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Nano-resolution X-CT 3D Imaging and Permeability Simulation of an Actual Shale Kaolinite

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Pore and pore network characterization in clays and claystones is essential as they are of longtime and continuing importance in conventional hydrocarbon exploration, unconventional reservoirs and gas (e.g. CO2 and N2; Vernooij et al., 2020), and radioactive waste (Plúa et al., 2021) storage caprocks. Nonetheless, they also occur within the reservoir where they can act as local baffles (Benham et al., 2018) or exceptionally lie at the origin of secondary porosity generation like in the pre-salt formation offshore Brazil (Tosca and Wright, 2015). Porosity and permeability are key factors in assessing the hydrocarbon productivity of unconventional (as shales) reservoirs, which are complex due to their heterogeneous mineralogy and poorly connected nano- and micro-pore systems (Goral et al., 2020). Kaolinite is a kind of clay mineral from the kaolin group with an asymmetric structure similar to stacked layers of pseudo-hexagonal tiles, or platelets, with a few tens of nanometers in thickness (Brigatti et al., 2013; Varga, 2007, Johnston, 2010). Each of these platelets can be considered as an individual kaolinite crystal that can be stacked forming macrostructures (aggregates), as booklets and vermiform morphologies (Mansa et al., 2017). Numerical permeability simulations on these structures are quite rare due to the difficulty in properly imaging them. Due to their small dimensions, most of the registered images of kaolinites are achieved in 2D space with the SEM (scanning electron microscopy) technique (Ivanić et al., 2015; Mansa et al., 2017; Alcázar-Vara and Cortés-Monroy, 2018). This makes kaolinite (and clays in general) permeability estimation challenging since numerical simulations are performed with 3D images of the porous system, whether they are pore networks or voxel-based digital structures. Even though 3D models of shales reconstructed based on 2D image information can be performed (Chen et al., 2015), running simulations on an actual 3D image of the porous media represent a direct process, bypassing the modeling reconstruction. The relatively new focused ion beam (FIB) technology improves the SEM technique making it capable to provide 3D images in high resolution of samples such as clays (Zhu et al., 2021). However, an alternative to FIB-SEM and 3D modeling is high-resolution X-ray nanotomography (nanoCT). NanoCT performs image acquisition in the area of submicron X-ray tomography (Withers, 2007). Since X-ray microtomography (micrometer scale version of tomography) is often employed to analyze the 3D pore network structures of materials, nanoCT is a promising technique that aims to improve this analysis, enabling one to reach the nanometer scale. Besides improving qualitative insight into kaolinites by providing an actual 3D image of it on the nanoscale, this work also aimed to estimate its absolute permeability. A 117⊠m diameter cylindrical sample containing the kaolinite mineral was drilled from a shale sample with a laser ablation system and an Xradia/Zeiss nanoCT scanner UltraXRM-L200 was employed to generate images with 64nm/voxel spatial resolution. The lattice Boltzmann method was used to simulate permeability that was found to be 0.09 mD.

Participation

In-Person

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Primary author: Dr CAMARGO MOREIRA, Anderson (Federal University of Santa Catarina, Mechanical Eng. Dept. LMPT)

Co-authors: Dr PERES FERNANDES, Celso (Federal University of Santa Catarina, Mechanical Eng. Dept. LMPT); Dr SURMAS, Rodrigo (Cenpes - Petrobras); Dr FRANGIOTTI MANTOVANI, Iara (Federal University of Santa Catarina, Mechanical Eng. Dept. LMPT); Ms DEBATIN VIEIRA, Lucas (University of São Paulo); Dr CLAES, Hannes (KU Leuven)

Presenter: Dr CAMARGO MOREIRA, Anderson (Federal University of Santa Catarina, Mechanical Eng. Dept. LMPT)

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