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A Multiscale Approach to Pore-Network Two-Phase Flow Simulation Applied to a Carbonate Reservoir

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Pore Network Models (PNM) are an important approach to flow simulation in porous media, alongside direct numerical simulation and Lattice Boltzmann Models. Those methods are usually applied in the context of digital rocks, in which images of rock samples are used to extract the geometric information used in the simulation. When compared to the other approaches, PNM is considered to be a more computationally efficient solution, both in processing time and memory requirements, specially for sensitivity tests where the network is extracted once and multiple simulations with diverse flow parameters are performed.
A prevalent challenge in porous media flow simulation is the handling of multiscale media: samples with a broad distribution of pore sizes. Pore sizes can be separated in two different classes of image elements, depending on the imaging resolution: resolved elements (clear distinction between void and solid space) and subresolution elements (resolved image elements containing both void and solid space). Important reservoir rock types such as carbonates present such multiscale behaviour. Multiscale models aim to address the lack of pore geometry information on the subscale phase and the computational challenge of taking in account all subscale pores in a representative volume.
There are multiple ways to include multiscale elements in PNM, such as the one proposed by Bultreys (2016), in which the extraction of the network creates two categories of pores: Navier-Stokes pores from resolved elements and Darcy pores from subresolution elements. Navier-Stokes pores are evaluated using the method by Valvatne(2004) in which a regular cross section geometry is assigned to pores and throats based on their shape factor. The present work changes the approach to the solution of the Darcy pores, using a bundle of tubes model to calculate their flow properties. This approach was selected because the bundle of tubes model may be solved with the pore radii information, which can be obtained experimentally from the readily available mercury injection capillary porosimetry (MICP) test.
The method was implemented in Geoslicer, an open source software platform for Digital Rock visualization, analysis and simulation. Simulation was performed on a pre-salt carbonate rock formation of the Campos basin and both absolute permeability and relative permeability data were obtained and compared with experimental values. Absolute permeability has shown good agreeability between simulated and experimental values. Relative permeability results showed the necessity of parameter calibration to take into account the shape factor of subscale pores, compensate for the intrinsic subestimation of pore radius in MICP, and the distribution of contact angles. It should be noted that contact angle distribution is a complicating phenomena also present in single scale simulations.

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References

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