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Anisotropic Permeability Prediction at the pore scale: A Lattice Boltzmann and Machine Learning Approach

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Understanding the directional properties of porous media is crucial for accurately predicting flow behavior, reactive transport, and fluid solid interactions in applications such as geothermal systems, energy storage devices, and biological systems. Directional permeability values, which reflect the medium's response to flow at various angles, are especially important for complex geometries with an inherent anisotropy. In this study, we used a Lattice Boltzmann (LBM) model to calculate directional permeabilities from porous media patterns with different angles of flow inlet.

Three classes of porous media were generated for this study: (1) media with circular grains, (2) media with elliptical grains, and (3) media combining circular and elliptical grains. For circular grains, we varied parameters such as grain diameter distributions, a number of circles, and inter-circular distances. For elliptical grains, we varied eccentricity, semi-major and semi-minor axes, and the number of ellipses. The mixed media combined features from both types. Our investigation primarily aims to analyze the anisotropy of porous media. Isotropic media theoretically permit permeability prediction in any direction via linear transformation from the principal direction. However, it is not thoroughly investigated in anisotropic porous media. Circular grains serve as a baseline for the isotropic geometry, whereas elliptical and mixed grains represent cases of anisotropy. Using our LBM flow model, permeability was calculated at 10° intervals across 360°, producing 36 data points per image of porous media. This approach generated a comprehensive dataset for the three media classes, each yielding unique functional relationships between angle and permeability.

We aim to train a machine learning model to predict permeability as a function of inlet flow angle for a porous medium image input. We would be able to compare machine learning performance as response to three different classes of obstruction patterns. Additionally, we want to explore the feasibility of using linear transformations from the principal direction to estimate permeability in anisotropic media. Apart from these, we would study the effects of geometrical properties like eccentricity, radium, axis lengths on the relationship between permeability and angle of inlet for a same class of porous medium.

Our findings could significantly enhance the understanding of directional transport properties in porous structures, providing deeper insights into the impact of geometric anisotropy on flow behavior. Additionally, they could pave the way for developing more accurate and efficient predictive models for complex geometries, with potential applications in fields such as filtration, energy storage, and subsurface fluid flow. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

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References

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