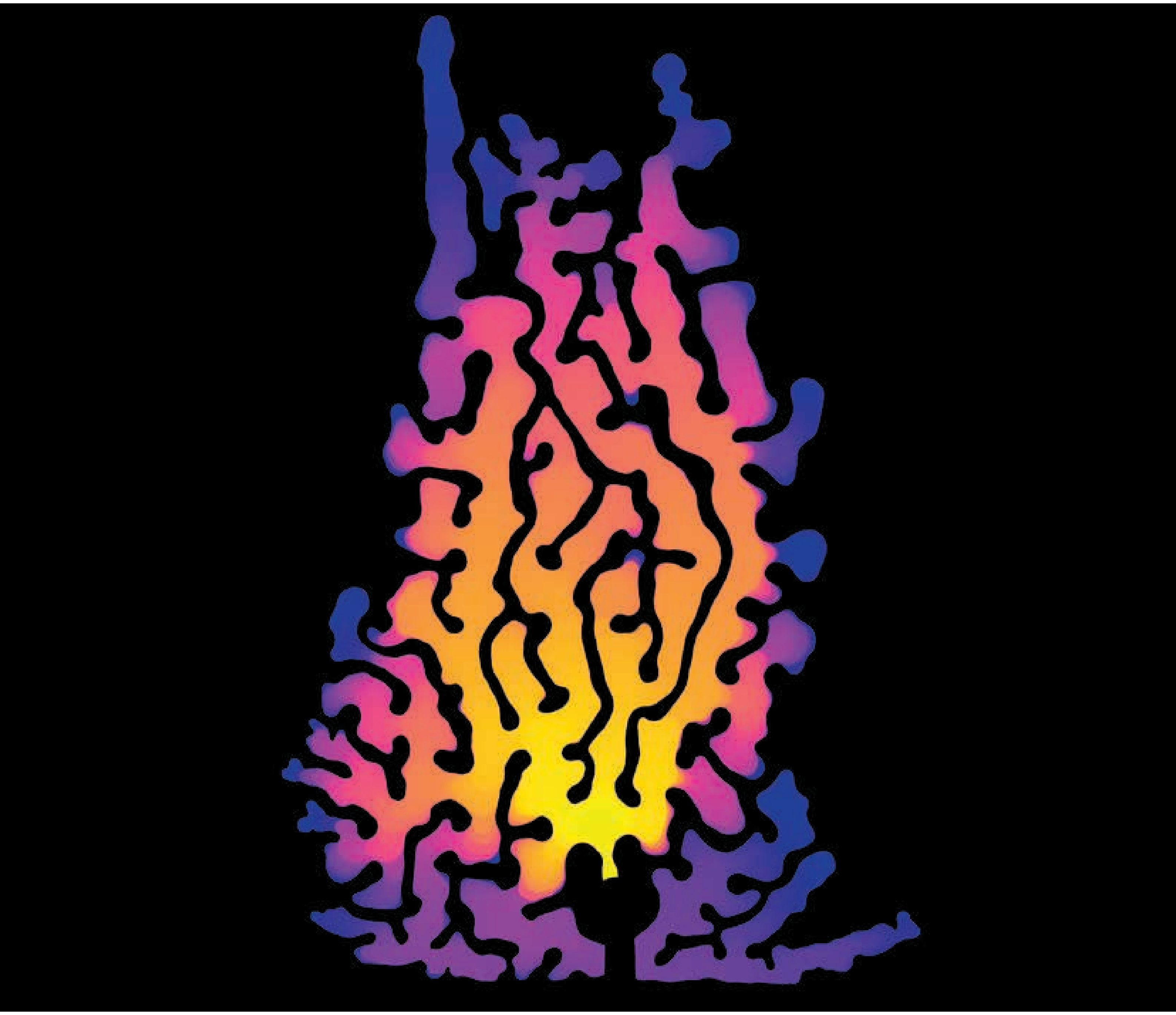
PoreLab
NTNU-UiO Porous Media Laboratory

Annual Report 2021



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

An artificial representation of an underground aquifer produced by filling up a transparent quasi-two-dimensional porous network with a dyed liquid. Picture by Marcel Moura, PoreLab UiO.

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

WHAT IS PORELAB?

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

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

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

The mission of PoreLab is to advance the understanding of flow in porous media, both at a fundamental level and in applications. Starting from a basis in physics we aim for a better description of flows that range from geological to biological and technological. Our objective is to link together observations of how fluids behave at the pore scale with a proper description of flow in porous media at much larger scales – the scales that typically are relevant for applications. In other words, our aim is to construct a large-scale theory for flow in porous media based on the detailed physics at the pore level. To achieve this, we combine hydrodynamics, non-equilibrium thermodynamics and statistical physics using theoretical, computational, and experimental methods.

PoreLab receives an annual funding from the Norwegian Research Council of about 15 MNOK for an initial six-year 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.

Different stages of a fluid mixed with glass beads being injected between two parallel glass plates. As the fluid flows, grains are accumulated along its front and any inhomogeneity in their distribution grows as the experiment advances, resulting in the formation of small dunes. Picture by Antoine Dop, PoreLab UiO and ENS Lyon

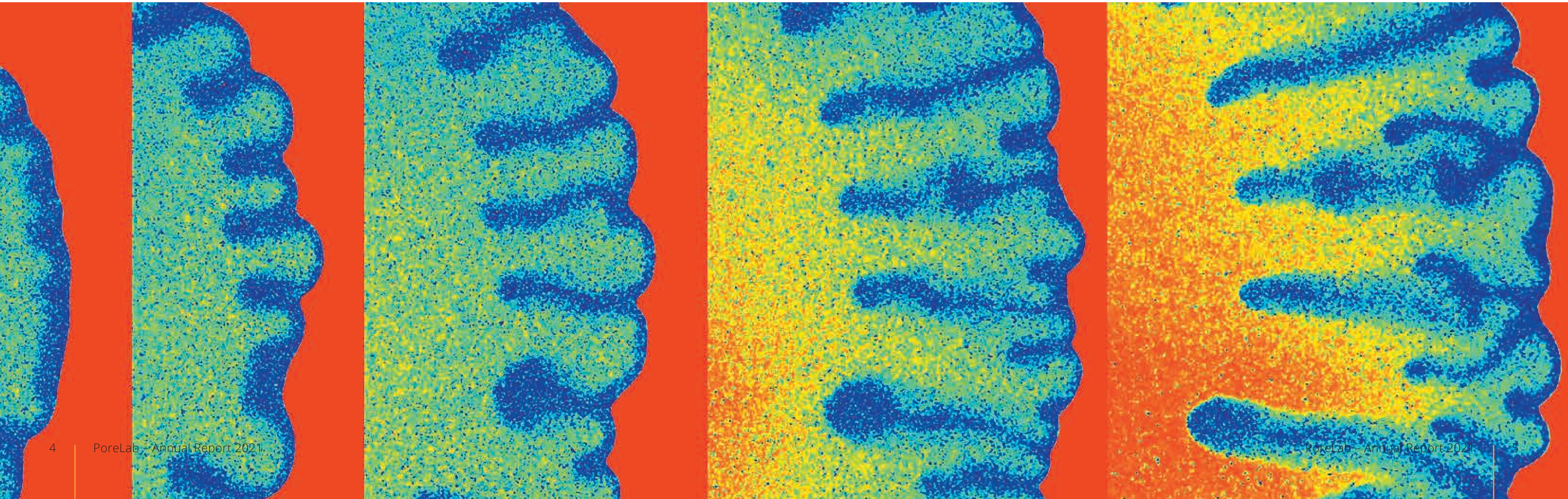


TABLE OF CONTENTS

Alex Hansen, Director for PoreLab

Photo: Per Henning, NTNU

DIRECTOR'S COMMENTS

We had high hopes for 2021. When vaccination against Covid-19 became available during the summer of 2021, there was a collective sigh: done, over with and now, back to normal a.s.a.p. But no. The Delta variant showed up that summer too, outcompeting the previous variants quickly. Not only was it more contagious than before, but also more dangerous. So, back to masks and the "meter." And Zoom. But, not as intensely as in 2020.

We were beginning to learn how to live with Covid-19 now, becoming more relaxed. In December we got really bad news: A new mutation had shown up in South Africa, and this time as contagious as Measles – and that means contagious. We soon started hearing that this new variant, Omicron, was much milder than the previous variants. In fact, so much so that it essentially could be compared to a cold. With this combination, high transmissibility and low risk, the Covid-19 game changed completely. At the time of writing this, mid-February of 2022, it looks like we will be getting back to normal for real. We'll see. But, enough here about Covid-19. For more, see *Staying productive in the prolonged pandemic* on page **48**.

PoreLab in Oslo has had major interruptions in their experimental work when the university locked down over some periods in 2021. The interruptions in PoreLab Trondheim have been less as the work there is more on the theoretical side. We have had almost no visitors at either place and physical travel by us has been severely hampered.

On the other hand, Zoom meetings have flourished. We have had talks by external speakers every week during the semesters for our seminars. And we have given talks externally. In fact, the ease at which we may exchange information this way is just astounding.

Two of our principal investigators have entered emerita(us) status, Signe Kjelstrup and Ole Torsæter. Carl Fredrik Berg at the NTNU Department of Geoscience and Petroleum has since 2020 replaced Ole Torsæter as principal investigator. Øivind Wilhelmsen, professor at the NTNU Department of Chemistry, is now principal investigator replacing Signe Kjelstrup. Erika Eiser, now professor in the NTNU Department of Physics, has also taken up her position, a new professorship created by the department.

But our new emeriti have by no means quit. They are as productive as ever. Among the present or earlier but very active principal investigators of PoreLab, there is an age span of 50 years.

We have rearranged the seven work packages that constitute PoreLab. Work packages 3 and 4, "Experimental Characterization of Steady-State properties of Flow in Porous Media" and "Experimental transient immiscible two-phase flow" have been merged into a new Work package 3, "Experimental Characterization of immiscible two-phase flow in porous media." As our understanding has developed, it no longer made any sense to separate the two types of flow: In an injection experiment, which in the laboratory reference frame is transient, will in a frame of reference following the invasion front be in a steady state. In place of the old Work package 4, we have created a new Work package 4 "Nanoporous media and gels" which will be led by Erika Eiser.

Erika Eiser is a soft matter physicist. Soft matter is according to Wikipedia matter that deforms by thermal or mechanical forces at the level of the thermal fluctuations. Amorphous matter, on the other hand, is matter without crystalline order. This makes glass an amorphous matter but not a soft one. And this makes sense: glass is a hard material. Or does it make sense? It is an unsolved question whether glass is a liquid with extremely high viscosity, or a solid at low enough temperatures. In my mind, liquids are soft no matter how viscous they are. What about granular matter, for example sand? The thermal fluctuations in the sand grains are certainly much less than the forces needed to move the grains around in the sand, excluding them from the soft matter definition of Wikipedia. Yet, sand flows like a liquid when poured. One of the attractions of beaches as the Copacabana is their *soft* sand. Perhaps a better definition of soft matter is matter that flows under the applied forces.

Clay and other unconsolidated porous media are then examples of soft matter. Soft matter science is rapidly advancing; it is simply "hot." Connecting porous media closely to this branch of science is extremely interesting.

The collaboration with the NTNU Physics Department X-Ray Group is increasing. PoreLab Trondheim and the X-Ray Group now form the Section for Porous Media at the Department. Dag Breiby and his collaborators have already many common projects with us, and with Erika Eiser on board, we expect great things to happen when they combine their efforts.

We also note that Raffaela Cabriolu has become associate professor in the NTNU Physics Department in 2021. She has already collaborated with us on Onsager symmetries in porous media.[1] And now a proposal for the Research Council of Norway has been sent by her involving PoreLab.

Let us now get into some details of what we did in 2021. We highlight some results here. However, we refer the reader to the descriptions on pages **18** to **47** for a more complete, but still not exhaustive, list.

- Nanoporous media is a class of materials that are far from understood even though they constitute some of our most important and ubiquitous materials. Concrete is an example. An important step forwards in our understanding of transport through such materials has been made by Galteland et al.[2] "A local thermodynamic description of isothermal single-phase flow in nanoporous media." Here they consider the Darcy law for single phase flow using non-equilibrium thermodynamics, essentially constructing an equation of state. This contrasts with the traditional approach to finding a pore level derivation of the Darcy law based on moment transfer, as done by Whitaker.[3]

- How to go beyond relative permeability theory without the complexity exploding in your face? This is the central question in the scale-up problem: Finding a way to get from the physics of immiscible two-phase flow at the pore scale to an effective description, i.e., equations to solve, at scales where the pores are vanishingly small? Euler theory, first described in Hansen et al.[4] in 2018, is such an attempt. A central concept in this theory is a velocity parameter, the co-moving velocity. Together with the average flow velocity, this velocity parameter determines how the two immiscible fluids move. Roy, Pedersen, Sinha, and Hansen[5] have studied how the co-moving velocity depends on the other variables in the problem using experimental results from the literature and computational methods. It turns out to be a very simple dependency. There must be a reason for this simplicity which is not yet uncovered.

- In 2017 the first interstellar object passing through the solar system was discovered, 'Oumuamua. A big surprise was that it did not follow a trajectory according to gravity alone. Something else was also acting on it. It could be that 'Oumuamua is an ice block and outgassing close to the sun would perturb its trajectory. Or it could be a light-sail constructed by some alien civilization. Flekkøy and coworkers published two papers in 2020[6, 7], proposing that 'Oumuamua is a "dust bunny," i.e., a fractal structure consisting of coalescing dust particles. This would be light enough for sun light to force it away from the trajectory determined by gravity alone. This proposal made quite a stir, but a central question lingered on: How to distinguish observationally between these theories. With the deployment of the James Webb infrared telescope in 2021, this question became urgent. Flekkøy and Brodin[8] worked out the infrared signature that would ensue from the different theories in a paper that was published in early 2022 making it possible to distinguish between them.

- Eriksen et al.[9] investigated the following question: When injecting a non-wetting fluid into a porous medium saturated with a wetting fluid – drainage in other words – and the injected fluid is less viscous than the displaced fluid, viscous fingers develop. But what happens after the viscous fingers have developed? That is, if we go on injecting. A compact mixture of fluid clusters is then formed in the wake of the viscous fingers. This compact region shows remarkable scaling properties. This work is an important piece in understanding the upscaling problem.

- Erika Eiser constructed in 2012 for the first time a new type of gel as described in Varrato et al.[10] A gel at the molecular scale is a network that acts as a rigid scaffold holding it in place. Varrato et al. describe a bigel where there are two separate networks in place. Each network is separate from the other one, but they are completely intermixed. During a meeting we organized with our collaborators at Université Paris-Saclay, it occurred to us that this in fact constitutes a very interesting percolation problem. So, with Hans Herrmann in Paris and José Soares Andrade Jr. in Fortaleza, a project on this problem has been initiated.

- Hafskjold et al.[11] considered shock waves. Common sense would tell us that they are as far as it is possible from equilibrium. But still, in a reference frame travelling with the front, one may still apply equilibrium thermodynamics. It still works!

- Imaging techniques keep improving in characterizing porous media. This necessitates better and better methods to analyze the data that are obtained. Berg et al.[12] consider CT scans of whole cores, and then use methods from artificial intelligence – neural networks – to interpret them. They introduce a classification scheme for the lithography of the cores they analyze and how to automatize this work.

AMBITIONS FOR 2021: DID WE DO WHAT WE SET OUT TO DO?

Despite the problems caused by the pandemic, it was a good year as can be seen from the highlights on pages **16** and **17**.

Scientifically, we met our ambitions for 2021. Our priority number one from the very start has been the integration of our research projects. That is, weave a tight network of collaborations among us where the interdisciplinary nature of PoreLab is used to the full. We are now in a position where we can say that this is so.

The three-pronged approach to the upscaling problem – how to get from a pore-scale understanding of two-phase flow in porous media to an effective description on large scales – which is a core ambition of PoreLab has advanced considerably, but with some adjustments. I would now describe the three approaches as 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. Identifying the relevant length scales associated with the different mechanisms driving the flow.

In last years annual report, item 3 was "Expressing the thermo-dynamic functions at the coarse-grained level in terms of the Minkowski functionals." This has now been absorbed into item 1. The new item 3 concerns the integration of the vast knowledge and understanding amassed by the Oslo group into the approach.

But, besides this central project, there are many other projects going on: the efficiency of the reindeer nose (which is a porous medium), heat transport in water-saturated soil near freezing, flow of compressible fluids in porous media, fluid film dynamics in porous media… And in these projects, we see the structure of interlocked collaborations emerge. As described earlier, the structure of PoreLab is now that of the "star club". We are a mature group.

We wrote in the annual report for 2020 that "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. Well, Covid-19 still has a grip on us. Visitors are rare and far apart. But we have many virtual visitors. Our seminars do an excellent job in making us known. Our branding ambitions do have an effect.

Our focus on gender balance is working. Every year, we are better off than the year before.

AMBITIONS FOR 2022

The midway evaluation starts in the fall of 2022. This is the opportunity to properly evaluate where we are, not only for the Research Council of Norway (RCN), but also for ourselves. It will be a year of self-examination. But, as important, it will be a year of planning ahead – even beyond 2027 when the RCN funding ends. We have concrete ideas, but none to reveal now.

A very interesting opportunity has appeared through the initiation of the journal Frontiers in Science. This is an entirely new concept in scientific publishing where "Game-changing scientific advances, paradigms, frameworks, and solutions" are published by leading scientists after invitation, some 20 lead articles per year. We have been invited to write a lead article on our upscaling approach. This is the opportunity to synthesize what we have accomplished since the inauguration of PoreLab.

We repeat what we wrote in the 2020 annual report: "Our efforts to integrate our research will continue. We will continue and strengthen the use of double advisors for our doctoral students. This is an excellent way to accomplish this."

We will also continue our efforts furthering gender balance.

And lastly, we will continue our efforts to understand porous media. This is our main task.

Alex Hansen

[1] Winkler, M., Gjennestad, M. Aa., Bedeaux, D., Kjelstrup, S., and Hansen, A., Onsager-Symmetry obeyed in a thermal mesoscopic system: two-phase flow in porous media, Front. Phys. 8, 60 (2020).

[2] Galteland, O., Rauter, M. T., Bratvold, M. S., Trinh, T. T., Bedeaux, D. and Kjelstrup, S., A local thermodynamic description of isothermal single-phase flow in nanoporous media, to be submitted.

[3] Whitaker, S. Flow in porous media I: A theoretical derivation of Darcy's law. Transport in Porous Media 1, 3 (1986).

[4] Hansen, A., Sinha, S., Bedeaux, D., Kjelstrup, S., Gjennestad, M. A., & Vassvik, M. (2018). Relations between seepage velocities in immiscible, incompressible two-phase flow in porous media. Transport in Porous Media, 125(3), 565-587.

[5] Roy, S., Pedersen, H., Sinha, S., & Hansen, A. (2021). The Co-Moving Velocity in Immiscible Two-Phase Flow in Porous Media. arXiv preprint arXiv:2108.10187.

[6] Flekkøy, E. G., Luu, J., & Toussaint, R. (2019). The interstellar object 'Oumuamua as a fractal dust aggregate. The Astrophysical Journal Letters, 885(2), L41.

[7] Luu, J. X., Flekkøy, E. G., & Toussaint, R. (2020). 'Oumuamua as a cometary fractal aggregate: The "Dust Bunny" model. The Astrophysical journal letters, 900(2), L22.

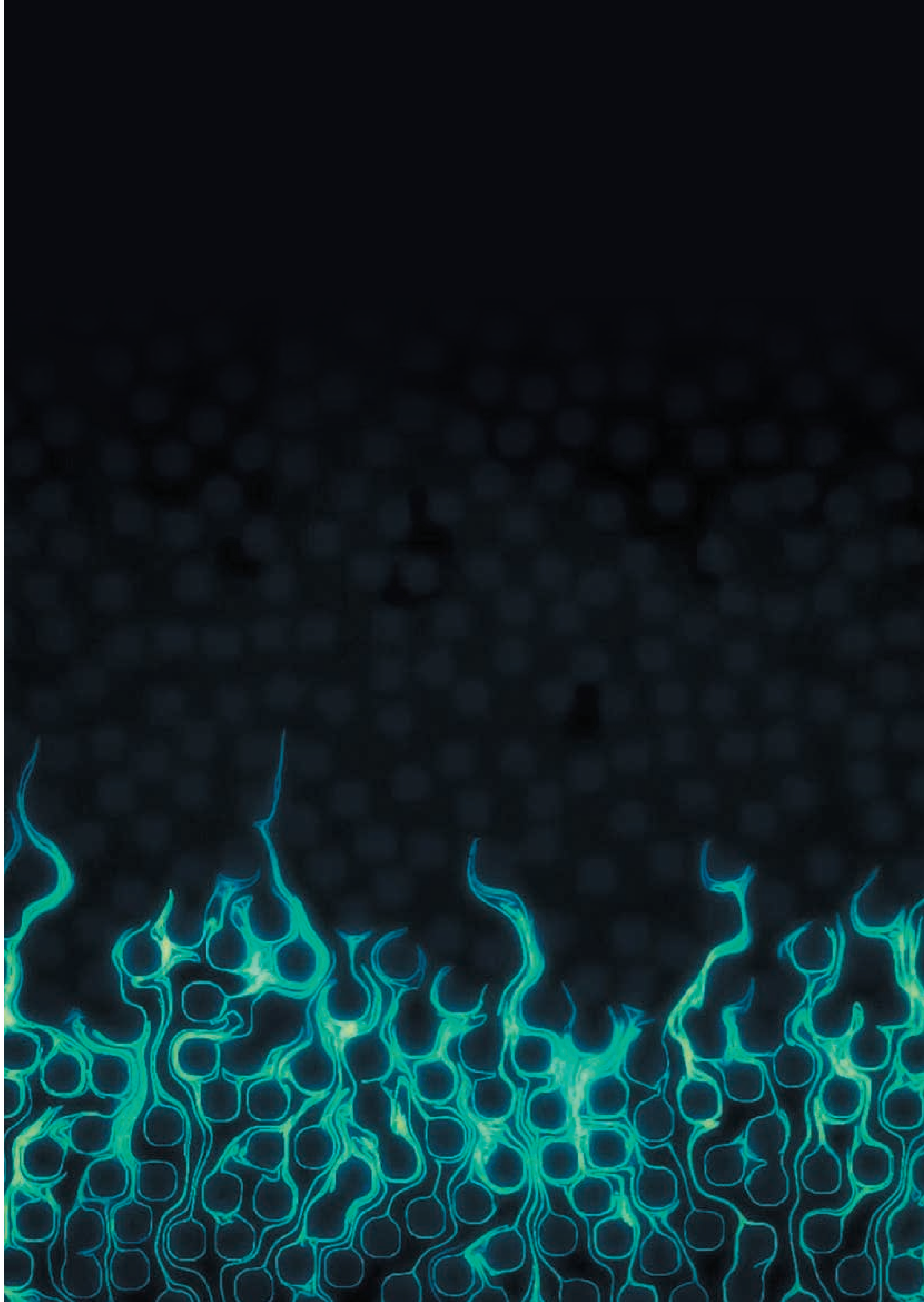
[8] Flekkøy, E. G., & Brodin, J. F. (2022). Discerning between Different 'Oumuamua Models by Optical and Infrared Observations. The Astrophysical Journal Letters, 925(2), L11.

[9] Eriksen, F. K., Moura, M., Jankov, M., Turquet, A. L., & Måløy, K. J. (2022). Transition from viscous fingers to compact displacement during unstable drainage in porous media. Physical Review Fluids, 7(1), 013901.

[10] Varrato, F., Di Michele, L., Belushkin, M., Dorsaz, N., Nathan, S. H., Eiser, E., & Foffi, G. (2012). Arrested demixing opens route to bigels. Proceedings of the National Academy of Sciences, 109(47), 19155-19160.

[11] Hafskjold, B., Bedeaux, D., Kjelstrup, S., & Wilhelmsen, Ø. (2021). Theory and simulation of shock waves: Entropy production and energy conversion. Physical Review E, 104(1), 014131.

[12] Chawshin, K., Berg, C. F., Varagnolo, D., & Lopez, O. (2021). Lithology classification of whole core CT scans using convolutional neural networks. SN Applied Sciences, 3(6), 1-21.



COMMENTS FROM MIGUEL RUBI, UNIVERSITY OF BARCELONA, SPAIN

Interest in the study of porous media has a long history dating back to antiquity and was consolidated from the late 18th century when the conceptual framework of science began to be used systematically to find solutions to practical problems. This was the case for the study of soil mechanics, the construction of filters to purify urban water supplies and the adsorption of gases in charcoal. Interest in porous media has experienced exceptional growth in recent decades, attracting researchers from different disciplines and incorporating new case studies and new experimental methodologies and techniques. The study of porous media is a multidisciplinary research field that invites researchers to explore porous media for scientific and industrial purposes.

Today, the possibility of exploring matter at ever smaller scales, thanks to the development of new experimental techniques and artificial intelligence methods, is demonstrating that porosity is a ubiquitous property of matter that can be found, for example, in structured materials, biological tissues, and geological settlements where the spatial distribution of matter is uneven. Knowing under what conditions a liquid phase can seep through a solid phase containing voids and how the effective macroscopic transport parameters are influenced by the microscopic geometric structure of the medium are basic problems of enormous impact in basic science and engineering.

Despite the long tradition in the study of porous media, there are still many basic problems to be solved and many potential applications to be explored. On one hand, this is due to the very nature of the process of liquid invasion in a medium with a disordered distribution of voids in which a wide range of phenomena such as capillarity, adsorption, and liquid phase rheology may occur. The presence of a strong disorder can invalidate simpler treatments based on effective medium theories and induce unique global properties. On the other hand, the growing casuistry promoted by, for example, the discovery of new materials, petroleum engineering, CO_2 capture, and medical therapies based on drug delivery is expanding the field of porous media to unexpected situations. It is therefore of vital importance to have a multi-scale framework that can be applied to problems where porosity is the common factor. The study of porous media thus offers numerous possibilities for senior and young scientists to orient research towards this fruitful multidisciplinary field.

PoreLab is a strong commitment to excellence in porous media research. Although its beginnings date back to a few years ago, founded in 2017, this Centre of Excellence is already a benchmark institution in the study of the properties of porous media and their multidisciplinary applications to materials science, geoscience, and life sciences. At its Trondheim and Oslo sites, research revolves around groups led by a principal investigator, with a large number of PhD students, postdocs, and visitors. The organization of numerous scientific and academic activities makes the Centre a permanent forum for the discussion of new ideas and applications. An efficient administration facilitates the work of the researchers and their international outreach. PoreLab will undoubtedly remain a leading Centre for porous media research and thus contribute to the development and consolidation of this promising research area in Norway.

Professor in physics, Miguel Rubi, receives his Honorary Doctorate at NTNU in Trondheim from NTNU's Rector Gunnar Bovim (on the left) in 2016. Picture by Thor Nielsen/NTNU

ORGANIZATIONAL CHART OF PORELAB

Structure of the organization

PoreLab Steering Board
Chair: Øyvind Gregersen, NTNU

Scientific Advisory Committee

Center Director
Alex Hansen

Deputy Director
Knut Jørgen Måløy

Administrative leader
Marie-Laure Olivier

Project coordinator UiO
Nina Mino Thorud

Financial officer
Veronica Birkeland Mo

Technical coordinator
Mihailo Jankov

THEME 1
Thermodynamics of flow in porous media
Alex Hansen, NTNU

THEME 2
Deformable porous media
Eirik Flekkøy, UiO

UNTIL OCTOBER 2021
THEME 3
Experimental characterization of steady-state properties of flow in porous media
Knut Jørgen Måløy, UiO

UNTIL OCTOBER 2021
THEME 4
Experimental transient immiscible two-phase flow
Knut Jørgen Måløy, UiO

FROM NOVEMBER 2021
THEME 3
Experimental characterization of immiscible two-phase flow in porous media
Knut Jørgen Måløy, UiO

FROM NOVEMBER 2021
THEME 4
Nanoporous media and gels
Erika Eiser, NTNU

THEME 5
Thermodynamic driving forces
Signe Kjelstrup until July 2021
Øivind Wilhelmsen from August 2021, NTNU

THEME 6
Microfluidics and field studies
Carl Fredrik Berg, NTNU

THEME 7
Applications: porous layers for PEM Fuel cells and CO_2 sequestration
Signe Kjelstrup until July 2021
Øivind Wilhelmsen from August 2021, NTNU

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, Marie-Laure Olivier (NTNU).

PoreLab's research has been organized in seven Research Themes lead by the Principal Investigators (PIs). During PoreLab's strategy meeting in October 2021, the Leader Group decides to merge Themes 3 and 4, becoming Theme 3 on "Experimental characterization of immiscible two-phase flow in porous media". A new Theme 4 on "Nanoporous media and gels" is now led by Professor Erika Eiser who joined NTNU and PoreLab in July 2021. PoreLab welcomed as well Professor Øivind Wilhelmsen who, from August 2021, replaces Professor Signe Kjelstrup now retired. The organizational structure of the Center is flat. The team of now six 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 combined as theme 3 from November 2021

Erika Eiser
Professor
PI New Theme 4 from November 2021

Signe Kjelstrup
Professor
PI Themes 5 and 7 until July 2021

Øivind Wilhelmsen
Professor
PI Themes 5 and 7 from August 2021

Carl Fredrik Berg
Associate Professor
PI Theme 6

Marie-Laure Olivier
Administrative leader

PORELAB EXECUTIVE BOARD

Øyvind Gregersen
Dean
NV faculty, NTNU

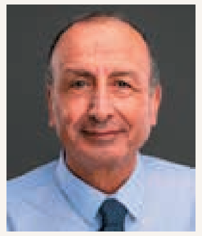
Erik Wahlström
Head of Department
Department of Physics
NTNU

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

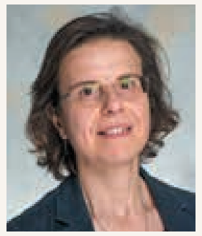
Susanne Viefers
Head of department
Department of Physics
University of Oslo

François Renard
Professor
Department of Geosciences,
Director for Njord Center,
University of Oslo

SCIENTIFIC ADVISORY BOARD



Dani Or
Professor
Soil and Terrestrial Environmental Physics
ETH, Zürich
Switzerland



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 2021
2 publications from Olav Galteland et al. and Eivind Bering et al., both PhD candidates at PoreLab, are selected as Editor's choice by Nanomaterials

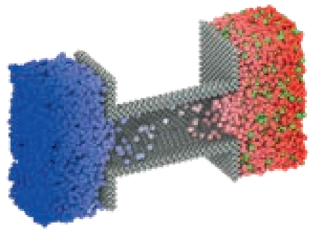
February 2021
Nanomaterials - Special issue on "Nanoscale Thermodynamics" (Signe Kjelstrup, PI at PoreLab)

29 March 2021
Tom Vincent Dospital, PhD candidate and now postdoctoral researcher both at PoreLab, is awarded the PhD award from the research commission of the University of Strasbourg

April 2021
Nanomaterials - Special issue on "Application of Nanoparticles for Oil Recovery" (Ole Torsæter, PI at PoreLab)

16 April 2021
2nd machine learning workshop hosted by PoreLab / IGP, NTNU

30 April 2021
Publication in Nature Communication by Louison Thorens, PhD candidate at PoreLab



25-27 May 2021
International Meeting on Thermodiffusion, IMT 14, PoreLab, NTNU, Trondheim

June 2021
5 PoreLab related projects get funding, 4 from the RCN, and 1 from the Norwegian Ministry of Education and Research

June 2021
PoreLab exhibition next to the city hall in Oslo

3 June 2021
EarthFlows Meeting at the University of Oslo

6 June 2021
Ailo Aasen's PhD thesis is awarded the *Excellence Award in Thermodynamics and Transport Properties* from the European Federation of Chemical Engineers (EFCE)

24 June 2021
Joachim Falck Brodin, former Master student and now PhD candidate, both at PoreLab, is awarded the Martin Landrø prize for outstanding master thesis in physics from the Norwegian Physical Society (NFS)

August 2021
Erika Eiser, new Professor in Physics and PI at PoreLab
Øivind Wilhelmsen, new Professor in Chemistry and PI at PoreLab

29 October 2021
Official opening for the new Micro-CT at PoreLab/Department of Geoscience and Petroleum, NTNU

December 2021
Frontiers in Physics – E-book on "The Fiber Bundle Model" (Alex Hansen and Srutarshi Pradhan, PoreLab with Ferenc Kun and Purusattam Ray)

THE CO-MOVING VELOCITY: WHY IS ITS BEHAVIOR SO SIMPLE?

Subhadeep Roy[1], Håkon Pedersen[1], Santanu Sinha[2] and Alex Hansen[1]

[1] PoreLab, Department of Physics, NTNU, Norway
[2] PoreLab, The Njord Center, Department of Physics, University of Oslo, Norway

Two immiscible fluids flow simultaneously through a homogeneous porous medium under steady state conditions so that averages over different parameters remain constant, both in time and in space. Each fluid may then be characterized by a seepage velocity, i.e., the average velocity of the fluids in the pores.

The two seepage velocities may be combined to form an average velocity, i.e., the velocity of the fluids, irrespective of what kind it is. The seepage velocity of each fluid and their average depend on the pressure drop across the porous medium.

In 2009, Tallakstad et al. [1] found that the average velocity depends on the pressure drop raised to a power close to ½ over a wide range of pressure drops. This immediately raises the question, what about the seepage velocity of each fluid? What is the relation between each of them, and the pressure drop? In the experiments, the volumetric flow rate of each fluid was controlled, and the pressure drop was measured. The fractional flow rates, i.e., the volumetric flow rate of each fluid divided by the total volumetric flow rate, were kept constant when the total volumetric flow rate was changed. Despite all this, no conclusions could be drawn about the individual seepage velocities since the saturation of each fluid would change as the average velocity changed.

Mathematically, the problem is the following: We can readily combine the two seepage velocities into an average velocity. However, from knowing the average velocity alone, we cannot construct the seepage velocities. We need another velocity parameter in addition to the average velocity to express the seepage velocities in terms of the average velocity.

One candidate for this additional velocity parameter would be the difference between the seepage velocities. But this begs the question: How do you measure the seepage velocity difference without measuring the seepage velocities – the velocities that were to be calculated?

Hansen et al. [2] proposed another velocity parameter, the *co-moving velocity*. It appears as a result of demanding the flow to be invariant under dilation (i.e., changing the size of the system). It is an abstract velocity parameter that has no direct simple interpretation [3,4]. This allows us to construct the two-way mapping

(average velocity, co-moving velocity) ◄─► (seepage velocity of fluid 1, seepage velocity of fluid 2).

Tallakstad et al. [2] provided a constitutive equation between the average velocity and the pressure drop. To construct the constitutive equations for the two seepage velocities, we also need *a constitutive equation for the co-moving velocity*. This is the subject matter of Roy et al. [3]. Having no preconception on what it should look like, we set out to construct the co-moving velocity from data published in the literature in the form of relative permeability curves. By "reverse engineering" these data sets, we could construct the co-moving velocity.

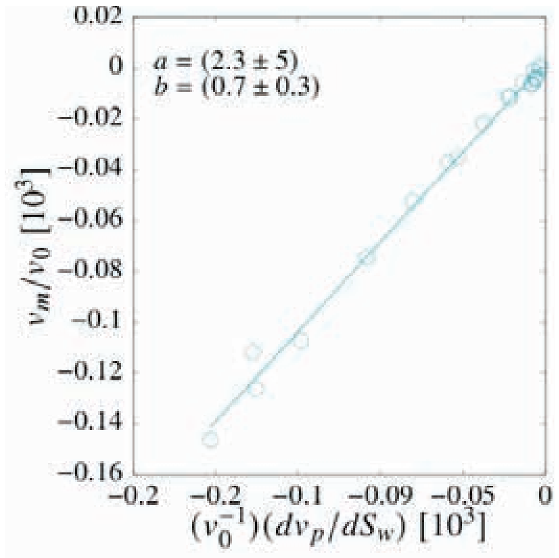
These relative permeability data sets all stem from relatively slow-moving fluids. We also measured the co-moving velocity using a dynamic pore network model, allowing us to explore a much wider set of flow velocities, well into the non-linear regime of Tallakstad et al. [1], where the viscous and the capillary forces compete, and beyond where the viscous forces dominate.

Our remarkable finding was that the constitutive equation for the co-moving velocity is *simple* when expressed using the right variables. When plotted against the derivative of the average velocity with respect to the saturation, it is a *straight line*. And this is true whether the flow is slow, fast or in between.

We illustrate this with the co-moving velocity reconstructed from primary drainage of Berea sandstone [4]. This is Figure 2c in Roy et al. [3]. A velocity scale v_0 has been divided out. The data are consistent with $v_m = a\,v_0 + b\,dv_p/dS_w$, where v_p is the average velocity and S_w is the saturation of the wetting fluid.

The essential question is *why* this form, which seems to apply to a very wide range of flow parameters. Why is the constitutive equation for the co-moving velocity so simple?

We think we are beginning to understand why. If we are right, we have the topic for our contribution to the PoreLab Annual Report for 2022.



RECOMMENDED READING

[1] K. T. Tallakstad, H. A. Knudsen, T. Ramstad, G. Løvoll, K. J. Måløy, R. Toussaint and E. G. Flekkøy, *Steady-State Two-Phase Flow in Porous Media: Statistics and Transport Properties*, Phys. Rev. Lett. **102**, 074502 (2009).

[2] A. Hansen, S. Sinha, D. Bedeaux, S. Kjelstrup, M. Aa. Gjennestad and M. Vassvik, *Relations between Seepage Velocities in Immiscible, Incompressible Two-phase Flow in Porous Media*, Transport in Porous Media, **125**, 565 (2018).

[3] S. Roy, H. Pedersen, S. Sinha, and A. Hansen, *The Co-moving Velocity in Immiscible Two-phase Flow in Porous Media*, arXiv:2018.10187 (2021).

[4] M. Oak, L. Baker and D. Thomas, Three-phase relative permeability of Berea sandstone, J. of Petr. Tech. **42**, 1054 (1990).

FLUCTUATION-DISSIPATION THEOREMS FOR POROUS MEDIA: A NEW ROUTE TO CONDUCTIVITIES

Håkon Pedersen[1], Christian Ulrichsen[2], Dick Bedeaux[2], Signe Kjelstrup[2], Santanu Sinha[3], Øivind Wilhelmsen[2], Alex Hansen[1]

[1] PoreLab, Department of Physics, NTNU, Norway
[2] PoreLab, Department of Chemistry, NTNU, Norway
[3] PoreLab, The Njord Center, Department of Physics, University of Oslo, Norway

Several procedures have been proposed over the years on how to define **porous media conductivities**. The scale and the coarse-graining procedure is essential in this endeavour. To find the transport properties is challenging, since many variables can be involved. We have recently proposed to utilize the system's fluctuations, to determine porous media conductivities.

Pressure fluctuations in porous media are well studied [1], but we have focused on flow fluctuations [2]. Their auto- and cross-correlation functions can be directly related to the extended Darcy law's permeabilities. We have made our investigations using an open source Lattice-Boltzmann model of two-phase flow [3] in CT-scans of a Bentheimer sandstone. The system is filled with equal amounts of components A and B, surface tension between the fluids is 30 mN/m, and a pressure gradient of 100 MPa/m was applied. The flow was measured through a slice perpendicular to the overall flow direction.

The velocity of the wetting component through the medium is shown in fig. 1. The figure shows fluctuations around a well-defined mean value. Can we extract information on the system's conductivities from these fluctuations? The relevant time- and length-scales for the fluctuations of interest are small compared to the slowly varying time- and length-scales in the transport problem.

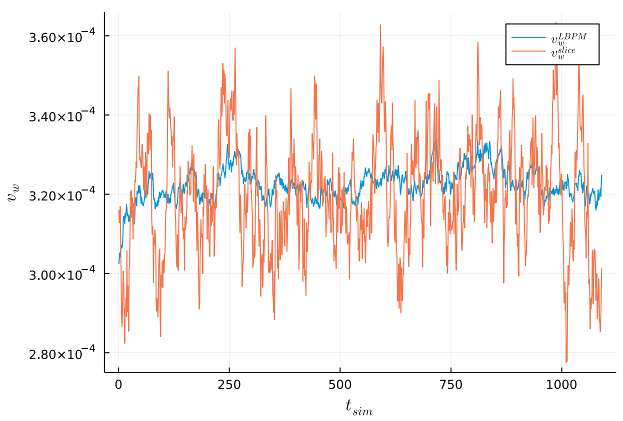


Figure 1: Velocity of wetting fluid from Lattice-Boltzmann flow simulator. The blue line shows the average value of the velocity. Fluctuations appear to be bounded.

A thermodynamic description of porous media transport must handle the size- and shape-dependence of the thermodynamic properties. This poses a challenge, in particular on the nano-scale, but also on the micrometer scale, where there is a difference in phase pressures (a capillary pressure) from the Young-Laplace law. We have proposed a new way to construct average densities of additive variables suitable for integration on the course-grained scale [2], and we have argued that these average densities of the porous medium obey the Gibbs equation. Given the Gibbs equation, we have derived the entropy production using balance equations for the system. The entropy production per unit of length of the total system was obtained by integrating the dissipation function over the cross-sectional area and the length of the system which is at temperature *T*.

$$T\ dS_{irr}\ / dt = - Q_w \rho_w \Delta \mu_w \ - Q_n \rho_n \Delta \mu_n$$

Here Q_i $i = w,n$ are the volume fluxes of the wetting and non-wetting fluids respectively, ρ_w and ρ_n their molar densities, and μ_w and μ_n are their chemical potentials. The resulting flow-

$$Q_w = - L_{ww} \rho_w \Delta \mu_w \ - L_{wn} \rho_n \Delta \mu_n$$

$$Q_n = - L_{nw} \rho_w \Delta \mu_w \ - L_{nn} \rho_n \Delta \mu_n$$

The conductivity matrix L_{ij} can be found by measuring the fluid flows that result from a difference in chemical potentials.

An unexplored option for coefficient determination exists, however. For equilibrium systems, we know from Kubo that coefficients can be computed from auto- and cross-correlation studies of diffusive flows [4]. In Kubo's formulation of the fluctuation-dissipation theorem, there are fluctuating contributions $Q_{j,R}$ (R for random) to the slowly varying average flow, $Q_T = Q_j + Q_{j,R}$. These fluctuations, and not the pressure fluctuations, are used for determination of the coefficients.

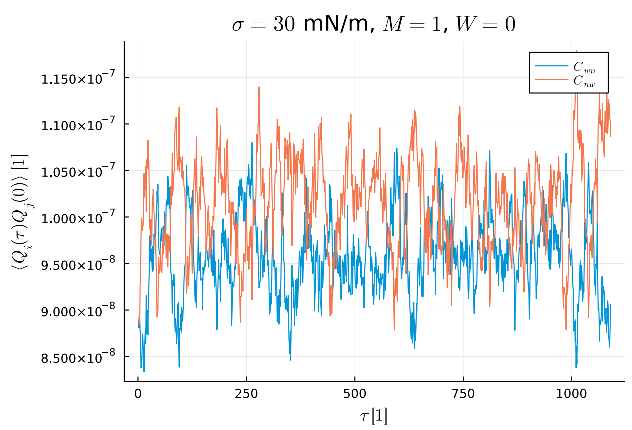


Figure 2: Flux cross correlations for two phase flow in a LB simulator.

The averages of the random contributions are zero, but their correlations are related to the Onsager conductivities. These relations constitute **the fluctuation-dissipation theorem**:

$$\langle Q_{i,R}(x,t)\, Q_{j,R}(x',t') \rangle = \langle Q_{j,R}(x,t)\, Q_{i,R}(x',t') \rangle = 2\, k_B\, L_{ij}\, \delta(x-x')\, \delta(t-t')$$

Symmetry of the Onsager conductivity matrix means that the correlation functions are also symmetric. A first study of the integrated cross-correlation function (averaged over a time τ is shown in fig. 2. The blue and red curve give the wn- and the nw-cross correlation functions, respectively.

Our formulation of the fluctuation-dissipation theorems for porous media is new, and we are thus not able yet to refer to supporting experimental work. In principle, it should be possible to determine random fluctuations, via optical techniques on a Hele-Shaw cell. The first support for the ideas has been obtained from network simulations: Winkler et al. [5] simulated auto- and cross-correlation coefficients of two-phase flow in a honeycomb lattice network. The pore flow was modeled with the Washburn equation. The authors found that the correlation-matrix of the fluctuating component flows were symmetric for relaxation times between 0.001 and 1 second. Our first study with the Lattice-Boltzmann model point to symmetric components in steady-state flow. Systematic studies are now needed to confirm the usefulness of the fluctuation-dissipation theorem as a convenient way to determine the Onsager conductivity-matrix.

ACKNOWLEDGMENT The authors are grateful to the Center of Excellence Funding Scheme of the Research Council of Norway, project no 262644 PoreLab.

RECOMMENDED READING

[1] S Schlüter, S Berg, T Li, H-J Vogel, D Wildenschild, Time scales of relaxation dynamics during transient conditions in two-phase Flow, Water Resour. Res. 2017, 53, 4709—4724

[2]. D Bedeaux, S Kjelstrup, Fluctuation-dissipation theorems for flow in porous media, Entropy 2022, 24, 46. doi.org/10.3390/e24010046

[3]. McClure, J. E., Li, Z., Berrill, M., \& Ramstad, T. (2021). The LBPM software package for simulating multiphase flow on digital images of porous rocks. Computational Geosciences, *http://dx.doi.org/10.1007/s10596-020-10028-9*

[4]. R Kubo, The fluctuation-dissipation theorem, Re. Prog. Phys. 1966, 29, 255

[5]. M Winkler, MA Gjennestad, D Bedeaux, S Kjelstrup, R Cabriolu, A Hansen, Onsager-Symmetry Obeyed in Athermal Mesoscopic Systems: Two-Phase Flow in Porous Media, Front. Phys. 2020, 8, 60.

THERMODIFFUSION AND THERMO-OSMOSIS IN POROUS MEDIA

Bjørn Hafskjold[1], Dick Bedeaux[1], Signe Kjelstrup[1], and Øivind Wilhelmsen[1]

[1] PoreLab, Department of Chemistry, Norwegian University of Science and Technology - NTNU, Trondheim, Norway

When a temperature difference is applied over a porous medium soaked with a fluid mixture, two phenomena may occur simultaneously, thermodiffusion and thermo-osmosis. In general, thermodiffusion leads to a separation of the fluid components while thermo-osmosis leads to a pressure difference. In both cases, the temperature difference is the driving force. This is different from normal diffusion and osmosis, where a concentration difference is the driving force. There are many examples of natural and industrial processes where these effects play a role, such as coupled heat- and mass transport in fuel cell membranes, desalination of water by membrane distillation, the fluid composition in oil and gas reservoirs, frost heave damaging roads at springtime, and formation and growth of salt lenses in the carbon cathode during aluminum electrolysis.

We use nonequilibrium thermodynamics and molecular dynamics to find out more about these phenomena. The model layout is shown in Figure 1 along with typical results from a non-equilibrium molecular dynamics simulation. The fluid is a two-component isotope mixture, and the membrane is a matrix of particles with fixed positions in a FCC lattice. The symmetry of the model layout is due to the use of periodic boundary conditions in the simulations.

The temperature profile was generated by thermostating the fluid in the bulk compartments to different temperatures, while the concentration profile and the bulk fluid pressures are the system's responses to the temperature difference. At steady state, heat is flowing from hot to cold, but there is no mass diffusion or fluid flow despite the concentration and pressure differences. A balance between the three forces is established. This is the combined effects of thermodiffusion and thermo-osmosis.

The Soret coefficient is used to quantify the effect of thermodiffusion. It is defined as

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

where x_i is the mole fraction of component i and T is the temperature.

The Δ means the difference between the hot and cold bulk fluid properties. The subscript $J_1=J_2=0$ means stationary state. The thermo-osmotic coefficient quantifies the thermo-osmotic effect. It is defined as

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

where P is the pressure.

We have found that these coefficients depend strongly on the porosity of the membrane and to some extent on the difference in wettabilities of the two fluid components. Figure 2 shows the effects of the temperature difference across the porous medium on the components separation and the pressure difference in a binary isotope mixture with overall 50/50 fluid composition. If we use a methane/decane mixture in bulk as an example, the result for the Soret coefficient means that a temperature difference of 10 K will separate the mixture to about 49.5/50.5 and give no pressure difference. In a hydrocarbon reservoir with 30% porosity, the separation will be 49.9/50.1 whereas the pressure difference will be about 15 bar. This large difference is a consequence of the fact that the system used in this work is a closed system, whereas a reservoir is an open system. The hydrostatic and thermo-osmotic pressures are therefore not additive. However, thermo-osmotic pressures of this order of magnitude have been measured in laboratory experiments on frost heave.

We have shown that thermodiffusion and thermo-osmosis will occur simultaneously as coupled processes in a porous medium and as such a unique feature of the porous medium, unlike bulk fluids.

RECOMMENDED READING

B. Hafskjold, D. Bedeaux, S. Kjelstrup, and Ø. Wilhelmsen, Soret separation and thermo-osmosis in porous media (in preparation)

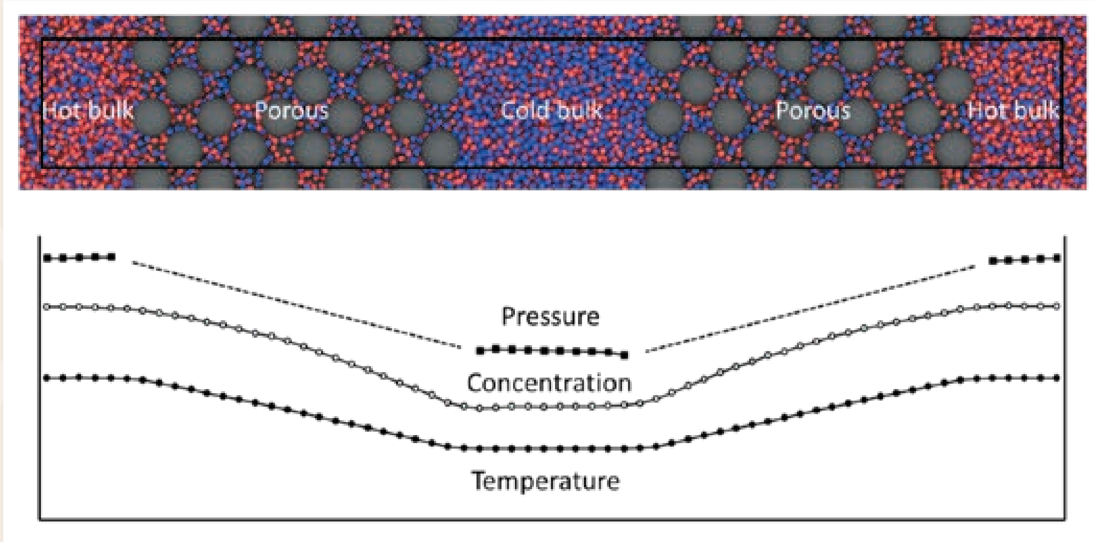


Figure 1. Model system with two porous membranes and bulk fluid on each side. The graph shows the imposed temperature profile and the system's response with pressure and concentration profiles.

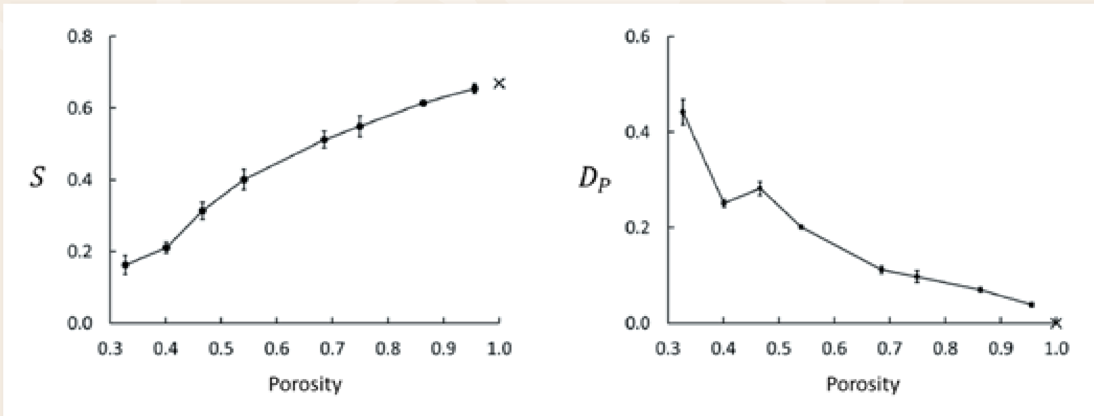


Figure 2. Soret coefficient (left) and thermo-osmotic coefficient (right) as function of porosity. The crosses mark the values in a bulk fluid without a porous medium present. Note that the values of S and D_P are given in dimensionless units scaled by potential parameters in the fluid model.

SUPER-DIFFUSIVE MELTING IN FROZEN ROCKS OR SOILS

Eirik Grude Flekkøy[1], Alex Hansen[2] and Erika Eiser[2]

[1] PoreLab, The Njord Center, Department of Physics, University of Oslo, Norway
[2] PoreLab, Department of Physics, NTNU, Norway

The melting of water in frozen soils or rocks may be strongly affected by freezing point depression. This thermodynamic effect, which causes melting at sub-zero temperatures may be important in frost-heave and melting of tundras.

Water that freezes in porous media will still leave pockets of liquid water in pores that are sufficiently small. This is due to the Gibbs-Thomson effect and causes a residual concentration of liquid water that may be several 10's of degrees below the bulk freezing temperature. As heat passes through such a system some of the ice melts, but the heat by-passes all the pores in which the water is not at the melting point determined by the pore size. Consequently, the melting front spreads out and causes water to melt at much larger depths than it would without the freezing point depression effect. When described analytically this process may be shown to give rise to super-diffusive behavior. In some cases it may even result in hyper-ballistic spreading of the liquid concentration. Experimental studies are on the way to observe this effect by optical means.

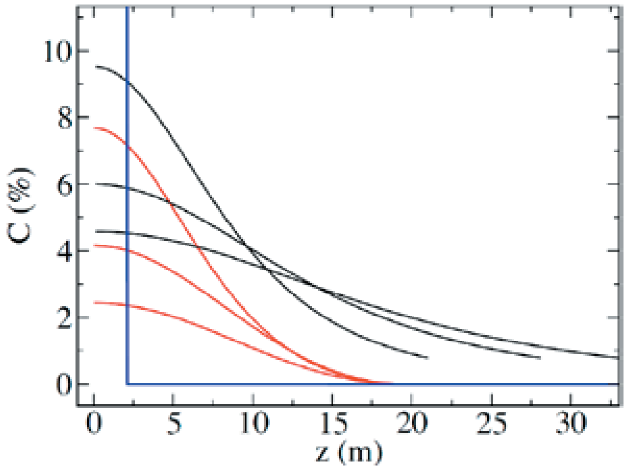


Figure 1. Concentration of liquid water with depth. The blue curve shows the case with no freezing point depression, the colored curves the case where pores freeze/melt at different temperatures depending on the pore size.

RECOMMENDED READING

Hyperballistic superdiffusion and explosive solutions to the Non-Linear diffusion equation. Eirik G. Flekkøy, Alex Hansen and Beatrice Baldelli, *Frontiers in Physics*, **9**, 640560 (2021)

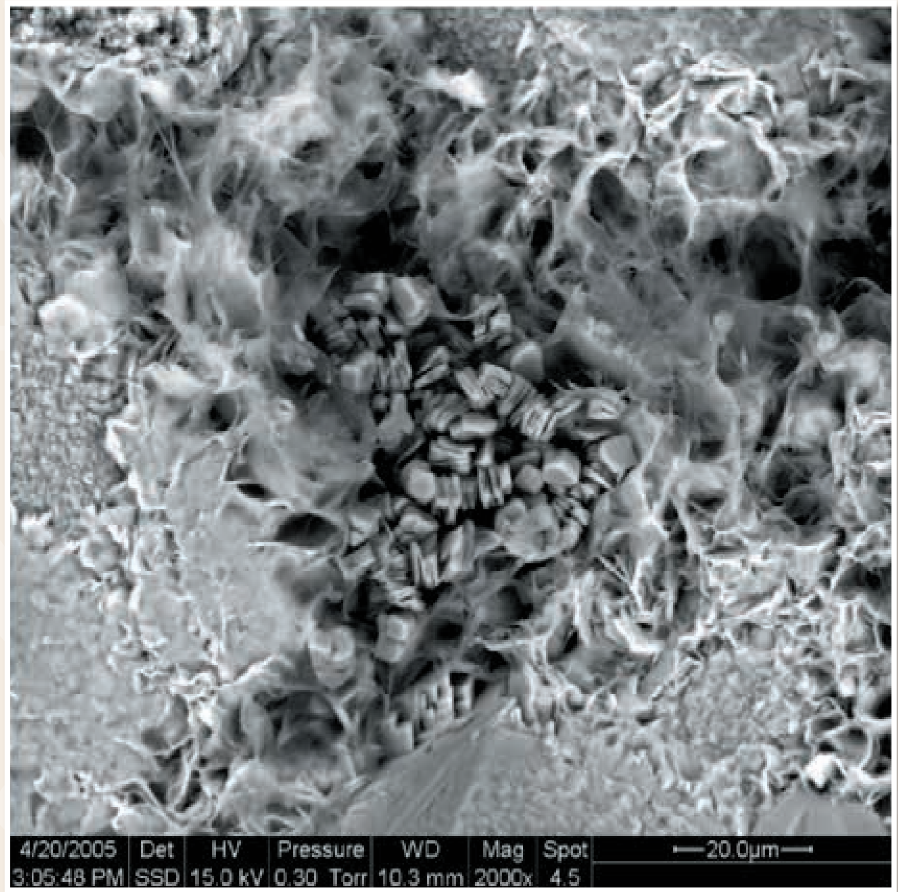


Figure 2. Micron- to nanopores that may contain frozen water.

RESEARCH PROJECTS – **STATISTICAL PHYSICS OF POROUS MEDIA**

BURST DYNAMICS, UPSCALING AND DISSIPATION OF SLOW DRAINAGE IN POROUS MEDIA

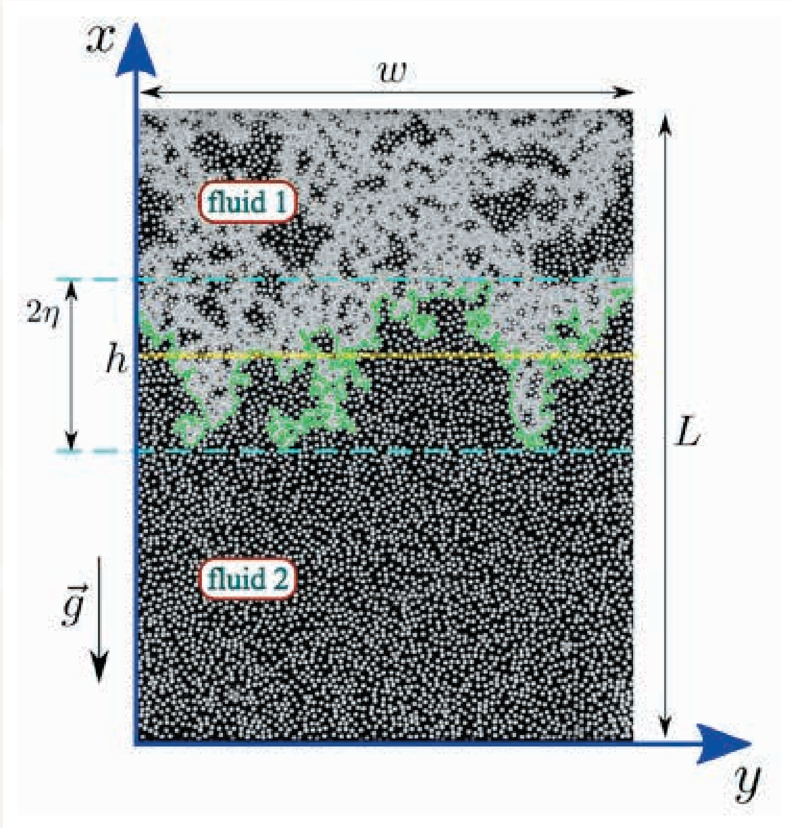
Knut Jørgen Måløy[1], Marcel Moura[1], Alex Hansen[2], Eirik Grude Flekkøy[1], and Renaud Toussaint[1]

[1] PoreLab, The Njord Center, Department of Physics, University of Oslo, Norway
[2] PoreLab, Department of Physics, University og Science and Technology (NTNU), Trondheim, Norway
[3] CNRS, Institut Terre et Environnement de Strasbourg, University of Strasbourg, Strasbourg, France

The enormous diversity of scales is one of the most challenging and fascinating features of porous media science. Hydrocarbon reservoirs or water aquifers are in the range of kilometers. Pores are typically ten to hundred micrometers in diameter, or seven orders of magnitude smaller. How can we infer large-scale flow dynamics from small-scale physics? A top-down approach using Darcy's law on a mesoscopic level is commonly used to solve these problems. However, this approach does not take into account local fluctuations, like capillary or viscous fluctuations, which are averaged out. In this work, we choose a bottom-up approach where we compare the capillary fluctuations with the characteristic forces which are set up by the external fields on the system which are gravitational or viscous fields. The work is limited to slow displacement of stabilized drainage fronts. We demonstrate how dissipation at small scales is related to dissipation at larger scales, as well as how we can predict saturation, dissipation, and surface energy at large scales if we know the characteristic length scales set by the characteristic forces involved. Furthermore, our theoretical description explains how the Haines jumps' local activity and dissipation relate to dissipation on larger scales. In a consistent description, the presented theory is compared to both previous and new experiments. When considering a viscous and gravitational field, the theory describes well the scaling of the width of the fluid front and the final saturation of the fluid left behind the invasion front observed in experiments. The characteristic width of the front is thus of primary importance in defining a relevant Representative Elementary Volume REV for an average Darcy description of the two-phase flow problem.

RECOMMENDED READING

[1] Knut Jørgen Måløy, Marcel Moura, Alex Hansen, Eirik Grude Flekkøy, and Renaud Toussaint. (2021). Burst Dynamics, Upscaling and Dissipation of Slow Drainage in Porous Media. Front. Phys. 9:796019. doi: 10.3389/fphy.2021.796019



A model experiment of a nonwetting fluid 1 (air, lighter color) invading another wetting fluid 2 (glycerol-water mix, darker color) in a porous model of width w and length L. A syringe pump is connected to the lower side and the model is open to air on the upper side. The model can be tilted with an effective gravitational constant $g=g_0 \sin(\theta)$ along the x direction of the model, where $g_0 = 9.82\ m/s^2$. The average position of the active front (seen in green) is h and the width of the front is 2η.

THE ROLE OF ADSORBED LAYERS AND THIN FILMS IN POROUS MEDIA

Ø. Wilhelmsen,[1,†], and M. Aa. Gjennestad[2]

[1] PoreLab, Department of Chemistry, Norwegian University of Science and Technology, Trondheim, Norway
[2] PoreLab, SINTEF Energy Research, Trondheim, Norway

Glancing at the surface of an office desk, it may appear dry. After all, no coffee has been spilled yet. However, if you could observe the table surface through an atomic force microscope, you would be able to detect a thin layer of water molecules covering the entire table. Since the adsorbed layer is only a few molecular diameters thick, it cannot be seen by the naked eye. For most practical purposes, the adsorbed water layer can safely be neglected in regular systems. However, this is not necessarily true for porous media. Because of the high surface-to-volume ratio of porous materials, the amount that is adsorbed can be large. Let us take stone wool as example. This is a typical insulation material used in the walls of our houses to keep us warm, or in the industry to prevent loss of heat to the ambient. Even though stone wool consists of 98% air on a volumetric basis (see Fig. 1), about 95% of the water molecules are adsorbed on the fibers of the porous material at a relative air humidity of 70%. Stone wool is not the only example of relevance. Adsorption has made porous materials like zeolites and metal organic frameworks (MOFs) candidates to store hydrogen or capture CO_2 or methane to combat global warming. To describe heat and mass transport into these porous media, it is necessary to understand the interplay between adsorption, desorption and other transport mechanisms like diffusion and convection. Let us revisit stone wool; if the adsorption kinetics is very quick, the adsorbed layer can be assumed to be in local equilibrium with the vapor phase. The equilibrium water content of the porous medium can then be characterized by the sorption isotherm, where an example is shown in Figure 2. The figure shows the amount of water adsorbed in the porous material as a function of the relative air humidity (RH), where the profile shown in the figure is relatively independent of temperature.

In many cases, like in Fig. 2, the vapor is not in equilibrium with the adsorbed phase in the porous medium. This can be seen by the large difference between the desorption and the adsorption isotherms in the figure, despite of a 70-hour duration of the experiment. Predictive theories to describe this discrepancy are currently lacking.

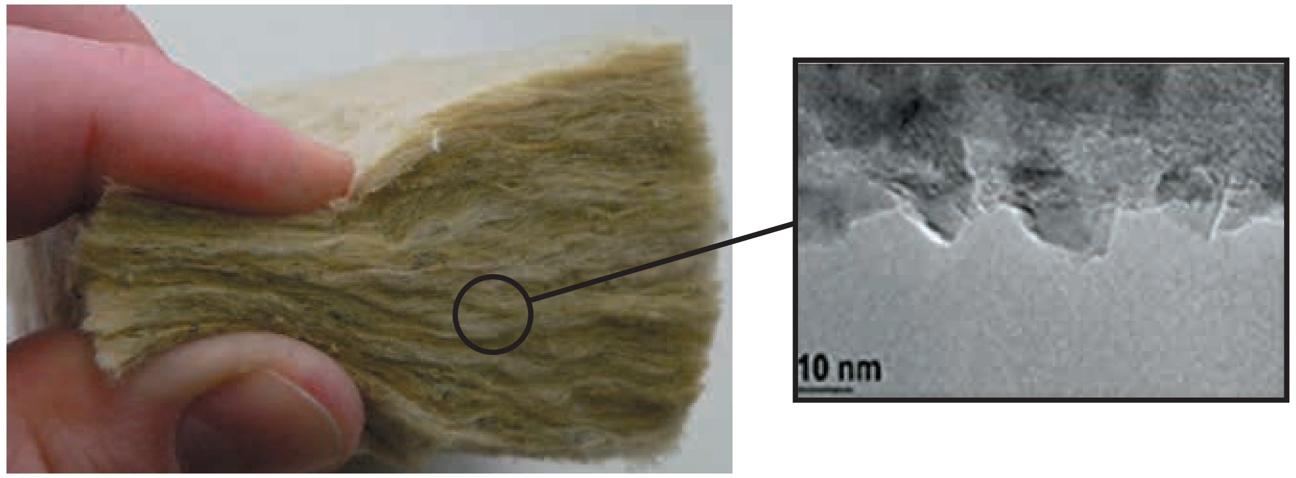


Fig. 1 Illustration of a piece of stone wool insulation material which is highly porous. By using a Scanning Transmission Electron Microscope, we can detect an interesting nanoscale structure at the surfaces which can influence adsorption.

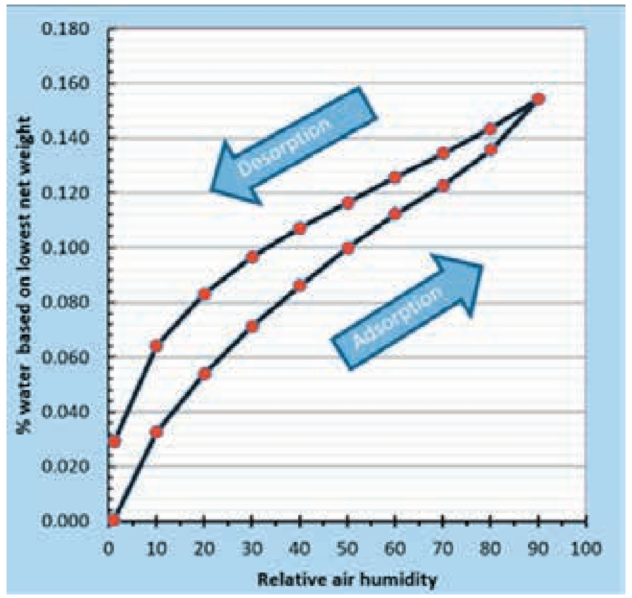


Figure 2. Amount of water in a sample of stone wool as function of the relative air humidity during adsorption and desorption during a 70 hour experiment.

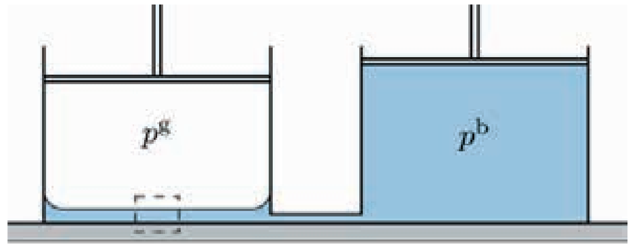


Figure 3. An illustration of the disjoining pressure concept. The left container contains an adsorbed layer (blue) and a bulk gas phase (white) with pressure p^g and the right container contains a bulk liquid phase with pressure p^b. As indicated by the curved liquid menisci along the walls of the left container, $p^g \neq p^b$. The disjoining pressure is then defined by $\Pi = p^g - p^b$.

Similar to evaporation and condensation, adsorption and desorption is associated with a latent heat that can cause local cooling and warming effects. To account for this in a description of flow through the porous medium, models and methods are needed to describe the thermodynamic properties of the adsorbed phase, such as its enthalpy and heat capacity.

It is an open research question how adsorbed phases migrate through the porous medium. Sufficiently thick films can migrate through the porous medium driven by gradients in the capillary pressure. Adsorbed layers are often assumed to be stagnant, but the exact nature of the adsorbed phase can be unknown. For instance, if an adsorbed layer coexists with small droplets that reside on the surface of the porous matrix, the droplets can have a higher mobility than the adsorbed layer.

There is not a clear distinction in the literature between an "adsorbed phase" and a "thin film". A "thin" film is characterized by thermodynamic properties that deviate from those of a bulk liquid phase at the same temperature and chemical potential. This deviation can be modeled by using a disjoining pressure, a concept first introduced by Derjaguin in the 1930s. The concept is illustrated in Fig. 3. Typical models for the disjoining pressure diverge when the thickness of the film goes to zero, and they can fail to describe adsorbed layers that are only a few molecular diameters thick. Adsorbed layers are usually described with statistical mechanical models such as the Langmuir or the Brunauer-Emmett-Teller Methods. A theory that bridges these two descriptions and provides a thermodynamic theory both at equilibrium and nonequilibrium for adsorbed phases/thin films is currently missing. In particular, the curvature and shape of pores might influence the adsorption characteristics, which is not accounted for in present formulations. Such a theory would be very valuable in the description of transport through porous media for examples were adsorption is of importance, such as hydrogen adsorption in MOFs and zeolites as well as water migration in insulation materials. We foresee that new tools, techniques and a close collaboration between experimentalists, simulators and theoreticians is needed to progress on this topic.

RECOMMENDED READING

[1] Churaev, N. V.; Derjaguin, B. V.; Muller, V. M. Surface Forces; Springer: New York, 1987.

[2] Gjennestad, M. Aa; Wilhelmsen Ø.; Thermodynamic Stability of Volatile Droplets and Thin Films Governed by Disjoining Pressure in Open and Closed Containers Langmuir; 36, 7879−7893, 2020.

[3] MacDowell, L. G.; Computer simulation of interface potentials: Towards a first principle description of complex interfaces. Eur. Phys. J.: Spec. Top. 2011, 197, 131−145.

CAPILLARY PUMPING: THE SPREADING OF POLLUTION IN POROUS MEDIA

Marcel Moura[1], Joachim Falck Brodin[1], Per Arne Rikvold[1], Eirik Grude Flekkøy[1] and Knut Jørgen Måløy[1]

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

If you look at a rain drop rolling down a car's windshield you will see that it frequently leaves behind a thin water trail. As the drop moves down the glass, the area just behind it does not get immediately dry: a thin water film persists, sometimes even for a long time after the drop passes by. If the glass surface were not so smooth, such films would remain for much longer, and this is precisely what happens inside porous media like natural soils and rocks. When a wet portion of the soil gets dry, say after some hours of sunshine following a storm, thin liquid films remain on the surface of the soil grains. These thin films bring an interesting consequence: they can interconnect different parts of the soil, like a whole set of water bridges forming a large network of water streets and avenues. Plant roots can use this network to obtain nutrients from far away, but pollutants can also take a high-speed road to spread quickly in the soil (see figure). In this project, we are interested in understanding the dynamics of the transport of polluted water through a network of thin water films in a porous medium. This is analogous to the scenario in which some polluted water is spilled on the ground and starts to seep through the porous space. We employ artificial porous samples in our study (either made of glass or 3D printed in a transparent plastic) which allow us to directly track the motion of the pollutant. We have observed that the residual water content in the sample (how wet or dry the soil is) plays a key role in the pollution spreading dynamics. We have found that for intermediate residual water content, the thin liquid films in the sample behave as a network of tiny pumps, which act to spread the pollution very quickly. Once this behavior is properly understood, we believe it will allow us to understand how we can make use of the thin film network for soil remediation measures. The same transport mechanisms that aid the pollution spreading can be tailored to spread a cleaning agent in the soil, to remediate the damage caused by the pollution.

RECOMMENDED READING

[1] Marcel Moura, Joachim Falck Brodin, Per Arne Rikvold and Knut Jørgen Måløy, Capillary pumping: the spreading of pollution in a porous medium (in preparation).

[2] Marcel Moura, Eirik Grude Flekkøy, Knut Jørgen Måløy, Gerhard Schäfer and Renaud Toussaint, "Connectivity enhancement due to film flow in porous media," *Phys. Rev. Fluids 4, 094102 (2019)*.

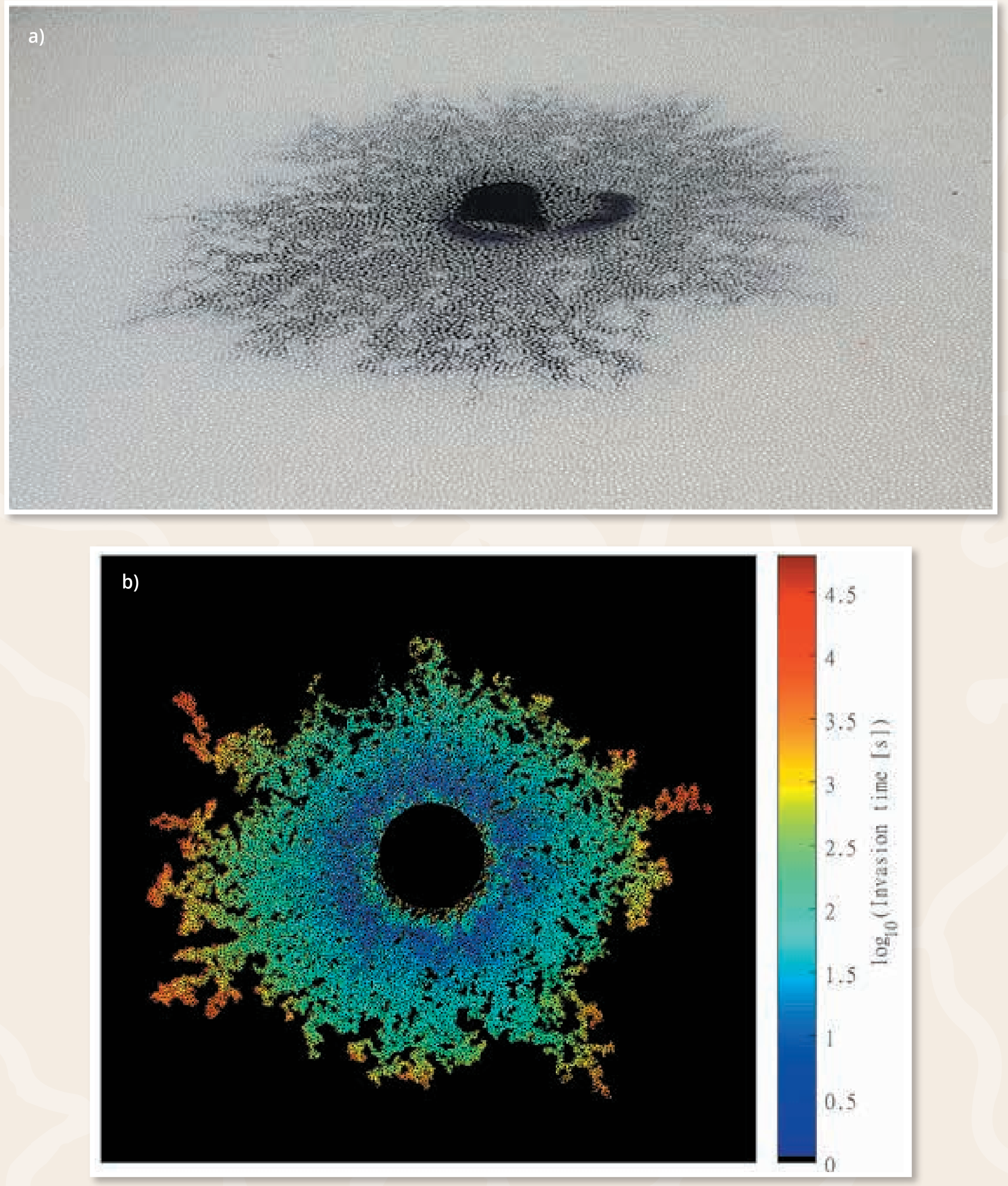


Figure: a) Experiment illustrating how a source of pollution (central dark blob) spreads through a partially wet porous network (here made of glass beads). Water films covering the internal surfaces of the porous medium can act as a fast pathway for the spreading of pollution. b) Spatiotemporal invasion map of a typical experiment. The color code shows the time (in seconds, logarithmic scale) for the pollution to reach a given point in the network.

DISPLACEMENT UNDER DIFFERENT WETTING PROPERTIES AND VISCOSITY RATIOS

Salem Akarri[1], Mohamed Omran[1], Danial Arab[2] and Ole Torsæter[1]

[1] PoreLab, Department of Geoscience and Petroleum, NTNU, Trondheim, Norway
[2] University of Calgary, Calgary, Canada

Wettability, viscosity ratio, pore structure and injection rates are considered the governing parameters for multiphase flow in porous media. For drainage of subsurface reservoirs, all these parameters are widely varying. For drainage of oil reservoirs, extreme viscosity ratios are found in heavy oil fields in Canada, and these reservoirs have served as motivating examples for the current studies.

To investigate the distribution of fluids under different wetting conditions, viscosity ratios, and flow rates, we have used micro-models. These micro-models consist of an etched pore-structure squeezed between two glass-plates. The opaque glass enables optical inspection of the fluid distribution inside the model. To enlarge the color contrast between the fluids, we use color agents.

The glass models are originally water-wet. This wettability was altered using a methodology developed in the reservoir lab in Trondheim. The micro-models are thereby injected with a solvent containing SurfaSil as the active solute. The SurfaSil will coat the surface and make the surface more oil-wet. The resulting fluid distribution in one experiment after wettability alteration is shown in Fig. 1. We observe that the contact angles are in the range of 150-160 degrees, which is considered oil wet. The contact angles in an untreated model are in the range of 60-70 degrees, and intermediate wettability can be obtained by changing the solute concentration and duration of treatment.

The effect of flooding under different wettability conditions are clearly seen in Fig. 2. The displacement under water-wet conditions is much more piston-like than the other displacements. We also observe by-passed oil for the intermediate- and oil-wet conditions. For the oil-wet case, the by-passed oil can be drained after the front has passed through thin oil films which connected the by-passed oil with the oil at the outlet.

For the experiments with different viscosity ratios, we used the same deionized water, while the oil viscosities varied from 1.7E-3Pas to 14.8Pas. The models were kept oil-wet. We observe distinctly different displacement behavior for the different viscosities. For all viscosity ratios, the recovery increased with increased flow rate. When comparing different flow rates, there was a significant increase in recovery when the pressure drop over the sample was similar to the capillary entry pressure for an average pore-throat size. This effective breakthrough pressure $P_{(c\text{-}ebt)}$ was thus found to be a function of permeability and oil viscosity.

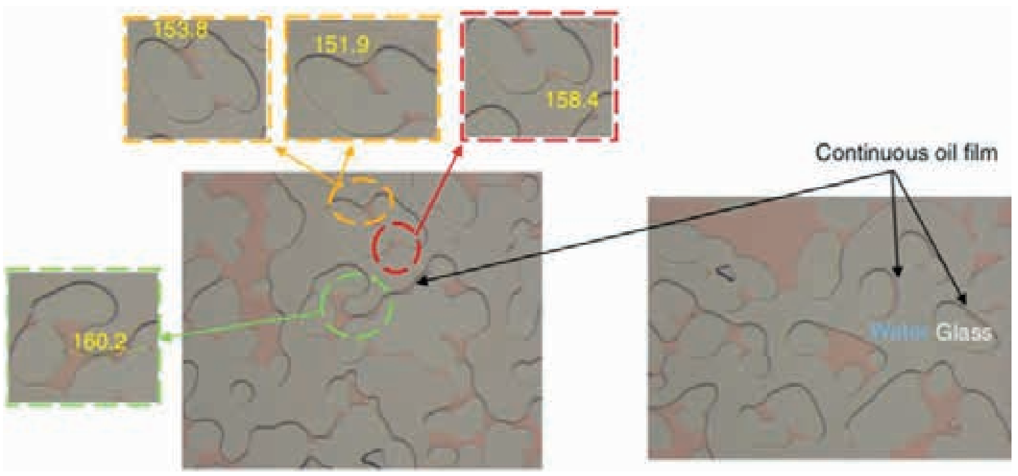


Figure 1. Image of a part of a micromodel, showing the glass model in gray, water in a similar gray color, and oil with a light red color. The contact angle at several three-phase contact points are highlighted. This figure is from reference [2].

We used the effective breakthrough pressure to define a viscous drainage number as:

$$\frac{L\Delta P - P_{c-ebt}}{\sigma/\sqrt{K/\phi}}\frac{\mu_w}{\mu_o}$$

As seen in Fig. 3, there is a good correlation between the introduced viscous drainage number and the residual saturation after displacement. This viscous drainage number can thus be used to predict the residual saturation for different viscosity ratios and flow rates.

RECOMMENDED READING

[1] Omran, Mohamed, Salem Akarri, and Ole Torsæter. "The effect of wettability and flow rate on oil displacement using polymer-coated silica nanoparticles: a microfluidic study." Processes 8, no. 8 (2020): 991.

[2] Arab, Danial, Apostolos Kantzas, Ole Torsæter, Salem Akarri, and Steven L. Bryant. "A Crucial Role of the Applied Capillary Pressure in Drainage Displacement." SPE Journal 26, no. 04 (2021): 2148-2166.

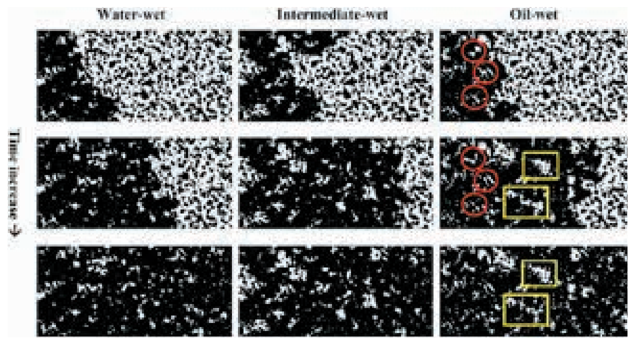


Figure 2. Water (white) and oil (black) in a micro-model with solid phase also shown in black. We observe clearly different displacements under different wetting conditions, depending on time, for equal flow rates. Figure is from reference [1].

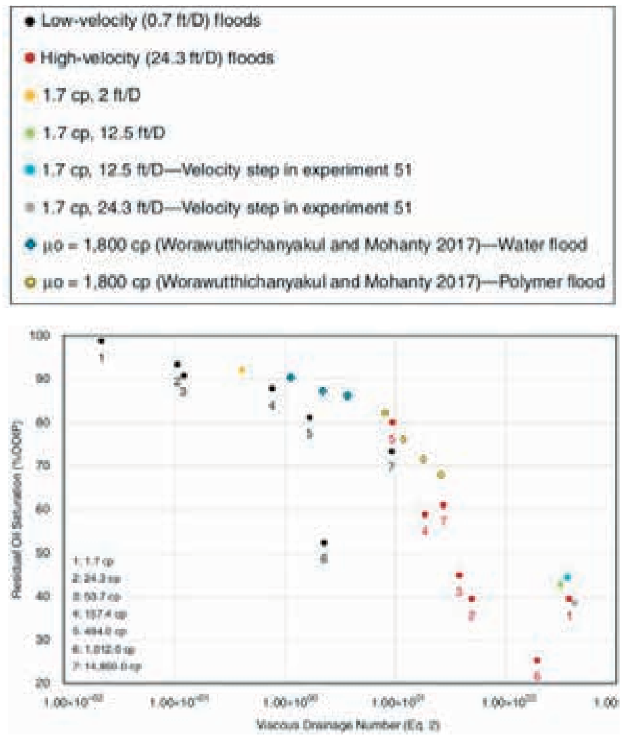


Figure 3. Cross-plot of the residual oil saturation versus the introduced viscous drainage number. Plot from reference [2].

TUNABLE INTERACTIONS INSIDE DEFORMABLE POROUS MEDIA

L. Thorens[1,2], K. J. Måløy[1], M. Bourgoin[2], S. Santucci[2], E. G. Flekkøy[1]

[1] PoreLab, The Njord Centre, Department of Physics, University of Oslo, Norway
[2] University of Lyon, ENS de Lyon, Université Claude Bernard, CNRS, Laboratoire de Physique, F-69342 Lyon, France

Interactions between grains are known to affect the shape and the behavior of a granular assembly. We propose to use ferromagnetic grains (typically steel), which acquire a magnetic momentum under the influence of an external magnetic field, leading to grain/grain interactions inside the medium.

First, we highlighted the existence of a novel tunable magnetic Janssen effect in a static grain column (fig. 1) where we can control the pressure exerted on the walls even for a mixture of ferromagnetic and non-ferromagnetic particles [1-2]. Second, based on the static observations of a ferromagnetic granular medium, we propose to look at a classical granular dynamic system: the discharge of a silo. Based on the observations of [3], we study a magnetic hourglass (fig. 2) where we highlight the apparition of a stick-slip behavior during the discharge [4]. Finally, we investigate the bulldozing experiment previously discussed by [5] where a bead/liquid mixture is slowly sucked out of confined geometry. Based on our results on ferromagnetic granular physics, we intend to control the apparition of the bulldozing instability (fig. 3) and its resulting pattern.

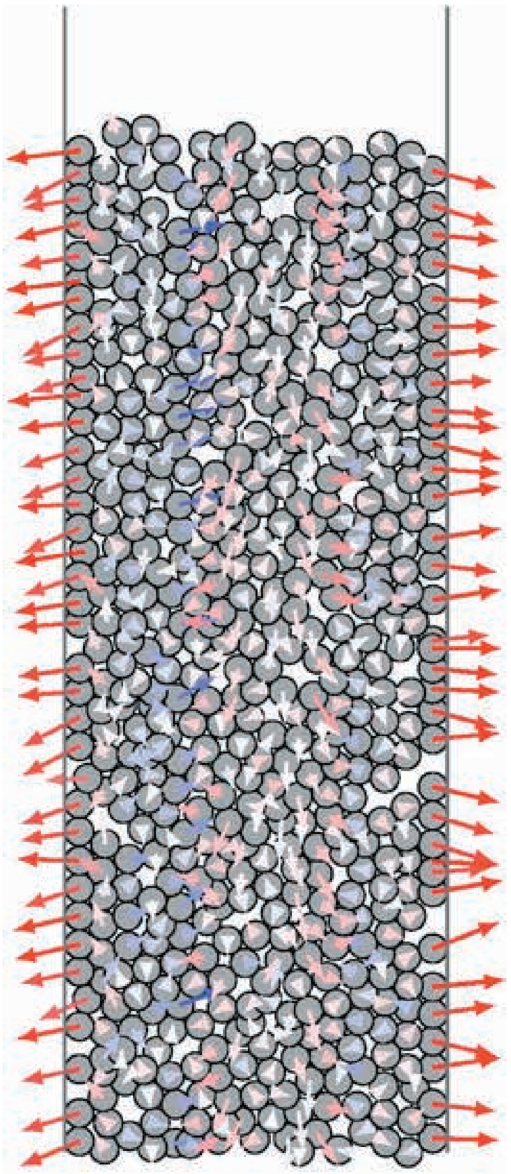


Figure 1. Local forces in a magnetic Janssen configuration

RECOMMENDED READING

[1] Thorens L., K. J. Måløy, M. Bourgoin, S. Santucci, (2021), "Magnetic Janssen Effect", Nature Communications, 12:2486, *https://doi.org/10.1038/s41467-021-22722-y*
[2] Thorens L., K. J. Måløy, M. Bourgoin, S. Santucci, (2021), "Tamming the Janssen Effect", EPJ, **249**, 08004,
[3] G. Lumay, N. Vandewalle, (2008) "Controlled flow of smart powders", Phys. Rev. E 78, 061302.
[4] Thorens L., M. Viallet, K. J. Måløy, M. Bourgoin, S. Santucci, (2021) "Discharge of a 2D magnetic silo", EPJ, **249**, 03017
[5] G. Dumazer, B. Sandnes, M.Ayaz, K. J. Måløy, E. G. Flekkøy, (2016), "Frictional Fluid Dynamics and Plug Formation in Multiphase Millifluidic Flow." Phys. Rev. Lett., **117**, 028002

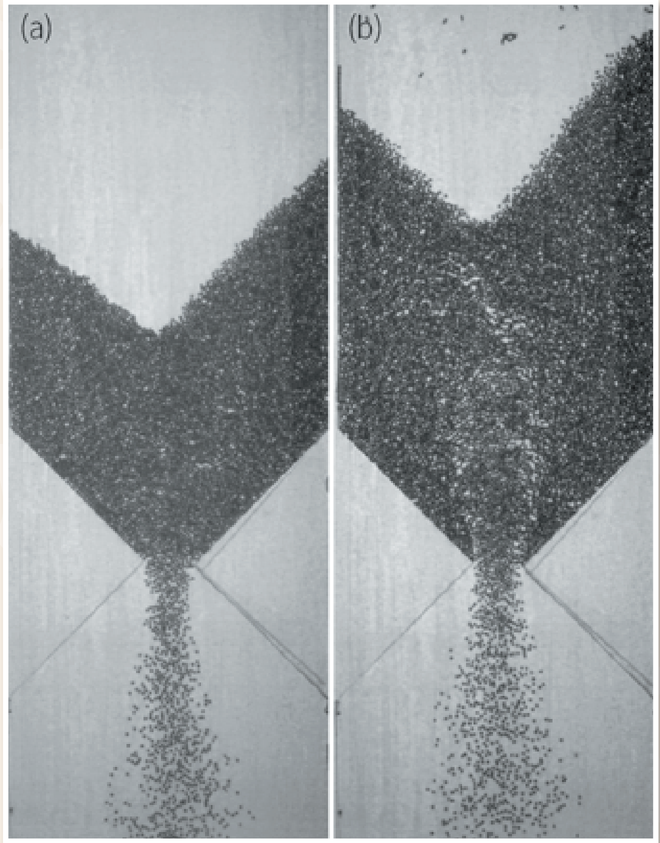


Figure 2. Discharge of a 2D-silo filled with ferrromagnetic particles (a) In the absence of external magnetic field, the granular flow is continuous. (b) With a strong external magnetic field normal to the plan, strong density fluctuations appear inside the granular packing

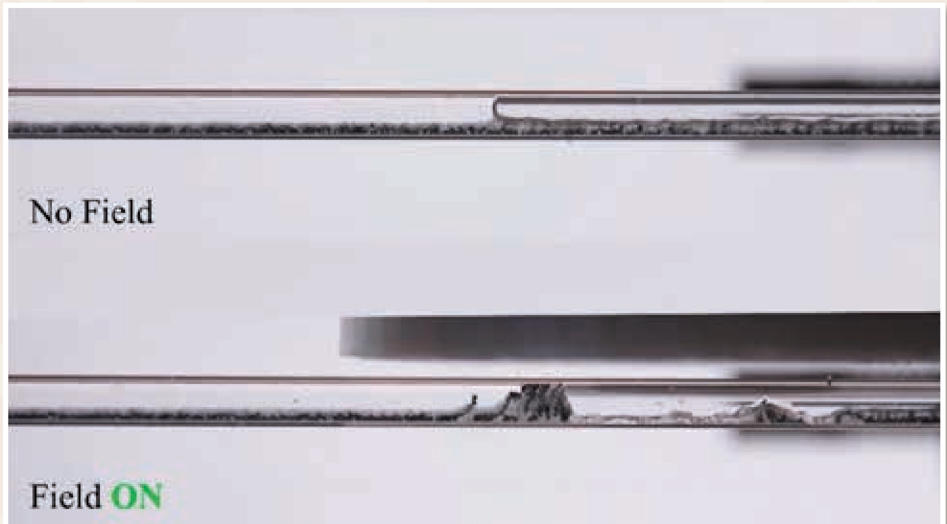


Figure 3. Using ferromagnetic interactions, the bulldozing instability is triggered. The right side is being invaded by air. There is no magnetic field and no bulldozing in the upper figure. The magnetic field is activated in the lower figure by the formation of a particle plug.

COLLOIDAL AND POLYMER NETWORKS AS MODELS FOR POROUS MODEL SYSTEMS

A. Hansen[1], E. G. Flekkøy[2], T. Erdem[3], R. Cabriolu[1] and E. Eiser[1,4]

[1] PoreLab, Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway
[2] PoreLab, The Njord Center, department of Physics, University of Oslo, Norway
[3] Department of Electrical-Electronics Engineering, Abdullah Gül University, Kayseri 38080, Turkey
[4] Cavendish Laboratory, Dept. of Physics, Univ. Cambridge, Cambridge CB3 0HE, UK

Understanding and predicting transport of complex fluids or heat through porous materials remains a challenging exercise. This is because every individual porous material, whether it is a clay-rich soil, the porous structure of bone tissue, or the cathode material in rechargeable lithium-ion batteries, will depend on the individual pore-sizes distribution and the interaction between the porous material and the property being transported. Recently developed theory for heat transport though nanoporous media [1] predicts hyper-ballistic diffusion when the material's average pore-size distribution is both lower than a few nanometer and displays a logarithmic scale. This represents an opportunity to determine size distributions of various nanoporous materials by simply measuring the transport properties, thus replacing highly difficult and often indirect techniques such as NMR. The Eiser group used DNA- and synthetic-polymer functionalized particles to design percolating colloidal networks with well-defined pore-size distributions – see Fig. 1 [2]. Having developed synthesis routes for colloids of different materials and size we are now able to design porous samples with well-defined nano-porous distribution. One project focuses on the flow of complex fluids through such nano-porous materials embedded in microfluidic devices. Moreover, we can use these systems to verify the theories on hyperdiffusion of heat.

In a separate project we study hydrogels made of Pluronic®, which are commercially available, symmetric triblock copolymer surfactants. They show solvent mediated micellization upon heating the sample. Hence, at high enough Pluronic concentrations and temperatures the micelles crystallize reversibly into soft, cubic crystals [5]. Conversely, at low temperatures all polymer chains will be dispersed as unimers in aqueous solutions. A phase diagram is shown in Fig. 2.

Here we aim to study and explore the mechanical and structural properties of such hydrogels. In particular, functionalizing these gels with bio-molecules such as DNA and antigens may lead to measurable volume changes of the gel phase. Such volume changes can then be explored in the presence of other biomolecules and exploited in the development of bio-sensors. Another application lies in designing nano-actuators.

The phase diagram dramatically changes when the Pluronic chain ends are functionalized with DNA such that at low temperatures the individual chains can concatenate into long polymer chains due to DNA-hybridization, which in turn can form an entangled, viscoelastic polymer network. At intermediate temperature the DNA-bond will

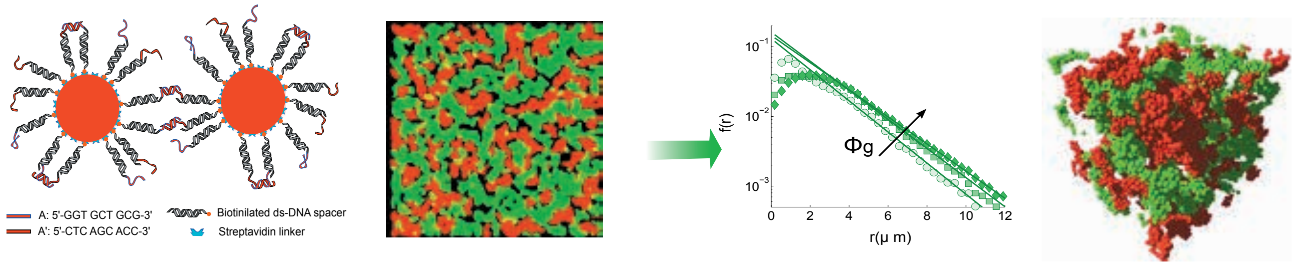


Figure 1. Experimental and simulation data of bicontinuous colloidal gels, known as bigels [3]. Left to right: Cartoon of DNA functionalization of red fluorescent polystyrene particles. Grafting double-stranded (ds)DNA with commentary sticky single-stranded (ss)DNA, α and α', allows the colloids to bind to each other below the DNA's melting temperature. Similarly green fluorescent particles can be prepared, using β and β' ssDNA such green colloids can only bind to green ones, but not to red colloids. These form 3D percolating colloidal gels, as shown in the binarized microscopic image shown here, using a total colloidal volume fraction of 20%. Using cord-analysis of these images we can extract the systems poresize distribution. The rightmost image shows a simulation snapshot of such a bigel [3, 4].

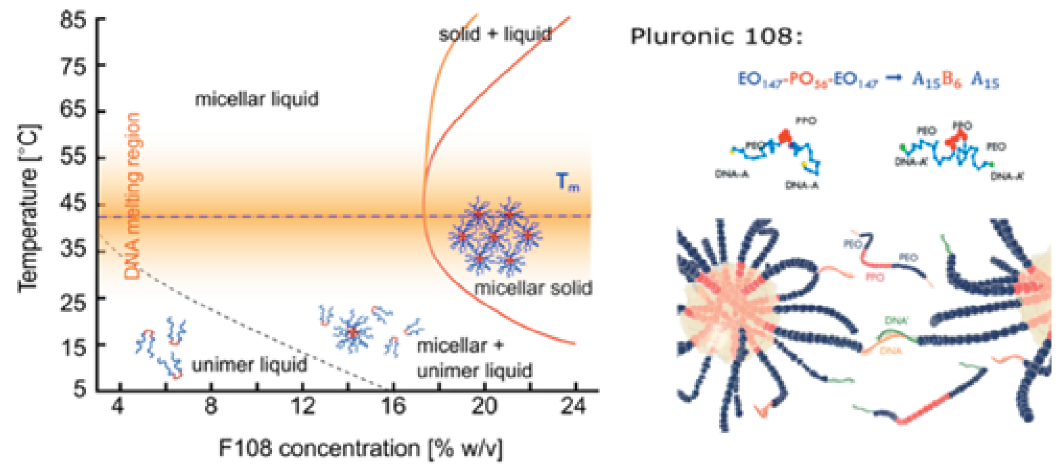


*Figure 2. Left: Phase diagram of pure Pluronic® F108 in deionized water, studied in the Eiser group. Right: Coarse-grained model of F108. Functionalizing half the chains with ssDNA **A** and the other half with the complementary **A'** leads to chain formation at low temperatures rendering the phase diagram of F108 increasingly complex.*

compete with the solvent driven micellization of the unimers leading to mechanical strains that may lead into inhomogeneities in the sample. By mapping our system onto a course-grained bead-spring model of the chains, with sticky end groups representing the DNA, we explore such as larger network as function of temperature. In particular, the length and therefore melting temperature of the DNA sticky ends can be easily shifted up and down, giving us an extra handle to tune the systems phase behavior.

RECOMMENDED READING

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

[2] M. Zupkauskas, Y. Lan, D. Joshi, Z. Ruff & E. Eiser 'Optically Transparent Dense Colloidal Gels', *Chemical Sciences* **8**, 5559 (2017).

[3] L. Di Michele, F. Varrato, J. Kotar, S.H. Nathan, G. Foffi, E. Eiser 'Multistep kinetic self-assembly of DNA-coated colloids' *Nature Communications* **4**:2007 (2013).

[4] F. Varrato, L. Di Michele, M. Belushkin, N. Dorsaz, S.H. Nathan, E. Eiser, G. Foffi, PNAS, 10.1073/pnas.1214971109 (2012).

[5] E. Eiser, F. Molino, G. Porte and O. Diat, *Phys. Rev.* E, **61**, 6759 (2000).

LITHOFACIES CLASSIFICATION FROM WHOLE CORE CT-SCAN IMAGES

Kurdistan Chawshin[1], Carl Fredrik Berg[1,2], Damiano Varagnolo[1,3] and Olivier Lopez[4]

[1] BRU21 – NTNU Research and Innovation Program on Digital and Automation Solutions for the O&G Industry
[2] PoreLab, Department of Geoscience and Petroleum, NTNU, Trondheim, Norway
[3] Department of Engineering Cybernetics, NTNU
[4] Equinor ASA, Trondheim

When classifying rock materials, a lithofacies is a unit that can be distinguished by its depositional environment, mineralogy, grain size, grain sorting, cementation etc. Lithofacies classification is an essential step for characterizing (subsurface) rocks and understanding their depositional environment. When drilling wells into subsurface reservoirs, it is traditional to use different logging techniques to infer the subsurface lithology. Down-hole logs due to their poor resolution (centimeter scale), typically overlook small-scale heterogeneities. Extracting core material from wells is expensive, but valuable for higher resolution description of the subsurface and the possibility to do experiments directly on core material.

Currently, the whole cores extracted from wellbores are described through direct visual inspections. However, this process is time-consuming, and the resulting facies classification can be affected by subjective interpretation. Therefore, rapid, automated core classification and associated core analysis is seen as a key technology for improving the rock classification process.

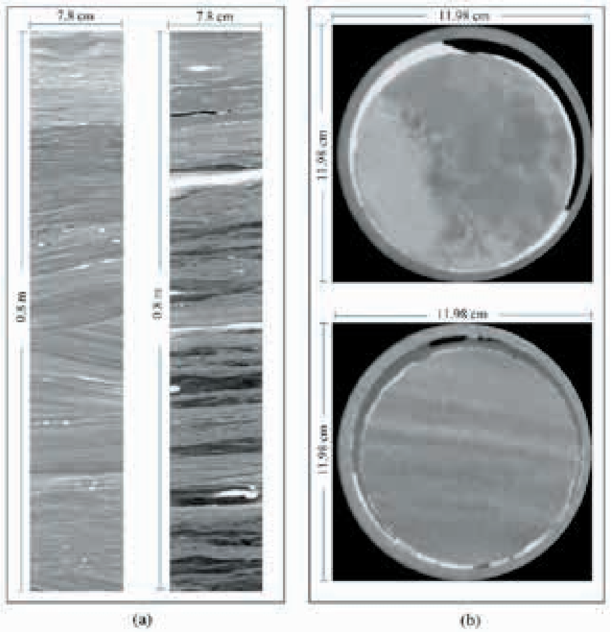


Figure 1. Examples of 2D cross-sectional (a) and image slices (b) of a whole core from an offshore oil well. This figure is from reference [4].

X-ray computerized tomography (CT) imaging is an effective nondestructive method for inspecting whole cores at a submillimeter resolution. An example of parts of a CT imaged core is shown in Figure 1, where the core barrel can be seen as an outer rim on the cross-sectional images. In this project we have investigated the possibility of incorporating CT images in the lithology classification workflow.

The project used several approaches for lithofacies classification. The first approach investigated the lithofacies classification based on textural features of the 2D cross-sectional images. The features were obtained from first-order statistics and grey-level co-occurrence matrix (GLCM). These features were used to train a support vector machine (SVM) to classify lithofacies. The training data were an expert-derived lithofacies description. Additionally, a pre-processing step was considered, where a step of principal component analysis (PCA) was applied to reduce the dimensionality of the extracted features before model training. The resulting SVM was able to classify unseen data to a fair degree, with a recall of 91%. When including the pre-processing PCA step, the classification results worsened. This might indicate that the low power components of the PCA are needed to distinguish the lithofacies [1].

The second tested method employed convolutional neural network (CNN); first on 2D cross-sectional images [2], then on 3D images [3]. The recall for the test set prediction was slightly higher than the one obtained from SVM, with a recall of 92% for the 2D CNN. However, the automated classification has a much higher prediction resolution, as seen in Figure 2. This goes some way to explain the low recall.

Misclassifications were also linked to similarities in transport properties and can therefore be used to merge lithofacies into coarser flow units. A dendrogram based on the confusion matrix from the CNN classifier is shown in Figure 3. These results were later used to merge the similar lithofacies classes into rock classes. Then, the CNN model was retrained this smaller set of rock classes and resulted in a higher prediction recall.

RECOMMENDED READING

[1] K. Chawshin, C.F. Berg, D. Varagnolo, A. Gonzalez and Z. Heidari, and O. Lopez. Classifying Lithofacies from Textural Features in Whole Core CT-Scan Images. SPE Reservoir Evaluation and Engineering, 2021.
[2] K. Chawshin, C.F. Berg, D. Varagnolo, and O. Lopez. Lithology Classification of Whole Core CT Scans Using Convolutional Neural Networks. SN Applied Sciences, 2021.
[3] K. Chawshin, C.F. Berg, D. Varagnolo, and O. Lopez. A Deep Learning Approach for Lithological Classification Using 3D Whole Core CT Scan Images. SPWLA 62nd, 2021.
[4] K. Chawshin. "Automated Lithology Classification Employing Whole Core CT-Scans", PhD thesis, 2021.

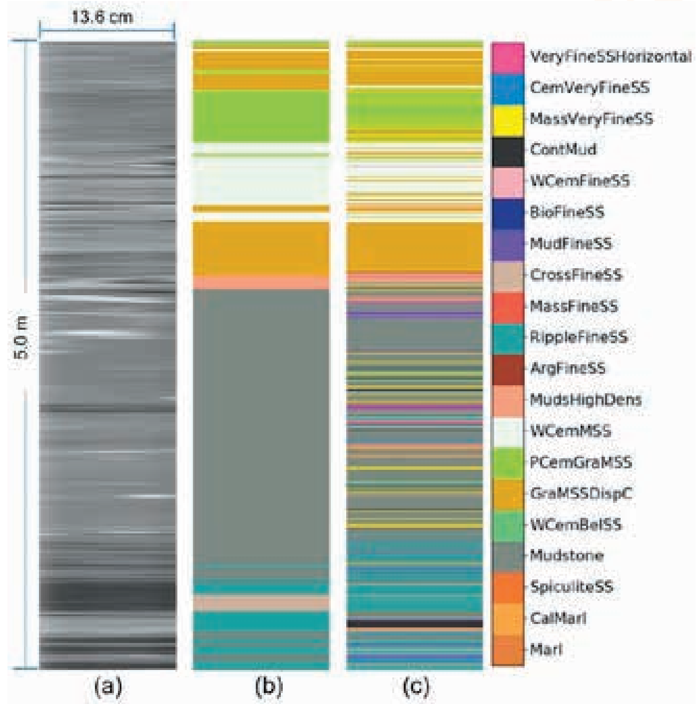


Figure 2. Plot of the imaged core data, together with the expert description and the output from the CNN classifier. This figure is from reference [2].

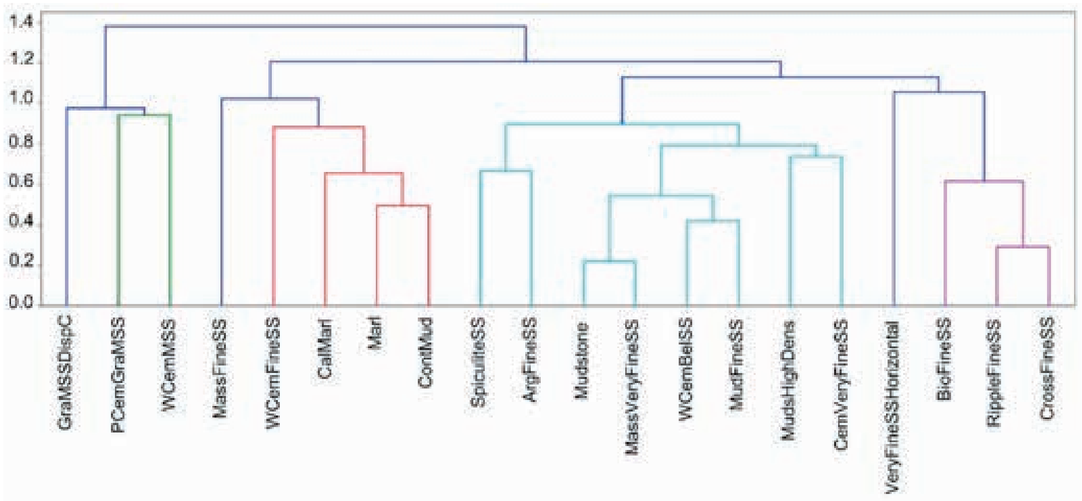


Figure 3. The dendrogram of the confusion matrix from the 2D CNN classifier. This dendrogram indicates similarities between the different lithofacies and can be used to group them into fewer rock classes. This figure is from reference [2].

DISENTANGLING HIERARCHICAL NANOSTRUCTURES

Fredrik K. Mürer[1], Aldritt Scaria Madathiparambil[1], Kim Robert Tekseth[1], Kristin Olstad[3], Magnus B. Lilledahl[1], Basab Chattopadhyay[1], and Dag W. Breiby[1,4*]

[1] PoreLab, Department of Physics, NTNU, Trondheim, Norway
[2] The European Synchrotron ESRF, Grenoble, France
[3] Norwegian University of Life Sciences (NMBU), Ås, Norway
[4] Department of Microsystems, University of South-Eastern Norway, Horten

Hierarchical materials share the feature of having their physical properties determined by a range of different structures spanning a wide range of length scales. One fascinating example is *bone*, which is a complex light-weight porous construction enabling vertebrates to be erect and grow, carry loads, and protect vital organs. Diagenized bones are typically the only remains of extinct prehistoric animals like dinosaurs, and thus the only source to their long-gone anatomy. The wide span of structures in hierarchical materials, for bones spanning from the atomic scale to decimetres, makes it challenging to unravel and fully understand their physical behaviour. Standard microscopy methods tend to either provide high resolution across a small field of view, or insufficient resolution across a wider field of view. The spatial *orientation* of nano-crystalline structures strongly affects the macroscopic physical properties in a wide range of hierarchical materials such as bones, composites, and shales.

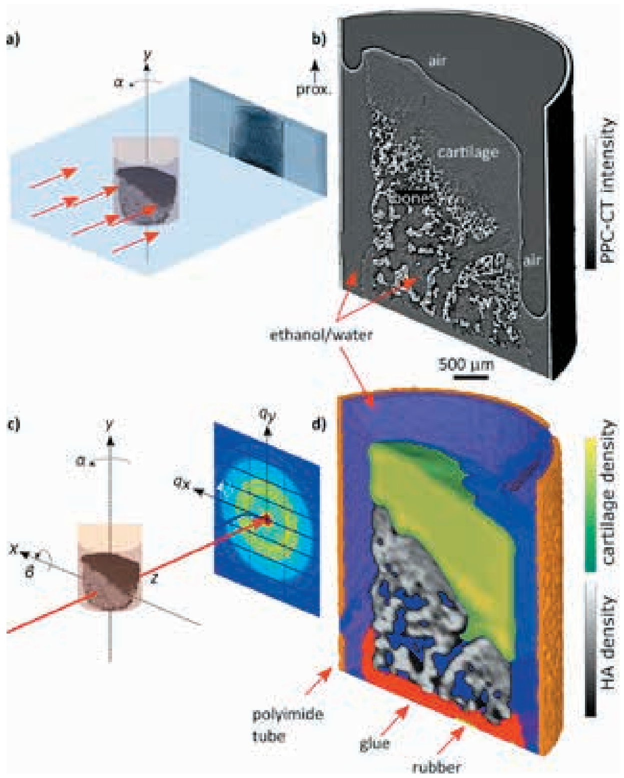


Figure 1. a) Conventional full-field CT, casting a shadow onto the detector, b) corresponding 3D reconstruction. c) XRD-CT scanning with pencil-shaped beam, collecting diffraction patterns, d) corresponding material-specific 3D reconstruction. [Mürer et al, Sci. Rep. 2021, CC BY 4.0].

X-ray computed tomography (CT), based on intensity attenuation of the beam, has recently become a working horse for studies of complex natural and manmade material structures. Despite its successes, conventional CT has some important limitations: The spatial resolution is usually in the micrometre range, and it is difficult to distinguish materials of similar density. X-ray diffraction (XRD) has since the early 20th century been used to study crystalline materials, enabling both the atomic structure of crystals and their crystallographic orientation to be retrieved. Recently, XRD has been combined with CT to become XRD-CT, a technique providing 3D images with diffraction-based contrast. Consequently, rather than being limited to resolving density variations, one can search within 3D structures using *mineral-*, *crystal orientation-*, and even *magnetic* contrast. Because the scattered beam carries information from the atomic scale, XRD-CT is excellently suited for studying heterogeneous and hierarchical materials: one can "zoom" in and out of interesting structures at will, large volumes can be scanned while observing information from the atomic scale.

In the X-Ray Physics Group, we are particularly interested in computational *imaging techniques*, relying on computers to enhance the imaging process, with one key concept being multidimensional imaging, e.g., 3D + *time* (= 4D); 3D + spectroscopic information (= 4D); and 3D + 3D orientation (= 6D), as exemplified by XRD-CT. Enabled by recent developments in X-ray instrumentation, and powerful algorithms running on GPUs, XRD-CT facilitates multidimensional reconstructions consistent with a priori information and experimental data. 3D orientation distributions are conveniently described using spherical harmonics, and data fitting is done using conjugated gradient methods with pre-calculated analytical gradients.

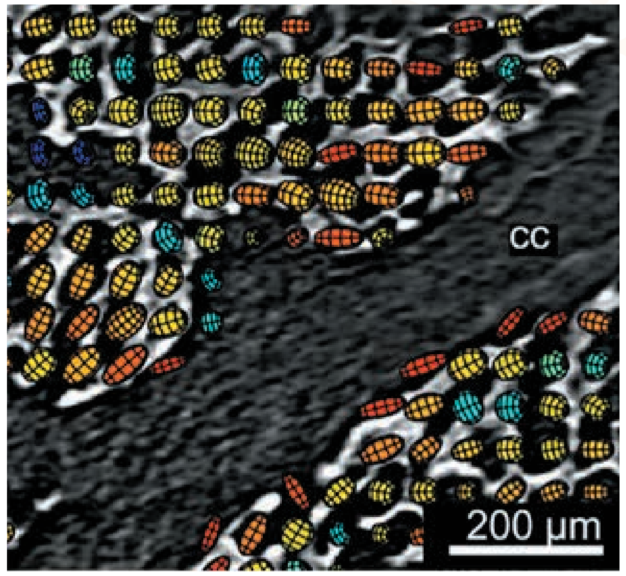


Figure 2. Ellipsoids indicating the orientation and degree of local preferred orientation, superposed on a conventional CT cross section of cortical bone surrounding a cartilage canal (CC). [Mürer et al, Sci. Rep. 2021, CC BY 4.0].

Here, we briefly present our use of tensorial imaging using XRD-CT to study biomineral crystallite *orientations* near the bone-cartilage transition region in piglet bone samples. Bones contain the mineral hydroxyapatite (HA) embedded in collagen fibrils which together give bones their unique combination of light weight, stiffness, and strength. The orientation of HA is closely connected to the orientation of the collagen fibrils, and the XRD signal from HA thus gives information also about the orientation of the collagen. We have used similar methods to study fossilized bone samples, where the mineral orientation (after diagenesis) still carries information about the muscle attachments in the outer (cortical) regions of the bone – a topic of great interest to palaeontology. Also for geomaterials, diffraction tomography is promising. For example, shales are known to have a complex and anisotropic structure with a nano-porous network, containing mainly quartz and smaller amounts of various clay minerals and iron-containing minerals like pyrite, and are not well understood. Using XRD-CT we have recently demonstrated how inclusion minerals can be non-destructively identified and localized in 3D within shale samples, and also how the orientation of the clay minerals slightly varies with position

While XRD has been used for *sample averaged* texture measurements for decades, assigning spatial positions to each measured crystallite orientation is a huge leap forward that is enabled using *tensor* tomography as outlined above. This new methodology holds promise of resolving many outstanding problems in materials physics, including the quantitative study of structural gradients and confinement-induced ordering of complex fluids flowing in porous media, which we are currently investigating.

The authors thank Pierre Cerasi, Manuel Guizar-Sicairos, Marianne Liebi, Marco di Michiel and Sophie Sanchez for valuable discussions. ESRF – The European Synchrotron and Swiss Light Source are acknowledged for beamtimes. This research was financed by the Research Council of Norway through its FRINATEK (#275182) and Centre of Excellence (#262644) programmes

RECOMMENDED READING

[1] F.K. Mürer, et al. *Scientific Reports*, 2021, **11**, 2144
[2] B. Chattopadhyay, et al. *J Appl Cryst*, 2020, **53**, 1562-1569
[3] F.K. Mürer, et al. *Scientific Reports*, 2018, **8**, 10052
[4] F.K. Mürer, et al. *IUCrJ*, 2018, **8**, 747-756
[5] E.T.B. Skjønsfjell, et al. *J Appl Cryst*, 2016, **49**, 902-908

FLUID GEOMETRY DESCRIPTION OF CONDUCTIVITY IN PARTIALLY SATURATED POROUS MEDIA

Carl Fredrik Berg[1], W. David Kennedy[2] and David C. Herrick[3]

[1] PoreLab, Department of Geoscience and Petroleum, NTNU, Trondheim, Norway
[2] QED Petrophysics LLC, Montgomery, Texas, USA
[3] Yellowstone Petrophysics LLC, Cody, Wyoming, USA

This work investigates the relationships between the conductance of a porous medium partially filled with an electrolyte, the porosity of the porous medium, and the saturation of the electrolyte. Such relations are typically based on empirical relationships such as Archie's law or the Bruggeman correlation. Archie's law can be formulated as

$$\sigma_t = a \;\; \sigma_w \phi^m S_w^n, \tag{1}$$

where the conductance over the porous medium σ_t is linked to the electrolyte conductance σ_w and saturation S_w through a set of adjustable parameters a,m and n. Several authors have attempted to connect these adjustable parameters to physical properties, thereby linking the empirical models to first principles.

Through our developments, we present a complete first principles-based description of conductivity in partially saturated porous media. A geometrical factor, E_t, is introduced which, together with porosity and saturation, describes the conductivity of partially saturated porous media as

$$\sigma_t = \phi S_w E_t \sigma_w, \tag{2}$$

As the geometry of the pore volume filled with electrolyte depends on saturation, the geometrical factor E_t can be split into two parts, one part describing the geometry of the pore space, E_0, and the relative change of the geometrical factor at different saturations, e_i:

$$\sigma_t = (\phi S_w)(E_0 e_i)\sigma_w = \sigma_0 S_w e_i, \tag{3}$$

which is simplified in the second equality above using the conductance of the fully saturated porous medium σ_0.

The geometrical factor is separated into two intrinsic geometrical descriptors of the electrolyte distribution accounting for tortuosity and constriction, as introduced in [1,2]:

$$E_t = \tau_t^{-2} C_t^{-1}, \tag{4}$$

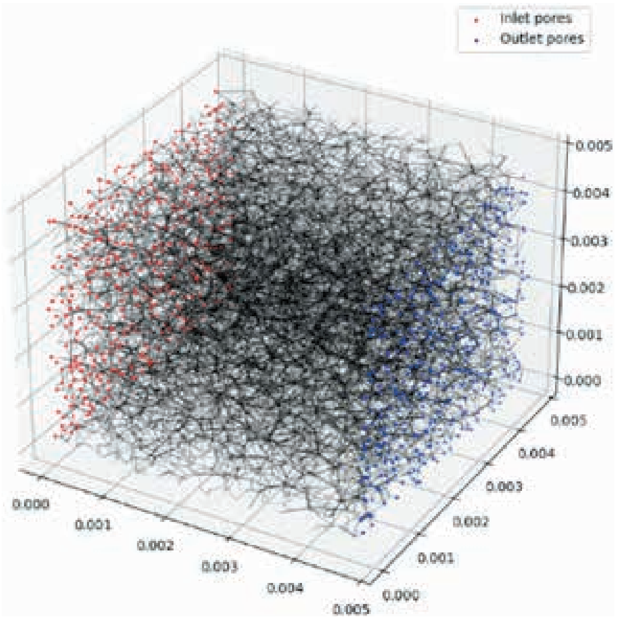


Figure 1. A plot of the network model used for the displacement simulations. This figure is from reference [3].

This tortuosity and constriction factor are obtained from integration over the electrical field lines traversing the electrolyte, thereby expressing the conductivity from well-defined descriptors of the fluid distribution. See [1,3] for a full definition of these two parameters.

As with the geometrical factor, we can define the relative change of the tortuosity and constriction as functions of saturation:

$$e_i = \left(\frac{\tau_t^{-2}}{\tau_0^{-2}}\right)\left(\frac{C_t^{-1}}{C_0^{-1}}\right) = \tau_i^{-2} C_i^{-1}. \tag{5}$$

These descriptors will show the influence on the conductance from changes in the geometry of the electrolyte. The traditional resistivity index can now be expressed using these geometry descriptors as

$$I_R(S_w) = \frac{C_i \tau_i^2}{S_w}. \tag{6}$$

To investigate the changes in electrolyte geometry, and the corresponding influence on the porous medium conductance, we simulated the displacement of an electrolyte by an immiscible insulating phase in a network model. This network model is shown in Figure 1.

For the different saturation steps, we calculated the tortuosity and constriction factor. The resulting relative changes are shown in Figure 2. We observe a non-trivial development for the tortuosity, while the change in constriction factor is several orders of magnitude larger than the changes in the tortuosity.

This indicates that the controlling factor for the conductance is the change in constriction factor in addition to the saturation change, while the change in tortuosity plays a minor role. Given the nearly exclusive focus on tortuosity in the literature, this result might be surprising.

Additionally, the simulated fluid distributions expose non-trivial changes in fluid geometry which are masked by traditional descriptions, e.g., using a resistivity index. This exemplifies how our introduced conductance description through porosity, saturation, and a geometrical factor, decomposed into separate terms accounting for tortuosity and constrictivity, opens up new insights and understanding of conductance in porous media.

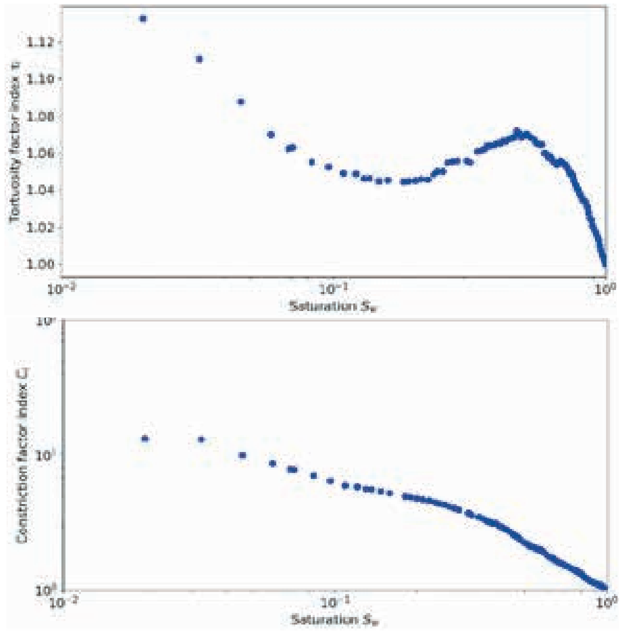


Figure 2. Plot of the relative change in tortuosity and constriction factor when the electrolyte is displaced by an insulating fluid. This figure is from reference [3].

RECOMMENDED READING

[1] Berg, C. F. (2012). Re-examining Archie's law: conductance description by tortuosity and constriction. Physical Review E, 86(4).

[2] Berg, C. F., & Held, R. (2016). Fundamental transport property relations in porous media incorporating detailed pore structure description. Transport in porous media, 112(2).

[3] Berg, C. F., Kennedy, W. D., & Herrick, D. C. (2022). Conductivity in partially saturated porous media described by porosity, electrolyte saturation and saturation-dependent tortuosity and constriction factor. Geophysical Prospecting, 70(2).

THERMAL PROCESSING OF METAL-SEMICONDUCTOR MIXTURES

Ursula Gibson[1], Seunghan Song[1]

[1] PoreLab, Department of Physics, NTNU, Trondheim, Norway

In studies of silicon refining, Pfann[1] observed that metals on the surface, when subjected to a thermal gradient, could form liquid droplets that would migrate through a solid silicon wafer. Anthony and Cline[2,3] explored this technology for doping of semiconductors, but the detailed trajectory of the droplet was indeterminate, and ion implantation, with greater spatial resolution, dominated further developments. However, in the confined geometry of the silica clad, semiconductor core fibers now being explored for optical waveguiding and electrical applications such as solar energy, this thermomigration process can be utilized to make a variety of devices. In this project, we have examined the fundamental process and applications.

We measured the velocity that the droplets could attain, to assure that the theoretical description was valid, and to determine processing speeds that could be adopted for device formation at the high temperatures and temperature gradients that we apply using CO_2 laser heating the fiber. Figure 1 shows the flow velocity we measured, plotted against earlier data and theory by Anthony and Cline.[2,3]

The theoretical model allowed us to choose suitable temperatures, thermal gradients and scan rates for practical applications. The laser creates the chosen thermal conditions in a semiconductor core fiber, and there is a specific transport goal, such as a drawing a small amount of one metal through the core. Figure 2 shows some of the geometries in which thermomigration has been used to accomplish manipulation of the composition of the fibers with which we work.

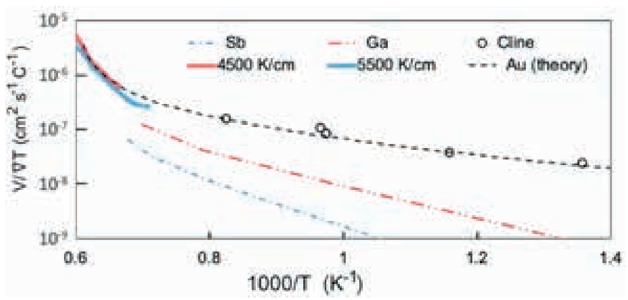


Figure 1: Theoretical velocities for Si alloys with the three metals shown thermomigrating through pure silicon, together with earlier data and high gradient data from this study of gold in silicon. (Ref 6)

The gold-in-silicon system has been employed for technological goals such as purifying silicon-core fibers to allow THz transmission waveguides[4], and to utilize the material for high speed optical modulation of the transmitted signal[5]. We used the geometry of Fig 2d to load gold into the core, then a slow translation of the laser beam to draw the melt along the fiber. Figure 3a shows a near infrared image of the end of the fiber while illuminated with the modulation signal, and Fig. 3b shows the difference in the temporal response of the transmission through pure untreated silicon, compared to that of silicon processed using thermomigration of gold through the core. The transmission is measured as a function of the delay after the optical pump pulse that generates free carriers.

We have expanded the range of materials processed with this technology, and have used the geometry of Fig 2d to form a miniaturized infrared GaSb light source inside a silicon fiber. This source has potential applications for telecom and spectroscopy. The theoretical predictions about the relative speed with which the processing could be performed were valuable; Sb could not be drawn through the fiber at a speed near to that possible with gold.

The geometry shown in Fig 2e was used to make a surface rib waveguide on a silicon wafer, as shown in Figure 4a, and the geometry in Fig 2f was used to segregate Si and GaSb along the length of the fiber as show in Figure 4b. The segregated fiber will be tested electrically for potential solar and detector applications.

RECOMMENDED READING

[1] W. Pfann, Temperature gradient zone melting, JOM 7 (1955) 961–964

[2] Anthony, T. R. & Cline, H. E. Thermal Migration of Liquid Droplets through Solids. J. of Appl. Phys. 42, 3380–3387 (1971).

[3] Anthony, T. R. & Cline, H. E. Thermomigration of Gold-Rich Droplets in Silicon. J. of Appl. Phys. 43, 2473–2476 (1972)

[4] Sørgård, T. et al. Broadband infrared and THz transmitting silicon core optical fiber. Opt. Mater. Express, OME 10, 2491–2499 (2020)

[5] Sørgård, T. et al. All-optical high-speed modulation of THz transmission through silicon core optical fibers. Opt. Express, OE 29, 3543–3552 (2021).

[6] Preprint: doi 10.21203/rs.3.rs-1009349/v1

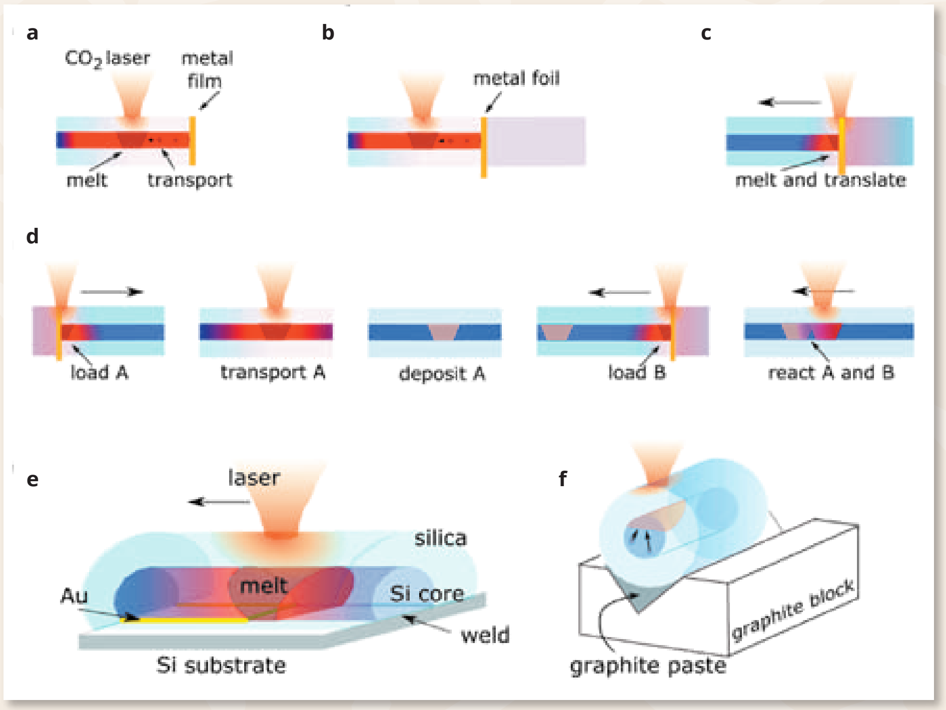


*Figure 2: Geometries for thermomigration assembly of metal-semiconductor structures within silica clad fiber. (Ref 6) **a** and **b**, thermomigration loading of a metal into the fiber, **c** loading by direct melting, **d** formation of a compound within the silicon core, **e** formation of a rib waveguide and **f** geometry used to create vertical thermal gradient allowing separation of eutectic forming components along the core.*

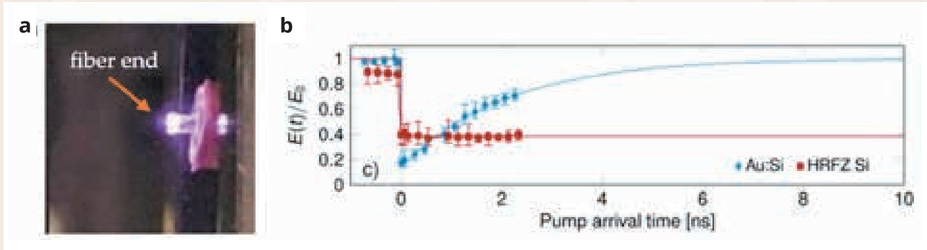


*Figure 3: THz modulation in fiber processed using thermomigration. **a** infrared image of illuminated fiber end, and **b** Transmission signal; time response for treated and untreated silicon when illumination-generated free carriers blocked the signal.*

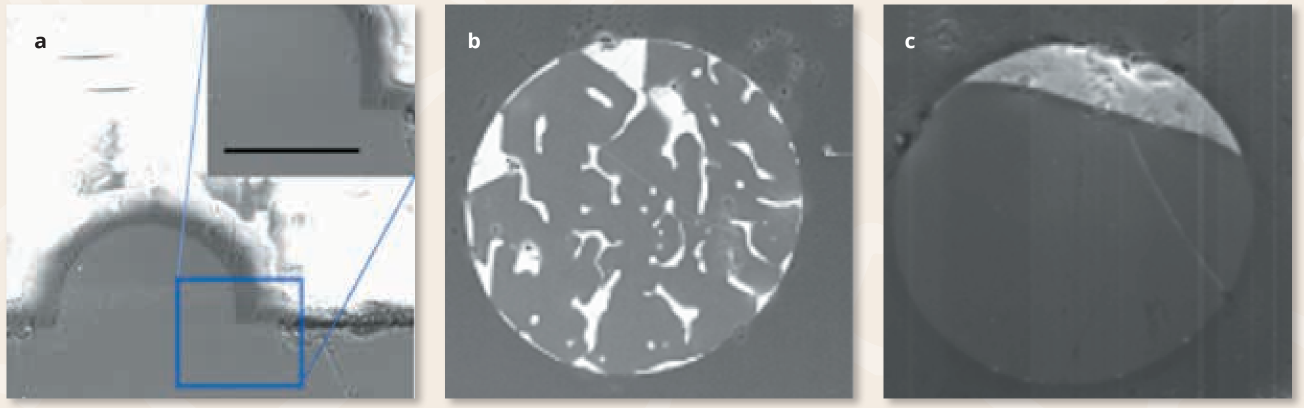


*Figure 4: (Ref 5) Thermomigration-created structures: **a** rib waveguide welded to a silicon wafer suitable for long wavelength waveguiding, **b** as-drawn Si-GaSb fiber core and **c** lateral structure created after annealing using geometry of Fig 2f.*

THERMAL EXCHANGE IN THE NOSE OF A SEAL

Eirik G. Flekkøy[1], Signe Kjelstrup[2] and Øivind Wilhelmsen[2]

[1] PoreLab, The Njord Center, Department of Physics, University of Olso, Norway
[2] PoreLab, department of Chemistry, NTNU, Norway

The figure shows the structure of a maxilloturbinate in a seal, an organ that serves to bring the air close to the temperature and humidity in the lungs. It also serves to conserve heat and water during out-breath. The labyrinthine structure of this biological porous medium closely resembles the structure that results from granular displacement experiments, where the interplay between capillary forces and static friction is the governing mechanism. Even though these forces cannot be the ones at play in the formation of the turbinate, the similarity may point to a common optimization principle.

We have studied the thermal exchange process that takes place during breathing and found that the size and internal length scales of the turbinate also come close to optimize its biological function: The channel widths are large to allow easy breathing, narrow and numerous enough to allow efficient thermal exchange and long enough to supply the required amount of heat and humidity. By modelling the thermal exchange and comparing to measured outbreath temperatures we also found that in arctic seals a layer of water freezes in the outer part of the turbinate, a process that enhances the cooling of the air and thus the energy conservation of the animal.

RECOMMENDED READING

Eirik G. Flekkøy, Lars Folkow, Signe Kjelstrup, Matthew J Mason and Øivind Wilhelmsen *Thermal modelling of the respiratory turbinates in arctic and subtropical seals*, submitted to Journal of Comparative physiology

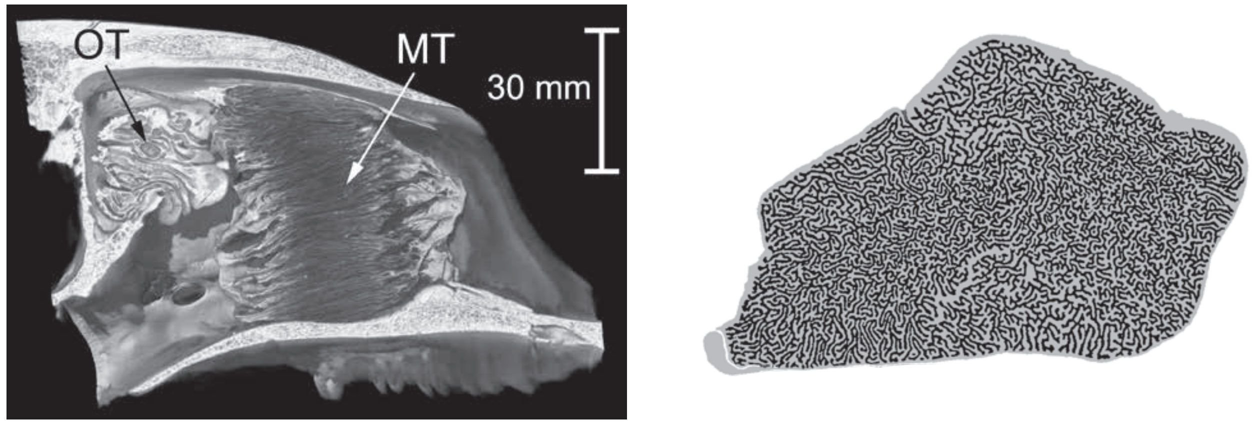


Figure 1: The Maxilloturbinate (MT) structure of a seal in front of the olfactory organ (OT). In the left image air flows from left to right during outbreath, while, in the right image air flows in the direction perpendicular to the cross-section; one half of the turbinate is shown.

STAYING CREATIVE IN THE PROLONGED PANDEMIC

By the end of 2020 we were hopeful for a pandemic-free 2021. Vaccination had started, and it seemed science had won. But during 2021 reality hit us, up to several times actually, and by the end of 2021 the situation was far too much alike the situation 12 months earlier than we had envisioned. The virus had continued to spread and mutate throughout the year, and with it, there was a continuous series of intermittent lockdowns, mandatory home-office, and restrictions on travel both in and out of Norway. These measures made their impact on all aspects of our lives – including work life.

In our annual report for 2020 we reviewed the challenges that the containment measures posed for an interdisciplinary center such as PoreLab. The covid-19 pandemic forced us to stay put and go online. We have had to adapt and find new ways of working and communicating. The home-office became where we spent most of our time in 2021. So how did we manage to keep a balance between home and work while working from home?

"I think it was great", starts Olav Galteland, PhD candidate at PoreLab, and new father. *"It was horrible"* replies Hamidreza Erfani Gahrooei, postdoctoral researcher. The debate has started! Remote work is definitively a divisive topic. Home-office means no commuting, therefore more time to spend with your family. Being able to shape one's daily routine can be beneficial especially when you have kids. But working from home tend to blur the boundaries between work and personal life. *"There is no separation between your work and your home, especially when your office is in your bedroom. As soon as I would wake up, I would see my desk"*, explains Hamidreza. *"The more you stay at home, the less you want to go out"*, adds Federico Lanza, PhD candidate. Increased isolation, lack of contact with colleagues, risk of overworking and risk of low productivity are the typical drawbacks named during the discussion. *"At the beginning I was more productive, because there was nothing else to do but at some point, I started to experience a lack of motivation"*, explains Michael Rauter, PhD candidate. Can we see these statements reflected in PoreLab's productivity in 2021? Here comes a few key numbers: we published 76 journal articles in 2021 versus 71 in 2020, 49 in 2019 and 34 in 2018. These numbers indicate that research efforts have been increasing every year since the start of the center. But research at our level is a long-term effort. Many conferences planned in 2020 were either cancelled or postponed. That led to a drop in the number of our conference lectures from 80 in 2019 to only 33 in 2020. With time more conferences became hybrid or digital events, and the number of conference lectures raised again to 56 in 2021. We managed to follow the intended recruitment plan by organizing interviews via Zoom and Skype. Five externally funded projects were developed in 2021. We participated to a similar number of applications compared to 2020 and 2019. Looking at the numbers it seems that we were able to "hold the fort" for the time the corona period has lasted, but that a longer close-down could have been detrimental.

PoreLab is not just about people in Trondheim and Oslo. Because of restrictions on travels, the number of guests visiting PoreLab at NTNU or UiO dropped from 64 in 2019 to 14 in 2020 and we welcomed only 7 guests in 2021. One had to be highly motivated and prepared in order to enter Norway during times of restrictions. This is nicely summarized by Stefan Windisch-Kern, PhD candidate at the Department of Environmental and Energy process Engineering at the University of Leoben in Austria. Stefan struggled with Norwegian entry restrictions and had to fight for his research stay at PoreLab NTNU: *"Due to strict entry regulations, my stay at PoreLab got off to a somewhat bumpy start, leaving me stranded in Austria at the end of March 2021 with no perspective of getting better. The 3 months of waiting until I could finally travel to Trondheim at the beginning of July were frustrating, but the time that followed made it all worthwhile. The time I spent at PoreLab and in Norway in general was a wonderful, enriching and educational experience. Many thanks to everyone for the warm welcome, the unconditional help with problems and the support I received."*

There have been tremendous efforts from all of PoreLab to mitigate all the negative effects from the restrictions brought by the pandemic, and the effort has proved effective and let to an impressive production in 2021. Fortunately, it is now time to return to the normal, with face-to-face time, student exchange, visitors and physical attendance to conferences, all of which we have deeply missed.

PHD

LOUISON THORENS

Department of Physics, UiO

Who are you? What is your background?

My name is Louison Thorens, and I come from France. I recently completed my PhD at the University of Oslo (UiO) division of PoreLab, and I hold a bachelor's degree and a master's research degree both in Physics from the École Normale Supérieure de Lyon (ENSL), France.

Tell us about your project

Magnetic interactions between grains are the foundation of this project. When an external magnetic field is applied to individual ferromagnetic grains (steel ball bearings for example), they act as small magnets interacting with their neighbors. These interactions are easily remotely tunable, paving the way for external control of grain interactions.

This idea arose during my master's final project in France. With the assistance of Dr. S. Santucci in Lyon, I contacted Pr. K. J. Måløy, and we decided to begin this collaboration between PoreLab (UiO) and the Laboratoire de Physique of ENSL for my PhD thesis.

How are you performing your research?

Since this project was split up between Norway and France, I worked on two complementary experiments at the same time. On the French side I conducted fundamental experiments on a magnetic Janssen effect, revisiting a well-known granular physics effect.

Back in Norway, I used this novel idea to control the behavior of deformable porous media in the previously set-up "bulldozing" experiment putting in competition capillary action and friction between grains.

I am a self-driven person, and I believe that the trust relationship with my thesis supervisors, as well as the excellent communication between both parties, were the driving forces behind my work.

How is it to be a PhD at PoreLab?

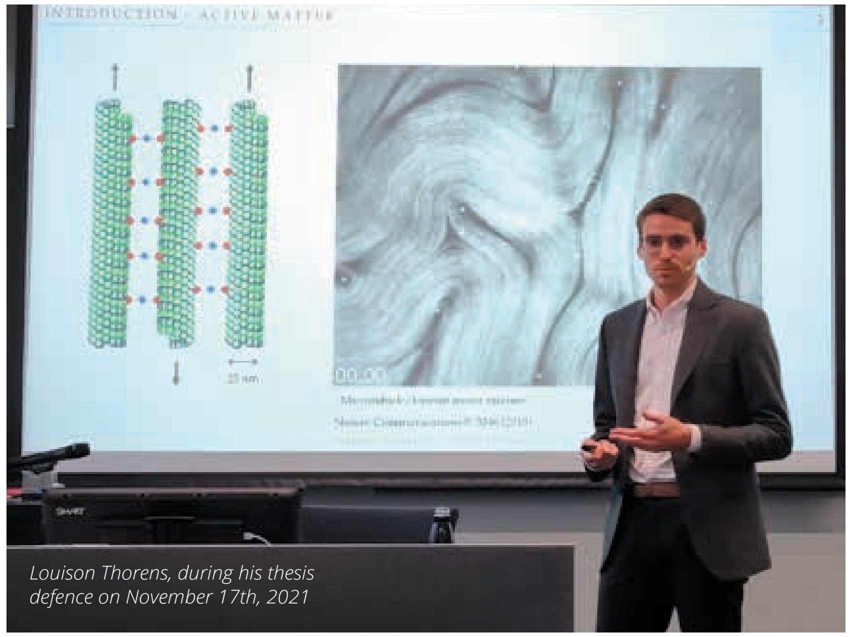
PoreLab is a fantastic place to conduct research because there are numerous opportunities to learn from seminars and people within and outside the group. The new facilities and offices in Oslo improved things even more, and it has been a pleasure to work here for the past three years.

Working as a PhD student in an international project during a pandemic may sound terrifying, but the wonderful work environment at PoreLab, as well as the joyful group energy, made things go very smoothly.

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

Just after finishing my PhD at the end of 2021, I relocated to Boston to begin a postdoctoral position studying bacterial flagella movement and viscoelastic fluids.

With this new project, which is still closely related to some aspect of porous media flow, I wanted to broaden my horizons and experimentation skills. And, without a doubt, I am already thinking of going back to Norway to see the people I met there!



Louison Thorens, during his thesis defence on November 17th, 2021

PHD

HYEJEONG CHEON

Department of Physics, NTNU

Who are you? What is your background?

I am Hyejeong Cheon (Hye-jeong, HyeJeong and Hye Jeong, all names are correct and consistent in Korean), a PhD candidate at PoreLab and the department of Physics at NTNU. I was born in Seoul and lived most of my life in Yongin, South Korea. I moved to Trondheim in Norway in 2017. I studied Materials Science and Engineering during my bachelor and worked in the semiconductor industry. I came to Trondheim to study physics as a master student at NTNU afterwards.

Tell us about yourself

I am someone who wants to learn. I feel happy when I succeed and get the achievement even after many times of failing because I feel that I am learning something. I have this passion for searching and learning new things, not just at work, but also for everything in daily life including sports and art.

What made you decide to come to Norway and Trondheim?

I studied Physics at Umeå University in Sweden as an exchange student and travelled to European countries including Norway and Finland. I became interested in Scandinavian countries because of the culture, especially perspective on environment and equality. I was accepted at NTNU, Charmers and Lund University, and decided finally to come to NTNU. I wanted to live in a northern city far from the capital. Honestly, I enjoy cold weather more than warm weather.

Tell us more about your project

I am working now on two projects. The first one, called PredictCUI, is about studying how water vapour and liquid behave in porous media. The other project is related to the nose of the seal. Here we study how and why a seal (or any animal) nose has an interesting and complicated structure. I am looking forward in developing additional and as exciting projects during my PhD.

What is your favorite activity in your research?

Programming! Writing a code from scratch is like starting with a cornerstone or drawing the first line in a canvas. Debugging is like being a detective by following clues in a written code.

How is the working environment at PoreLab?

In my opinion, having many colleagues from various departments make a good synergy in PoreLab. Sometimes I got clues of problems in projects from the conversation with colleagues during lunch or coffee time, even from people who come from different departments or are working on different projects than mine. In addition, I personally think that it is important to provide as well fun spaces to the employees. At PoreLab Trondheim, we have a ping pong table, a library, and a table football. I am very happy about these facilities; they are a great way to improve morale in the office and to relax during a hard-working day. Having these facilities may sound trivial, but I think that a small change makes a big difference in the working environment.

PHD

MOHAMMAD HOSSEIN GOLESTAN

Department of Geoscience and Petroleum, NTNU

Who are you? What is your background?

My name is Mohammad Hossein Golestan, and I am from Iran. My academic background is in petroleum engineering. I got my bachelor's degree from the Petroleum University of Technology in Ahwaz (Iran) and my master's degree from Shahid Bahonar University in Kerman (Iran). I did my master's thesis on developing an opensource Matlab package for quasistatic pore network modeling called MatlabPNM (https://github.com/mhgolestan/MatlabPNM) which was my first steps in the world of porous media. It is worth mentioning that the contribution in the opensource development helped me to get closer to the scientists in porous media field of research.

Tell us more about your project

Low salinity water injection is one of the enhance oil recovery methods in petroleum industry. This method might lead to the increase in oil recovery due to the underlying submechanisms which depend on the water-oil-rock characteristics. One of the sub-mechanisms which was discovered by Dr. Sunniva B. Fredriksen is known as oil droplet mobilization by diffusion and osmosis. It is explained thoroughly in the research article "Porescale mechanisms during low salinity waterflooding: Oil mobilization by diffusion and osmosis".

During my PhD I evaluated this phenomenon both experimentally and numerically. We conducted the experiments in collaboration with Lifei Yan (PhD candidate at Utrecht University) and Wenyu Zhou (MSc student at NTNU). For the modeling part, we used the Lattice Boltzmann in collaboration with Dr. Olav Aursjø (NORCE research institute).

How is the working environment at PoreLab?

Doing the PhD in PoreLab is an amazing experience. The working environment is excellent, and the colleagues are so eager to share their knowledge. The best side is its international atmosphere with people from different fields of research (Physics, chemistry, Petroleum and so on) and whenever you have a question there is always someone who can help you finding the answer.

PoreLab's Junior forum which is a biannual event gave me a sense of commitment in which we could exchange idea about PoreLab's activities. PoreLab has an active participation in InterPore community which gave the possibility to know other researchers in my field. In particular, the PoreLab weekly lecture series (which is recorded and published at PoreLab YouTube channel) was an exceptional opportunity for me to boost my knowledge in porous media field.

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

It might not be an easy question to answer to but based on the experience and knowledge I gained I would prefer to use them either in industrial applications or academia.

PHD

MICHAEL TOBIAS RAUTER

Department of Chemistry, NTNU

Who are you? What is your background?

My name is Michael Rauter, and I am originally from Esslingen, Germany. I started as a PhD candidate at PoreLab (NTNU Trondheim) at the beginning of 2019 after I've finished my master's in process engineering at the University of Stuttgart. My project is about thermal driving forces, liquid-vapor phase transition and the impact of nano confinement on transport in porous media.

What made you decide to come to Norway and Trondheim

During my master's I had the chance to do a research project at the NTNU in Trondheim. I enjoyed the driving atmosphere at the NTNU as well as the life in Trondheim with its beautiful nature and friendly people so much that I decided to stay. I have never regretted that decision and could imagine staying for a long time in Norway.

What is your favorite activity in your research?

What I enjoy most are the scientific discussions with my peers, supervisors and other researchers at PoreLab.

Porous media is a multidisciplinary field of research – by being together in one center with people from different research groups creates a very fruitful atmosphere with a lot of opportunities to learn and to develop, and thereby making progress with one's own research.

Tell us more about your project

Clean and potable water is one of the most important substances to mankind and in some regions a very limited resource. About 4 billion people experience serious water shortages for at least one month each year. Current methods, which are trying to tackle that problem mostly treat seawater and brackish water to obtain fresh water. However, a common problem is the high energy input and thus large production costs.

We are therefore aiming for the development of an application that utilizes waste heat for the simultaneous production of drinking water and power generation.

The idea is to use a liquid repelling membrane, a so called vapor gap membrane. When a temperature difference is applied to such membrane with liquid on both sides, fluid is allowed to pass in the vapor phase. This occurs by evaporation on one side and condensation on the other, resulting in selective fluid transport across the vapor gap away from the contaminated fluid. The mass flux can take place against a pressure difference, with the help of the temperature difference. The pressure buildup could ideally enable a turbine to produce work.

We are trying to understand the first principles and fundamentals of mass transport that is caused by a thermal driving force across a vapor-gap membrane.

What are your activities at PoreLab?

Besides my research activities I am trying to be an active member of PoreLab. I am the speaker for the PhDs in Trondheim and also help organizing different events like the Junior Forum, the PoreLab lecture series or Porebuzz.

For me it is a lot of fun not only to focus on research, but also to contribute to a functioning center with a good atmosphere which enhances exchange between the members. Another major activity is spending time in the table-tennis room, which is a great way to take a break between the bouts of research.

PHD

CHUANGXIN LYU

Department of Civil and
Environmental Engineering, NTNU

Who are you? What is your background?

My name is Chuangxin Lyu and I come from China. My academic background is geotechnical engineering. I completed my master in offshore geotechnic in 2017 at King Abdullah University of Science and Technology in Saudi Arabia and successfully obtained my PhD degree in NTNU in October 2021. The research topic of my PhD was about mechanical behavior of frozen saline clay: laboratory, field, and numerical investigation. I continue my academic career as a researcher at Norwegian Geotechnical Institute (NGI) and start my teaching experience as associated professor in Oslo Metropolitan University (OsloMet) now. I worked with the PoreLab center of excellence during my PhD period.

How did you come being interested in geotechnics?

I enjoyed studying mechanics and physics, and I am very interested to apply them into the research of soil behaviors. Besides, I think that geotechnics plays an important role in infrastructure building, renewable energy development and the evaluation of natural geohazard etc. Among the different subjects in civil engineering, I gained more interest in laboratory test and field practice and used these results to perform numerical simulation to have better understanding of complicated physical process for soils.

Tell us more about your research activities during your PhD

My doctoral study is a part of the NUNATARYUK project, which is financially supported by the European Union's Horizon 2020 Research and Innovation Programme. This project involves 26 research partners including NTNU, DTU and UNIS from 11 countries and aims for the estimate of longterm impacts and risk assessment posed by permafrost thawing. The work package (WP6-Coastal Infrastructure), contributed by my doctoral study, intends to quantify the impact of permafrost thawing on coastal Arctic infrastructures by means of site investigations and local scale modelling.

Therefore, my research field can be generally divided into a few topics:

(1) The estimate of unfrozen water content (UWC) for various frozen soil types based on the acoustic and electrical resistivity techniques.

(2) A new experimental framework to resolve difficulties regarding mechanical testing of frozen soils. It includes a new sample preparation method ('slow' freezing), the strategies for pore pressure measurement at subzero temperature (application of anti freezing liquid) and a new test procedure including preconsolidation for triaxial test of frozen soils.

(3) Plate loading test on saline clay permafrost to study the longterm mechanical behaviour of frozen soil in a large scale in Longyearbyen, Svalbard.

(4) A systematic thermo-hydro-mechanical simulation to estimate the permafrost degradation and risk assessment to infrastructures in a longer time scale (next 50 years or more).

The most challenging and meaningful work I conducted in my PhD is pile test to monitor thawing permafrost effect in Longyearbyen, Svalbard. The details regarding this research activity can be found by clicking the following link: https://www.unis.no/pile-test-campaign-to-monitor-thawing-permafrost/.

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. I remember having a problem regarding thermodynamics in my research. Finally, I took the chance provided by PoreLab to discuss with Professor Signe Kjelstrup, who is the great name in non-equilibrium thermodynamics. She just spent a few minutes to clearly answer all my questions. Finally, this work has been published in the Journal of geophysical research: solid earth. PoreLab provides the opportunity to make the communication possible for researchers with different background.

Tusen takk, PoreLab!

PHD

OLAV GALTELAND

Department of Chemistry, NTNU

Tell us about yourself, what is your background?

My name is Olav Galteland, and I am from Holmestrand, in southeastern Norway. I have a bachelor's and master's degree in chemistry from NTNU. In my bachelor's degree, I specialized in physical chemistry, and in my master's thesis, I studied non-spherical particles adsorbed on liquid-vapor interfaces with thermodynamics and molecular dynamics simulations. I studied how the non-spherical particles adsorbed on interfaces interact with each other, which is important for the stability of emulsions and aerosols. From this, I acquired a solid background in chemistry, thermodynamics, and molecular simulations, which has been valuable in my Ph.D. project.

What is your PhD project about?

In my Ph.D. project, I study the transport of fluids that are confined in nanoporous media. This can for example be the mass transport of hydrogen, oxygen, and water through the various membranes in a fuel cell, or CO_2 storage in zeolites and metal-organic frameworks. The thermodynamic properties of confined fluids can be vastly different from non-confined fluids. These confined fluids are described by applying thermodynamics and then later simulated with molecular simulations.

Tell us more about the methods you use in your research

Specifically, I use nanothermodynamics to describe properties such as energy, pressure, and temperature of fluids in confinement and non-equilibrium thermodynamics to describe the transport of the confined fluids. The transport can be for example mass, heat, or charge transport. I apply molecular simulations to investigate the assumptions of the theories we develop.

Who is involved in your research?

I work together with Signe Kjelstrup, Dick Bedeaux, Bjørn Hafskjold, Michael Rauter, Eivind Bering, and Kim Kristiansen at PoreLab, and have also collaborated with researchers at TU Delft and Imperial College London. The research entails discussions with my colleagues to develop theories and molecular simulations on the Norwegian high-performance computing infrastructure provided by UNINETT Sigma2 to investigate those theories. We present our work by publishing articles in peer-reviewed journals and presenting at international conferences such as InterPore and Symposium on Thermophysical Properties.

How is the working environment at PoreLab?

PoreLab has a friendly working environment with pleasant and productive discussions during coffee and lunch breaks. It is an interdisciplinary center, where researchers have backgrounds from chemistry, physics, petroleum engineering, geotechnical engineering, and more. Researchers in PoreLab have expertise in experiments, simulations, and theory, and there is often help available if one has a problem. PoreLab lays the foundation for researchers to do valuable science in the field of porous media.

HEADING FOR THE FUTURE:

OUR NEW EXTERNALLY FUNDED PROJECTS

On June 24th, 2021, there was much jubilation on the third floor of the Physics building at the outcome of the RCN's calls for proposals. Two PoreLab young researchers at UiO got their applications granted in the category "Researcher Project for Young Talents". It was a major accomplishment for both. Since PoreLab started in August 2017, PoreLab researchers have been very much involved in the development of grant applications. PoreLab developed or collaborated to 16 grant applications early in 2021, a number equivalent to the ones in 2020 and 2019. We present in this page the five externally funded projects that were granted in 2021, four of them from the Research Council of Norway and one from the Norwegian Ministry of Education and Research. These five projects come in addition to our eight projects that were granted in 2020 and 2019. Let us specify that previous granted projects become part of the research projects of our annual reports.

FlowConn: Connectivity enhancement due to thin liquid films in porous media flows

Project leader : Marcel Moura, UiO

Duration: 2021 - 2025

The flow of liquids and gases inside porous networks is a rather common process. It happens for example when rain falls on a dry soil: as the water moves in, it displaces air from the pores between the soil grains. It is also very important for many industrial and environmental applications related for example to the storage of CO_2 inside depleted oil reservoirs and the remediation of contaminated soils.

In many of those fluid displacement processes, thin layers of liquid are left on the surface of the grains forming the porous network (for example, seemingly dry soils frequently have thin layers of water covering their grains). Those thin layers play a significant role: they can connect distant parts of the system. This effect brings some positive and negative consequences. The enhanced thin film connectivity is used by plants to obtain water and nutrients, but it also provides a pathway for the fast spreading of pollutants inside the soils. It is very important to understand these effects, and this is the primary goal of this project: to produce a physics grounded explanation for the stability and transport properties of the thin liquid film network. This will be done via experiments, theoretical analysis and numerical simulations.

Our experimental approach will be based on the use of custom-built transparent porous samples, where we can directly map the whole thin film network. This mapping is very useful and prior to our recent work it had

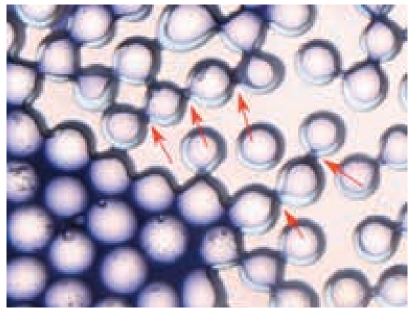


Figure: Thin liquid films and capillary bridges (red arrows) can create new pathways for the transport of fluids in a porous medium, effectively enhancing the overall connectivity of a sample.

never been experimentally obtained. The ability to map the film network will serve as an input for a new theoretical investigation of the problem, based on solid concepts from network theory (graph theory). This approach, coupled with network simulations, will allow us to have a full understanding of the physics of the problem. This new understanding will allow us for example to propose physics-based numerical routines to better describe the transport of liquids and the spreading of pollutants inside dry soils.

The project's budget covers the costs for a researcher for 4 years, a postdoc for 2 years starting during the spring 2022, equipment in the laboratories, as well as attendance to conferences.

M4: Mixing in Multiphase flows through Microporous Media

Project leader: Gaute Linga, UiO

Duration: 2021 – 2025

Solute mixing in porous media flows is a key process in a vast range of natural and industrial systems. The degree of mixing determines the rate of chemical reactions, and thereby controls processes as wide ranging as degradation of pollutants in the subsurface, sequestration of CO_2 in deep saline aquifers, and drug delivery in the human body. In many applications, the target is to maximize mixing, such as in microfluidic devices for reagent homogenization in biomedical analysis. In other cases, mixing should ideally be limited, such as in flow batteries or to avoid precipitation near CO_2 injection wells. However, despite the obvious need for predicting and controlling mixing, the mixing dynamics in these complex flow topologies are only beginning to be understood. M4 assembles an interdisciplinary team to explore, simulate and predict mixing dynamics in porous media, with a focus on the key challenge of mixing in multiphase flows. M4 is a collaboration between partners from the UiO, the University of Rennes and SINTEF Digital, and is hosted at and leverage the excellent research facilities of the PoreLab CoE at the Njord Centre, UiO.

Figure: Numerical simulation of the deformation of an initially square-shaped solute blob during multiphase flow in a 3D porous medium. Dark (light) color indicates low (high) local elongation. The two fluid phases are transparent, and the solid in the periodic unit cell is shown as semi-transparent beads

The ultimate goal of the M4 project is to establish a firm understanding of how mixing of solutes occurs in microscale multiphase flows in porous media.

The main outcomes of the project will be:

- A novel theoretical framework to explain and predict the mixing dynamics in multiphase flow through porous media, supported by simulations and experiments.
- Efficient, robust, scalable and user-friendly open-source computational tools for simulating mixing in time-dependent flow in complex geometries based on phase-field models and diffusive-strip/sheet methods
- New geo-inspired (inspired by geophysical porous media flows) microfluidic mixer designs based on the theoretical framework.

PhD position in Experimental porous media physics under the CO_2Basalt project

Project leader: Knut Jørgen Måløy, UiO

Duration: 2022 - 2025

This position is part of 3 early career positions financed by the Ministry of Education and Research to the Njord center. The PhD position involves a collaboration between geologists and physicists at PoreLab. It is part of the project *CO_2Basalt: Flow and mineral sequestration of carbon dioxide in basalts offshore Norway* funded by UiO.

The PhD project plans experiments on density-driven convection which is a central importance for CO_2 storage. When CO_2 is dissolved in water, it forms carbonic acid, resulting in a slight increase in density and a change in acidity (pH).

The purpose of the project entitled Gravitational instabilities during water-CO_2 flows in fractures, is to investigate the convective mechanics of CO_2 dissolved in water in model porous media and fractures and estimate the pH field using a pH analysis methods developed by PoreLab. Along with flow experiments on 3D printed fractures and porous models, the candidate may develop numerical models that can simulate density-driven convection.

The position was advertised in February 2022.

Sustainable Stable Ground (Bærekraftig Grunn)

Project leader: Klaartje de Weerdt, NTNU

Duration: 2022 - 2026

Soft soil, such as marine clay, gives challenging conditions for infrastructure development in many places in the world, which requires enormous amounts of ground stabilization.

Picture: Småröd slide, photo Wenche Marie Jacobsen

In Norway the major challenge is quick-clay (highly sensitive illite). Due to the cost effectiveness, ground improvement with lime-cement stabilization using deep-mixing technology is widely used. However, considering the huge amount of lime and cement used in ground improvement projects and the carbon intensity of lime and cement production, the contribution from these geotechnical works, to the carbon inventory of large infrastructure projects in Norway (and in the world in general), is very high. Many times, it is the largest single contributor. At the same time waste from concrete and bricks, and ashes are the largest contributors to the masses being deposited in Norway. These materials have a great potential as additives in the stabilizing technology.

This project aims to radically change the deep-mixing technology by introducing sustainable alternative stabilizers based on solid wastes and creating a circular economy around this technology.

To achieve this goal, we need interdisciplinary research with a bottom-up combined experimental and modelling approach, across the scales and disciplines. At nano and sub-nano scale, we will employ a combination of numerical and experimental work starting with the water and ions interactions at illite-clay particle surfaces. At micro scale, we will combine thermodynamic modelling with experiments to investigate how the interactions between illite-clay and cementitious materials contribute to the microstructure and strength development. At macro scale, representative elements of stabilized clay will be tested and full-scale geotechnical problems simulated. Finally, we will calculate and compare the total environmental impacts of the alternative technologies.

This project is an interdisciplinary collaboration gathering researchers from the dept. of structural engineering, dept. of mechanical and industrial engineering, dept. of chemistry, dept. of physics and dept. of civil and environmental engineering, all at NTNU, in addition to NGI.

MoreIsLess – Design of electrodes for Li-ion batteries with optimized balance of energy and power

Project leader: Julia Wind, IFE

Duration: 2021 – 2025

Li-ion batteries (LIBs) are currently considered as the most promising energy storage technology for portable and mobile applications. High-capacity materials - silicon (Si) and Si-based materials as well as high voltage cathodes have long been considered as materials for the next generation of LIBs. Despite significant efforts the use of these materials is still limited due to poor long-term stability. An alternative pathway to increase the performance of the modern LIBs is the development of thicker electrodes. However, the increase of the electrode's thickness leads to a number of challenges. An increase in energy density comes with the cost of lower power densities. In addition, the currently adopted preparation routines for LIB's electrodes (slurry/tape casting) have substantial limitations: preparation of thicker electrodes typically results in cracking and delamination of active material layer. Therefore, new methods and procedures are required to obtain electrode's thicknesses above current state-of-art (usually > 100 micrometer).

The aim of this project is to develop electrodes for LIBs with optimized ionic and electronic transport properties capable of delivering higher energy densities without compromising power density (i.e., deliver fast charging performance to LIBs with high energy density).

This project is a collaboration between IFE, NTNU, UiO, UCL, Equinor, Morrow Batteries AS and Norsk Hydro

In addition to the permanent staff, a PhD student is to be hired by NTNU. The candidate will be supervised by Prof. Burheim in collaboration with Prof. Shearing, Prof. Kjelstrup from PoreLab and Dr. Vie. The project of the student will focus on different techniques for changing and characterizing transport processes of electrodes, foremost through experiments, but also supported by models. Measurements on electrode materials from the different work packages will bridge the project together.

LABORATORY FACILITIES

Constant efforts are done at PoreLab to upgrade and consolidate our laboratories such that they continue to offer excellent working conditions with state-of-the-art equipment and instrumentation.

Professor Emeritus Ole Torsæter posing in front of the new CT-scanner named after him

Postdoctoral researcher Haili Long-Sanouiller, performs a demonstration of the new CT-scanner during the opening of the laboratory (the sample is provided by senior engineer Stefanie Lode)

A NEW CT-SCANNER AT THE DEPARTMENT OF GEOSCIENCE AND PETROLEUM, NTNU

On October 29th, 2021, was organized the ribbon-cutting ceremony for the new CT-scanner at the department of Geosciences and Petroleum, NTNU. The new scanner was named "Ole" after Professor Ole Torsæter who had been a mentor and a driving force for the acquisition of this up-to-date equipment. Ole Torsæter has been the Principal Investigator for the Work Package related to Microfluidics and Field Studies at PoreLab until he retired in November 2019. His successor is Associate Professor Carl Fredrik Berg. Ole is now Professor Emeritus and still very much involved in PoreLab's activities.

The new CT-scanner is part of the equipment financed by the Research Council of Norway under PoreLab's umbrella.

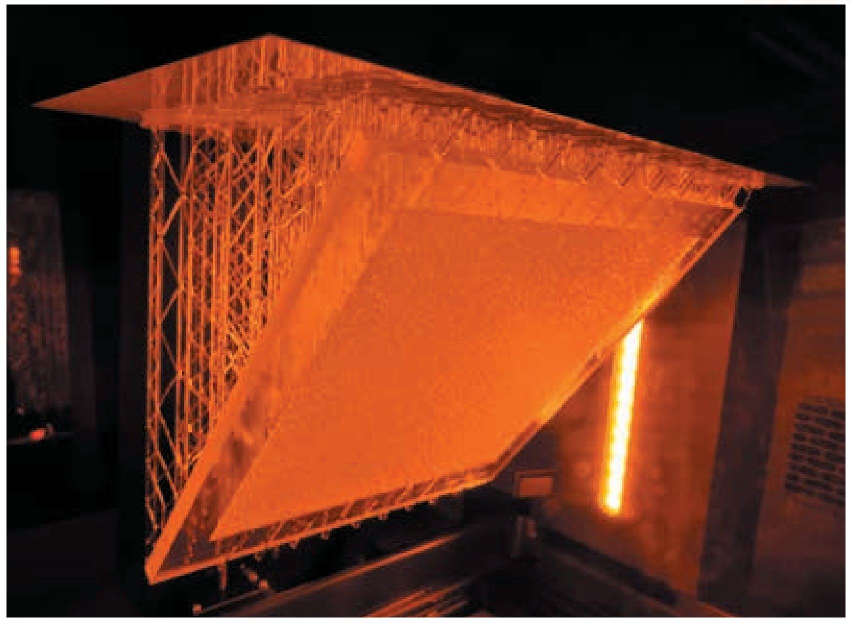
Post-doctoral researcher, Haili Long-Sanouiller explains that: *"Detailed capture and measurement of internal component and assembly features is often vital for material and porous media research, quality control and failure analysis. The Nikon, XT H 225 system offers a microfocus X-ray source, an inspection volume to accommodate small to medium sized parts and high image resolution in 3D. Ready for ultrafast CT reconstruction, the XT H 225 covers a wide range of applications, including the inspection of pore spaces, plastic parts, small castings and complex mechanisms as well as researching materials and natural specimens."*

The same day, on October 29th, the department of Geosciences and Petroleum was also celebrating the 70th anniversary for Ole Torsæter. In addition to the ribbon-cutting ceremony for the new CT-scanner, the day was marked with flowers, cakes and speeches.

Professor Emeritus Ole Torsæter cutting the ribbon during the official opening ceremony for the new CT-scanner laboratory at the department of Geosciences and Petroleum, NTNU. Alex Hansen, PoreLab's director is on the right

LABORATORIES AT THE PHYSICS DEPARTMENT AT UIO

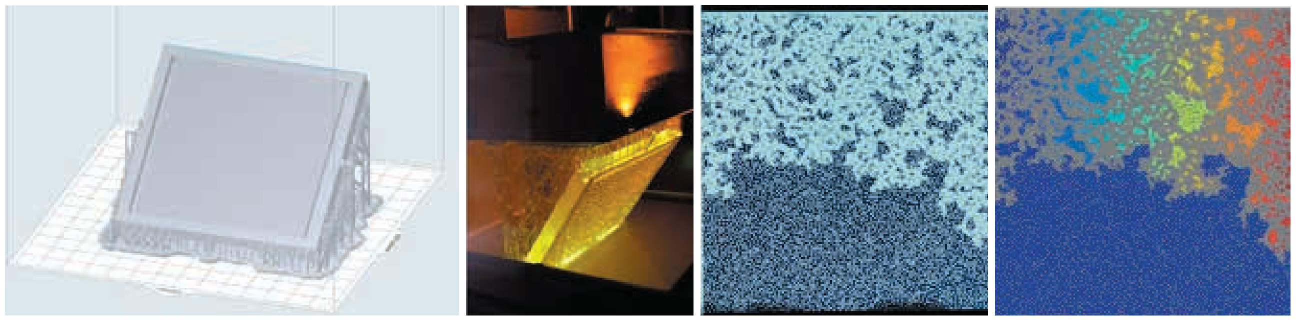
in a continuous effort to improve our experimental toolbox, we are constantly investigating possibilities of new technologies for fabricating quasi 2-D and 3D porous models suitable for different experimental needs. Those models are at the core of a good fraction of our experimental activity in porous media flows. Glass beads models, which have become our labs signature approach in this type of research, are now complemented with 3D printed models based on a Low Force Stereolithography technology. Since 2020, we have been able to successfully employ this 3D printing technique in a number of different projects. In 2021 we received a brand new Formlabs Form 3L printer having a five times larger build volume than its predecessor. The Formlabs Form 3L printer is the newest addition to Formlabs portfolio and to our labs. We were lucky enough to get one of the first five printers that came to Norway after their release in 2020 and this printer is now at full operation in our labs at the University of Oslo. Apart from being able to print incredibly high-quality parts with horizontal resolution down to 25 micrometers, the newest addition to our printer farm (currently 3 SLA printers) is also able to print in a variety of functional resins.



A large 3D printed model produced by the new Formlabs Form 3L printer.

3D printing the porous networks opens a new avenue of experimental research in the field: we can now directly control the porosity and permeability of our systems, and even design configurations of immediate practical relevance, like layered media or systems with dual porosity. These investigations were previously only accessible numerically, so we are very enthusiastic to bring now the much-needed experimental validation to these works. Having several printers at our disposal allows for faster prototyping and parallel production of the models. This in practice makes the experimental workflow much smoother and potential issues can be addressed in a faster way.

All this being said, our legacy glass beads models, something that our group built its status and name on, are still going to be used in scenarios where they are more appropriate.



Different stages of the 3D printing stereolithography technique applied to the study of porous media flows. From left to right: preparation of a 3D model to be sent to the printer. Stereolithography printing in which a laser hardens a clear liquid resin to define the 3D geometry. An example of an experiment with such a porous medium in which air enters from the top and displaces a liquid phase (a water-glycerol mix, seen in blue). Application of image analysis techniques to map individual trapped clusters (colored from left to right for visualization purposes only)

PORELAB GRADUATE SCHOOL

TRAINING THE NEXT GENERATION OF RESEARCH LEADERS

As the pandemic did not slow down in 2021, the Norwegian authorities continued to take a wide range of measures to tackle COVID-19 such as campus closure, limited gatherings, and travel restrictions. As both NTNU and UiO were following infection control regulations along the year, digital teaching became the main rule, while, at the same time, in-person teaching was maintained where this was possible. It was arduous to travel abroad and even more laborious to receive guests and students at PoreLab. Employees were encouraged or even mandated at some times to work from home. Conferences and meetings remained online. PhD defenses were held online or in a hybrid format. The crisis that struck us at the beginning of 2020 became a norm in 2021. It is our ambition that each junior researcher has a scientifically stimulating and inclusive workday, but did we succeed to overcome the negative consequences of the containment measures, and maintain an interdisciplinary and international training ground for our juniors, as was always our ambition?

Courses

All PhD candidates registered at UiO and NTNU follow their respective institutional training and course program..

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

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

The PoreLab course "Experimental techniques in porous and complex systems" (FYS4420/FYS9240) is organized every year during the fall semester by UiO. The course contains four projects that give students an introduction to important experimental techniques in the field of condensed matter physics. Each project assignment amounts to 1-2 full working days in the laboratory. Despite the pandemic, students from NTNU travelled to UiO to attend the laboratory courses. The course lecturer is Professor Knut Jørgen Måløy, PI at PoreLab.

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

PoreLab Lecture series, Porous Media Tea Time Talks and Thursday's talks

The use of video conferencing intensified already in 2020. It allowed us to broaden our pool of lecturers and we noticed a boost in attendance. This trend continued in 2021, with no less than 28 lectures. The PoreLab lecture series was given mainly by external lecturers. The list of our guest's lectures can be found on page **65** of this report.

Porous Media Tea Time Talks

The PoreLab lecture series was organized alternating with the Porous Media Tea Talks (#PorousMediaTTT), a webinar series, sent via YouTube and organized by a team of young porous media researchers, including PoreLab members. 18 sessions of the Porous Media TTT with 2 talks each were organized in 2021. More information about the Porous Media Tea Time Talk can be found page **63** of this report.

PoreLab's own Thursday's talks were reserved for internal speakers at PoreLab. They are meant for PoreLab members to present and receive feedback on their own problems. It is a goal that each PoreLab member should participate with at least one presentation during the year.

Both PoreLab lecture series and Thursday's talks are administered and organized by dedicated PoreLab juniors.

The catalogue of our Master students

Similar to the two previous years, a dedicated catalogue presents our suite of excellent Master students. In 2019, we had the great pleasure to welcome five international master students at our PoreLab premises. This was a result of international collaboration. Unfortunately, due to the pandemic, this fruitful exchange did not continue neither in 2020 nor in 2021. Nevertheless 12 students chose to work on their master project at PoreLab in 2021. Coming from physics, chemistry, mechanical and industrial engineering, material science, and geoscience and petroleum, they represent the interdisciplinarity of PoreLab.

The catalogue provides an overview of projects performed by our Master students in 2021. Students can also find suggestions for new master projects in this catalogue. Hopefully, this can inspire new students to join the team.

PoreLab Junior Forum

The PoreLab junior forum is a gathering for all PhDs, postdocs, and early career researchers at PoreLab. It is organized and run by the Juniors themselves. The primary purpose is to provide the juniors with a lasting network. As such, it also serves to bind the two hubs in Oslo and Trondheim together. Newly and old members, can then experience PoreLab as one center at two physical locations.

The main goal of this forum is thus to bring together the group of juniors with the objective of allowing them to better know each other, share and develop their respective work and scientific interests.

The junior forum meets regularly and normally twice a year. Because of lock-down and restrictions on gathering, it was impossible for the juniors to meet physically in the spring 2020 and 2021. The 5th junior forum was organized online in the fall 2020. At last, the juniors managed to meet physically during the fall 2021. The 6th PoreLab junior forum was held at the University of Oslo for a full day, on November 26th, 2021. The program started with a tour in the laboratories, followed by a short introduction of all new recruits. Catherine Taylor Nordgård, Vice-dean for innovation at the faculty of natural science at NTNU, gave an online presentation on "Intellectual Property Rights within innovation". Social activities were organized in the evening with a dinner and shuffleboard games.

6th Porelab Junior Forum at UiO on November 26th, 2021

PORELAB AND THE INTERPORE NETWORK

InterPore, the International Society for Porous Media, is a non-profit independent scientific organization established in 2008. It aims to advance and disseminate knowledge for the understanding, description, and modeling of natural and industrial porous media systems. InterPore's mission is to promote and support innovative research by increasing dialog between public and private scientific communities, to support and facilitate the participation of promising young scientists to InterPore activities and to support educational activities of InterPore society.

PoreLab has been an institutional member of InterPore since its creation. The close cooperation between PoreLab and InterPore led to the organization of annual workshops since 2017. The InterPore-PoreLab award for young researchers, sponsored by PoreLab, is granted annually since 2018.

PoreLab is also actively represented at the InterPore Academy, a new division of InterPore established to promote porous media via Short Courses, Webinars, Thematic workshops and Young Academy activities. PoreLab researcher Marcel Moura is a member of the Scientific Advisory Board of the academy and is currently also co-chairing the InterPore Young Academy, a division that focuses on the promotion of activities targeted at Master students, PhD candidates and early career researchers across all fields connected to porous media science.

13TH ANNUAL MEETING INTERPORE, 2021

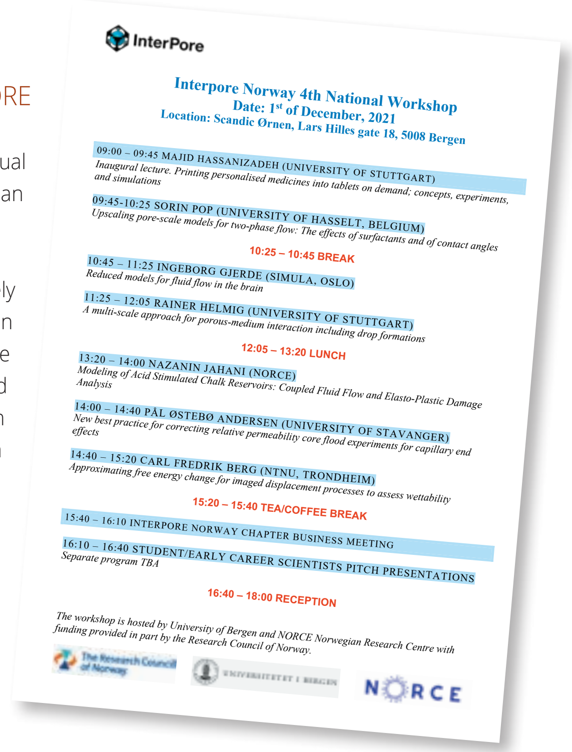
The annual meetings of the International Society of Porous Media are the focal events for the diverse porous media community worldwide, bringing together professionals and students to learn about new and exciting advances in porous media. The 13th Annual Meeting, held from May 31st to June 4th, was organized online due to Covid-19 restrictions. It included both pre-recorded orals and poster presentations. PoreLab was again this year largely represented at this event. PoreLab got not less than 16 abstracts accepted for the conference, including 11 presentations and 5 posters prepared by nearly 30 professors, researchers, PhDs and master students from PoreLab.

NATIONAL WORKSHOP OF THE NORWEGIAN CHAPTER OF INTERPORE

The close cooperation between PoreLab and InterPore led to the organization of annual national workshops. InterPore Norway is meant to provide a platform for the Norwegian porous media researchers and scientists to meet and exchange ideas.

The three first workshops of the Norwegian Chapter were organized respectively in October 2017 in Trondheim, in November 2018 in Oslo and in October 2019 in Stavanger. The 2020 Norwegian national workshop was unfortunately cancelled due to the covid-19 outbreak and following some restrictions on major events established by the Norwegian authorities at that time. The fourth national workshop was then postponed to 2021 and was organized by NORCE on December 1st in Bergen as a physical event.

The program consisted of technical talks from invited speakers both from Norway and abroad, and who represented a broad spectrum of porous media research. Associate Professor and PoreLab PI, Carl Fredrik Berg, held a presentation on "Approximating free energy change for imaged displacement processes to assess wettability".


InterPore

Interpore Norway 4th National Workshop
Date: 1st of December, 2021
Location: Scandic Ørnen, Lars Hilles gate 18, 5008 Bergen

09:00 – 09:45 MAJID HASSANIZADEH (UNIVERSITY OF STUTTGART)
Inaugural lecture. Printing personalised medicines into tablets on demand; concepts, experiments, and simulations

09:45-10:25 SORIN POP (UNIVERSITY OF HASSELT, BELGIUM)
Upscaling pore-scale models for two-phase flow: The effects of surfactants and of contact angles

10:25 – 10:45 BREAK

10:45 – 11:25 INGEBORG GJERDE (SIMULA, OSLO)
Reduced models for fluid flow in the brain

11:25 – 12:05 RAINER HELMIG (UNIVERSITY OF STUTTGART)
A multi-scale approach for porous-medium interaction including drop formations

12:05 – 13:20 LUNCH

13:20 – 14:00 NAZANIN JAHANI (NORCE)
Modeling of Acid Stimulated Chalk Reservoirs: Coupled Fluid Flow and Elasto-Plastic Damage Analysis

14:00 – 14:40 PÅL ØSTEBØ ANDERSEN (UNIVERSITY OF STAVANGER)
New best practice for correcting relative permeability core flood experiments for capillary end effects

14:40 – 15:20 CARL FREDRIK BERG (NTNU, TRONDHEIM)
Approximating free energy change for imaged displacement processes to assess wettability

15:20 – 15:40 TEA/COFFEE BREAK

15:40 – 16:10 INTERPORE NORWAY CHAPTER BUSINESS MEETING

16:10 – 16:40 STUDENT/EARLY CAREER SCIENTISTS PITCH PRESENTATIONS
Separate program TBA

16:40 – 18:00 RECEPTION

The workshop is hosted by University of Bergen and NORCE Norwegian Research Centre with funding provided in part by the Research Council of Norway.

The Research Council of Norway
Universitetet i Bergen
NORCE

INTERPORE-PORELAB AWARD FOR YOUNG RESEARCHERS

The close cooperation between InterPore and PoreLab has led to the creation of the InterPore-Porelab award for young researchers. The award, allocated for the first time in 2018, is given in recognition of outstanding contributions to fundamental research in the field of porous media.

This year InterPore reported having a large number of high-quality nominees leading to a strong competition, but the members of the Honors and Awards Committee have made their choice. The 2021 winner of the InterPore-PoreLab award for young researchers is **Maja Rücker**, assistant professor at the Eindhoven University of Technology in the Netherlands. Maja received her PhD in Petroleum Engineering in a joint project of the Rock & Fluid Physics team at Shell Global Solutions International B.V. and Imperial College London. She holds a BSc and MSc degree in Geoscience from the Johannes-Gutenberg University in Mainz. She worked from 2018-2020 as a Research Assistant and later as Research Associate in the Chemical Engineering Department at Imperial College London. In November 2020, she joined the Energy Technology group at the Mechanical Engineering Department at the Eindhoven University of Technology as an Assistant Professor.

Maja is one of the main initiators of the Porous Media Tea Time Talks, a webinar series, sent via YouTube, created and organized by a team of young porous media researchers including Marcel Moura, researcher at PoreLab, University of Oslo.

Maja summarizes her research activities as follow: *"Treatment and development of sub-surface fluid reservoirs in rocks, such as aquifers, hydrocarbon reservoirs, H_2 or CO_2 storage sites, is crucial for the reduction of stress on water supply, energy demand, climate and environment. Insight in how fluids behave within the confined space of the porous rock is key for decision-making processes in the associated applications. I study molecular interactions of fluids within porous materials and how these link to the macroscopic flow phenomena (incl. multiphase flow responses, reactive transport), develop integrated experimental workflows for upscaling and advance digital modelling approaches used, e.g. to assist decision making for effective utilization of sub-surface resources".*

THE INTERPORE STUDENT AFFAIRS COMMITTEE, SAC

PoreLab researchers (both PhD candidates and postdoctoral researchers) have been deeply involved in the InterPore Student Affairs Committee, or SAC, since its creation, with not less than 4 PoreLab researchers among the committee until 2020.

SAC aims to attract, involve, and include more PhD students and postdocs into the InterPore activities, by organizing educational, career and social oriented activities. The objective of the SAC is also to create multiple student sections to support young researchers new to the field of porous media to create a platform where students, academia and industry meet and to intensify collaboration among students of the InterPore society. Marco Sauermoser, who got his PhD degree at PoreLab on February 19th, 2021, and is now postdoctoral researcher at the Department of Mechanical and Industrial Engineering at NTNU, has been a member of the SAC since 2019 and continues with his participation in 2021.

THE POROUS MEDIA TEA TIME TALKS AND THE INTERPORE YOUNG ACADEMY

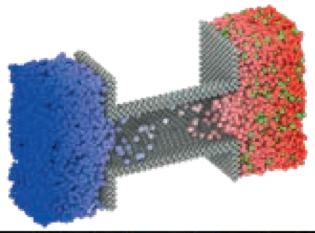
Motivated by the new challenges brought upon the scientific community by the pandemic in 2020, a group of young porous media researchers from different institutions teamed up to create the Porous Media Tea Time Talks initiative (PMTTT). The PMTTT is a YouTube channel which serves as an online platform for early career scientists to promote their research via live streaming of talks. This initiative became particularly important as many conferences worldwide were canceled in 2020 and 2021. The idea was extremely well received and the PMTTT accumulates now (Feb/2022) more than 10 000 views which is far more than anyone could have expected in the beginning. PoreLab researcher Marcel Moura and PhD candidate Federico Lanza are part of the PMTTT organizing team, and PoreLab has contributed with several talks to the platform.

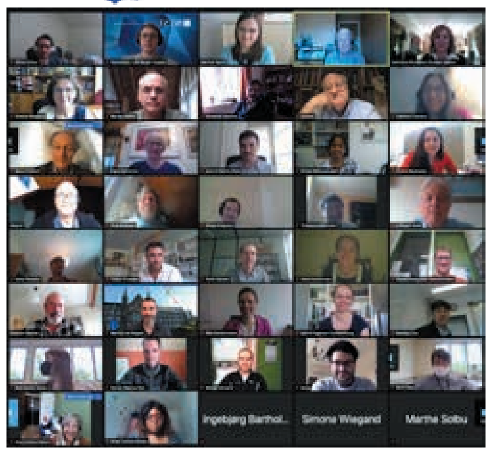
The Porous Media Tea Time Talks initiative has always received support from InterPore through the dissemination of information about the talks to their network. This fruitful collaboration has led to the creation of the InterPore Young Academy which counts now with the PMTTT as its seed activity.

MEETINGS, WORKSHOP, AND GUEST LECTURES

Researchers at PoreLab have numerous opportunities to present their scientific activities and research results to both internal and external events. Scientists at PoreLab also organize international meetings and specialized workshops alongside other experts in their field.

14TH INTERNATIONAL MEETING ON THERMODIFFUSION





The 14th International meeting, IMT 14, is part of a series which has been arranged every second year since 1994. IMT provides a unique opportunity for sharing ideas about theoretical, experimental, and numerical research on Diffusion and Thermal Diffusion. The series is aimed at discussing the latest results on transport properties in multicomponent fluids: innovative theoretical approaches, new experimental results and techniques as well as state of the art numerical methods. The most fundamental aspect of the conference is the discussion amongst scientists, the sharing of ideas and creating new and reinforced existing collaborations. The 14th meeting was organized at NTNU, Trondheim, in May 25-27, 2021. It was planned originally in 2020 but due to the COVID-19 outbreak, the event was postponed to 2021. It was organized as a digital event with pre-recorded videos. Professor Bjørn Hafskjold was leading the local organizing committee mainly composed of PoreLab members. 43 abstracts and 10 posters were presented with a large representation from PoreLab members. The international scientific committee for IMT 14 agreed with the European Physical Journal E (EPJE) to make a topical issue on Thermal non-equilibrium phenomena in fluid mixtures. It will be published in 2022 and its purpose is to present recent advances to the wider scientific communities.

2ND MACHINE LEARNING WORKSHOP HOSTED BY PORELAB / IGP, NTNU

On May 16th, Friday, 2021, PoreLab at IGP (Department of Geoscience and Petroleum), NTNU, organized the 2nd machine learning workshop in IGP. Most partic-ipants were from PoreLab and BRU21, as well from NGU, Equinor and Petricore. The workshop was organized in a hybrid format. External participants from PoreLab/IGP joined online. In total, there were 6 talks. Professor Ivan Tyukin from the Department of Mathemat-ics, University of Leicester, gave an open presentation about instabilities in high-dimensional data-driven AI systems. Three talks were focusing on core analysis problems, i.e., measurements of fluid flow through rock samples. This involves high-resolution images of rock samples, and simulations of fluid flow directly on these images. The last two talks focused on larger scales, typically oil reservoirs. The aim for this workshop was to give the opportunities to Master and PhD students to present their works, to learn from other research groups, especially from industries about the demand and the application area of machine learning techniques, and to open the network with other research groups who were working on machine learning topics.

EARTHFLOWS JUNE MEETING 2021

The 2021 EarthFlows Meeting was an annual event on its 7th edition, and part of a strategic research initiative for cross-disciplinary research at the University of Oslo (UiO), Norway. This year's seminar was held on June 3rd and 4th 2021 on Zoom. This annual event is organized by the EarthFlows research group at UiO, and more precisely by Professors François Renard and Luiza Angheluta-Bauer, both associated members to PoreLab, and Fabian Barras, postdoctoral researcher, for the 7th edition.
The EarthFlows Meetings bring together top international researchers from various disciplines (geoscience, mathematics, material science, theoretical and experimental physics), who have different perspectives on interface dynamics, flows and deformations in complex systems.

GUEST LECTURES

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 and 2021. Nevertheless, it is important for us to maintain communication and the exchange of ideas under these restricted travel conditions. As a result, we learned using video conferencing more intensively and broaden our pool of lecturers.

Here is below the list of our guests' lectures for 2021.

DATE	NAME, AFFILIATION	TITLE
Jan. 13	Nima Shokri, head of institute, Hamburg University of Technology, Institute of Geo-Hydroinformatics, Germany	*Soil salinization: From pore- to global-scale processes*
Jan. 14	Marco Sauermoser, PhD candidate, PoreLab, department of Chemistry, NTNU, Norway	*Non-equilibrium thermodynamics and nature-inspired chemical engineering applied to PEM fuel cells*
Jan. 20	Timo Koch, Postdoctoral researcher, University of Oslo, Norway	*Mixed-dimension models for flow and transport processes in porous media with embedded tubular network systems*
Jan. 21	David Weitz, Professor, Harvard University, USA	*Pore-scale studies of multiphase fluid flow in micromodel porous media*
Feb. 3	Zbigniew Rozynek, AMU, Poznan, Poland	*Method for efficient particle deposition on a substrate using electric field and capillary interactions*
Feb. 17	Anna Herring, postdoctoral fellow, Department of Applied Mathematics, Australian National University	*Robust Topological Characterization of Fluid Microstructure via Persistent Homology*
Feb. 24	Amy Ryan, Postdoctoral Associate, Rock and Mineral Physics laboratory, University of Minnesota, USA	*Healing of crystal-rich granular materials in volcanic environments by solid-state sintering: implications for fluid flow, deformation and explosivity*
March 3	Philippe Poncet, Professor, Lab. Mathematics and their Applications, University of Pau & Pays Adour, France	*Particle methods for pore-scale modeling of reactive flows*
March 10	Tannaz Pak, Senior lecturer, Teesside University, UK	*Use of Nanoparticles (non-reactive or reactive) to Impact Flow and Entrapment of Fluids in Porous Media – A Pore-scale Discussion*
March 11	Ryan Armstrong, Professor, University of New South Wales, Australia	*Probing Effective Wetting in Subsurface Systems: The Role of Curvature and Topology*
March 24	Ashim Datta, Professor, Cornell University, NY	*Poromechanics as a food process modeling framework*
April 7	Ran Holtzman, Associate Professor, Coventry University, UK	*Hysteresis, memory and energy dissipation in fluid-fluid displacement in disordered media*
April 14	Amir Raoof, Assistant Professor of Hydrogeology and Geochemistry at Utrecht University, NL	*Fluid Flow and Particle Transport in Porous Media: Microscopic Experiments, Pore Scale Modeling, and Upscaling*
April 21	Yves Meheust, Assistant Professor in Geosciences, University of Rennes, France	*Chaotic advection/mixing in 3D granular porous media*
April 28	Sujit Datta, Assistant Professor, Chemical and Biological Engineering, Princeton University, NJ	*Life in a tight spot: how bacteria move in porous media*
May 5	Stephane Santucci, Laboratoire de Physique, CNRS, Ecole Normale Supérieure de Lyon, France	*Inertial effects on the multi-scale stick-slip dynamics in adhesive tape peeling*
May 12	Muhammad Sahimi (as part of the InterPore Kimberly-Clark Lecture Series), Professor of Chemical Engineering and Materials Science, University of Southern California in Los Angeles, CA	*Characterization, Modeling and Upscaling of Large-Scale Porous Media and Fluid Flow Therein: Applications of Wavelet and Curvelet Transformations*
May 19	Bjørnar Sandnes, Associate Professor, College of engineering, Swansea University, UK	*Frictional fluid flow shaped by viscous and capillary forces*
Sept. 8	Kamaljit Singh, Assistant Professor, Institute of GeoEnergy Engineering, Heriot-Watt University, Edinburgh, UK	*3D imaging of flow in porous materials*
Sept. 15	Dag Chun Standnes, Leading researcher at Equinor, Bergen, Norway	*Dissipation Mechanisms for Fluids and Objects in Relative Motion Described by the Navier-Stokes Equation*
Sept. 22	Bo N.J. Persson, Multiscale Consulting and Peter Grünberg Institute (PGI), Germany	*Multiscale contact mechanics for rough surfaces with applications to fluid flow at interfaces*
Sept. 29	Marcio Carvalho, Professor, Laboratory of Microhydrodynamics and Flow in Porous Media (LMMP), Pontifícia Universidade Católica do Rio de Janeiro (PUC-Rio), Brazil	*Microscale Phenomena of Complex Liquid Flow in Porous Media*
Oct. 6	Brice Lecampion, Assistant Professor, Ecole Polytechnique de Lausanne (EPFL), Switzerland	*Planar 3D hydraulic fracture growth in transversely isotropic rocks*
Oct. 13	Endre Joachim Lerheim Mossige, Researcher, UC, Santa Barbara, USA	*Measuring macromolecule diffusion with microfluidic Fabry–Pérot interferometry (μFPI)*
Oct. 20	Laciel Alonso, graduate student, Universities of Havana (Department of Applied Physics) and Strasbourg (Institut Terre Et Environnement)	*Penetration of intruders in granular media*
Oct. 27	Varun Hegde, graduate student at Squires group at UCSB; Santa Barbara, CA, USA	*Transport through polymer membranes*
Nov. 24	Lucilla De Arcangelis, Department of Engineering, University of Campania "Luigi Vanvitelli", Italy	*Acoustic fluidization and remote earthquake triggering*
Nov. 25	Clare P. Grey, Professor, Department of Chemistry, University of Cambridge, UK	*Developing and applying new tools to understand how materials for Li and "beyond-Li" battery technologies function*

OUTREACH AND MEDIA HIGHLIGHTS

PoreLab aims to communicate our research activities and novel findings to the public in an informative way. The members of PoreLab are accessible to media and enjoy contributing with their competence on issues of public concerns whenever their expertise is applicable. PoreLab has gotten quite a bit of media coverage since the start in 2017. You find in these 4 pages a few stories the PoreLab scientists have participated in during 2021.

29 November 2021 –
Alex Hansen participates to a Frontiers forum with former US Vice president, Al Gore, on the climate crisis

In his November 29 talk at the Frontiers Forum, the Former US Vice president Gore outlined encouraging progress on the sustainability revolution – and why we can be optimistic about our future. The session was attended by nearly 6 000 representatives from science, policy and business across the world.

https://forum.frontiersin.org/

4 November 2021 –
Alex Hansen is invited to the NTNU's webinar "Science Conversations @NTNU" to talk about why Ethics and Open Access are important when publishing.

Open access to research results is a requirement from granting authorities both nationally and internationally. This is a demanding landscape because it must comply with ethical guidelines and a number of laws and regulations.

In this webinar, Alex Hansen answers the questions of Pernille Feilberg, Head of communication at the Faculty of Natural Sciences, NTNU, on open access of data and publications. Alex explains especially what Open Access is, why science must be made public with today's technology and talks about quality in publication channels.

https://www.ntnu.edu/science-conversations/ethics-open-access

19 July 2021 - All coffee brewing methods are flow in porous media experiments in disguise!

Photo: Marcel Moura discussing with Ludvik Bonna Hopstock at Fuglen Coffee Roasters on light roasted coffee. Photo by Hilde Lynnebakken/ UiO

Whether you prefer the sweet complexity of a filtered coffee or the nice intensity punch of an espresso, you are always performing a flow in porous media experiment when you make coffee at home. In this popular science article from Titan, Marcel Moura, PoreLab researcher at the physics department at the University of Oslo, was interviewed about the interesting connections between porous media physics and the process of coffee brewing.

He also had the chance to meet Charlotte Sletten Bjorå, a botanist working at the Botanical Garden in Oslo and learn more about the coffee tree and some truly fascinating aspects of coffee growing. Marcel also visited a coffee roaster right during roasting hour and learned how roasting profiles have to be adapted to get the best flavors out of the different types of coffee beans.

https://titan.uio.no/fysikk-biologi/2021/slik-lager-du-bedre-kaffe-med-litt-fysikk-og-litt-botanikk

29 November 2021 – When the tearing of unfrozen porcine skin shows that mechanical injuries in biological tissues can generate enough heat to stimulate the neural network

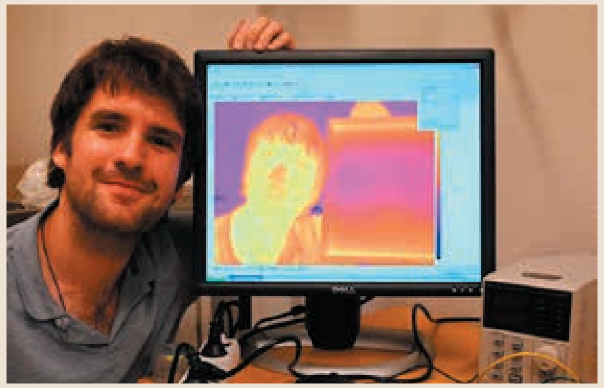
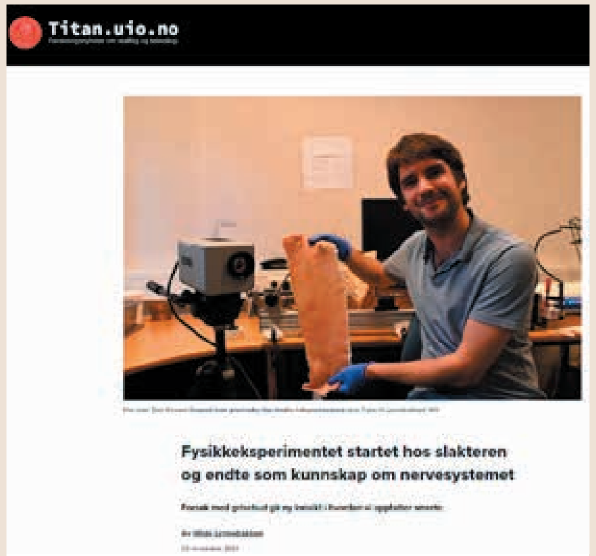


Photo: Tom Vincent-Dospital studies the tearing of porcine skin in front of an infrared camera and shows that mechanical injuries in biological tissues can generate enough heat to stimulate the neural network. Photo by H. Lynnebaken/UiO



Tom Vincent-Dospital is a postdoctoral researcher at the department of Physics from the University of Oslo. His research focuses on the dynamics of fracture and friction such as cracks in the earth's crusts during earthquakes. In this popular science article from Titan, Tom turned instead to skin damage and explains how his experiments with pig skin can provide new insight into how we perceive pain. His goal is to check if the rupture of biological tissues can create enough heat to trigger our nervous system.

https://titan.uio.no/livsvitenskap/2021/fysikkeksperimentet-startet-hos-slakteren-og-endte-som-kunnskap-om-nervesystemet

OUTREACH AND MEDIA HIGHLIGHTS

3 October 2021 – PoreLab goes pink … again!

On October 3rd, 2021, PoreLab participated for the second time to the Pink Ribbon Run in Trondheim with a group of 20 PoreLab members. In 2020 due to the pandemic, the Pink Ribbon Run was organized "virtually", but in 2021 we could participate in person. The Pink Ribbon is an international symbol of breast cancer awareness, and the Pink Ribbon Run helps increase awareness of early detection for breast cancer. Why a PoreLab team at the Pink Ribbon Run? Because at PoreLab we work on improving cancer therapy, especially by optimizing focused ultrasound for improved drug delivery by nanoparticles to the tumor interstitium. Congratulations to Ailo Aasen who arrived 10th on the finishing line!

6 December 2021: Do not leave your soda drinks in your vehicle when it is very cold outside, especially over night!

Professor emerita Signe Kjelstrup was interviewed by trd.by following the video of an accident featuring pepsi cans! A young lady from Trondheim purchased 48 cans of pepsi sodas and left them at the back of her car overnight while it was freezing outside. The video of the exploded cans and the sticky mess in the car's trunk went viral on the social medias.

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!

7 to 21 July 2021 – The PoreLab Art Exhibition exposed during 2 weeks next to the city hall in Oslo

Over the years, we have collected at PoreLab beautiful images from experiments and simulations. Due to the pandemic, a virtual porous media art gallery was set up with those images in 2020 (see pages 60 and 61 of the annual report 2020). With the slow reopening of the society, we decided to take the gallery out in the streets of Oslo. The PoreLab Art exhibition was exposed during 2 weeks next to the city hall in Oslo. We are planning to expose our art in other arenas both in Oslo and Trondheim in the future.

10 November 2021:
Their Majesties King Willem-Alexander and Queen Máxima of the Netherlands together with The Crown Prince Haakon met PoreLab members during the state visit from the Netherlands in Trondheim

During their state visit to Norway, their Majesties King Willem-Alexander and Queen Máxima of the Netherlands together with The Crown Prince Haakon visited NTNU's campus in Gløshaugen to learn about the NTNU and SINTEF efforts to promote the transition to green energy. They were accompanied by NTNU's rector, Anne Borg. The topics of the visit were related to energy conversion, carbon capture and storage (CCS) and hydrogen technology.

They met and discussed with PoreLab members when visiting the laboratories at SINTEF Energy research and the department of Mechanical and Industrial Engineering from NTNU.

Former PoreLab PhD candidate, Ailo Aasen, now research scientist at SINTEF Energy Research and affiliated researcher at PoreLab, presented the possibility to transport hydrogen over long distances by liquefying it and then shipping it, and compared it to today's industry of shipping liquefied natural gas (for more information, see PoreLab annual report 2020 page 49)

Elisa Magnanelli, research scientist at SINTEF Energy Research and former PhD candidate with Signe Kjelstrup, explained how the energy consumption can be minimized during the process of hydrogen production, using as inspiration the reindeer nose and new 3D printing technology (for more information, see PoreLab annual report 2019 pages 48 and 49).

Former PoreLab PhD candidate, Marco Sauermoser, now postdoctoral researcher at the department of Mechanical and Industrial Engineering at NTNU, presented the experimental work he performed during his PhD at PoreLab, i.e. the use of nature-inspired chemical engineering to design new flow patterns for the flow field plate in PEM fuel cells. The design was inspired by the human lung, which provides uniform gas distribution inside the fuel cell. Marco explained that this design can help to increase the fuel cell's performance and efficiency, and showed the very promising results obtained in this study (for more information, see PoreLab annual report 2019 pages 46, 47 and PoreLab annual report 2020 page 47).

Following the lab visits, the Royals attended a panel discussion on the North Sea as a platform for energy transition and energy conversion. They were joined by the Norwegian Minister of Petroleum and Energy, and the Dutch Minister of Foreign Affairs. The panel debate focused on hydrogen as well as other relevant technologies such as offshore wind and CO_2 storage. Professor Signe Kjelstrup, PI at PoreLab, was a member of the panel and talked about energy conversion.

Above: King Willem-Alexander, Queen Máxima, Crown Prince Haakon and NTNU's rector, Anne Borg, discuss hydrogen technology with Elisa Magnanelli, Ailo Aasen and Marco Sauermoser (from top to bottom)

Left: Professor Signe Kjelstrup, PoreLab PI, talks about energy conversion at the closing panel debate.

AWARDS AND PRIZES 2021

Ailo Aasen received the *Excellence Award in Thermodynamics and Transport Properties* from the European Federation of Chemical Engineers (EFCE)

Dr. Ailo Aasen won the European Federation of Chemical Engineering's 2021 Excellence Award for an outstanding PhD thesis in *"Bulk and interfacial thermodynamics of mixtures: From aqueous systems to ultracryogenic fluids"*.

His thesis dealt with understanding and modelling the thermodynamics of mixtures. His supervisors were Professor Øivind Wilhelmsen (PoreLab, department of chemistry, NTNU) and Dr. Morten Hammer (SINTEF Energy Research).

The excellence award consists of a diploma, a cash prize of 1500 Euros, and the opportunity to present his work in a plenary talk. The award was presented to Dr. Ailo Aasen during the 31st European Symposium on Applied Thermodynamics (ESAT 2021) on July 6th.

The judging committee of EFCE's Thermodynamics and Transport Properties Working Party was highly complimentary of the technical quality of Aasen's work, which included his innovative approach to include quantum effects into classical Helmholtz energy equations of state. The thesis also focused heavily on fluid interfaces, and his work on nucleation of fluid mixtures featured in PoreLab's Annual Report 2019.

Ailo performed large parts of his PhD thesis at PoreLab. Today he works at SINTEF Energy Research and continues his presence at PoreLab through collaboration with PoreLab Principal Investigator Øivind Wilhelmsen.

Congratulation to **Tom Vincent-Dospital** with the *Prix de Thèse de la Commission de la Recherche de l'Université de Strasbourg*

Dr. Tom Vincent-Dospital has been awarded the Prix de Thèse de la Commission de la Recherche de l'Université de Strasbourg, i.e. the PhD award from the research commission of the University of Strasbourg. The title of his thesis is: *" Interfacial fractures: thermal effects and material disorder."*

This prize is awarded to 20 PhD fellows every year (394 PhDs were granted in 2021). This is a great achievement!

The rigorous selection of the winner is first performed at the level of the doctoral schools according to their area of expertise, followed by the members of the research commission of the University. Tom received his prize on June 18th, during a ceremony in Strasbourg. Tom performed his PhD in geophysics and fracture physics as a Cotutelle between the Institut de Physique du Globe de Strasbourg, ITES (France) and PoreLab at the department of physics, University of Oslo (UiO), Norway. His supervisors were Professor Renaud Toussaint from the Institute for Earth and Environment of Strasbourg (as well adjunct professor at PoreLab, UiO) and Professors Knut Jørgen Måløy and Eirik Grude Flekkøy from PoreLab, department of Physics, UiO.

Early in 2021 he joined PoreLab UiO as a Post-doctoral researcher and works together with professors Knut Jørgen Måløy and Eirik Flekkøy on the dynamics of fractures and flows in porous materials.

Joachim Falck Brodin was awarded the *Martin Landrø prize* for outstanding master thesis in physics from the Norwegian Physical Society (Norsk Fysisk Selskap – NFS)

Congratulations to Joachim Falck Brodin who was awarded the Martin Landrø prize for outstanding master thesis in physics from the Norwegian Physical Society (Norsk Fysisk Selskap – NFS). He received his prize on June 24th.

The Martin Landrø prize for outstanding master thesis in physics was established by NFS in 2011 based on a gift of NOK 150,000 from Martin Landrø. The prize consists of NOK 5,000 as well as a diploma and is awarded during the NFS annual meeting every second year.

Joachim's master thesis is entitled *"A new vision for 3D experiments on flow in porous media"*. During his master thesis, Joachim built an entirely new setup for the imaging of multiphasic flows in porous media with a 3D scanner. The majority of previous micromodel studies was performed in 2D systems, and this has been substantial in the success of PoreLab based on systems developed experimentally by PoreLab at UiO and numerically by PoreLab at NTNU. With the new 3D scanner, the researchers at PoreLab are now able to extend much of their previous work to 3D systems.

In addition to the accomplishment being highly valuable for PoreLab the work itself is quite impressive. There are only a couple of groups in the world that have developed similar systems in the past years (one in Harvard and another at MIT for example).

Joachim is now a PhD candidate at PoreLab, department of Physics, UiO.

Swarms of active particles, like birds or bacteria, tend to break up into smaller clusters due to inherent noise in the system. This breaking of the collective states can be suppressed by confinement or a porous media, which hinders break-away clusters from straying too far from each other. Picture by Kristian Stølevik Olsen

COMPLETED PHDs IN 2021

NAME	DEPARTMENT	DATE	THESIS	SUPERVISORS
Kristian Stølevik Olsen	Department of Physics, University of Oslo	29.01.2021	*Active and passive Brownian particles in complex environments*	Eirik Grude Flekkøy, Knut Jørgen Måløy
Marco Sauermoser	Department of Chemistry, NTNU	19.02.2021	*Non-equilibrium thermodynamics and nature-inspired chemical engineering applied to PEM fuel cells*	Signe Kjelstrup, Bruno G. Pollet
Fredrik Kristoffer Mürer	Department of Physics, NTNU	09.04.2021	*Diffractive X-ray Tomography of Oriented Mineralized Structures in Hierarchical Materials*	Dag Werner Breiby, Magnus Borstad Lilledahl, Kristin Olstad
Eivind Bering	Department of Physics, NTNU	04.06.2021	*Stretching, breaking, and dissolution of polymeric nanofibres by computer experiments*	Alex Hansen, Astrid Silvia de Wijn
Chuangxin Lyu	Department of Civil and Environmental Engineering, NTNU	19.10.2021	*Mechanical behavior of frozen saline clay: laboratory, field and numerical investigation*	Gustav Grimstad, Seyed Ali Ghoreishian Amiri
Louison Thorens	Department of Physics, University of Oslo and Laboratoire de Physique, Ecole Normale Supérieure de Lyon, France	17.11.2021	*Unstable drainage of frictional fluids and magnetic control of the mechanical behavior of confined granular media*	Knut Jørgen Måløy, Eirik Grude Flekkøy, Mickaël Bourgoin, Stéphane Santucci
Seunghan Song	Department of Physics, NTNU	09.12.2021	*Thermal processing of semiconductor alloy core glass fibers*	Ursula Gibson, Alex Hansen, Signe Kjelstrup

GUEST RESEARCHERS AT PORELAB

The Covid-19 outbreak and following restrictions on travels led to a drop in the number of visitors both in 2020 and 2021. We had 64 visitors in 2019, 14 in 2020 and only 7 in 2021.

NAME	POSITION	AFFILIATION	PERIOD
Zbigniew Rozynek	Associate Professor	Adam Mickiewicz University, Poznan, Poland	01.09.2020 - current
Andrès Arango Restrepo	PhD candidate	Department of condensed Matter Physics, Faculty of Physics, University of Barcelona, Spain	15.01.2021 – 20.03.2021
Stefan Windisch-Kern	PhD candidate	Department of Environmental and Energy process Engineering, University of Leoben, Austria	01.07.2021 – 21.10.2021
Matthieu Fumagalli	Assistant Professor	Polymer Materials Engineering lab, University Claude Bernard of Lyon, France	26.10.2021 – 29.10.2021
Khobaib Khobaib	PhD Student	Adam Mickiewicz University, Poznan, Poland	08.11.2021 – current
Clare Grey	Professor	Yusuf Hamied Department of Chemistry, University of Cambridge, UK	21.11.2021 – 02.12.2021
Maja Rücker	Assistant Professor	Department of Mechanical Engineering, Eindhoven University of Technology, The Netherland	02.12.2021 – 18.12.2021

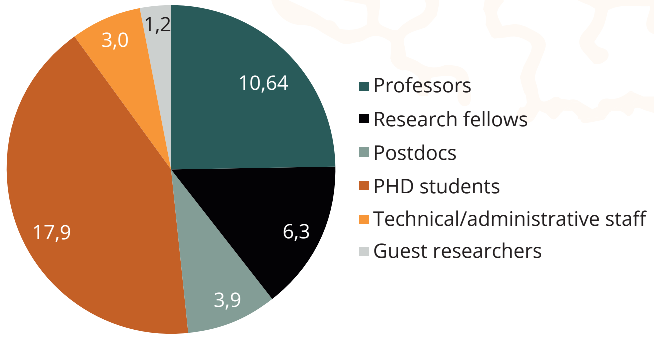
FUNDING IN 2020

FUNDING (1000 NOK)	AMOUNT	PERCENTAGE
The Research Council	15 247	45 %
NTNU	13 432	39 %
University of Oslo	5 587	16 %
TOTAL	34 266	100 %

FACTS AND FIGURES 2021

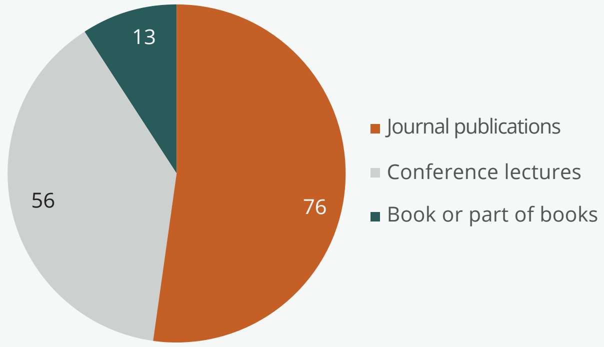
PORELAB STAFF categorized by position

PoreLab staff equals 42,9 man-years in 2021
The pie chart on the right shows the categorization of our staff by position



PUBLICATIONS in 2021

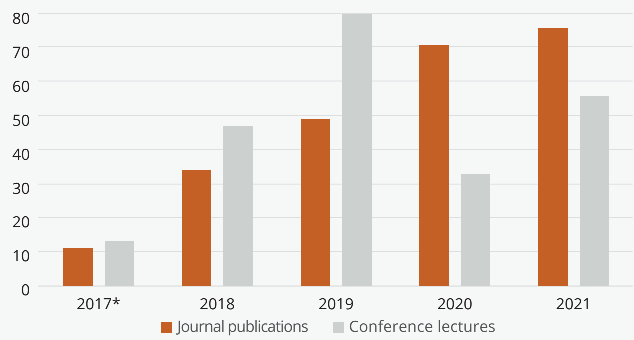
- 76 Journal publications
- 56 Conference lectures and academic presentations
- 13 books, part of book and reports



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

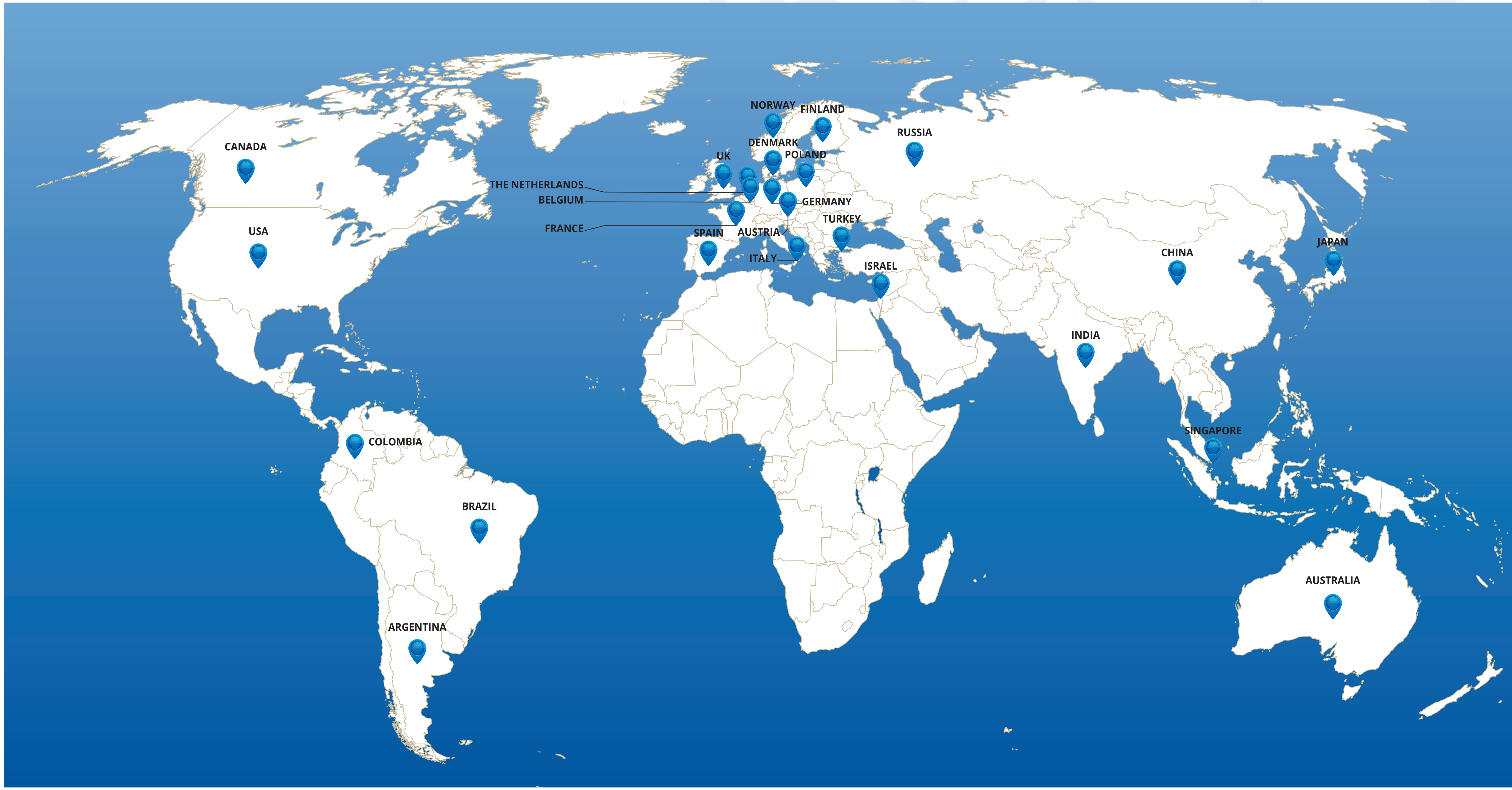
Although 2020 has seen a decrease in our contribution to conferences compared to the previous years. This result was expected since conferences planned in 2020 were either cancelled or postponed due to the virus outbreak and restrictions on travel.

With the reorganization of many conferences in 2021 as digital events, we observe an increase of the conference lectures between 2020 and 2021.



*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*
James McClure: *Virginia Tech*

CANADA
Steven Bryant, Marie Macquet, Somayeh Goodarzi, Ali Telmadarreie, Ellen Liu, Carter Jordan Dziuba, Ian Gates: *University of Calgary*

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

ARGENTINA
Diego Kingston: *University of Buenos Aires*

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

NORWAY
Jan Øystein Haavig Bakke: *Schlumberger Stavanger*
Asbjørn Solheim, Olaf Trygve Berglihn, Torleif Holt, Erik Lindeberg, Dag Wessel-Berg, Vegard Brøtan, Pierre Cerasi: *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*
Marianne Øksnes Dalheim, Kristin Syverud: *RISE PFI AS*
Harald Berland, Olav Aursjø: *NORCE Norwegian Research center AS*
Thomas Ramstad: *Equinor Research Center, Trondheim*
Bjørn Karlsen: *Jotun, Sandefjord*

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

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*
Steffen Berg, *Shell Research, Amsterdam*
Maja Rücker, *Eindhoven University of Technology*

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

AUSTRIA
Sofia Kantorovich: *University of Vienna*
Stefan Windisch-Kern: *University of Leoben*

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

FRANCE
Sunniva Indrehus: *Pierre and Marie Curie University, Paris VI*
Alberto Rosso: *Laboratoire Physique Théorique et Modèles Statistiques (LPTMS), Université Paris-Saclay, Orsay*
Laurent Talon: *Laboratoire FAST, Université de Paris-Saclay, Orsay*
Renaud Toussaint, Monem Ayaz: *Institut 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*
Wei Dong : *CNRS, Lyon*
Osvanny Ramos: *Department of Physics, Claude Bernard University, Lyon*
Jean-Noël Jaubert, Silvia Lasala : *Université de Lorraine*

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

ITALY
Luciano Colombo: *University of Cagliari*

POLAND
K. Khobaib, R. Rozynek: *Institute 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
L. Laurson, Mikko Alava: *Department of Applied Physics, Aalto University, Espoo*

RUSSIA
Sergey Abaimov: *Skolkovo Institute of Science and Technology, Moscow*

TURKEY
Talha Erdem: *Abdullah Gul University, Kayseri*

ISRAEL
Ran Holtzman: *Hebrew University of Jerusalem*

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

CHINA
Ye Xu: *School of Mechanical Engineering and Automation, Beihang University, Beijing*
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 and Engineering, Molecular Chirality Research Center, Chiba University, Chiba*
Koji Amezawa: *Institute of Multidisciplinary Research for advanced materials, Tohoku University*
Hironori Nakajima: *Department of Mechanical Engineering, Faculty of Engineering, Kyushu University*
Satoshi Nishimura: *Faculty of Engineering, Field Engineering for the Environment, Hokkaido University*
Yasuhiro Fukunaka: *Research Organization for Nano and Life Innovation, Waseda University, Shinjuku, Tokyo*

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

AUSTRALIA
Peter Daivis: *RMIT, Royal Melbourne Institute of Technology, Melbourne*
Benjy Marks: *University of Sydney*
Ryan Armstrong: *UNSW, School of Petroleum Engineering, Sydney*
Mark Knackstedt: *Australian National University, Department of Applied Mathematics, Canberra*

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

Susanne Viefers
Head of department
Department of Physics
University of Oslo
(from May 2020)

François Renard
Professor, department of Geosciences, Director for Njord Center, University of Oslo

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

Erika Eiser
Professor,
Department of Physics,
NTNU

Signe Kjelstrup
Professor,
Department of Chemistry,
NTNU

Øivind Wilhelmsen
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, Zürich,
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

Veronica Birkeland Mo
Senior executive officer,
Faculty of Natural Sciences,
NTNU

Katharina Scheidl
Senior engineer,
Department of Physics,
NTNU

Mihailo Jankov
Senior Engineer,
Department of Physics,
UiO

PostDocs

Haili Long-Sanouiller
PostDoc,
Department of Geoscience and Petroleum, NTNU

Hamidreza Erfani Gahrooei
PostDoc, Department of Geoscience and Petroleum,
NTNU

Tom Vincent-Dospital,
PostDoc,
Department of Physics,
UiO

Gaute Linga
PostDoc,
Njord Center,
UiO

Fabian Barras
PostDoc,
Njord center,
UiO

Mathias Winkler
PostDoc,
Department of Physics,
NTNU

Erik Malm
PostDoc,
Department of Physics,
NTNU

Fredrik Kristoffer Mürer
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

Jonas Rønning
PhD,
Department of Physics,
UiO

Håkon Pedersen
PhD,
Department of Physics,
NTNU

Sebastian Everard Nordby Price
PhD,
Department of Chemistry,
NTNU

Fazel Mirzaei
PhD,
Department of Physics,
NTNU

Hristina Dragovic
PhD,
Department of Energy and Process Engineering,
NTNU

Beatrice Baldelli
PhD,
Department of Physics,
UiO

Vilde Bråten
PhD,
Department of Materials Science and Engineering,
NTNU

Mohammad Hossein Golestan
PhD,
Department 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

Reza Haghanihasanabadi
PhD,
Department of Geoscience and Petroleum, 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

Caroline Einen
PhD,
Department of Physics,
NTNU

Davood Dadrasajirlou
Department of Civil and Environmental Engineering,
NTNU

Chuangxin Lyu
Department of Civil and Environmental Engineering,
NTNU

Kim Robert Tekseth
PhD,
Department of Physics,
NTNU

Aldritt Scaria Madathiparambil
PhD,
Department of Physics,
NTNU

Federico Lanza
Cotutelle PhD
between U. Paris-Saclay,
France
and NTNU

Jennifer Sheehan
PhD,
Department of Mechanical and Industrial Engineering,
NTNU

Christopher Devik Fjelstad
PhD,
Department of Mechanical and Industrial Engineering, NTNU

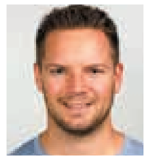
Researchers and Associates


Srutarshi Pradhan
Researcher,
Department of Physics,
NTNU


Bjørn Hafskjold
Professor,
Department of Chemistry,
NTNU


Dick Bedeaux
Professor Emeritus
Department of Chemistry,
NTNU


Santanu Sinha
Researcher,
Department of Physics,
UiO


Fredrik K. Eriksen
Researcher,
Department of Physics,
UiO


Ursula Gibson
Professor
Department of Physics,
NTNU

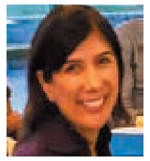

Renaud Toussaint Adjunct
Adjunct Professor,
Department of Physics,
UiO


Ole Torsæter
Professor,
Department of Geoscience and Petroleum,
NTNU


Dag Werner Breiby
Professor,
Department of Physics,
NTNU

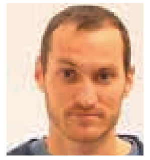

Catharina de Lange Davies,
Professor,
Department of Physics,
NTNU


Seyed Ali Amiri
Researcher,
Department of Civil and Environmental Engineering,
NTNU

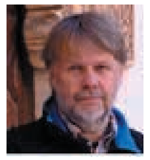

Veronica Perez-Simonsen
Researcher
Department of Physics,
NTNU


Luiza Angheluta-Bauer
Associate Professor,
Department of Physics,
UiO

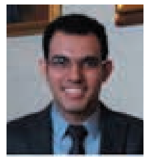

Marcel Moura
Researcher,
Department of Physics,
UiO


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

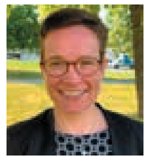

Sondre Kvalvåg Schnell
Associate Professor,
Department of Materials Science and Engineering,
NTNU

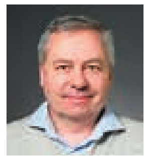

Roberto Troncoso
Researcher,
Department of Mechanical and Industrial Engineering,
NTNU


Anders Lervik
Associate Professor,
Department of Chemistry,
NTNU


Subhadeep Roy
Researcher,
Department of Physics,
UiO


Kristian S. Olsen
Researcher,
Department of Physics,
UiO


Antje van der Net
Associate Professor,
Department of Geoscience and Petroleum,
NTNU


François Renard
Professor,
Department of Physics,
UiO


Basab Chattopadhyay
Researcher,
Department of Physics,
NTNU

PUBLICATIONS

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

JOURNAL PUBLICATIONS

Arab, Danial; Kantzas, Apostolos; Torsæter, Ole; Akarri, Salem Saeed Fadhl; Bryant, Steven L..
A Crucial Role of the Applied Capillary Pressure in Drainage Displacement. *SPE Journal* 2021 26.(04) 2148-2166
NTNU

Arango-Restrepo, Andrés; Rubi, Capaceti Jose Miguel; Kjelstrup, Signe; Angelsen, Bjørn Atle Johan; Davies, Catharina de Lange.
Enhancing carrier flux for efficient drug delivery in cancer tissues. *Biophysical Journal* 2021 120.(23) 5255-5266
NTNU

Arango-Restrepo, Andrès; Rubi, Capaceti Jose Miguel; Pradhan, Srutarshi.
A Thermodynamic Framework for Stretching Processes in Fiber Materials. *Frontiers in Physics* 2021 9.
NTNU

Ballato, John; Gibson, Ursula.
Core opportunities for future optical fibers. *JPhys Photonics* 2021 3.(4)
NTNU

Barragán, V. María; García Villaluenga, Juan Pedro; Izquierdo-Gil, Maria Amparo; Kristiansen, Kim.
On the electrokinetic characterization of charged polymeric membranes by transversal streaming potential. *Electrochimica Acta* 2021387.
NTNU

Galteland, Olav; Bering, Eivind; Kristiansen, Kim; Bedeaux, Dick; Kjelstrup, Signe Helene.
Legendre-Fenchel transforms capture layering transitions in porous media. *arXiv.org* 2021
NTNU

Bila, Alberto Luis; Torsæter, Ole.
Experimental investigation of polymer-coated silica nanoparticles for EOR under harsh reservoir conditions of high temperature and salinity. *Nanomaterials* 2021 11.(765) 1-17
NTNU

Bråten, Vilde; Bedeaux, Dick; Wilhelmsen, Øivind; Schnell, Sondre Kvalvåg.
Small Size Effects in Open and Closed Systems: What Can We Learn from Ideal Gases about Systems with Interacting Particles?. *Journal of Chemical Physics* 2021 155.(24)
NTNU

Bråten, Vilde; Wilhelmsen, Øivind; Schnell, Sondre Kvalvåg.
Chemical Potential Differences in the Macroscopic Limit from Fluctuations in Small Systems. *Journal of Chemical Information and Modeling* 202161.(2) 840-855
NTNU ENERGISINT

Chakrabarti, Bikas K.; Biswas, Soumyajyoti; Pradhan, Srutarshi.
Cooperative Dynamics in the Fiber Bundle Model. *Frontiers in Physics* 2021 8.
NTNU

Charan, Harish; Hansen, Alex; Hentschel, H. George E.; Procaccia, Itamar.
Aging and Failure of a Polymer Chain under Tension. *Physical Review Letters* 2021 126.(8)
NTNU

Chawshin, Kurdistan; Berg, Carl Fredrik; Varagnolo, Damiano; Lopez, Olivier.
Lithology classification of whole core CT scans using convolutional neural networks. *SN Applied Sciences* 2021 3.(6) 1-21
NTNU

Chawshin, Kurdistan; Gonzalez, Andres; Berg, Carl Fredrik; Varagnolo, Damiano; Heidari, Zoya; Lopez, Olivier.
Classifying Lithofacies from Textural Features in Whole Core CT-Scan Images. *SPE Reservoir Evaluation and Engineering* 2021 24.(02) 341-357
NTNU

Debski, Wojciech; Pradhan, Srutarshi; Hansen, Alex.
Criterion for Imminent Failure During Loading — Discrete Element Method Analysis. *Frontiers in Physics* 2021 9.
NTNU

Egbe, Daniel Isong Otu; Jahanbani Ghahfarokhi, Ashkan; Nait Amar, Menad; Torsæter, Ole.
Application of Low-Salinity Waterflooding in Carbonate Cores: A Geochemical Modeling Study. *Natural Resources Research* 2021 30.(1) 519-542
NTNU

Flekkøy, Eirik Grude; Hansen, Alex; Baldelli, Beatrice.
Hyperballistic Superdiffusion and Explosive Solutions to the Non-Linear Diffusion Equation. *Frontiers in Physics* 2021 9.
UiO NTNU

Fromreide, Mads; Hansen, Alex.
Predicting Motion Patterns Using Optimal Paths. *Frontiers in Physics* 2021 9.
NTNU NORCE

Fyhn, Hursanay; Sinha, Santanu; Roy, Subhadeep; Hansen, Alex.
Rheology of Immiscible Twophase Flow in Mixed Wet Porous Media: Dynamic Pore Network Model and Capillary Fiber Bundle Model Results. *Transport in Porous Media* 2021 139. 491-512
NTNU

Gahrooei, Hamidreza Erfani; Karadimitriou, Nikolaos; Nissan, Alon; Walczak, Monika S.; An, Senyou; Berkowitz, Brian; Niasar, Vahid.
Process-Dependent Solute Transport in Porous Media. *Transport in Porous Media* 2021 140.(1) 421- 435
NTNU

Galteland, Olav; Bedeaux, Dick; Kjelstrup, Signe.
Nanothermodynamic Description and Molecular Simulation of a Single-Phase Fluid in a Slit Pore. *Nanomaterials* 2021 11.(165)
NTNU

Geiker, Mette Rica; Danner, Tobias; Michel, Alexander; Belda Revert, Andres; Linderoth, Oskar; Hornbostel, Karla.
25 years of field exposure of pre-cracked concrete beams; combined impact of spacers and cracks on reinforcement corrosion. *Construction and Building Materials* 2021 286.
NTNU SINTEF

Ghoreishian Amiri, Seyed Ali; Grimstad, Gustav; Gao, Hao; Kjelstrup, Signe.
Numerical modelling of distinct ice lenses in frost heave. *IOP Conference Series: Earth and Environmental Science* (EES) 2021 710.
NTNU

Ghoreishian Amiri, Seyed Ali; Taheri, Ehsan; Alimardani Lavasan, Arash.
A hybrid finite element model for non-isothermal two-phase flow in deformable porous media. *Computers and geotechnics* 2021 135.
NTNU

Gibson, Ursula; Wei, Lei; Ballato, John.
Semiconductor core fibres: materials science in a bottle. *Nature Communications* 2021 12.
NTNU

A team from the Physics Laboratory at the ENS of Lyon in collaboration with PoreLab in the framework of Louison Thorens's co-supervised PhD and the CNRS International Research Project (D-FFRACT) published their recent research activities on the "magnetic Janssen effect" in **Nature Communications**.

Grimstad, Gustav; Long, Michael; Dadrasajirlou, Davood; Ghoreishian Amiri, Seyed Ali.
Investigation of Development of the Earth Pressure Coefficient at Rest in Clay During Creep in the Framework of Hyper-Viscoplasticity. *International Journal of Geomechanics* 2021 21.(1)
NTNU

Gunnarshaug, Astrid Fagertun; Vie, Preben Joakim Svela; Kjelstrup, Signe.
Review - Reversible heat effects in cells relevant for lithium-ion batteries. *Journal of the Electrochemical Society* 2021 168.(5) 1-20
NTNU IFE

Gurfinkel, Aleks Jacob; Rikvold, Per Arne.
Adjustable reach in a network centrality based on current flows. *Physical review*. E 2021 103.(5)
UiO

Hadia, Nanji; Ng, Yeap Hung; Stubbs, Ludger P.; Torsæter, Ole.
High salinity and high temperature stable colloidal silica nanoparticles with wettability alteration ability for EOR application.. *Nanomaterials* 2021 11.(707) 1-14
NTNU

Hafskjold, Bjørn; Bedeaux, Dick; Kjelstrup, Signe; Wilhelmsen, Øivind.
Theory and simulation of shock waves: Entropy production and energy conversion. *Physical review*. E 2021 E104.
ENERGISINT NTNU

Hansen, Alex; Kun, Ferenc; Pradhan, Srutarshi; Ray, Purusattam.
Editorial: The Fiber Bundle. *Frontiers in Physics* 2021 9.(795803)
NTNU

Hasanzade, Mojde; Hussain, Nazabat; Breiby, Dag Werner; Akram, Muhammad Nadeem.
Fourier ptychography algorithm based on scaled Fourier transform. *Electronics Letters* 2021 57.(3) 123-125
USN NTNU

Islam, Mohammad Akhsanul; Lubbad, Raed; Ghoreishian Amiri, Seyed Ali; Isaev, Vladislav; Shevchuk, Yaroslav; Uvarova, Alexandra Vladimirovna; Afzal, Mohammad Saud; Kumar, Avinash.
Modelling the seasonal variations of soil temperatures in the Arctic coasts. *Polar Science* 2021 30.
NTNU

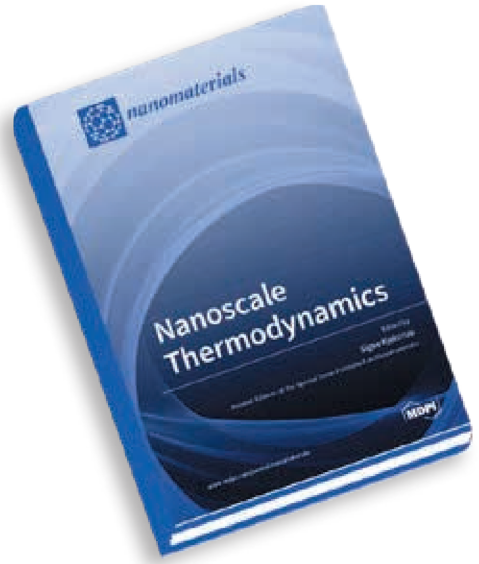
Kandhasamy, Sathiyaraj; Haarberg, Geir Martin; Kjelstrup, Signe; Solheim, Asbjørn.
Thermo-electrochemical cell performance and physicochemical properties of the molten carbonate electrolyte dispersed with different solid oxides. *Electrochimica Acta* 2021 386.
NTNU SINTEF

Khobaib, K; Mikkelsen, Alexander; Vincent-Dospital, Tom; Rozynek, Zbigniew Jerzy.
Electric-field-induced deformation, yielding, and crumpling of jammed particle shells formed on non-spherical Pickering droplets. *Soft Matter* 2021
UiO

Kjelstrup, Signe.
Special issue on nanoscale thermodynamics. *Nanomaterials* 2021 11.(3) 1-2
NTNU

Kjelstrup, Signe; Ghoreishian Amiri, Seyed Ali; Loranger, Benoit; Gao, Hao; Grimstad, Gustav.
Transport coefficients and pressure conditions for growth of ice lens in frozen soil. *Acta Geotechnica* 2021 16.(7) 2231-2239
NTNU

Kjelstrup, Signe; Lervik, Anders.
The energy conversion in active transport of ions. *Proceedings of the National Academy of Sciences of the United States of America* 2021 118.(45)
NTNU



This special issue of Nanomaterials on **"Nanoscale Thermodynamics"** edited by Prof. Signe Kjelstrup concerns the development of a theory for energy conversion on the nanoscale, namely, nanothermodynamics. Two publications from Olav Galteland et al., and Eivind Bering et al., that belong to this special issue are selected as Editor's choice by **Nanomaterials**.

Kristiansen, Kim; Kjelstrup, Signe.
Particle flow through a hydrophobic nanopore: Effect of long-ranged wall-fluid repulsion on transport coefficients. *Physics of Fluids* 2021 33.(10)
NTNU

Kristoffersen, Brage Strand; Bellout, Mathias; Silva, Thiago Lima; Berg, Carl Fredrik.
An Automatic Well Planner for Complex Well Trajectories. *Mathematical Geosciences* 2021 53. 1881- 1905
NTNU

Kristoffersen, Brage Strand; Silva, Thiago Lima; Bellout, Mathias; Berg, Carl Fredrik.
Efficient well placement optimization under uncertainty using a virtual drilling procedure. *Computational Geosciences* 2021
NTNU SINTEF

Levi dit Vehel, Victor; Hatani, Tokahiro; Vanel, Loïc; Måløy, Knut Jørgen; Ramos, Osvanny.
Dilation as a precursor in a continuous granular fault. *The European Physical Journal Conferences* 2021 249.
UiO

Li, Shidong; Sng, Anqi; Daniel, Dan; Lau, Hon Chung; Torsæter, Ole; Stubbs, Ludger P..
Visualizing and Quantifying Wettability Alteration by Silica Nanofluids. *ACS Applied Materials & Interfaces* 2021 13. 41182-41189
NTNU

Lyu, Chuangxin; Nishimura, Satoshi; Ghoreishian Amiri, Seyed Ali; Zhu, Feng; Eiksund, Gudmund Reidar; Grimstad, Gustav.
Pore-water pressure development in a frozen saline clay under isotropic loading and undrained shearing. *Acta Geotechnica* 2021 16. 3831-3847
NTNU

Mürer, Fredrik Kristoffer; Chattopadhyay, Basab; Madathiparambil, Aldritt Scaria; Tekseth, Kim Robert Bjørk; Di Michel, Marco; Liebi, Marianne; Lilledahl, Magnus Borstad; Olstad, Kristin; Breiby, Dag Werner.
Quantifying the hydroxyapatite orientation near the ossification front in a piglet femoral condyle using X-ray diffraction tensor tomography. *Scientific Reports* 2021 11.
NTNU NMBU USN

Mürer, Fredrik Kristoffer; Madathiparambil, Aldritt Scaria; Tekseth, Kim Robert Bjørk; Di Michiel, Marco; Cerasi, Pierre; Chattopadhyay, Basab; Breiby, Dag Werner.
Orientational mapping of minerals in Pierre shale using X-ray diffraction tensor tomography. IUCrJ 2021 8.(5) 747-756
NTNU SINTEF USN

Måløy, Knut Jørgen; Moura, Marcel; Hansen, Alex; Flekkøy, Eirik Grude; Toussaint, Renaud.
Burst Dynamics, Upscaling and Dissipation of Slow Drainage in Porous Media. *Frontiers in Physics* 2021 9.
UiO NTNU

Olsen, Kristian Stølevik; Angheluta, Luiza; Flekkøy, Eirik Grude.
Active Brownian particles moving through disordered landscapes. *Soft Matter* 2021
UiO

Perez Simonsen, Veronica; Bedeaux, Dick; Simonsen, Ingve.
Nonparametric reconstruction of the statistical properties of penetrable, isotropic randomly rough surfaces from in-plane, co-polarized light scattering data: Application to computer-generated and experimental scattering data. *Physical Review A (PRA)* 2021 104.(4)
NTNU

Rauter, Michael Tobias; Schnell, Sondre K.; Kjelstrup, Signe.
Cassie-Baxter and Wenzel States and the Effect of Interfaces on Transport Properties across Membranes. *Journal of Physical Chemistry* B 2021
NTNU

Rauter, Michael Tobias; Schnell, Sondre Kvalvåg; Hafskjold, Bjørn; Kjelstrup, Signe Helene.
Thermo-osmotic pressure and resistance to mass transport in a vapor-gap membrane. *Physical Chemistry, Chemical Physics - PCCP* 2021 23. 12988-13000
NTNU

Roy, Subhadeep.
From Nucleation to Percolation: The Effect of System Size when Disorder and Stress Localization Compete. *Frontiers in Physics* 2021 9.
NTNU

Roy, Subhadeep; Biswas, Soumyajyoti.
Size distribution of emitted energies in local load sharing fiber bundles. *Frontiers in Physics* 2021 9.
NTNU

Roy, Subhadeep; Hatano, Takahiro.
Model for creep failure with healing. *arXiv.org* 2021
NTNU

Roy, Subhadeep; Sinha, Santanu; Hansen, Alex.
Role of Pore-Size Distribution on Effective Rheology of Two-Phase Flow in Porous Media. *Frontiers in water* 2021 3.
UiO NTNU

Sauermoser, Marco; Pollet, Bruno; Kizilova, Nataliya; Kjelstrup, Signe.
Scaling factors for channel width variations in tree-like flow field patterns for polymer electrolyte membrane fuel cells - An experimental study. *International Journal of Hydrogen Energy* 2021
NTNU

Sheehan, Jennifer; Andersson, David; de Wijn, Astrid S..
Thermal effects and spontaneous frictional relaxation in atomically thin layered materials. *Physical review B (PRB)* 2021 103.(19)
NTNU

Shirmohammadi, Ali; Hajialilue-Bonab, Masoud; Dadrasajirlou, Davood.
Application of a Simplified Anisotropic Constitutive Model for Soft Structured Clay on Embankment Failure. *International Journal of Geomechanics* 2021 21.(8)
NTNU

Sinha, Santanu; Gjennestad, Magnus Aashammer; Vassvik, Morten; Hansen, Alex.
Fluid Meniscus Algorithms for Dynamic Pore-Network Modeling of Immiscible Two-Phase Flow in Porous Media. *Frontiers in Physics* 2021 8.
NTNU

Sinha, Santanu; Roy, Subhadeep; Hansen, Alex.
Crack localization and the interplay between stress enhancement and thermal noise. *Physica A: Statistical Mechanics and its Applications* 2021 569.
NTNU

Song, Seunghan; Laurell, Fredrik; Meehan, Bailery; Hawkins, Thomas A.; Ballato, John; Gibson, Ursula.
Thermal structuring of metal-semiconductor core fibres: toward optoelectronic device fabrication. *Research Square* 2021
NTNU

Spitthoff, Lena; Gunnarshaug, Astrid Fagertun; Bedeaux, Dick; Burheim, Odne Stokke; Kjelstrup, Signe
Peltier effects in lithium-ion battery modeling. *Journal of Chemical Physics* 2021 154.(11) 1-17
NTNU

Stoev, Iliya D.; Caciagli, Alessio; Mukhopadhyay, Anasua; Ness, Christopher; Eiser, Erika
Bulk rheology of sticky DNA-functionalized emulsions. *Physical review*. E 2021 104.(5)
NTNU

Strøm, Bjørn André; Bedeaux, Dick; Schnell, Sondre Kvalvåg
Adsorption of an Ideal Gas on a Small Spherical Adsorbent. *Nanomaterials* 2021 11.(2)
NTNU

Sun, Chao; Swirk, Katarzyna; Wang, Ye; Scheidl, Katharina; Breiby, Dag Werner; Rønning, Magnus; Hu, Changwei; Da Costa, Patrick.
Tailoring the yttrium content in Ni-Ce-Y/SBA-15 mesoporous silicas for CO_2 methanation. *Catalysis Today* 2021 382. 104-119
NTNU

Sørgård, Trygve Reinertsen; Hawkins, Thomas; Ballato, John; Österberg, Ulf Lennart; Gibson, Ursula.
All-optical high-speed modulation of THz transmission through silicon core optical fibers. *Optics Express* 2021 29.(3) 3543-3552
NTNU

Taheri, Amir; Torsæter, Ole; Lindeberg, Erik Gøsta Brun; Hadia, Nanji; Wessel-Berg, Dag.
Effect of convective mixing process on storage of CO_2 in saline aquifers with layered permeability. *Advances in Chemical Research* 2021 3.(1) 1-21
SINTEF NTNU

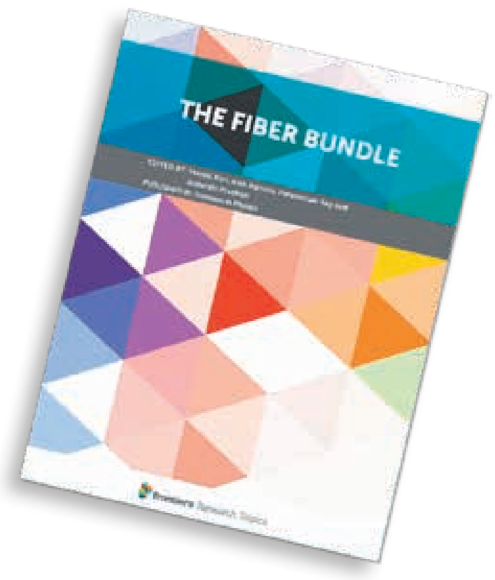
Thorens, Louison; Måløy, Knut Jørgen; Santucci, Stephane; Bourgoin, Mickael.
Magnetic Janssen effect. *Nature Communications* 2021 12.
UiO

Thorens, Louison; Måløy, Knut Jørgen; Santucci, Stephane; Bourgoin, Mickael.
Tamming the Janssen effect. *The European Physical Journal Conferences* 2021 249. 08004
UiO

Thorens, Louison; Viallet, Maud; Måløy, Knut Jørgen; Bourgoin, Mickael; Santucci, Stephane.
Discharge of a 2D magnetic silo. *The European Physical Journal Conferences* 2021 249. 03017
UiO

Tian, C.; Kristiansen, Kim; Kjelstrup, Signe; Barragán, V. María.
Two Methods for Determination of Transport Numbers in Ion-Exchange Membranes. *International journal of thermophysics* 2021 43.
NTNU

Torsæter, Ole.
Application of nanoparticles for oil recovery. *Nanomaterials* 2021 11.(1063)
NTNU



Alex Hansen and Srutarshi Pradhan from PoreLab together with Ferenc Kun and Purusattam Ray publish an e-book on "The Fiber Bundle Model" at **Frontiers in Physics**

Vincent-Dospital, Tom; Steyer, Alain; Renard, Francois; Toussaint, Renaud.
Frictional anisotropy of 3D-printed fault surfaces. Frontiers in Earth Science 2021
UiO

Vincent-Dospital, Tom; Toussaint, Renaud.
Thermo-mechanical pain: the signaling role of heat dissipation in biological tissues. New Journal of Physics 2021 23.
UiO

Vincent-Dospital, Tom; Toussaint, Renaud; Cochard, Alain; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
Thermal dissipation as both the strength and weakness of matter. A material failure prediction by monitoring creep. Soft Matter 2021 17.(15) 4143-4150
UiO

Vincent-Dospital, Tom; Toussaint, Renaud; Måløy, Knut Jørgen.
Heat Emitting Damage in Skin: A Thermal Pathway for Mechanical Algesia. Frontiers in Neuroscience 2021 15.
UiO

Vincent-Dospital, Tom; Cochard, Alain; Santucci, Stephane; Måløy, Knut Jørgen; Toussaint, Renaud.
Thermally activated intermittent dynamics of creeping crack fronts along disordered interfaces. Scientific Reports 2021
UiO

CONFERENCE LECTURES AND ACDEMIC PRESENTATIONS

Aasen, Ailo; Wilhelmsen, Øivind; Reguera, David.
A missing thermodynamic ingredient in classical nucleation theory?. Twenty-First Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-26
NTNU ENERGISINT

Berg, Carl Fredrik.
Wettability and efficiency of quasi-static displacements. Njord seminar; 2021-01-22 - 2021-01-22
NTNU

Bering, Eivind; Kjelstrup, Signe; Bedeaux, Dick; Rubi, Miguel; de Wijn, Astrid S..
Entropy Production Beyond the Thermodynamic Limit: Single-Molecule Stretching Simulations. 21th Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-25
NTNU

Breiby, Dag Werner.
Invited talk: Multidimensional computational X-ray microscopy applied to soft and biological materials. SINTEF Workshop: Structural and chemical characterization of organic nanomaterials; 2021-11-30 - 2021-11-30
NTNU

Breiby, Dag Werner.
X-ray imaging of organic films and particles. Jotun-NTNU Collaboration Conference; 2021-09-20 - 2021-09-20
NTNU

Bråten, Vilde; Wilhelmsen, Øivind; Schnell, Sondre Kvalvåg.
Chemical Potential Differences from Fluctuations in Small Systems. Recent progress in the statistical mechanics of solutions through Kirkwood-Buff integrals and related approaches; 2021-09-20 - 2021-09-22
NTNU

Bråten, Vilde; Zhang, Daniel Tianhou; Hammer, Morten; Aasen, Ailo; Schnell, Sondre Kvalvåg; Wilhelmsen, Øivind.
Equation of State for Nanosystems. Norsk Kjemisk Selskap - Functional Inorganic Materials; 2021-11-01 - 2021-11-02
NTNU ENERGISINT

Bråten, Vilde; Zhang, Daniel Tianhou; Hammer, Morten; Aasen, Ailo; Schnell, Sondre Kvalvåg; Wilhelmsen, Øivind.
Perturbation Theory Based Equation of State for Small Systems under Confinement. Twenty-First Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-26
ENERGISINT NTNU

Bråten, Vilde; Zhang, Daniel Tianhou; Hammer, Morten; Aasen, Ailo; Schnell, Sondre Kvalvåg; Wilhelmsen, Øivind.
Perturbation Theory for Fluids under Confinement. InterPore2021; 2021-05-31 - 2021-06-04
ENERGISINT NTNU

Cheon, Hyejeong; Sinha, Santanu; Fyhn, Hursanay; Roy, Subhadeep; Hansen, Alex.
Rheology of compressible and incompressible immiscible fluids in the capillary fiber bundle model. InterPore 2021; 2021-05-31 - 2021-06-04
UiO NTNU

Fyhn, Hursanay.
Rheology of Immiscible Twophase Flow in Mixed Wet Porous Media: Dynamic Pore Network Model and Capillary Fiber Bundle Model Results
International Meeting on Non-Newtonian Flow; 2021-12-09 - 2021-12-10
NTNU

Fyhn, Hursanay.
Rheology of immiscible two-phase flow in mixed wet porous media: Dynamic pore network model and capillary fiber bundle model results.
InterPore 2021; 2021-05-31 - 2021-06-04
NTNU

Fyhn, Hursanay; Sinha, Santanu; Roy, Subhadeep; Hansen, Alex.
Rheology of two-phase flow in mixed-wet porous media: Dynamic network model and capillary fiber bundle results. InterPore 2021; 2021-05-31 -2021-06-04
NTNU UiO

Gahrooei, Hamidreza Erfani; Niasar, Vahid; masoud, babei.
Reactive CO_2 Density-Driven Flow in Aquifers. Interpore 2021 Conference; 2021-07-01 - 2021-07-04
NTNU

Galteland, Olav; Rauter, Michael Tobias; Erds, Máté; Kjelstrup, Signe; Bedeaux, Dick; Schnell, Sondre K.; Vlugt, Thijs J.H.; Moultos, Othonas A..
Pressures of nanosized systems described by Hill's thermodynamics of small systems. 4th Erwin Schrödinger Symposium 2021: Advanced Materials; 2021-01-11 - 2021-01-12
NTNU

Gunnarshaug, Astrid Fagertun; Bedeaux, Dick; Kjelstrup, Signe.
The heat of transfer and the Peltier coefficient of electrolytes. 14International Meeting on Thermodiffusion; 2021-05-25 - 2021-05-27
NTNU

Gunnarshaug, Astrid Fagertun; Spitthoff, Lena; Vie, Preben Joakim Svela; Kjelstrup, Signe.
Peltier Heats in Lithium-Ion Batteries. InterPore 2021; 2021-05-31 - 2021-06-04
NTNU

Hafskjold, Bjørn; Bedeaux, Dick; Kjelstrup, Signe; Wilhelmsen, Øivind.
Entropy production in shock waves. Twenty-First Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-25
NTNU

Hafskjold, Bjørn; Kjelstrup, Signe; Galteland, Olav; Bedeaux, Dick.
Soret effects in porous media. International meeting on thermodiffusin - IMT14; 2021-05-25 - 2021-05-27
NTNU

Hafskjold, Bjørn; Kjelstrup, Signe; Galteland, Olav; Bedeaux, Dick.
Soret effects in porous media. InterPore2021; 2021-05-31 - 2021-06-04
NTNU

Hafskjold, Bjørn; Kjelstrup, Signe; Galteland, Olav; Bedeaux, Dick.
Soret effects in porous media. Twenty-First Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-25
NTNU

Hansen, Alex.
Handling Viscous Finger in Two-Phase Flow in Porous Media. Indo-Norwegian Workshop on Computational Challenges and Modelling of Coupled Processes in Porous Media; 2021-10-01 - 2021-10-03
NTNU

Hansen, Alex.
Immiscible Two-Phase Flow in Porous Media: Getting from the Meso-Scale to the Continuum Scale. Seventeenth International Conference for Mesoscopic Methods in Engineering and Science; 2021-07-12 - 2021-07-16
NTNU

Hansen, Alex.
Life Time Distribution of Stretched Polymers. Fracmeet; 2021-03-08 - 2021-03-11
NTNU

Hansen, Alex.
Predicting Failure: Fiber Bundle Model Studies. Composites Zoominar Series; 2021-01-26 - 2021-01-26
NTNU

Hasanzade, Mojde; Hussain, Nazabat; Breiby, Dag Werner; Akram, Muhammad Nadeem.
Reflective Fourier Ptychographic Microscopy Using the Scheimpflug Scheme. The CLEO Technical Conference; 2021-05-09 - 2021-05-14
NTNU USN

Kjelstrup, Signe; Bedeaux, Dick; Galteland, Olav; Rauter, Michael Tobias; Berg, Carl Fredrik; Hansen, Alex.
Energy dissipation as heat in porous media flow. InterPore 2021; 2021-05-31 - 2021-06-04
NTNU

Kjelstrup, Signe; Bedeaux, Dick; Galteland, Olav; Rauter, Michael Tobias; Berg, Carl Fredrik; Hansen, Alex.
Energy dissipation in porous media flow. Interpore; 2021-05-31 - 2021-06-04
NTNU

Kjelstrup, Signe; Bedeaux, Dick; Gjennestad, Magnus Aashammer; Rauter, Michael Tobias; Berg, Carl Fredrik; Hansen, Alex.
From Pore Scale to Darcy Scale with Entropy Production as Tool. SIAM Conference on Mathematical & Computational Methods in Geoscience, GS21; 2021-06-21 - 2021-06-24
NTNU

Kjelstrup, Signe; Galteland, Olav; Rauter, Michael Tobias; Bedeaux, Dick.
Single-phase fluids confined within slit pores. CECAM Flagship Workshop; 2021-09-20 - 2021-09-22
NTNU

Kristiansen, Kim; Kjelstrup, Signe.
Particle Flow Through a Hydrophobic Nanopore. InterPore2021; 2021-05-31 - 2021-06-04
NTNU

Kristiansen, Kim; Kjelstrup, Signe.
Thermal Diffusion Through a Hydrophobic Nanopore. 14International Meeting on Thermodiffusion; 2021-05-25 - 2021-05-27
NTNU

Kristiansen, Kim; Kjelstrup, Signe.
Transport Coefficients of a Rarefied Gas in a Hydrophobic Nanopore. Twenty-first Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-25
NTNU

Lervik, Anders.
The Soret Effect in Li-Ion Battery Electrolytes. Twenty-First Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-25
NTNU

Madathiparambil, Aldritt Scaria; Mürer, Fredrik Kristoffer; Tekseth, Kim Robert Bjørk; Agofack, Nicolaine; Cerasi, Pierre; Cordonnier, Benoit; McBeck, Jessica Ann; Renard, Francois; Chattopadhyay, Basab; Breiby, Dag Werner.
In situ computed tomography studies of strain evolution in Draupne shales. InterPore 2021; 2021-05-31 - 2021-06-04
SINTEF NTNU UiO

Moura, Marcel.
Formação de padrões, sistemas complexos e mecânica de fluidos em meios porosos: mais é diferente. Colóquio do Departamento de Física; 2021-11-11 - 2021-11-11
UiO

Moura, Marcel; Eriksen, Fredrik Kvalheim; Turquet, Antoine Leo; Flekkøy, Eirik Grude; Toussaint, Renaud; Jankov, Mihailo; Måløy, Knut Jørgen.
Complexity: "More is Different" also in porous media flows. 5Summer School on Flow and Transport in Porous and Fractured Media; 2021-07-20 - 2021-07-31
UiO

Moura, Marcel; Måløy, Knut Jørgen; Flekkøy, Eirik Grude; Toussaint, Renaud.
Coffee is for drinking, tea is for porous media science: intermittent burst dynamics in slow drainage experiments in porous media. InterPore 13th International Conference on Porous Media & Annual Meeting; 2021-05-31 - 2021-06-04
UiO

Mürer, Fredrik Kristoffer; Madathiparambil, Aldritt Scaria; Tekseth, Kim Robert Bjørk; Cerasi, Pierre; Chattopadhyay, Basab; Breiby, Dag Werner.
Non-destructive 3D mapping of mineral composition and clay mineral orientation in shale. InterPore2021; 2021-05-31 - 2021-06-04
USN SINTEF NTNU

Mürer, Fredrik Kristoffer; Tekseth, Kim Robert Bjørk; Hasanzade, Mojde; Schnell, Knut Olav; Akram, Muhammad Nadeem; Lilledahl,
Magnus Borstad; Olstad, Kristin; Chattopadhyay, Basab; Breiby, Dag Werner.
Multimodal Microscopy Methods for Growth Cartilage. CLEO 2021; 2021-05-10 - 2021-05-14
USN NTNU NMBU

Pradhan, Srutarshi.
Strength and stability of fractured rocks. Interpore 2021; 2021-05-31 - 2021-06-04
NTNU

Pradhan, Srutarshi; Toresen, Martin Alexander.
A discrete element model (DEM) for swelling behavior of clay. Interpore 2021; 2021-05-31 - 2021-06-04
NTNU

Rauter, Michael Tobias; Hafskjold, Bjørn; Schnell, Sondre Kvalvåg; Kjelstrup, Signe.
Coupled Fluid Transport Through Vapor-Gap Membranes for use in Cleaning Contaminated Liquids. 14International Meeting on Thermodiffusion; 2021-05-25 - 2021-05-27
NTNU

Rauter, Michael Tobias; Hafskjold, Bjørn; Schnell, Sondre **Kvalvåg; Kjelstrup, Signe.**
Coupled Fluid Transport Through Vapor-Gap Membranes for use in Cleaning Contaminated Liquids. 21st Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-25
NTNU

Roy, Subhadeep; Pedersen, Håkon; Sinha, Santanu; Hansen, Alex.
From the non-linear Darcy law for immiscible two-phase flow in porous media to constitutive equations for each fluid species. InterPore 2021; 2021-05-31 - 2021-06-04
NTNU UiO

Roy, Subhadeep; Sinha, Santanu; Hansen, Alex.
How does the power law dependency of flow rate on pressure gradient when viscous and capillary forces compete, scale with system size?. InterPore 2021; 2021-05-31 - 2021-06-04
NTNU UiO

Sauermoser, Marco; Baglo, Kjetil Skar; Bock, Robert; Svartvatn, Preben Johnsen; Hoem, Svenn Ove; Kjelstrup, Signe; Kizilova, Nataliya; Pollet, Bruno G.; Torgersen, Jan.
Innovative designs for PEM fuel cell components. NTNU Nano Seminar; 2021-12-08
NTNU

Sauermoser, Marco; Kjelstrup, Signe; Pollet, Bruno.
Peltier and Dufour Effects in the Polymer Electrolyte Membrane Fuel Cell. Twenty-First Symposium on Thermophysical Properties; 2021-06-20 - 2021-06-26
NTNU

Sauermoser, Marco; Kjelstrup, Signe; Pollet, Bruno.
The Impact of Peltier and Dufour Coefficients on Heat Fluxes and Temperature Profiles in the Polymer Electrolyte Fuel Cells. 14International Meeting on Thermodiffusion; 2021-05-25 - 2021-05-27
NTNU

Sinha, Santanu; Fyhn, Hursanay; Roy, Subhadeep; Meheust, Yves; Hansen, Alex.
Growth and upscaling of viscous fingers in immiscible two-phase flow in porous media. Interpore 2021; 2021-05-31 - 2021-06-04
UiO NTNU

Slotte, Per Arne; Hosseinzade Khanamiri, Hamid.
Wettability and efficiency of quasi-static displacements. Njord Seminar; 2021-01-22 - 2021-01-22
NTNU

Berg, Carl Fredrik; Slotte, Per Arne; Long-Sanouiller, Haili; Gahrooei, Hamidreza Erfani.
Approximating free energy change for imaged displacement processes to assess wettability. Interpore Norway 4National Workshop; 2021-12-01 - 2021-12-01
NTNU

Tekseth, Kim Robert Bjørk; Breiby, Dag Werner.
Fluid rearrangements during Haine's jumps using time-resolved home-laboratory micro-computed X-ray tomography. InterPore 2021; 2021-05-31 - 2021-06-04
NTNU

Wilhelmsen, Øivind; Skaugen, Geir; Aasen, Ailo; Kingston, Diego; Kjelstrup, Signe; Bedeaux, Dick; Meyer, Ole; Gjennestad, Magnus Aashammer; Ervik, Åsmund.
What can Irreversible Thermodynamics do for us?. Twenty-First Symposium on Thermophysical Properties; 2021-06-21 - 2021-06-25
NTNU ENERGISINT

Yan, Lifei; Golestan, Mohammad Hossein; Zhou, Wenyu; Hassanizadeh, S. Majid; Berg, Carl Fredrik.
Impact of osmosis and emulsification on constrained oil remobilization in pore-scale experiments. InterPore2021 Online Conference; 2021-05-31 - 2021-06-04
NTNU

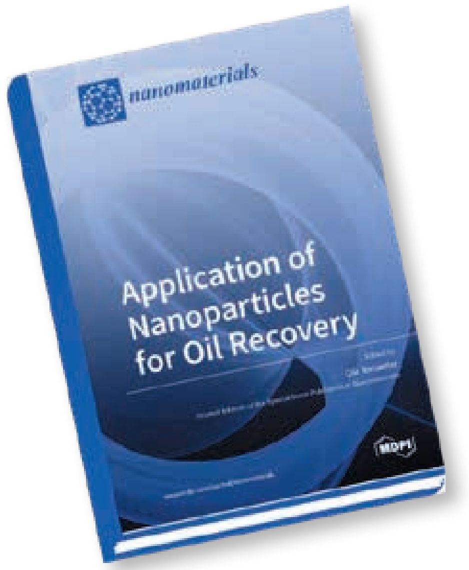
Younas, Daniyal; Mürer, Fredrik Kristoffer; Ucar, Seniz; Chushkin, Yuriy; Zontone, Federico; Gibaud, Alain; Breiby, Dag Werner; Chattopadhyay, Basab.
Coherent X-ray diffraction imaging to investigate structure and morphological evolution of calcium carbonate microparticles. 25Congress and General Assembly of the International Union of Crystallography; 2021-08-14 - 2021-08-22
NTNU

BOOKS, PART OF BOOKS, REPORTS

Bering, Eivind.
Stretching, breaking, and dissolution of polymeric nanofibres by computer experiments. Trondheim: Skipnes Kommunikasjon AS 2021
(978-82-326-5216-7) 122 Doktoravhandlinger ved NTNU(2021:176)
NTNU

Chawshin, Kurdistan; Berg, Carl Fredrik; Varagnolo, Damiano; Lopez, Olivier.
A Deep-Learning Approach for Lithological Classification Using 3D Whole Core CT-Scan Images. I: SPWLA 62nd Annual Logging Symposium.
Society of Petroleum Engineers 2021 000-0-00-000000-0.
NTNU

Hansen, Alex.
2021 Frontiers in Physics Editor's Pick. Lausanne: Frontiers Media S.A. 2021 (978-2-88971-076-8) 179
NTNU



This special issue of **Nanomaterials** on **"Applications of Nanoparticles for Oil Recovery"** edited by Prof. Ole Torsæter includes a selection of research articles on the use of nanoparticles for EOR application. The articles are discussing nanoparticles as additive in waterflooding, and surfactant flooding, stability and wettability alteration ability of nanoparticles and nanoparticle stabilized foam for CO_2-EOR. The book also includes articles on nanoparticles as an additive in biopolymer flooding and studies on the use of nanocellulose as a method to increase the viscosity of injection water. Mathematical models of the injection of nanoparticle-polymer solutions are also presented.

Kjelstrup, Signe.
Nanoscale Thermodynamics. MDPI 2021 (978-3-0365-1168-9) 168
NTNU

Kun, Ferenc; Hansen, Alex; Ray, Purusattam; Pradhan, Srutarshi.
The Fiber Bundle. Lausanne: Frontiers Media S.A. 2021 (978-2-88974-011-6) 150
NTNU

Li, Shidong; Lau, Hon Chung; Torsæter, Ole; Hendraningrat, Luky; Temizel, Cenk.
Nanoparticles for enhanced oil recovery. I: Sustainable materials for oil and gas application. Gulf Professional Publishing 2021 978-0-12-824380-0. 125-174
NTNU

Olsen, Kristian Stølevik.
Active and passive Brownian particles in complex environments. Oslo: UiO 2021 133
UiO

Sari, Mufrettin Murat; Temizel, Cenk; Canbaz, Celal Hakan; Saputelli, Luigi A.; Torsæter, Ole.
Sustainable materials for transitional and alternative energy. Gulf Professional Publishing 2021 (978-0-12-824379-4) 274
NTNU

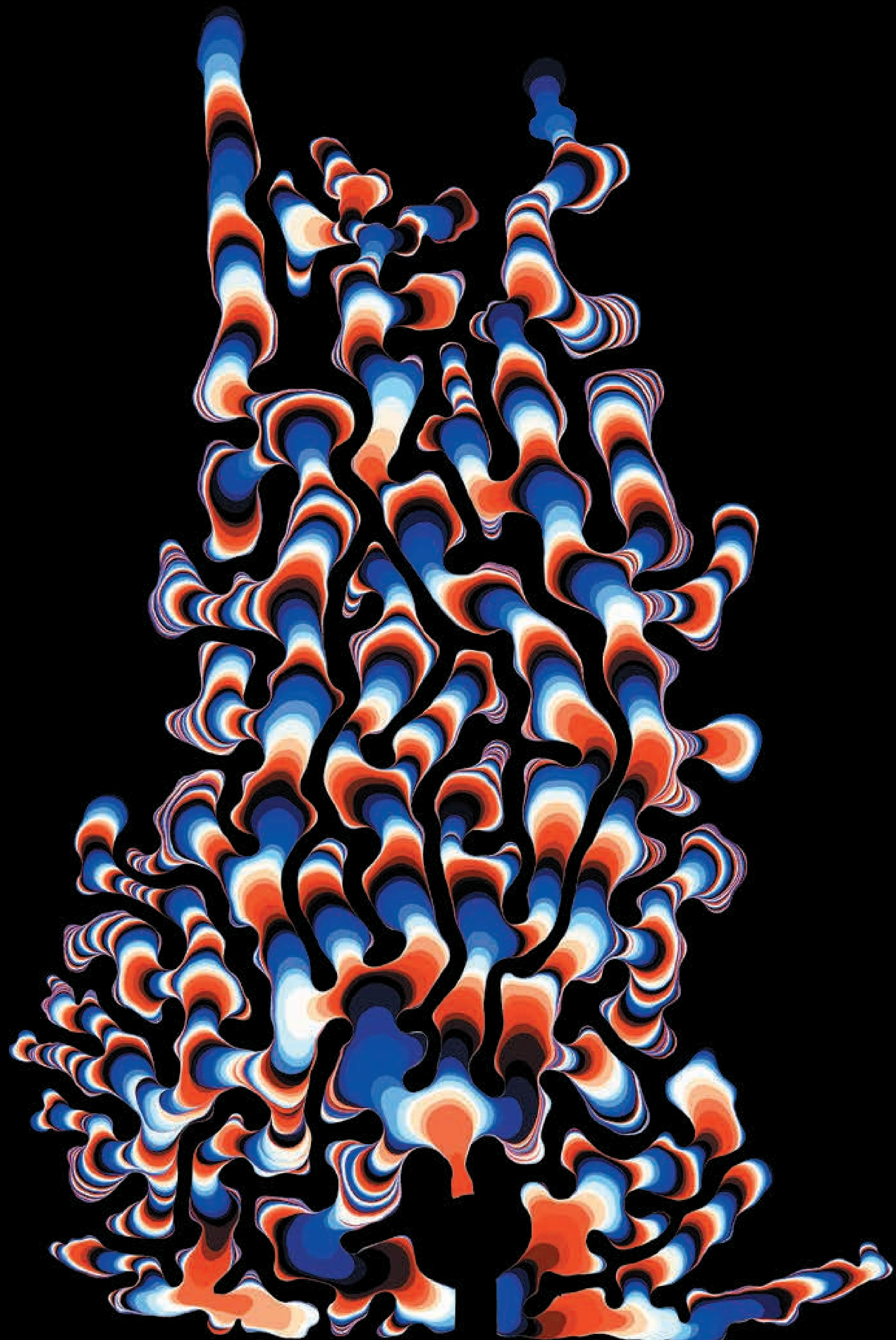
Sauermoser, Marco.
Non-equilibrium thermodynamics and nature-inspired chemical engineering applied to PEM fuel cells. NTNU 2021 (978-82-326-4752-1) 219
NTNU

Song, Seunghan.
Thermal processing of semiconductor alloy core glass fibers. NTNU 2021 144
NTNU

Temizel, Cenk; Sari, Mufrettin Murat; Canbaz, Celal Hakan; Saputelli, Luigi A.; Torsæter, Ole.
Sustainable materials for oil and gas application. Gulf Professional Publishing 2021 (978-0-12-824380-0) 255
NTNU

Thorens, Louison.
Unstable Drainage of Frictional Fluids and Magnetic Control of the Mechanical Behavior of Confined Granular Media. Universitetet i Oslo 2021 70 Series of dissertations submitted to the Faculty of Mathematics and Natural Sciences, University of Oslo.(2456)
UiO

Torsæter, Ole.
Application of Nanoparticles for Oil Recovery. MDPI 2021 (978-3-0365-1317-1) 136
NTNU



Porous Media Laboratory
NTNU, UiO

VISITING ADRESSES:

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

Oslo:
The Physics building
Sem Sælands vei 24
0316 Oslo

POSTAL ADDRESSES:

Trondheim:
Department of Physics, NTNU
PoreLab
7491 Trondheim

Oslo:
P. O. Box 1048
Blindern
0316 Oslo

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

Professor Eirik Grude Flekkøy, Deputy Director
Phone: +47 22 85 50 34
E-mail: E.G.Flekkoy@fys.uio.no

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

Visit our website
www.porelab.no
for more information and research results

Skipnes.no Nordic swan ecolabel - printed matter, 2041 0731