Geophysical Research Abstracts
Vol. 21, EGU2019-6232, 2019
EGU General Assembly 2019

New insights into dynamics of non-isothermal evaporation from porous media consisting of spheres and rods

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Understanding loss of water from different porous systems is crucial in many sectors such as in agriculture, food processing, and in electronic cooling devices. We studied evaporation from two different types of porous media. One is the conventional porous media (CPM) consisting of nearly mono-disperse spheres. The other is closely packed circular rods, either oriented vertically or horizontally, which we term as rod-based porous medium (RBPM). In all experiments, the porous medium, initially saturated, kept in containers (∼30 cm2 area of cross section and ∼10 cm high) was exposed at the top to infra-red (IR) radiation with an intensity of ∼1000 W/m2. The container was open at the top and thermally insulated on the other five sides. Using three diagnostics, (a) mass loss measurement with time, (b) IR imaging to obtain surface temperature, (c) drying front visualization using fluorescein dye, we studied the evaporation processes in the two types of porous media.

In CPM, we observed the standard three stages: a high evaporation rate for some time, followed by a transition period, and then finally a drastically reduced rate. The average surface temperature increased as the evaporation rate reduced, which is explained using surface energy budget (SEB). The IR images showed non-uniform surface temperature distributions, clearly revealing the presence of wet and dry regions. The transition from the first stage, believed to be related to break-up of liquid films at the top surface, coincided with the disappearance of the surface wet patch(es). The transition may be written in terms of an evaporative length (L_cap), defined as the average water depth, measured from the top, at the end of stage 1. From experiments using a range of sphere sizes and two liquids (water and pentane), we show that a dimensionless L_cap may be defined that is a unique function of Bond number (Bo). The evaporation characteristics for the RBPM were quite different from that for CPM. In the case when the rods were horizontally aligned, the transition stage was gradual, and in general the evaporation rates were lower compared to those for same sized CPM. In contrast, when the rods were aligned vertically we observed the evaporation rate to be high, or transition occurred, till almost all the liquid was fully evaporated, which implies that L_cap values are expected to extremely high. The unusually long first stage is due to the near-zero radius of contact between adjacent rods leading to very high (theoretically infinite) capillary rise length. Thus, during evaporation, the liquid menisci between rods are pinned near the top, while the bulk meniscus recedes and a high and sustained evaporation rate is maintained. In the case of RBPM also, SEB may be used to connect evaporation rate and surface temperature.