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Predicted Disappearance of Saturation Hysteresis in Coarse Granular Media Based on Capillary and Gravity Scaling, and Experimental Tests

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Since the classic work of W. B. Haines (1930), hysteresis in the relation between matric (capillary) potential versus water content has been recognized as a basic aspect of interactions between water and variably saturated porous media. This lack of unique correspondence between potential and saturation has well-recognized consequences for equilibrium, flow, and transport. Although hysteresis in moisture characteristic relations has several causes, the existence of different pore-sizes within porous media (the "ink bottle" effect) is primary. This capillarity-dependent phenomenon has a grain-size limit imposed by the influence of gravity, and more generally by the relations between surface and body forces, and length scales. Above this limit, capillary hysteresis vanishes. The grain-size associated with vanishing of capillary hysteresis was predicted in two ways; first with a simple pore-size model, and second by Miller-Miller scaling. Both methods predict that hysteresis vanishes when characteristic grain-sizes exceed about 8 mm, when the water-air surface tension is 72 mN/m, and when the body force is due to ordinary gravity. More generally, capillary hysteresis is predicted to disappear when the Haines Number (dependent on grain-size, surface tension, the body force, density difference between immiscible fluids) exceeds 8. The predicted critical grain-size was experimentally supported through measurements of drainage and wetting curves of sands and gravels, with grain-sizes ranging from 0.2 up to 11 mm. We also consider effects of interfacial tension variation (surfactants), variation of the body force (centrifugal field), and capillarity associated with grain-surface roughness.