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Physical Insights into Phase Transition and Capillary Transport in Porous Media with In-situ NMR-MRI Characterization

Interfacial transport and phase transition are essential for a large variety of energy and sustainability applications, while in-situ characterization provides instrumental ways of probing and enhancing thermal-fluid transport in porous media. In this talk, I will share our recent progresses on water evaporation and ice melting in homogeneous and heterogeneous opaque porous media, by utilizing non-destructive nuclear magnetic resonance (NMR) and magnetic resonance imaging (MRI). By characterizing the amplitude variation of NMR transverse relaxation time T2, we find that cavitation occurs across the entire porous media along with the water evaporation from open surface. Disconnected void clusters at different depths in the porous medium are also observed from MRI scanning and optical images. These evidences confirm the occurrence of cavitation in porous media because the water is stretched to metastable state by large capillary pressure from the evaporating meniscus. Moreover, transient T2 distributions from NMR enable us to reveal the substantial role of inherent throat and pore confinements in ice melting among various porous media. The increase in minimum T2 offers new findings on how the confinement between ice crystal and particle surface evolves inside the pores of mushy zone. The evolution of melting front and 3D spatial distribution of water content are directly visualized by a stack of temporal cross-section images from MRI, in consistency with the associated NMR results. For heterogeneous porous media like lunar regolith simulant, the T2 curves show two distinct pore size distributions with different pore-scale melting dynamics, and the maximum T2 keeps increasing throughout the whole ice melting process instead of reaching steady for homogeneous porous media. These transport and phase change physics opens up new avenues to develop novel solutions for water-energy-food nexus and in-situ resource utilization towards deep space exploration.

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