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Stability analysis of gravity-driven infiltrating flow

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Abstract

Stability analysis of gravity-driven unsaturated flow is examined for the general case of Darcian flow with a generalized nonequilibrium capillary pressure-saturation relation. With this nonequilibrium relation the governing equation is referred to as the nonequilibrium Richards equation (NERE). For the special case where the nonequilibrium vanishes, the NERE reduces to the Richards equation (RE), the conventional governing equation for describing unsaturated flow. A generalized linear stability analysis of the RE shows that this equation is unconditionally stable and therefore not able to produce gravity-driven unstable flows for infinitesimal perturbations to the flow field. A much stronger result of unconditional stability for the RE is derived using a nonlinear stability analysis applicable to the general case of heterogeneous porous media. For the general case of the NERE model, results of a linear stability analysis show that the NERE model is conditionally stable, with lower-frequency perturbations being unstable. A result of this analysis is that the nonmonotonicity of the pressure and saturation profile is a requisite condition for flow instability.

Keywords

Dynamic capillary pressure, Gravity-driven flow, Richards' equation, Stability analysis, Traveling wave solution