Geophysical Research Abstracts
Vol. 13, EGU2011-5592, 2011
EGU General Assembly 2011
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Evaporation – Condensation Dynamics Affecting Vapor Transport in Partially Saturated Porous Media - Models and Experiments

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In contrast with inert gas diffusion, vapor diffusion of condensable phase (water vapor) in partially - saturated porous media may be enhanced in the presence of liquid phase occupying pore spaces. The enhancement mechanisms involve evaporation - condensation across liquid islands down macroscopic thermal or capillary gradient and enhance local thermal gradients due to the variation in thermal conductance. These often postulated mechanisms were seldom studied at the pore scale and the objective of this study was to quantify experimentally and theoretically potential roles of liquid bridges and local thermal gradients on the dynamics of vapor transport at pore scale. We conducted pore scale experiments using synchrotron X-ray tomography to measure and verify a mechanistic model of evaporation and condensation dynamics as a building block for the modeling of vapor diffusion through porous media. Simulations of vapor diffusion in the presence of liquid phase reveal that the so-called enhanced vapor diffusion under isothermal condition is attributed to simple reduction in diffusion path length. Presence of a thermal gradient may augment or hinder this effect depending on the direction of thermal relative to capillary gradients. We have used a simple 1-D upscaling scheme to translate pore scale to sample scale transport regimes under different saturation conditions. “True” pore scale vapor transport enhancement as postulated by Philip and de Vries [1957] takes place at low water contents and may account for doubling of the vapor flux under common (mild) thermal gradient assistance, relative to diffusion of an inert gas through the same system. As liquid saturation exceeds the percolation threshold, transport becomes dominated by capillary flow. The study offers consistent mechanistic explanation for the complex vapor transport processes in unsaturated porous materials which is of interest in many natural and engineering porous media applications.