** – Administrative coordinator for Njord Center and PoreLab, Faculty of Mathematics and Natural Sciences, UiO
- **Anita Reime** – Finance advisor for Njord Center and PoreLab, Faculty of Mathematics and Natural Sciences, UiO
- **Mihailo Jankov** – Senior Engineer, Department of Physics, UiO
- **Magdalena Edvardsen** – Research Consultant, Department of Physics, UiO
- **Eivor Maria Onsum** – Senior executive officer, Faculty of Natural Sciences, NTNU (Until Feb. 2020)
- **Veronica Birkeland Mo** – Senior executive officer, Faculty of Natural Sciences, NTNU (From Nov. 2020)
- **Hedda Susanne Molland** – Administrative coordinator for Njord Center and PoreLab, Faculty of Mathematics and Natural Sciences, UiO

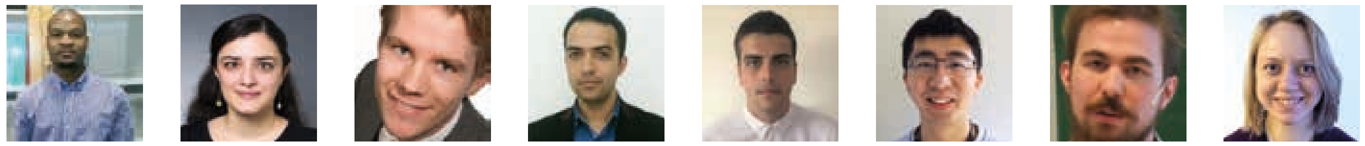
PostDocs

- **Haili Long-Sanouiller** – PostDoc, Department of Geoscience and Petroleum, NTNU
- **James M. Campbell** – PostDoc, Department of Physics, UiO
- **Hamid H. Khanamiri** – PostDoc, Department of Geoscience and Petroleum, NTNU
- **Mathias Winkler** – PostDoc, Department of Physics, NTNU
- **Gaute Linga** – PostDoc, Department of Physics, UiO
- **Subhadeep Roy** – PostDoc, Department of Physics, NTNU

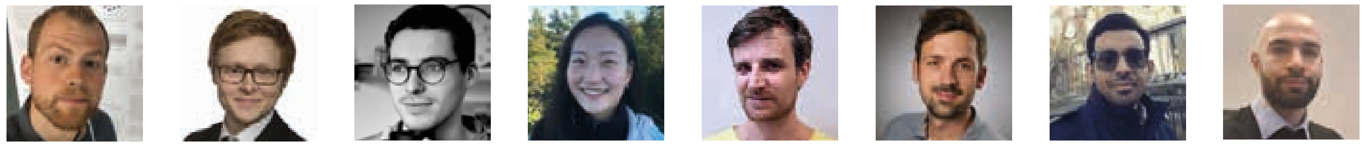
PhD Students



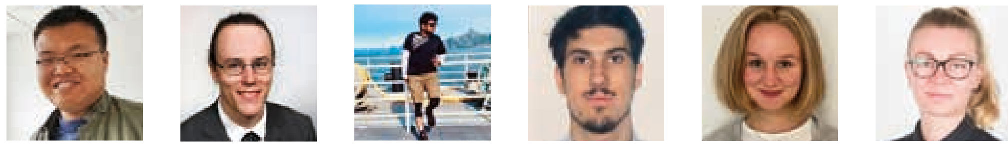
- **Marco Sauermoser** – PhD, Department of Chemistry, NTNU
- **Olav Galteland** – PhD, Department of Chemistry, NTNU
- **Seunghan Song** – PhD, Department of Physics, NTNU
- **Hursanay Fyhn** – PhD, Department of Physics, NTNU
- **Kristian S. Olsen** – PhD, Department of Physics, UiO
- **Håkon Pedersen** – PhD, Department of Physics, NTNU
- **Sebastian Everard Nordby Price** – PhD, Dept. of Chemistry, NTNU
- **Fazel Mirzaei** – PhD, Department of Physics, NTNU



- **Alberto Luis Bila** – Department of Geoscience and Petroleum, NTNU
- **Beatrice Baldelli** – PhD, Department of Physics, UiO
- **Magnus A. Gjennestad** – PhD, Department of Physics, NTNU
- **Mohammad Hossein Golestan** – PhD, Dept. of Geoscience and Petroleum, NTNU
- **Tomislav Vukovic** – PhD, Department of Geoscience and Petroleum, NTNU
- **Hao Gao** – PhD, Department of Civil and Environmental Engineering, NTNU
- **Kim R. Kristiansen** – PhD, Department of Chemistry, NTNU
- **Astrid F. Gunnarshaug** – PhD, Department of Chemistry, NTNU



- **Eivind Bering** – PhD, Department of Physics, NTNU
- **Ailo Aasen** – PhD, Dept. of Energy and Process Engineering, NTNU
- **Louison Thorens** – PhD, Department of Physics, UiO
- **Hyejeong Cheon** – PhD, Department of Physics, NTNU
- **Joachim Falck Brodin** – PhD, Department of Physics, UiO
- **Michael Tobias Rauter** – PhD, Department of Chemistry, NTNU
- **Salem Saeed Akarri** – PhD, Dept. of Geoscience and Petroleum, NTNU
- **Davood Dadrasajirlou** – PhD, Dept. of Civil and Environmental Eng., NTNU

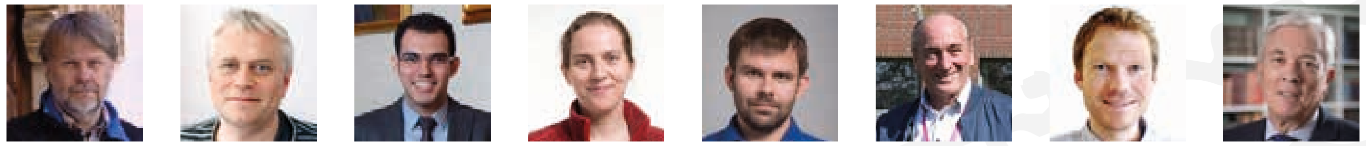


- **Chuangxin Lyu** – PhD, Department of Civil and Environmental Engineering, NTNU
- **Kim Robert Tekseth** – PhD, Department of Physics, NTNU
- **Aldritt Scaria Madathiparambil** – PhD, Department of Geoscience and Petroleum, NTNU
- **Federico Lanza** – Cotutelle PhD between U. Paris-Saclay, France and NTNU
- **Caroline Einen** – PhD, Department of Physics, NTNU
- **Vilde Bråten** – PhD, Department of Materials Science and Engineering, NTNU

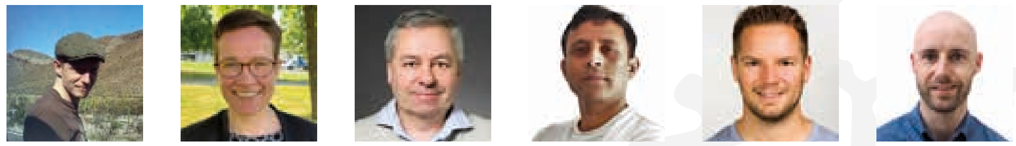
Researchers and Associates

- **Srutarshi Pradhan** – Researcher, Department of Physics, NTNU
- **Bjørn Hafskjold** – Professor, Department of Chemistry, NTNU
- **Dick Bedeaux** – Professor Emeritus, Department of Chemistry, NTNU
- **Øivind Wilhelmsen** – Research Scientist, SINTEF Energy Research
- **Per Arne Rikvold** – Researcher, Department of Physics, UiO
- **Ursula Gibson** – Professor, Department of Physics, NTNU
- **Renaud Toussaint** – Adjunct Professor, Department of Physics, UiO
- **Ole Torsæter** – Professor, Department of Geoscience and Petroleum, NTNU

- **Dag Werner Breiby** – Professor, Department of Physics, NTNU
- **Catharina de Lange Davies** – Professor, Department of Physics, NTNU
- **Seyed Ali Amiri** – Researcher, Department of Civil and Environmental Engineering, NTNU
- **Bjørn Jamtveit** – Professor, Department of Geosciences, UiO
- **Luiza Angheluta-Bauer** – Associate Professor, Department of Physics, UiO
- **Marcel Moura** – PostDoc/Researcher, Department of Physics, UiO
- **Gustav Grimstad** – Professor, Department of Civil and Environmental Engineering, NTNU
- **Steinar Nordal** – Professor, Department of Civil and Environmental Engineering, NTNU



- **Per Arne Slotte** – Researcher, Department of Geoscience and Petroleum, NTNU
- **Ragnvald Mathiesen** – Professor, Department of Physics, NTNU
- **Ashkan J. Ghahfarokhi** – Associate Professor, Department of Geoscience and Petroleum, NTNU
- **Astrid de Wijn** – Associate Professor, Department of Mechanical and Industrial Engineering, NTNU
- **Sondre Kvalvåg Schnell** – Associate Professor, Dept. of Materials Science and Engineering, NTNU
- **Jon Kleppe** – Professor, Department of Geoscienceand Petroleum, NTNU
- **Anders Lervik** – Associate Professor, Department of Chemistry, NTNU
- **Miguel Rubi,** – Professor, Department of Chemistry, NTNU



- **Olav Aursjø** – Researcher, Department of Physics, UiO
- **Antje van der Net** – Associate Professor, Department of Geoscience and Petroleum, NTNU
- **François Renard** – Professor, Department of Geosciences, UiO
- **Basab Chattopadhyay** – Researcher, Departement of Physics, NTNU
- **Fredrik K. Eriksen** – Researcher, Department of Physics, UiO
- **Fredrik Kristoffer Mürer** – Researcher, Departement of Physics, NTNU

PUBLICATIONS

The following lists journal publications, books, reports, conference lectures and academic presentations generated in 2020.

JOURNAL PUBLICATIONS

Aadland, Reidun Cecilie Grønfur; Akarri, Salem Saeed Fadhl; Heggset, Ellinor Bævre; Syverud, Kristin; Torsæter, Ole.
A core flood and microfluidics investigation of nanocellulose as a chemical additive to water flooding for EOR. *Nanomaterials* **10**, 1296 (2020).
NTNU

Aasen, Ailo; Reguera, David; Wilhelmsen, Øivind.
Curvature Corrections Remove the Inconsistencies of Binary Classical Nucleation Theory. *Physical Review Letters* **124**, 045701 (2020).
ENERGISINT NTNU

Arango-Restrepo, A.; Barragán, Daniel; Rubi, Capaceti Jose Miguel.
Modelling non-equilibrium self-assembly from dissipation. *Molecular Physics* **118**, e1761036 (2020).
NTNU

Arango-Restrepo, Andrès; Rubi, Capaceti Jose Miguel.
Entropic transport in a crowded medium. *Journal of Chemical Physics* **153**, 034108 (2020).

Arango-Restrepo, Andrès; Rubi, Capaceti Jose Miguel.
Role of Interfacial Entropy in the Particle-Size Dependence of Thermophoretic Mobility. *Physical Review Letters* **125**, 045901 (2020).

Ayaz, Atta-Ul-Monem; Toussaint, Renaud; Schäfer, Gerhard; Måløy, Knut Jørgen.
Gravitational and Finite-Size Effects on Pressure Saturation Curves During Drainage. *Water Resources Research* **56**, e2019WR026279 (2020).
UiO

Bedeaux, Dick; Flekkøy, Eirik Grude; Hansen, Alex; Måløy, Knut Jørgen; Kjelstrup, Signe; Torsæter, Ole.
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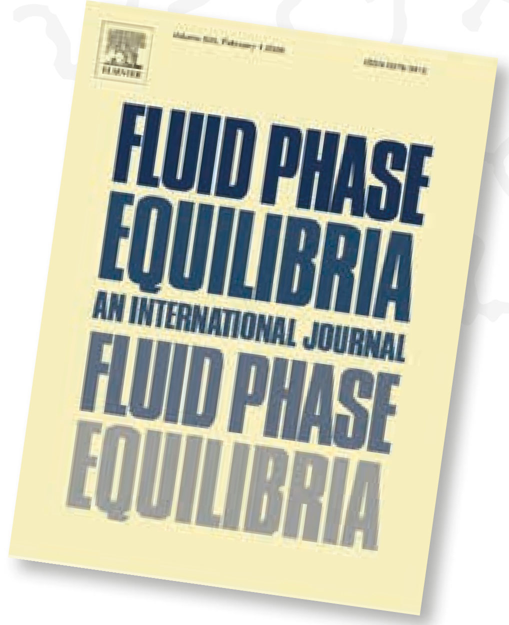

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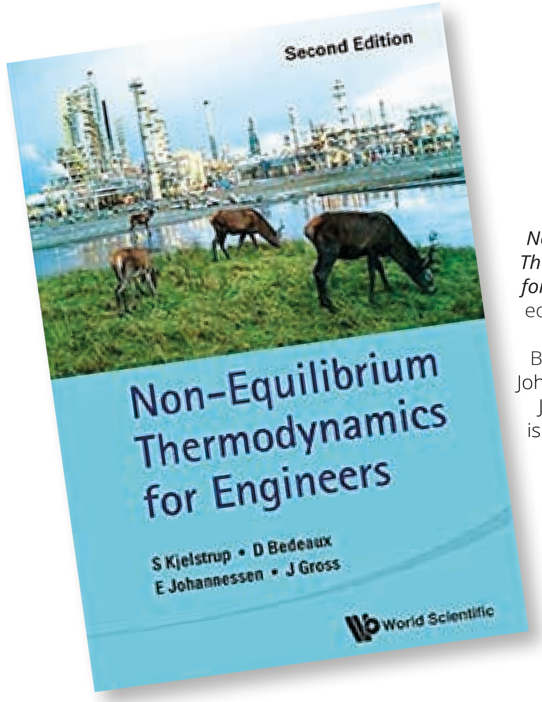

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