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Liquid redistribution behind a drainage front in porous media imaged by neutron radiography

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Drainage from porous media is a highly dynamic process involving the motion of a displacement front with rapid pore scale interfacial jumps and phase entrapment, but also a more gradual host of liquid redistribution processes in the unsaturated region behind the front. Depending on the velocity of the drainage process, liquid properties and the permeability of the porous medium, redistribution lingers long after the main drainage process is stopped, until gravity and capillary forces regain equilibrium. The rapid and often highly inertial Haines jumps at the drainage front challenge the validity of Buckingham-Darcy law and thus representation of the process based on the foundation of Richards equation. To quantify front displacement and liquid reconfiguration and to test validity of Richards equation with respect to fast drainage dynamics, we carried out drainage experiments by withdrawing water from the bottom of initially saturated sand-filled Hele-Shaw cells at constant water flux (2.6 or 13.1 mm/minute). Water content distribution and evolution of drainage front were measured with neutron radiography at spatial and temporal resolutions of 0.1 mm and 3 seconds, respectively. Water pressure was measured above and below the front using pressure transducers and a tensiometer. After the pump was stopped (at a front depth around 100 mm), capillary pressure values in the unsaturated region (above the front) gradually converged to a new equilibrium. The pressure signal in the saturated region below the front reflected viscous losses during flow that were relaxed when the pump stopped. During pressure relaxation water was redistributed primarily downward in the unsaturated region. Pressure signals and dynamics of water content profiles for fast process (13.6 mm/minute) could not be reproduced with Richards equation based on hydraulic functions determined in preceding laboratory experiments. To explore if the deviations stem from inappropriate hydraulic functions we redefined them based on fitting the slow experiment (2.6 mm/min) and apply the optimized functions for the fast experiment. Finally we will discuss application of alternative formulation based on foam drainage equation to represent liquid redistribution dynamics behind the front.