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Dynamic capillary pressure, hysteresis and gravity-driven fingering in porous media

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The unsaturated flow of water in soil occurring through unstable wetting fronts has been documented widely both in the field and the laboratory over the past three decades . Wetting front instability leads to the development of unstable or fingered flow profiles which significantly increase the transport velocity of dissolved pollutants to groundwater through the unsaturated zone. To be able to make effective and realistic predictions concerning groundwater quality requires a thorough understanding of the physics of the transport mechanisms through the unsaturated zone and their corresponding mathematical representation. A key characteristic feature of fingers is that the capillary pressure distribution is non-monotonic, and there is a reversal in the pressure gradient immediately behind the advancing finger tip. For experimental conditions under which these fingers have developed it has been shown that solutions of Richards' equation must be monotonic. Consequently a modified Richards' that takes into account non-equilibrium or dynamic processes have been proposed in order to produce non-monotonic profiles. This presentation compares three such models, developed by Hassanizadeh and Grey (HG), Glass and co-workers and Barrenblatt and co-workers. We present both one and two-dimensional numerical profiles which include effects of hysteresis. While both the HG and Glass models can produce non-montonic profiles and finger like structures, we show through a travelling wave analysis that the Barrenblatt model can only develop monotonic solutions. As such the Barrenblatt model, which has been successfully used to simulate two-phase non-equilibrium counter current flow, does not have the capacity to simulate saturation profiles which occur under fingered flow conditions.