Droplet impact and evaporation on a porous surface

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Abstract

Droplet impact and evaporation on a porous surface is an important phenomenon in inkjet applications on porous surfaces, such as papers and bio materials, and in treatment of chemical agents in porous soil and fabrics. However, its general predictive model has not yet been developed due to the complexity of the liquid-gas-solid multiphase phenomena coupled to heat and mass transfer.

Recently, numerical simulation of droplet impact and evaporation on a non-porous surface has been performed using a finite-element method (FEM), a body-fitted moving-grid method, and a level-set (LS) method. However, the numerical methods were not extended on the porous surface where the multiphase characteristics are much more complicated by the porous solid structures.

In this study, the LS method for tracking the liquid-gas interface is further extended for computation of droplet impact and evaporation on a porous surface. The volume averaged conservation equations of mass, momentum, energy and vapor fraction are employed for the porous media including the effects of porosity, drag force and conjugated heat transfer caused by the porous solid. The conservation equations are coupled with those in the external region of the porous media through the matching conditions of velocity, pressure, temperature and vapor fraction at the porous surface. The velocity for each phase is extrapolated into the entire domain (or a narrow band near the interface) from the real velocity. The ghost liquid/gas velocity is evaluated by the first-order extrapolation from the real liquid/gas velocity. The effective density, viscosity, thermal conductivity, and vapor diffusion coefficient are interpolated by using the porosity and the fraction function evaluated from the LS function. The temperature and the vapor fraction at the interface and the evaporation mass flux are simultaneously determined from the coupled equations for the mass and energy balances at the interface and the thermodynamic relation. The governing equations are discretized in a staggered grid system where the velocity components are defined at cell faces whereas the other dependent variables are defined at cell centers. A second-order, essentially nonoscillatory (ENO) scheme is used for the convection terms and the distance function, and a second-order central difference scheme for the other terms. While discretizing the governing equations temporally, we use a first-order explicit scheme for the convection and source terms and a fully implicit scheme for the diffusion term. The momentum equation including the drag force terms and the mass equation are solved by employing a second-order projection method.

The present LS method is first tested through an axisymmetric computation of non-evaporating droplet impact and spread on a porous substrate. The numerical prediction of droplet shape is observed to have a good agreement with the numerical result available in the literature. The LS method is applied to the liquid evaporation in porous media to investigate the effects of porosity, permeability, porous contact angle and solid properties.

Keywords: Evaporation, Level-set method, Heat and mass transfer, Porous media.