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Simulation of condensation and liquid break-up on a micro-object with upper and lower movable walls using Lattice Boltzmann Method

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HIGHLIGHTS

- Liquid behavior and breaking up.
- Liquid removal.
- Micro-object with moving walls.
- LBM.

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ABSTRACT

In this paper, two-dimensional condensation, liquid behavior on the micro-object with moving walls, and breaking up have been investigated by the Shan and Chen multiphase Lattice Boltzmann Method (LBM), which has the ability to incorporate interactions such as fluid–fluid, and also fluid–solid.

Four test cases with low, medium, high, and very high Weber numbers are investigated considering the velocity control of walls in detail. Vertical spread fraction n/h (where n is the minimum liquid thickness after deformation and h is the maximum length of liquid deformation in each time) decreases quickly indicating the liquid tendency to breakup in all cases. Except for the case of a very high Weber number, the separation will not happen and finally after fluctuation the fixed bulk of condensed liquid will be placed on the side of the micro-object. The maximum value of reaction parameter h/d becomes larger as the Weber number increases. It is shown that an increase in the Weber number leads to liquid breakup and this mechanism provides an effective way for removing the condensed liquid from micro-devices surfaces.

The results by LBM reveal the liquid evolutionary behavior and breaking up over time and show that it is a controllable situation by manipulating the walls velocity. Moreover, it can be used in order to centralize and aggregate all the liquid to a specific direction.

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Nomenclature

c	Characteristic velocity (–)
C_s	Lattice sound speed (–)
d	Square channel length (m)
e	Discrete particle velocity (–)
f	Velocity distribution function (–)
F	Force (N/m^3)
G	Interaction strength (–)
h	Reaction parameter (m)
L	Square domain length (m)
P	Pressure (Pa)
V	Channel velocity (m/s)
$rand$	Random number (–)
s	Switch function (–)
t	Time (s)
u	Velocity (m/s)
w	Weight coefficient (–)
W	Wetness fraction (–)

Greek symbols

δt	Lattice time step (–)
δx	Mesh spacing (–)
ψ	Interaction potential function (–)
ν	Kinematic viscosity (m^2/s)
ρ	Density (kg/m^3)
τ	relaxation time (s)

Subscripts/Superscripts

ads	Adhesive between fluid and surface (–)
cr	Critical (–)
eq	Equilibrium (–)
int	Between fluid particles (–)
k	Discrete velocity direction (–)
n	North wall of channel (–)
o	Reference value (–)
v	Vapor or vertical (–)

1. Introduction

Liquid break-up and its behavior on the solid surfaces is a common phenomenon which has a wide scientific and industrial background. Also, the majority of technological advances in modern sciences are moving towards the miniaturization of equipment and devices. By considering the aforementioned facts, understanding the behavior of liquid phase can be extremely significant and complicated due to its diverse applications in mini/micro devices. The characterization of liquid behavior and its breakup finds relevance in a host of microfluidic problems, such as drop on demand applications, inkjet and genome printing, pharmaceuticals, compact heat exchangers, and internal combustion engines.

Some researchers investigated two phase flows, condensation and evaporation process in micro and mini-scales [1–3]. Carton et al. [4] studied the movement and accumulation of water droplets and water slugs in mini-channels. Their results indicated that the size and frequency of slugs reduce for higher values of flow rate. Moreover, they presented that the minichannel surface coatings are needed to reduce the slug formation. Rayleigh [5] predicted the jet breakup of an inviscid liquid using the stability theory.

There has been some experimental investigations of the problem. For instance, Feng et al. [6] studied the influences of film thickness and cross-sectional geometry on condensation flow in a rectangular hydrophilic microchannel. The computed results showed that the flow pattern transition is delayed for larger values of hydraulic diameter and higher values of vapor flux rate. Jiang et al. [7] performed a visualization experimental study on the ethanol–water vapor mixtures condensation flow in an array of microchannels. They observed streak and droplets in the microchannel for higher values of the inlet ethanol concentration. As well as, some experimental researches have been carried out to study the behavior of liquid