Contribution ID: **246**

Type: **Oral Presentation**

Regularization strategies to improve the numerical efficiency of a fully-implicit pore-network model

Thursday, 16 May 2024 14:05 (15 minutes)

Porous media coupled with free-flow systems are prevalent in both natural and technical applications. A classic example of such systems in the nature is the interaction between wind and partly saturated soil, leading to soil drying through evaporation. In fuel cells, as an example of technical applications, the understanding of interface process between the free flow (gas distributor channel) and the porous medium (gas diffusion layer) is crucial for optimizing fuel cell performance. In order to simulate these strongly non-linear coupled systems, efficient, monolithic model concepts are required.

Pore-network model (PNM) has been proven to be an efficient tool to capture pore-scale phenomena. Through simplified representation of porous media geometry, a pore-network model describes the porous medium as large void spaces, pore bodies, connected by narrow paths, pore throats. In this work, we focus on the fully implicit pore-network model and discuss the related modeling and numerical challenges. A central concern in this type of pore-network models is dealing with the discontinuity in local conductivity of fluid phases due to displacement processes, i.e., invasion and snap-off, in the pore throat, which causes numerical convergence issues during simulation. To tackle this issue, we first propose regularization strategies to smoothen the local conductivity curve. In addition, we introduce a generalized flux function formulation using a Heaviside function to scale the flux within a pore-throat with a factor parameter. We analyze the impact of employing the aforementioned approaches on the numerical efficiency and accuracy of the fully-implicit pore-network model. Finally, we show that the further development of our PNM allows simulating porous media coupled with free-flow systems.

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Presenter: WU, Hanchuan

Session Classification: MS09

Track Classification: (MS09) Pore-scale modelling