Advances in porous media science and engineering from InterPore2020 perspective

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Abstract: Natural, artificial, and biological porous media can be seen everywhere in our daily lives. Transport phenomena in porous media, such as flow, diffusion, reaction, adsorption and deformation, are encountered in a wide variety of practical applications and scientific interests over widely disparate length scales, from molecular, to pore, core, and field scales. However, determination of transport properties in porous media remains a challenging issue. During the 12\textsuperscript{th} Annual Meeting of the International Society for Porous Media (InterPore), held online from August 31-September 4, 2020, advances on porous media science and engineering in very broad areas were presented. The meeting was attended by more than 750 participants from across the globe, and a significant milestone was achieved in the history of InterPore conferences due to its online interactive platform. Participants could access the pre-recorded talks, leave comments and questions, chat with each other, one week before the conference. Then, all the feedback related to a talk was discussed in the presence of the author during several Q&A sessions. Invited and Keynote talks were live, and were also recorded. Each Q&A session was moderated by two experts, who first reviewed the 8 contributions of their session and then summarized the questions for each talk. The author could further elaborate their work and answer the questions.

1. Introduction

Porous media are solid materials composed of interconnected pores which are typically filled with fluids. Porous media can be found in many natural and industrial systems, such as subsurface reservoirs, artificial and engineering materials, biological tissues and plants (Ingham and Pop, 1998; Vafai, 2015). The pioneering studies on porous media can go back to the 19th century (Darcy, 1856). Due to the extremely complex pore structures and fluid distribution in many porous systems and their wide range of applications, major breakthroughs in theories and models are yet needed (Bear and Bachmat, 2012). These breakthroughs need to involve new concepts, modeling approaches, and experimental techniques, accounting for multi-scale and multi-disciplinary nature of the modern challenges with which our society is facing (Das and Hassanizadeh, 2005; Vadász, 2008).

Under this background, the non-profit-making scientific organization, the International Society for Porous Media (InterPore), was established in 2008, in order to advance and disseminate knowledge for understanding, describing, and modeling natural and industrial porous systems. The InterPore organization presents a platform for researchers active in modeling flow and transport in various porous media, in which the annual meeting is one of the most important activities since 2009.

During August 31-September 4, 2020, the 12\textsuperscript{th} Annual Meeting (hereafter InterPore2020) was held online. Several coherent complementary minisymposia, invited lectures, keynote
2. Minisymposia: extensive themes on porous media

The minisymposia, each based on a theme and topic on porous media, are extensive, ranging from flow, transport and thermal properties, to multi-scale, multi-physics, nonlinear and coupled processes. Further, biochemical and reaction processes, interfacial phenomena, modeling and imaging techniques, and utilization of porous media for energy, climate-driven research, ecohydrology and biogeochemistry of agro-ecosystems are also among them. The list of all minisymposia follows:

- Porous media for a green world: energy & climate
- Porous media for a green world: water & agriculture
- Flow, transport and mechanics in fractured porous media
- Swelling and shrinking porous media
- Biochemical processes and biofilms in porous media
- Physics of multi-phase flow in diverse porous media
- Interfacial phenomena in multiphase systems
- Mathematical and numerical methods for multi-scale multi-physics, nonlinear coupled processes
- Mixing, dispersion and reaction processes across scales in heterogeneous and fractured media
- Pore-scale modelling
- Advances in imaging porous media: techniques, software and case studies
- Microfluidics in porous systems
- Advances in modeling and simulation of poromechanics
- Fluids in nano-porous media
- Uncertainty quantification in porous media
- Machine learning and big data in porous media
- Fluid interactions with thin porous media
- Thermal processes, thermal coupling and thermal properties of porous media: modeling and experiments at different scales
- Innovative methods for characterization, monitoring, and in-situ remediation of contaminated soils and aquifers
- Electrochemical processes in porous media
- Biophysics of living porous media: theory, experiment, modeling and characterization
- Effective elastic, thermal, electrical and optical properties of porous materials, cellular materials, foams and metamaterials
- Catalysis and adsorption/absorption processes in porous media

Besides the topics on porous media, a special session was organized in recognition of professor Rainer Helmig’s contributions in porous media science.

3. Invited lecture: from basic porous flow in different scales to emerging technologies for global water problem

In this section, ten researchers introduced the current advances on a variety of flow and transport processes in porous media on different scales and perspectives.

Moran Wang, from Tsinghua University, presented a talk entitled “Electrokinetic and ion transport in micro/nanoporous media”. He discussed electrokinetic and interface theories for ion transport in a mesoscopic numerical framework for predictions. Validations by comparing with theories and experimental data, and multiscale analysis in both spatial and temporal scales for special applications are presented.

About the wettability, contact line dynamics and surface tension during the pore-scale motion of interfaces, Stéphane Zaleski, from Sorbonne University, reported the advances of his group on “Contact line motion using the Volume of Fluid method”. A slip length model was discussed in various regimes and a sharp interface model was implemented using a volume of fluid method in the context of several open-source codes. Despite significant advancements, in the discussion section, Stéphane highlighted that further research is still needed to consistently connect the multiphase pore-scale system to continuum scale and to cover a wider range of physically challenging transport phenomenon.

In a lecture entitled “Multiscale in-situ fluid monitoring to understand and model multiphase flow in porous media”, Olga Vizika, from IFP Energies Nouvelles, combined experimental observation and theoretical analysis, with selected examples at different scales, and demonstrated the necessity of adapting space and time scales to study multiphase flow in porous media, and discussed the complementarity of different methods.

In the lecture of “Porous media, small and large: From atomistic modeling of nano-porous membranes to modeling of flow and transport in geological formations” by Mohammad Sahimi, from University of Southern California, four classes of fundamental problems of flow, transport, reaction, adsorption and deformation in porous media were described and the corresponding modeling approaches were discussed. The challenge of upsampling from core to field scale was also discussed. It should be noted that Mohammad is the recipient of the Kimberley-Clark distinguished lectureship award and will give invited lectures in 2021 (see interpore.org/interpore-foundation).

In “Topology and its effects on fluid flow”, James McClure, from Virginia Polytechnic Institute and State University, presented the topological changes in multiphase flow in porous media in the context of geometric evolution, and used geometric laws to derive the relationship between geometric invariants. Noting that changes to the topology of an object occur as discrete events, the fundamental mechanisms that drive these changes need to be considered in detail. The associated physical consequences were examined from the molecular scale, the pore-scale, and the reservoir scale.

In “Coupling free flow and porous-media flow, and its applications to aerospace and mechanical engineering”, Guang Yang, Shanghai Jiao Tong University, presented fundamental research on the momentum transfer characteristics at the coupling interface, the roles of this coupling effect in three specific applications, and the progress of parameter optimization studies.

For the “Facilitating the Reproduction of Simulation Re-
multicomponent reactive transport during CO
of uranium dioxide in a geological repository, multiphase
in a heterogeneous micromodel and real rock, oil and water
phenomena. This included supercritical CO
direct numerical simulation of various flow and transport
Laboratory, presented a state-of-the-art research on pore-scale
direct numerical simulation of flow and transport in energy
in various energy and environmental systems. In "Pore-scale
erful numerical tool to analyze flow and transport processes
organ transport models
material design to water scarcity problem and
4. Keynote lecture: from flow simulation and
material design to water scarcity problem and
organ transport models
Pore-scale direct numerical simulation is a potentially pow-
erful numerical tool to analyze flow and transport processes
in various energy and environmental systems. In “Pore-scale
direct numerical simulation of flow and transport in energy
and environment”, Qinjun Kang, from Los Alamos National
Laboratory, presented a state-of-the-art research on pore-scale
direct numerical simulation of various flow and transport
phenomena. This included supercritical CO₂ displacing brine
in a heterogeneous micromodel and real rock, oil and water
two-phase flow in fractionally wet porous media, corrosion
of uranium dioxide in a geological repository, multiphase
multicomponent reactive transport during CO₂ dissolution
trapping, as well as hydrocarbon behavior in nanopores of
tight reservoirs.
Heterogeneous properties of polymer electrolyte mem-
brane fuel cell and electrolyzers and their interfacial contacts
have great influence on electrochemical performance. Aimy
Bazylak, from University of Toronto, gave the presentation
on “Designing porous materials for improved fuel cell and
electrolyzer performance” to discuss how the heterogeneous
porous materials and nature of interfacial contacts influence
the flow and mass transport behavior in polymer electrolyte
membrane fuel cells and electrolyzers, and introduced their
new designed and fabricated materials.

Besides the general pressure difference, chemical poten-
tial difference, electric and gravitational fields for flow and
transport in porous media, thermal driving forces are also
widely existing and encountered. In “Addressing the water
scarcity problem with thermal osmosis”, Signe Kjelstrup, from
Norwegian University of Science and Technology, focused on
the thermal osmosis, examined the theoretical and practical
conditions for a particularly important case of two-phase flow
in porous media, the flow of water using vapor-gap membranes
and a waste heat source to provide a driving force. She argued
that the theoretical basis of non-equilibrium thermodynamics
can help understand the mechanism of thermal osmosis.
Reliable and accurate diagnosis of diseases is important
for the early detection and targeted treatment of diseases. In
“Microscopical lesions of the transport system of organs and
their relation to clinically observable large-scale phenomena”,
Dominik Obrist, from University of Bern, presented multi-
scale models to infer the state of microscopic lesions from
observable large-scale phenomena, and presented several com-
putational and experimental multi-scale models of organs. He
demonstrated how they can be used to support the diagnosis
of diseases of the brain, heart and lung.

5. Invited poster presentation pitch: Flow
diagnostics and methodology for flow in porous
media in different scales

Due to the complex and uncertain geology factors of
fractured reservoirs, it is very difficult to characterize, develop,
and manage them. In the “Flow diagnostics for fractured
reservoirs: An innovative way to account for geological and
geo-mechanical uncertainty in modern reservoir modelling
and simulation workflows”, Sebastian Geiger, from Heriot-
Watt University, introduced a new flow diagnostics tool for
naturally fractured reservoirs which computed some of the
essential dynamic reservoir behaviours. His new flow diagno-
sics framework also accounts for geomechanical effects in the
reservoir. This new technology could screen large numbers of
geological models based on their approximate dynamic and
geomechanical behaviors. Flow diagnostics offers a natural
pre-processing step that complements modern coupled hydro-
mechanical reservoir simulation, uncertainty quantification,
and optimization workflows.

Contaminant transport and remediation in subsurface,
acidization to enhance permeability in oil recovery, and packed
bed reactors in chemical engineering, are the typical appli-
cations and phenomena of reactive transport of solutes in
porous media. A principal scientific problem in subsurface
reactive transport is to determine the effective reaction rates
from the pore-scale upwards. In “Scale-dependence of reaction
rates in porous media & physical and chemical heterogeneity”,
Branko Bijeljic, from Imperial College London, presented a
new methodology, termed screening pore-scale imaging and
modelling, to predict the fluid/solid reaction rates based on
the systematic characterization of both physical and chemical
heterogeneity in multi-mineral systems. Based on this method,
3D multispecies fluid/fluid reversible reactive transport in a
micro-CT image of carbonate rock is simulated to entail
spatially resolved information on connected micro-porosity. He concluded that reactive behavior in porous media is simultaneously influenced by pore space heterogeneity, multispecies reactive transport, and reaction reversibility.

6. Writing workshop: How to write a successful research paper

In the writing workshop “The 10 mistakes you should avoid”, J. Jaime Gómez-Hernández, from the Polytechnic University of Valencia, addressed the younger audience of InterPore2020 on the critical task of how to write a scientific paper. Using a case-based and flipped approach, Jaime presented bad examples of paper submission from his experience as a member of the Editorial Board of Mathematical Geosciences for the last ten years. Specifically, the common ten mistakes discussed are:

- To write in a language that looks like English, but it is not English
- Sloppiness, carelessness
- Choice of an inappropriate journal
- Lack of originality
- Don’t get too smart
- Inconclusive conclusions
- (Self) Plagiarism
- Lack of clarity
- Poor bibliography
- Poor state-of-the-art
- Not believing in your own work

The seminar ended with a discussion of what to do when a manuscript requires a major revision or it is rejected but the authors are convinced of the quality and originality of their work.

7. Career development event

The Student Affairs Committee organized a Career Development Event during this year’s InterPore conference. This event followed the overall structure of similar events that were organized in previous years in the physical conferences. This event has always been very well received, it also received some good attentions and positive feedbacks from the community even with the new challenges of the online format this year. Three researchers were invited, followed very different career paths in academia/industry, to share their experience with the community of students and early career researchers. Tiina Roose, from University of Southampton, Veerle Cnudde, from Ghent University and Utrecht University, and Benoît Noetinger, from IFP Energies Nouvelles, submitted their pre-recorded presentations which could be followed anytime by the attendees. A live Q&A session was also organized, where the attendees could directly interact with the three speakers, asking questions about the challenges of the different career paths and obtaining a direct personalized feedback from them. This is very important, since there are many early career researchers who, in spite of succeeding at their present activity (PhD, postdoc, etc.), struggling with planning the future steps of their careers. There is plenty information available about different challenges in porous media science, but many young researchers find it hard to understand the personal challenges faced by the people running the science. Not everyone is lucky enough to be close to a set of different professionals who are willing to have this important conversation. InterPore’s career development event aims precisely at filling that gap and we are very grateful to the speakers of this year’s event who did a truly excellent job. It would like to highlight the tremendously important issue of gender imbalance in science, technology, engineering and mathematics (STEM) that was eloquently raised by one of the speakers this year, Tiina Roose. It is easy to understand the issue, but sometimes people find it hard to turn this understanding into active measures to help mitigate the problem. We believe this is an important conversation to have the initial pathway for bringing the topic to InterPore this year. We hope that this conversation won’t stop and this initial input can act as a trigger for a more thorough discussion and action to raise awareness and act against the under-representation of women in the STEM fields.

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Conflict of interest

The authors declare no competing interest.

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