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The Drainage Foam Equation – New Formalism for Effective Relative Permeability Linking Unsaturated Flow across Textural Contrasts

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Capillary flows in unsaturated porous media are often confined to spaces behind curved air-water interfaces forming continuous liquid channels along grain contacts, pore corners and crevices. The resulting capillary liquid network resembles the structure liquid-filled channels between interacting bubbles in wet foam (known as Plateau borders). For a simple channel geometry and Darcy-type viscous dissipation, a continuity equation for the evolution of liquid channel cross-sectional area during drainage could be derived without using the standard Richards equation and associated constitutive relations (hydraulic functions). Potential advantages of the proposed drainage foam formalism include direct description of transient flow without requiring constitutive functions; evolution of capillary cross sections that provides consistent description of self-regulating internal fluxes (e.g., towards field capacity); and a more intuitive geometrical picture of capillary flow across textural boundaries (channel angle and number of channels). We will present sample applications and parameter estimation for specific experimental results focusing on unsaturated steady flow through layered media with related derivation of effective unsaturated hydraulic conductivity, and compare to standard estimation schemes. The foam drainage methodology expands the range of tools available for describing unsaturated flows and provides geometrically tractable links between evolution of liquid configuration and flow dynamics in unsaturated porous media.