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Impact of structural heterogeneity on fluid phase patterns in two-phase flow through two-dimensional porous micromodels

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The fluid phase saturation degree is often used to define multiphase flow conditions in porous media macroscopically. However, the microscopic (pore-scale) fluid phases'distribution pattern can be crucial and is usually not measured or quantified. For example, the topology and connectivity of the fluid phases impact the permeability and, thus, relative flow rates. Therefore, they will impact multiphase flow and related transport processes, including water leaching and drying in soils and the vadose zone, enhanced oil recovery, and CO_2 sequestration in deep geological formations. These processes will, in turn, impact the fate of nutrients and pollutants in the subsurface, the precipitation and dissolution of minerals, and the extent of microbial activity, to name a few. Still, the link between the porous medium's structure –the distribution of pore sizes and their relative positions –and the pore-scale fluid phase distribution during multiphase flow is still far from being understood. An essential requirement, at least experimentally, is to obtain direct observations of the displacement patterns. To this end, we use micromodel experiments with quasi-two-dimensional porous media. The samples are created from numerically generated geometries of circular posts positioned in a Hele Shaw-type flow cell and fabricated in PDMS. We vary the medium's heterogeneity by controlling the disorder in the circular posts'diameters and the correlation length of their spatial distribution. In the experiments, we simultaneously inject liquid and air to establish an unsaturated flow pattern with a connected liquid phase cluster. The liquid phase contains a fluorescent dye, and the flow cell is illuminated to excite the dye at the appropriate wavelength. We take images of the emitted light intensity and analyze them to determine the fluid phase clusters'location and geometric characteristics. We infer their number, position, area, and liquid-air interface length. In addition, we calculate the clusters'Minkowski functionals. We find that increasing the spatial correlation length of the posts (or, equivalently, pore sizes) decreases the number of air (the non-wetting phase) clusters while increasing their average area, perimeter length, and distance to the closest neighbor air cluster. In addition, the roughness of the air-liquid interface is smaller for longer correlation lengths. These characteristics impact the connectivity and tortuosity of the connected liquid (wetting) phase and could influence the liquid flow characteristics and, thus, solute transport and mixing processes. Our experimental study could also be used as a basis for a deep learning approach to derive more generalized relationships between porous medium structure and fluid phase distribution.

Participation

In-Person

References

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