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A multi-scale multi-step machine learning method for absolute permeability estimation from porous media low resolution medical-CT images

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Medical CT imaging is a key tool in porous rock characterization. Its
importance stems from its ability to provide large fields of view, enabling acquisitions of core samples of several centimeters in diameter and length. Consequently, analysis of more representative volumes of heterogeneous rocks becomes possible, since larger scale features and higher degrees of variability gets captured. That comes, however, with the downside of low resolution acquired images (voxel lengths greater than 100 μm), making it hard to fully resolve the sample pore space, since many pores, specially for carbonate rocks, will lie in the subresolution scale. Image-based permeability estimation methods, such as Lattice Boltzmann Method (LBM), rely on pore-matrix segmentation. However, LBM canonical form can yield incorrect results for samples with unresolved pores. To overcome this limitation, the present work proposes a multi-scale multi-step machine-learning-based methodology to estimate absolute permeabilities based on medical CT images. To accomplish that, dimensionless features derived from Minkowski functionals of 3D and 2D subdomains of high resolution (8 μm voxel length) micro-CT images of carbonate rocks. These features are matched against absolute permeability values estimated through LBM simulations. As a first step, the extracted features, along with the porosity of each subdomain, are subjected to an unsupervised classification model which identifies clusters of subdomains and labels them. Secondly, neural networks are employed in a regression step to find Kozeny-Carman parameters for each of the identified labels. Finally, based on the hypothesis that carbonate rocks display self-similar (or fractal) properties, a porosity and a segmented image of a 30 cm wide and 3.81 cm diameter carbonate core sample acquired through medical CT are subjected to the classification and regression models. With the sample subdomain types identified through the segmented image, the Kozeny-Carman models found by the neural networks are employed to estimate the permeabilities of the subdomains using the porosity image. Employing the proposed methodology, the absolute permeability of the sample was estimated to be 83.8 mD while core-flooding measurements indicate a permeability of 88.2 mD, representing an error of 5%. This result indicates that the fractal hypothesis is valid and that the methodology is reliable.

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References

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