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An image-based sphere insertion method for porous media drainage simulations with gravity

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Simulations of two-phase flow in porous media are of interest in a wide range of fields such as groundwater remediation, oil and gas extraction, and hydrogen storage devices [1–5]. In the field of hydrogen storage, the flow of gases and liquids in porous media layers of fuel cells greatly impact their performance [6]. Historically, continuum models have been the most prominent as they are useful for observing macroscopic phenomena, such as flow in deformable porous media or in electrochemical devices [7–10]. However, continuum methods do not lend themselves to investigating pore-scale phenomena in two-phase flow. Moreover, pore-scale simulations typically neglect gravity as it is assumed that the pores are small enough that capillary forces are dominant over gravitational forces [11,12]. In this study, we present our adaptation of the established full morphology method [1,2] that allows for the inclusion of gravitational forces during drainage simulations. Unlike traditional full morphology methods, our method does not rely on morphological image processes but rather utilizes calculated image-based sphere insertion (IBSI) to simulate an invading non-wetting phase.
To include the effect of gravity in the IBSI approach, we utilized a distance transform approach with two modifications. In previous studies that use the standard approach without gravity, a distance transform was used to determine the radius of a meniscus that can fit at each pixel of the pore space [1,2]. One key step for incorporating the effect of gravity was to convert the values of the distance transform to reflect their vertical distance from the inlet. This requires converting the distance values to a capillary pressure using the Young-Laplace equation, assuming the two interacting fluids are fully non-wetting and the interface is spherical in shape. Then, the pressure in each voxel was calculated based on their respective heights. A seed voxel was then placed at all locations of non-solid space in the image where the pressure was lower than the applied inlet pressure. Finally, to simulate the advancing meniscus, spheres were placed at the center of each seed point with a radius determined by the initial distance transform.
The IBSI method was validated using capillary tubes demonstrating a mean error of 1.83 ± 5.45 % compared to analytical solutions and further compared to experimental values from literature [13]. Simulations on 2D and 3D stochastically generated porous media were performed to demonstrate the impact of neglecting the effects of gravity in drainage simulations in the generated porous media. The absolute saturation error, defined as the difference between the saturation with and without the consideration of gravity, increases as the Bond number and the height of the porous media domain increases, as shown in the contour plot below. Through these results, it was shown that gravity can play a significant role in drainage at low bond numbers («1), especially in large domains (>10 mm in height). It is therefore recommended that gravity be considered when studying drainage in porous media domains at the centimeter or greater scale such as in large-scale fuel cell stacks.

Participation

In-Person

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