Universität Stuttgart
Cluster of Excellence EXC 2075 „Data-Integrated Simulation Science"

SimTech Colloquium

„Advanced Methods in Porous Media"

Place:
Hybrid: WebEx or
Universitätsstraße 32, Room 01.225

Friday, 4 November 2022
1:00 – 1:45 pm
Alexandra Vallet

3:00 – 3:45 pm
Elena Shabalina

Monday, 7 November 2022
1:00 – 1:45 pm
Sudeshna Roy

3:00 – 3:45 pm
Subhangi Gupta

5:00 – 5:45 pm
Rebecca Liyanage

Tuesday, 8 November 2022
1:00 – 1:45 pm
Maartje Boon

3:00 – 3:45 pm
Kseniya Ivanova

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Poroelastic Modeling of the Brain: Toward a Better Management of Pathological Brain Ageing?

Dr. Alexandra Vallet
University of Oslo, Norway

Worldwide, more than 50 million people have dementia, meaning they have severe cognitive alterations that reduce their independence in daily activities. However, the underlying processes of dementia are poorly understood and no cure exists. It is therefore urgent to promote new concepts and approaches in the neuroscience field.

To this extent, mechanical concepts are showing a growing potential. The functioning of the neurons relies on nutrient supply and waste clearance through solute transport and non-steady fluid flows in a complex and deformable structure made of cells, blood vessels and an heterogeneous extracellular matrix. The poroelastic theory is particularly relevant to describe and understand the multiscale/multiphysics couplings between fluid and solid mechanics at different scales in the brain.

My research focuses on the coupling of an oscillatory flow with a deformable porous structure and its effect on transport. I will present how modelling of transport, flow and deformation in the poroelastic brain constitutes a remarkable scientific challenge and how it can be used to better understand and manage pathological brain ageing.

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Wave Phenomena at the Porous-Media Free-Flow Interface: The Propagation of Sound Through Crowds and the Atmospheric Boundary Layer

Dr. Elena Shabalina
Ghent University, Belgium

The study of sound waves becomes more and more important, with noise pollution being a growing societal concern. Thereby the porous medium plays a crucial role because it contributes to the control and reduction of sound waves. Many natural media, such as soils, crops, forests or crowds, can be modelled using a porous media approach. Very often the porous medium is coupled to the free flow, such as the atmosphere or the ocean. This talk deals with wave phenomena on their interface.

First, we discuss the propagation of acoustic waves through a porous medium using a crowd of people as an example. We show a way to model a crowd as a set of upright rigid cylinders to predict the density-dependent speed of sound. Knowing the speed of sound, we can calculate reflections on the boundaries of a porous layer and evanescent waves caused by the finite height of it. By controlling the density of the layer, we can limit reflections, creating an acoustic black hole.

Second, we consider the wave propagation in the free flow – the atmospheric boundary layer. The flow speed profile in the atmosphere is complex and depends on its state; the transport and heat transfer phenomena alter the density and temperature profiles. This influences the wave propagation speed profile.

Certain profiles create downwards refraction of sound waves, causing them to interact with the porous layer multiple times. While it is possible to predict how the shape of a such a profile influences the wave propagation path, each interaction depends on the properties both of the profile and the porous layer and their uncertainties. This opens doors to future research and collaborations.

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Granular matter comprises all materials that consist of many particulate entities which are large enough not to be subjected to thermal motion at room temperature. They are ubiquitous in nature and widely used in various industries such as food, pharmaceutical, agriculture and mining. Bridging the gap between the particulate, microscopic state and the macroscopic, continuum description is one of the challenges of granular research. The main objective of my research is to investigate how the micro-mechanical properties influence the macroscopic bulk responses of granular materials. The focus of my research are

(i) the formulation of suitable constitutive equations for the hydrodynamic density-stress-strain relations,
(ii) the deduction of the constitutive equations from discrete element simulations, and
(iii) their validation with theoretical and experimental results.

My research includes a wide and systematic investigation of granular bulk behaviour in various applications under varying flow conditions, inter-particle cohesion and at various stress regimes.

Multiscale Modeling of Particulate Systems

Dr. Sudeshna Roy
Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

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Multi-physics processes in Earth systems: From complex phase-transitions in Gas Hydrates to evolving interfaces in Geomorphology

Dr. Shubhangi Gupta
Helmholtz Center for Ocean Research GEOMAR, Germany

The Earth is composed of five main systems: Geosphere, hydrosphere, atmosphere, cryosphere, and biosphere. All these systems are highly interconnected, and even have many overlapping sub-systems. Moreover, these systems do not exist in isolation; their fates are strongly intertwined. For example, gas hydrates form an integral part of the solid Earth (i.e. geosphere). Their formation is linked to organic matter fluxes (i.e. biosphere) that build up over continental margins over millennia. Changes in atmospheric and bottom-water conditions can destabilize the buried gas hydrates and accelerate the release of copious amounts of gas into the ocean (i.e. hydrosphere), leading to ocean acidification, and eventually, into the atmosphere, leading to global warming. Rising temperatures impact the glaciers and permafrost in the cryosphere and cause sea-level rise, which will further destabilize the gas hydrates.
This example demonstrates quite vividly how changes in one part of the Earth system can trigger a series of changes in other Earth systems, and how feedbacks across the system interfaces can amplify these changes. To study such systems, we require advanced and highly tailored multi-physics approaches that can handle the complex sub-structures as well as the characteristic physical processes of each of these systems, like free- and porous-media flow, transport, bio-geo-chemistry, fluid-solid interactions, fluid-fluid and fluid-solid phase transitions, evolving interfaces, and geo-mechanics (and related phenomena of lateral spreading, plastic flow, fracture formation, flow localization, etc.). In this talk, I will discuss modeling approaches and their challenges for some selected Earth systems like natural gas hydrates, polar permafrost, and continental margin landscapes..

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Interfacial instabilities and enhanced mixing in porous media across scales

Dr. Rebecca Liyanage
Pexapark AG, UK

Interfacial instabilities occur at the boundary between two fluids and are caused by differences in fluid properties or advective forces. What starts as a micro-scale perturbation can grow to macro-scale flow structures and can fundamentally alter the large-scale transport dynamics. This talk will focus on two examples of processes driven by interfacial instabilities, one in a single-phase system and the other in a multiphase system. Both were explored with a combination of 3D experimental imaging methodologies and modelling approaches that aimed to answer fundamental questions which have real-world applications. The first is the topic of convective mixing during subsurface carbon storage. Here, we used a range of fluids to mimic reservoir conditions and through x-ray CT imaging we revealed flow patterns and mixing behaviours which were directly compared to numerical simulations. The second topic is unsaturated flows in soils. In certain unsaturated porous media, the fluid can infiltrate as an even continuous front or channelise into fingered flow. We investigated this process with the addition of surface evaporation and found that fingered flow had the greatest impact on increasing deep infiltration in very dry conditions. Finally, the presentation will conclude with an outline of future research visions which broadly fall into two categories: 1. Fluid-fluid and fluid-solid interactions in the context of underground hydrogen storage. 2. Pore scale coupling of multiphase instabilities and evaporation.

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The Impact of Structural and Chemical Heterogeneity on Flow, Transport and Reaction in Porous Media

Dr. Maartje Boon
Delft University of Technology, The Netherlands

Flow, transport and reaction in porous media are coupled processes that are highly impacted by heterogeneities in both the structure and the chemical composition of the material. The complex nature of these heterogeneities in natural existing porous media makes it difficult to fully understand the effect of these heterogeneities on coupled reactive transport processes. Furthermore, the large spatial scales involved in many of the applications prohibits the direct inclusion of small scale heterogeneities into larger scale models. With the use of smartly engineered porous media I would like to address the following research question: *"How do heterogeneities across different scales impact flow, transport and reaction and how can we incorporate this into larger scale models?* This research will be relevant for a wide range of porous media applications, however, a specific focus will be placed on subsurface storage of CO_2 and H_2..

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Mathematical Model of Multi-Dimensional Shear Shallow Water Flows and ist Applications to Poweder-Snow Avalanches

Dr. Kseniya Ivanova
Swiss Federal Laboratories for Materials Science and Technology, Switzerland

For shear flows with varying in space and time vorticity a new model was recently proposed where the governing equations are obtained by depth averaging of Euler equations without assuming potential flow. This is a 2D hyperbolic non-conservative system of equations that is mathematically equivalent to the Reynolds-averaged model of barotropic turbulent flows. The model has three families of characteristics corresponding to the propagation of surface waves, shear waves and average flow (contact characteristics).The system is non-conservative: for six unknowns (the fluid depth, two components of the depth-averaged horizontal velocity, and three independent components of the symmetric Reynolds stress tensor) one has only five conservation laws (conservation of mass, momentum, energy and mathematical ‘entropy’). In present work a splitting procedure for solving such a system is proposed allowing us to define a weak solution. Each split subsystem contains only one family of waves (either surface or shear waves) and contact characteristics. The accuracy of such an approach is tested on 2D analytical solutions describing the flow with linear with respect to the space variables velocity, and on the solutions describing 1D roll waves. Finally, we model a circular hydraulic jump formed in a convergent radial flow of water and turbulent powder-snow avalanches. Obtained numerical results are qualitatively and quantitatively similar to those observed experimentally.

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