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Smart Fluids in Hydrology: Use of Non-Newtonian Fluids for Pore Structure Characterization

Majdi Abou Najm (1), Nabil Atallah (1), John Selker (2), Clément Roques (2), Ryan Stewart (3), David Rupp (4), George Saad (1), and Mutasem El-Fadel (1)

(1) Civil & Environmental Engineering, American University of Beirut, Beirut, Lebanon (majdian@aub.edu.lb), (2) Biological & Ecological Engineering Department, Oregon State University, Corvallis, OR, United States., (3) Crop and Soil Environmental Science Department, Virginia Polytechnic Institute and State University, Blacksburg, VA, United States, (4) Oregon Climate Change Research Institute, College of Earth, Ocean, and Atmospheric Sciences, Oregon State University, Corvallis, OR, United States.

Classic porous media characterization relies on typical infiltration experiments with Newtonian fluids (i.e. water) to estimate hydraulic conductivity. However, such experiments are generally not able to discern important characteristics such as pore size distribution or pore structure. We show that introducing non-Newtonian fluids provides additional unique flow signatures that can be used for improved pore structure characterization. We present a new method that transforms results of N infiltration experiments using water and N-1 non-Newtonian solutions into a system of equations that yields N representative radii (Ri) and their corresponding percent contribution to flow (wi). Those radii and weights are optimized in terms of flow and porosity to represent the functional hydraulic behavior of real porous media. The method also allows for estimating the soil retention curve using only saturated experiments. Experimental and numerical validation revealed the ability of the proposed method to represent the water retention and functional infiltration behavior of real soils. The experimental results showed the ability of such fluids to outsmart Newtonian fluids and infer pore size distribution and unsaturated behavior using simple saturated experiments. Specifically, we demonstrate using synthetic porous media composed of different combinations of sizes and numbers of capillary tubes that the use of different non-Newtonian fluids enables the prediction of the pore structure. The results advance the knowledge towards conceptualizing the complexity of porous media and can potentially impact applications in fields like irrigation efficiencies, vadose zone hydrology, soil-root-plant continuum, carbon sequestration into geologic formations, soil remediation, petroleum reservoir engineering, oil exploration and groundwater modeling.