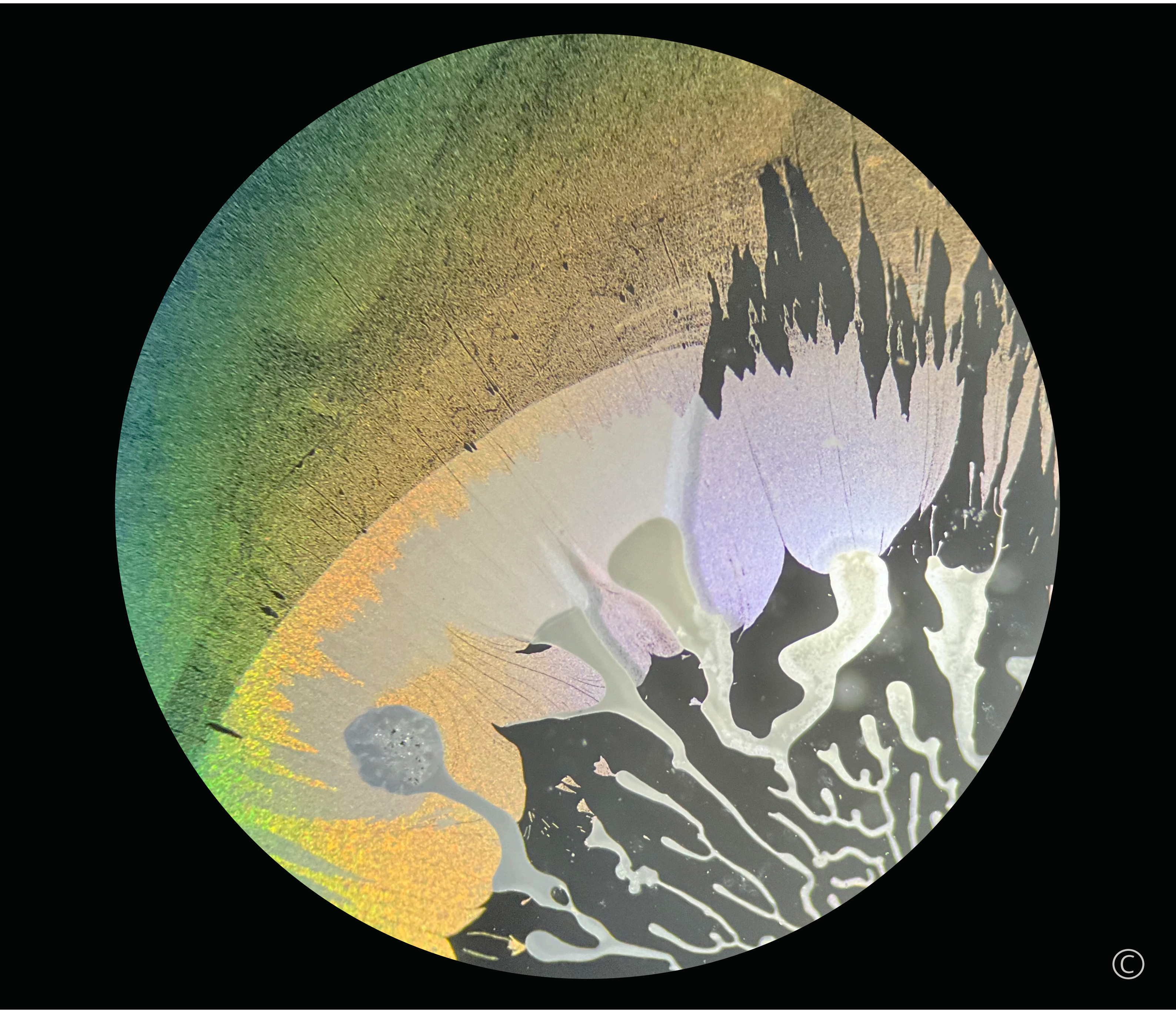
PoreLab
NTNU-UiO Porous Media Laboratory

Annual Report 2024



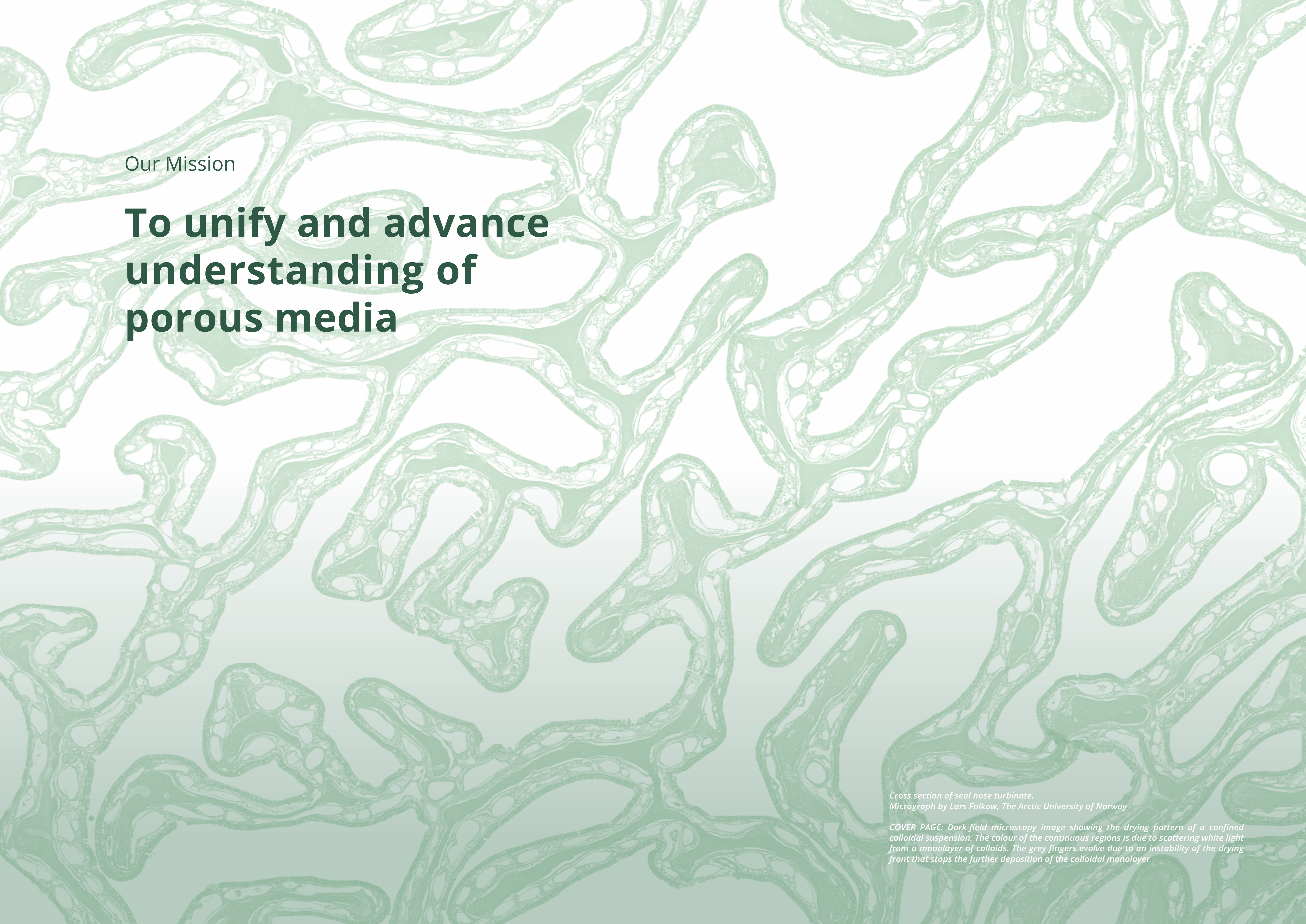
NTNU
Norwegian University of Science and Technology

UiO : University of Oslo

Norwegian Centre of Excellence
The Research Council of Norway

Our Mission

To unify and advance understanding of porous media



Cross section of seal nose turbinate.
Micrograph by Lars Folkow, The Arctic University of Norway

COVER PAGE: Dark-field microscopy image showing the drying pattern of a confined colloidal suspension. The colour of the continuous regions is due to scattering white light from a monolayer of colloids. The grey fingers evolve due to an instability of the drying front that stops the further deposition of the colloidal monolayer

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 eight principal scientists from physics, chemistry, and reservoir engineering. At UiO, PoreLab is part of the Njord Center which is a cross-disciplinary geoscience-physics center.

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

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

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

PoreLab receives an annual funding from the Norwegian Research Council of about 15 MNOK. NTNU and UiO contribute with the same financial support. In December 2022, we received the information from the Research Council of Norway that the mid-term evaluation planned originally during the spring 2023 was cancelled. In December 2024, the Research Council of Norway approved a 1-year prolongation for PoreLab. Our new date of completion is therefore August 2028.

X-ray computed tomography (CT) of an Icelandic basalt targeted for CO_2 storage reveals the internal rock structure at micron-scale resolution. The image displays three orthogonal cross-sections (left, centre, right) through the rock volume. A color LookUpTable (LUT) has been applied to colorize the greyscale data. Geological interpretation of the image includes: black regions of air-filled pores, dark red represents feldspars, light red signifies clinopyroxene, and bright yellow highlights Fe-Ti oxide mineral aggregates (ulvöspinel and ilmenite) with cubic crystalline structures. The high density of Fe-Ti oxide minerals results in high X-ray attenuation, making them appear bright in CT images. Scanning Electron Microscope data identifies them as ulvöspinel and ilmenite. Made in the mCTscan lab, IGV, NTNU, H2024, by Prescelli Annan, ETHZ.

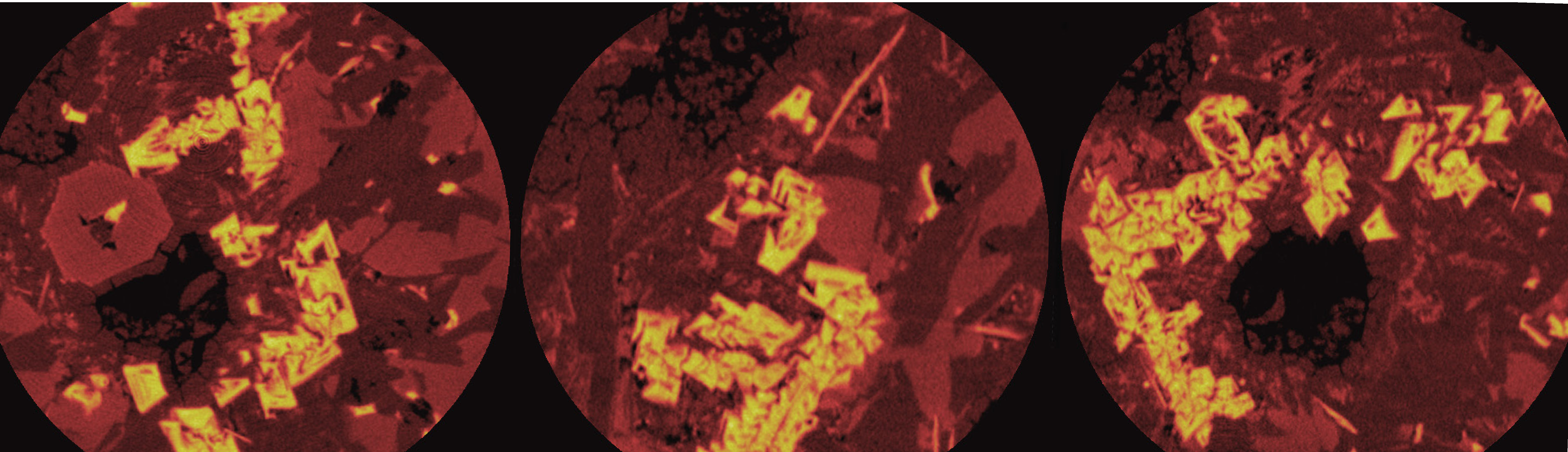


TABLE OF CONTENTS

CROSS-DISCIPLINARY BREAKTHROUGHS IN PORELAB

By Eirik G. Flekkøy, Deputy Director of PoreLab

During its existence, PoreLab has published in all the natural sciences. In addition to physics outlets, these publications have appeared in high level journals of geology, astronomy, biology and chemistry, as well as mechanics, a subject that traditionally sorts under mathematics. Our cross-disciplinary contributions have reached beyond our original mission statement and have come about by an enthusiastic drive to put basic physics to use in unconventional scientific territories. We have been in a good position to do this. Porous media, our main subject, exist everywhere: They are found in space, in living creatures, in a host of geological systems, and in technological ones. Also, our main working tools, those of hydrodynamics and statistical physics, are highly versatile and may be applied in widely different contexts.

For instance, in 2017, an unfamiliar astronomical object, the first interstellar visitor in our solar system appeared. This object was named 'Oumuamua, and it came with several hard-to-explain features. It turned out that the observations could be accounted for by viewing it as an ultra-porous medium the size of a large oil tanker.

A second example is our contributions to understanding the physiology of seals, dogs and reindeer. When it was pointed out to us that the heat exchange organ that exists inside the noses of seals, shared the same visual features as the man-made labyrinths that are portrayed in the PoreLab logo, we proposed a related algorithmic growth mechanism that could explain the formation of these organs. Third, when the cathedral in Strasbourg was threatened by earthquakes that originated from nearby hydrothermal wells, we studied the triggering mechanism, which could be explained as a result of flow in the porous medium of the fault zone, that contains the wells. The latter example is one of both cross- and trans-disciplinarity – bringing the science of porous media to the direct benefit of society.

After Ivar Giæver received the Nobel prize for his work on quantum tunneling, he expressed the view that no scientist should stay more than 5 years in his or her field. His idea was that entry into a new field allows for the most novel and original ideas. While this kind of scientific mobility may be hard to practice under the pressure of modern funding systems, the SFF programs do provide real and rare opportunities for scientific reorientation and expansion due to their broad scientific scope and long-term existence.

The idea of cross-disciplinary collaborations is celebrated, widely and enthusiastically. Yet, there are structural obstacles in place that counter-act such collaborations, most notably perhaps, the fact that university departments are still organized in highly mono-disciplinary ways. Yet, at NTNU the establishment of new permanent positions associated with the PoreLab activity is a promising and long-term measure to reduce this obstacle.

In our case, the cross-disciplinary spin-off effects have come about by encounters with other scientists: As members of the greater scientific community, they have come with unfamiliar scientific dialects and cultures. However, while the dialects are foreign, the language is not, and so, issues of terminology are rarely a real obstacle. Communication across the divide of disciplines has given rise to new ways of dealing with old problems, and even new problems. As physicists, we strive to 'make the model as simple as possible, but not simpler', to quote Einstein, and as a consequence, our model assumptions are often challenged in cross-disciplinary collaborations by the requirement of realism and detail. This is often highly valuable: Adapting to such demands from experts in fields that are new to us, often leads to a reinterpretation and deeper understanding of the model formulations and their results, which in turn may be both unconventional and lead to something entirely novel.

On the next page we illustrate a selection of our recently published, cross-disciplinary projects.

RECOMMENDED READING

[1] *Discerning between Different 'Oumuamua Models by Optical and Infrared Observations* E.G. Flekkøy and J.F. Brodin, Astrophys. J. Lett. 925 (2) (2022)

[2] *A model for phocid maxilloturbinate morphogenesis.* J. E. Kings1, L. P. Folkow, Øyvind Hammer, S. Kjelstrup, Matthew J. Mason, F. Xiong, and E. G. Flekkøy. To appear in PLOS ONE (2025)

[3] *The nasal cavity of the bearded seal: An effective and robust organ for retaining body heat and water* H.L. Cheon, N. Kizilova, E.G. Flekkøy, M. J. Mason, L. P. Folkow, S. Kjelstrup, J. Theor. Biology 7, 595 (2024)

[4] *Drainage explains soil liquefaction beyond the earthquake near-field.* S. Ben-Zeev, L. Goren, R. Toussaint & E. Aharonov, Nature Comm. 14, 5791 (2023)

[5] Seeking minimum entropy production for a tree-like flow-field in a fuel cell. M. Sauermoser, N. Kizilova, B. G. Pollet S. Kjelstrup, Physical Chemistry Chemical Physics, 22, 6993 (2020)

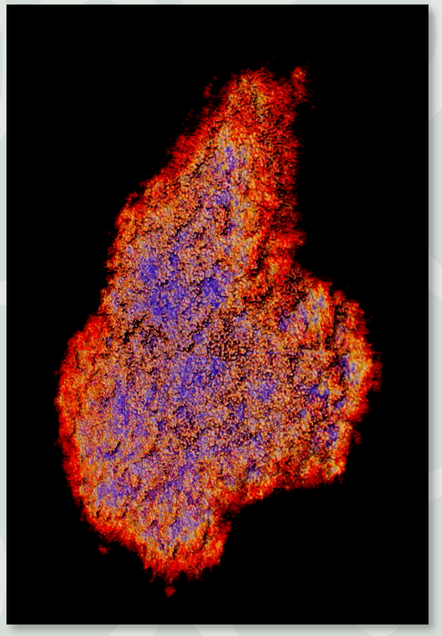


Figure 1: *Astronomy: A model image of 'Oumuamua seen in the infrared spectrum. This work suggests a method for discerning between different and conflicting explanations for such interstellar travelers using the James Web telescope [1].*

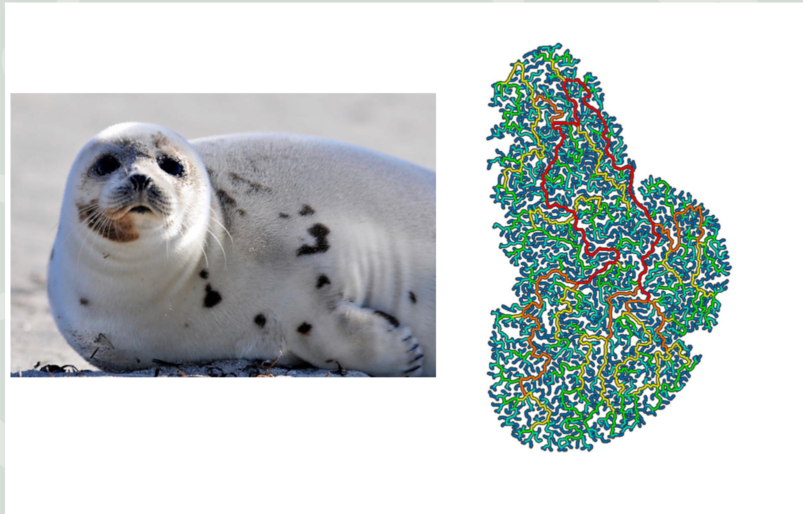


Figure 2: *Biology: A Harp seal and a model that seeks to explain the structure and formation of the heat exchange organ that it relies on to save heat and water in arctic environments [2, 3].*

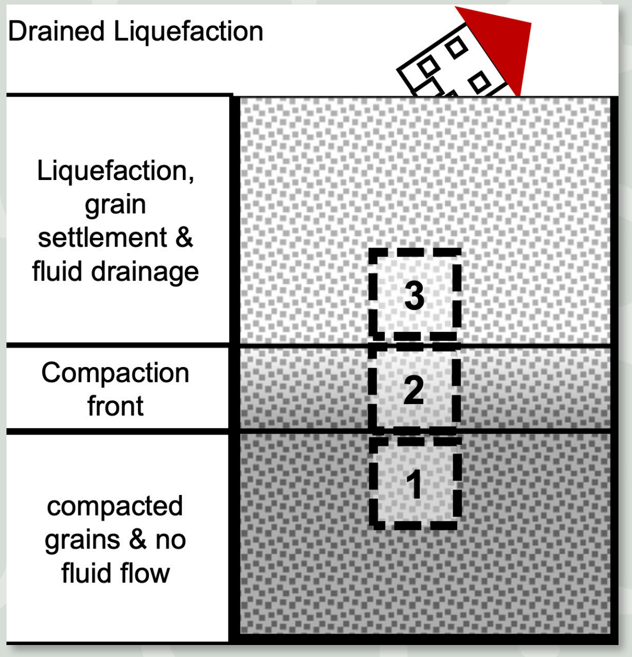


Figure 3: *Geoscience: Illustration of a model study that explains landslides, the collapse of building foundations and liquification events in terms of flow in porous media [4].*

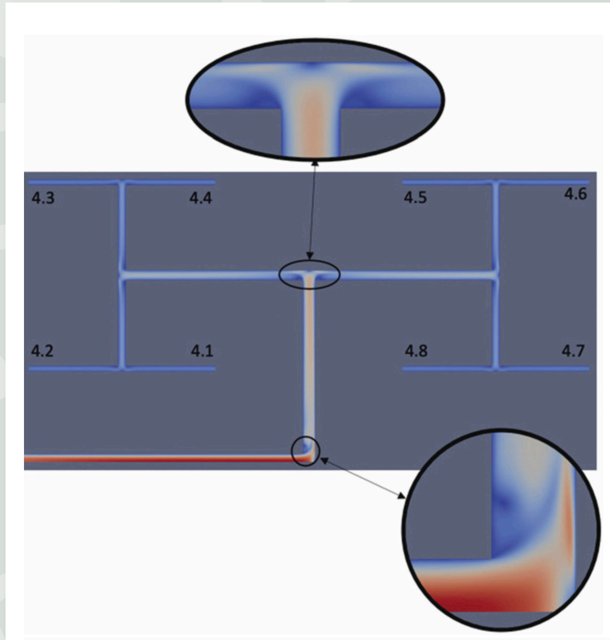


Figure 4: *Chemistry: Details of the flow field in a fuel cell where gases are supplied and removed via a tree-shaped porous media. This study seeked to optimize the conversion of chemical to electric energy [5].*

Alex Hansen, Director for PoreLab. Photo by Per Henning

DIRECTOR'S COMMENTS

2024 has ended and we have entered the last third of the ten years that the Research Council of Norway gave us to develop our ideas. Looking back, the starting phase took around two years before reaching cruising altitude – to use a metaphor. We are still at cruising altitude, but preparation for landing is about to commence. We do this by looking forwards. The RCN has announced that in May of 2025 there will be the call for a sixth generation of Centers of Excellence with a deadline in November. They will commence in the fall of 2027. And we have started preparing. Erika Eiser will lead the new center – if it materializes – with new focus and mostly new people. The overlap with original PI group of PoreLab is very small. The CoE competition is fierce, but no matter the outcome, the application process is a great generator of ideas and collaborations. We'll see what happens.

The world is different from when PoreLab started in 2017. I follow the Statistical Physics of Complex Systems seminars at the National Academy of Sciences of Ukraine in Lviv via Zoom, and it is frightening to experience having them broken off by air raid sirens warning of Russian missiles. Nationally, we see a shift of priorities and academic research as a result has fallen several notches. For the first time, there is talk of firing permanent scientific personnel. As a Center of Excellence, we feel shielded, but the future does not feel that certain anymore. Will our positions be filled when we retire? Decades of building a tradition in a given field may end in rapid collapse if succession is not handled properly. It worries me that the powers of the purse are prone to fashion fluctuations,[1] since position allocation essentially is a null-sum game. Strong growth in the field that is in fashion, means the opposite in other fields.

Enough about my worries. 2024 was a very good year for PoreLab. Gaute Linga has joined us as Onsager fellow and associate professor in the NTNU Physics Department. He has been elected member of the Young Academy of Norway and to the NTNU Star Program. He is at present running a program at the Young Center for Advanced Studies (Norwegian Academy of Sciences), *Mixing by Interfaces: How Does Water Infiltration Control Mixing and Reaction in Soils?* And he is now a PI in PoreLab. This is the second new position created at the NTNU Physics Department together with that of Erika Eiser who joined us in 2023.[2] I got an ERC Advanced Grant – AGIPORE – which will keep me occupied for the next five years. This is the second ERC grant that PoreLab has gotten after Øivind Wilhelmsen's ERC Starting Grant in 2023. In fact, the grant situation is excellent. Our income from external grants now exceeds the RCN and university contributions to PoreLab. We are happy to see that finally Norway has become member of a CECAM (Centre Européen de Calcul Atomique et Moléculaire) with PoreLab as a large financial contributor.

Scientifically, we are making progress. Here are some highlights organized according to PI:

- For the first time, a relation has been found between the critical exponent governing transport at the percolation threshold in disordered systems and the exponents describing the morphology of the disorder (Carl Fredrik Berg).[3]
- Establishing how chemical modification of the fungal polymer schizophyllan can bind another biopolymer, chitosan, to form hydrogels that may be used in tissue engineering (Erika Eiser).[4]
- Cavitation appears in fluids when they are ripped apart, giving rise to empty bubbles that immediately collapse. Here is a theoretical and experimental study of the phenomenon (Eirik Grude Flekkøy).[5]

- Mixing fluids may lead to smaller or larger volume than one started with. How much does each fluid shrink or expand while in the mixture? A new simple thermodynamic function can answer that question (Alex Hansen).[6]

- Constructing a numerical framework for resolving concentration gradients involved in solute mixing at the pore scale. Further evidence that the onset of turbulence in a tube is related to directed percolation (Gaute Linga).[7, 8]

- Identifying a stability criterion for the fluid interface under drainage in a three-dimensional porous medium, based on experimental studies (Knut Jørgen Måløy).[9]

- Establishing theoretically and experimentally that the rheological properties of power-law fluids can be predicted by observing the capillary spreading of viscous droplets in a wedge-shaped geometry (Marcel Moura).[10]

- Developing a kinetic theory that also works for dense phases and can be used to predict transport properties in porous media. Explaining how to calculate metastable thermodynamic properties of fluids (Øivind Wilhelmsen).[11, 12]

More details about these highlights and other projects may be found on pages 22 to 51 in this annual report.

AMBITIONS FOR 2024: DID WE DO WHAT WE SET OUT TO DO?

Why waste ink: yes.

AMBITIONS FOR 2025

If we can keep up the pace we are now at, 2025 will be a productive year. We have managed to integrate our activities to a point where PoreLab is a unified group. We see shifting collaborations between the different PIs and their groups. Synergy is a well-worn but very appropriate term to use. Scientifically, we have no challenges as I see it. We need to deliver on our respective projects, but judging from the past, we will do so.

We will send a proposal for a Center of Excellence to the RCN in November.

What *is* a challenge is the message that the Trondheim part of PoreLab needs to move from its present location to the Science Building. This to save funds since NTNU is renting the premises where we are now. So, we will be squeezed into that building somehow using shoehorns and oil. People already at the premises will have to be moved. We'll do our best, but this is a challenge. But we will insist with all our force that we stay together as a center rather than being scattered about.

1 See e.g. R. Donangelo, A. Hansen, K. Sneppen and S. R. Souza, *Physics of Fashion Fluctuations*, Physica A, 287, 539 (2000).

2 A great thank you to the department!

3 C. F. Berg and M. Sahimi, Relation between critical exponent of the conductivity and the morphological exponents of percolation theory, Phys. Rev. E 110, L042104 (2024).

4 A. P. Vanin, M. Camassola, E. Eiser and B. T. Stokke, *Characterization of the polysaccharide schizophyllan and schizophyllan–chitosan hydrogel formation by diffusing-wave spectroscopy*, Carbohydrate Polymers, 352, 123168 (2025).

5 T. Combriat, D. K. Dysthe and E. G. Flekkøy, *Cavitation dynamics of creeping flow*, J. Fluid Mech. 999, A19 (2024).

6 K. P. Olsen, B. Hafskjold, A. Hansen and A. Lervik, *A new thermodynamic function for binary mixtures: the co-molar volume*, submitted.

7 P. Shafabakhsh, T. Le Borgne, F. Renard and G. Linga, *Resolving pore-scale concentration gradients for transverse mixing and reaction in porous media*, Adv. Water Res. 192, 104791 (2024).

8 G. Lemoult, V. Mukund, H. Y. Shih, G. Linga, J. Mathiesen, N. Goldenfeld and B. Hof, *Directed percolation and puff jamming near the transition to pipe turbulence*, Nature Physics, 20, 1339 (2024).

9 J. F. Brodin, K. Pierce, P. Reis, P. A. Rikvold, M. Moura, M. Jankov, K. J. Måløy, *Interface instability of two-phase flow in a three-dimensional porous medium*, arXiv:2412.10127.

10 M. Moura, A. Carlson and E. G. Flekkøy, to be submitted.

11 V. G. Jervell and Ø. Wilhelmsen, *Predicting viscosities and thermal conductivities from dilute gas to dense liquid: Deriving fundamental transfer lengths for momentum and energy exchange in revised Enskog theory*, J. Chemical Physics, 161, 234106 (2024).

12 A. Aasen, M. Hammer, D. Reguera and Ø. Wilhelmsen, *Estimating metastable thermodynamic properties by isochoric extrapolation from stable states*, J. Chem. Phys. 161, 044113 (2024).

PoreLab@NTNU is located on the second floor of PTS2, at S.P. Andersens vei 15B in Trondheim

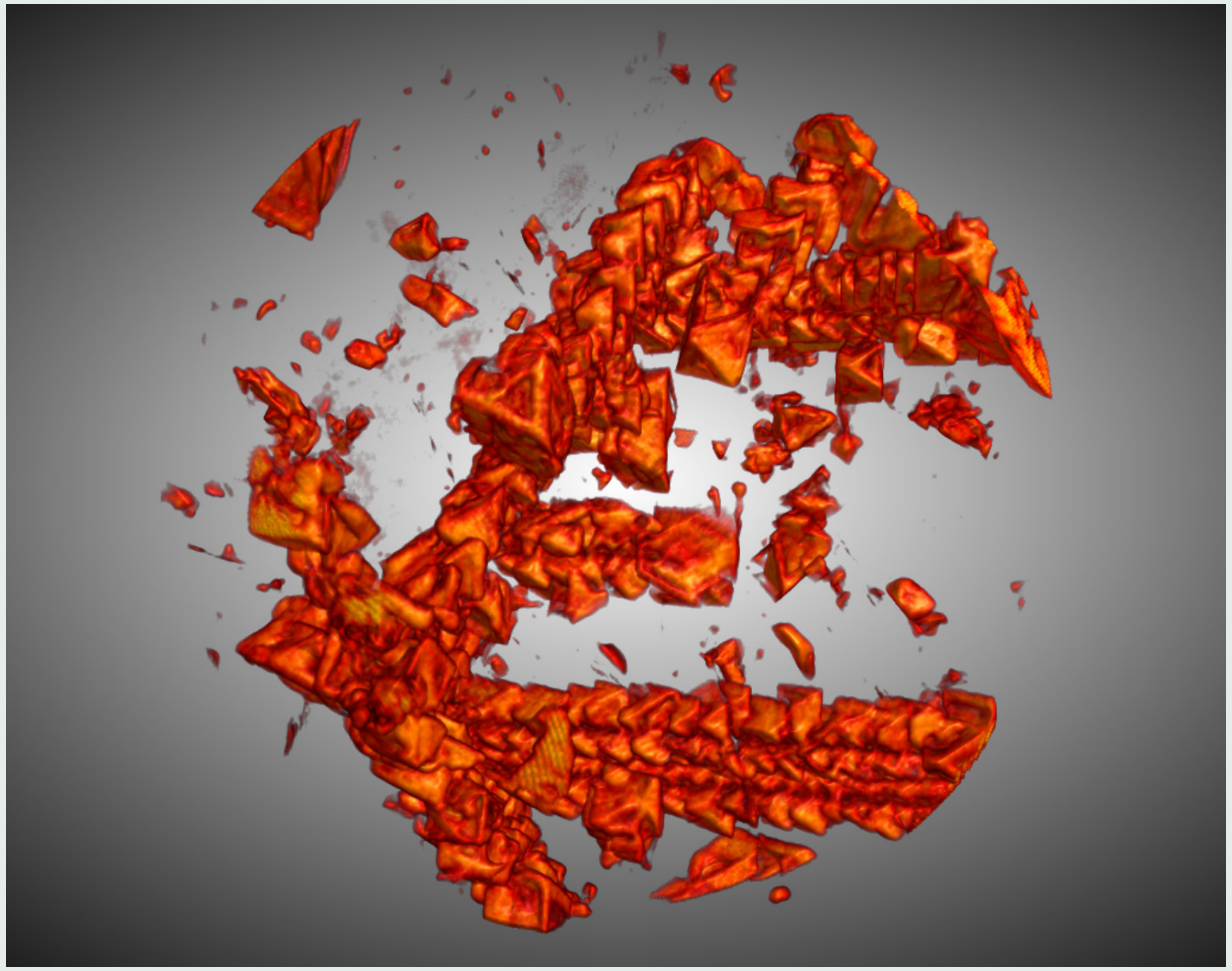


Figure: *3D visualisation of an aggregate of cubic mineral crystals in an Icelandic basalt, potentially magnetite or trigonal pyrite. Figure by Prescelli Annan (PhD Student in Geological Carbon Storage at ETH Zürich) and Antje van der Net (Associate Professor at IGV, NTNU), as part of the SMILE European Doctoral Network on Geo-Energy*

SHIFTING LANDSCAPES, STEADY CURIOSITY

BY BAUYRZHAN PRIMKULOV, ASSISTANT PROFESSOR AT YALE UNIVERSITY

In nature, granular materials are constantly in motion. Rivers sort and transport grains, forming layered sediment deposits downstream. Wind sculpts and moves sand dunes, creating perpetually shifting landscapes. Glaciers grind rocks into fine powders and carry them along icy flows, eventually depositing them in rivers or oceans. These natural processes are responsible for the landscape of fjords in Norway, breathtaking views in the Grand Canyon, and singing dunes in the Middle East.

As scientists, we strive to understand such natural processes, extract their underlying laws, and translate them into practical applications when possible. However, gaining a true understanding of a physical process is a laborious process that can often be frustrating: most of our guesses are wrong, most of our experiments don't work out the way that we imagined they would, and most of our theories lead us to dead ends. It is very easy to be wrong in science, and it is even easier to get discouraged.

While all scientists aspire to make a lasting, positive impact on people's lives, it's not what sustains us through the daily grind. What truly drives us is the thrill of understanding or discovering something new. That excitement is amplified when the discovery defies our expectations—there's nothing quite like being surprised by your own experiment or calculation. Surprises are abundant in the physics of porous and granular materials.

Bauyrzhan Primkulov, Assistant Professor at Yale University, Connecticut, USA, and winner of the InterPore-PoreLab award for Young Researchers in 2024

Take a very tall plastic cup, punch a hole through its base, and fill the cup with water; water will pour down and its flow rate will decrease as the height of the water column diminishes. Repeat the same experiment with sand and you'll be delighted to discover that it flows at a constant rate instead. This peculiar property of sand has been utilized for centuries through sand timers and grain silos. Furthermore, while most natural processes go from order to disorder (e.g. look at the mess of papers on your table), granular materials can pack a surprise. Shaking a cup of polydisperse grains orders them by their size, where larger grains float to the top. Shaking a box of nails aligns them perfectly with each other. Slow displacement of one fluid by another within rock formations creates universal fractal patterns, remarkably unaffected by the specifics of the pore geometry. The physics of porous and granular media is rich with unsolved problems, offering a window into the complexity and beauty of nature while holding the potential to address pressing environmental challenges.

Norway holds a special place for many scientists passionate about porous-media physics, thanks largely to PoreLab. This exceptional centre understands how scientists thrive and has cultivated a vibrant research community. Unsurprisingly, PoreLab has positioned itself as a leader in porous media research. My own PhD journey began during PoreLab's inaugural year, and the centre's work was instrumental in shaping my scientific trajectory. I am confident that PoreLab will continue to inspire and support young scientists in Norway and beyond for years to come.

ORGANIZATION
OF PORELAB

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

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

The organizational structure of the Center is flat. The team of the Principal Investigators (PIs) 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.

PoreLab's research is organized in eight Research Themes (RT) led by the Principal Investigators.

We were thrilled to welcome at PoreLab associate professor Gaute Linga as Onsager Fellow within computational porous media physics from January 2024. An Onsager Fellow is an entry level position (tenure track) which during the first years of employment is financially covered by funding from NTNU's Rectorate. The Onsager Fellowship program at NTNU is designed to attract exceptionally talented early-career scholars with documented excellent supervised work, ready to work independently and with the potential to become a research leader. The tenure-track associate professor's duties primarily include research, but also supervision, teaching, and other duties necessary to qualify for a permanent professor position within 6–7 years. Gaute has joined PoreLab's leader group as new PI since September 2023.

The PoreLab Executive Board includes members from the faculties involved at NTNU and UiO. It consists of 5 members: Professor Øyvind Gregersen, Dean at the Faculty of Natural Sciences at NTNU, Professor Erik Wahlström, head for the department of Physics at NTNU, Professor Sveinung Løset, vice dean for research and innovation at the Faculty of Engineering at NTNU, Professor Susanne Viefers, head of the Physics Department at the University of Oslo and Professor François Renard, director for the Njord center that hosts the Oslo node of PoreLab. 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 Research Council of Norway that funds PoreLab demands there to be a Scientific Advisory Board, or SAB. The main role of the SAB is to evaluate and make recommendations on the scientific status and progress of PoreLab. It aids in the development of a strategy for the scientific development of the center, thereby helping the leadership group by giving advice on implementing appropriate means of actions to achieve the stated scientific aims and fulfil the strategy plan. The SAB is composed of international experts and leading scientists who act as external advisors to the management of PoreLab.

The SAB includes:

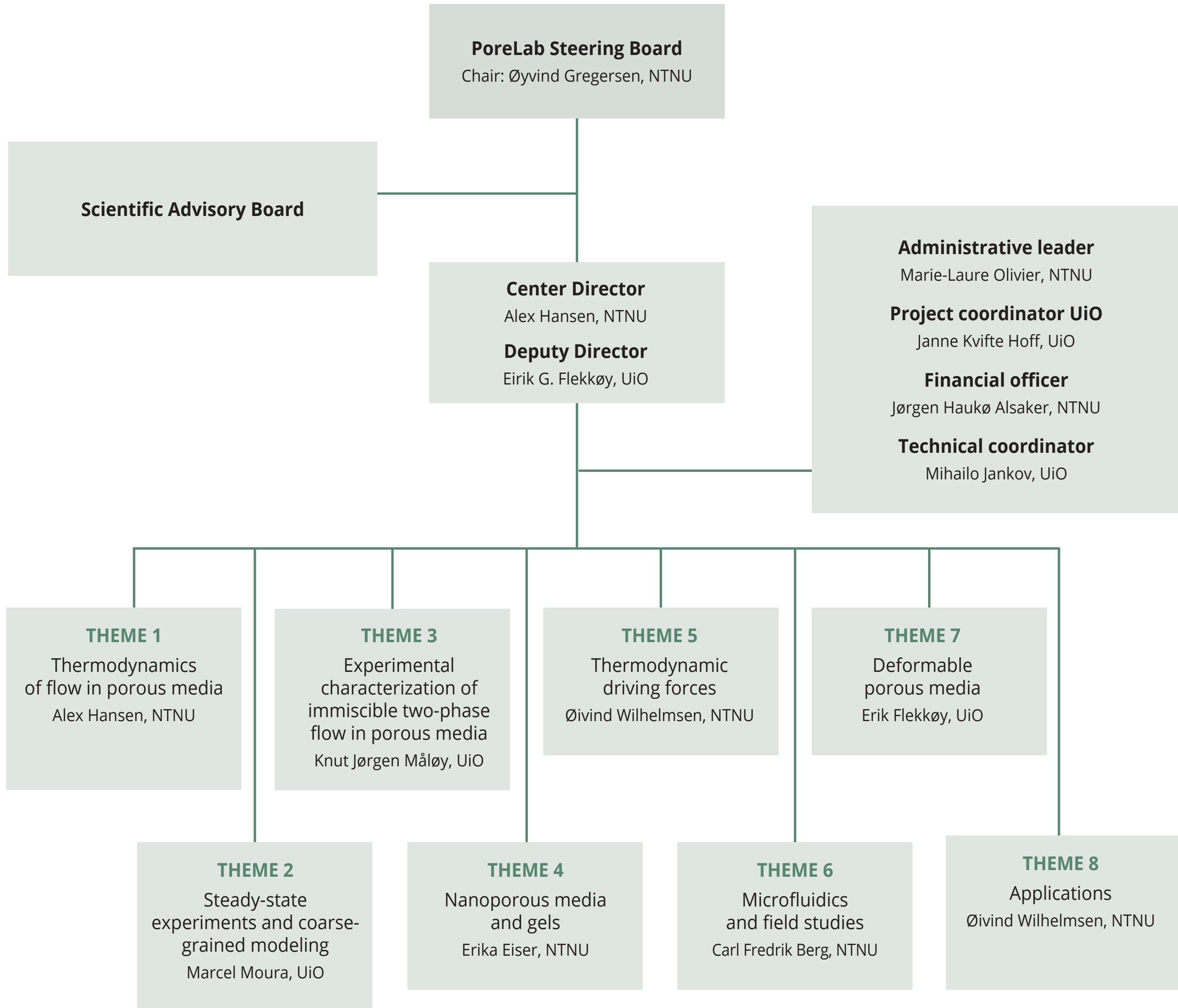
- Daniel Bonn, Professor at the Van der Waals-Zeeman Instituut at the University of Amsterdam in The Netherlands
- Pål-Eric Øren, Chief Technology Officer at Digital Rock Services at Petricore in Trondheim, Norway
- Douglas Durian, Mary Amanda Wood Professor of Physics and Astronomy at the Department of Physics and Astronomy at the University of Pennsylvania, USA
- Steffen Berg, Principal Science Expert at Shell Global Solutions International B.V. in The Netherlands

In 2024 both Emeritus Professor Majid Hassanizadeh from Utrecht University in the Netherlands and Emeritus Professor Dani Or from Eidgenössische Technische Hochschule (ETH) in Zürich stepped down from their positions in the SAB.

We welcomed thereafter Professor Veerle Cnudde as new member in our SAB. Professor Cnudde received a PhD in Geology in 2005 from Ghent University in Belgium where she has been a research professor since 2010. She is team leader of the Pore-scale Processes in Geomaterials Research Group (PProGRess) and is one of the coordinators of the Ghent University Expertise Centre for X-Ray Tomography (UGCT). In 2019, she obtained a dual professorship at Utrecht University in the Netherlands as Full Professor at the Environmental Hydrogeology group in the field of *'Porous media imaging techniques'*. Professor Cnudde specializes in non-destructive imaging of geomaterials and has a strong expertise in real-time imaging of processes in the pore space. Research projects which she has initiated are strongly linked to weathering and fluid flow processes of porous sedimentary rocks, as well as conservation of building stones.

The SAB meets with the PI group usually once a year. The next SAB meeting will be organized in April 2025.

Structure of the organization



MANAGEMENT AND ADMINISTRATION

THE LEADER GROUP


Alex Hansen
Director
Professor, PI Theme 1


Marcel Moura
Researcher
PI Theme 2


Knut Jørgen Måløy
Professor,
PI Theme 3


Erika Eiser
Professor
PI Theme 4


Øivind Wilhelmsen
Professor
PI Themes 5 and 8


Carl Fredrik Berg
Professor
PI Theme 6


Eirik Flekkøy
Deputy Director
Professor, PI Theme 7


Gaute Linga
Associate Professor


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

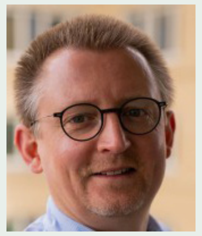
SCIENTIFIC ADVISORY BOARD


Veerle Cnudde
Professor
Ghent University, Belgium and
Utrecht University
The Netherlands


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


Douglas Durian
Professor
Mary Amanda Wood Professor of
Physics and Astronomy
University of Pennsylvania, USA


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


Steffen Berg
Principal Science Expert at Shell
Global Solutions International
B.V. in the Netherlands

PARTNERS

NTNU

UiO : University of Oslo

SINTEF

HIGHLIGHTS

2024
7 new projects granted to PoreLab members in 2024

1 January 2024
Dr. Gaute Linga, PI at PoreLab UiO is appointed Onsager Fellow and joins the Department of Physics at NTNU as associate professor

2024
Gaute Linga, Young CAS Principal Investigator, organized 3 Young CAS workshops in February, May and October 2024

12 February 2024
Welcome to Professor Veerle Cnudde as new member of PoreLab's Scientific Advisory Board

19–22 February 2024
IRP-DFFRACT Conference organized by PoreLab members in Courmayeur, Italy

13–16 May 2024
Time capsule Interview with Professors Signe Kjelstrup and Dick Bedeaux was presented during the 16th InterPore Annual Meeting in Qingdao, China

3 June 2024
Alex Hansen, PoreLab's director, receives an ERC Advanced Grant.

17–19 June 2024
FricFrac Conference – Friction and Fracture and the Onset of Geohazards, Oslo, Norway

14–19 July 2024
2nd workshop on Non-Newtonian Flows in Porous Media, BIRS, Banff, Canada

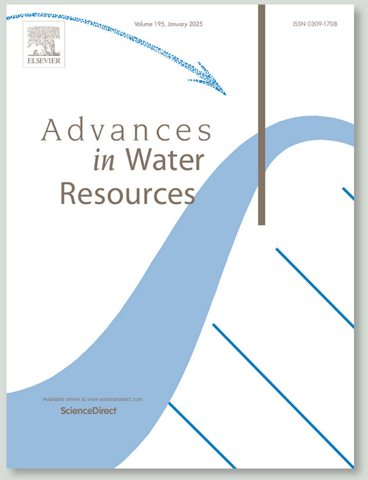
4 October 2024
Gaute Linga, new member of the Young Academy of Norway

PUBLICATIONS IN THE SPOTLIGHT

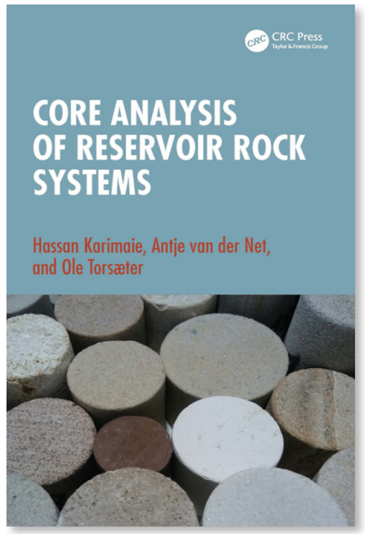
The publication from Alex Hansen and Srutarshi Pradhan from PoreLab and Bikas Chakrabarti from Saha Institute of Nuclear Physics, India, entitled *"Failure Processes in Elastic Fiber Bundles"* and published in 2010 in the *Reviews of Modern Physics*, has passed 400 citations.

Gaute Linga, PI at PoreLab, & his co-workers from the University Le Havre Normandie in France, the University of Illinois in USA, the Institute of Science and Technology in Austria and the Niels Bohr Institute in Denmark, had their article entitled *"Directed percolation and puff jamming near the transition to pipe turbulence"* published in Nature Physics on May 27th, 2024.

Carl Fredrik Berg, PI at PoreLab, and his co-worker Muhammad Sahimi from the University of Southern California, USA published their article entitled *"Relation between critical exponent of the conductivity and the morphological exponents of percolation theory"* in *Physical Review E* on October 24th, 2024.

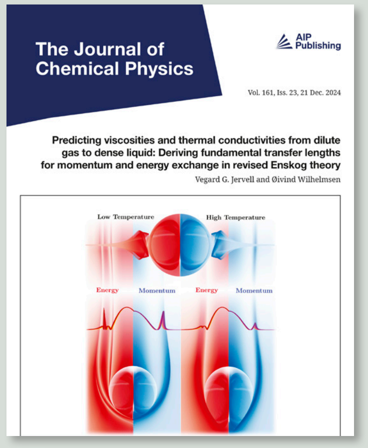


Paiman Shafabakhsh, François Renard, Gaute Linga, PI at PoreLab, and Tanguy Le Borgne from the Njord center and the University of Rennes 1, had their article entitled *"Resolving pore-scale concentration gradients for transverse mixing and reaction in porous media"* published in *Advances in Water Resources* in October 2024.



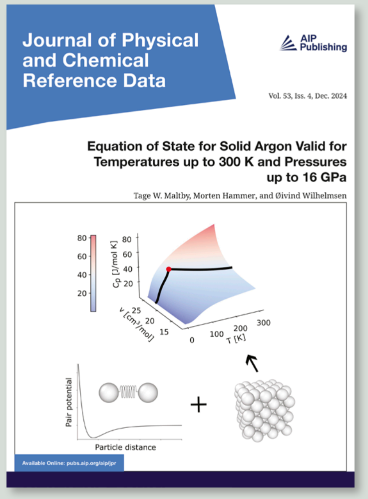
"Core Analysis of Reservoir Rock Systems", the book manuscript by Hassan Karimaie, Antje van der Net and Ole Torsæter was released in November 2024. The publisher is CRC Press.

The article from Hao Gao, Ali Amiri, Signe Kjelstrup, Gustav Grimstad, Benoit Loranger and Elena Scibilia, *"Formation and growth of multiple, distinct ice lenses in frost heave"*, was one of the most downloaded during its first 12 months of publication in the *International Journal for Numerical and Analytical Methods in Geomechanics.*



The publication from Vegard Jervell and Øivind Wilhelmsen entitled *"Predicting viscosities and thermal conductivities from dilute gas to dense liquid: deriving fundamental transfer lengths for momentum and energy exchange in revised Enskog theory"* was selected as a Featured article by the journal Editor and an artistic illustration of the work ended up at the front page of the journal for Volume 161, Issue 23.

Thomas Combriat, Dag K. Dysthe and Eirik G. Flekkøy from PoreLab UiO had their article entitled *"Cavitation Dynamics in Creeping Flow"* published in the *Journal of Fluid Mechanics* on November 12th, 2024.



The paper from Tage Maltby, Morten Hammer and Øivind Wilhelmsen on the *"Equation of state for solid argon valid for temperature up to 300 K and Pressures up to 16 GPa"* was published in the *Journal of Physical and Chemical Reference Data* on December 9th, 2024. An artistic representation of the article was selected by the Editor to be on the coverpage.

Kim Robert Tekseth, Fazel Mirzaei, Dag W. Breiby and Basab Chattopadhyay from the X-ray Physics Group at the Porous Media Physics section at NTNU & Bratislav Lukic from the European Synchrotron in Grenoble had their article entitled *"Multiscale drainage dynamics with Haines jumps monitored by stroboscopic 4D X-ray microscopy"* published in *PNAS* on December 26th, 2023.

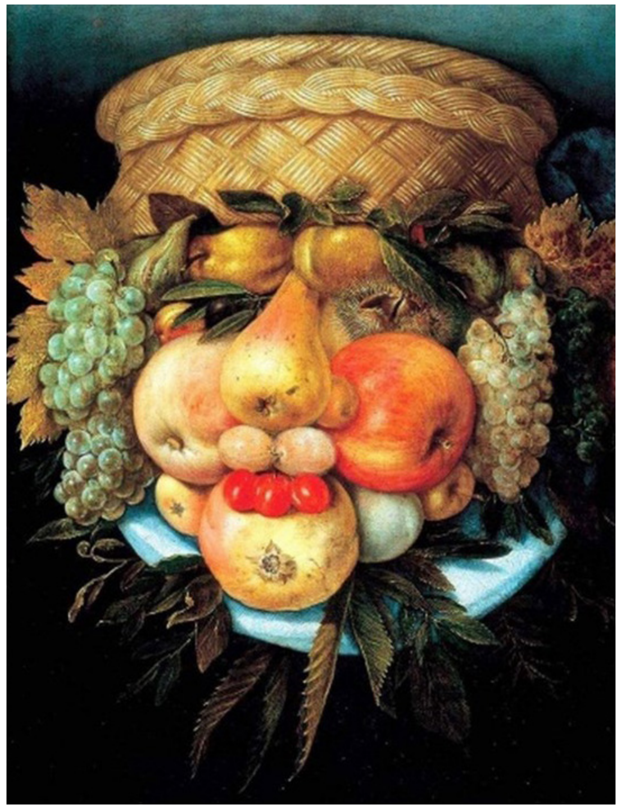
Ailo Aasen, Morten Hammer, Øivind Wilhelmsen, from PoreLab and their co-worker David Reguera from the University of Barcelona, published the article entitled *"Estimating metastable thermodynamic properties by isochoric extrapolation from stable states"* in the *Journal of Chemical Physics* on July 25th, 2024

EFFECTIVE RHEOLOGY OF IMMISCIBLE TWO-PHASE FLOW IN THE CONTINUUM LIMIT

Subhadeep Roy[1], Santanu Sinha[2], Alex Hansen[3]

[1] Birla Institute of Technology, Pilani, India
[2] PoreLab, Department of Physics, Norwegian University of Oslo, Oslo, Norway
[3] PoreLab, Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway

This strange renaissance painting by Guiseppe Archimboldo (1526-1593) represents a great example of upscaling. Upscaling in this context means stepping away from the painting. Close-up the painting shows an up-side down fruit basket. Backing away from the painting, it turns into a portrait of a man. Now consider immiscible two-phase flow in porous media. Close-up we see a network of pores generating a complex and shifting flow field. Moving away, the picture changes into an evolving continuous saturation field.



Upscaling is a central theme in PoreLab. In the context of immiscible two-phase flow in porous media, we have focused on making a connection between a pore-scale description of the flow and a description at the scale where the porous medium appears continuous.

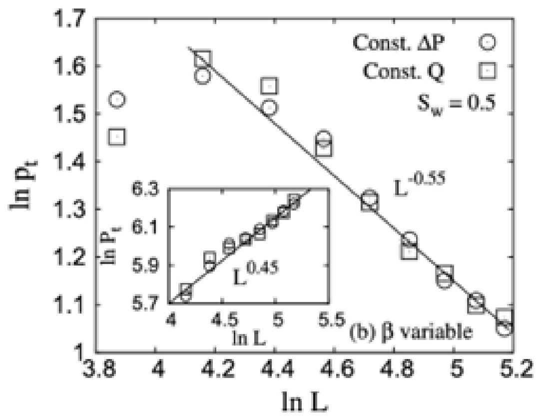
But even at the continuum scale, the description of the flow may change as we continue to scale up to larger and larger scales. Here is an example of this.

In 2009, Tallakstad et al. [1] studied steady-state flow in a two-dimensional model porous medium, finding that the flow rate would be proportional to the pressure drop to a power close to two over a wide range of flow rates. The reason for this behavior would be that the higher the pressure drop, the more interface would move, resulting in an effective mobility that would increase with increasing the pressure drop.

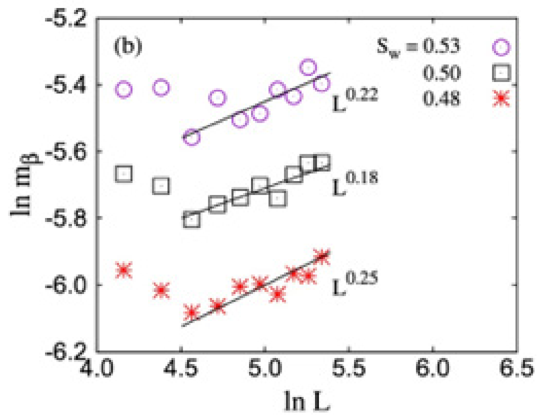
Later work would show that the power law regime would be the middle of three regimes, when plotting flow rate as a function of pressure drop. The first one, at very low pressure drops, has the flow rate being linear in the pressure drop. This is due to the interfaces not moving. The middle regime is the one we just described with the flow rate being a power law in the pressure drop. The last regime, appearing at high pressure drops, shows again a linear relationship between the flow rate and the pressure drop.

We asked ourselves in this project what happens to the crossover pressure drop where the power law regime ends, and the linear regime starts if we increase the size of the porous medium sample we use [2]. If the crossover pressure drop increases with increasing sample size, the non-linear regime will be increasingly prevalent. If it stays the same, it retains its importance with increasing system size. However, if it drops, the non-linear regime goes away with increasing system size.

By using the capillary fiber bundle model, we showed analytically that the threshold pressure p_t to mobilize the fluids would drop as the inverse square root of the system size L. Using a dynamic pore network model, we tested this numerically and indeed, that is what we found, see figure under.

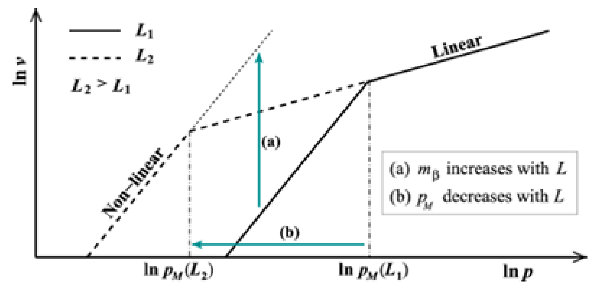


We then calculated the mobility in the non-linear regime, finding that it would increase with increasing system size. To be more precise, it would increase as the system size to a power ¼. This is indeed close to what we observed when measuring the growth of the mobility m_b as a function of the system size L, see the figure under.



But how does the fact that the effective mobility increases with system size lead to the non-linear regime going away? This may be understood from the sketch in the upper right corner. Here n is the average fluid velocity, which we plot against the pressure drop p on a log-log scale. We have the linear regime to the right. To the left we have the non-linear regime. p_M is the crossover pressure drop where the flow crosses over from non-linear to linear flow. The effective mobility in the linear regime is independent of system size. The non-linear mobility m_b increases with increasing system size. As seen in the figure this results in the crossover pressure drop p_M to decrease. Our conclusion: the non-linear regime goes away with increasing system size.

Indeed a surprising result: The existence of the non-linear regime is a finite-size effect.



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] S. Roy, A. Hansen, A. Hansen, Immiscible two-phase flow in porous media: effective rheology in the continuum limit, *Transport in Porous Media*, **151**, 1295 (2024).

A NEW THERMODYNAMIC FUNCTION FOR BINARY MIXTURES

Kristian P. Olsen[1], Bjørn Hafskjold[2], Alex Hansen[1], Anders Lervik[2]

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

One plus one is two. Not always though: Mix one liter of water with one liter of ethanol. The result is around 1.92 liters mixture. Why? Fill a one cubic meter container with coarse gravel. There will be space between the gravel, roughly amounting to a total of some 400 liters or so. This we can fill up with sand. So, we can mix one cubic meter of gravel with 400 liters of sand and end up with a volume of the mixture still being one cubic meter. The water and ethanol molecules will arrange themselves in such a way that they take less space than being separate.

In the gravel-sand example, it was intuitively clear that the volume occupied by the gravel would leave space for the sand grains. There would be no trouble measuring the gravel volume and thereby the void volume experimentally. This is not possible with the water-ethanol mixture. We cannot measure experimentally the volume occupied by the water molecules inside the water-ethanol mixture. This is however possible computationally using molecular dynamics. We simply do a Voronoi tessellation around each molecule. This results in a computationally measurable volume around each molecule. We then just sum the volumes around each water molecule and the volumes around each ethanol molecule.

Thermodynamics, which was developed even before the atomistic hypothesis was firmly established, has nothing to say about the physical volumes that each species of a binary fluid mixture occupies. Rather, what thermodynamics does say something about in this context is the specific molar volume of each fluid species. This volume is the volume change of the mixture given the addition or subtraction of a specified amount of that fluid. This is of course a very different quantity from the specific physical volumes of each fluid in the mixture.

In connection with immiscible two-phase flow in porous media, we have developed a formalism that is closely related to that of thermodynamics [1]. In it we operate with the seepage – or average pore – velocity of each fluid. And we define a *thermodynamic velocity* for each fluid. The two seepage velocities and the two thermodynamic velocities may be related through a single velocity variable we named the *co-moving velocity* [2-4].

It turns out that we the thermodynamic and seepage velocities fit within the thermodynamics-like formalism precisely in the same way as the partial molar volumes and the specific physical volumes do within the thermodynamics of binary mixtures. The co-moving velocity maps onto a new thermodynamic function we have named the *co-molar volume* [5]. As is the case in two-phase flow in porous media, the co-molar volume turns out to have a simple form when expressed in the natural variables (albeit somewhat more complex than the co-moving velocity).

We show in the figure v_m, the co-molar volume plotted against $w=dV/dx_1$, where V is the volume of the mixture and x_1 the mixing ratio of fluid 1. The data are for three different fluid mixtures.

The result of this is that the specific physical volumes become part of ordinary thermodynamics.

But it is also important to note that the thermodynamics-like formalism could point to a missed quantity in ordinary thermodynamics.

RECOMMENDED READING

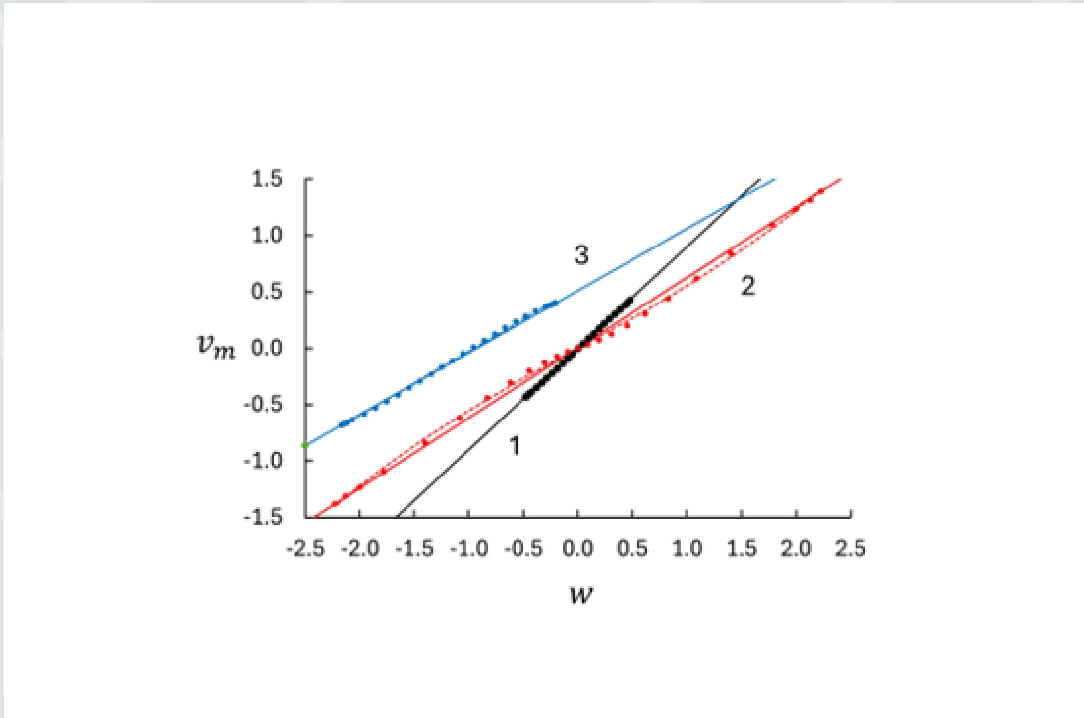
[1] A. Hansen, S. Sinha, D. Bedeaux, S. Kjelstrup. M. Aa. Gjennestad and M Vassvik, Relations between seepage velocities in immiscible, incompressible two-phase flow in porous media, *Transport in Porous Media*, **125**, 565 (2018).

[2] S. Roy, H. Pedersen, S. Sinha and A. Hansen, The co-moving velocity in immiscible two-phase flow in porous media, *Transport in Porous Media*, **143**, 69 (2022).

[3] F. Alzubaidi, J. E. McClure, H. Pedersen, A. Hansen, C. F. Berg, P. Mostaghimi and R. T. Armstrong, The impact of wettability on the co-moving velocity of two-fluid flow in porous media, *Transport in Porous Media*, **151**, 1967 (2024).

[4] A. Hansen, Linearity of the co-moving velocity, *Transport in Porous Media*, **151**, 2477 (2024).

[5] K. P. Olsen, B. Hafskjold, A. Hansen and A. Lervik, A new thermodynamic function for binary mixtures: the co-molar volume, in review.



MEASURING MELT, RAIN-ON-SNOW AND PERCOLATION IN SNOW WITH RAPID MICRO-MRI PROFILING

Quirine Krol[1,2,3], Alex Hansen[1], Joseph Seymour[2]

[1] PoreLab, Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway
[2] Magnetic Resonance Laboratory, Chemical Engineering, Montana State University, Bozeman, Montana, USA
[3] SubZero Laboratory, Environmental Engineering, Montana State University, Bozeman, Montana, USA

The first wetting events in a snowpack, caused by either melt or rain-on-snow events, are often associated with unstable snowpacks. The observed mechanical failures and subsequent avalanches are triggered by the activation of the "old snow" depth hoar avalanche problem. However, after subsequent wetting and refreezing, the stability of the snowpack tends to increase. Predicting these initial wetting events in a timely manner is challenging because snowmelt and the transport of meltwater within snow are governed by out-of-equilibrium thermodynamics. These phenomena are also critical to snowmelt rates and runoff processes but remain difficult to model at the macroscale.

In this project, we visualized the dynamic liquid water content of a melting snow sample using rapid profiling with magnetic resonance imaging (MRI). This method achieved a resolution of 70 microns in depth and temporal resolutions of 25, 50, and 100 milliseconds. A combination of multiple measurements, as shown in Fig. 2, allowed us to conduct experiments lasting up to 45 minutes.

MRI experiments were performed on snow samples subjected to melting or simulated rainfall, modeled by a simple drip-flow system. The samples were prepared using natural snow placed atop a bed of 2 mm glass beads (see Fig. 1) to mimic snow-soil interactions.

The data in Fig. 2 clearly demonstrate the dynamic saturation behavior during snowmelt. Ponding was observed above the capillary barrier formed by the interface between the snow and the glass beads. As meltwater accumulated, the pressure head increased until it overcame the capillary barrier, triggering percolation into the soil. Once the entire sample became saturated, the integrity of the ice matrix was gradually compromised. This led to steady compaction and the discharge of meltwater. During the experiment, rapid 2D image slices were captured to quantify the liquid water content (LWC) and categorize the saturation states, as detailed in the right column of the figure.

In a second experiment (see Fig. 3), we applied a drip flow of Magnevist-doped water onto a snow sample. When water moved rapidly through the ice matrix, signal intensity was attenuated due to the loss of coherence in the spin states of the water. These attenuation events, highlighted in red, provide valuable insights into the time and length scales involved in these out-of-equilibrium processes. This imaging method offers a novel perspective on the dynamics of wetting and meltwater transport in snowpacks.

RECOMMENDED READING

[1] Rapid MRI profiling of liquid water content in snow: Melt and Stability during first wetting and rain on snow events. Q.Krol, E. Scherrer, M. Skuntz, S. Codd, A. Hansen, J.D. Seymour. Rapid MRI profiling of liquid water content in snow: Melt and Stability during first wetting and rain on snow events. *Proceedings, International Snow Science Workshop, Tromsø, Norway, 2024: https://arc.lib.montana.edu/snow-science/objects/ISSW2024_O3.11.pdf*

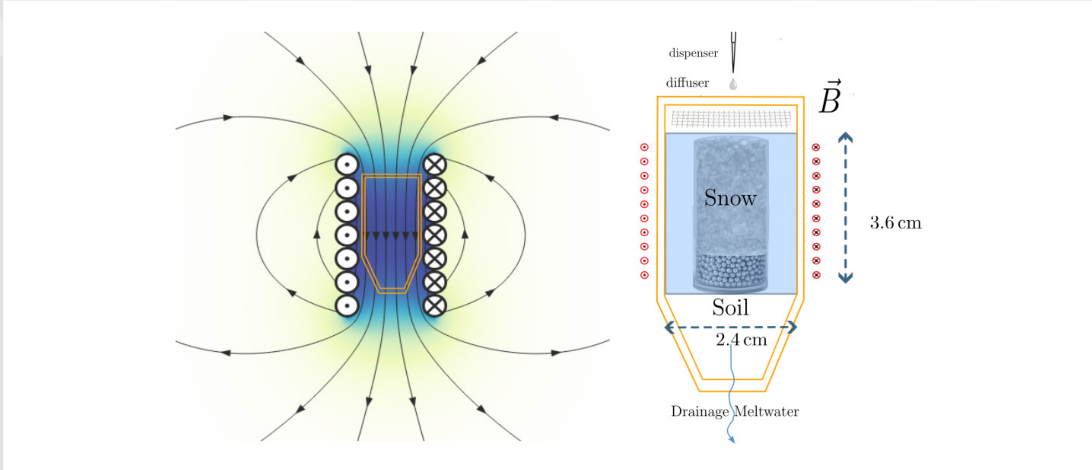


Figure 1: *Schematic of the sample setup in the spectrometer.*
Left: The placement of the sample in a homogeneous background magnetic field B = 7 T.
Right: Setup of the snow sample in the sample holder, equipped with a dispenser, catchment volume, and a drainage tube.

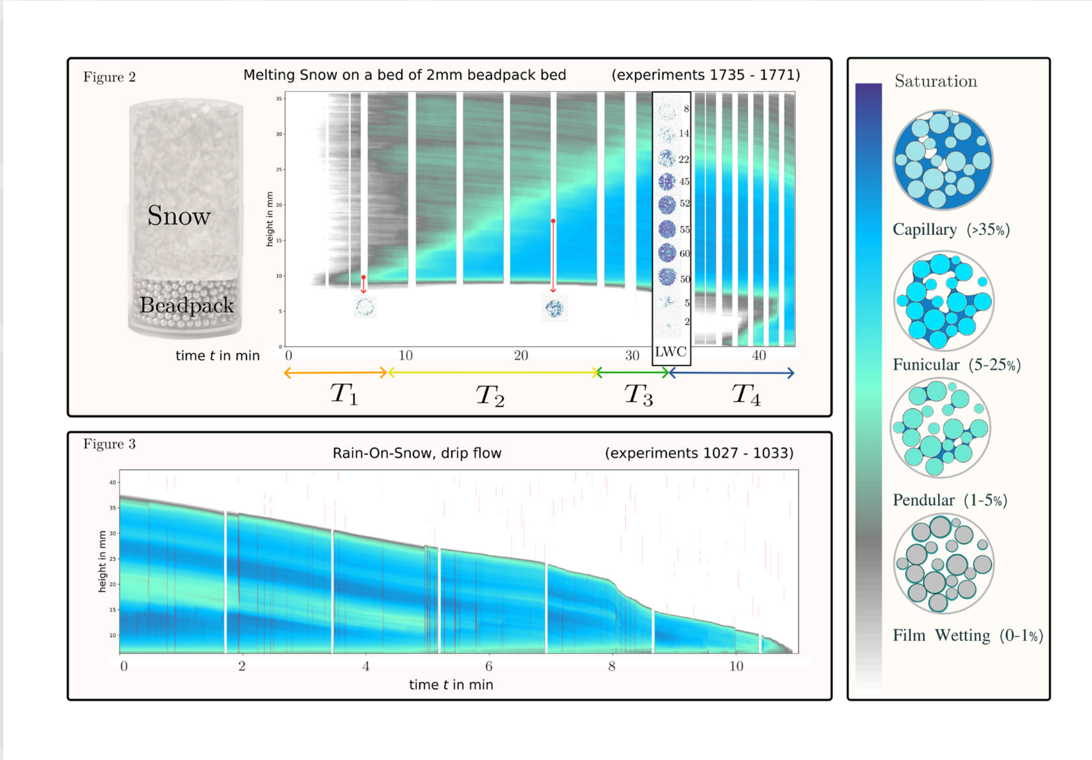


Figure 2: *MRI rapid profiling results of a fast melting, ponding by the capillary barrier between snow and soil (glass beads), and break-through (percolation) from buildup of pressure head in the ponding area. On the left, a scaled illustration of the sample is depicted for reference. The white spaces in between single measurements are observation moments of 2D slice images. A column with slices images and estimated LWC (in %) is shown at time of percolation around t = 32 minutes. The different time zones represent the different stages of the experiment. During T_1 the sample starts to melt in rings from the boundary of the snow sample inwards. During T_2: the pressure head build up. During T_3, the onset of percolation and T_4: full percolation that allows meltwater to be discharged.*

Figure 3: *MRI rapid profiling results of percolation of Rain on Snow. In addition to the liquid water content, the results are overlaid with vertical stripes in red that show rapid flow events. Above the snow-air interface these lines capture falling water droplets, whilst below the interface it shows the extent of the water column that is associated with the catchment of the droplet.*

On the right we show an illustration of the different types of water distribution and estimated range of saturation. The colors represent the signal intensity on a logarithmic scale.

THE ANOMALOUS DYNAMICS OF A TINY DROPLET SPREADING ON A CORNER

Marcel Moura[1], Vanessa Kern[2], Knut Jørgen Måløy[1,3], Andreas Carlson[2], Eirik Grude Flekkøy[1,4]

[1] PoreLab, The Njord Centre, Department of Physics, University of Oslo, Oslo, Norway
[2] Department of Mathematics, University of Oslo, Oslo, Norway
[3] PoreLab, Department of Geosciences, Norwegian University of Science and Technology, Trondheim, Norway
[4] PoreLab, Department of Chemistry, Norwegian University of Science and Technology, Trondheim, Norway

Porous media, such as sandstone or soil, are frequently formed by the aggregation of particles. These natural processes often leave behind materials with intricate networks of crevices, grooves, and tiny corners, typically formed where particles come into contact like sand grains in sandstone. These microscopic features play an important role in how liquids interact with porous materials. A particularly fascinating phenomenon occurs in these corners: due to capillarity, they tend to retain thin liquid films.

You can see that everywhere: try drying a flat surface and then one that is full of grooves. You will see that the groovy one is much harder to dry, water just tend to stick to those tiny corners no matter what you do. This tendency of water to wet the grooves has many important consequences for porous media flows: for instance water films in grooves can connect distant parts of a porous material, providing a new pathway for the transport of liquids and solutes [1,2].

In our research, we've uncovered an additional intriguing feature of liquid motion within these grooves. Using a simplified model of a triangular corner, we investigated how the temporal dynamics of liquid spreading—how far a droplet travels over time—can reveal intrinsic properties of the liquid itself [3]. Specifically, we focused on a class of fluids known as power-law fluids. These are fluids whose viscosity changes as a power-law function of the local shear rate, characterized by a parameter n that we call the "rheology exponent."

Our theoretical work demonstrated that the dynamics of droplet spreading in a triangular corner can be fully described by a nonlinear diffusion equation. Importantly, we discovered a direct link between the diffusion exponent τ, which describes how the liquid spreads, and the rheology exponent n of the fluid. This theoretical insight has a practical implication: by measuring the spreading dynamics of a liquid, we can infer its rheological properties.

To put this idea into practice, we designed an experimental setup capable of capturing the spreading dynamics with a regular camera. Using this setup, we successfully measured the rheology exponents of several power-law fluids, see Figure 1. Unlike a commercial rheometer, our setup has no moving solid parts and no force or torque sensors are involved. It certainly does not produce the myriad of results that can be obtained from a commercial rheometer (in particular it does not measure explicitly stresses or torques in any way, providing only the rheological exponent), but it stands as a proof of concept and a realization that there's more than meets the eye to the ever present grooves in porous media.

ACKNOWLEDGEMENTS

The authors thank the Research Council of Norway through its following funding schemes: FlowConn Researcher Project for Young Talents (project number 324555), PoreLab Center of Excellence (project number 262644) and NANO2021 program (project number 301138).

RECOMMENDED READING

[1] Moura, M., Flekkøy, E. G., Måløy, K. J., Schäfer, G., & Toussaint, R. (2019). Connectivity enhancement due to film flow in porous media. *Physical Review Fluids*, 4(9), 094102.

[2] Reis, P., Moura, M., Linga, G., Rikvold, P. A., Toussaint, R., Flekkøy, E. G., & Måløy, K. J. (2023). A simplified pore-scale model for slow drainage including film-flow effects. *Advances in Water Resources*, 182, 104580.

[3] Moura, M., Kern, V., Måløy, K. J., Carlson, A., & Flekkøy, E. G. (2025). Anomalous dynamics of a liquid corner film. Submitted to *Physical Review Letters*. arXiv preprint, arXiv:2501.14571 [physics.flu-dyn].

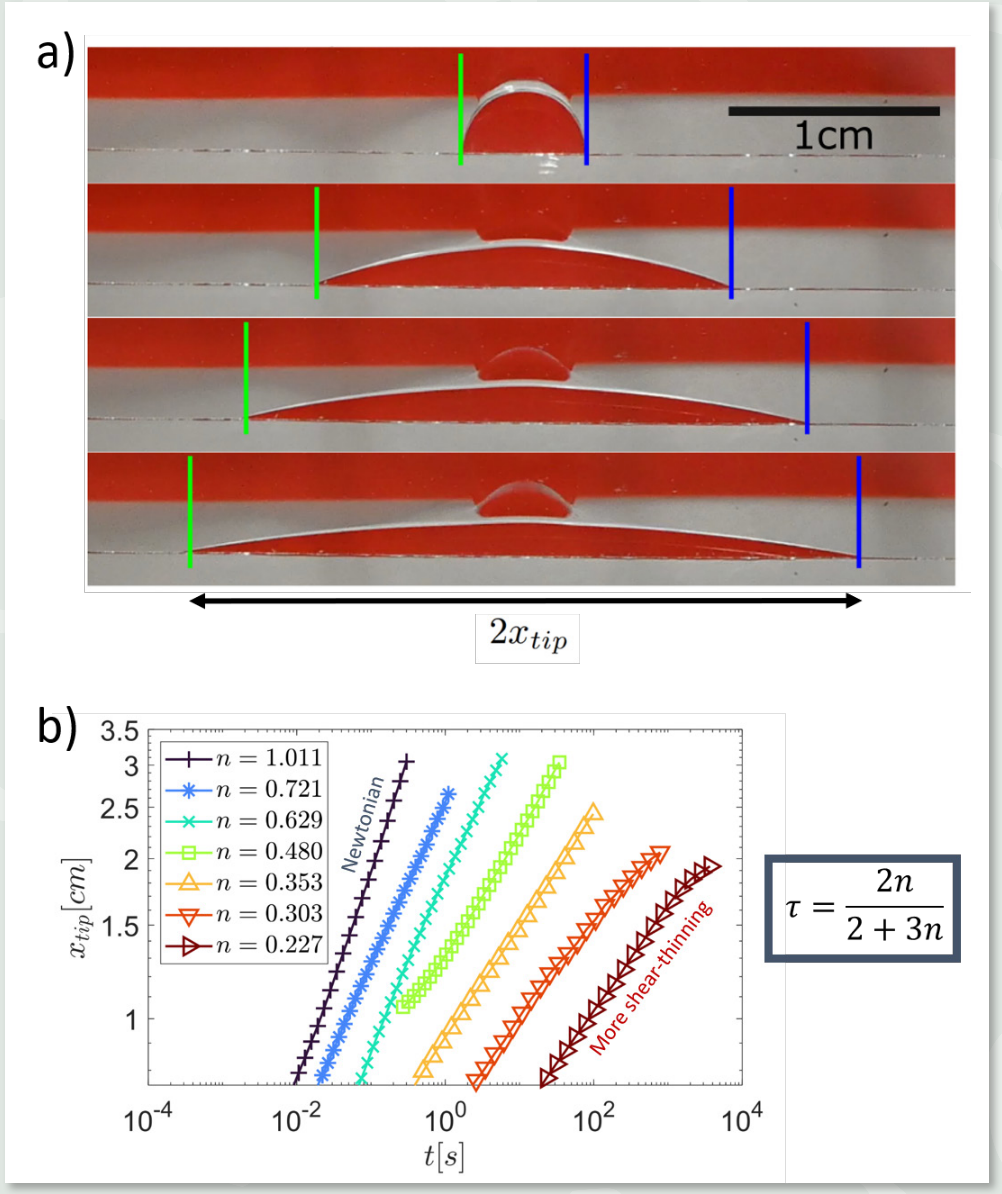


Figure 1:
a) *Snapshots illustrating the evolution of a highly wetting silicone oil droplet spreading in a corner formed by two glass slides arranged in a V-shape. The time interval between the top and bottom snapshots is Δt=10s.* ***b)*** *Spreading dynamics for various fluids with differing rheological properties, ranging from a Newtonian fluid (leftmost) to a strongly shear-thinning fluid (rightmost). The equation on the right highlights the relationship between the rheological exponent n and the diffusion exponent τ derived from the observed dynamics*

INTERFACE INSTABILITY OF TWO-PHASE FLOW IN A THREE-DIMENSIONAL POROUS MEDIUM

Joachim Falck Brodin[1], Kevin Pierce[1], Paula Reis[1], Per Arne Rikvold[1,3], Marcel Moura[1], Mihailo Jankov[1], and Knut Jørgen Måløy[1,2]

[1] PoreLab, The NJORD Centre, Department of Physics, University of Oslo, Oslo, Norway.
[2] PoreLab, Department of Geosciences, Norwegian University of Science and Technology, Trondheim, Norway.
[3] Department of Physics, Florida State University, Tallahassee, USA

We present an experimental study on how two immiscible fluids move through a 3D porous material made of randomly packed, uniform glass spheres. Using refractive-index matching and laser-induced fluorescence imaging, we were able to capture time-resolved, detailed images of how the fluid interface moves and changes stability as a dense, viscous fluid (glycerol) is injected into a less dense, less viscous one (rapeseed oil) from above. We varied the injection rate to investigate how the balance of gravitational and viscous forces affected interface patterns that range from unstable, finger-like structures at low rates to stable, sheet-like fronts at high flow rates.

In addition to the imaging, we tracked the pressure difference across the flow cell over time. By analyzing the 3D images and pressure data, we developed a theoretical criterion to predict the stability of the fluid interface. This criterion incorporates the Darcy permeability for each phase and the rate of pressure change over time. We also found that the relative permeability of the invading fluids changes with the flow rate, affecting how the two fluids interact.

We observed that local areas of crystalline order within the bead pack influence the stability of the invading fluid front. This study sheds light on how different types of disorder in porous materials interact with viscous, capillary, and gravitational forces to shape the behavior and stability of fluid interfaces.

ACKNOWLEDGEMENTS

We would like to thank Eirik Grude Flekkøy, Renaud Toussaint, Gloria Buendía, Salvatore Torquato, and Paul Meakin for useful discussions. We gratefully acknowledge support from the University of Oslo and from the Research Council of Norway, through projects 262644 (PoreLab), 325819 (M4), and 324555 (FlowConn).

RECOMMENDED READING

[1] Brodin, Joachim Falck, Kevin Pierce, Paula Reis, Per Arne Rikvold, Marcel Moura, Mihailo Jankov, and Knut Jørgen Måløy. "Interface instability of two-phase flow in a three-dimensional porous medium." *arXiv preprint arXiv:2412.10127* (2024).

[2] Brodin, Joachim Falck, Per Arne Rikvold, Marcel Moura, Renaud Toussaint, and Knut Jørgen Måløy. "Competing gravitational and viscous effects in 3d two-phase flow investigated with a table-top optical scanner." *Frontiers in Physics* 10 (2022): 936915.

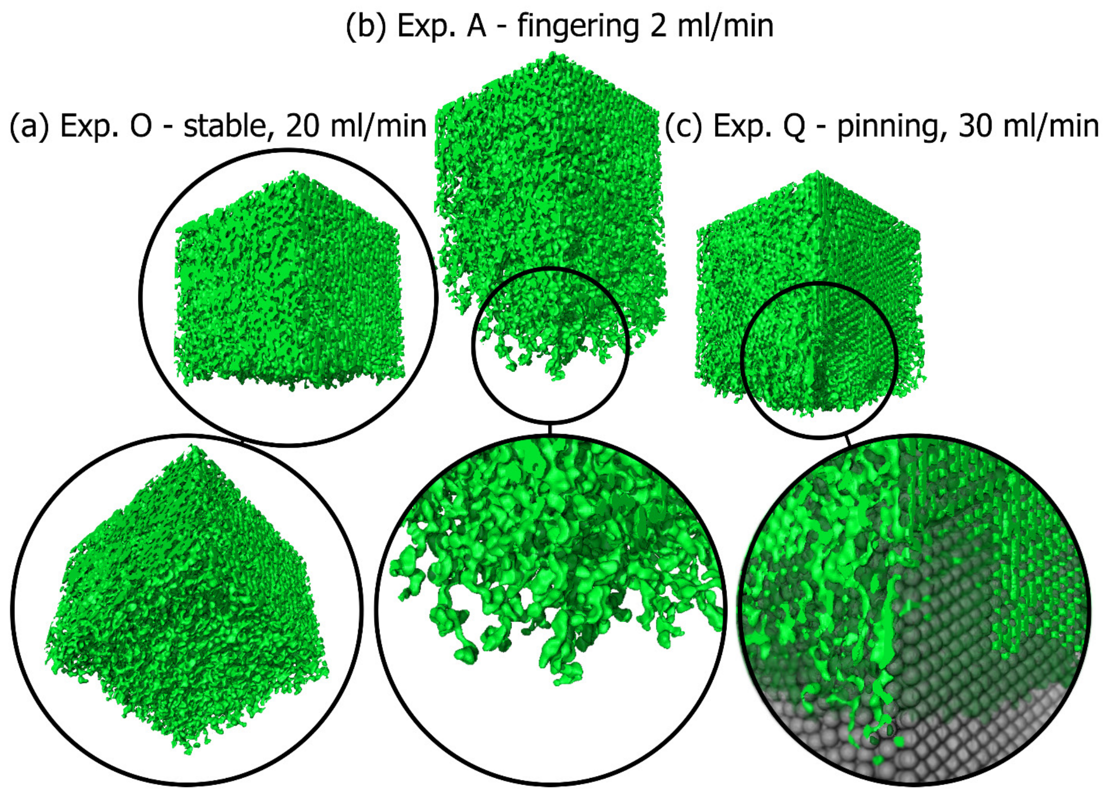


Figure: *The three distinct modes of interface motion seen as the flow rate is changed from low (Exp. A, 2 ml/min: unstable fingering) to high (Exp. O, 20 ml/min: stable, sheet-like front), and to instability due to pinning behind the front by locally crystalline structures in the porous medium (Exp. Q, 30 ml/min). From arXiv.2412.10127, Copyright by the authors, CC BY 4.0.*

RESEARCH PROJECTS

GRAVITY STABILIZED DRAINAGE IN POROUS MEDIA WITH CONTROLLED DISORDER

Khobaib Khobaib[1], Paula Reis[1], Marcel Moura[1], Renaud Toussaint[1,2], Eirik Grude Flekkøy[1], and Knut Jørgen Måløy[1]

[1] PoreLab, The Njord Centre, Department of Physics, University of Oslo, Oslo, Norway
[2] University of Strasbourg, France

Liquids can flow through connected pores in rocks, soil, concrete, and sponges. Understanding of liquid flow in such porous medium is important for many natural and commercial processes, such as groundwater filtration and oil recovery. The shape, size, and arrangement of these pores are critical factors that influence fluid flow, mechanical properties, and overall system performance. Capillary pressure, permeability, and flow efficiency are directly affected by pore disorder.

In this research, we present a theoretical, experimental, and numerical analysis of the influence of pore disorder on invasion patterns (see Fig. 1 & Fig. 2) during slow drainage in a porous medium. The study involved conducting experiments on 3D printed porous models including varying degrees of pore disorder and model was produced using the Formlabs 3D printer.

By controlling the varied levels of disorder, ranging from the least to the most disordered pore we explored how the invasion front width, maximum trapped cluster length, and non-wetting phase saturation are influenced. Both experiments and simulations demonstrate that the invasion front, trapped cluster and residual fluid remaining behind the fluid front, is predominantly governed by the dimensionless fluctuation number ***F***, which exhibits an inverse relationship with the pore disorder parameter ***ε***. Previous studies [1, 2] have explored fluctuation number F in relation to variations in viscous and gravitational forces, as well as systematic gradients in pore geometry.

Our findings give a better understanding of fluid drainage in porous media and describe why fluid behavior varies among different materials. By defining scaling laws and evaluating pore-scale disorder, we present a framework for predicting and managing multiphase flow. These insights have practical applications in industries like oil and gas, where they can help optimize extraction methods and reduce inefficiencies caused by pore-related liquid trapping. In water filtration, they can guide the design of more efficient filter structures. This study advances the understanding of liquid flow in disordered porous media, ultimately improving the design and performance of systems reliant on porous materials.

RECOMMENDED READING

[1] K. J. Måløy, M. Moura, A. Hansen, E. G. Flekkoy, and R. Toussaint, Burst dynamics, upscaling and dissipation of slow drainage in porous media, *Frontiers in Physics* 9,10.3389/fphy.2021.796019 (2021).

[2] T. Vincent-Dospital, M. Moura, R. Toussaint, and K. J. Måløy, Stable and unstable capillary fingering in porous media with a gradient in grain size, *Communications physics* 10.1038/s42005-022-01072-1 (2022).

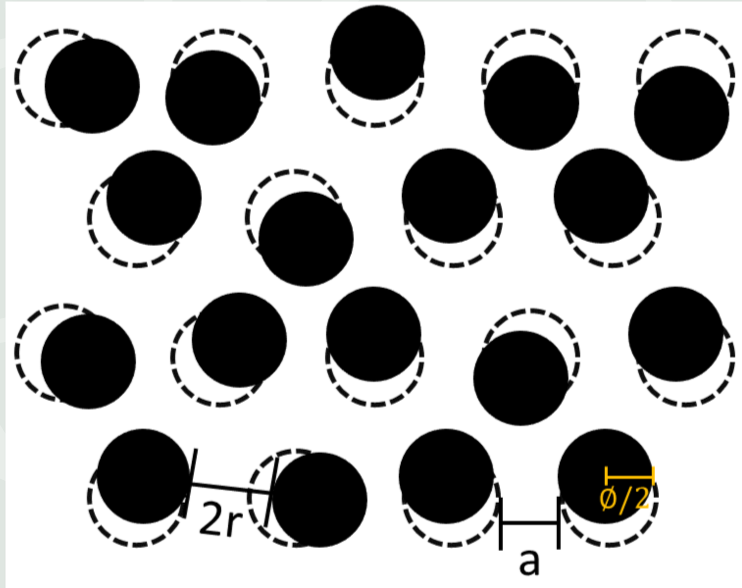


Figure 1: *A drawing of pore-scale disorder in a 3D-printed model, where r is the pore throat radius, ø is the cylinder diameter, and a is the separation at zero disorder. Dashed circles show cylinder positions at zero disorder, and solid circles indicate positions with disorder.*

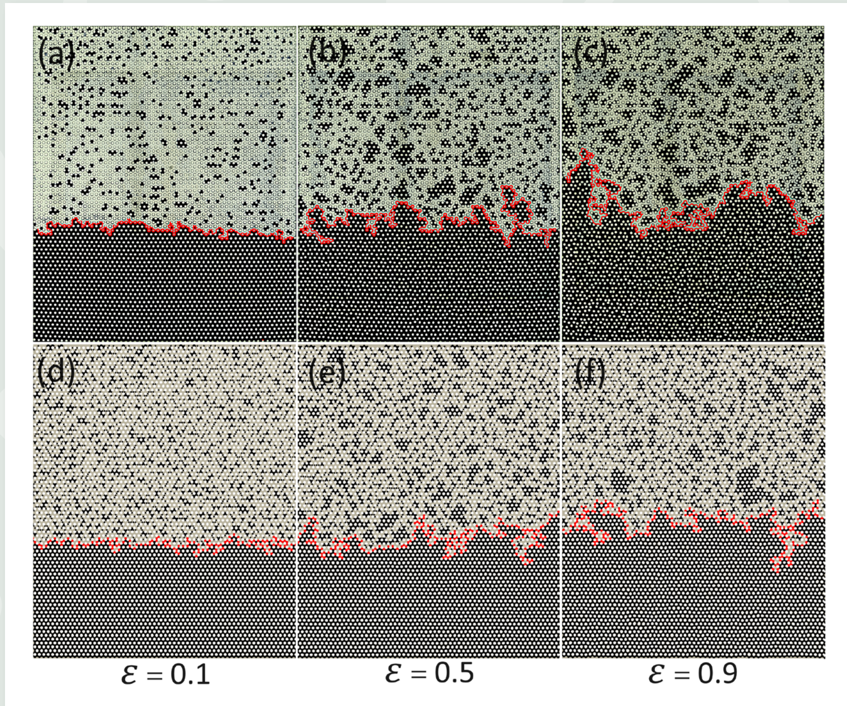


Figure: *(a-c) show experimental images for disorder levels ε = 0.1, 0.5, and 0.9, and (d-f) show simulated images. Black represents the wetting phase, light color the non-wetting phase, and the red line marks the drainage front.*

RESOLVING PORE-SCALE CONCENTRATION GRADIENTS FOR TRANSVERSE MIXING AND REACTION IN POROUS MEDIA

Paiman Shafabakhsh[1], Tanguy Le Borgne[1,2], François Renard[1,3], Gaute Linga[1,4,5]

[1] The Njord Centre, Departments of Geosciences and Physics, University of Oslo, Oslo, Norway
[2] Geosciences Rennes, University of Rennes, Rennes, France
[3] ISTerre, University Grenoble Alpes, University Savoie Mont Blanc, University Gustave Eiffel, CNRS, IRD, Grenoble, France
[4] PoreLab, The Njord Centre, Department of Physics, University of Oslo, Oslo, Norway
[5] PoreLab, Department of Physics, Norwegian University of Science and Technology, Trondheim, Norway

Understanding how fluids mix and react within porous materials, such as soils, rocks, and industrial filters, is critical to solving environmental and engineering challenges. Processes like groundwater cleanup, carbon storage, and oil recovery all depend on chemical reactions that are limited by the mixing of fluids at the pore scale. However, capturing the chaotic and uneven nature of these processes in three-dimensional porous environments is a complex challenge. Traditional models often fail to account for pore-scale concentration gradients, leading to inaccurate predictions of reaction rates. In this study, we developed a numerical framework using a stabilized finite-element method to capture concentration gradients and mixing dynamics in 3D porous geometries (Workflow is shown in Figure 1). The adaptive mesh refinement strategy further enhances the model's efficiency by focusing computational power on areas with sharp concentration gradients, where the most significant mixing and reactions occur. By solving the steady-state advection-diffusion equation for scalar transport and assuming instantaneous chemical reactions, the method predicts the spatial distribution of reactants and products with high precision. The study validates the framework against analytical solutions for simple flow cases, showing excellent agreement. It then extends the methodology to more complex systems, such as chaotic flow in the bead pack (Figure 2) and natural sandstone samples. The results demonstrate the ability to accurately simulate transverse mixing and mixing-limited reactions, highlighting the influence of chaotic pore-scale flow on concentration gradients and localized reaction zones. By capturing chaotic mixing and its impact on reactions, the methodology opens new possibilities for advancing our understanding of fluid mixing and reactive transport in complex systems.

RECOMMENDED READING

[1] Paiman Shafabakhsh, Tanguy Le Borgne, François Renard, Gaute Linga: Resolving pore-scale concentration gradients for transverse mixing and reaction in porous media, *Advances in Water Resources*, Volume 192, October 2024, 104791

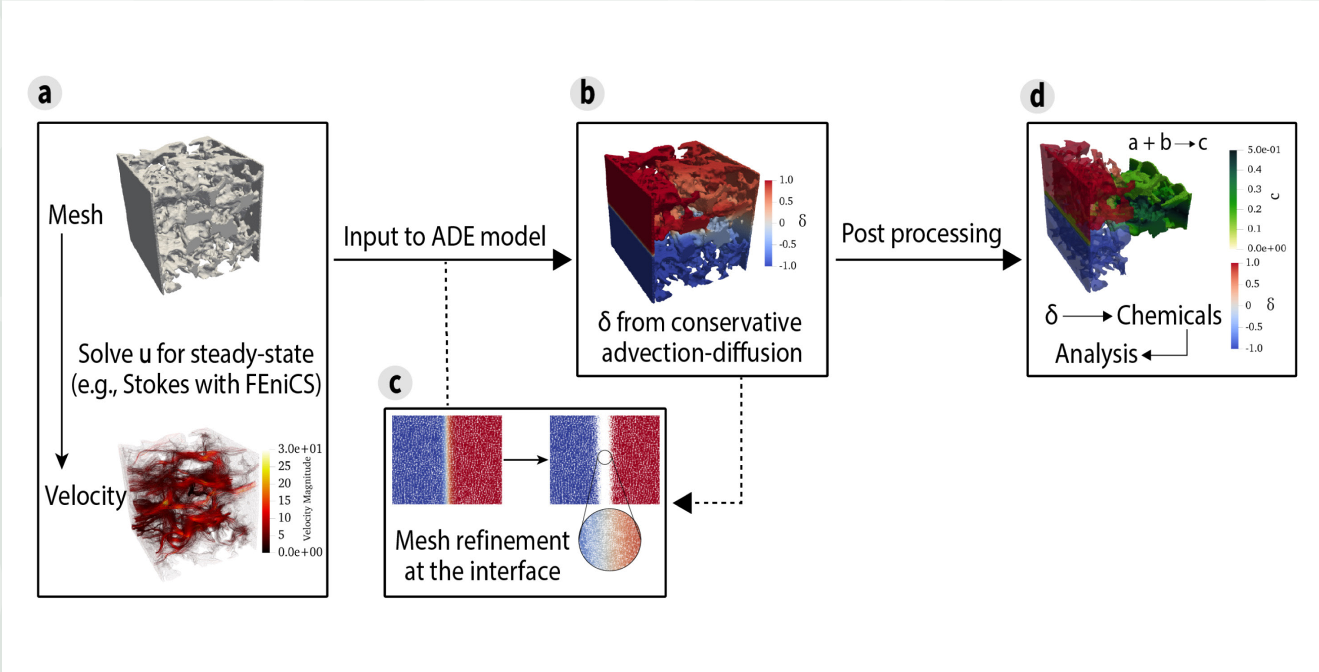


Figure: *Workflow for simulating mixing and reactions in porous media:* ***(a)*** *Begin with a computational mesh and steady velocity field.* ***(b)*** *Solve the advection–diffusion equation to calculate the concentration field.* ***(c)*** *Refine the mesh in key mixing zones if needed, then repeat the calculation.* ***(d)*** *Finally, analyze the distribution of chemical species using post-processing.*

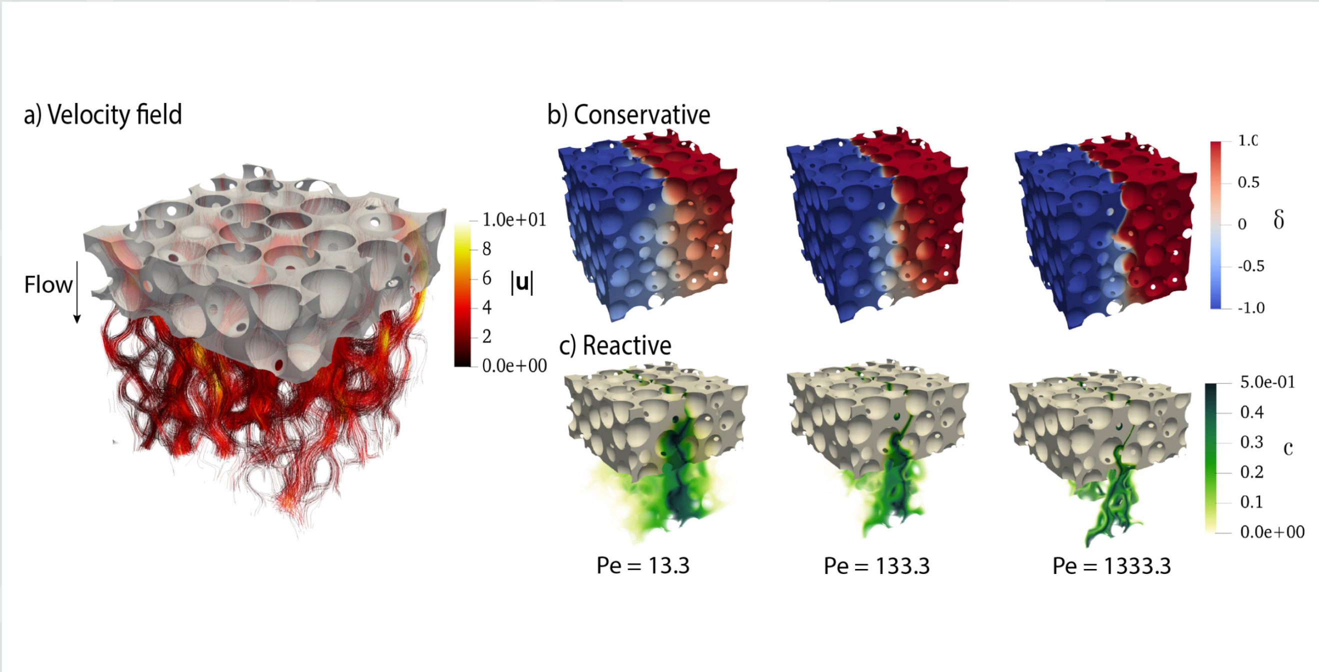


Figure: ***(a)*** *Steady-state velocity field in a bead pack computed using the Stokes equations.* ***(b)*** *Distribution of conserved species δ within the bead pack based on the velocity field.* ***(c)*** *The concentration of product C from a first-order bimolecular reaction, calculated using the distribution of δ.*

EFFECT OF A CONFINING SURFACE ON THE HYDRODYNAMIC INTERACTIONS BETWEEN COLLOIDS

Erika Eiser[1], Grace (Xiaoying) Tang[2]

[1] PoreLab, Department of Chemistry, Norwegian University of Science and Technology, NTNU, Trondheim, Norway
[2] Cavendish Laboratory, University of Cambridge, UK

In the seminal paper on free diffusion of thermally driven particles, suspended in a liquid, Einstein derived the famous Stokes-Einstein equation that relates their diffusive motion to their size and their friction with the solvent (viscosity) [1]. The beauty of the result is the fact that the free diffusion of such a Brownian particle is completely independent of the material it is made of. Hence, it applies to the diffusion of red blood cells in water, latex particles in water-based paints or the fat droplets in milk. There are many examples.

However, near a surface colloidal particle will experience different friction than in bulk, simply because the hydrodynamic flow set up by the thermal motion of the particles will no longer be symmetric. In other words, the friction coefficient $y = 6\pi\eta a$ of a sphere with radius a, immersed in a fluid with viscosity η, will increase monotonically near a solid wall (Figure A). The effect has been studied and is known as Faxén's corrections [2]. Recently, the Eiser group has discovered that when trapping DNA-tethered particles with optical tweezers near a liquid-liquid interface additional hydrodynamic effects are observed [3]. Although the particles studied were dielectric, they still heated up weakly, thereby causing a thermal gradient in the vicinity of the particle. This thermal gradient sets up a strong convective flow around it (Figure D) that gives rise to a lateral hydrodynamic force that can be described like an electrostatic potential. This very long-ranged, lateral force drives other particles that are tethered to the liquid-liquid interface but free to diffuse along it, towards the trapped particle forming an out-of-equilibrium 2D crystal.

The temperature increase of the trapped particle depends on the intensity of the trapping laser. Dr. Xiaoying (Grace) Tang has investigated the strength of this lateral hydrodynamic force using single and dual optical tweezers at the Cavendish Laboratory, University of Cambridge and at PoreLab, NTNU, respectively. In particular, she measured the cross correlations of the thermal fluctuations of two trapped particles held near a solid surface as function of separation between them and their height above said surface (Figure B). In addition, we collaborate with Prof. Chantal Valeriani and Dr. C. Miguel Barriuso Gutierrez (University of Madrid, Spain) on exploring the short-term interactions between such trapped particles using Brownian Dynamics Simulations. The results have been summarized in the PhD thesis of Dr. Tang [4].

RECOMMENDED READING

[1] A. Einstein, *Annalen der Physik* iv, 289 (1906) & A. Einstein, *Annalen der Physik* iv, 591 (1911)

[2] H. Faxe'n, *Annalen der Physik*, vol. 373, no. 10, 89-119 (1922)

[3] A. Caciagli, R. Singh, D. Joshi, R. Adhikari, E. Eiser, *Physical Review Letters* 125, 068001 (2020)

[4] PhD thesis of Dr. Xiaoying Tang 'Effect of Heating on the Thermal Fluctuations of Trapped Colloids Near a Surface', University of Cambridge

[5] R. Singh and R. Adhikari, *European Journal of Computational Mechanics*, 26, 78-97, (2017)

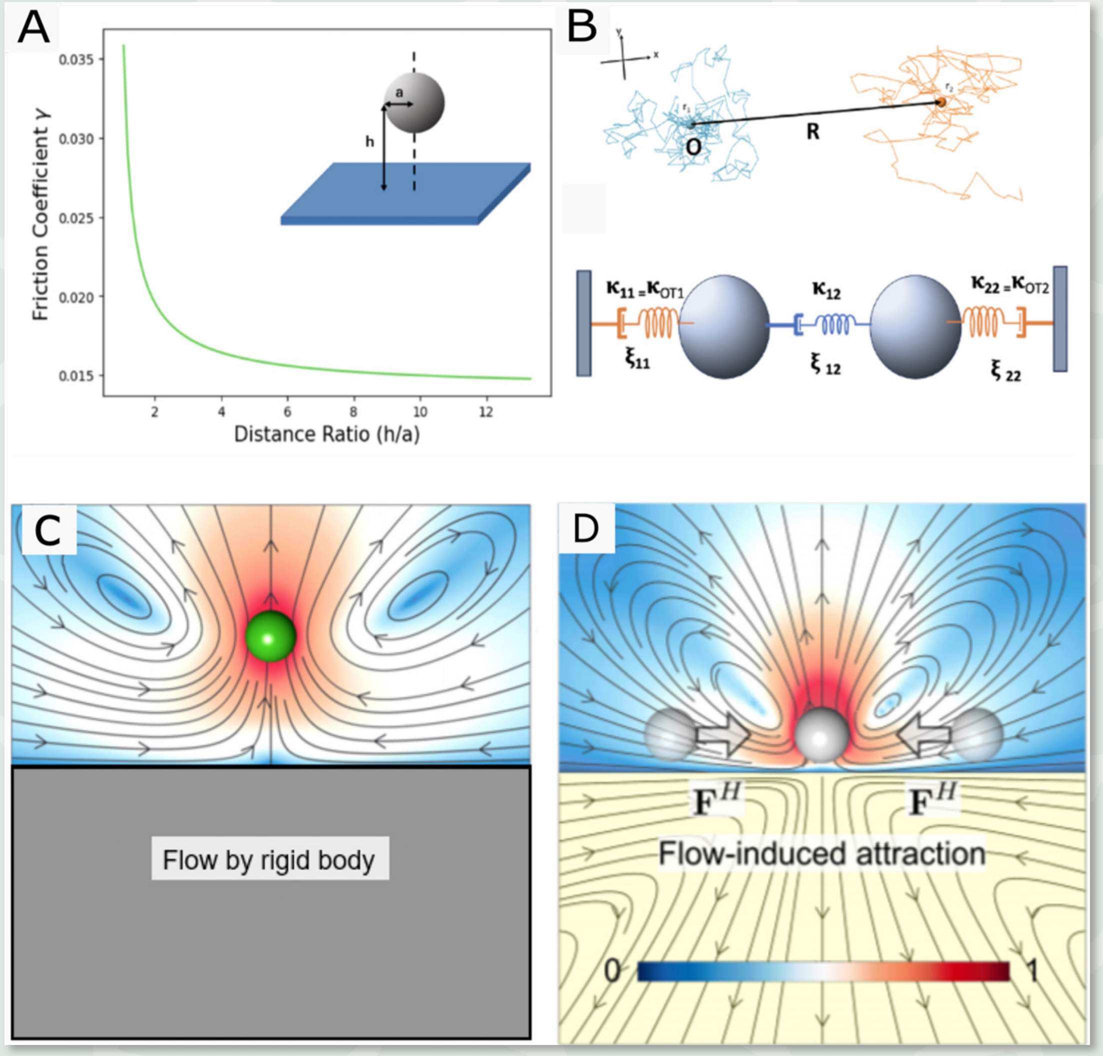


Figure:* *(A) *Friction coefficient a colloidal sample experiences near a confining wall.* ***(B)*** *Real trajectories of two trapped colloidal particles separated by a distance R, showing their thermal motion. These can be modelled with a bead spring model.* ***(C)*** *Typical flow lines computed by Dr. Rajesh Sing for a colloid trapped with optical tweezers above a solid surface [5]* ***(D)*** *Computed flow lines that develop when a colloid is trapped via a DNA tether to a liquid-liquid interface [3]. The lower, yellow half represents the oil phase. The scalebar from 0 to 1 expresses the temperature gradient in the aqueous phase, and F^H is the hydrodynamic attraction.*

TIME RESOLVED X-RAY NANOSCOPY TO EXPLORE PRECIPITATION MECHANISMS OF CALCIUM CARBONATE

Daniyal Younas[1], Joe Stickland[1], Kristian A. Oksavik[1], Mukul Jaiswal[1], Jessica A. Zeman[1], Chayene G. Anchieta[1], Seniz Ucar[2], Yuriy Chushkin[3], Dag W. Breiby[1,4] and Basab Chattopadhyay[1]

[1] Department of Physics, NTNU, Trondheim
[2] Department of Metallurgical and Materials Engineering, Middle East Technical University, Turkiye
[3] The European Synchrotron ESRF, Grenoble, France
[4] Department of Microsystems, University of South-Eastern Norway, Horten

Precipitation of solid from a liquid is an important phenomenon in several research fields, including physics, material science, chemistry, biology and engineering. The phase transformation from liquid to solid can be understood in terms of the classical nucleation theory where the transition occurs via a single step. Two step or multistep processes have also been proposed and experimentally observed. However, the fundamental mechanism of this process is still debated and presents open scientific problems to researchers in statistical as well as condensed matter physics.

In this context, the X-ray Physics Group at NTNU has made efforts to develop a 3-dimensional imaging methodology based on Coherent X-ray diffraction Imaging (CXDI) to enable the study of nucleation and growth of model systems relevant to materials and geosciences. In our case we have investigated the structure and morphology of calcium carbonate ($CaCO_3$) particles as they were precipitated from solution. $CaCO_3$ is one of the most common biominerals, and it can exist in three different anhydrous polymorphic forms: vaterite, aragonite and calcite, besides an amorphous state.

CXDI is a lensless 3D imaging technique that can image microscopic objects at high resolution better than 10 nm under ideal conditions. In CXDI the 3D object is numerically recovered from the far-field diffraction pattern. CXDI is better suited to studying internal structures and surface morphologies than e.g. electron microscopy which requires destructive sectioning of the sample. Being a lensless methodology, the images produced from CXDI are aberration–free and do not require the use of complex optical elements. In CXDI, the "phase problem" of crystallography is solved by iterative phase retrieval algorithms that rely on the use of coherent X-rays and oversampling of the diffraction pattern. The phase retrieval algorithm works by alternating between real and reciprocal space with constraints applied in both regimes at each step in the iteration. The recorded object is essentially obtained by inverse Fourier transform of the diffraction patterns.

A central research theme in the X-ray Physics Group is to develop and apply computational imaging methodologies where the computer can enhance the imaging process and facilitate multimodal and dynamic imaging. CXDI is a representative method within computational imaging; here the 3D object in real space is numerically recovered from the field diffraction patterns. A complementary 2D detector is used to capture the Bragg diffraction signal of the samples, hence also giving access to the crystal structure of the particles.

Here, we present recent results on the use of CXDI to image the evolution of the morphology and structure of $CaCO_3$ particles as they were precipitated from solution. The first results are shown in Figure 1(i) where time resolved 2D CXDI was demonstrated. It allowed us to visualize the gradual growth of a seed vaterite particle with a bespoke sample cell where the precursor reactants were mixed during the experiment. The reconstructed electron density maps (pixel size of 28 nm) are shown in Figure 1(ii) where the systematic increase in the particle diameter is evident; the colour variation results from the porous internal structure of the imaged vaterite particle. The growth of the particle estimated from the reconstructed data in Figure 1(ii) and the raw data showed an increase in diameter from 4.4 μm to 6.3 μm (corresponding to a volume increase by a factor 3) over 270 s.

The second set of results is shown in Figure 2 where time-resolved small-angle X-ray scattering was performed to observe the formation of $CaCO_3$ from supersaturated solutions, starting from the first few milliseconds of the reaction. The experiment was performed with different salt (NaCl) concentrations, and we were able to follow the nucleation and subsequent early growth process. In Figure 2(i), the average size evolution of the precipitated $CaCO_3$ particles is shown. Here we observe the growth until 10 seconds of reaction time, after which the spherical particles form amorphous agglomerates and eventually transform to crystalline $CaCO_3$. Figure 2(ii) shows the 3D structure of amorphous agglomerated $CaCO_3$ particles and Figure 2(iii) shows the porous internal and external structure of the crystalline vaterite particle after 300 seconds of reaction time. The reconstructed images have ~10 nm voxel size. Complementary Bragg diffraction performed during the experiments helped us to identify the solid-state polymorphic forms of the precipitated particles.

The methods and results (yet to be published) presented here allowed us to investigate the crystallisation pathway from nucleation to crystal with $CaCO_3$ as a model system and provide the possibility of performing liquid phase and dynamic nanoscale analyses with CXDI. We look forward to utilizing this methodology to study other scientific problems, e.g. salt precipitation during CCS and electrode structure evolution during battery cycling.

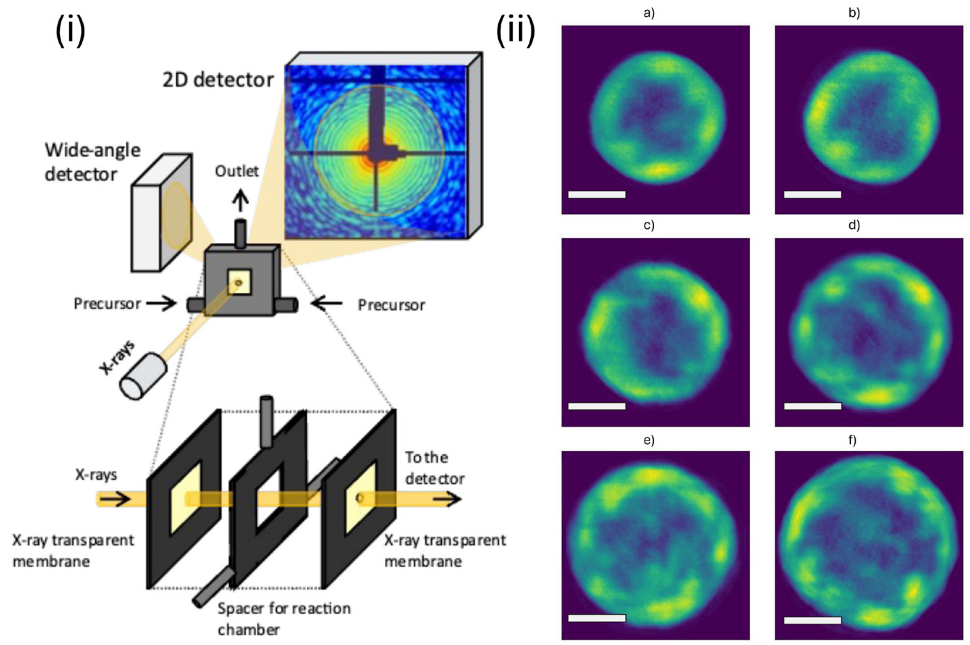


Figure 1: *(i) Experimental setup of the 4D CXDI measurement at the ID10 beamline at ESRF, and (ii) Reconstructed images from 2D CXDI data showing a gradual increase in the size of a vaterite seed at times (a) 0s, (b) 60, (c) 90, (d) 120, (e) 180 and (f) 240 s. Scale bar in (ii) is 2 μm.*

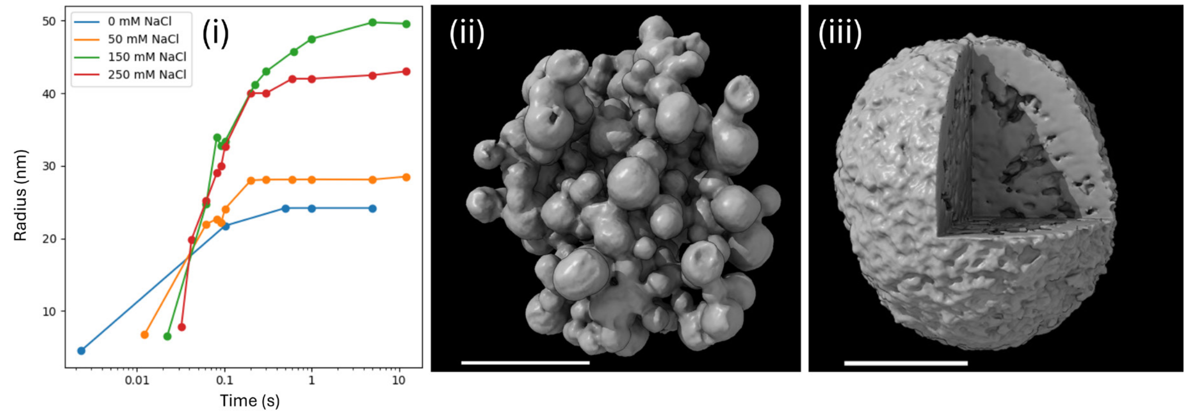


Figure 2: *(i) Evolution of average radius with time as $CaCO_3$ particles precipitate in solutions with different concentrations of NaCl; 3D reconstructed image from CXDI of (ii) agglomerated amorphous $CaCO_3$ particles and (iii) porous crystalline vaterite form of $CaCO_3$ having formed after 300 seconds of reaction. Scalebars in (ii) and (iii) are 1 μm.*

ACKNOWLEDGEMENTS

The authors thank M. Cammarata, F. Zontone, T. Narayanan, R. Lund and L. Mathews for help with the experiments and valuable discussions. ESRF – The European Synchrotron is acknowledged for beamtime provisions. This research was financed by the Research Council of Norway through its FRINATEK (#303252, ICONIC) programme.

RECOMMENDED READING

[1] *Nature* (2025) 637, 281–295
[2] *J. Synchrotron Rad.* (2018) 25, 1162–1171
[3] *Cryst. Growth Des.* (2017) 17, 4183–4188
[4] *J. Appl. Cryst.* (2020) 53, 1562–1569
[5] *Nature Comm.* (2019) 10, 751
[6] *J. Appl. Cryst.* (2023) 56, 1114–1124

HOW BIG IS A MOLECULE? EXTENDING KINETIC THEORY FOR PREDICTION OF TRANSPORT PROPERTIES TO THE LIQUID PHASE

Vegard G. Jervell and Øivind Wilhelmsen

PoreLab, Department of Chemistry, Norwegian University of Science and Technology, NTNU, Trondheim, Norway

The atoms and molecules that make up the world around us can be described in many ways: At a large scale, molecules like proteins can be well described in terms of large structures such as beta-sheets and alpha-helixes. At the quantum level, molecules are described by a wavefunction and the boundary between one atom or molecule and another becomes blurred. Between these two extremes, we can describe molecules as particles interacting through a pair potential, which describes the forces acting from one molecule on another.

The description of molecules as distinct particles interacting through a pair potential is particularly useful when developing thermophysical models for the properties of a fluid. Specifically, transport properties such as the viscosity or thermal conductivity of pure fluids and mixtures are important parameters to determine in industrial applications ranging from CO_2-capture and hydrogen storage to reservoir modelling and drying processes.

In the case of low-pressure gases, classical Chapman-Enskog theory (CET) is a well-established tool for prediction of transport properties. For gases at experimentally challenging conditions, such as hydrogen below 30K, predictions from CET have been deemed more reliable than experimental values. However, CET is not applicable to liquids, or even moderately pressurized gases.

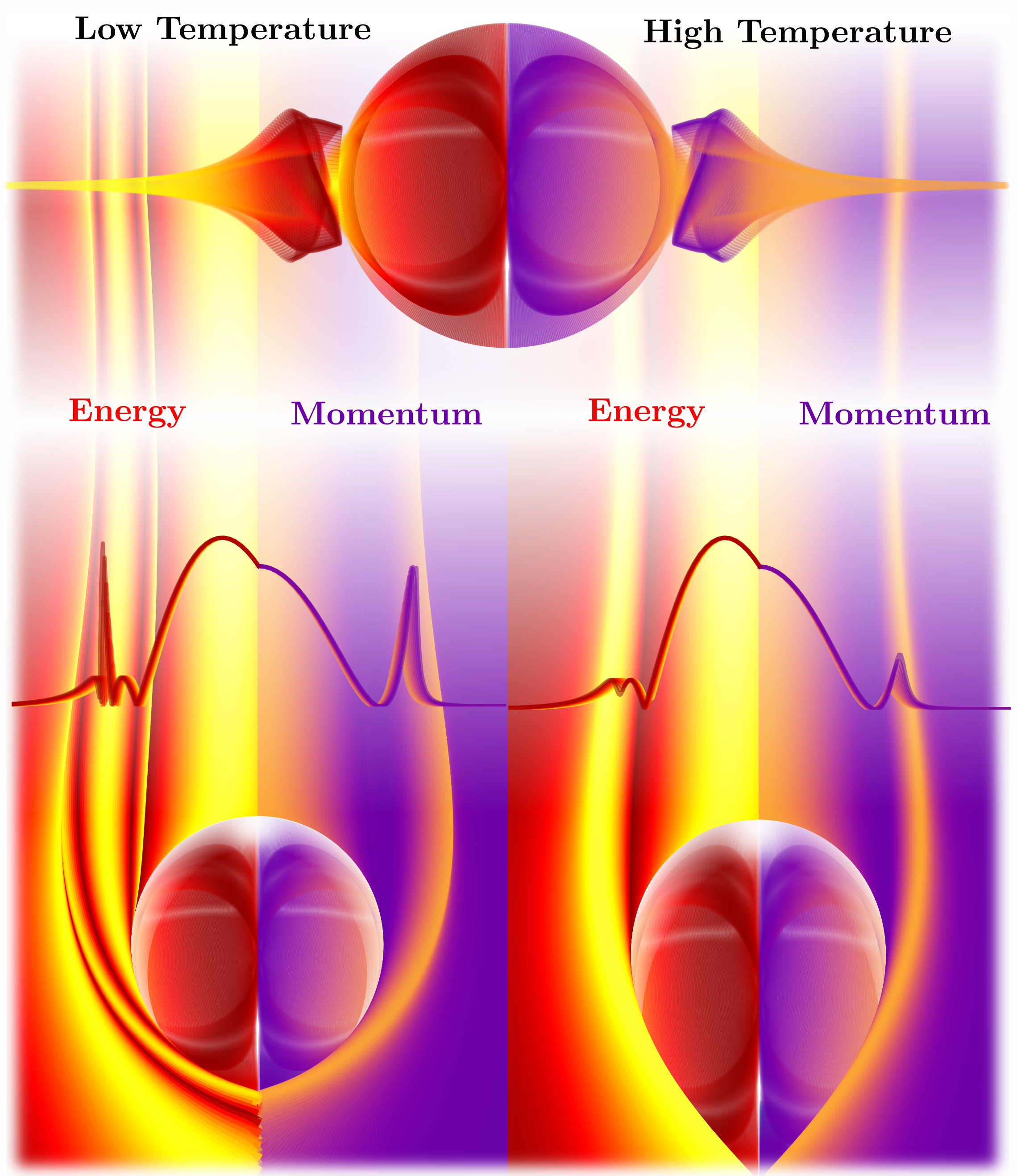
Several attempts at developing models capable of predicting the transport properties of liquids have been based on an extension of classical Chapman-Enskog theory termed Revised Enskog theory (RET). A key parameter that must be determined in order to apply these RET-based models is a value describing the size of the fluid molecules, often referred to as a "core volume" or "molecular diameter". This "molecular size parameter" typically varies with temperature, and we find that previously published models are completely reliant on determining an accurate value for this parameter at any given temperature, and that they rely on fitting to experimental transport property data to do so.

In this work, we have recognized that the "molecular size parameter" is intimately linked to the exchange of momentum and energy between colliding molecules, and we have introduced the concept of "transfer lengths" which describe how far momentum and energy are transferred from one molecule to the next in a collision. From this description, we have developed a model for predicting the transfer lengths of a molecule from its interaction potential. Combining this transfer length model with Revised Enskog theory has allowed us to predict the viscosity and thermal conductivity of several fluids from the dilute gas state up to liquid-phase densities. For argon, the predicted thermal conductivity is within 5% of reference correlations up to a density of 1600 kg m^{-3} at temperatures above 600 K.

Prediction of transport properties in liquids has remained an unresolved challenge for over a century. In this work, we have found that the key to predicting liquid-phase transport properties may lie in answering the question "How big is a molecule?". Further, we have found that the answer to this question may have different answers depending on what properties of the fluid you are aiming to describe. Finally, we have introduced the concept of "transfer lengths", which can be interpreted as descriptions of the molecular size, and developed a model for predicting the transfer lengths of a molecule interacting through a given pair potential.

RECOMMENDED READING

[1] Vegard G. Jervell and Øivind Wilhelmsen: Predicting viscosities and thermal conductivities from dilute gas to dense liquid: Deriving fundamental transfer lengths for momentum and energy exchange in revised Enskog theory, *J. Chem. Phys.* 161 (2024)



RESEARCH PROJECTS

COLOR-GRADIENT-BASED PHASE-FIELD EQUATION FOR MULTIPHASE FLOW

Reza Haghani[1], Hamidreza Erfani[2], James E. McClure[3], Eirik Grude Flekkøy[4], and Carl Fredrik Berg[1]

[1] PoreLab, Department of Geosciences, Norwegian University of Science and Technology, NTNU, Trondheim, Norway
[2] Equinor, Trondheim, Norway
[2] Department of Physics, Center for Soft Matter and Biological Physics, Virginia Tech National Security Institute, USA
[2] PoreLab, Department of Physics, University of Oslo, Oslo, Norway

Multiphase phenomena are prevalent in both natural and industrial processes, such as multiphase flow within porous media during hydrocarbon recovery, CO_2 sequestration, and rainwater infiltration. Due to the complexity of these phenomena, experimental studies are often limited, which has driven the development of numerical methods. Among these, the lattice Boltzmann method (LBM) has been extensively developed and applied, particularly in porous media.

The color-gradient (CG) method, a multiphase method of the LBM, has demonstrated superior performance in porous media compared to other methods, primarily due to its ability to accurately capture small ganglia. However, the CG method was originally designed for density-matched fluids, and numerous modifications have been proposed to adapt it for density-contrast fluids.

In this study [1], for the first time, the fundamental limitation of the original CG method for density-matched fluids is investigated. This is achieved by non-dimensionalizing the density field through the introduction of two phase-field variables, which leads to the derivation of the macroscopic equations. It is shown that the original CG method lacks fluid invariance, and although it conserves the total mass of the system, it exhibits a compressibility-like behavior for density-contrast fluids. To address this issue, the density field is computed from the two phase-field variables, leading to the formulation of what we term the color-gradient-based phase-field equations [2]. A lattice Boltzmann solver is subsequently developed to solve these equations, with the density field calculated using linear interpolation of the phase fields. This approach effectively resolves the limitations of the original CG method, enabling its application to density-contrast fluids in porous media.

Two sets of benchmarks are employed to validate the developed equations. The first set focuses solely on the interface-capturing equations, while the second set incorporates the hydrodynamic equations, which are solved using an existing robust lattice Boltzmann (LB) model. The first set of benchmarks includes tests such as diagonal translation, the rotation of Zalesak's disk, and the deformation of circular interfaces. Figure 1 illustrates the deformation of a circular interface within a predefined velocity field. The analytical solution is represented by the black dashed line, which is closely matched by the results of the present model (solid blue line) and compared with the Allen-Cahn model (solid red line) [3].

The second set of benchmarks includes the Laplace test, high-density Rayleigh-Taylor instability, and droplet splashing on thin films. These tests demonstrate that the proposed model delivers accurate solutions for density and viscosity ratios up to 1000 and remains robust in high Reynolds number (Re) flows. Figure 2 compares the interfaces captured by the original CG method (upper frame) and the proposed method (lower frame) for three density ratios: $\rho^*=0.5$ (left frame), $\rho^*=1.0$ (middle frame), and $\rho^*=2.0$ (right frame). Unlike the original CG method, which struggles to accurately capture the interface at varying density ratios, the proposed method performs consistently well across all tested densities, showcasing its improved accuracy and robustness.

The Rayleigh-Taylor Instability at high density ratios and high Reynolds numbers has historically been a challenging problem. Figure 3 presents snapshots of an RTI system with a density ratio of $\rho^*=1000$ and a Reynolds number of $Re=3000$. These results highlight the capability of the proposed model to accurately simulate such complex systems, demonstrating its robustness and effectiveness in handling extreme density and Reynolds number conditions.

In summary, the original color-gradient (CG) method lacks fluid invariance, limiting its applicability to systems with high density and viscosity contrasts. By reformulating the original equations as a phase-field method and developing a corresponding lattice Boltzmann (LB) solver, a robust and accurate method has been established. This new approach effectively handles high density and viscosity ratios, addressing the limitations of the original CG method and broadening its applicability in complex multiphase flow systems.

RECOMMENDED READING

[1] Haghani, R., Erfani, H., McClure, J.E., Flekkøy, E.G. and Berg, C.F., 2024. Color-gradient-based phase-field equation for multiphase flow. *Physical Review E*, 109(3), p.035301.

[2] Haghani, R., Erfani, H., McClure, J.E. and Berg, C.F., 2023. A note on the summation relation in phase-field equations. *Physics of Fluids*, 35(9).

[3] Fakhari, A., Mitchell, T., Leonardi, C. and Bolster, D., 2017. Improved locality of the phase-field lattice-Boltzmann model for immiscible fluids at high density ratios. *Physical Review E*, 96(5), p.053301.

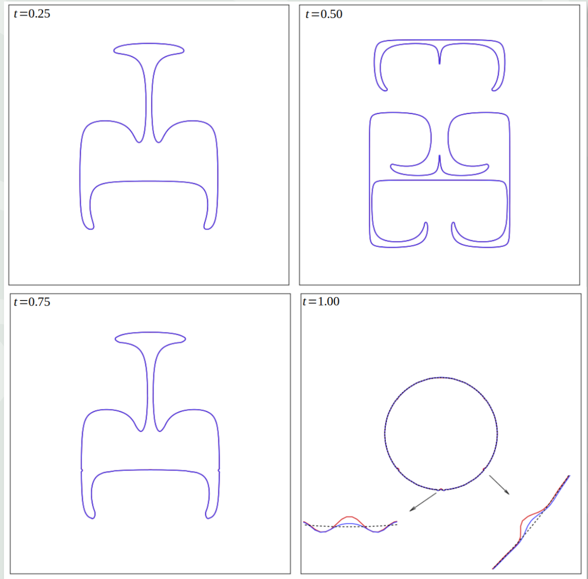


Figure 1: *Snapshots of the interface location at various dimensionless times*

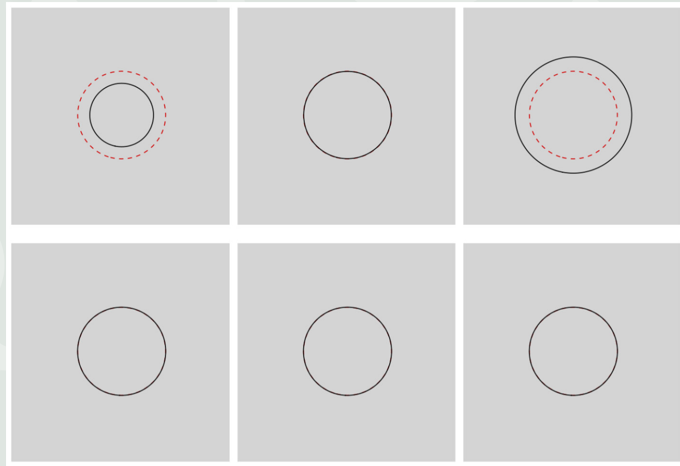


Figure 2: *Snapshots of the interface location for a droplet in a periodic domain. Initial interface is shown by the red dashed line and the simulated one by the black solid line.*

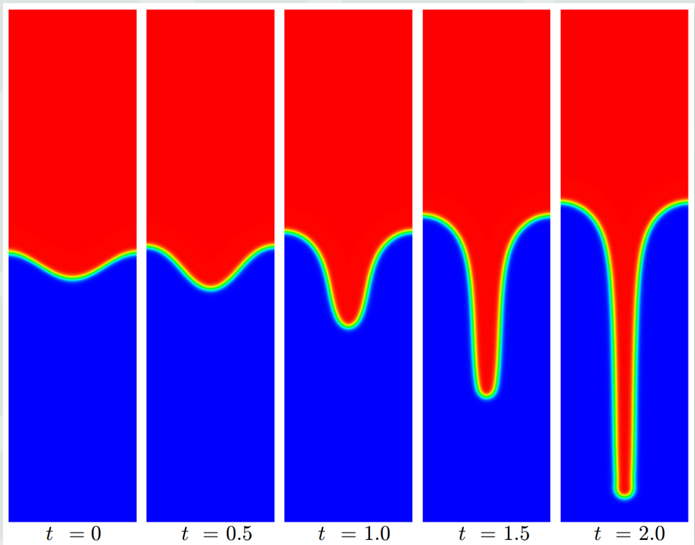


Figure 3: *Time evolution of high density and high Raynolds number RTI.*

DECOMPOSITION OF THE CRITICAL EXPONENT OF THE CONDUCTIVITY, AND RELATIONS FOR EVOLVING DISORDERED MEDIA

Carl Fredrik Berg[1], Muhammad Sahimi[2]

[1] PoreLab, Department of Geosciences, Norwegian University of Science and Technology, NTNU, Trondheim, Norway
[2] Department of Chemical Engineering and Materials Science, University of Southern California, USA

In a recent work [1], we have derived a decomposition of the contributions to the effective electrical conductivity into several groups representing the structure of percolation networks, including mass, tortuosity, and constrictivity. This decomposition leads to a relationship between the critical exponent of conductivity and the critical components of the three different structure parameters, given as:

$$t/\nu = (d-D_{bb}) + 2(D_{op}-1) - d_C$$

Here t is the critical exponents that characterize the power-law behavior of the effective electrical conductivity near the percolation threshold, while the morphology of percolation clusters is described by the correlation length exponent ν, the fractal dimension of the backbone D_{bb}, and the optimal paths D_{op}, and the exponent that characterizes the constrictivity d_C.

This relation was validated numerically in 2D and 3D, while it was confirmed analytically for one and six dimensions, where six is the upper critical dimension of percolation. The numerical validation for 2D networks is shown in *Figure 1*. In this figure, we have:

$$\zeta = d_{bb} + 2d_\tau - d_C$$

where $\zeta = t/\nu$, $d_{bb} = d - D_{bb}$, and $d_\tau = D_{op} - 1$. The values in the figure are the geometrical average of thousands of realizations of networks with side-length sizes up to 2048.

We also considered networks with a distribution of bond conductance values given by the probability distribution function:

$$h(g) = \tfrac{1}{\alpha}\, g^{1/\alpha - 1}$$

Here, large values of α give a broad distribution of conductance values. In [2] we gave a rigorous proof that $\zeta \geq \min(-\alpha/\nu, -t/\nu)$. This proof was based on the conductance of evolving networks, where the power law behavior of their conductance value gives a limiting value for the traditional percolation exponent ζ.

In [1] the different morphological exponents were investigated for different values of α, and it was shown that the exponent d_C is responsible for the non-universal behavior of ζ as the other exponents are either constant or limited. A numerical verification of this is shown in *Figure 2*.

RECOMMENDED READING

[1] Berg, C.F. and Sahimi, M., 2024. Relation between critical exponent of the conductivity and the morphological exponents of percolation theory. *Physical Review E*, 110(4), p.L042104.

[2] Berg, C.F. and Sahimi, M., 2023. Percolation and conductivity in evolving disordered media. *Physical Review E*, 108(2), p.024132.

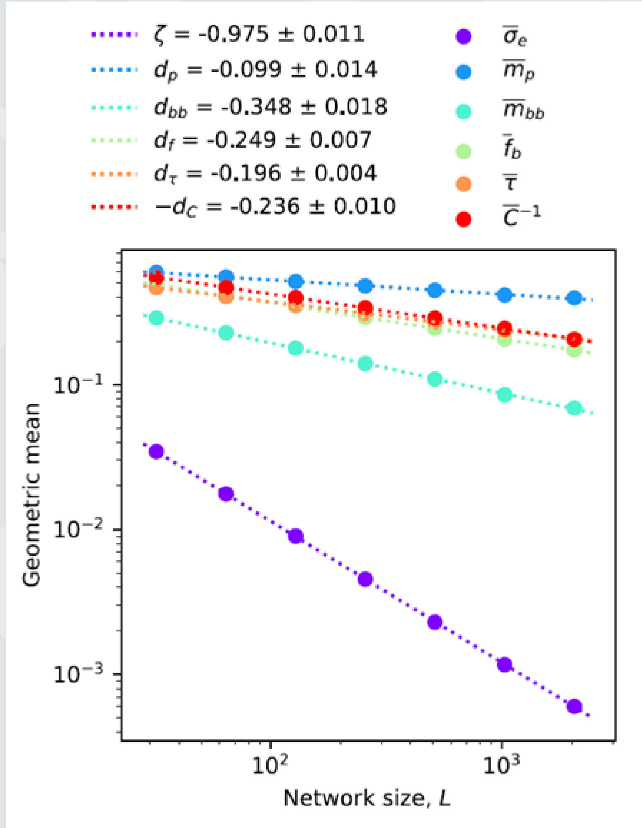


Figure 1: *The geometric mean of the various structure parameters, and slopes for the scaling exponents. This figure is from [1].*

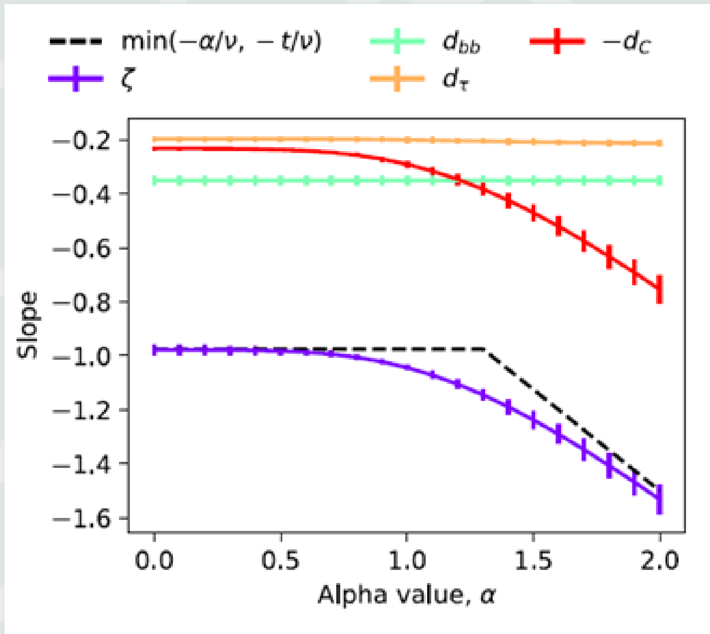


Figure 2: *Change in critical exponents with values of α. Note that the exponents ζ and d_C has similar behavior, just shifted. This figure is from [1].*

WHEN WATER RUPTURES IN SMALL PORES

Thomas Combriat[1], Dag K. Dysthe[2] and Eirik G. Flekkøy[3]

[1] Center of Excellence Hybrid Technology Hub, Department of Physics, University of Oslo, Oslo, Norway
[2] Department of Physics, University of Oslo, Oslo, Norway
[3] PoreLab, Department of Physics, University of Oslo, Oslo, Norway

Since water molecules exert a strong attractive force on one another, liquid water can support large negative pressures, or tensions. This is the reason why trees may grow taller than 10 meters, some reaching almost 100 meters. When the tension becomes too large however, the water ruptures into cavitation bubbles of vapor, a process that may be fast and violent. Such bubbles are known to peel the paint off propellors, damage water pumps and cause a variety of other technological challenges.

In order to study such fast and small-scale processes we have carried out experiments where a spherical lens is pulled away from a glass plate under water, leaving a penny-shaped cavitation bubble. These bubbles are only about a micrometer thick, some tens of micrometers wide and exist for less than a millisecond. The experiment and bubbles are illustrated in figures 1 and 2. Light that is sent in from below, interferes with itself as it is reflected both from the surface of the lens and the glass window. By measuring the radii of the circles where this interference causes shadows, the lens-plate separation may be measured to an accuracy of less than a nanometer.

The branch-formation around the bubbles is known as viscous fingering and may be predicted theoretically by solving the hydrodynamic equations for slow, small-scale flows. These calculations are based on the accurate measurements of the lens-plate separation. One of the most striking features of the bubbles is the fact that their lifetime is shorter the larger they are. More precisely, the lifetime is inversely proportional to their maximum area. This behavior is in sharp contrast to bubbles that are not formed between confining solid surfaces as the lifetime of such bubbles increases with the bubble size rather than the other way around.

The cracking sound that may be heard from joints, such as those in a finger, when it is bent or manipulated, may be explained by the formation of cavitation bubbles like those we have studied.

RECOMMENDED READING

[1] Thomas Combriat, Dag K. Dysthe and Eirik G. Flekkøy, Cavitation dynamics in creeping flow, *J. Fluid Mech.* Vol. 999, A19 (2024)

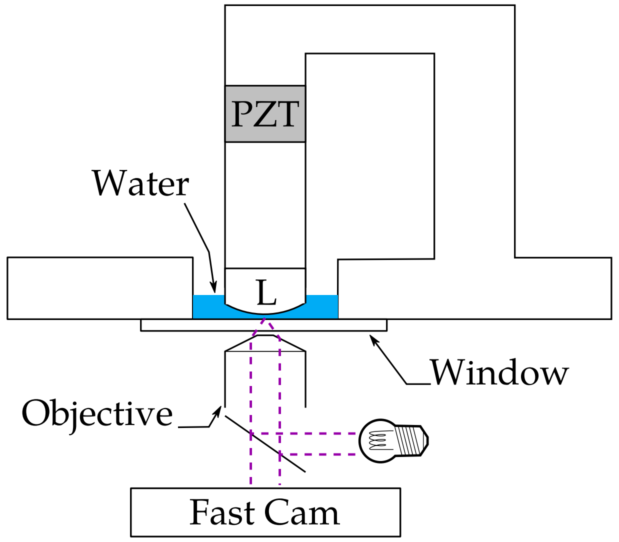


Figure 1: *The experimental setup: The glass lense is positioned a few tens of nanometers above the glass plate before it is pulled away. The separation between the lense and the plate is monitored via the radius of the Newton rings that are formed by light interference. Such a ring is seen as the dark circle in figure 2 where the separation is 40 nm*

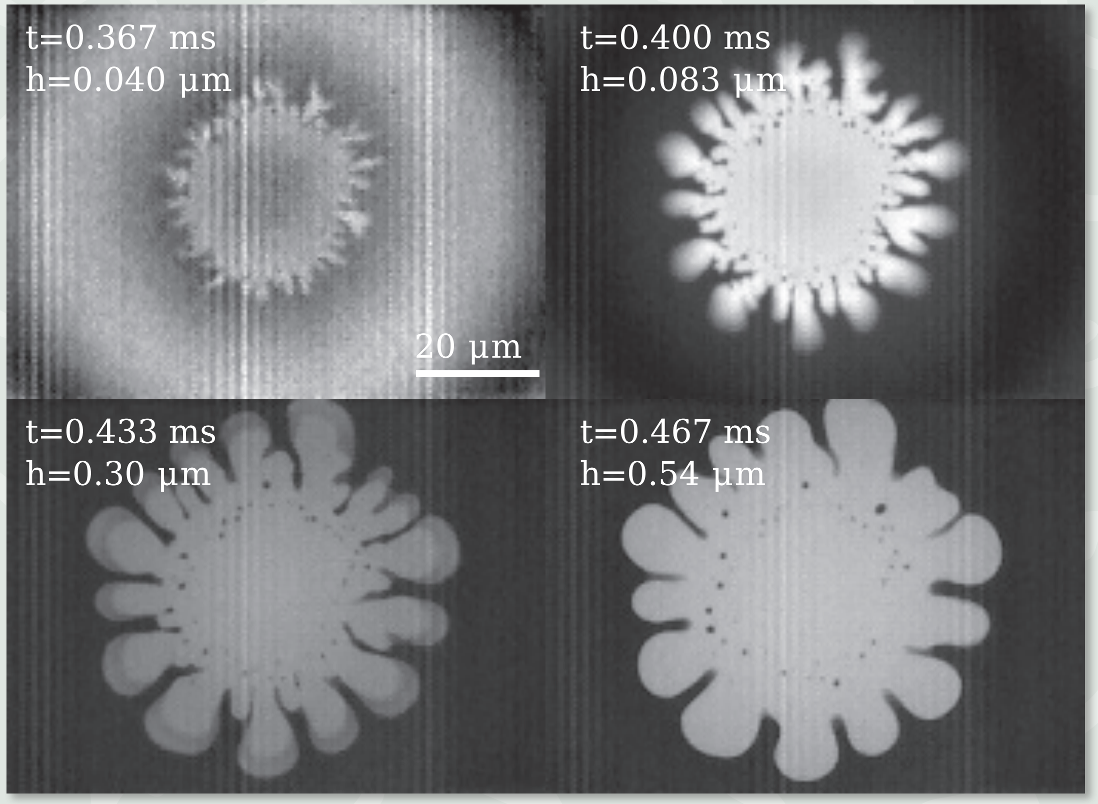


Figure 2: *The cavitation bubble at different times and sizes with its characteristic fingering structures that branch out once the bubble is formed*

ULTRASOUND TO ENHANCE NANOPARTICLE DRUG DELIVERY TO TUMORS

Sebastian E. N. Price[1], Magnus Aa. Gjennestad[2], Signe Kjelstrup[1] and Rune Hansen[3]

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

Cancer remains a major health concern, despite significant progress in developing effective treatments. One of the most important treatments is chemotherapy, which suffers from insufficient accumulation of the drug in the cancerous cells, as well as being unspecific in its delivery. Encapsulating the therapeutics in nanoparticles makes it possible to perform more targeted drug delivery into the cancerous tumor, and limit the damage on healthy tissue, because of the enhanced permeability and retention effect. However, the accumulation of the medicine is still low, due to the relatively complicated transport path of having to extravasate over the capillary wall of the blood vessel and navigate through the heavily obstructed tumor interstitium.

More recently, there has been promising research on combining nanoparticle drug delivery with focused ultrasound. Results indicate an increase in drug uptake when combined with microbubbles, but there remains a significant gap in understanding the underlying mechanisms behind this increase. Gaining this understanding is crucial for optimizing the procedure.

There are several mechanisms that could be important during the focused ultrasound-enhanced transport of nanoparticles. One of these is acoustic streaming, which is the net movement of fluid generated by propagation of sound waves. The source of the acoustic streaming is the acoustic radiation force, which is a result of the ultrasound dissipation. Increasing the intensity of the focused ultrasound will increase the acoustic radiation force and thus increase the acoustic streaming. However, the dissipation will also increase the temperature of the exposed medium. The aim of this work was to explore the possibilities of obtaining noticeable acoustic streaming effect in cancerous tumors, without exceeding the temperature limit of 50°C, the typical minimum temperature used for thermal ablation.

Two common tumor cases not obstructed by bone were selected: in the breast and in the abdomen. The acoustic streaming was calculated using equations derived in our previous work, whilst the temperature was calculated using the Pennes' bioheat equation without the perfusion term. In all simulations, a duty cycle (DC) of 1% was used and a pulse repetition frequency of 1s. Despite the low DC, the maximum peak temperature did not reach a steady-state but rather followed a logarithmic time-dependence. Therefore, fitted logarithmic equations were used to calculate the temperature for longer treatment times.

The time taken to stream 10 µm and the corresponding temperature was calculated for different frequencies, probe radii and acoustic power values. Increasing the frequency f (indicated as dashed lines for 0.5 MHz, dotted lines for 1.0 MHz and dash-dotted lines for 2.0 MHz in Figure 1) or increasing the probe radius a of the focused ultrasound probe (indicated with the color red for 3.0 cm, blue for 4.0 cm and yellow for 5.0 cm in Figure 1) reduced the increase in temperature relative to the treatment time, but at the cost of treating a smaller area.

The results from this work showed that it may be possible to reach distances of several micrometers within reasonable time without exceeding 50°C. A distance of 50 µm in the breast case can be reached in less than one and a half hours or up to 93 hours depending on the ultrasound parameters, demonstrating the importance of selecting the correct focused ultrasound probe settings.

ACKNOWLEGMENTS

The work has been done with support from the Norwegian Research Council under project number 301581 and through its Centre of Excellence funding scheme, project number 262644, PoreLab.

RECOMMENDED READING

[1] Price, S. E. N., Gjennestad, M. Aa., Kjelstrup, S. and Hansen, R. The effect of temperature constraints on the treatment of tumors using focused ultrasound-induced acoustic streaming. *Sci Rep* 15, 49 (2025)

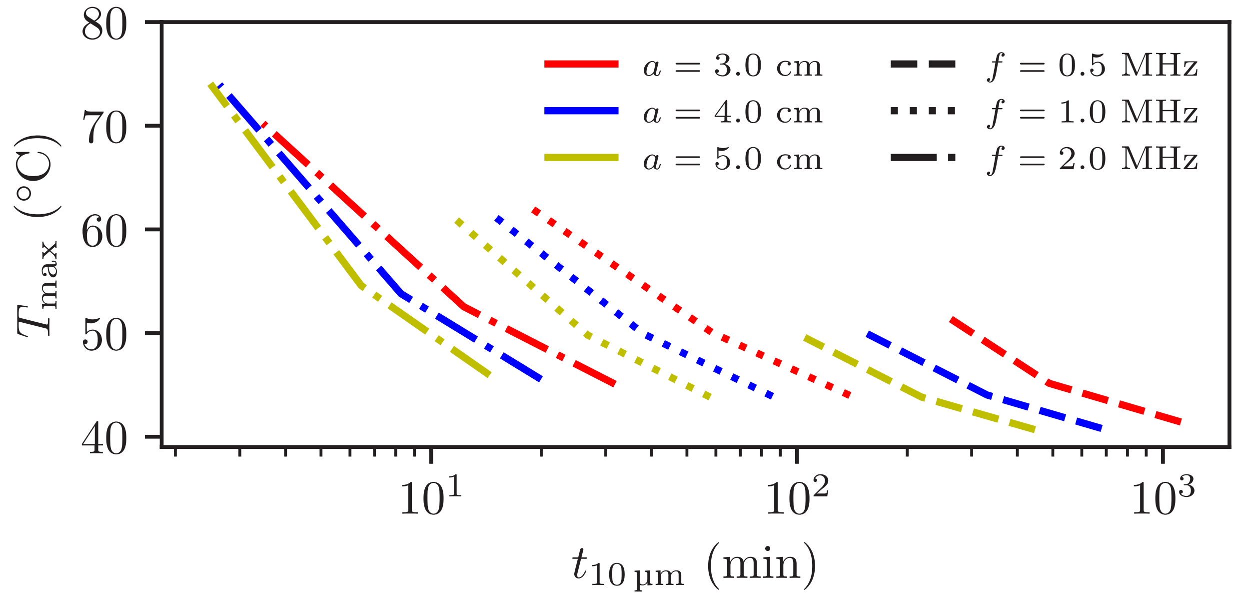


Figure 1: *The maximum temperature T_{max} against the time $t_{10\,\mu m}$ it takes for the fluid to stream 10 µm for the breast case. Acoustic power values of 50, 100 and 200 W were used for each combination of frequency and probe radius, where the greater power value gives the higher temperature. Dashed lines indicate a frequency f of 0.5 MHz, dotted lines a frequency of 1.0 MHz and dash-dotted lines a frequency of 2.0 MHz with probe radius a of 3.0 cm (red), 4.0 cm (blue) and 5.0 cm (yellow).*

RESEARCH PROJECTS

THE MAZE-LIKE NOSE OF THE BEARDED SEAL

Signe Kjelstrup

PoreLab, Department of Chemistry, Norwegian University of Science and Technology, NTNU, Trondheim, Norway

SUMMARY

Thanks to the maze-like structure of the nasal bones, Arctic seals lose less heat and water through nasal exchange than subtropical seals do, when both are exposed to the same conditions. This may provide an evolutionary advantage for the Arctic seal where heat and water loss means energy dissipation that must be replenished by food.

The bearded seal, Erignathus barbatus, (photo) is a pinniped living in Arctic and subarctic regions. The anatomy of the maxilloturbinate structure inside the seal's nose is tree-like. A branched structure of bones is filling the nasal cavity creating a maze, see Fig. 2. This maxilloturbinate (MT) structure is more complex in bearded seals than in that of lower-latitude seals. We have therefore suggested that the nasal structure of the Bearded seal may give an evolutionary advantage to this seal in a cold climate, compared to the equivalent in seals from subtropical regions [1,2].

Arctic animals that live in very cold marine environments would benefit from energy-efficient heat and water exchange with their surroundings. It is known since long from experiments that the complex nasal structure, not only plays an important role in humidifying and warming cold, ambient air before it enters the lungs, but it also serves to retain heat and water on exhalation. This is the case not only in seals. Even the comparatively simple human nose is capable of warming and humidifying air at quite low temperatures. But the much more complex bone structure in the seal nasal cavity (cf. Fig.2) appears to be linked to an essential ability to save heat and water, suited for life in the Arctic.

Our work [1,2] has aimed to gain more insight in these issues. How can we characterize the ability to retain heat and water by breathing? Does the respiratory system of the seal operate with relatively low dissipation of heat, of water, or perhaps both?

METHOD OF ANALYSIS

Computer simulations can be used to overcome difficulties of experiments in living animals, and this tool was also used in the present study. The heat and water exchanges in the nasal cavity of Arctic animals were simulated solving the proper set of differential equations for boundary conditions taken from life in the Arctic as well as in the mediterranean surroundings.

In order to evaluate and compare the performance of the different species under the different conditions, we computed the entropy production of the organ. A small entropy production means near-reversible conditions and therefore a large efficiency. The entropy production is therefore a suitable yard stick, as it is in industrial processes also.

RESULTS AND DISCUSSION

Using a computer model that measured how much entropy is produced in physical processes in the nose, we compared how well the seals would keep heat and moisture when both were exposed to -30°C and 10°C. Per breath at -30°C, the mediterranean monk seal lost 1.45 times as much heat and 3.5 times as much water as the bearded seal. Similarly, at 10°C, the monk seal lost about 1.5 times as much water and heat as the Arctic seal.

We found that the entropy production could be related to the perimeter of the cross-sectional area for air flow [1]. The longer the perimeter; the smaller the entropy production. We next computed the entropy production associated with heat and water transfer within the MT over the course of a breathing cycle [2]. In principle, if the exchange at any local position along the MT occurs without losses in water and heat, the exhaled gas would be of exactly the same temperature and relative humidity as the ambient air that was breathed in. In such an ideal situation, the overall entropy production relating to heat and mass transfer would be zero. In reality, the exhaled gas is likely to be warmer and wetter than the ambient air. We calculated the value for this entropy production, and considered how changes in various parameters affected the value.

The tidal volume and MT length affected the entropy production largely. An interesting minimum was found for the tidal volume, indicating that the actual seal nose is working at optimal conditions. For normal values of tidal volume and MT length, the air temperature in the channels was reaching the body temperature before the air left the channels. The earlier this happens along the path, the better protected the lung will be. The current conditions for heat and water exchange at the mucus lining in the seal's nasal cavity are such that the organ is tailored for such protection and efficient use.

Natural designs can inspire engineering.

Photo 1: *The Bearded Seal in Svalbard –* **Photo** *Signe Kjelstrup*

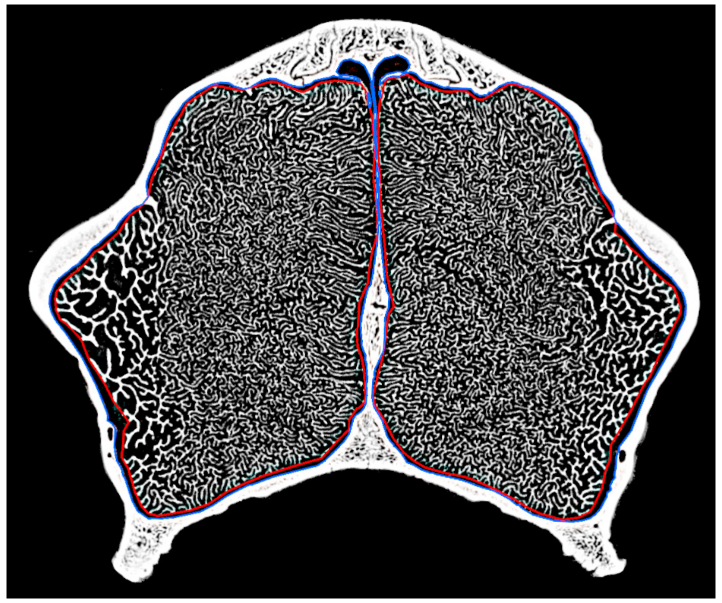


Photo 2: *Cross-section of maxilla turbinate structure of the nose of Erignathus Barbatus. Courtesy of Ø. Hammer*

ACKNOWLEGMENT

Research Council of Norway through its center of Excellence Funding Scheme, PoreLab project no 262644.

RECOMMENDED READING

[1] Hyejeong L. Cheon, Signe Kjelstrup, Nataliya Kizilova, Eirik G. Flekkøy, Matthew J. Mason, Lars P. Folkow, Structure-function relationships in the nasal cavity of Arctic and subtropical seals, *Biophys. J*, **122**, (2023) 1–13 doi: 10.1016/j.bpj.2023.11.012

[2] Hyejeong Lee Cheon, Nataliya Kizilova, Eirik G. Flekkøy, Matthew J. Mason, Lars P. Folkow, Signe Kjelstrup. The nasal cavity of Erignathus barbatus: An effective and robust organ for retaining heat and water, *J. Theoretical Biology* (2024) doi: 10.1016/j.jtb.2024.111933

LINKS: *https://scientias.nl/antarctische-zeehonden-blijken-superneus-te-hebben-die-efficienter-werkt-dan-moderne-ventilatiesystemen/*

RESEARCH PROJECTS

RESEARCHER

GAUTE LINGA

PoreLab, Njord Center for Studies of the Physics of the Earth, UiO

Who are you? What is your background?

I am Gaute Linga, Norwegian citizen and physicist. I was born in Trondheim but spent my formative years in Bergen. I graduated with a MSc (siv.ing.) degree in Physics and Mathematics/Applied Physics from NTNU in 2014 and got my PhD in Physics from the Niels Bohr Institute, University of Copenhagen, in 2018. I joined PoreLab in 2019, but before this I also had two brief spells at SINTEF.

Apart from porous media physics, I enjoy spending time with my family, outdoor activities like skiing, hiking, fishing and biking, taking trains across Europe, and supporting the football team Brann from my hometown, among many other things.

How did you become interested in porous media physics?

For as long as I remember, I have wanted to figure out how things work – both technological and natural things. I was early on fascinated by coding, mathematics and natural science, so it was a natural step to start my studies at NTNU, where I chose the specialization Applied physics. More than what occurs at extremely large (astrological) or small (atomic) scales, I was particularly fascinated by fluid dynamics and complex systems, where many parts interact and often lead to behaviour that cannot be predicted from the constituents alone. Porous media physics turned out to be a perfect mix of tangible scales, complexity, and fluid flows, and a field full of important unsolved problems with far-reaching practical consequences. It's also beautiful, as shown in the many patterns and striking visualizations made by simulations and experiments (as shown in this report), as well as theory and computer code.

What are you doing now in your research?

My research is about transport of dissolved chemicals and pollutants in porous media such as soil. In particular, together with collaborators I study how flowing water, often in conjunction with air, interplays with spreading, mixing and reaction of solutes in these porous environments. I try to attack these problems from the pore scale and up using a combination of numerical simulations and theory, and working closely with experimentalists. The research spans from development of numerical methods and codes, to model development and more applied studies. Since natural systems can be rather complex, we often study idealized systems and look for behaviour that can be general across different systems.

What are your activities at PoreLab?

A typical day as a PoreLab researcher is quite varied – no day is the same as the previous one. This is what makes being a researcher fantastic (and admittedly, sometimes frustrating) – you are constantly trying to do something you don't really know how to do.

When I'm working alone, I often find myself in front of a computer, programming or launching simulations, analyzing data, or working with pen and paper for theory and modelling purposes. I also spend quite a bit of time writing and editing papers I am co-authoring. When I'm around the PoreLab offices, significant part of my time goes into discussing with colleagues, either informally or in meetings in-person or online. This includes discussions with PhD and MSc students that I co-supervise. I enjoy going to the lab downstairs and interacting with experimentalists (like Kevin, see interview on the next page) that are trying to answer similar questions to me, but using experiments instead of simulations. When experimentalists find that their experiment is no longer working, it is often because I have unintentionally perturbed their setup during one of those visits.

A few times a year, I travel for conferences and workshops to present my results, and visit groups which I collaborate with. I also regularly write research grant applications, which before deadlines can get quite intense. Between these periods, I'm almost constantly pondering about the next big idea.

Why is your research important?

My research is predominantly basic research, leading to new basic knowledge, which I believe has an important value in its own right – much like Nature, art, and culture.

That said, I believe my research has some particularly important consequences especially related to groundwater resources. Earth's aquifers are under increasing strain, and describing how chemicals, say, pollutants, spread from the surface to the water table is a key to managing them responsibly. This is directly related to what we are trying to do. Furthermore, as we are looking for generic descriptions, the research may with some adaptation be applied to other important areas of research like CO_2 storage and geothermal energy.

POSTDOC

JAMES KEVIN PIERCE

PoreLab, Njord Center for Studies of the Physics of the Earth, UiO

Tell us about yourself

I'm from a small mountain town in the US – a river valley between steep cliffs where my family has been for some centuries. I completed a master degree in condensed matter physics and a PhD in geoscience, both at University of British Columbia in Vancouver, Canada. Now I'm a postdoc at PoreLab studying solute mixing in multiphase flows through porous media. This is a fun combination of my interests in both physics and geoscience.

Tell us more about your project.

I study how chemicals mix into liquids flowing through fractured rocks and soils. In particular, I am focused on mixing in the dynamic multiphase flows that occur near the surface of the Earth, like drainage and imbibition. Chemical transport in these contexts controls environmental contamination, rates of chemical reactions, and the supply of nutrients to plants and bacteria. I fabricate transparent porous models designed to imitate natural materials using 3D printing, then I image fluorescent dyes as they mix into flows through these models. The fluorescent dyes deform into beautiful striated patterns, where tendrils of the chemical substance diffuse out and overlay with one another inside the porous medium. We are working to describe the deformation process with non-equilibrium statistical mechanics and understand how the movement of the air-water interfaces in drainage and imbibition modify it.

How did you come being interested in physics?

I remember a particular family vacation when I was maybe eight years old. My parents took us to the place where the Wright brothers built the first airplane. It's now a museum among the sand dunes where they did their test flights. I was fascinated seeing their notes and materials. The story is fun: two bike mechanics combined French glider plans with a custom car engine, argued endlessly figure out the best way to do things, risked their lives crashing wooden airplanes off of sand dunes, and somehow came out with an airplane. After that trip, I thought the process of engineering seemed neat, so I paid special attention in my science classes. Much later on, I realized I liked physics more than the other science disciplines.

What made you decide to come to Oslo?

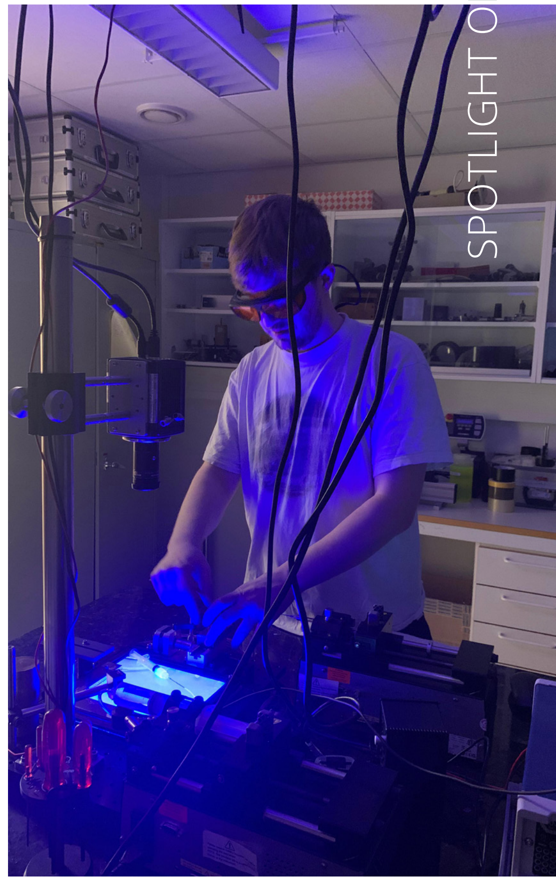
After my PhD, I was looking for labs with research topics that used physics methods on geoscience problems. Having previously been in Vancouver Canada, I also wanted to work somewhere with good access to outdoors. I saw the position studying solute mixing at PoreLab just as I had finished my PhD, so now we're here.

What do you find most fulfilling in working at PoreLab?

The experimental laboratories working environment in Oslo is amazing. Between our engineer Mihailo, the E-lab team for electronics support, and the I-lab team for mechanics and instrumentation, the research is super well supported. Couple this with the freedom to try new things, and it's easy to try new things.

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

I want to work on problem solving, where every few months it's something different. Whether I find that in academic research, geoscience consulting, scientific computing, or something else – anything dynamic with a chance to be creative is good with me. For now, I'm enjoying the laboratory research.



POSTDOC

GE LI

Department of Mechanical and Industrial Engineering, NTNU

Who are you? What is your background?

My name is Ge Li, and I come from China. I earned a bachelor's degree in Materials Chemistry and a master's degree in Materials Science and Engineering from Wuhan University of Technology. During this time, I was an experimental materials scientist, focusing on the synthesis and characterization of fluorescent transparent ceramics and thermal energy storage materials. However, I realized that many experimental observations were difficult to explain using state-of-the-art techniques, which motivated me to pursue a Ph.D. in computational chemistry.

I completed my Ph.D. in Theoretical Chemistry and Biology at KTH Royal Institute of Technology in Sweden. My research focused on using first-principles calculations (Density Functional Theory, DFT) and classical simulations (Molecular Dynamics, MD) to unravel the catalytic mechanisms of the water oxidation reaction—widely regarded as the bottleneck in redox reactions aimed at storing energy in chemical bonds.

Currently, I am a postdoctoral researcher working on the Sustainable Stable Ground (SSG) project at PoreLab and the Department of Mechanical and Industrial Engineering at NTNU.

Tell us more about your project

Soft clays, particularly sensitive quick clays, pose significant challenges in infrastructure construction due to their high compressibility and low mechanical strength. Quick clay is primarily found in the glacial sedimentary belts of northern high latitudes, such as Norway, Sweden, and Canada. Its formation results from the leaching of salts by underground water, which reduces the salt concentration in the clay to a critical threshold. In Norway, deep-mixing with lime and cement is commonly used to stabilize such soils, improving slope stability, reducing settlement, and mitigating vibrations in the foundations of roads and railroads. The SSG project aims to develop a sustainable deep-mixing stabilization technology for quick clay and significantly reduce the carbon footprint associated with the use of lime and cement in ground improvement projects.

What are you doing now in your research?

The SSG project spans a wide range of scales, from sub-nanoscale and nanoscale to microscale, mesoscale, and macroscale. My contribution focuses on using molecular dynamics simulations to bridge the nanoscale and microscale. I collaborate with researchers from the Department of Chemistry and the Department of Physics at NTNU, integrating sub-nanoscale DFT calculations and microscale clay experiments. The primary component of Norwegian quick clay, negatively charged illite clay, plays a central role in my work. Given the importance of salt types and concentrations in shaping the electric double layer (EDL) surrounding illite clay, both atomistic and coarse-grained models are employed to construct illite clay particles. These approaches aim to elucidate how different salts enhance the interactions between clay particles, providing theoretical insights into the factors that can improve the mechanical strength of clay materials.

How are you performing your research?

My research primarily focuses on developing an atomistic friction model and a coarse-grained model to study the behavior of illite clay particles. First, an atomistic model of an illite clay particle is constructed, and a friction model is developed to explore the effects of different salts on clay particle interactions. Next, this atomistic model is used to generate a force field for the coarse-grained model, enabling simulations on a larger scale. Finally, illite clay particles at the microscale are constructed to investigate the macroscopic properties of illite clay materials, such as shear strength. All simulations are conducted using the open-source program GROMACS, leveraging both local computing resources and the HPC cluster provided by NTNU Idun.

PHD

HÅKON PEDERSEN

Departmentof Physics, NTNU

Who are you? What is your background?

My name is Håkon Pedersen. I hail from a small town called Alsvåg in the region of Vesterålen in Nordland. I initially studied music in secondary school, before pivoting into something else I've always been interested in, natural science, and in particular physics. Growing up, I had several positive influences which drove me to studying natural sciences more seriously, both in my family, among my friends and my teachers. I moved to Trondheim in 2014 for a bachelor in physics at NTNU, finished my masters degree in 2019, and started my PhD at PoreLab in 2020. I have now put down some roots in Trondheim, where I live with my partner, my daughter and a golden retriever.

Tell us more about your project

I am working on the theoretical basis of a thermodynamic theory of two-phase flow in immiscible and incompressible two-phase flow in porous media. These kinds of systems are ubiquitous in nature, industry and technology, but often contain many parameters and variables depending on the theoretical framework. Our interest lies in the continuum limit, where one cannot resolve the individual pores and the two fluids acts as a single "effective" fluid. One can define steady-state flow in such a system to be an equilibrium state in the sense of statistical mechanics, effectively mapping an "athermal" system onto the mathematics of thermodynamics. This mathematical framework, called contact geometry, is quite rigid, and imposes restrictions upon what relations one can have in the system.

Our motivation is to leverage the relations and principles of thermodynamics to obtain relations for the flow, with the selection of a set of macroscopic variables that determine the system state. In working with this theory, the relation between actually measurable velocities and a set of unphysical "thermodynamic" velocities is given by an unmeasurable quantity called the co-moving velocity. It turns out that leveraging geometry allows one to parametrize the co-moving velocity very effectively, with the parameters having a clear mathematical interpretation given by projective geometry. This offers an advantage over many other parametrizations of the fluid velocities in porous media two-phase flow, where the number of parameters can be quite large and have no clear interpretation other than for purposes of fitting data.

What is your favorite activity in your research?

I've always been fond of the mechanisms of how and why something works. Doing physics research, such inquiries are the driving force for discovery. Having a heap of questions, only to get answers further down the road (sometimes years later), is immensely satisfying. Diving into a new subject, finding relevant references and research, and coming out on the other side having learned about something you had not even heard about before has been my favorite activity. Actually, applying the ideas is an added bonus. I have also had great fun presenting my work to co-workers at PoreLab and on conferences, and I have been particularly fond of writing notes and articles. Recently, reading and attempting to describe relations in the framework of Cayley-Klein models has been great fun and very interesting.

How is it to be a PhD at PoreLab?

A PhD at PoreLab has many great facets. One is encouraged to meet, talk to and collaborate with co-workers, both through actual events and the culture at the centre. There are many opportunities to present one's work, receive feedback, and discuss with people from other fields of study. The interdisciplinary profile of PoreLab is unique, and one always has the opportunity to talk to someone with a different view of the same problem. There is also a constant stream of external guests. The social life at PoreLab is excellent for PhDs, with everything from cozy coffee breaks, board games and conferences to dinners, workshops and attempting to complete the jigsaw puzzle on the table in the common area.

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

PHD

CHRISTOPHER D. FJELDSTAD

Department of Mechanical and Industrial Engineering, NTNU

Tell us about yourself

My name is Christopher, I have a MSc in Nanotechnology Engineering, and I am currently working on my PhD. In my spare time I love sailing, skiing, cooking, and being a huge nerd! Whilst working on my MSc and PhD, I spent 5 years volunteering at the Student Society in Trondheim selling and brewing beer. Be advised that asking me a beer related question might leave you involuntarily stuck in a thorough examination of the topic. This goes for any other subject I am interested in as well.

And the topic of your PhD?

My PhD topic is about understanding and connecting the behavior and properties of the microscopic world to the macroscopic world. Specifically, I am working on analytical models for the shear viscosity of complex fluids. What is a complex fluid you might ask? Anything with interactions that are more complex than a marble. In other words, every fluid that is interesting. Something as deceptively simple as water is very much considered complex to me.

Why is your research important?

The key property of any lubricant is the viscosity and how the viscosity depends on system parameters such as pressure and temperature. Hundreds of years of research has provided us with a reasonable phenomenological understanding of how certain lubrication systems work. However, at a more theoretical level, the viscous behavior is still poorly understood. The hope is that, by deepening our theoretical understanding, we can somehow aid in the development of novel, and preferably environmentally friendly lubricants.

Tell us about an interesting result

In the first paper I ever published, we studied the viscous properties of dipolar hard sphere fluids, or DHS for short. DHS fluids serve as a simplified model for dipolar systems. We realized early on that, if exposed to an electric field, these fluids might exhibit some form of anisotropic viscous behavior, that depended on the orientation of the applied field relative to the shearing direction. What we did not realize at the time was how strong this effect would be, especially at lower densities. It turns out that DHS particles form short lived chain like clusters at low density that will orient themselves in the direction of the electric field. This effect has a massive impact on how momentum is transported through the fluid. Depending on the strength of the dipoles and the field, we observed as much as a factor six times difference in the viscosity.

What is your favorite activity in your research?

Although I enjoy several aspects of my research, I must admit I have a certain soft spot related to extracting useful information from my simulations. Because the fluids we study are model systems and not real fluids, we use molecular dynamics to simulate our fluids and give our theories something to compare to. The output of these simulations comes in two forms: 1) Basic thermodynamic output calculated as statistical averages of the system, and 2) a dump file, a list of particle positions, velocities, orientation, etc., of every particle for each time step. Thinking about how to extract interesting information from the dump file, and then writing code that achieves this goal in an efficient way, provides a nice combination of physics, programing, and problem solving.

PHD

JENNIFER R. SHEEHAN

Department of Mechanical and Industrial Engineering, NTNU

Tell us about yourself

I go by many names. Friends call me Jenny, family call me Jen, legally I am Jennifer, I publish as J. Roadnight Sheehan, and one individual calls me Jennoula. You might be able to tell from this interview that I value silliness and apply playfulness to all that I do. I am educated in physics with a specialty in nuclear radiation detection, modelling and safety. I am originally from the UK, where I spent several years teaching in schools at various levels across many subjects: physics, chemistry, biology, maths, ICT, and electronics. A Jen of all trades, if you will. I have been living in Norway since 2018, and this wonderful country has my gratitude for supporting me with my disabilities so I can work to my full potential and obtain a PhD while performing other normal human activities like having friends and being well enough to leave the house.

What is your PhD about?

The theme of my PhD is looking through the lens of escape rates and decay behaviour at different complex systems. To enable the viewing of such complex systems through my decay goggles, the systems must be simplified. The scope of systems that can be viewed through these goggles is very broad. My PhD work features just two systems: nanoscale frictional phenomena of layered materials and drug resistance in chronic myeloid leukaemia treatment.

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

In short: job hunting! The job market for part-time academic and research work in Trondheim is mostly vacant of vacancies. Reader, would you employ a highly skilled individual for part-time work? Would you consider changing a job advertisement to include that part-time work could be negotiated? How accessible and inclusive are your employment processes? If you find this job-hunt rant appealing, please see my webpage *jennifer.sh/cv*, it has lots of useful information about my skillset and expertise.

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

The year is 2030, the newest social media app's logo flashes on the moon, advertising itself globally. The only way to reach the targets of the 2021 Glasgow Climate Pact is for a global switch to nuclear power. Luckily, Norway has a fresh network of nuclear power stations to support its growing population of climate refugees. This subsequently has created a boom in the nuclear energy research industry that is on its way to cracking cold fusion. I am employed in modelling different environments within nuclear facilities and assessing their safety. I recently won a company award for excellence due to my superior PowerPoint skills. My dog, Jacky, is now 8 years old, going grey, and somehow still spreading chaos. My garden thrives in the ever-warming weather and my squash crop is the talk of the town. The robot vacuum-cleaner sings songs to me while I make wrestle with the regret of choosing sentient mode for my electric vehicle.

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

PHD

REZA HAGHANI

Department of Geosciences, NTNU

Who are you? What is your background?

My name is Reza, and I hold both a Bachelor's and Master's degree in Mechanical Engineering, earned in Iran. During my Master's studies, I developed a strong interest in multiphase fluid flow and computational fluid dynamics (CFD). At the end of 2021, I began my PhD journey at the Norwegian University of Science and Technology (NTNU) in Trondheim. My research focuses on multiphase flow in porous media, encompassing everything from challenging established assumptions to developing new models using the lattice Boltzmann method (LBM). My PhD combines theoretical and numerical approaches, allowing me to bridge the gap between complex fluid dynamics theories and practical computational modeling.

Tell us more about your project.

In multiphase fluid systems, when an interface interacts with a solid surface, a contact angle (or wettability) forms. This angle plays a crucial role in determining the behavior of the medium. This phenomenon is seen in various industrial applications, such as the gas diffusion layers in fuel cells, hydrocarbon reservoirs, and CO_2 sequestration. My PhD project focuses on developing a new method to characterize wettability in porous media using multiphase fluid simulations. By minimizing the differences between initial states (captured via segmented micro-CT images) and the multiphase steady states, the contact angle can be accurately determined. This novel approach offers deeper insights into the multiphase configurations that define porous media.

How did you come being interested in multiphase physics?

I've always been captivated by the elegance of multiphase flow in nature—be it a droplet of water resting on a lotus leaf or raindrops dancing on a lake's surface. This natural beauty drove me to delve deeper into the physics behind multiphase flows. My passion for programming further inspired me to specialize in numerical modeling of these systems during my master's studies. Today, I am pursuing a PhD in this field, focusing on the characterization of wettability in porous media—a topic that combines my interests in physics, nature, and computation.

How was it to be a PhD at PoreLab?

PoreLab offers a vibrant, interdisciplinary environment filled with opportunities for academic and personal growth. The institute fosters collaboration and idea exchange through lectures, workshops, and coffee breaks. One of the highlights of my experience has been the Junior Forum, where early-career researchers come together to discuss ideas and share insights. PoreLab's diverse community—spanning fields such as Petroleum Engineering, Physics, Chemistry, and Geoscience—creates a fertile ground for innovation and learning. Additionally, having visitors from both national and international institutions brings fresh perspectives and enriches the porous media research community.

PHD

FAZEL MIRZAEI

Department of Physics, NTNU

Tell us about yourself

My name is Fazel Mirzaei, and I was born in Saqqez, a historic city in Kurdistan, Iran. I started my academic journey studying physmath and later earned a bachelor's degree in electrical engineering. For my master's, I focused on medical physics with a specialization in imaging science and its medical applications. In the late 2020, during the COVID-19 lockdown, I moved to Norway and have been living in Trondheim ever since. I am currently in the final stages of my PhD, focusing on completing my research, drafting papers, and writing my thesis.

Tell us more about your project.

My work involves tackling societal, environmental, and industrial challenges using computational imaging methods like X-ray and neutron imaging, with a focus on time-resolved and in-situ experiments. One particular example is frost heave and ice-lens formation in soil. Frost heave is a phenomenon many Norwegians are quite familiar with. I think anyone living in the Nordic countries has probably noticed bumpy roads or damaged railways caused by seasonal frost heave at least once. During my PhD, I developed and built a specialized cell capable of replicating the frost heave process. This setup allowed us to perform 4D (3D + time) bi-modal computed tomography experiments using both X-ray and neutron beams. These techniques enabled us to quantitatively study soil samples under a unidirectional temperature gradient, monitoring the initiation and growth of ice lenses in 4D. The combination of X-ray and neutron imaging provided complementary contrast mechanisms, offering deeper insights into the process.

How is your favorite activity in your research?

Being an experimentalist means frequently encountering challenging questions and finding ways to address them by designing experiments and building the necessary apparatus. This often requires an extensive literature review and in-depth discussions with supervisors and collaborators to devise a solid approach for data acquisition or to interpret experimental results. While this process can sometimes be frustrating, the joy of uncovering answers and explaining findings makes it all worthwhile. For me, one of the most exciting parts of my research is working with experimental data. Analyzing data not only provides opportunities to learn new theoretical concepts but also helps me develop technical skills, such as learning new programming languages, improving coding skills, and exploring advanced visualization techniques. This stage is where discovery and personal growth truly come together.

Who is involved in your research?

I think every research study is a team effort, involving many talented individuals working together to find answers. In my case, alongside my supervisor, Prof. Dag W. Breiby, and my colleagues in the X-ray Physics group, I have collaborated with scientists from PoreLab, the Njord center at UiO, SINTEF, and USN on various projects. I have also frequently visited major research facilities, such as the Paul Scherrer Institute (PSI) in Switzerland, the European Synchrotron Radiation Facility (ESRF), and the Institute Laue-Langevin (ILL) in France, to conduct and participate in experiments. These collaborations have provided me with valuable experiences and played a significant role in achieving my research goals.

SPOTLIGHT ON EIGHT YOUNG RESEARCHERS

HEADING FOR THE FUTURE:

OUR NEW EXTERNALLY FUNDED PROJECTS

PoreLab researchers and associated members developed 7 new externally funding projects in 2024, either as project leader or in collaboration with our partners. This includes a highly prestigious ERC Advanced Grant allocated to Professor Alex Hansen, Director for PoreLab and PI for the research theme on thermodynamics of flow in porous media. This is a major milestone for him and for PoreLab. Four projects were developed by Professor Dag W. Breiby and Dr. Basab Chattopadhyay from the X-ray Physics group at the Department of Physics, NTNU. Both are associated members at PoreLab. Two of the projects, SaltyPore and HeaLiSelf, are financed by the Research Council of Norway. MISSION-CCS is an EU funded Marie Skłodowska-Curie Actions Doctoral Network (MSCA-DN) program. TeSCAL is a new KPN project developed by SINTEF Industry in collaboration with Associate Professor Antje van der Net, associated member at PoreLab. The last project, SMILE, is a Marie Sklodowska-Curie doctoral network funded by Horizon Europe. PoreLab members will be following two NTNU PhDs, both working on CO_2 storage within SMILE. Note that the results from the previously granted project are highlighted as part of the Research projects in our annual reports.

SaltyPore

Full title: Salt Precipitation in Porous Aquifers during CO_2 injection
Project leader: Dr. Elvia Anabela Chavez Panduro at the Department of Materials Science and Engineering, NTNU. Dr. Basab Chattopadhyay at the Department of Physics, NTNU, is the main PhD supervisor.
Application type: Research project for Young Talents (FRIPRO) at the Research Council of Norway
Duration: 2023 – 2027

One of the challenges that needs to be better understood during the process of CO_2 injection in abandoned oil and gas reservoirs, is the tendency of clogging by salt formation, including how it can be mitigated. The huge, abandoned oil and gas reservoirs are porous rocks filled with brine (salt water), and when injecting CO_2, water is absorbed by the dry gas, and the brine salt concentration increases, leading to salt precipitation. This solidification might clog the porous rock and reduce the amount of CO_2 that can be stored in a specific reservoir.
Through advanced X-ray imaging methods like quantitative computed tomography (CT) at high temperature and pressure, combined with thermodynamical measurements, the SaltyPore project aims to reach a better scientific understanding of this specific phenomenon, as a key applied example of phase transitions in porous media.
In collaboration with in-operando imaging beamlines at the synchrotron ESRF, national X-ray and CO_2 expertise, and industry through the Centre for Environment-Friendly Energy Research (FME) of NCCS led by SINTEF, SaltyPore aims to indirectly contribute also to the technical solutions to this challenge.
The project includes a PhD position in experimental physics, 3D in-situ X-ray imaging for CCS applications. PhD candidate Jessica Zeman (picture on the right) was hired with Basab Chattopadhyay as supervisor. Her project involves designing, constructing and using state-of-the-art experimental setups. Major emphasis is put on developing advanced 4-dimensional (3D + time resolution) X-ray imaging methods based on scattering and phase contrast.

EXCITE2

Full title: Enhanced X(cross)-disciplinary Community-driven Imaging Technologies for Earth and Environmental material research
Project leader: Dr. Oliver Plümper at Utrecht University, Netherlands. Dr Basab Chattopadhyay is the coordinator at the Department of Physics, NTNU.
Duration: 2024 – 2028
Webpage: *https://excite-network.eu/*

EXCITE2 has received funding from the Horizon Europe program to establish an international and interdisciplinary research infrastructure. It is a continuation of the EXCITE project that was funded through the Horizon 2020 program.

The EXCITE2 Network consolidates 18 research facilities in 12 European and associated partner countries into a unified infrastructure and providing transnational access to advanced imaging technologies. The X-ray Physics Group at NTNU is a participant in the EXCITE2 and provides transnational access to its X-ray microscopy laboratory. A key goal of the network is to facilitate training of a new generation of researchers and fosters cross-fertilization and knowledge-sharing across scientific disciplines, academic institutions, and industry.
Contacts at NTNU are Dr. Chattopadhyay, Prof. Breiby and Prof. Mathiesen, all associated members of PoreLab.

Excite Network

HeaLiSelf

Full title: Self-healing lithium-ion batteries enabled by fiber/nano optic sensing and convergent data-driven analytics
Project leader: Professor Steven Tyler Boles at the department of Energy and Process Engineering, NTNU. Professor Dag W. Breiby, from the Department of Physics, NTNU, is involved as project partner.
Application type: Researcher Project for Technological Convergence Related to Enabling Technologies at the Research Council of Norway
Duration: 2024 – 2027

Lithium-ion batteries have become a ubiquitous part of modern society, enabling a new era of electric vehicles and energy storage systems, in addition to an ever-increasing range of consumer electronics products. Batteries typically have a shorter lifetime than the devices they are providing with energy, which leads to excessive waste. Being able to quantitatively monitor the state of health of batteries nondestructively and during usage is essential to both further improvement and better understanding of their limitations and performance.

X-ray computed tomography is well-suited for in-situ/operando studies of battery related processes and assemblies, however, it is expensive, and unsuitable for battery health monitoring on a commercial scale.
Optical fibers, notably fiber Bragg gratings, constitute a complementary low-cost and light-weight technology, enabling temperature, chemical environment, and mechanical strain to be measured also in comparably small batteries. With their inert chemical nature, optical fibres can even be present inside battery cells during operation, despite the harsh electrochemical environment.

For the HeaLiSelf project, the working hypothesis is that data collected from fiber Bragg grating sensors will serve as a highly efficient proxy for X-ray computed tomography observations. Novel binder and additive chemistries are promising approaches to introduce self-healing into batteries, but an effective system combining physical observations and effective sensors will bring self-healing batteries one step closer towards the real-world, and this is the vision for the HeaLiSelf project. The strategy of HealLiSelf relies on the convergence of fiber optic sensing, nanoscale material characterization, and advanced data analytics.

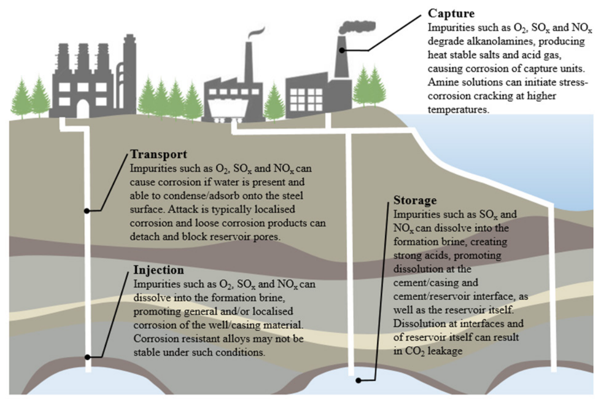
Three PhD candidates are hired within the HeaLiSelf project including Shibi Palliyalil (picture on the right) at the Department of Physics, having Prof. Dag W. Breiby as her main supervisor.

MISSION-CCS

Full Title: Material Science Innovation for Accelerated, Sustainable and Safe Implementation of Carbon Capture and Storage
Call: Marie Skłodowska-Curie Actions Doctoral Network (EU-MSCA-DN)
Project leader: Dr. Wei Yan at Technical University of Denmark and Prof. Richard Barker, University of Leeds are coordinating the project. Prof. Hanna Knuutila, Department of Chemical Engineering, and Prof. Dag W. Breiby and Dr. Basab Chattopadhyay, Department of Physics, NTNU, are involved in the project.
Duration: 2024 – 2028
Webpage: *https://www.mission-ccs.eu/*

MISSION-CCS is a Marie Skłodowska-Curie Actions Doctoral Network (MSCA-DN) program that will provide a bespoke training environment for 13 Doctoral Candidate Researchers (DCRs), focused on understanding and mitigating material degradation phenomena across the entire CCS chain, from production, via transport to storage.

The interdisciplinary network consists of 16 internationally leading organizations (consisting of 4 academic institutions (DTU, Univ. of Leeds, NTNU, and INSA Lyon) and 12 other associated members including Equinor ASA) across 7 countries, who are at the scientific forefront of combining material science, engineering, physics, chemistry and techno-economics to develop the next generation of research and innovation leaders in the field of CCS.



The X-ray group at NTNU is hosting 2 DCRs: DCR8, Arshitha Mathew, and DCR9, Soumya Pallipotta, with respectively Professor Dag W. Breiby and Dr. Basab Chattopadhyay as supervisors.

Picture: PhD candidates Arshitha Mathew, on the left, and Soumya Pallipotta, on the right

SMILE

Full title: European Doctoral Network on Geo-energy
Application type: Marie Sklodowska-Curie doctoral network funded by Horizon Europe (2021–2027) framework program of the European Union

Geo-energies, such as geothermal energy, CO_2 storage and underground energy storage, have a great potential to contribute to meet the Paris Agreement targets on climate change. Yet, their deployment has been hindered by a lack of a full understanding of the processes that are induced in the subsurface by large-scale fluid injection/extraction. The various processes involved (e.g., fluid flow, geomechanical, geochemical and thermal effects) imply complex interactions that cannot be predicted without considering the dominant coupled processes, which is rarely done. As a result, some early geo-energy projects have occasionally developed unpredicted consequences, such as felt and damaging induced earthquakes, gas leakage and aquifer contamination, dampening public perception on geo-energies.

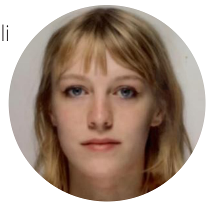
SMILE aims at overcoming these challenges in developing geo-energy solutions by training a new generation of young researchers that will become experts in understanding and predicting coupled processes. Thus, they will be capable of proposing innovative solutions for the successful deployment of subsurface low-carbon energy sources while protecting groundwater and related ecosystems.

SMILE is researching eleven innovative geo-energies projects thanks to eleven doctoral candidates that have the guidance and support of researchers and companies around Europe

Professor Philip Ringrose, Professor in Energy Transition Geoscience at NTNU, Professor Carl Fredrik Berg, PI at PoreLab, and Associate Professor Antje van der Net, associated member at PoreLab belong to the SMILE team. PoreLab is connected to two NTNU PhDs, both working on CO_2 storage.

The first PhD (Mateja Macut, photo on the right) focuses on modeling CO_2 migration using invasion percolation methods.

The second PhD (Tae Kwon Yun, photo on the left)) focuses on coupled modeling, including chemical and thermal reactions into the more traditional flow physics modeling.



In addition, ETH Zürich PhD candidate Prescelli Annan (photo on the right) is working with PoreLab on Multi-scale Fluid-Rock Interactions in reservoir and caprocks for Geological CO_2 Storage. She spent 2 months at PoreLab during the fall 2024 and will come back in 2025.

TeSCAL

Full title: Testing the foundations of special core analysis
Project leader: Bård Bjørkvik at SINTEF Industry and Antje van der Net at NTNU
Application type: Collaborative and Knowledge-building Project, Petromaks2, at the Research Council of Norway
Duration: 2025 – 2028
Partners: University of Eastern Finland and 2 oil companies

Special core analysis (SCAL) is a set of laboratory procedures to determine essential reservoir engineering properties like oil displacement, permeability and wettability by conducting flow experiments and other tests on reservoir core material. These properties – wettability in particular – are important to assess the resources in place in a reservoir, estimate fluid flow characteristics and in developing optimal strategies for hydrocarbon recovery. Wettability is the most basic rock-fluid interaction at pore level. It largely governs the mobility of reservoir fluids and their distribution in the pore spaces and thereby strongly affects conventional and enhanced oil recovery processes. The in-situ reservoir wettability is usually not known in advance and the wettability of a rock sample extracted from the reservoir may be altered unnoticed at any of several handling stages before the sample reaches the laboratory.

The aim of the project is to employ advanced mass spectrometric (MS) techniques for compositional oil analysis to develop test protocols that can characterize and reduce the uncertainty of traditional SCAL wettability preservation and restoration methods. More reliable laboratory data can have huge impact on oil recovery processes in terms of better operational decisions, both in the short and long term, less risk of failed investments and better chances of optimization, regarding oil volumes recovered and energy expended.

The project is financing one PhD position in reservoir technology/analytical chemistry at the department of Geosciences at NTNU with Associate Professor Antje van der Net, associated member at PoreLab, as main supervisor and Professor Carl Fredrik Berg, PI at PoreLab, as co-supervisor. The PhD candidate to be recruited will be working mainly in the laboratory with MS techniques to investigate how interactions between oil components and mineral surfaces influence wettability in reservoir rock. The position was advertised in the fall 2024 and the recruitment is expected at the beginning of 2025.

AGIPORE

Full Title: A Statistical Mechanics Framework for Immiscible Two-Phase Flow in Porous Media
Program: ERC (European Research Council) Advanced Grant 2023
Principal Investigator: Alex Hansen
Duration: 2025 – 2029

Viscous fingers form when a less viscous fluid invades a porous medium saturated by a more viscous fluid, creating instabilities. Two types exist: drainage, producing fractal structures, and imbibition, which retains density across scales. While drainage fingers can be modeled effectively, imbibition fingers remain challenging due to wetting film complexities. Current models rely on outdated permeability theory, prompting efforts to derive new equations that better capture pore-scale physics for large-scale applications.

If we consider porous media on the nanometer range, we will need to base our description on a molecular point of view. Moving up to the pore scale, perhaps on the micrometer scale, we need a detailed hydrodynamic/thermodynamic description of the motion of the fluids and their interfaces. Moving further up in scale, we reach the Darcy scale, perhaps measured in centimeters, where the pores seem so small that we are essentially dealing with a continuum. At this scale, it is appropriate to formulate the flow problem through effective differential equations. Lastly, we reach the reservoir scale, perhaps on the kilometer scale. In order to determine how fluids flow in the reservoir, the differential equations from the Darcy scale must be solved with the proper boundary conditions.

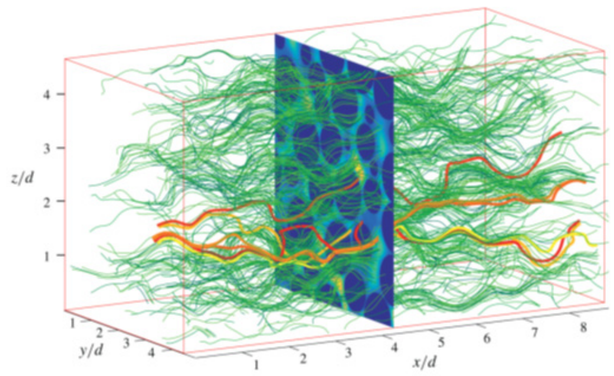


***Figure:** Streamlines of the flow field in a porous medium streaming left to right, Souzy et al. JFM 891, A19 (2020)*

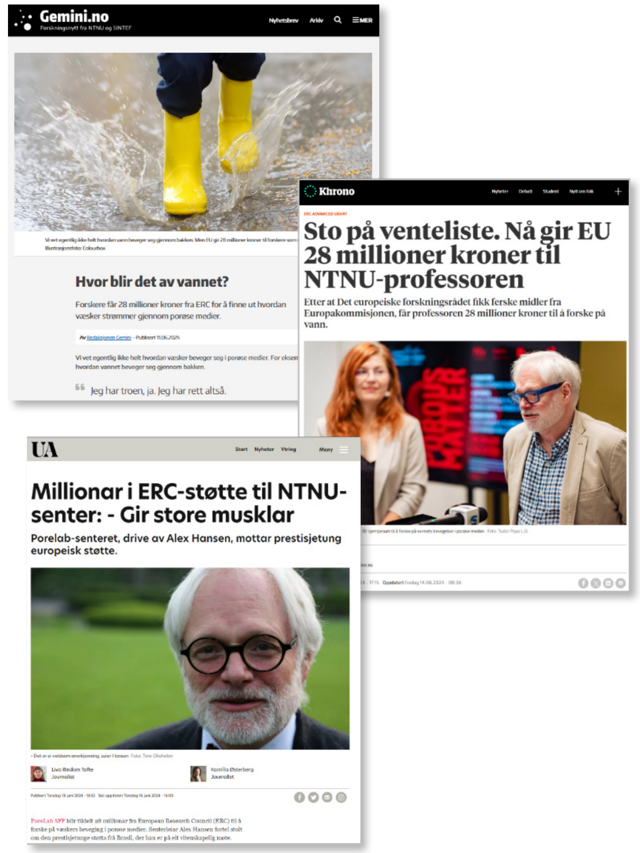
Upscaling is the central theme of AGIPORE, i.e., getting the right equations on the continuum scale. How well we reproduce viscous fingers on large scales is the test whether the upscaling was successful or not. AGIPORE's hypothesis is based on the possibility to construct an equilibrium statistical mechanics for immiscible two-phase flow in porous media, which is not in equilibrium. The main objective of the project is therefore to bring this working hypothesis to the level of a theory and to develop from it a comprehensive theory for immiscible two-phase flow in porous media at the Darcy scale derived from the pore scale physics, which is capable of faithfully reproducing viscous fingers on the Darcy scale. In other words, to develop a new theory of multiphase flow in porous media that outperforms existing theories.

AGIPORE's hypothesis opens a new direction and way of thinking in immiscible multiphase flow in porous media. It will provide tools for practical calculations that are not more complex than what is used today, but with much wider applicability. This is groundbreaking work that goes beyond existing approaches.

The project plans to recruit two PhD students, two postdoctoral researchers for three-year positions, and a five-year research position for Dr. Santanu Sinha.

An ERC (European Research Council) Advanced Grant is a prestigious research funding program awarded by the European Union to support established, leading researchers in conducting high-risk, high-gain projects across all scientific disciplines. These grants aim to enable groundbreaking, ambitious research that can push the frontiers of knowledge.

AGIPORE holds significant relevance for society, particularly in areas that directly impact our daily lives, environmental sustainability, and technological advancement. It will have wide applications in industries such as energy, water management, and environmental protection. For example, it could play a crucial role in tackling water scarcity, a major global challenge. According to a 2024 study by Jasechko et al., published in Nature, groundwater levels are declining in 71% of the 1,700 aquifers worldwide. Getting the physics of multiphase flow in porous media right will have direct applications in water resources management and could lead to better management of groundwater and contamination control. It is no surprise therefore that AGIPORE caught the attention of several popular science journals. Alex was interviewed by Gemini, Krono, and Universitetsavisa, among others:



PORELAB GRADUATE SCHOOL

TRAINING THE NEXT GENERATION OF RESEARCH LEADERS

Training of Master and PhD students, as well as of postdoctoral researchers, is a core activity at PoreLab. An essential part of NTNU's and UiO' s mission as universities, is student and researcher education. PoreLab is a valuable contributor in this respect. Our ambition is for each junior researcher at PoreLab to have a scientifically stimulating and inclusive work environment that goes beyond the standard PhD/Postdoc program. To achieve this, our researcher training program is organized across institutions and in collaboration with international partners, creating an interdisciplinary and global training platform for our junior researchers.

Training for our students and young researchers

Each student and fellow follow their regular institutional training program which includes specific demands for scientific work, supported by course work and other activities.

What sets PoreLab apart is its cluster-based approach to scientific work, centered around each PhD candidate. Each cluster naturally includes two supervisors, along with master's students, postdocs, or visiting researchers who are working on or interested in the same problem. This structure enhances collaboration, fosters interdisciplinary exchange, and strengthens professional networks, providing valuable mentoring opportunities.

National and international collaborations are strongly encouraged and actively supported among students and young researchers. The Center provides funding to host international students and researchers, as well as to enable our own students, PhDs, postdocs, and young researchers to gain experience abroad. A few examples are provided below.

PhD candidate Hristina Dragovic spent a total of 4 months at Eindhoven Technical University in the Netherlands from January to May 2024.

PoreLab researcher Santanu Sinha spent 3 weeks at the Indian Institute of Technology Guwahati (IITG) in India in February 2024 collaborating with Professor Sitangshu Bikas Santra and PhD candidate Jnana Ranjan Das on various research problems related to percolation and flow in porous media. He then attended the *FRACMEET* workshop at the Institute of Mathematical Sciences (IMSc) in Chennai in March.

Training and collaboration between PoreLab and IITG in India. From left to right: Santanu Sinha, Sitangshu Bikas Santra and Alex Hansen

Gaute Linga, a researcher at PoreLab UiO, spent a month in Brittany, France, during the fall of 2024. He first attended the Workshop on Flow in Pores and Fractures at Île-Grande, followed by three weeks at Géosciences Rennes at the University of Rennes. There, he collaborated on two projects related to mixing in porous media, working closely with Tanguy Le Borgne and Joris Heyman.

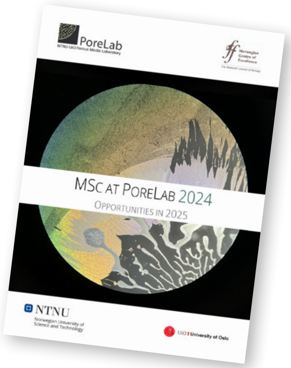
Everyone at PoreLab—including master's students, PhD candidates, and postdocs—is invited to attend, organize, and contribute to all PoreLab events, such as the PoreLab Lecture Series and the Journal Club. Junior members are encouraged to submit abstracts and present posters or talks at national and international conferences, with expenses covered by the Center.

Each year, the Center hosts numerous visitors, including renowned national and international researchers. These visits provide junior researchers with valuable opportunities to meet and engage with leading scientists. A list of visitors can be found on page 86.

PoreLab Master Students 2024

As in previous years, a dedicated catalog showcases our outstanding master's students. With backgrounds in physics, chemistry, computer science, and geosciences, they embody PoreLab's interdisciplinary nature.

The catalog offers an overview of the master's projects completed in 2024 and includes suggestions for new project opportunities. We hope it will inspire future students to join our team.



PoreLab Lecture series, Porous Media Tea Time Talk and Journal Club

The use of video conferencing grew significantly during the pandemic, enabling us to expand our pool of lecturers and leading to increased attendance. This trend continued in 2024, with no fewer than 33 lectures (see page 87 for the list). The PoreLab Lecture Series is now primarily delivered by external speakers and is consistently held online to ensure accessibility for everyone.

The PoreLab Lecture Series is scheduled alongside the Porous Media Tea Time Talks (#PorousMediaTTT), a webinar series streamed on YouTube and organized by a group of young porous media researchers, including PoreLab members. In 2024, twelve sessions of the Porous Media TTT, each featuring at least two talks, were organized.

PoreLab @ NTNU restarted the Journal Club in Spring 2024 to foster discussion and critical analysis of recent or significant research papers. Our junior researchers are given a short preparation time to help them quickly read, grasp the key content, and effectively present the papers. A key concept of the Journal Club is that all PhD candidates are required to present a paper at least once a year.

Two PoreLab courses and beyond...

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

The PoreLab course *"Experimental Techniques in Porous and Complex Systems"* (FYS4420/ FYS9420) is organized every year during the fall semester by UiO. The course gives students an introduction to important experimental techniques in the field of condensed matter physics. The teaching is based on four projects in which the students apply techniques on realistic problems in condensed matter physics. Students from NTNU travel to UiO to attend the laboratory courses with a financial support from PoreLab. The course lecturer is Professor Knut Jørgen Måløy, PI at PoreLab.

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

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

Postdocs are offered a variety of courses and workshops suitable for their career plan at the host institutions, NTNU and UiO. Examples are courses on PhD supervision, or workshops on publishing practice in international journals.

Pedagogical courses, offered by UNIPED (NTNUs Educational Development Unit) may be relevant.

Additional external courses and workshops can be funded for our students and young researchers when needed. As an example, several PoreLab juniors attended the 6th Cargèse Summer school on FLOW and Transport In porous and fractured MEdia (FLOWTIME). Jointly organized by CNRS, NSF, the university of Rennes and the university of Oslo, it took place from June 10 to June 21, 2024 at the Cargèse Institute in Corsica in France. The summer school particularly focused on life supporting functions of the subsurface at interfaces between hydrology, geophysics and biological processes. It combined lectures and research seminars (see picture above).

PoreLab Junior forum

The PoreLab Junior Forum was founded by and is led by the junior members themselves. Its primary goal is to bring together PhD students, postdocs, and early-career researchers at PoreLab, fostering greater interaction and allowing them to share their work and scientific interests. The forum plays a crucial role in connecting the two PoreLab hubs in Oslo and Trondheim. Held annually, the forum enhances opportunities for scientific collaboration and networking.

The 2024 Junior Forum was postponed several times due to various events, but it finally took place in Trondheim on January 24th, 2025. Tage Maltby, a PhD candidate at PoreLab NTNU and the organizer of the 2024 edition, summarizes the event as follow: *"On Friday, January 24th, the PoreLab Junior Forum gathered for the PoreLab Junior Forum. The forum was primarily held at Scandic Lerkendal, where the conference room overlooked Lerkendal*

Stadium. Each junior presented their topic of interest—often with a dash of humor—and answered questions from other members. Lunch was enjoyed, and the afternoon sessions consisted of juniors offering each other advice and discussing the experiences of young researchers. In the evening, the juniors gathered at PoreLab for a silly quiz, and the day concluded at a restaurant, followed by a visit to a bar where games like shuffleboard were enjoyed".

WORKSHOPS AND CONFERENCES

Researchers at PoreLab have numerous opportunities to present their scientific activities and research results to both internal and external events. We list in the following pages the meetings and specialized workshops organized by PoreLab members alongside other experts in their field in 2024, as well as important events for PoreLab.

INTERPORE NORWAY, STAVANGER, 5 DECEMBER 2024

The 7th meeting of the Norwegian Chapter of InterPore took place in Stavanger on December 5th, 2024. Organized by Siv Marie Åsen, Johan O. Helland, Lisa Watson, Sarah Gasda, and Aksel Hiorth (Chair), the event was hosted by NCS2030 and the University of Stavanger. Around 40 participants attended the annual workshop, representing a well-balanced mix of academia, industry, and research institutes—both among attendees and speakers. During the closing business meeting, Alex Hansen and Marcel Moura stepped down from the board after eight successful years of helping to establish and shape InterPore Norway. Elections were held to appoint their successors, with Paula Reis, a researcher at PoreLab UiO, and Santanu Sinha, a researcher at PoreLab NTNU, being elected.

LII WINTER MEETING ON STATISTICAL PHYSICS, PUEBLA, MÉXICO, 10–13 JANUARY 2024

Alex Hansen was an invited speaker at the 52th Winter Meeting on Statistical Physics organised by the Statistical Physics and Thermodynamics Division of the Mexican Physical Society. The meeting was organised on January 10 to 13, 2024, in Puebla in México. This 52th chapter featured worldwide experts and an online keynote lecture by the 2021 Nobel Laureate, Giorgio Parisi. Alex gave a talk on *Statistical Mechanics of Immiscible Two-Phase Flow in Porous Media*.

INTERPORE 2024, QINGDAO, CHINA, 13–16 MAY 2024

As a long-standing partner of InterPore, PoreLab is a regular participant in InterPore conferences. The 16th Annual Meeting was held in Qingdao, China, from May 13 to 16. The theme of InterPore 2024, "Porous Media and Biology", explored occurrence and applications of biology in living organs, plants, and in medicine, as well as in soil, oil and gas reservoirs.

PoreLab members contributed significantly to the conference, delivering a total of nine presentations. Among them, Alex Hansen gave an invited talk titled "*What is the co-moving velocity, and why should we care?*"

Subhadeep Roy, former postdoc and researcher at PoreLab, now assistant professor at Birla Institute of Technology and Science in India, held a mini-symposia on "*Interfacial phenomena across scales*".

WORKSHOP ON FLOW IN PORES AND FRACTURES, BASE NAUTIQUE DE L'ILE GRANDE, FRANCE, 16–20 SEPTEMBER 2024

The workshop on Flow in Pores and Fractures was organised jointly by Tanguy Le Borgne, adjunct Professor at the Njord Center, UiO, and Professor at Géosciences Rennes at the University of Rennes, France, togeher with Joris Heyman, Scientist at Géosciences Rennes at the Base Nautique of Ile Grande in France. This 5-day workshop welcomed several researchers from PoreLab and the Njord Center. Several sessions were reserved for article reshuffling: the main idea was for early career researchers to bring the draft of an article they are working on, send it to the organizer one week before the workshop, and have it presented by another early career researcher with five slides. Sailing class and low tide fishing were also organised.

FRICFRAC CONFERENCE, FRICTION AND FRACTURE AND THE ONSET OF GEOHAZARDS, 17–19 JUNE 2024

The FricFrac Conference 2024, organized by Professor François Renard, Director of the Njord center, was held at the Norwegian Academy of Science and Letters. It convened experts to discuss friction, fracture, and the onset of geohazards. The program featured sessions on earthquake mechanics, glacier and landslide instabilities, the physics of fracture, friction, and creep, flow in complex media and microstructures controls on deformation processes. The FricFrac project's research sheds light on the dynamics of geohazards, providing new understanding of landslides, earthquakes, and glacier surges.

WORKSHOP ON NON-NEWTONIAN FLOW IN POROUS MEDIA, BANFF, CANADA, 14–19 JULY 2024

In 2020, the Research Council of Norway awarded PoreLab an INTPART project on Non-Newtonian Flow in Porous Media. This initiative was developed in collaboration with Université Paris-Saclay (France) and Universidade Federal do Ceará (Brazil). The project facilitates the exchange of master's students, PhDs, postdocs, and researchers while also supporting the organization of two major workshops.

The first workshop took place in Fortaleza, Brazil, from June 28–30, 2022 (see PoreLab Annual Report 2022, page 69).

The second and significantly larger workshop was held at the Banff International Research Station in the Canadian Rocky Mountains from July 14–19, 2024. This event was a collaborative effort between the Universities of British Columbia, Purdue, Princeton, Paris-Saclay, and PoreLab.

The objective of the meeting was to bring together experts in different fields, complex fluids mechanics, porous media, statistical physics to share their different approaches and advances. Calling it a success would be an understatement: more than 80 participants attended (some virtually), 46 scientific presentations were delivered, and ample opportunities for networking and discussions were provided. PoreLab was represented with eight participants, all of whom gave talks. The workshop also fostered new and valuable collaborations. For instance, after meeting Associate Professor Davide Picchi from the University of Brescia (Italy) at the event, PoreLab is now hosting his PhD student, Paolo Botticini, for a six-month research stay at PoreLab.

Banff International Research Station for Mathematical Innovation and Discovery

3 YOUNG CAS WORKSHOPS, JANUARY, MAY AND OCTOBER 2024

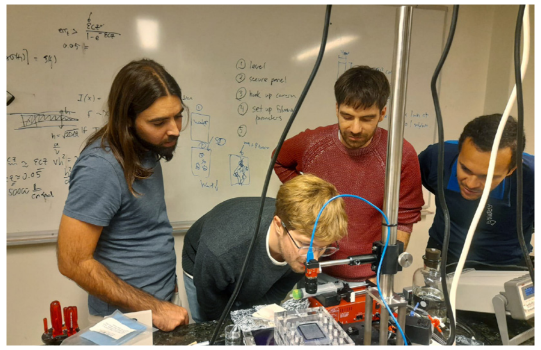
Last year, Dr. Gaute Linga, PI at PoreLab, received a one-year grant from the Center for Advanced Study (CAS) at the Norwegian Academy of Science and Letters (see PoreLab annual report 2023 page 61).

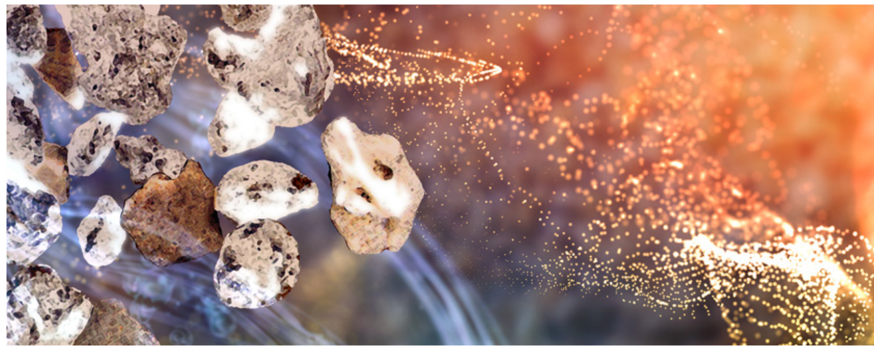
His Young CAS project, titled "Mixing by interfaces: How does water infiltration control mixing and reaction in soils?" aims to address the fundamental challenge of understanding and predicting mixing and reaction dynamics during dynamic infiltration in soils.

As part of the project, three workshops were organized throughout the year, all at CAS:

- First workshop (January 29 – February 2): this inaugural workshop brought together experts to delve into the complex interactions occurring beneath the Earth's surface, focusing on the partially water-saturated soil region that extends down to the water table. This crucial layer influences the flow of nutrients and contaminants into the Earth's aquifers. Traditionally, understanding of mixing and reaction at the pore scale has been limited to steady flow conditions; however, this workshop emphasized the dynamic nature of infiltration, aiming to redefine existing paradigms.
- Second workshop (May 21–24): this gathering built upon the insights from the first workshop. Participants engaged in collaborative discussions and presentations, further exploring the dynamics of water infiltration and its impact on soil mixing and reactions.
- Third Workshop (October 21–25): Titled "Quantifying Mixing and Reaction in 2D Systems, Gearing Towards 3D Systems". The program included a series of talks by experts such as Marcel Moura, Guillem Sole-Mari, Tomás Aquino, Tanguy Le Borgne, Kevin Pierce, Manuel Maeritz, and Alexandre Puyguiraud. Topics ranged from theoretical models to flow simulation cases, experimental data analysis and simulations analyzing of the full 2D problem. The workshop also featured open discussions, collaborative work sessions, and plans for future research directions.

Centre for Advanced Study at The Norwegian Academy of Science and Letters

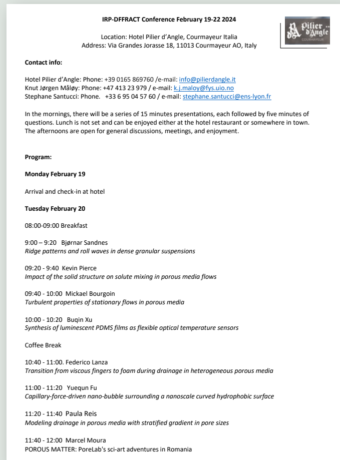




IRP-DFFRACT CONFERENCE, 19–22 FEBRUARY 2024, COURMAYEUR, ITALY

The IRP-DFFRACT Conference 2024 was organized by Professor Knut Jørgen Måløy, PI at PoreLab, and Stéphane Santucci, CNRS Researcher at the Ecole Normale Supérieure of Lyon, France. It was held at the Hotel Pilier d'Angle in Courmayeur in Italy.

PoreLab researchers were heavily involved with a series of talks from Marcel Moura, Kevin Pierce, Federico Lanza, Yuequn Fu, Paula Reis, Gaute Linga, Yao Xu, Renaud Toussaint and Eirik G. Flekkøy.



IRP-DFFRACT Conference February 19-22 2024

Location: Hotel Pilier d'Angle, Courmayeur Italia
Address: Via Grandes Jorasse 18, 11013 Courmayeur AO, Italy

Contact info:

Hotel Pilier d'Angle: Phone: +39 0165 869760 /e-mail: info@pilierdangle.it
Knut Jørgen Måløy: Phone: +47 413 23 979 / e-mail: k.j.maloy@fys.uio.no
Stephane Santucci: Phone. +33 6 95 04 57 60 / e-mail: stephane.santucci@ens-lyon.fr

In the mornings, there will be a series of 15 minutes presentations, each followed by five minutes of questions. Lunch is not set and can be enjoyed either at the hotel restaurant or somewhere in town. The afternoons are open for general discussions, meetings, and enjoyment.

Program:

Monday February 19

Arrival and check-in at hotel

Tuesday February 20

08:00-09:00 Breakfast

9:00 – 9:20 Bjørnar Sandnes
Ridge patterns and roll waves in dense granular suspensions

09:20 - 9:40 Kevin Pierce
Impact of the solid structure on solute mixing in porous media flows

09:40 - 10:00 Mickael Bourgoin
Turbulent properties of stationary flows in porous media

10:00 - 10:20 Buqin Xu
Synthesis of luminescent PDMS films as flexible optical temperature sensors

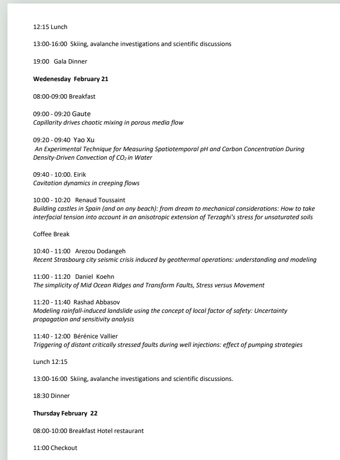
Coffee Break

10:40 - 11:00. Federico Lanza
Transition from viscous fingers to foam during drainage in heterogeneous porous media

11:00 - 11:20 Yuequn Fu
Capillary-force-driven nano-bubble surrounding a nanoscale curved hydrophobic surface

11:20 - 11:40 Paula Reis
Modeling drainage in porous media with stratified gradient in pore sizes

11:40 - 12:00 Marcel Moura
POROUS MATTER: PoreLab's sci-art adventures in Romania



12:15 Lunch

13:00-16:00 Skiing, avalanche investigations and scientific discussions

19:00 Gala Dinner

Wedenesday February 21

08:00-09:00 Breakfast

09:00 - 09:20 Gaute
Capillarity drives chaotic mixing in porous media flow

09:20 - 09:40 Yao Xu
An Experimental Technique for Measuring Spatiotemporal pH and Carbon Concentration During Density-Driven Convection of CO_2 in Water

09:40 - 10:00. Eirik
Cavitation dynamics in creeping flows

10:00 - 10:20 Renaud Toussaint
Building castles in Spain (and on any beach): from dream to mechanical considerations: How to take interfacial tension into account in an anisotropic extension of Terzaghi's stress for unsaturated soils

Coffee Break

10:40 - 11:00 Arezou Dodangeh
Recent Strasbourg city seismic crisis induced by geothermal operations: understanding and modeling

11:00 - 11:20 Daniel Koehn
The simplicity of Mid Ocean Ridges and Transform Faults, Stress versus Movement

11:20 - 11:40 Rashad Abbasov
Modeling rainfall-induced landslide using the concept of local factor of safety: Uncertainty propagation and sensitivity analysis

11:40 - 12:00 Bérénice Vallier
Triggering of distant critically stressed faults during well injections: effect of pumping strategies

Lunch 12:15

13:00-16:00 Skiing, avalanche investigations and scientific discussions.

18:30 Dinner

Thursday February 22

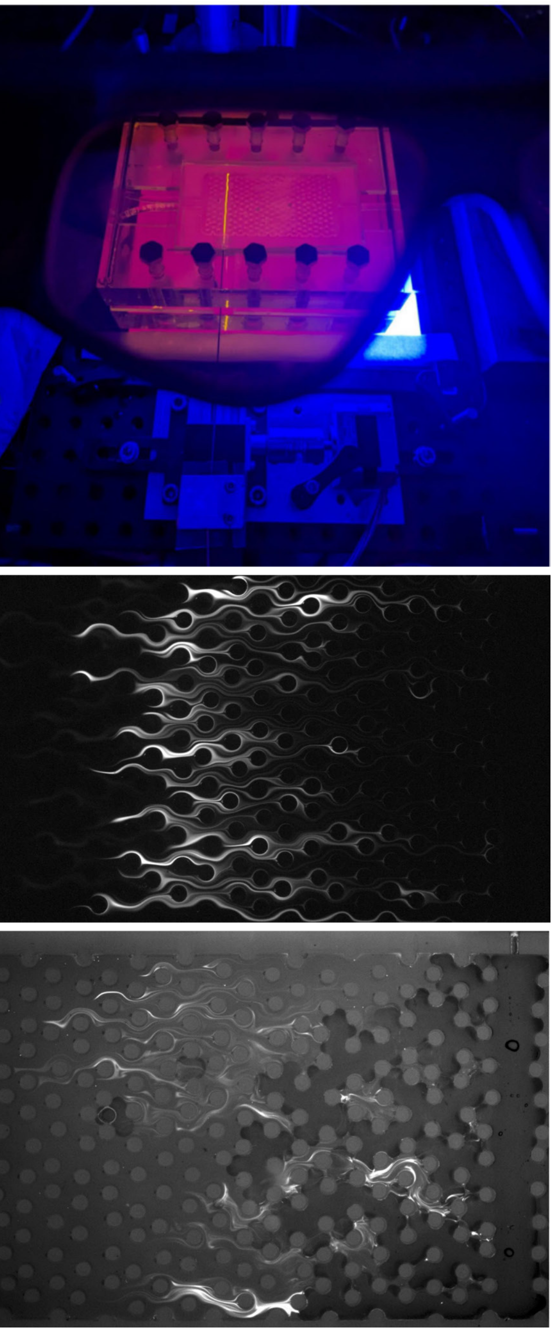
08:00-10:00 Breakfast Hotel restaurant

11:00 Checkout

LABORATORIES

As technology advances and the technical staff expands, our laboratories have undergone significant upgrades. They continue to provide excellent working conditions and are equipped with state-of-the-art equipment and instrumentation.

NEW LAB FACILITIES FOR FLUORESCENCE-BASED IMAGING OF POROUS MEDIA FLOWS



At the Oslo node of PoreLab, we now have a state-of-the-art fluorescence-based imaging system for studying flow and mixing in porous media. The table-top setup and technique was developed by PoreLab researcher Kevin Pierce in collaboration with partners at UiO and the University of Rennes. It allows us to investigate fundamental questions such as: *How do chemical solutes mix within fluid flow through a porous medium? How do flow conditions (single phase vs. multiphase, steady vs. transient) affect the mixing dynamics?* The idealized experimental system represents for example how a streak of pollution enters a wet soil and disperses into the surrounding water. Our fluorescence-based imaging system captures high-resolution images of multiphase porous media flows, revealing solute mixing, flow dynamics, and interface motion with precision, making it an excellent complement to the existing imaging techniques at PoreLab.

In the accompanying figure, the top panel shows a 3D-printed experimental setup viewed through filtering goggles, where a fluorescent solute, appearing in bright green, is introduced. The solute's transport and mixing depend on several factors. When a single-phase fluid flows through the system, as seen in the middle panel, the solute moves and mixes in a relatively smooth manner. However, when two phases are present, a much more intermittent and complex mixing pattern emerges, as shown in the bottom panel. Our setup allows us to precisely image local solute concentrations and the subsequent mixing by using the Hamamatsu ORCA®-Flash4.0 LT3 Digital CMOS camera. This camera provides low readout noise, high-speed readout, a large field of view, and high resolution, ensuring that subtle variations in fluorescence intensity are accurately captured. With its 16-bit depth, it can record a much wider range of brightness levels, which is particularly useful for fluorescence imaging where local concentration gradients are crucial.

With these capabilities, our new imaging system significantly enhances our ability to study transport and mixing in porous media, providing new insights into a host of natural and industrial processes in single- and multiphase flow.

Figure: *Fluorescence-based imaging of solute transport and mixing in porous media. (Top) A 3D-printed experimental setup viewed through filtering goggles, where a fluorescent solute (bright green) is introduced. (Middle) Solute transport and mixing in a single-phase flow where the gradients in solute concentration are clearly seen. (Bottom) Solute transport and mixing in two-phase flow, exhibiting more intermittent and complex mixing dynamics. This system enables precise visualization and quantification of solute concentrations and flow structures in porous media.*

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

Phase contrast X-ray computed tomography (CT)

A new custom-made CT instrument that utilizes phase variation as the main contrast mechanism is under commissioning at the X-ray Physics Group. The instrument adds to the existing setups in the group *viz.* attenuation-based CT, X-ray scattering setup, and Fourier ptychographic microscope. The X-ray source is the state-of-the-art Excillum Nanotube N2 110 kV capable of having 150 nm spot size, giving significant spatial coherence. The detector is a combination of a Hamamatsu Orca-Flash4.0 camera and a scintillator from Optique Peter. The setup will facilitate 3D imaging of soft materials with high spatial resolution of 200 nm when fully optimized. The first images from the setup are shown in Fig. 1.

Core flooding setup for in situ fluid dynamics

Another new development of the lab is the design and building of a core flooding setup that can be used for in-situ fluid dynamics experiments inside our CT instrument. In general, core flooding setups are used to study the injection of one of more fluids into a porous rock, under an environment with controlled temperature and fluid injection pressure. This setup is specifically designed to be compatible with supercritical CO_2, which is the relevant phase for underground storage in the North Sea. Fluids enter the supercritical phase when they are at a temperature and pressure above the critical point, where the distinct liquid and gas phases do not exist. This setup is currently built for fluid pore pressure up to 100 bar and temperatures up to 50°C. It is under commissioning, and we look forward to doing experiments as an integral part of our own research activities and also welcoming external users.

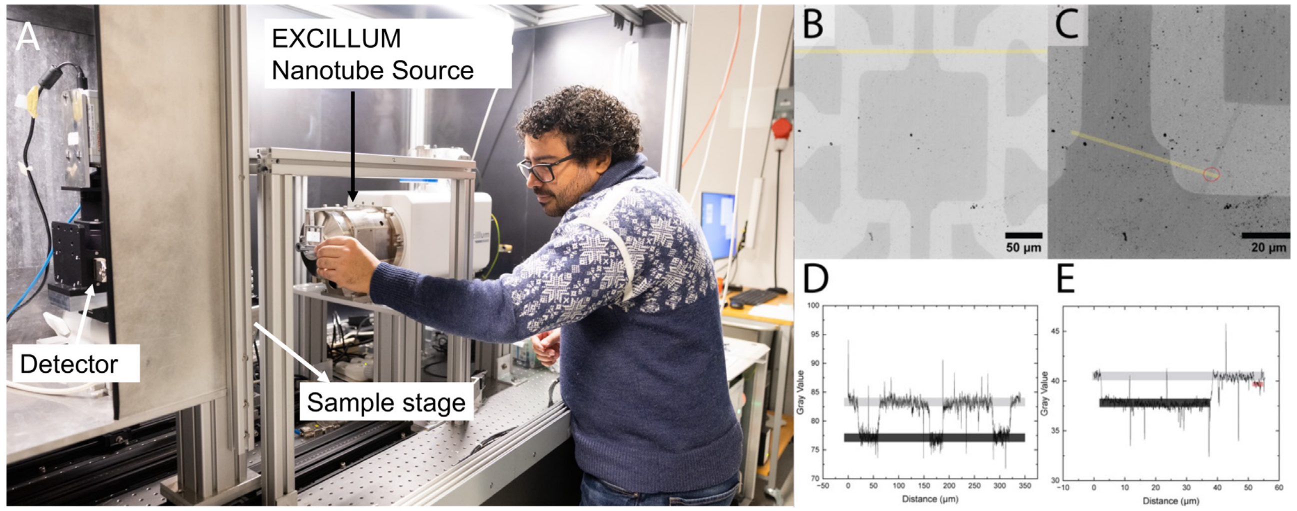


Figure 1: *(A) Picture of the Phase Contrast setup, showing the detector, the sample stage and X-ray source with our engineer Osvaldo Neto. Two radiographs of a microchip are shown in (B) and (C) with the red circle pointing to a thin wire (ca. 2µm). The line profiles of the yellow lines are shown in (D) and (E), indicating promising sub-micron resolution.*

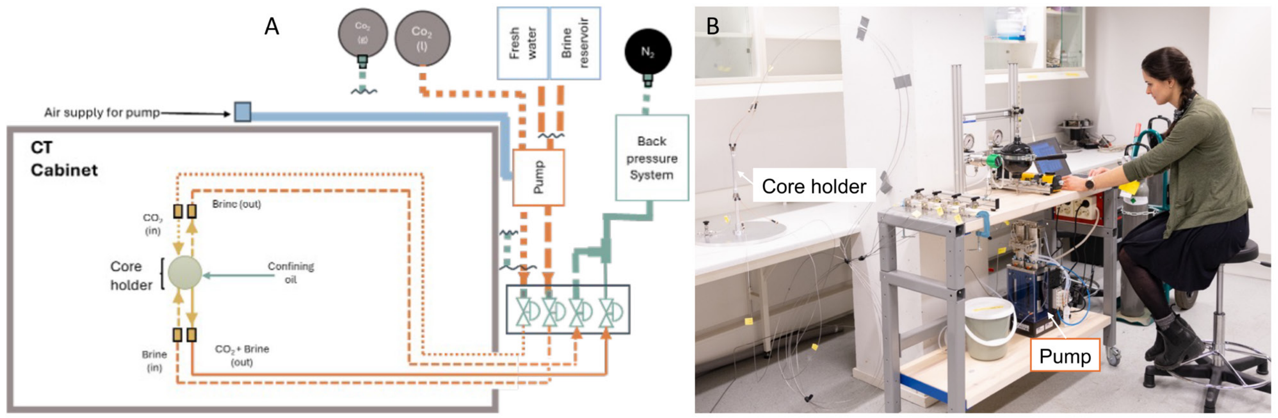


Figure 2: *(A) Schematic drawing of the core flooding setup. (B) The complete setup being tested in the laboratory by PhD candidate Jessica Zeman.*

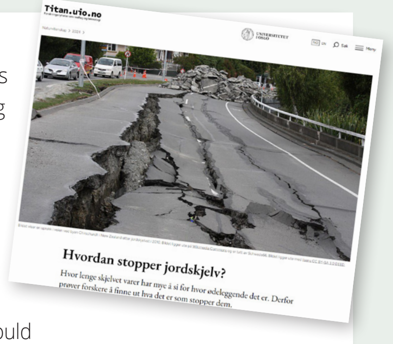
OUTREACHS

A key objective of PoreLab is to share its research and discoveries, while also fostering a greater appreciation and understanding of science overall. These next pages highlight some of the activities PoreLab scientists were involved in throughout 2024.

On February 2nd, 2024, **Kim Robert Tekseth**, PhD candidate in the X-ray physics group at NTNU presents to Gemini how to create a 3D film of fluid flow. By using X-ray microscopy, his research team has successfully created a 3D film that captures the microscopic behavior of liquid as it drains out from a porous medium. They have set a "world record" by measuring this process approximately 1000 times faster than anyone has previously achieved, allowing a study of the process in slow motion. This new method was achieved in collaboration with the international X-ray source ESRF in Grenoble and resulted in an article published in PNAS.


Gemini.no
Verdensrekord hjelper oss å studere porøse materialer

There are two key questions when it comes to understanding earthquakes: How do they start, and how do they stop? The latter is especially important, as the duration of an earthquake plays a significant role in its level of destruction. If researchers can predict when and how an earthquake will cease, they could offer more accurate warnings to those in its path. This is the insight shared by **Fabian Barras**, a Postdoctoral Researcher at the Njord Center at UiO, in an interview with Titan on March 11th, 2024.


Titan.uio.no
Hvordan stopper jordskjelv?

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 Bluesky as well, and YouTube

On April 18th, 2024, the French Minister of Higher Education and Research, Sylvie Retailleau, and the French Ambassadress to Norway, Florence Robine, visited the Njord and PoreLab laboratories at the University of Oslo. The purpose of the visit was to discuss cutting-edge research and collaborations between UiO and France. Centre director François Renard presented groundbreaking research projects and highlighted several joint initiatives with French researchers, including the ERC DIME and BREAK projects, the INTPART project COLOSSAL, the International Research Project D-FFRACT co-funded by the CNRS, and student training through the Erasmus+ programme. Researcher **Marcel Moura** demonstrated experiments on viscous fingering and steady-state flows. Marcel says: *"I learned that both the minister and ambassadress have background in physics and the minister was rector of the University Paris-Sud. She had a bunch of questions and seemed pretty interested so this was good fun"*. Overall, the visit was an excellent opportunity to showcase the groundbreaking research and collaborations between Norway and France taking place at Njord and PoreLab.

Carl Fredrik Berg, PI at PoreLab, was invited to Bangkok and Chiang Mai by the Royal Thai Embassy in Oslo together with Cathrine Ringstad from Bellona. The first part of the trip was the *"International CCS symposium: A "supercritical" research toward industrial solution"* in Bangkok June 6th 2024.

This invitation was a response to the visit of the Chang Mai University to NTNU last year (see annual report 2023 page 74). During the symposium, Carl Fredrik Berg and Cathrine Ringstad gave an overview of the history of CCS in Norway and how academia, NGOs, industry and the government policies have been collaborating to shape CCS projects. During the same symposium, Carl Fredrik Berg participated to a panel on research, current and future challenges.

The second part was a visit to Chiang Mai CCS at CMU, June 7–8 2024. Carl Fredrik Berg and Cathrine Ringstad gave lectures, visited the reservoir lab and discussed their set-up for core flooding with supercritical CO_2.

Carl Fredrik says that as an international participant, it was very interesting to observe status and plans for emission reductions in Thailand, in particular the plans for CCS.

"Waste heat from industrial processes is an enormous resource," says **Kim Kristiansen** to Gemini on June 11th, 2024. Kim has recently completed his PhD at PoreLab NTNU on a technology that can capture some of the waste heat that is currently being squandered. Today, nearly all the heat generated by industrial processes is released directly into the air or the sea. And it's no small amount. In Norway alone, industry produces around 20 TWh of waste heat every year. That figure might be hard to grasp, but according to the Norwegian Water Resources and Energy Directorate (NVE), it's equivalent to half of the total electricity consumption of all households in the country combined—enough to meet nearly the entire demand for heating.


Gemini.no
Spillvarme fra industrien kan varme alle hus i Norge

The School Laboratory (Skole-Laboratoriet) at NTNU offers virtual meetings with researchers through an initiative called "Researchers on Screen" (Forsker på Skjerm). This opportunity is available for VG2 and VG3 students (equivalent to junior and senior years of high school) in biology, physics, geoscience, and chemistry programs.

Bringing scientific culture and researcher close to pre-university educational levels and promoting research vocation is of great importance to PoreLab.

Embracing this initiative, Alex Hansen volunteered for *Researchers on Screen* to deliver three talks titled *"Where Does the Rain Go?"* during the fall of 2024. He gave one lecture in person at Byborgen School in Trondheim and the remaining two remotely for Greåker High School.

SKOLE-LABORATORIET

The Kavli Prize is a partnership between The Norwegian Academy of Science and Letters, The Kavli Foundation (US) and The Norwegian Ministry of Education and Research. The Kavli Prize honors scientists for breakthroughs in astrophysics, nanoscience and neuroscience – transforming our understanding of the big, the small and the complex.

The Kavli Prize Nanoscience Symposium 2024 was held on September 5th, 2024 in Trondheim. **Erika Eiser**, PI at PoreLab was invited to give a talk at the *Symposium on Whole Genome Detection Using Multivalent DNA-Coated Colloids.*

THE KAVLI PRIZE

INTERPORE TIME CAPSULE INTERVIEW WITH PROFESSORS SIGNE KJELSTRUP AND DICK BEDEAUX

Both Professors Signe Kjelstrup and Dick Bedeaux were invited by InterPore in 2024 in joining the InterPore Time Capsule Series. These interviews are meant to act as inspirations to the younger generation of porous media scientists. InterPore selects interviewees who have made long-lasting and major contributions to porous media science and engineering in the course of a rich career. The interview was performed by Professor Alex Hansen, Director of PoreLab and the video was edited by Per Hennig, webmaster at the Faculty of Natural Sciences at NTNU. The video was published by InterPore prior to their 16th Annual Meeting in Qingdao. In these three double pages we present the transcripts of the interview.

Interviewer
Professor Alex Hansen

Participants
Professor Signe Kjestrup
Professor Dick Bedeaux

Video editing
Per Henning

Photo: *Professor Dick Bedeaux and Professor Signe Kjestrup*

NTNU
Norwegian University of Science and Technology

Alex Hansen
This interview is in the Interpore Time Capsule Series, where people behind important contributions to porous media science tell the background history. And I'm here with Signe Kjelstrup and Dick Bedeaux, who have done important contributions to irreversible thermodynamics on transport phenomena, across surfaces and interfaces. They have more recently developed the thermodynamics of confined fluids in nano-porous media based on the Hill approach. Before we get into what these contributions are, let's delve into their respective backgrounds.

Signe, we start by your background. So why science, why chemistry and why irreversible thermodynamics?

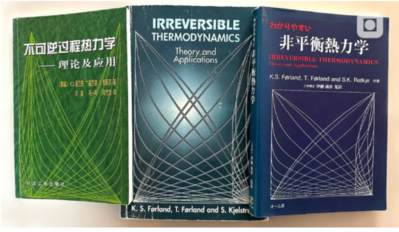
Signe Kjelstrup
As you know Alex, I was growing up in the north of Norway and to do that makes a spectacular impression on a child because nature and everything is so dramatic: the midnight sun, the polar light, you name it. So, I was always interested in nature and my father fostered that. He had radio lectures on astronomy, and I thought that this was fascinating when I looked at the Northern light. He also encouraged me to study science. He advised me to come to the Norwegian University of Sciences and Technology.

But when I came here and about to start in physics, there were no female professors and there were only a few out of the about thousand students starting in physics that were women, 2, I think. The advice from friends of my father was no, "She will not get a job". So, I started chemistry, but there is such a thing as physical chemistry where I ended.

Then, I was only in my second year when there was a big event on the campus and that was on the occasion of the Nobel Prize to Onsager in 1968.

I could not enter the lecture, but my coming thesis advisor did, and he was very enthusiastic. So, when I eventually found him (Tormod Førland) as a teacher, he said to me: "Let us do something in this field". Then, we decided to seek for applications in chemistry.

Alex Hansen
Thank you. I note that your first book, Signe, was Irreversible Thermodynamics 'without tears' from 1988. Who did you write it for?



Signe Kjelstrup
Irreversible Thermodynamics 'without tears', the 'tears' were what we hoped to avoid with the chemists. Big efforts were put into writing the book as clearly or simple as possible. My co-author, professor Kathrine Seip Førland, should be mentioned in that respect.

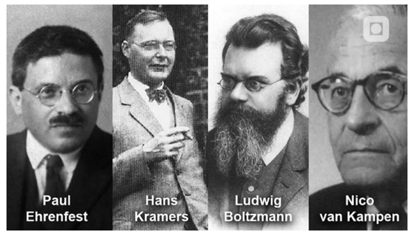
Alex Hansen
Why is it that irreversible thermodynamics is part of the field of chemistry much more than physics?

Signe Kjelstrup
What is essential in irreversible thermodynamics compared to the simple transport laws we had before, like Fick, Fourier, Ohm and Darcy, is that irreversible thermodynamics introduces coupling, and coupling is much more important in chemistry. You can't have a process across a membrane of an ion without it dragging along water, so you immediately have coupling. There is also coupling to charge, and to chemical reactions. To describe this, the full matrix (of coefficients) is actually needed, for example to describe a lithium battery like we have just published. So, I think that the physicists are not so much in need of this coupling, that's why there is a difference.

But when that is said, I really wish that the subject should be taught, because it has also *other aspects. It gives a precise definition of the second law, not as an inequality but as a precise analytical expression. The world is needing that, in its effort to obtain better energy efficiency of processes.*

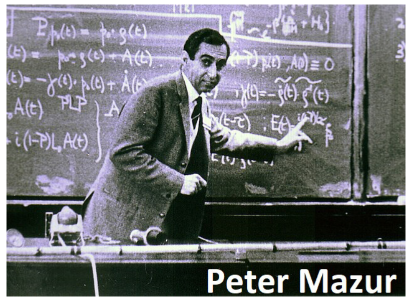
Alex Hansen
Dick, your background, you originate from the strong Dutch tradition in statistical mechanics.

Dick Bedeaux
The tradition for me in a sense started by Ehrenfest who is, scientifically, my great grandfather and my grandfather was then Kramers. And my scientific father, Nico van Kampen, was my thesis advisor. He was a person that was extremely clear in his lectures, defining concepts properly, clearly, and so that attracted me. That made that I ended up being his graduate student. Now, that was not quite as easy as you would like. I mean it was difficult to get to talk to him, and in that sense, he was a difficult thesis advisor, but he made me strong because I had to explain things to him very well whenever I then got the opportunity. By the time I had my thesis kind of nearing the end, he disappeared for sabbatical to the USA. In that time, he clearly never read what I was sending him because when he came back, he had, according to his notes in what I had sent him, read it until page 14. Then he asked me: "Is the rest also correct?". I was by that time hard enough to say: "Of course otherwise I wouldn't have written it". Then he said: "Well, you rewrite it a bit and then you should make an appointment for your defense", which I then did.



Alex Hansen
I remember meeting Nico van Kampen once and he was clearly quite a character. How was it to be a graduate student with him?

Dick Bedeaux
van Kampen was very clever and in that sense a wonderful thesis advisor. However, he was also difficult. He, himself, got his degree with Kramers, who got his degree with Ehrenfest, who got his degree with Boltzman. My scientific heritage is, in that sense, very much into statistical mechanics. Of course, van Kampen was very good in statistical mechanics. He was a little bit strange in the sense that he would tend to not believe anything that other scientists in the field would do. He would explain us that the Kubo relations were wrong, and why they were wrong. Of course, that was very stimulating because I immediately studied the Kubo relations and I saw that they were perfectly OK. In that sense, it taught me to disagree with him. In addition to that, he had of course much against the work of Prigogine. I also studied that, and I fear that, there, I agreed to a large extent with him.



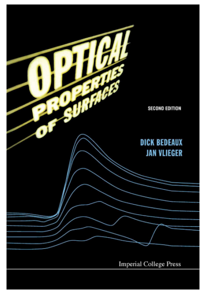
After my thesis I went to America. When I came back, I worked with Peter Mazur. Of course, Peter Mazur was a very good friend of Prigogine. He also disagreed with Prigogine on these things but that was all extremely interesting.

But Nico van Kampen was, in a sense, interesting because he always tried to not see me. If I would ask him to talk to me, he would say yes but then he would run away. So, I taught myself to corner him such that he could not run away. When he would say yes, I would say: "What about this afternoon?" Then he would – kind of – say yes again, and then run away again! But then I had an appointment.

He had a very clear tendency to do everything using differential equations. After his advice trying to do that did not work, I went other ways. I used linear perturbation theory of operators which is an extremely interesting field. Van Kampen did not like it. But I used it to prove what I had to prove. That was the reason, I think, when I got my thesis ready, why he escaped to America for a sabbatical. When he came back, he had read the first 14 pages, and said to me: "You have to rewrite it, but is the rest also correct?" and I said: "Yes, otherwise, I would not have written it" and he said: "After you have re-written it, you can make your appointment for a defense". That was Nico van Kampen!

Alex Hansen
Dick, you have written a book on light scattering from rough surfaces. Where does that fit into your career?

Dick Bedeaux
That was in fact a very important moment and it related to the observation that in order to describe surfaces you need excess densities, and in that particular case, it was the polarization. You had an excess polarization along the surface and an excess polarization parallel to the surface. The excess polarization parallel to the surface causes actually the dielectric constant to have a singularity at the surface. The parallel dielectric constant causes the electric field not to be continuous across the surface. In the normal direction, there is a polarization normal to the surface, but that finds its origin in the inverse dielectric constant which has to have a singularity. And that causes the displacement field to be discontinuous at the surface. After all the work I did with Jan Vlieger on the subject, we wrote a book about that subject.

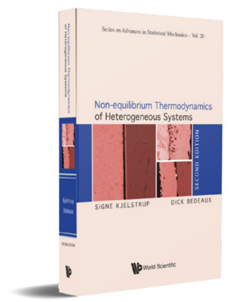


But meanwhile I had also realized the work that Gibbs had been doing, in which he defines excess densities. He had only been doing that for equilibrium systems and you could extend that. In addition to have excess densities of variables, you could also have excess fluxes along the surface and that makes it possible to develop non-equilibrium thermodynamics for surfaces where quantities like the normal fluxes (i.e. fluxes normal to the surface) are all the sudden scalar. They are no longer vectorial, and they can therefore directly couple to the reactions at the surface. Also, the temperature difference across the surface can drive the reactions at the surface.

I started to work with Albano and with Mazur on formulating non-equilibrium thermodynamics for surfaces. That drove the attention of for instance Majid Hassanizadeh, an important person in Interpore. He came to Leiden to discuss exactly this work about non-equilibrium thermodynamics and transport for surfaces, along and through surfaces. (This was).. in his quest to derive equations on the macro level – the Darcy level – for porous media, starting with the description in the pores. In the pores of course, the surfaces and lines are important, therefore he consulted me. That was a very interesting discussion, but it took I fear, another 15 years before you, Alex, personally, got me and Signe going into doing non-equilibrium thermodynamics for porous media.

Alex Hansen
Your first common book was on Irreversible Thermodynamics of heterogeneous systems. Please explain.

Signe Kjelstrup
When we first met and discussed, it was clear that we didn't understand each other. I came from the chemistry background, and he came from the statistical mechanical background, but we did understand that there was something to gain by combining our experiences, because everything in chemistry happens at interfaces. The catalyst interface, the electrode, the membrane, the interfaces are crucial. And here he was with all this knowledge about how things should be properly written for the interface.



Dick Bedeaux
The work for this book made me realize that one needed excess densities and fluxes for a proper description of transport through and along the surface. The reason I wanted to talk to Signe about this issue was that in order to derive Maxwell's equations for the surface, you have to use the Maxwell equations in vacuum, which are Lorentz invariant. However, the description for the surface is Galilean invariant. That implies that you have to neglect certain things and I was seeking advice on what would be important or not. Now, it was clear that this question was not a question to put to chemists. But I did listen to her, and it was clear that she understood what she was talking about, and that made me eager to get closer to experimental interpretation of matters at the surface, and then to talk again. And the book is the result!

Signe Kjelstrup
Yes, so the book is an extension of the irreversible thermodynamics for bulk phases, like everybody had been doing it after Onsager. We extended it such that we could deal with the dynamic surface. That is the extension, the combination of the two things: the bulk and the surface. And this is our big contribution, I think, to transport.

Dick Bedeaux
The surface can move, and the fluxes on both sides have velocities that are different from the velocity of the surface. The whole theory has to deal with that and not in the barycentric frame of reference as de Groot and Mazur typically do. You have to do it in the frame of reference of the surface. That's an important ingredient in getting an excess entropy production for the surface that makes any sense.

Signe Kjelstrup
So, then you have a precise description of the entropy production at the surface, and you also have a dynamic boundary connection. But it's only transport perpendicular to the surface that we have treated. So, there is still the transport along, that is waiting, of course.

Alex Hansen
Trondheim has an interesting place in the history as far as irreversible thermodynamics goes. Can you elaborate on this?

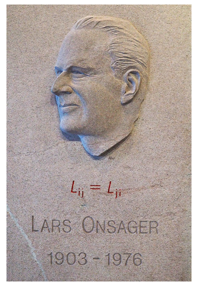
Dick Bedeaux
Well, I have a lot of contact with Trondheim because I was appointed to be a professor in Theoretical Physics in 1981. The reason that they appointed me was because of my work on statistical mechanics and in particular on the description of surfaces, and also the non-equilibrium thermodynamics of surfaces. So, I went to Trondheim and there I had a lot of contacts with Per Christian Hemmer and Eivind Hiis Hauge who were both very good colleagues in that field. They were also very much connected to the Netherlands where they were good friends of Hans van Leeuwen and Matthieu Ernst, and they would visit the Netherlands to visit these people. Matthieu Ernst and Hans van Leeuwen would also come here in Trondheim, and they would write papers together. In that sense Trondheim was clearly a center in which statistical mechanics was very actively done.

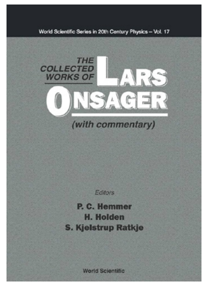
Signe Kjelstrup
And Alex, you, yourself are a part of that group and tradition. So, you are the flag carrier right now.

Alex Hansen
Thank you!

Signe, you have co-edited The Collected Works of Lars Onsager. What's his place in history or in this field?

Signe Kjelstrup
The Collected Works! That was obvious (to do). We celebrated his birthday in '93 and then people said to us: "Why don't you make his collected works?". And of course we should do that! And we have since then collected all his things and papers here (at NTNU). The aim or the purpose is of course to show the younger generations that we have this ideal role model, I would say, in science right here at his alma mater! He never got a job in Norway, but he came back every year and with his stature in the field that makes even us a bit visible.

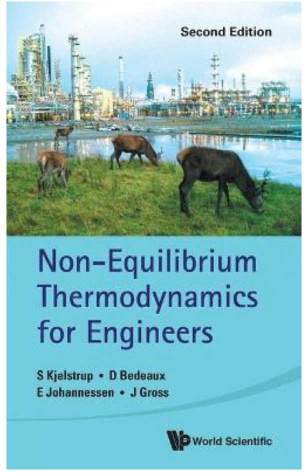




Onsager has a tremendous important role in many fields, but he got the Nobel Prize for irreversible thermodynamics. Everybody asked: For what did he get it, but it was for irreversible thermodynamics. This university is his alma mater, but he did not get a job in Norway. Nevertheless, he always kept contact and came every year back to Norway. So, it was logical for the group (of editors), my colleagues in physics, mathematics and me, to celebrate that we had Onsager as an ideal for this school of science. When we did that in 93, Onsager's birthday, and we were asked "Why don't you make the collected works?". They were not done yet at that point. Everybody meant that this was important because of his contribution to many fields. We could do it with some confidence because there has always been a strong group in statistical mechanics in this university. You, Alex, are one of them who can lift that flag high. So, I think, all together, I am happy to have that role model so strongly present for younger generations, here, now.

Alex Hansen
Where do you see this field is going? Irreversible thermodynamics is applicable in many settings. You wrote a book which recently came in a second edition, namely, Irreversible Thermodynamics for Engineers. Is this something that engineers can use in their daily work?

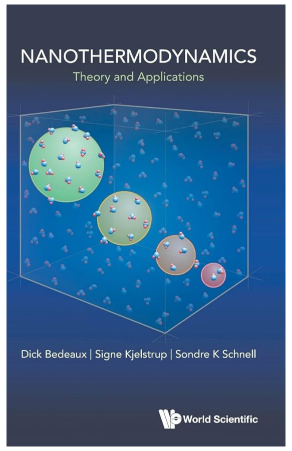
Signe Kjelstrup
Well, this is my dream or vision you could say, that such a book could be the standard textbook for teaching thermodynamics in a modern way in universities world over. And the reason is obvious. Equilibrium thermodynamics has to do with equilibrium and states. You can compare different states, but non-equilibrium thermodynamics includes the dynamics going from one state to the other, and it computes precisely the entropy production along the way, which you don't compute in another way. And speaking about the need for energy efficient processes and precise models for what is the interaction of phenomena in electrolytes and wherever, I think that, if we want to improve what is already there in the industry, this theory is needed. So, that is my hope! We, and the world, could benefit in using this.



Alex Hansen
You also have several books behind you. The latest one being Nanothermodynamics. Can you say a few words about it?

Dick Bedeaux
Yes, Nanothermodynamics is an extremely interesting field because it goes into a spectrum of systems that cannot be properly described with thermodynamics. And the reason for that is that they are too small. One of the reasons we got ourselves entangled in that, was that we had this feeling that when we were doing simulations, which by nature is not an infinitely large system (it is always a relatively small system), the question came up: how do we use the data there to obtain results for the large system? Well, that did not work so well until we discovered the book by Hill about thermodynamics of small systems.

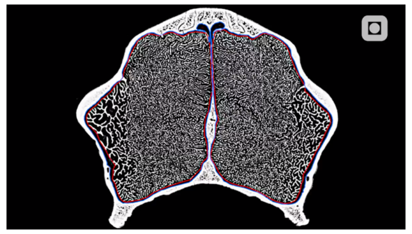
Hill is very clever in the sense that he extends the theory that was developed by Carnot, Clausius, and Gibbs, by introducing an additional term. That additional term describes the smallness of the system, and it comes in by looking at an ensemble of small systems. The ensemble of small systems together forms a big system. So as a function of the number of small systems of the number of replicas, the system is again Euler homogeneous of the first order and you can go through the whole analysis. And then you obtain new equations and an important quantity called the sub-division potential. This actually measures the energy that you need to subdivide a given amount of internal energy, entropy, or number of particles, over a larger subset of replicas. That, of course, gives you a measure of the energy difference, that depends on the size of the replicas. That aspect we have used and expanded on in the book. And we have done, contrary to what Hill, I fear, is doing, he tends so say: well, you know, when you control the volume, you need two pressures, not one. Then he comes to another case where he controls the number of particles, and makes the observation that: well, this is exactly the same as when you control the volume, you do not control the number of particles. With this, you have to do everything yourself. For an uninitiated person in the field, this is not easy. That is why we wrote the book: We do it explicitly for six ensembles, expanding on Hill and extending Hill also, because we actually bring forward the importance of the subdivision potential. We just wrote the paper on how to measure it.



Signe Kjelstrup
In short, the hope is that it could serve as an alternative path to get the continuum equations that we do need for the complicated porous media. A path that you, Alex, also are pioneering an effort to find. So, I hope in the end that we will be able to more directly compare and see and learn what the assumptions behind each systematic approach are, and how they can complement each other. So, there is a lot to do in the future.

Alex Hansen
Signe, you have recently published papers with biologists on the structure of the seal nose. Elaborate!

Signe Kjelstrup
Yes! And that was extremely fun because the seal nose has a very interesting labyrinthic structure. And why is that? It is, we think, because it has a very efficient system for saving heat (body heat) and water in the Arctic climate where it lives. That structure function relationship is fascinating, and I would really like to explore it in other contexts as well. Because, what if nature has invented porous structures that are so efficient, shouldn't we then try and copy them in technology? That is a question I could pose to many people, including myself.



Alex Hansen
Looking back at your long careers, any advice to young scientists?

Dick Bedeaux
Yes! The important thing is to be independent, to trust yourself and to not believe was all the established older people are telling you as the truth about the world.

Signe Kjelstrup
And I would like to add: Follow your heart and find a group where you can enjoy working … one person … it doesn't have to be many in the group.

It could be only you and one more.

Watch the whole interview on our website:
https://porelab.no/2024/05/24/do-not-miss-the-time-capsule-video-with-signe-kjelstrup-and-dick-bedeaux/

Read more about InterPore's Time Capsule:
https://www.interpore.org/foundation/time-capsule

AWARDS and prestigious nominations in 2024

The 2024 InterPore-PoreLab award: **Dr. Bauyrzhan K. Primkulov**

The close cooperation between Interpore and PoreLab has led to the creation of the InterPore-PoreLab award for young researchers. The award, awarded for the first time in 2018, is given in recognition of outstanding contributions to fundamental research in the field of porous media. Award winners receive a grant of 1000 euros and is offered to spend up to 60 days at PoreLab, supported with a daily stipend.

The 2024 winner of the InterPore-PoreLab award for young researchers is Dr. Bauyrzhan Primkulov, now Assistant Professor of Mechanical Engineering & Materials Science at Yale University, Connecticut, USA.

Bauyrzhan earned his Ph.D. from the Department of Civil and Environmental Engineering (CEE) at MIT, where he worked on interfacial fluid dynamics problems in porous media. The Honors and Awards Committee at Interpore concluded that:

"While only having completed his PhD in the Spring of 2022, Bauyrzhan has already displayed a high level of scientific accomplishment and academic maturity and has already demonstrated the ability to bridge disciplines, from fluid dynamics and interfacial phenomena to geoscience and engineering. Bauyrzhan is an outstanding young scientist and engineer with a very strong background in fluid mechanics, which he combines with an exceptional talent for laboratory experiments to make fundamental advances in our understanding of the physics of flow through complex, disordered media."

Bauyrzhan spent a month at PoreLab NTNU and UiO in August 2024, and we look forward to welcoming him back soon.

Alex Hansen is appointed Chair of the Working Group on Open Science (WG20)

Working Group 20 (WG20) was created by the International Union of Pure and Applied Physics (IUPAP) in 2022 at the 31st IUPAP General Assembly, that was held in Trieste, Italy. Its mission is to:

- Make a recommendation for a strategy to foster a culture of open science and aligning incentives for open science across all disciplines of physics—in particular, lay out the requirements to be put in place, with regards to open science, for IUPAP sponsored and endorsed conferences.
- Closely follow the implementation of the UNESCO Recommendation on Open Science and take part in relevant UNESCO Open Science Working Groups to advocate the interest of physics.
- Survey open science practices in physics and share the findings with the IUPAP commissions.
- Establish a resource for physics of open science infrastructures, tools, and techniques.
- In October 2024, the 33rd IUPAP General Assembly, held in Haikou in China, approved the appointment of Alex Hansen as Chair of the Working Group on Open Science (WG20) and charged him with starting the organization of the corresponding working group.

Gaute Linga is appointed Onsager Fellow at NTNU

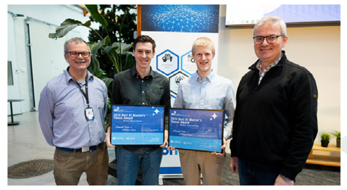
In 2023, we got the wonderful news that an Onsager fellowship position within computational porous media physics was allocated to PoreLab by the leadership at NTNU. An Onsager Fellow is an entry level position (tenure track) which during the first years of employment is financially covered by funding from NTNU's Rectorate. The Onsager Fellowship program at NTNU is designed to attract very talented early-career scholars with documented excellent supervised work, ready to work independently and with the potential to become a research leader.

The tenure-track associate professor's duties primarily include research, but also supervision, teaching, and other duties necessary to qualify for a permanent professor position within 6–7 years.

Following an intensive recruitment process, Dr. Gaute Linga, researcher at PoreLab UiO was appointed Onsager Fellow. He joined NTNU as associate professor at the Physics department at NTNU in January 2024. Gaute joined PoreLab's leader group as PI in September 2023.

Henrik Friis and **Håkon Nese** won second place in the *"NAIL Best Master Thesis Award 2024"*

Master's students Henrik Friis (Department of Physics at NTNU) and Håkon Nese (Department of Computer Science and Informatics at NTNU) won second place in the "NAIL Best Master Thesis Award 2024," organized by the Norwegian Open AI Lab (NAIL), for their thesis *"NeCT: Neural Computed Tomography for Sparse-View and 4D CT"*. Their thesis explores how neural networks can be used to significantly improve temporal resolution in computed tomography. By using the new program NeCT, dynamic 4D (3D and time) datasets can now be reconstructed with a temporal resolution on the scale of seconds instead of hours. This enables studies of, for example, multiphase flow in porous media for CO_2 storage. The work has been carried out as part of an ongoing collaboration between the Department of Physics at NTNU, the Department of Computer Science and Informatics at NTNU, and Equinor's research center in Rotvoll. For more information, read page 13 of our 2024 PoreLab Master Catalogue. The picture shows (from left to right) Prof. Ole Jakob Mengshoel, Håkon Nese, Henrik Friis, and Prof. Dag W. Breiby.



Gaute Linga new member of the Young Academy of Norway

Congratulations to Gaute Linga, Associate Professor at the Department of Physics, NTNU and PI at PoreLab, on being admitted as a member of the Young Academy of Norway (AYF).

The Young Academy of Norway consists of talented, junior researchers from all disciplines with a demonstrated commitment to science policy and innovative research dissemination. The academy works to amplify the voice of young researchers in society and provides its members with a platform for professional development, interdisciplinary collaboration, and scientific outreach.

This year, AYF received 72 applications—one of the highest numbers ever recorded. Gaute Linga was one of just eleven applicants who made it through the highly competitive selection process.

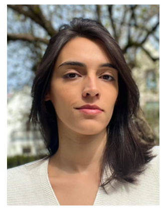
"I am interested in everything that flows, but my main focus is on understanding the fundamental mechanisms of how different liquids, gases, and chemical substances move through materials such as rock and soil—so-called porous media,"

Linga explains in an interview with AYF

Paula Reis and **Santanu Sinha**, new board members of the Norwegian Chapter of InterPore

The International Society for Porous Media (InterPore) 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. The Norwegian Chapter of Interpore, Interpore Norway, was established in 2016 at a kick-off meeting in Bergen.

During the business meeting that closed the 7th meeting of the Norwegian Chapter of InterPore, held in Stavanger on December 5th, 2024, Alex Hansen, director for PoreLab, and Marcel Moura, PI at PoreLab, rotated out of the board after eight successful years of creating and shaping InterPore Norway. Elections were held to find their successors. Paula Reis, researcher at PoreLab UiO, and Santanu Sinha, researcher at PoreLab NTNU, were elected.




Reza Haghani won the Bronze medal in the 4th International Invention and Innovation Competition of the IFIA

Reza Haghani, PhD candidate at PoreLab/department of Geosciences, NTNU, won third place (Bronze medal) in the fourth international invention and innovation competition of the International Federation of Inventors' Associations (IFIA) in 2024 with the invention of *a device to examine the alignment of the axes*. This year's fourth International Invention Competition saw impressive participation, with over 600 innovative inventions submitted by inventors from over 40 countries across the globe. Participants from diverse regions, including the USA, Canada, Australia, Morocco, Indonesia, Turkey, Iran, Russia, Qatar, Bahrain, the UK, China, Hong Kong, Malaysia, Thailand, the United Arab Emirates, Poland, and many others, contributed their pioneering ideas to the competition.


COMPLETED PHDs IN 2024

NAME	DEPARTMENT	DATE	THESIS	SUPERVISORS
Aldritt Scaria Madathiparambil	Department of Physics, NTNU	25.01.2024	*Multiscale X-ray tomography for shale microstructure and mechanical behaviour*	Dag W. Breiby, Pierre Rolf Cerasi, Alain Gibaud and Basab Chattopadhyay
Hao Gao	Department of Civil and Environmental Engineering, NTNU	29.04.2024	*Thermo-hydro-mechanical Simulation of Frost Heave using Extended Finite Element Method*	Gustav Grimstad, Seyed Ali Ghoreishian Amiri and Elena Scibilia
Øystein Gullbrekken	Department of Materials Science and Engineering, NTNU	22.05.2024	*Coupled Transport in Li-ion Battery Electrolytes*	Sverre Magnus Selbach and Sondre Kvalvåg Schnell
Kim Robert Bjørk Tekseth	Department of Physics, NTNU	27.05.2024	*Computational imaging of structure and liquid dynamics in porous media*	Dag Werner Breiby and Alain Gibaud
Kim Roger Kristiansen	Department of Chemistry, NTNU	31.05.2024	*Thermal Driving forces Across Membrane Systems: Energy Conversion and Water Purification*	Signe Kjelstrup and Knut Jørgen Måløy
Hyejeong Cheon	Department of Physics, NTNU	16.09.2024	*Water transport in porous media: From pore scale to biological applications*	Kathrine Røe Redalen, Signe Kjelstrup
Sebastian Price	Department of Chemistry, NTNU	25.11.2024	*Modelling the effect of acoustic streaming and ultrasound-enhanced diffusion on nanoparticle transport in a soft porous media*	Anders Lervik, Signe Kjelstrup, Catharina de Lange Davies, Magnus Aa. Gjennestad

Defense of thesis for ***Aldritt Scaria Madathiparambil***

From left to right:
Associate Professor Auke Barnhoorn, Associate Professor Antje van der Net, Associate Professor Erika Tudisco, Dr. Aldritt Scaria Madathiparambil, Senior Scientist Pierre Rolf Cerasi, Professor Dag Werner Breiby, Dr. Basab Chattopadhyay

Defense of thesis for ***Hao Gao***

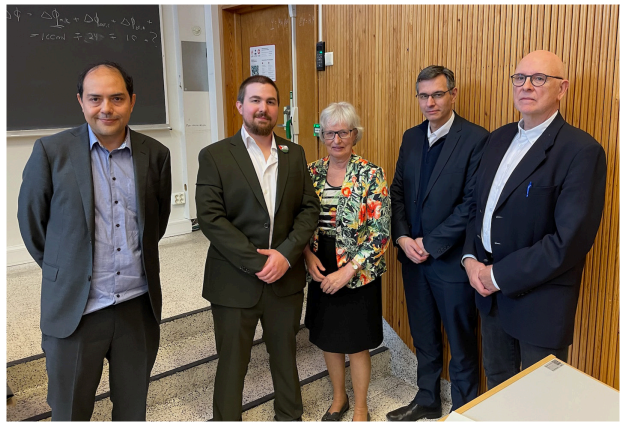
From left to right:
Professor Gudmund R. Eiksund, Professor Jelke Dijkstra, Associate Professor Claire Chassagne, Dr. Hao Gao, Professor Gustav Grimstad, Researcher Seyed Ali Ghoreishian Amiri, Professor Emerita Signe Kjelstrup and Professor Emeritus Dick Bedeaux

Defense of thesis for ***Øystein Gullbrekken***

From left to right:
Professor Frode Seland, Associate Professor Mahinder Ramdin, Associate Professor Amber Mace, Dr. Øystein Gullbrekken, Professor Sverre Magnus Selbach and Associate Professor Sondre Kvalvåg Schnell

Defense of thesis for ***Kim Robert Bjørk Tekseth***

From left to right:
Professor Maria Fernandino, professor Veerle Cnudde, Dr. Kim Robert Bjørk Tekseth and Professor Robert Krarup Feidenhans'l



Defense of thesis for ***Kim Roger Kristiansen***

From left to right:
Professor Carlos Dorao, Dr. Kim Roger Kristiansen, Professor Emerita Signe Kjelstrup, Professor Fernando Bresme, Senior scientist Torleif Holt

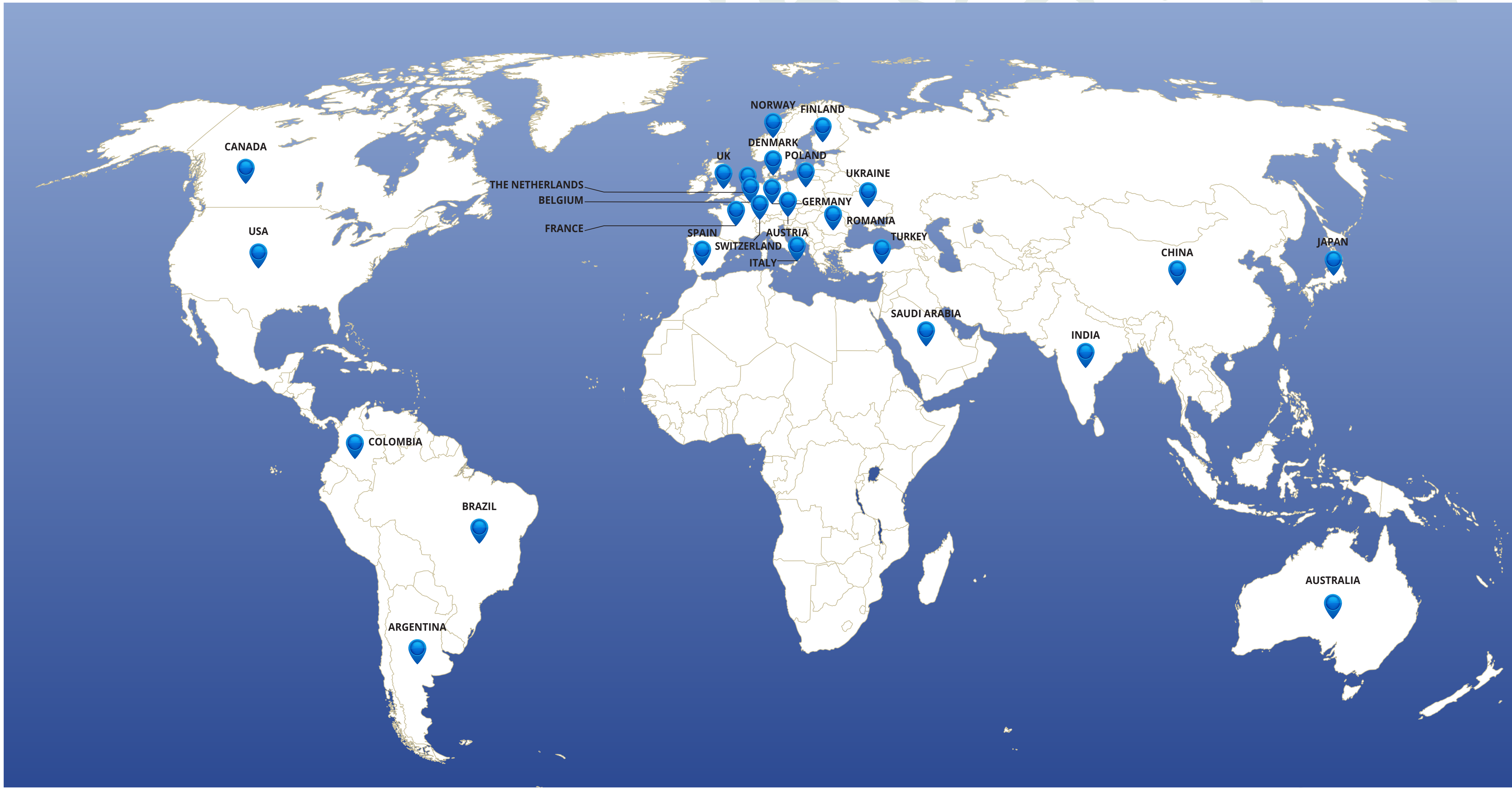
Defense of thesis for ***Hyejeong Cheon***

From left to right:
Professor Kathrine Røe Redalen, Professor Emerita Signe Kjelstrup, Associate Professor Rita Dias, Dr. Hyejeong Cheon, Professor Andrei Zvelindovsky and Chief Technology Officer Audun Røsjorde

Defense of thesis for ***Sebastian Price***

From left to right:
Dr. Marie-Laure Olivier, Professor Sofia Calero, Dr. Sebastian Price, Professor Constantin Coussios, Professor Emerita Signe Kjelstrup, Associate Professor Anders Lervik, Professor Catharina de Lange Davies and Dr. Magnus Aa. Gjennestad

NATIONAL AND INTERNATIONAL COLLABORATION



USA
Sarah L. Codd, Joseph Seymour: College of Engineering, *Montana State University, Bozeman*
James E. McClure: *Virginia Tech*
Peter Kang: *University of Minnesota*
Saman Aryana: *University of Wyoming*
Douglas Durian: *University of Pennsylvania*
Catherine Spurin: *Stanford University*
Muhammad Sahimi: *University of Southern California*
Bauyrzhan Primkulov: *MIT*

CANADA
Apostolos Kantzas: *University of Calgary*
Ian Frigaard: *University of British Columbia*

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

ARGENTINA
Diego Kingston: *University of Buenos Aires*

BRAZIL
José Soares Andrade Jr., Hans J. Herrmann, Humberto de Andrade Carmona: *Universidade Federal do Ceara*
Fernando A. Oliveira: *University of Brasilia*
Vinicius Martins: *UNICAMP, Campinasl*
Rodrigo Surmas, Rodrigo Skinner, Fatima Brazil: *Petrobras*

NORWAY
Magnus Aa. Gjennestad, Rune Hansen, Ailo Aasen, Asbjørn Solheim, Vegard Brøtan, Pierre Cerasi: *SINTEF*
Preben Vie, Geir Helgesen, Kenneth Knudsen: *Institute for Energy Technology, IFE*
Lars Folkow: *The Arctic University of Norway*
Bernt O. Hilmo: *Asplan Viak AS*
Marianne Øksnes Dalheim, Kristin Syverud: *RISE PFI AS*
Harald Berland, Olav Aursjø: *NORCE Norwegian Research center AS*
Thomas Ramstad, Lars Rennan, Colin Pryme, Anders Kristoffersen, Haili Long-Sanouiller: *Equinor*
Kim Roger Kristiansen: *Ocean GeoLoop AS, Steinkjer*

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

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

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

SWITZERLAND
Berend Smit: *Ecole Polytechnique Fédérale de Lausanne (EPFL)*
Frank Scheffold: *Adolphe Merkel Institute, Fribourg*
Prescelli Annan: *ETH, Zurich*
Anders Kaestner, Andreas Menzel: *PSI*

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

BELGIUM
Tom Bultreys, Veerle Cnudde: *Gent University*

AUSTRIA
Sofia Kantorovich: *University of Vienna*

UK
Bjørnar Sandnes: *Energy Safety Research Institute, College of Engineering, Swansea University*
Fernando Bresme, Erich A. Müller: *Imperial College London*
Daan Frenkel, Matthew Mason, Mike Cates: *University of Cambridge*
Robin Cleveland: *Oxford University*
Ran Holtzman: *Coventry University*
Alin Marin Elena: *Daresbury Laboratory*
Richard Barker: *University of Sheffield*

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, Yves Méheust: *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*
Francesco Puosi: *University Gustave Eiffel*
Yuriy Chushkin, Bratislav Lukic: *ESRF – The European Synchrotron Radiation Facility*

SPAIN
Miguel Rubi, David Reguera, Jordi Ortín, Ramon Planet, Ignacio Pagonabarraga: *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*
Juan José Hidalgo González, Marco Dentz: *Institute of Environmental Assessment and Water Research (IDAEA)*

ITALY
Luciano Colombo: *University of Cagliari*
Davide Picchi, Paolo Botticini: *University of Brescia*

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

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

UKRAINE
Natalya Kizilova: *Department of Theoretical and Applied Mechanics, Kharkov National University*

TURKEY
Talha Erdem: *Abdullah Gul University, Kayseri*
Levent Akyalçin: *Eskişehir Technical University, Eskişehir*
Seniz Ucar: *Middle Eastern Technical University*

INDIA
Purusattam Ray: *Institute of Mathematical Sciences, Chennai*
Subhadeep Roy: *BITS Pilani, Hyderabad*
Sitangshu B. Santra, Jnana Das: *Indian Institute of Technology, Guwahati*

SAUDI ARABIA
Cenk Temizel, *ARAMCO*

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

JAPAN
Pieter Krüger: *Graduate School of Science and Engineering, Molecular Chirality Research Center, Chiba University, Chiba*
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*
Taiki Yanagishima: *Kyoto University*

AUSTRALIA
Benjy Marks: *University of Sydney*
Ryan Armstrong: *University of New South Wales*
Mark Knackstedt: *Australian National University, Department of Applied Mathematics, Canberra*
Christoph Arns: *UNSW, Sidney*

GUEST RESEARCHERS AT PORELAB

At PoreLab, we have fostered an open, inclusive, and collaborative culture since the very beginning. Guests are always welcomed, whether visiting for a short stay or an extended collaboration. They come from diverse disciplines and communities. They bring with them a wealth of knowledge, experience and fresh perspectives that enrich our research activities. Hosting guest researchers not only broaden our academic horizons but also fosters collaboration and interdisciplinary exchange. Most of them gave lectures and workshops were organized when international delegations visited us.

NAME	POSITION	AFFILIATION	PERIOD
Natalya Kizilova	Professor	Department of Theoretical and Applied Mechanics, Kharkov National University, Ukraine	01.04.22 – 30.04.24
Joachim Mossige	Postdoc	University of Oslo, Norway	01.01.24 – 03.01.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	02.01.24 – 16.01.24
Xiaoying (Grace) Tang	PhD candidate	University of Cambridge, UK	14.01.24 – 04.02.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	20.01.24 – 22.01.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	05.02.24 – 17.02.24
Juan José Hidalgo González	Researcher	Institute of Environmental Assessment and Water Research, Spain	07.03.24 – 12.03.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	11.03.24 – 23.03.24
Vinicius Martins	Researcher	Universidade Estadual de Campinas, Brazil	01.04.24 – 30.09.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	01.04.24 – 13.04.24
Sylvie Retailleau	Minister	French Minister of Research and Higher Education	18.04.24
Florence Robine	Ambassadress	French Ambassadress in Norway	18.04.24
Benjamin Rotenberg	Senior Research Fellow	CNRS, University of Sorbonne, France	26.04.24
Steffen Berg	Principal Science Expert	Shell Global solutions, The Netherlands	26.04.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	26.04.24 – 14.05.24
Tomás Aquino	Researcher	Institute of Environmental Assessment and Water Research, Spain	20.05.24 – 24.05.24
Oshri Borgman	Research Group Leader	MIGAL – Galilee Research Institute, Israel	20.05.24 – 24.05.24
Sitangshu Santra	Professor	Indian Institute of Technology, Guwahati, India	24.05.24 – 10.06.24
Jnana Ranjan Das	PhD candidate	Indian Institute of Technology, Guwahati, India	24.05.24 – 24.06.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	02.06.24 – 08.06.24
Natalya Kizilova	Professor	Department of Theoretical and Applied Mechanics, Kharkov National University, Ukraine	15.06.24 – 05.07.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	16.06.24 – 22.06.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	03.07.24 – 13.07.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	04.08.24 – 12.08.24
Bauyrzhan Primkulov	Applied Math Instructor	Massachusetts Institute of Technology, MIT, USA	08.08.24 – 28.08.24
Gloria Buendia	Professor	Universidad Simon Bolivar, Venezuela	10.08.24 – 17.09.24
Anna Mareike Kostelecky	PhD candidate	Institute for modelling Hydraulic and Environmental Systems, University of Stuttgart, Germany	15.08.24 – 25.10.24
Sarah Codd	Professor	Montana State University, USA	18.08.24 – 20.08.24
Joe Seymour	Professor	Montana State University, USA	18.08.24 – 20.08.24
Sona Rustamova	PhD candidate	University of Strasbourg, France	19.08.24 – 30.08.24
Arezo Dodangeh	PhD candidate	University of Strasbourg, France	19.08.24 – 30.08.24
Christoph Arns	Professor	UNSW, Sidney, Australia	23.08.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	07.09.24 – 28.09.24
Andrei Zvelindovsky	Professor	School of Mathematics and Physics, University of Lincoln, UK	13.09.24 – 16.09.24
Audun Røsjorde	Chief Technology Officer	Equinor, Trondheim, Norway	16.09.24
Prescelli Annan	PhD candidate	Swiss Seismological Service (SED) at ETH Zürich, Switzerland	23.09.24 – 30.11.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	01.10.24 – 21.10.24
Daan Frenkel	Professor Emeritus	University of Cambridge, UK	27.10.24 – 16.12.24
Andreas Stillits	PhD candidate	Niels Bohr Institute, Denmark	04.11.24 – 06.11.24
Mathias Klahn	Postdoc	Niels Bohr Institute, Denmark	19.11.24 – 21.11.24
Natalya Kizilova	Professor	Department of Theoretical and Applied Mechanics, Kharkov National University, Ukraine	25.11.24 – 29.11.24
Rodrigo Surmas	Professor	Petrobras, Brazil, and Federal University of Rio de Janeiro	06.12.24 – 09.12.24
Rodrigo Skinner	Researcher	Petrobras, Brazil	06.12.24 – 09.12.24
Fatima Brazil	Researcher	Petrobras, Brazil	06.12.24 – 09.12.24

PORELAB LECTURE SERIES LIST OF LECTURES

The **PoreLab Lecture Series** is organized in rotation with the **Porous Media Tea Time Talks** (#PorousMediaTTT) and the **Journal Club**. The lectures take place simultaneously at UiO in Oslo and NTNU in Trondheim and are now almost exclusively delivered by external speakers. Below is the list of guest lectures for 2024.

DATE	NAME, AFFILIATION	TITLE
Jan. 10	Associate Professor Claire Chassagne, TU Delft, the Netherlands	*Modelling the properties of soft slurries*
Jan. 24	Professor Joachim Mathiesen, head of Niels Bohr Institute, University of Copenhagen, Denmark	*Dispersion in slow capillary force dominated flows*
Feb. 7	Dr. Joachim Mossige, University of Oslo, Norway	*Microfluidic interferometry as an alternative method for measuring concentration-dependent diffusivities of large molecules*
Feb. 9	Daniel Rothman, MIT, USA	*Slow Closure of Earth's Carbon Cycle*
Feb. 16	Associate Professor Jelena Popovic-Neuber, University of Stavanger, Norway	*Electrolytes and interfaces in batteries: Why are they important, how do we improve and control them?*
March 6	Harish Pruthviraj Jain, Njord center, University of Oslo, Norway	*Active Reorganisation in Tissues*
March 11	Juan Hidalgo, IDAEA, the Spanish National Research Council (CSIC), Barcelona, Spain	*Convective mixing in heterogenous porous media*
March 13	Professor Ken Elder, Department of Physics, Oakland University, USA	*Defect structures and patterns in ultrathin layers*
March 15	Professor Jan Martin Nordbotten, Department of Mathematics, University of Bergen, Norway	*Flow, transport and mechanics in fractured porous media*
March 20	Zhongzheng Wang, Queensland University of Technology (QUT), Brisbane city, Australia	*Microfluidics Inspired from Multiphase Flow in Porous Media*
April 3	Dr. Joachim Mossige, Postdoctoral Fellow at RITMO Centre for Interdisciplinary Studies in Rhythm, Time and Motion (IMV), University of Oslo, Norway	*Concentration-dependent diffusivity in a microfluidic pore*
April 17	Benzhong Zhao, Assistant Professor in Civil Engineering, McMaster University, Hamilton, Canada	*Pattern formation in fluid-fluid displacement through simple porous media*
May 15	Alexander Shapiro, Associate Professor, Dept. of Chemical and Biochemical Engineering, Technical University of Denmark, Lyngby, Denmark	*Continuous upscaling*
May 22	Oshri Borgman, Researcher in environmental hydrology and soil science, MIGAL, Galilee Research Institute, Qiryat Shemona, Israel	*Solute mixing in heterogeneous and variably saturated porous media: flow patterns, mixing rates, and reaction rates*
May 29	Joaquim Jimenez-Martinez, Research Scientist-Group Leader, Eawag (Swiss Federal Institute of Aquatic Science and Technology) and Adjunct Professor, Dept. of Civil, Environmental, and Geomatic Engineering, ETH Zürich, Switzerland	*Microbial behavior in porous media: hydrodynamics control on bacterial chemotaxis and morphogenesis of biofilms*
June 5	Associate Professor Peter K. Kang, University of Minnesota, USA	*Inertia effects on mixing and reaction in porous and fractured media: From mixing-induced chemical reactions to mineral dissolution and precipitation*
June 6	Prof. Dr. Sitangshu Bikas Santra, Indian Institute of Technology, Guwahati, India	*Mixed wet percolation I: Geometrical Properties*
June 6	PhD candidate Jnana Ranjan Das, Indian Institute of Technology, Guwahati, India	*Mixed wet percolation II: Transport Properties*
Aug. 21	Dr. Bauyrzhan Primkulov, instructor of applied mathematics, MIT (Massachusetts Institute of Technology), USA	*Non-resonant effects in pilot-wave hydrodynamics*
Aug. 28	Professor Francisco Vega Reyes, Department of Physics, Universidad Extremadura, Spain	*The properties of fluctuations for a two-dimensional chiral particle*
Sept. 4	Professor Gloria Maria Buendia, Universidad Simón Bolívar, Venezuela	*Novel non-equilibrium behavior of spin systems: experiments and simulation match*
Sept. 11	Prof. Ranjini Bandyopadhyay, Raman Research Institute, Bengaluru, India	*Distinct morphologies and growth kinetics of interfacial patterns formed by the radial displacement of an aging viscoelastic suspension*
Oct. 2	Prescelli Annan, doctoral student, Swiss Seismological Service (SED), ETH Zurich, Switzerland	*Multi-scale study into the structural control on fluid-rock interactions in caprocks and reservoir rocks for geological CO_2 storage*
Oct. 9	Dr. Steffen Berg, principal science expert, Shell Global Solutions International B.V. in the Netherlands	*Viscous Fingering Revisited – General Criterium for Onset & Darcy Scale Wavelength*
Oct. 16	Prof. Einat Aharonov from the Hebrew University of Jerusalem, Israel	*The importance of seepage forces in soil-liquefaction*
Oct. 23	Dr. Johan Olav Helland, senior researcher, Computational Geosciences and Modelling group at NORCE – Norwegian Research Centre, Norway	*Ostwald ripening of trapped gas in the presence of oil and water in subsurface storage – A level set pore-scale modelling approach*
Oct. 30	PhD candidate Reza Haghani, PoreLab/NTNU	*Multiphase modeling using phase field method*
Nov. 6	Prof. Pietro de Anna, University of Lausanne, Switzerland	*Flow, transport and mixing limited (bio-)processes in confined & heterogeneous media*
Nov. 13	PhD candidate Paolo Botticini, Università degli Studi di Brescia, Italy	*Compressibility-induced destabilisation of falling liquid films: an integral approach*
Nov. 20	Dr. Thomas Ramstad, discipline leader reservoir technology in Area Subsurface Development North (ASDN), Equinor, Norway	*Aspects of Relative Permeability: Theory, Applications and Limitations*
Dec. 4	Dr. Laurent Talon, Laboratoire FAST, University Paris-Saclay, France	*On the flow of yield stress fluid in porous media: statistical properties, universality class and boundary conditions*
Dec. 6	Rodrigo Surmas, Digital Rocks Physics Advisor, Petrobras, Brazil and guest Professor, Federal University of Rio de Janeiro	*SCAL and DRP Applications in Petrobras*
Dec. 18	Prof. Davide Picchi, Università degli Studi di Brescia, Italy	*Motion of an elongated bubble through a shear-thinning fluid*

FUNDING IN 2023

PoreLab's funding varies annually based on its activities. The combined contributions from the Research Council of Norway (RCN), NTNU, and UiO will total 272,5 MNOK over the center's entire duration.

In January 2025, the Research Council of Norway approved our request to extend PoreLab's duration until the end of September 2028. This extension, resulting from delayed recruitments, does not impact the total budget, which remains unchanged.

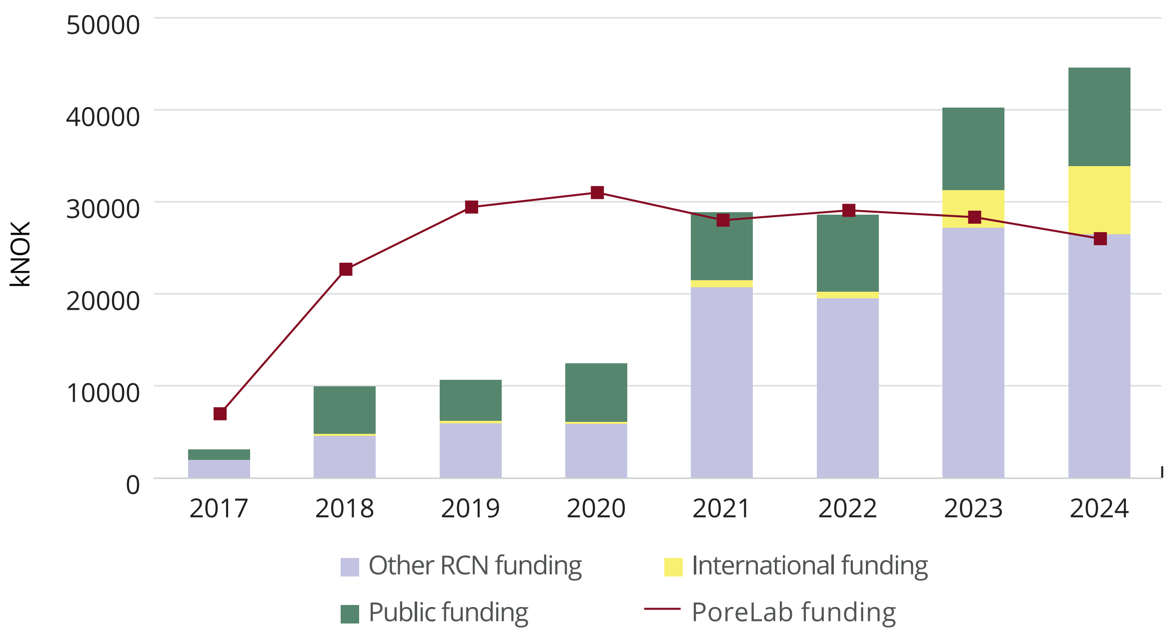
PoreLab's funding consists of the resources allocated to establish and sustain the Center, covering its operational costs. Over 11 years (2017–2028), the Research Council of Norway (RCN) will provide a total of 148,1 MNOK. During the same period, NTNU and UiO will contribute a combined 126,3 MNOK, with NTNU providing 72 MNOK (57%) and UiO contributing 54,3 MNOK (43%).

FUNDING (kNOK)	AMOUNT	PERCENTAGE
The Research Council	13 247	51%
NTNU	7 836	30%
University of Oslo	4 905	19%
TOTAL	25 988	100%

As part of the Center of Excellence (CoE) agreement with the Research Council of Norway (RCN), PoreLab researchers are encouraged to develop additional externally funded projects (see "Heading for the Future: Our New Projects" in PoreLab's annual reports). These projects, carried out under PoreLab's umbrella, can receive funding from the RCN, the EU, industry partners, university internal funds, and other sources. The graph under illustrates annual funding (in kNOK) by source. "Other RCN funding" denotes financial support from additional projects funded by the Research Council of Norway. "International funding" primarily refers to support from the European Commission, while "Public funding" mainly represents internal contributions from NTNU and UiO.

Two important results are worth noting:

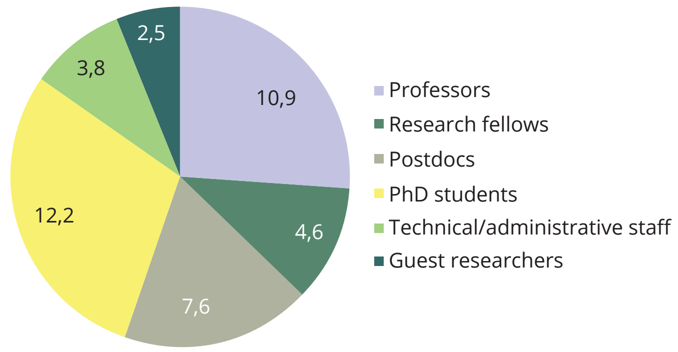
1. Funding from additional externally funded projects has continued to grow, reaching an impressive 44,6 MNOK in 2024.
2. 2023 marked a pivotal year when funding from these additional projects significantly surpassed PoreLab's core funding.



FACTS AND FIGURES

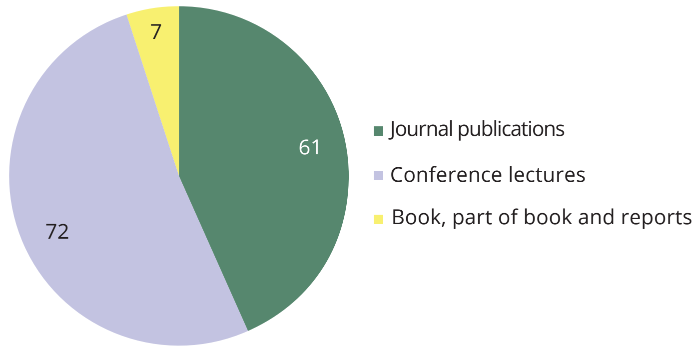
PORELAB STAFF categorized by position

PoreLab equals 41,5 man-years in 2024
The pie chart on the right shows the categorization of our staff by position



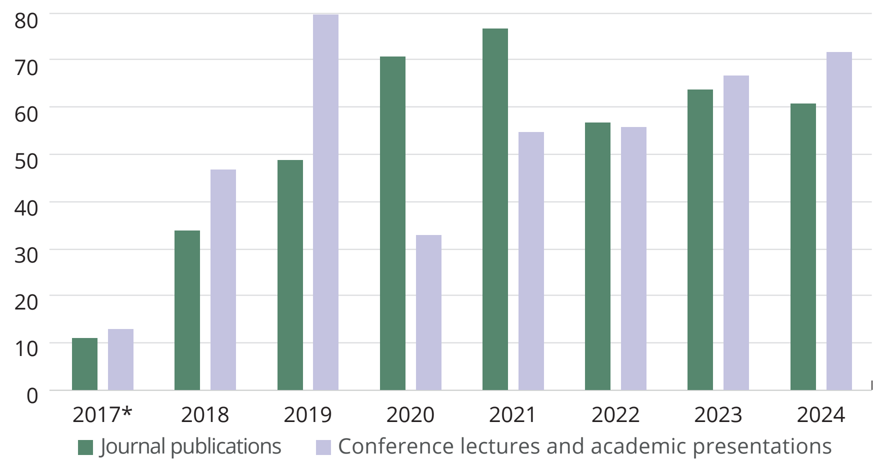
PUBLICATIONS in 2024

61 Journal Publications
72 Conference lectures and academic presentations
7 books, part of book and reports



PUBLICATIONS since 2017

H-index in 2024 = 34
The H-index has been calculated based only on the number of peer-reviewed journal publications



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

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

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

The Leader Group

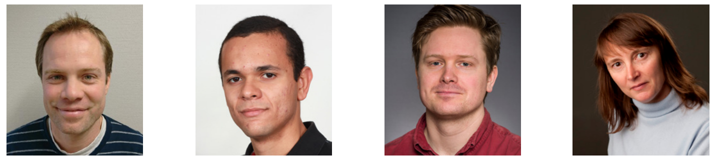
Alex Hansen
Director
Professor,
Department of Physics,
NTNU

Eirik Flekkøy
Deputy Director,
Professor, Department of Physics,
UiO

Knut Jørgen Måløy
Professor Department of Physics,
UiO

Erika Eiser
Professor,
Department of Physics,
NTNU

Øivind Wilhelmsen
Professor,
Department of Chemistry,
NTNU



Carl Fredrik Berg
Professor,
Department of Geosciences,
NTNU

Marcel Moura
Researcher,
Department of Physics,
UiO

Gaute Linga
Researcher at the Njord center, UiO, and Associate Professor at the Department of Physics,
NTNU

Marie-Laure Olivier
Administrative leader,
Department of Physics,
NTNU

Scientific Advisory Board

Veerle Cnudde
Professor
Ghent University, Belgium and Utrecht University
The Netherlands

Douglas Durian
Mary Amanda Wood Professor of Physics and Astronomy,
University of Pennsylvania,
USA

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

Steffen Berg
Principal Science Expert at Shell Global Solutions International B.V.,
The Netherlands

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

PhD Students

Ilaria Beechey-Newman
PhD,
Department of Physics,
NTNU

Fazel Mirzaei
PhD,
Department of Physics,
NTNU

Håkon Pedersen
PhD,
Department of Physics,
NTNU

Sebastian Everard Nordby Price
PhD, Department of Chemistry,
NTNU

Kim Robert Tekseth
PhD,
Department of Physics,
NTNU

Mukul Jaiswal
PhD,
Department of Physics,
NTNU

Caroline Einen
PhD,
Department of Physics,
NTNU

Reza Haghanihasanabadi
PhD,
Department of Geosciences,
NTNU

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

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

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

Vegard Jervell
PhD,
Department of Chemistry,
NTNU

Tage Maltby
PhD,
Department of Chemistry,
NTNU

Jonas Bueie
PhD,
Department of Chemistry,
NTNU

Rene Tammen
PhD,
Department of Physics,
NTNU

Øystein Gullbrekken
PhD,
Department of Materials Science and Engineering,
NTNU

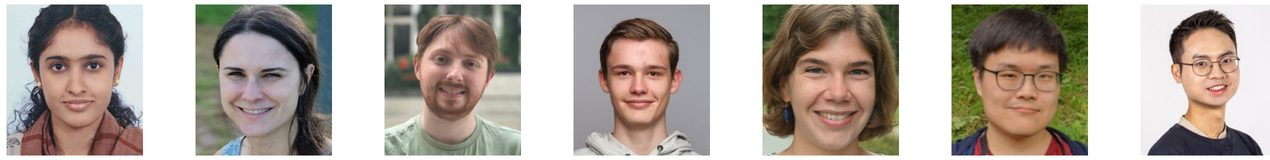
Kamila Zablocka
PhD,
Department of Structural Engineering,
NTNU

Andreas Henning
PhD,
Department of Physics,
NTNU

Mohammad Hemayati
PhD,
Department of Civil and Environmental Engineering,
NTNU

Arshitha Mathew
PhD,
Department of Physics,
NTNU

Shibi Palliyalil
PhD,
Department of Physics,
NTNU



Soumya Pallipotta
PhD,
Department of Physics,
NTNU

Jessica Zeman
PhD,
Department of Physics,
NTNU

Joe Stickland
PhD,
Department of Physics,
NTNU

Bjarte Matre
PhD,
Department of Physics,
NTNU

Mateja Macut
PhD,
Department of Geosciences,
NTNU

Tae Kwon Yun
PhD,
Department of Geosciences,
NTNU

Yao Xu
PhD,
Department of Physics,
UiO

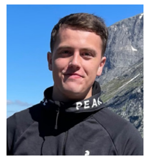
Maud Viallet
PhD,
Department of Physics,
UiO

Paiman Shafabakhsh
PhD,
Department of Geosciences,
UiO

Administrative and Technical Staff


Janne Hoff
Administrative coordinator for Njord Center and PoreLab UiO


Thuat Trinh
Senior engineer, Department of Chemistry, NTNU


Jørgen Haukø Alsaker
Senior executive officer, Faculty of Natural Sciences, NTNU


Augusta Hlin Aspar Sundbø
Senior engineer, Department of Physics, NTNU

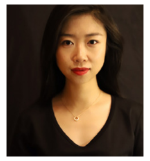

Mihailo Jankov
Senior Engineer, Department of Physics, UiO

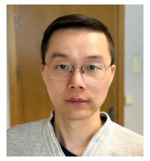

Corinna Dannert
Head Engineer, Department of Physics, NTNU


Osvaldo T. Neto
Head Engineer, Department of Physics, NTNU

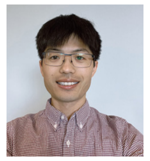
PostDocs


Quirine Krol
PostDoc, Department of Physics, NTNU


Lu Xia
PostDoc, Department of Chemistry, NTNU


Ge Li
PostDoc, Department of Mechanical and Industrial Engineering, NTNU


Quoc-Anh Tran
PostDoc, Department of Civil and Environmental Engineering, NTNU


Yuequn Fu
PostDoc, Njord center, UiO


Kevin Pierce
PostDoc, Njord center, UiO


Khobaib Khobaib
PostDoc, Department of Physics, UiO


Farid Aligolzadeh
PostDoc, Department of Chemistry, NTNU


Federico Lanza
PostDoc Department of Physics, UiO


Antoine Dop
PostDoc, Department of Physics, UiO

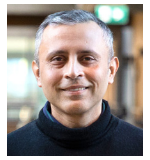
Researchers and Associates


Signe Kjelstrup
Professor Emerita, Department of Chemistry, NTNU


Bjørn Hafskjold
Professor Emeritus, Department of Chemistry, NTNU

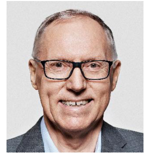

Dick Bedeaux
Professor Emeritus Department of Chemistry, NTNU


Santanu Sinha
Researcher, Department of Physics, NTNU


Basab Chattopadhyay
Associate professor, department of Physics, NTNU

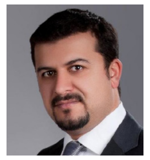

Morten Hammer
Adjunct Professor, department of Chemistry, NTNU


Renaud Toussaint
Adjunct Professor, Department of Physics, UiO


Ole Torsæter
Professor Emeritus, Department of Geosciences, NTNU


Dag Werner Breiby
Professor, Department of Physics, NTNU

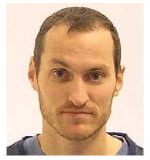

Catharina de Lange Davies
Professor, Department of Physics, NTNU


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


Raffaela Cabriolu
Associate Professor, Department of Physics, NTNU


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


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


Gustav Grimstad
Professor, Department of Civil and Environmental Engineering, NTNU

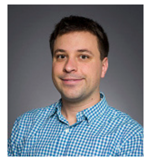

Steinar Nordal
Professor, Department of Civil and Environmental Engineering, NTNU

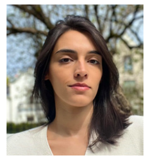

Astrid de Wijn
Professor, Department of Mechanical and Industrial Engineering, NTNU


Anders Lervik
Associate Professor, Department of Chemistry, NTNU


Antje van der Net
Associate Professor, Department of Geosciences, NTNU


Thomas Combriat
Researcher, Department of Physics, UiO


Fabian Barras
Researcher, Njord center, UiO


Paula K. P. Reis
Researcher, Department of Physics, UiO

PUBLICATIONS 2024

The following lists journal publications, books, reports, conference lectures and academic presentations generated in 2024

JOURNAL PUBLICATIONS

Aasen, Ailo; Hammer, Morten; Reguera, David; Wilhelmsen, Øivind.
Estimating metastable thermodynamic properties by isochoric extrapolation from stable states. *Journal of Chemical Physics* 2024; Volume 161.(4) ENERGISINT NTNU

Aasen, Ailo; Jervell, Vegard Gjeldvik; Hammer, Morten; Strøm, Bjørn; Skarsvåg, Hans Langva; Wilhelmsen, Øivind.
Bulk and interfacial thermodynamics of ammonia, water and their mixtures. *Fluid Phase Equilibria* 2024; Volume 584. ENERGISINT NTNU

Abbasov, Rashad; Fahs, Marwan; Younes, Anis; Nowamooz, Hossein; Måløy, Knut Jørgen; Toussaint, Renaud.
Modeling rainfall-induced landslide using the concept of local factor of safety: Uncertainty propagation and sensitivity analysis. *Computers and geotechnics* 2024; Volume 167. UiO

Alfazazi, Umar; Bedeaux, Dick; Kjelstrup, Signe; Moura, Marcel; Ebadi, Mohammad; Mostaghimi, Peyman; McClure, James E.; Armstrong, Ryan T.
Interpreting pore-scale fluctuations: Predicting transport coefficients in multiphase flow through porous media using the Green-Kubo formulation – An experimental investigation. *Physics of Fluids* 2024; Volume 36.(3) NTNU UiO

Alzubaidi, Fatimah; McClure, James E.; Pedersen, Håkon; Hansen, Alex; Berg, Carl Fredrik; Mostaghimi, Peyman; Armstrong, Ryan T..
The Impact of Wettability on the Co-moving Velocity of Two-Fluid Flow in Porous Media. *Transport in Porous Media* 2024; Volume 151.(10–11) s.1967-1982 NTNU

Arran, M.I.; Mangeney, A.; De Rosny, Rosny; Toussaint, Renaud.
Simulated Slidequakes: Insights From DEM Simulations Into the High-Frequency Seismic Signal Generated by Geophysical Granular Flows. *Journal of Geophysical Research (JGR): Earth Surface 2024;* Volume 129.(8) UiO

Bedeaux, Dick.
On the Elimination of Fast Variables from the Langevin Equation. *Entropy* 2024; Volume 26.(10) NTNU

Bedeaux, Dick; Kjelstrup, Signe.
On How to Measure the Subdivision Potential in Nanothermodynamics. *Preprints* 2024 NTNU

Berg, Carl Fredrik; Sahimi, Muhammad.
Relation between critical exponent of the conductivity and the morphological exponents of percolation theory. *Physical Review E (PRE)* 2024; Volume 110.(4) NTNU

Cheon, Hyejeong; Kizilova, Nataliya; Flekkøy, Eirik Grude; Mason, Matthew J.; Folkow, Lars; Kjelstrup, Signe.
The nasal cavity of the bearded seal: An effective and robust organ for retaining body heat and water. *Journal of Theoretical Biology* 2024; Volume 595. s.1–12. NTNU UiO UiT

Combriat, Thomas Michel Daniel; Dysthe, Dag Kristian; Flekkøy, Eirik Grude.
Cavitation dynamics in creeping flow. *Journal of Fluid Mechanics* 2024; Volume 999. UiO

Dadrasajirlou, Davood; Grimstad, Gustav; Ghoreishian Amiri, Seyed Ali; Degago, Samson Abate; Houlsby, G. T..
Modified cam clay bounding surface hyper-viscoplastic model. *Géotechnique* 2024 NTNU

Delic, Asmira; Lindgren, Mikael; Psarrou, Maria; Economopoulos, Solon; Mariussen, Espen; Krivokapic, Alexander; Torsæter, Ole; Omran, Mohamed; Einarsrud, Mari-Ann.
Design of multi-luminescent silica-based nanoparticles for the detection of liquid organic compounds. *Chemistry – A European Journal* 2024; Volume 30.(17) FHI NILU IFE NTNU

Do, Ha T.; Tong, Hien Duy; Tran, Khanh-Quang; Trinh, Thuat.
The role of chemical functional groups in dewaterability of hydrochar: A molecular simulation study. *Journal of Molecular Liquids* 2024; Volume 400.(15) NTNU

Do, Tuong Ha; Tran, Khanh-Quang; Trinh, Thuat.
Modeling Hydrothermal Gasification of Digestate Sludge: Reaction Kinetic from Molecular Simulations. *Computer-aided chemical engineering* 2024 NTNU

Dziadkowiec, Joanna; Linga, Gaute; Kalchgruber, Lukas; Kavunga, Sunil; Cheng, Hsiu-Wei; Nilsen, Ola; Campsteijn, Coen; Pokroy, Boaz; Valtiner, Markus.
Electrochemically Assisted Growth of Hopper and Tabular Calcite under Confinement. *Crystal Growth & Design* 2024; Volume 24. s.4930–4943 UiO

Gjennestad, Magnus Aashammer; Wilhelmsen, Øivind.
Thermodynamically consistent modeling of gas flow and adsorption in porous media. *International Journal of Heat and Mass Transfer* 2024; Volume 226. ENERGISINT NTNU

Golestan, Mohammad Hossein; Berg, Carl Fredrik.
Simulations of CO_2 Dissolution in Porous Media Using the Volume-of-Fluid Method. *Energies* 2024; Volume 17.(3) Suppl. 629. NTNU

Gullbrekken, Øystein; Gunnarshaug, Astrid Fagertun; Lervik, Anders; Kjelstrup, Signe; Schnell, Sondre Kvalvåg.
Effect of the Ion, Solvent, and Thermal Interaction Coefficients on Battery Voltage. *Journal of the American Chemical Society* 2024; Volume 146.(7) s.4592 4604 NTNU

Ha, Do Tuong; Tong, Hien Duy; Tran, Khanh-Quang; Trinh, Thuat.
Molecular Simulation of Hydrothermal Gasification of Digestate Sludge with Copper Catalyst Addition. *Chemical Engineering Transactions* 2024; Volume 109. s.193–198 NTNU

Ha, Do Tuong; Tong, Hien Duy; Trinh, Thuat.
Insights into hydro thermal gasification process of microplastic polyethylene via reactive molecular dynamics simulations. *Scientific Reports* 2024; Volume 14.(1) NTNU

Haghanihasanabadi, Reza; Gahrooei, Hamidreza Erfani; McClure, James E.; Flekkøy, Eirik Grude; Berg, Carl Fredrik.
Color-gradient-based phase-field equation for multiphase flow. *Physical Review E (PRE)* 2024; Volume 109.(3) NTNU UiO

Hammer, Morten; Aasen, Ailo; Wilhelmsen, Øivind.
Extrapolating into no man's land enables accurate estimation of surface properties with multiparameter equations of state. *Fluid Phase Equilibria* 2024; Volume 586. NTNU ENERGISINT

Hansen, Alex.
Editorial: Editor's challenge in interdisciplinary physics: what is interdisciplinary physics?. *Frontiers in Physics* 2024; Volume 12. NTNU

Hansen, Alex.
Linearity of the Co-moving Velocity. *Transport in Porous Media* 2024 NTNU

Heijkoop, Selwin; Rieder, David; Moura, Marcel; Rücker, Maja; Spurin, Catherine.
A Statistical Analysis of Fluid Interface Fluctuations: Exploring the Role of Viscosity Ratio. *Entropy* 2024; Volume 26.(9) UiO

Ho, Thi H.; Hien, Tong Duy; Wilhelmsen, Øivind; Trinh, Thuat.
Thermophysical properties of polyethylene glycol oligomers via molecular dynamics simulations. *RSC Advances* 2024; Volume 14.(38) s.28125- 28137 NTNU

Ho, Thi H.; Hoang, Nguyen-Hieu; Wilhelmsen, Øivind; Trinh, Thuat.
Water adsorption on surfaces of calcium aluminosilicate crystal phase of stone wool: a DFT study. *Scientific Reports* 2024; Volume 14.(1) ENERGISINT NTNU SINTEF

Ho, Thi H.; Tong, Hien Duy; Trinh, Thuat.
Molecular insights into the interactions between PEG carriers and drug molecules from Celastrus hindsii: a multi-scale simulation study. *Scientific Reports* 2024; Volume 14.(1) NTNU

Holtzman, Ran; Dentz, Marco; Moura, Marcel; Chubynsky, Mykyta V.; Planet, Ramon; Ortín, Jordi.
Emergence of dissipation and hysteresis from interactions among reversible, nondissipative units: The case of fluid-fluid interfaces. *Physical Review Fluids* 2024; Volume 9.(6) UiO

Hossein Khoeini, Mohammad; Vukovic, Tomislav; van der Net, Antje; Luna-Troguero, Azahara; Ruecker, Maja.
A novel application of inverse gas chromatography for estimating contact angles in porous media. *Journal of Colloid and Interface Science* 2024; Volume 680. NTNU

Jervell, Vegard Gjeldvik; Gjennestad, Magnus Aashammer; Trinh, Thuat; Wilhelmsen, Øivind.
The influence of thermal diffusion on water migration through a porous insulation material. *International Journal of Heat and Mass Transfer* 2024; Volume 227. ENERGISINT NTNU

Jervell, Vegard Gjeldvik; Wilhelmsen, Øivind.
Predicting viscosities and thermal conductivities from dilute gas to dense liquid: Deriving fundamental transfer lengths for momentum and energy exchange in revised Enskog theory. *Journal of Chemical Physics* 2024; Volume 161.(23) NTNU

The publication from Vegard Jervell and Øivind Wilhelmsen entitled "Predicting viscosities and thermal conductivities from dilute gas to dense liquid: deriving fundamental transfer lengths for momentum and energy exchange in revised Enskog theory" was selected as a ***Featured article*** *by the journal Editor and an artistic illustration of the work ended up at the* ***front page*** *of the journal for Volume 161, Issue 23*

Kjelstrup, Signe; Bedeaux, Dick; Schnell, Sondre Kvalvåg.
Commentaries on Nanothermodynamics. *InterPore Journal* 2024; Volume 1.(1) s.113–118 NTNU

Kozlowski Pitombeira Reis, Paula; Linga, Gaute; Moura, Marcel; Rikvold, Per Arne; Toussaint, Renaud; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
Interaction between corner and bulk flows during drainage in granular porous media. *arXiv.org* 2024 UiO

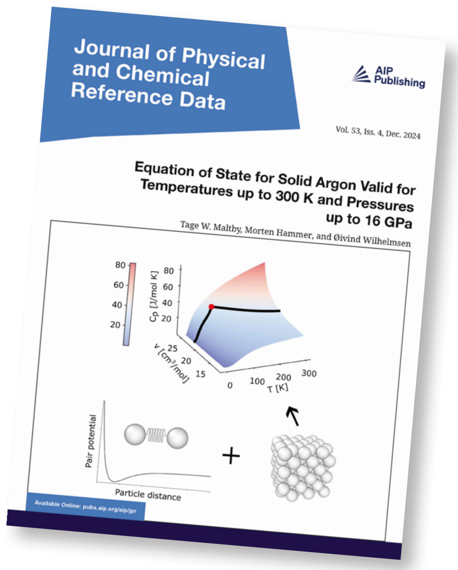
Kristiansen, Kim Roger; Wilhelmsen, Øivind; Kjelstrup, Signe.
Thermo-osmotic coefficients in membrane distillation: Experiments and theory for three types of membranes. *Desalination* 2024; Volume 586. NTNU

Krol, Quirine Eibhilin; Scherrer, Evan; Skuntz, Matthew; Codd, Sarah; Seymour, Joseph; Hansen, Alex.
Rapid MRI profiling of liquid water content in snow: Melt and Stability during first wetting and rain on snow events. *International Snow Science Workshops (ISSW) Proceedings* 2024 NTNU

Lemoult, Grégoire; Mukund, Vasudevan; Shih, Hong-Yan; Linga, Gaute; Mathiesen, Joachim; Goldenfeld, Nigel; Hof, Björn.
Directed percolation and puff jamming near the transition to pipe turbulence. *Nature Physics* 2024 UiO

Lima, Henrique A.; Luis, Edwin E. Mozo; Carrasco, Ismael S. S.; Hansen, Alex; Oliveira, Fernando A..
Geometrical interpretation of critical exponents. *Physical Review E (PRE)* 2024; Volume 110.(6) NTNU

Maltby, Tage Winther; Hammer, Morten; Wilhelmsen, Øivind.
Equation of State for Solid Argon Valid for Temperatures up to 300 K and Pressures up to 16 GPa. *Journal of Physical and Chemical Reference Data* 2024; Volume 53.(4) ENERGISINT NTNU



The paper from Tage Maltby, Morten Hammer and Øivind Wilhelmsen on the "Equation of state for solid argon valid for temperature up to 300 K and Pressures up to 16 GPa" was published in the Journal of Physical and Chemical Reference Data on December 9th, 2024. An artistic representation of the article was selected by the Editor to be on ***the coverpage****.*

Natalya, Kizilova; Shankar, Akash; Kjelstrup, Signe.
A Minimum Entropy Production Approach to Optimization of Tubular Chemical Reactors with Nature-Inspired Design. *Energies* 2024; Volume 17.(2) s.432 NTNU

Olsen, Kristian Stølevik; Hansen, Alex; Flekkøy, Eirik Grude.
Hyper-Ballistic Superdiffusion of Competing Microswimmers. *Entropy* 2024; Volume 26.(3) s.1-8 NTNU UiO

Price, Sebastian Everard Nordby; Einen, Caroline; Moultos, Othonas A.; Vlugt, Thijs J. H.; Davies, Catharina de Lange; Eiser, Erika; Lervik, Anders.
Ultrasound enhanced diffusion in hydrogels: An experimental and non-equilibrium molecular dynamics study. *Journal of Chemical Physics* 2024; Volume 160.(15) NTNU

Mendes, Celeste; Buendia, Gloria M; Rikvold, Per Arne.
Numerical simulation of a two-dimensional Blume-Capel ferromagnet in an oscillating magnetic field with a constant bias. *Physical Review E (PRE)* 2024; Volume 110.(4) UiO

Roy, Subhadeep; Sinha, Santanu; Hansen, Alex.
Immiscible Two-Phase Flow in Porous Media: Effective Rheology in the Continuum Limit. *Transport in Porous Media* 2024; Volume 151. s.1295–1311 UiO NTNU

Shafabakhsh, Paiman; Cordonnier, Benoit; Pluymakers, Anne Marie Henriette; Le Borgne, Tanguy; Mathiesen, Joachim; Linga, Gaute; Hu, Yi; Kaestner, Anders; Renard, Francois.
4D Neutron Imaging of Solute Transport and Fluid Flow in Sandstone Before and After Mineral Precipitation. *Water Resources Research* 2024; Volume 60.(3) UiO NTNU

Shafabakhsh, Paiman; Le Borgne, Tanguy; Renard, Francois; Linga, Gaute.
Resolving pore-scale concentration gradients for transverse mixing and reaction in porous media. *Advances in Water Resources* 2024; Volume 192. UiO NTNU

Sheehan, Jennifer Ruth; de Wijn, Astrid S.; Freire, Thales Souza; Friedman, Ran.
Beyond IC_{50}—A computational dynamic model of drug resistance in enzyme inhibition treatment. *PLoS Computational Biology* 2024; Volume 20.(11) NTNU

Sinha, Santanu; Méheust, Yves; Fyhn, Hursanay; Roy, Subhadeep; Hansen, Alex.
Disorder-induced non-linear growth of fingers in immiscible two-phase flow in porous media. *Physics of Fluids* 2024; Volume 36.(3) UiO NTNU ENERGISINT

Snipstad, Sofie; Einen, Caroline; Kastellet, Andrea Berge; Lage Fernandez, Jessica; Mühlenpfordt, Melina; Kurbatskaya, Anna; Årseth, Charlotte; Berg, Sigrid; Bjørkøy, Astrid; Davies, Catharina de Lange.
Ultrasound and Microbubble-Induced Reduction of Functional Vasculature Depends on the Microbubble, Tumor Type and Time After Treatment. *Ultrasound in Medicine and Biology* 2024; Volume 51.(1) s.33–42 NTNU STO SINTEF

Solberg, Simon Birger Byremo; Gómez-Coma, Lucía; Wilhelmsen, Øivind; Forsberg, Kerstin; Burheim, Odne Stokke.
Electrodialysis for efficient antisolvent recovery in precipitation of critical metals and lithium-ion battery recycling. *Chemical Engineering Journal* 2024; Volume 486. NTNU

Solberg, Simon Birger Byremo; Hammer, Morten; Wilhelmsen, Øivind; Burheim, Odne Stokke.
An activity coefficient model for mixed-solvent electrolyte mixtures based on Gibbs–Duhem's equation: A case study of mixtures of water, KCl and ethanol. *Fluid Phase Equilibria* 2024; Volume 586. NTNU

Solberg, Simon Birger Byremo; Wilhelmsen, Øivind; Burheim, Odne Stokke.
Transport numbers of ion-exchange membranes in ternary mixtures of KCl, H_2O and ethanol relevant for electrodialysis and desalination processes. *Electrochimica Acta* 2024; Volume 506. NTNU

Talon, Laurent; Hennig, Andreas Andersen; Hansen, Alex; Rosso, Alberto.
Influence of the imposed flow rate boundary condition on the flow of Bingham fluid in porous media. *Physical Review Fluids* 2024; Volume 9.(6) NTNU

Tran, Khanh-Quang; Bui, Hau Huu; Chen, Wei-Hsin; Naqvi, Salman Raza; Trinh, Thuat; Chang, Jo-Shu.
Pyrolysis Kinetics of Microalgae Residues—A Comparative Study on DAEM Using Different Distribution Functions. *Springer Proceedings in Earth and Environmental Sciences* 2024 NTNU

Trinh, Thuat; Hammer, Morten; Sharma, Vishist; Wilhelmsen, Øivind.
Mie–FH: A quantum corrected pair potential in the LAMMPS simulation package for hydrogen mixtures. *SoftwareX* 2024; Volume 26. ENERGISINT NTNU

Trinh, Thuat; Tran, Khanh-Quang.
On application of molecular dynamics simulation for studying the effect of temperature and heating rate on HTL of biomass. *IOP Conference Series: Earth and Environmental Science (EES)* 2024 NTNU

Vanin, Ana Paula; Camassola, Marli; Eiser, Erika; Stokke, Bjørn Torger.
Characterization of the polysaccharide schizophyllan and schizophyllan–chitosan hydrogel formation by diffusing-wave spectroscopy. *Carbohydrate Polymers* 2024; Volume 352. s.123168 NTNU

Vu, Tuan V.; Kartamyshev, A.I.; Nguyen, Minh D.; Pham, Khang D.; Trinh, Thuat; Nhuan, Nguyen P.; Hien, Nguyen D..
First-principles insights on electronic and transport properties of novel ternary AlMX3 and quaternary Janus Al2M2X3Y3 (M= Ge, Sn; X/Y= S, Se, Te) monolayers. *Materials Science in Semiconductor Processing* 2024; Volume 181. NTNU

Zhang, Yu; Liu, Xintong; Shi, Qiao; Qu, Yongxiao; Hao, Yongchao; Fu, Yuequn; Wu, Jianyang; Zhang, Zhisen.
Mechanical properties and cage transformations in CO2-CH4 heterohydrates: a molecular dynamics and machine learning study. *Journal of Physics D: Applied Physics 2024;* Volume 57.(46) UiO NTNU

Zimmermann, Pauline; Wahl, Kristin; Tekinalp, Önder; Solberg, Simon Birger Byremo; Deng, Liyuan; Wilhelmsen, Øivind; Burheim, Odne Stokke.
Selective recovery of silver ions from copper-contaminated effluents using electrodialysis. *Desalination* 2024; Volume 572. NTNU

CONFERENCE LECTURES AND ACADEMIC PRESENTATIONS

Bedeaux, Dick; Kjelstrup, Signe.
On How to Measure the Subdivision Potential in Nanothermodynamics. 28th Thermodynamic Conference; 2024-09-04 – 2024-09-07 NTNU

Beechey-Newman, Ilaria; Eiser, Erika.
Hierarchical drying patterns of confined colloidal suspensions. BIRS Workshop; 2024-07-14 – 2024-07-19 NTNU

Berg, Carl Fredrik.
Relations between evolving micro-structures and effective transport properties. SPWLA Houston meeting; 2024-09-18 – 2024-09-18 NTNU

Berg, Carl Fredrik; Ringstad, Cathrine.
Norway's CCS Partnership between the State, Industries, Academia, and NGO's. International CCS symposium: A supercritical research toward industrial solution; 2024-06-06 – 2024-06-06 SINTEF NTNU

Einen, Caroline; Wesche, Håkon Fossland; Kastellet, Andrea Berge; Kurbatskaya, Anna; Lage Fernandez, Jessica; Nordlund, Veronica; Davies, Catharina de Lange; Snipstad, Sofie.
Effect of ultrasound and microbubbles on nanoparticle delivery and functional vasculature in three tumor models. The 29th European symposium on Ultrasound Contrast Imaging; 2024-01-18 – 2024-01-19 UiO NTNU UIS

Eiser, Erika.
DNA-Coated Colloids for Whole Genome Detection. 8th International Soft Mater Conference; 2024-07-29 – 2024-08-02 NTNU

Eiser, Erika.
Microrheology in Hydrogels. Workshop on Non-Newtonian Flows in Porous Media; 2024-07-14 – 2024-07-19 NTNU

Eiser, Erika.
Multivalency & Super-Selectivity in Bacterial Genome Detection. Adolf Merkel Institute AMI Seminar series; 2024-03-21 NTNU

Eiser, Erika.
Self-Assembly. Young Investigator Workshop, International Soft Matter Conference 2024; 2024-07-26 – 2024-07-28 NTNU

Eiser, Erika.
Structure and rheology of aqueous suspensions of triblock copolymers. Visit to Tempel University , Philadelphia, USA; 2024-07-22 – 2024-07-25 NTNU

Eiser, Erika.
Two-phase flow in confined geometries. Kick-off meeting of HORIZON – MSCA – 2022– DN FLUXIONIC; 2024-03-06 – 2024-03-08 NTNU

Eiser, Erika.
Whole Genome Detection Using Multivalent DNA-Coated Colloids. Kavli Prize lectures at the NTNU; 2024-09-05 NTNU

Eiser, Erika; Beechy-Newman, Ilaria; Kizilova, Natalya; Henning, Andreas.
Hierarchical drying patterns of colloidal solutions. Computer Simulations in Physical and Life Sciences; 2024-10-24 – 2024-10-25 NTNU

Eiser, Erika; Frenkel, Daan.
Thermodynamics of Multivalent Nanoparticles in Bacterial Genome Detection. 28th Thermodynamics Conference; 2024-09-04 – 2024-09-06 NTNU

Eiser, Erika; Xu, Peicheng; Cao, Ting.
DNA-Coated Colloids: A new Approach to Pathogen Detection using Supe-Selectivity. 12th Liquid Matter Conference; 2024-07-22 – 2024-07-27 NTNU

Hafskjold, Bjørn; Kjelstrup, Signe; Løken, Johannes Salomonsen.
Thermal Marangoni Effects, Thermodiffusion, and Thermo-osmosis in Membranes. Twenty-Second Symposium on Thermophysical Properties; 2024-06-23 – 2024-06-28

Haghani, Reza; Gahrooei, Hamidreza Erfani; McClure, James; Boek, Edo; Berg, Carl Fredrik.
Spatial characterization of wetting in porous media using local lattice-Boltzmann simulations. Interpore 2024 – 16th annual meeting; 2024-05-12 – 2024-05-17 NTNU

Hansen, Alex.
A new kind of thermodynamics for two-phase flow in porous media. Non-Newtonian Flow in Porous Media; 2024-07-14 – 2024-07-19 NTNU

Hansen, Alex.
A survey of the fiber bundle model: avalanches, localization, and signals of imminent failure. International Conference on Plasticity, Damage and Fracture; 2024-01-03 – 2024-01-09 NTNU

Hansen, Alex.
Porous and granular media: so common, so unknown. National Science Day; 2024-02-28 – 2024-02-28 NTNU

Hansen, Alex.
Scaling up immiscible two-phase flow in porous media. Euromech Colloquium 642; 2024-09-23 – 2024-09-27 NTNU

Hansen, Alex.
Statistical mechanics of immiscible two-phase flow in porous media. LII Winter Meeting on Statistical Physics; 2024-01-10 – 2024-01-13 NTNU

Hansen, Alex.
The co-moving velocity, a new concept in immiscible two-phase flow in porous media. Department Seminar; 2024-03-29 – 2024-03-29 NTNU

Hansen, Alex.
The co-moving velocity, a new concept in immiscible two-phase flow in porous media. Nordic Rheology Conference; 2024-05-29 – 2024-05-31 NTNU

Hansen, Alex.
The co-moving velocity, a new concept in immiscible two-phase flow in porous media. Pore Scale Physics Seminar Series; 2024-01-30 – 2024- 01-30 NTNU

Hansen, Alex.
The co-moving velocity, a new concept in immisicble two-phase flow in poros media and in thermodynamics. Fracmeet; 2024-03-05 – 2024-03-08 NTNU

Hansen, Alex.
The co-moving velocity, an example of a new concept in thermodynamics. Department Seminar; 2024-02-29 – 2024-02-29 NTNU

Hansen, Alex.
What is the co-moving velocity and why should we care?. InterPore Conference; 2024-05-13 – 2024-05-16 NTNU

Hansen, Alex.
1984 to 2024 and back: Following up an HJH paper. 70th Birthday Symposium in Honor of Hans J. Herrmann; 2024-06-11 – 2024-06-14 NTNU

Jervell, Vegard Gjeldvik.
Prediction of transport properties in dense cryogenic gases. Symposium on thermophysical properties; 2024-06-24 – 2024-06-28 NTNU UiO

Kern, Vanessa Ruth; Carlson, Andreas; Måløy, Knut Jørgen; Flekkøy, Eirik Grude.
Linking anomalous diffusion and rheology for a droplet spreading in a corner: A rheometer for power-law liquids. BIRS workshop on Non-Newtonian Flows in Porous Media; 2024-07-14 – 2024-07-19 UiO NTNU

Kozlowski Pitombeira Reis, Paula; Linga, Gaute; Moura, Marcel; Rikvold, Per Arne; Toussaint, Renaud; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
Investigation of liquid connectivity and drainage in granular porous media. 2024 Cargese summer school on Flow and Transport in porous and fractured media; 2024-06-11 – 2024-06-21 UiO

Kozlowski Pitombeira Reis, Paula; Linga, Gaute; Moura, Marcel; Rikvold, Per Arne; Toussaint, Renaud; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
Investigation of liquid connectivity and drainage in granular porous media. Gordon Research Conference for Flow and Transport in Permeable Media; 2024-07-13 – 2024-07-19 UiO

Kozlowski Pitombeira Reis, Paula; Linga, Gaute; Moura, Marcel; Rikvold, Per Arne; Toussaint, Renaud; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
Network modeling of corner and bulk flows during drainage in granular porous media. Workshop on Flow in Pores and Fractures; 2024-09-16 – 2024-09 20 UiO

Kozlowski Pitombeira Reis, Paula; Vincent-Dospital, Tom Yannick Yves; Toussaint, Renaud; Måløy, Knut Jørgen.
Modeling drainage in porous media with stratified gradient in pore sizes. IRP-DFFRACT Conference; 2024-02-19 – 2024-02-22 UiO

Krol, Quirine Eibhilin.
Measuring Microscale Mechanisms of Snow Melt, Rain-on-Snow, Drainage, and Imbibition Using Rapid Magnetic Resonance Profiling. SLF Colloquium; 2024-04-09 – 2024-04-09 NTNU

Krol, Quirine Eibhilin; Codd, Sarah; Hansen, Alex; Seymour, Joseph.
Microscale fluid fluctuations during drainage and imbibition in porous media measured with rapid NMR profiling. MRPM; 2024-08-25 – 2024-08-30 NTNU

Krol, Quirine Eibhilin; Codd, Sarah; Seymour, Joseph; Hansen, Alex.
Microscale fluid fluctuations during drainage and imbibition in porous media measured with rapid NMR profiling. Non-Newtonian Flows in Porous Media; 2024-07-14 – 2024-07-20 NTNU

Krol, Quirine Eibhilin; Braun, Anna; Hidalgo, Juan; Hansen, Alex; Löwe, Henning.
Modeling Effective Water Vapor Transport and Subsequent Coarsening in Snow: A Rigorous Upscaling Approach. Applied Mathematics Seminar; 2024-04-18 – 2024-04-18 NTNU

Krol, Quirine Eibhilin; Scherrer, Evan; Skuntz, Matthew; Codd, Sarah; Hansen, Alex; Seymour, Joseph.
Rapid MRI profiling of liquid water content in snow. International Snow Science Workshop; 2024-09-22 – 2024-09-28 NTNU

Lanza, Federico; Baldelli, Beatrice; Linga, Gaute; Barras, Fabian; Flekkøy, Eirik Grude.
Dynamic instability of a temperature-dependent viscous fluid in a Hele-Shaw cell. BIRS Workshop – Non-Newtonian Flows in Porous Media; 2024-07-14 – 2024-07-19 UiO NTNU

Lanza, Federico; Baldelli, Beatrice; Linga, Gaute; Barras, Fabian; Flekkøy, Eirik Grude.
Simulating finger structures that may form when a warm liquid (lava) cools and becomes more viscous during flow through a fracture. Kick off meeting Beyond Elasticity project; 2024-04-29 – 2024-04-30 UiO NTNU

Lanza, Federico; Baldelli, Beatrice; Linga, Gaute; Barras, Fabian; Flekkøy, Eirik Grude.
The Cooling Instability. 6th Cargèse summer school: FLOW and Transport In porous and fractured MEdia (FLOWTIME); 2024-06-10 – 2024-06- 21 UiO NTNU

Lanza, Federico; Sinha, Santanu; Hansen, Alex; Rosso, Alberto; Talon, Laurent.
Transition from viscous fingers to foam during drainage in heterogeneous porous media. IRP-DFFRACT Conference; 2024-02-19 – 2024-02-22 UiO NTNU

Li, Ge; de Wijn, Astrid S..
Molecular Dynamics Simulations of Illite Clay Surface and Particle. Cimtec 2024 Materials in an Explosively Growing Informatics World; 2024-06- 20 – 2024-06-24 NTNU

Li, Ge; de Wijn, Astrid S.; Eiser, Erika; Høyvik, Ida-Marie; Xia, Lu; Tammen, Rene.
Molecular Dynamics Simulations of Porous Illite Clay Surfaces and Particles. InterPore 2024 16th Annual Meeting; 2024-05-13 – 2024-05-16 NTNU

Linga, Gaute.
Capillarity drives chaotic mixing in porous media flow. IRP-DFFRACT Conference; 2024-02-19 – 2024-02-22 NTNU UiO

Linga, Gaute.
How does capillarity control mixing in porous media?. Workshop on Flow in Pores and Fractures; 2024-09-16 – 2024-09-20 NTNU UiO

Linga, Gaute.
Mixing by interfaces. FricFrac Conference 2024 ;2024-06-17 – 2024-06-19 UiO NTNU

Linga, Gaute.
Mixing by interfaces: Impact of unsteady flow on solute transport in porous media. NTNU Physics colloquium; 2024-01-19 – 2024-01-19 UiO NTNU

Maltby, Tage Winther; Hafskjold, Bjørn; Bedeaux, Dick; Wilhelmsen, Øivind.
Local equilibrium in liquid-phase shock waves?. Thermodynamics 28th Conference; 2024-09-04 – 2024-09-08 NTNU

Maltby, Tage Winther; Hammer, Morten; Wilhelmsen, Øivind.
Equation of state for solid argon for prediction of hydrogen-argon mixtures. H2Science; 2024-06-18 – 2024-06-19 ENERGISINT NTNU

Maltby, Tage Winther; Hammer, Morten; Wilhelmsen, Øivind.
The quasi-harmonic approximation: Solid equation of state for the prediction of thermodynamic properties and solid formation in fluid mixtures. Twenty-Second Symposium on Thermophysical Properties; 2024-06-24 – 2024-06-28 ENERGISINT NTNU

Moura, Marcel; Eriksen, Fredrik Kvalheim; Jankov, Mihailo; Turquet, Antoine Leo; Hansen, Alex; Måløy, Knut Jørgen.
Experiments on transient and steady-state flows in porous media: the transition from viscous fingers to compact displacement during unstable drainage flows. FRACMEET 2024; 2024-03-05 – 2024-03-08 UiO NTNU

Moura, Marcel; Hansen, Alex; Flekkøy, Eirik Grude; Måløy, Knut Jørgen.
POROUS MATTER: PoreLab's sci-art adventures in Romania. IRP-DFFRACT Conference; 2024-02-19 – 2024-02-22 UiO NTNU

Moura, Marcel; Hansen, Alex; Måløy, Knut Jørgen; Flekkøy, Eirik Grude.
POROUS MATTER: Our sci-art adventures in Romania. Njord day 2024; 2024-05-24 NTNU UiO

Moura, Marcel; Kern, Vanessa Ruth; Carlson, Andreas; Måløy, Knut Jørgen; Flekkøy, Eirik Grude.
Linking anomalous diffusion and rheology for a droplet spreading in a corner: A rheometer for power-law liquids. Banff International Research Station Workshop on Non-Newtonian Flows in Porous Media; 2024-07-14 – 2024-07-19 UiO

Moura, Marcel; Måløy, Knut Jørgen; Flekkøy, Eirik Grude; Brodin, Joachim Falck; Kozlowski Pitombeira Reis, Paula; Linga, Gaute; Hansen, Alex.
A little bit of our activity at PoreLab and Njord. Group Seminar Rennes; 2024-09-11 UiO NTNU

Moura, Marcel; Måløy, Knut Jørgen; Flekkøy, Eirik Grude; Brodin, Joachim Falck; Kozlowski Pitombeira Reis, Paula; Linga, Gaute; Hansen, Alex.
A pool of two-phase flows experiments: films, bursts, patterns and avalanches. Workshop on Flow in Pores and Fractures; 2024-09-16 – 2024-09- 20 UiO NTNU

Olivier, Marie-Laure.
7 years of experience in the CoE program. Non-Newtonian Flows in Porous Media; 2024-07-14 – 2024-07-19 NTNU

Pierce, James Kevin.
Impact of Heterogeneity on Mixing in Porous Media Flows. Gordon Research Seminar on Flow and Transport in Permeable Media; 2024-07-13 - 2024-07-14 UiO

Pierce, James Kevin.
Impact of the solid structure on solute mixing in porous media flows. IRP-DFFRACT Conference; 2024-02-19 – 2024-02-22 UiO

Pierce, James Kevin; Linga, Gaute; Le Borgne, Tanguy.
Experimental imaging of pore scale stretching and coalescence as drivers for solute mixing in porous media. EGU General Assembly 2024; 2024- 04-14 – 2024-04-19 UiO NTNU

Price, Sebastian Everard Nordby; Einen, Caroline; Moultos, Othonas A.; Vlugt, Thijs J. H.; Davies, Ruth Catharina de Lange; Eiser, Erika; Lervik, Anders.
Ultrasound-Enhanced Diffusion in Hydrogels. The 28th Thermodynamics Conference; 2024-09-04 – 2024-09-06 ENERGISINT NTNU

Schloms, Felix; Kjelstrup, Signe; Gullbrekken, Øystein.
The effect of Ion, Solvent and Thermal Onsager Coefficients on the Lithium Battery Voltage. 28th Thermodynamic Conference; 2024-09-04 – 2024-09-07 NTNU

Sinha, Santanu.
Disorder-induced non-linearity in two-phase flow in porous media. National Science Day 2024; 2024-02-28 – 2024-02-29 UiO

Sinha, Santanu.
Growth of immiscible viscous fingers in porous media: Transition from linearity to non-linearity. Coupled Free Flow – Porous Medium Systems Workshop (2024); 2024-06-12 – 2024-06-14 UiO

Sinha, Santanu; Hansen, Alex; Méheust, Yves.
Non-linear growth of fingers during two-phase flow in porous media. InterPore2024; 2024-05-13 – 2024-05-16 UiO NTNU

Sinha, Santanu; Hansen, Alex; Méheust, Yves.
Non-linear growth of viscous fingers in two-phase flow of immiscible Newtonian fluids in porous media. Non-Newtonian Flows in Porous Media; 2024-07-14 – 2024-07-19 NTNU UiO

Tammen, Rene; de Wijn, Astrid S.; Eiser, Erika; Li, Ge; Høyvik, Ida-Marie; Xia, Lu.
Sustainable Ground Stabilisation of Norwegian Quick Clay. InterPore 2024 16th Annual Meeting; 2024-05-13 – 2024-05-16 NTNU

Vukovic, Tomislav; Luxbacher, Thomas; van der Net, Antje.
Streaming potential measurements in glass bead packs – Benchmarking zeta potential calculations. InterPore2024 16th Annual Meeting; 2024- 05-13 – 2025-01-16 NTNU

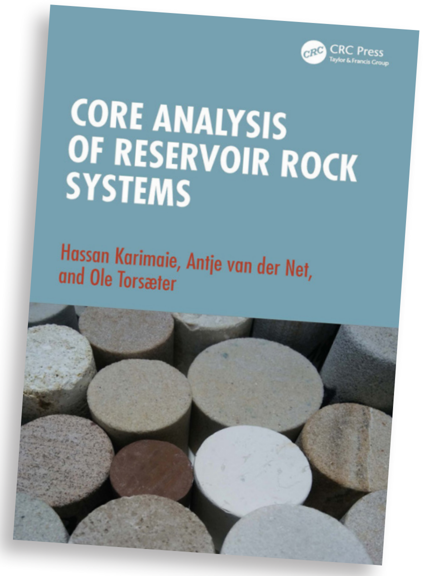
Yun, Tae Kwon; Macut, Mateja; Schulze, Katja; Ringrose, Philip; Berg, Carl Fredrik.
CO_2 storage in saline aquifers: multi-scale processes visualized using the Sleipner case. EGU General Assembly 2024; 2024-04-14 – 2024-04-19 NTNU

BOOKS, PART OF BOOKS, REPORTS

Bedeaux, Dick; Kjelstrup, Signe; Schnell, Sondre Kvalvåg.
Nanothermodynamics: Theory And Applications. World Scientific 2024 (ISBN 978-981-127-499-2) 390 s. NTNU

Cheon, Hyejeong.
Water transport in porous media: From pore scale to biological applications. Norges teknisk-naturvitenskapelige universitet 2024. 174 s. NTNU

Karimaie, Hassan; van der Net, Antje; Torsæter, Ole.
Core analysis of reservoir rock systems. CRC Press 2024 (ISBN 978-1-032-46618-7) 406 s. NTNU



"Core Analysis of Reservoir Rock Systems", the book manuscript by Hassan Karimaie, Antje van der Net and Ole Torsæter was **released** in November 2024. The publisher is CRC Press.

Kjelstrup, Signe; Bedeaux, Dick; Johannessen, Eivind; Gross, Joachim.
Non-Equilibrium Thermodynamics for Engineering Applications. World Scientific 2024 (ISBN 978-981-12-9458-7) 340 s. NTNU

Kristiansen, Kim Roger
Thermal Driving forces Across Membrane Systems: Energy Conversion and Water Purification. Norges teknisk-naturvitenskapelige universitet. 2024. 104 s. NTNU UiO

Price, Sebastian Everard Nordby.
Modelling the effect of acoustic streaming and ultrasound-enhanced diffusion on nanoparticle transport in a soft porous media. Norges teknisknaturvitenskapelige universitet 2024 131 s. NTNU ENERGISINT

Vidal, Mauricio Jesus.
Simulation of Mechanical Behaviour of Dogger Bank Sand with LS-DEM. Norges teknisk-naturvitenskapelige universitet 2024 75 s. NTNU NGI

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, Vice 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