Contribution ID: **631** Type: **Oral 20 Minutes**

LBM study of non-isothermal liquid evaporation in specifically designed porous media

Thursday, 17 May 2018 14:20 (15 minutes)

Liquid evaporation rate in porous media is often characterized by two distinct periods. A first drying period (stage I) is characterized by a relatively high and constant drying rate referred to as constant rate period (CRP) where evaporation is supported by a fast internal capillary flow and controlled by the boundary conditions. The second drying period (stage II) is characterized by a lower and gradually dropping evaporation rate also termed falling rate period, FRP, due to the transition to diffusion-limited vapor transport. We study here stage I evaporation for specifically designed porous media both numerically and experimentally with the aim to control their drying rate. We conduct evaporation experiments with quasi-two-dimensional microfluidic porous systems and model the behavior with a lattice Boltzmann model tailored to the specific needs of such phenomena.
A hybrid thermal entropic multiple-relaxation-time multirange pseudopotential lattice Boltzmann model (EMRT-MP LBM [1]) is applied to simulate the non-isothermal liquid-vapor phase change during evaporation and provide the exact water configuration within complex porous media. First this model is validated by comparing with the diameter square law for a single droplet evaporating in a closed cavity. Then liquid evaporation in spiral-shaped and gradient-shaped micro-pillared cavities, referred as SMC and GMC, is studied. For the experiments, microfluidic systems measuring 5 x 5 mm2 are imaged with fluorescent microscopy, under controlled boundary conditions.
Both simulation and experiment results show that in SMC the evaporation route follows the spiral shape, while in GMC the liquid evaporates layer by layer, i.e. from large pore rows to small pore rows. The explanation of the phenomenon is that, since the surrounding vapor pressure is almost constant, the liquid pressure at liquid-vapor interface with larger radius is higher due to surface tension effects. Thus liquid will flow from the large-radius menisci to the small-radius menisci between pillars due to the difference in liquid pressure. As a consequence, the evaporation front at the larger interface will move first while the interfaces at the smaller pillar distance will remain longer in place. The evaporation rate reduces slightly with time due to the decrease of the liquid-vapor interfacial area. Both the simulation and experiment results show that stage I liquid evaporation may occur in well-designed porous media for long time.

References

[1] Feifei Qin, Ali Mazloom Moqaddam, Qinjun Kang, Dominique Derome, Jan Carmeliet. (2017) Entropic multiple-relaxation-time multirange pseudopotential lattice Boltzmann model for two-phase flow, Physics of Fluids, under review.

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Session Classification: Parallel 11-G

Track Classification: GS 2: Computational challenges in porous media simulation