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SIMULATION OF NUCLEATE BOILING BUBBLE BY THE PHASE-FIELD AND LATTICE BOLTZMANN METHOD.

This article reviews the mathematical and computer modeling of the process of thermal phase transition in two-phase fluid flows. The nucleate boiling process is investigated in the presence of a constant heat source on a solid wall. Bubble formation and phase transition are taken into account. The flow characteristics and temperature distribution during nucleate boiling are obtained. The results of the numerical study were obtained using a 2D numerical algorithm implemented on the basis of the D2Q9 model of the Lattice Boltzmann method (LBM-Lattice Boltzmann method) and the phase field method. The calculations show that first the nucleation of a bubble is formed, then the bubble grows, breaks away from the boundary with the heat source, then, rising upward, undergoes deformation under the action of buoyancy forces. The effect of gravity and surface wettability on the bubble diameter during ascent is also numerically investigated. The results obtained are in good agreement with the experimental and numerical results of other authors.
Key words:Nucleate boiling, phase- field method,pool boiling, interface capturing, Lattice Boltzmann method, Cahn-Hilliard equation.

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Сұйықтың буға айналу процессін фазалық өріс пен Больцман торлық теңдеу әдісі бойынша моделдеу.

Берілген мақалада сұйықтықты екі фазалы ағындарындағы жылу фазасының ауысу процесін математикалық және компьютерлік модельдеу қарастырылған. Қатты қабырғада тұрақты жылу көзі болған кездегі, тамшының буға айналу процесі зерттелінеді. Көпіршіктің пайда болуы және фазалық ауысу ескеріледі. Тамшының қайнау кезіндегі пайда болатын ағын сипаттамалары мен температураның таралуы алынды.
Сандық зерттеудің нәтижелері (LBM- Lattice Boltzmann method) Больцман торлық теңдеуі әдісінің, D2Q9 моделі мен фазалық өріс әдісі негізінде жүзеге асырылған 2D сандық алгоритмінің көмегімен жүзеге асырылды. Есептеулер көрсеткендей, алдымен көпіршік пайда болады, содан кейін көпіршік өседі, сосын жылу көзінің әсерінен шекарадан арылады, содан кейін жоғары көтеріліп, кері итеру күшінің әсерінен деформацияға ұшырайды. Көтерілу кезінде ауырлық күші мен беттік керілу күшінің көпіршік диаметріне әсері де сандық зерттелген. Алынған нәтижелер басқа авторлардың эксперименталды және сандық нәтижелерімен салыстырыла отырып, жақсы сәйкестік көрсеткенін айтуға болады.
Түйін сөздер: Буға айналу, фазалық өріс әдісі, жылу беру, фазалық таралу, Больцман торлық теңдеуі әдісі, Кан- Хиллиард теңдеуі.

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Моделирование процесса испарения жидкости методом фазого поля и решеточного уравнения Больцмана.

В данной статье рассматривается математическое и компьютерное моделирование процесса теплового фазового перехода в потоках двухфазной жидкости. Исследуется процесс пузырькового кипения при наличии постоянного теплового источника на твердой стенке. Учитывается образование пузырьков и фазовый переход. Получены характеристики потока и распределение температуры в процессе пузырькового кипения. Результаты численного исследования получены с помощью использования 2D численного алгоритма, реализуемого на базе D2Q9 модели метода решеточных уравнений Больцмана (LBM) и метода фазового поля. Проведенные расчеты показывают, что сначала образуется зарождение пузырька, затем пузырь растет, отрывается от границы с источником тепла, затем, поднимаясь вверх, претерпевает деформацию под действием сил плавучести. Также численно исследовано влияние силы тяжести и смачиваемости поверхности на диаметр пузырька при всплытии. Полученные результаты имеют хорошее согласование с экспериментальными и численными результатами других авторов.

Ключевые слова: Испарение, фазовый переход, теплопередача, метод фазового поля, метод решеточного уравнения Больцмана, уравнение Кана-Хиллиарда.

1 Introduction

Thermal multiphase flows are widely used in various natural phenomena and industrial fields, from energy conversion in nuclear reactors to cooling of microelectronic devices. Over the past decades, various methods of direct numerical simulation of multiphase thermal flows have been presented. Despite the growing number of studies on two-phase multicomponent flows, direct modeling of two-phase flows with dynamic interfaces remains a challenge. The main difficulties are associated with the need to simultaneously take into account many effects, such as interfacial mass transfer, latent heat and surface tension, in accordance with the laws of conservation of mass, momentum and energy. One of the most important problems encountered in multiphase flow modeling is interface tracking, which can demonstrate the unsteady morphology of interface dynamics. The most commonly used numerical models for interface tracking can be divided into two categories: sharp interface methods such as the volume of fluid (VOF) method [1,11], interface tracking [2], immersed boundary method, and diffuse interface methods, such as, the level set method [3] and the phase field method [4]. In recent years, the lattice Boltzmann method (LBM) based on the molecular kinetic theory has attracted a lot of scientific attention and has become widely used for modeling complex multiphase systems due to its generality, ease of implementation and computational efficiency [5, 6]. This is a mesoscopic method based on the discretization of the Boltzmann equation. In particular, several LBM thermal models have been successfully developed for multiphase and multicomponent flows, mainly including Shan-Chen pseudopotential model [7], He et al. model [8], the Rothmann Keller color model [9], Swift et al. free energy model [10] and phase field based LBE model [12]. Among them, the color model and the pseudopotential model do not explicitly describe the evolution of the phase interface, where the interactions between liquid and vapor are modeled using a pseudopotential parameter that depends on the density, and the interfaces between different phases arise due to the interaction force between liquid and gas particles. Deformation, displacement, destruction and merging of phase interfaces occurs automatically, without using any special methods to track or capture the interfaces. In the model of He et al., mobility is related to density, but physics of interface capturing equation is not accurate. In contrast, the free energy model, which describes phase separation by the van der Waals equation of state, has wide application. However, it lacks Galilean

invariance, because of this, terms appear that are not related to the Navier - Stokes equation. Whereas, phase field models are capable of calculating topological changes such as splitting and merging, and thus are successfully applied to multiphase fluid flows involving large interface deformations. The phase field model describes the interface in terms of the mixing energy, which can be described using the Cahn-Hilliard equation. The energy description of the phase field model provides a unified set of thermodynamically consistent systems of basic equations for the two phases, which can be discretized on a fixed grid within the Euler approach. This model can also be used to simulate heat transfer during liquid-vapor phase transition. To this end, several hybrid two-dimensional LBM models have been proposed [13–16], in which the original terms are added to the corresponding Can-Hilliard equation and the thermal LB equation to determine the phase transition and latent heat, respectively. In this paper, we develop a mathematical model for simulation of liquid- vapor phase- change heat transfer problem based on the solution of Navier-Stokes equations, temperature equation and the convective Cana-Hilliard equation. The numerical model is built on the basis of the LBM using the D2Q9 model. The accuracy and efficiency of the existing method have been tested by solving the problem of droplet evaporation in a liquid medium. In addition, the effects of the gravity on the bubble diameter is numerically investigated. We demonstrate that the results obtained by this approach are in good agreement with other theoretical predictions.

1.1 Mathematical modeling

The investigated problem is considered in a limited area in the form of a rectangle. The dynamic behavior of a bubble on a heated wall is shown in Figure 1. The heat source is placed at the bottom of the rectangle.

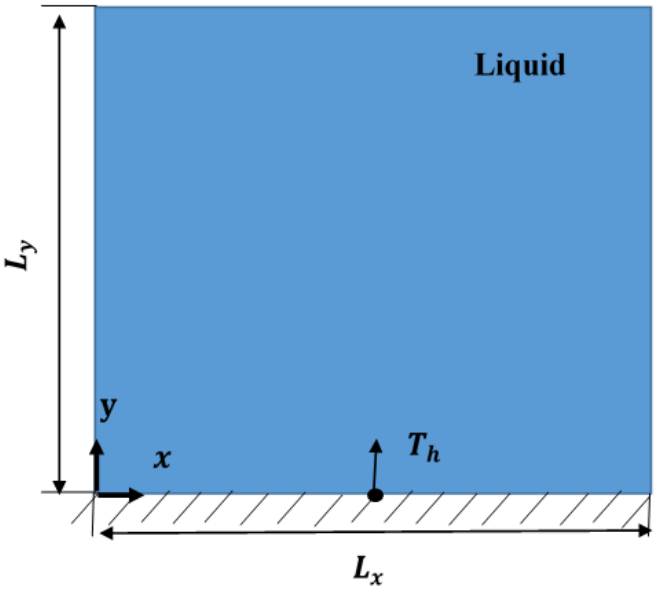


Figure 1: Computational domain of nucleate boiling bubble

The Governing equation for the thermal two-phase flows with phase change consist of the continuity equation, the momentum equation for the mixture, the equation for temperature, and the convection Cahn-Hilliard equation:

$$\begin{cases} \nabla u = Q, \\ \dfrac{\partial(\rho u)}{\partial t} + \nabla(\rho u u) = -\nabla p + \nabla[\eta(\nabla u + \nabla u^T)] + F_s + F_b, \\ \dfrac{\partial(c_i)}{\partial t} + \nabla(c_i u) = \nabla(M_i \nabla \mu_i) + Q_i, i = 1, 2 \\ \dfrac{\partial(T)}{\partial t} + \nabla(uT) = \nabla(\alpha \nabla T) + Q_T, \end{cases} \tag{1}$$

where u - is the velocity components, p- is the pressure, ρ- is the density, ρ_1, ρ_2- are the densities of fluid and vapor respectively, T - is the temperature, η- is the dynamic viscosity, c_i - is the phase field,g - is the gravitational acceleration, M_i - is the mobility, μ_i- is the mobility , $F = F_s + F_b = \sum_{i=1}^{2} \mu_i \nabla c_i + \rho g$ - is the summation of interface force and body force, $Q = \dfrac{1}{\rho_1^0} Q_1 + \dfrac{1}{\rho_2^0} Q_2$ - is the heat flux of liquid and vapor components, $Q_1 = -Q_2 = -\dfrac{1}{\rho} \dfrac{k \nabla T_2}{H_{Vop} V_{Vop}}$ - is the mass flux due to liquid- vapor phase transition, where k- is the thermal conductivity, $\alpha = \dfrac{k}{\rho c_p}$ - is the diffusion, $H_{Vop} = (-\Delta H)$- is the latent heat of evaporation ,$Q_T = -\dfrac{H_{Vop} R_2 c_2}{\rho c_p}$ - is the heat flux, due to evaporation, c_p- is the specific heat capacity.

To distinguish the region of space occupied by liquid and gas phases are used an order parameter c:

$$c = \begin{cases} c_1 & \text{liquid} \\ c_2 & \text{gas} \end{cases}$$

For a system of a two-phase medium consisting of a gas and a liquid, the Landau free energy function F is defined as:

$$F = (\overrightarrow{c}, \nabla \overrightarrow{c}) = \int_V [\Psi(\overrightarrow{c}) + \sum_{i,j}^{2} \frac{\lambda_{ij}}{2} \nabla c_i c_j] dV, \tag{2}$$

where $\Psi(c) = \sum_{i,j}^{2} \beta_{ij} [g(c_i) - g(c_j) - g(c_i + c_j)]$ – is the bulk free- energy density, $c = (c_1, c_2)$ - is the order of parameter, which consists from gas and liquid $c_1 + c_2 = 1$

For the isothermal system represented as:

$$g(c) = c^2 (1 - c)^2$$

The variation of the free-energy function F with respect to the order parameter c yields the chemical potential μ_i as:

$$\mu_i = \mu_{0,i} - \sum_j^2 \lambda_{ij} \nabla^2 c_j$$

Where the bulk free energy $\mu_{0,i} = \sum_{i,j}^2 2\beta_j[g(c_i) - g(c_j) - g(c_i + c_j)]$,$\lambda_{ij} = -\frac{3D}{4}$,$\beta_{ij} = \frac{3}{D}\sigma_{ij}$ - are the constant related from interfacial thickness and surface tension force, $\sigma_{ij} = \sigma_{ji}$ - is the surface tension formed between liquid i and gas j,D - is the interfacial thickness.

The system of equation (1) has following initial and boundary conditions:
Initial conditions:
$u = v = 0, T = T_{sat}, c_1 = 1, c_2 = 0$
Boundary conditions:
At the bottom wall ($y = 0$):
$u = v = 0, T = T_h,\ x = \frac{L_x}{2}, \frac{\partial c_1}{\partial y} = \frac{\partial c_2}{\partial y} = 0$
At the inlet and outlet walls ($x = 0, x = L_x$):
The periodic boundary conditions are applied for u, v, T, c_1, c_2
At the top wall ($y = L_y$):
$u = v = 0, \frac{\partial T}{\partial y} = 0, \frac{\partial c_1}{\partial y} = \frac{\partial c_2}{\partial y} = 0$

2 Phase field model for two-phase gas and liquid systems

The time dependence of the order parameter c_i given by the following advective Cahn-Hilliard equation to describe each phase:

$$\begin{cases} \frac{\partial c_1}{\partial t} + \nabla(c_1 u) = \nabla(M_1 \nabla \mu_1) + Q_1 \\ \frac{\partial c_2}{\partial t} + \nabla(c_2 u) = \nabla(M_2 \nabla \mu_2) + Q_2 \end{cases} \tag{3}$$

When $c_1^{(l)} \to c_2^{(g)} \Rightarrow Q_1 = -Q_2,\ Q_2 = \frac{1}{\rho_2^0} R_2 \rho_2 = \frac{1}{\rho_2^0} R_2 c_2 \rho_2^0,$

where $R_2 = \frac{\rho_2}{\rho}$ – is the vapor velocity at the interface due to evaporation.

For the heat transfer process, the intensity of the heat flux is determined by

$$q_T = -k \nabla T$$

To find the fraction of evaporated liquid into vapor, we equate the heat for converting the liquid into vapor by the intensity of the heat flux.

The heat spent on the transformation of liquid into vapor is determined by

$$q_V = q_T \Rightarrow H_{Vop} m = -k \nabla T$$

After equating, the flux of mass evaporating at the interface can be estimated from the heat-conducting as flowing:

$$m = -\frac{k \nabla T}{H_{Vop}}$$

on the other hand

$$m = \rho_V V_{Vop} = \rho_2 V_{Vop}$$

Next, we get the density of the bubble in the volume of the liquid due to heat.

$$\rho_2 = -\frac{k\nabla T}{H_{Vop} V_{Vop}}$$

where $V_{Vop} = \frac{1}{6}\pi d^3$ is the volume of the bubble,, d is the diameter of the bubble.
At least, the vapor velocity at the interface due to evaporation defined as:

$$R_2 = -\frac{1}{\rho}\frac{k\nabla T}{H_{Vop} V_{Vop}}$$

The volume fraction of the component c_i is defined as the ratio of the volume of the i component to the total volume of the mixture:

$$\sum_{i}^{2} c_i = 1$$

$$\rho_i = c_i \rho_i^0$$

where ρ_i^0 - is the physical density of components.
The density of the mixture ρ is defined by law

$$\rho = \sum_{i=1}^{2} \rho_i$$

3 Numerical method

The numerical solution in this work is based on the D2Q9 model of the Lattice Boltzmann method. The two dimensional Lattice Boltzmann equation in the Batnagar-Gross-Krook (BGK) approximation can be written as The two-dimensional LB equation for continuity, momentum and energy equations can be described as:

$$f_i(\overrightarrow{x} + \overrightarrow{e}_i \Delta t, t + \Delta t) - f_i(\overrightarrow{x}, t) = -\frac{\Delta t}{\tau_f}(f_i(\overrightarrow{x}, t) - f_i^{eq}(\overrightarrow{x}, t)) + (1 - \frac{\Delta t}{2\tau_f})F_i \Delta t \qquad (4)$$

The interface capturing is modeled by a convective Chan–Hilliard equation and the corresponding two-dimensional LB equation follows as:

$$g_i^m(\overrightarrow{x} + \overrightarrow{e}_i \Delta t, t + \Delta t) - g_i^m(\overrightarrow{x}, t) = -\frac{\Delta t}{\tau_c}(g_i^m(\overrightarrow{x}, t) - g_i^{m,eq}(\overrightarrow{x}, t)) + (1 - \frac{\Delta t}{2\tau_c})Q_m \quad (5)$$

$$h_i(\overrightarrow{x} + \overrightarrow{e}_i\Delta t, t + \Delta t) - h_i(\overrightarrow{x}, t) = -\frac{\Delta t}{\tau_T}(h_i(\overrightarrow{x}, t) - h_i^{eq}(\overrightarrow{x}, t)) + (1 - \frac{\Delta t}{2\tau_T})Q_T \tag{6}$$

where $m = 1, 2$ - liquid and gas components, f_i, g_i^m, h_i - are the velocity, phase- field and energy distribution functions respectively, e_i - is the discrete lattice velocity,
$\tau_f = \frac{1}{2} + c_1(\tau_l - \frac{1}{2}) + c_2(\tau_g - \frac{1}{2}), \tau_c = 1, \tau_T = \frac{1}{2} + c_1(\tau_{lT} - \frac{1}{2}) + c_2(\tau_{gT} - \frac{1}{2})$ - are the relaxation times,F_i- is the external force, Q_m,Q_T are the fluxes, Δt - is a time step, f_i^{eq},$g_i^{m,eq}$,h_i^{eq} - are equilibrium distribution functions for velocity,phase- field and energy respectively.

The equilibrium distribution functions can be written as: [17]:

$$f_i^{eq} = \begin{cases} p - \sum_{i\neq 0} f_i^{eq}, i = 0 \\ \omega_i\rho(1 + \frac{c_m\mu_m}{\rho c_s^2} + \frac{e_{i\alpha}u_\alpha}{c_s^2} + \frac{u_\alpha u_\beta(e_{i\alpha}e_{i\beta} - c_s^2\sigma_{\alpha\beta})}{2c_s^2}), i \neq 0 \end{cases} \tag{7}$$

$$g_i^{m,eq} = \begin{cases} c_m - \sum_{i\neq 0} g_i^{m,eq}, i = 0 \\ \omega_i(\frac{\Gamma_m\mu_m}{c_s^2} + \frac{c_m e_{i\alpha}u_\alpha}{c_s^2} + \frac{c_m u_\alpha u_\beta(e_{i\alpha}e_{i\beta} - c_s^2\sigma_{\alpha\beta})}{2c_s^2}), i \neq 0 \end{cases} \tag{8}$$

$$h_i^{eq} = \omega_i T(1 + 3e_i u) \tag{9}$$

where $c_s^2 = RT$ - is the speed of sound, R- is the universal gas constant, Γ_m- is a constant controlling the strength of mobility, $\sigma_{\alpha\beta}$- is the Kronecker delta.
The discrete velocity set of D2Q9 model is given by

$$e_{ix} = (0, 1, 1, 0, -1, -1, -1, 0, 1)c$$

$$e_{iy} = (0, 0, 1, 1, 1, 0, -1, -1, -1)c$$

The values of weight coefficients are taken as:

$$\omega_i = \begin{cases} \frac{4}{9}, i = 0, \\ \frac{1}{9}, i = 1 - 4, \\ \frac{1}{36}, i = 5 - 8, \end{cases} \tag{10}$$

The external force in the LB model proposed by Guo et al. [18] is used in this paper.

$$F_i = \omega_i(1 - \frac{\Delta t}{2\tau_f})[(\frac{\overrightarrow{e}_i - \overrightarrow{u})}{c_s^2} + \frac{\overrightarrow{e}_i(\overrightarrow{e}_i \overrightarrow{u})}{c_s^4}]\overrightarrow{F} \tag{11}$$

where the force F is given by $\overrightarrow{F} = \overrightarrow{F}_s + \overrightarrow{F}_b$.
The fluxes Q_m, Q_T in the LB model proposed by Seta et al. [19] are defined as:

$$Q_m = \omega_i(1 - \frac{2}{\tau_c})q_m$$

$$Q_T = \omega_i(1 - \frac{2}{\tau_T})q_T$$

The evolution equation is consists of two steps, collision and streaming

$$f_i^*(\overrightarrow{x}, t) = f_i(\overrightarrow{x}, t) + \Delta t(-\frac{f_i(\overrightarrow{x}, t) - f_i^{eq}(\overrightarrow{x}, t)}{\tau_f} + F_i)$$

$$g_i^{m,*}(\overrightarrow{x}, t) = g_i^m(\overrightarrow{x}, t) + \Delta t(-\frac{g_i^m(\overrightarrow{x}, t) - g_i^{m,eq}(\overrightarrow{x}, t)}{\tau_c}) + \Delta t Q_m$$

$$h_i^*(\overrightarrow{x}, t) = h_i(\overrightarrow{x}, t) + \Delta t(-\frac{h_i(\overrightarrow{x}, t) - h_i^{eq}(\overrightarrow{x}, t)}{\tau_h}) + \Delta t Q_T \tag{12}$$

$$f_i(\overrightarrow{x} + \overrightarrow{e}_i \Delta t, t + \Delta t) = f_i^*(\overrightarrow{x}, t)$$
$$g_i^m(\overrightarrow{x} + \overrightarrow{e}_i \Delta t, t + \Delta t) = g_i^{m,*}(\overrightarrow{x}, t)$$
$$h_i(\overrightarrow{x} + \overrightarrow{e}_i \Delta t, t + \Delta t) = h_i^*(\overrightarrow{x}, t) \tag{13}$$

The macroscopic dimensionless density, phase filed and temperature are calculated by:

$$\rho = \sum_{i=0}^{8} f_i, \rho u = \sum_{i=0}^{8} f_i \overrightarrow{e}_i + \frac{\Delta t}{2}\overrightarrow{F}, T = \sum_{i=0}^{8} \bar{g}_i^m + \frac{Q_T \Delta t}{2}, c_m = \sum_{i=0}^{8} h_i + \frac{Q_m \Delta t}{2} \tag{14}$$

The second-order central difference is used to approximate the directional derivatives in e_i direction as:

$$\frac{\partial^2 c}{\partial x^2} = \frac{1}{3(\Delta x)^2}[\sum_{i=2}^{9} c(x + e_i \Delta x) - 8c(x)]$$

The implementations of boundary conditions for each velocity distribution functions are as follows:

Zero velocity condition for all walls

$$f_i(\overrightarrow{x}_w, t + \Delta t) = f\_i(\overrightarrow{x}_w, t + \Delta t), \overrightarrow{e}_i \cdot \overrightarrow{n} > 0, \tag{15}$$

Where the phase and temperature are constant, the boundary conditions for the distribution functions are chosen as follows:

$$g_i^m(\overrightarrow{x}_w, t+\Delta t) = g\_i^m(\overrightarrow{x}_w, t+\Delta t) + 2\omega_i c_w, \overrightarrow{e}_i \cdot \overrightarrow{n} > 0,$$

$$h_i(\overrightarrow{x}_w, t+\Delta t) = h\_i(\overrightarrow{x}_w, t+\Delta t) + 2\omega_i T_w, \overrightarrow{e}_i \cdot \overrightarrow{n} > 0, \quad (16)$$

where c_w и T_w are the wall phase and temperature, respectively.

The Neumann boundary condition are used for temperature and phase – field distribution functions

$$g_i^m(\overrightarrow{x}_w, t+\Delta t) = g\_i^m(\overrightarrow{x}_w, t+\Delta t), \overrightarrow{e}_i \cdot \overrightarrow{n} > 0,$$

$$h_i(\overrightarrow{x}_w, t+\Delta t) = h\_i(\overrightarrow{x}_w, t+\Delta t), \overrightarrow{e}_i \cdot \overrightarrow{n} > 0, \quad (17)$$

4 Results and discussions

To verify the developed model for two-phase flow phase-change simulations, a two-dimensional Poiseuille problem was solved channel.

Analytical solutions of velocity and temperature fields are calculated as: [20]

$$u_{exact}(y) = u_{max}(1 - \frac{y^2}{L^2}).$$

$$T_{exact}(y) = T_{bot}(\frac{Ttop - T_{bot}}{H})y + \frac{1}{3}Pru_{max}^2[1 - (\frac{2y}{H} - 1)^4].$$

A comparison of velocity and temperature profiles of analytical solutions and numerical ones has been made, for $Pr = 0.7$(air) at different time step, as shown in Figures 2 and 3. It is clearly seen that the numerical results are in excellent agreement with the analytical solution.

In order to assess the validity of the model for two-dimensional (2D) problems, the simulation of a single bubble rising in a saturated liquid in a rectangular domain size 128×128 is carried out. The computational domain with $L = L_x = L_y = 0.1$ is considered.

Grid step and time step are defined as follows:
$\Delta x = \frac{L}{N_x}$, $\Delta t = 0.01\Delta x$.

We consider a two-phase flow of liquid and vapor with surface tension $\sigma = 0.01$ latent heat $H_{Vop} = 10\frac{kJ}{kg}$, mobility $M = 1$, $\Gamma = 2$ and interfacial thickness $W = 2$.

The physical parameters for the liquid phase properties are set as:
$\rho_l = 200kg/m^3$,$\mu_l = 0.1$ Pa*s,$c_{pl} = 200$ J/(kg*K),$k_l = 40$ W/(m*K),$\alpha_l = \frac{k_l}{\rho_1 c_{pl}}$.

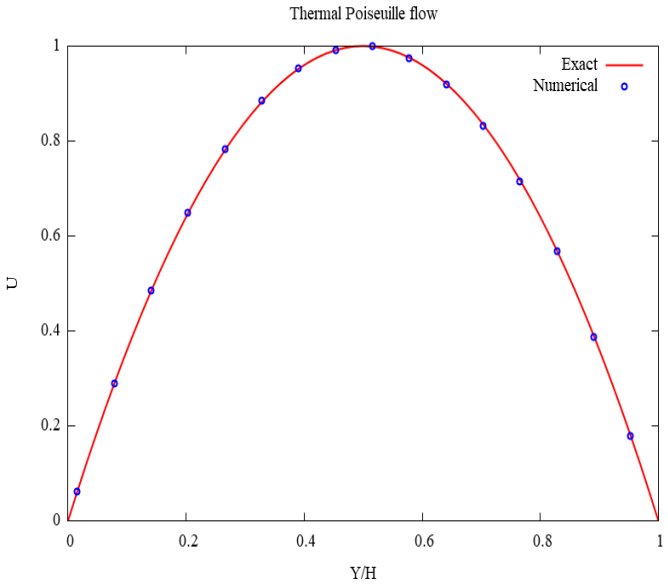


Figure 2: Velocity profile of two-dimensional Poiseuille flow. Comparison between numerical and analytical solutions at $T_{top} = 1$, $T_{bot} = 0$, $Pr = 0.7$, $u_{max} = 0.1$.

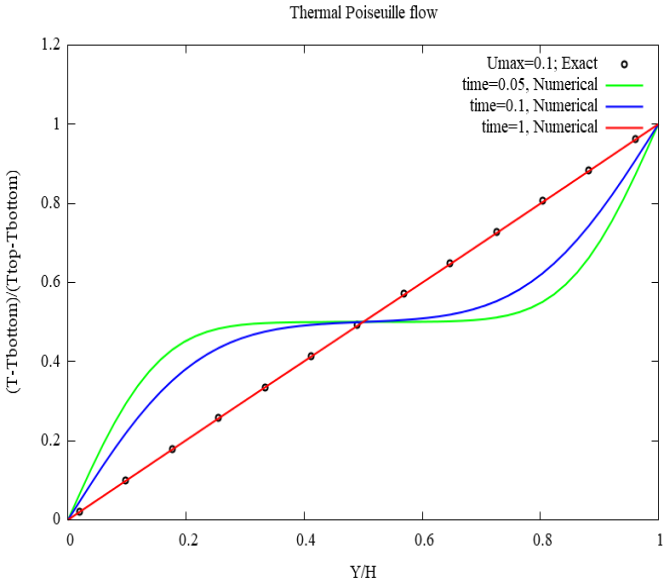


Figure 3: Temperature profile of two-dimensional Poiseuille flow. Comparison between numerical and analytical solutions at $T_{top} = 1$, $T_{bot} = 0$, $Pr = 0.7$, $u_{max} = 0.1$.

The vapor properties taken as follows:

$\rho_g = 5kg/m^3$,$\mu_g = 0.05$ Pa*s,$c_{pg} = 400$ J/(kg*K),$k_g = 1$ W/(m*K), $\alpha_g = \dfrac{k_g}{\rho_2 c_{pl}}$.

Other simulation parameters are determined as: The dimensionless numbers for this

problem are Reynolds number $Re = \rho UL/\eta$ and Atwood number $At = \dfrac{\rho_1 - \rho_2}{\rho_1 + \rho_2}$

At the initial time step, the uniform of temperature T_h is established with a constant heat flux is placed at the central point on the bottom wall for gas phase, while the temperature for liquid phase fixed to $T_{sat} = 500K$.

The required physical parameters are shown in Table 4.

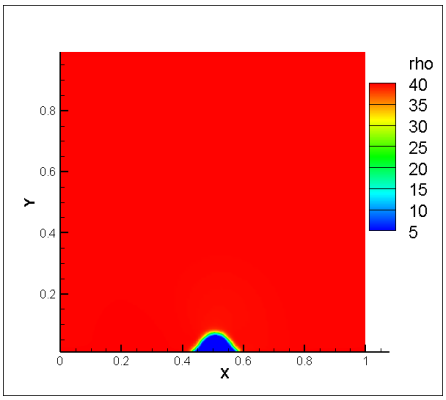
Table 1: LBM parameters for liquid and gas components

LBM parameters	Values
maximum velocity	$U_{lbm} = \dfrac{U}{c_u}$ where $c_u = \dfrac{\Delta x}{\Delta t}$
density of a mixture	$\rho_{lbm} = 1$
dynamic viscosity	$\eta_{lbm_l} = \eta_l/\eta$,$\eta_{lbm_g} = \eta_g/\eta$
kinematic viscosity	$\nu_{lbm_l} = \dfrac{\mu_l}{\rho_l}\dfrac{\Delta t}{\Delta x^2}, \dfrac{\mu_g}{\rho_g}\dfrac{\Delta t}{\Delta x^2}$
density of liquid and gas	$\rho_{lbm_l} = \dfrac{\rho_l}{\rho}$, $\rho_{lbm_g} = \dfrac{\rho_g}{\rho}$
diffusion coefficients	$\alpha_{lbm_l} = \alpha_l\dfrac{\Delta t}{\Delta x^2}$, $\alpha_{lbm_g} = \alpha_g\dfrac{\Delta t}{\Delta x^2}$
relaxation coefficients of liquid and gas for temperature	$\tau_{lT} = 3\alpha_{lbm_l} + 1/2$, $\tau_{gT} = 3\alpha_{lbm_g} + 1/2$
gravitational acceleration	$g_{lbm} = \dfrac{g}{c_g}$ где $c_g = \dfrac{\Delta x}{\Delta t^2}$

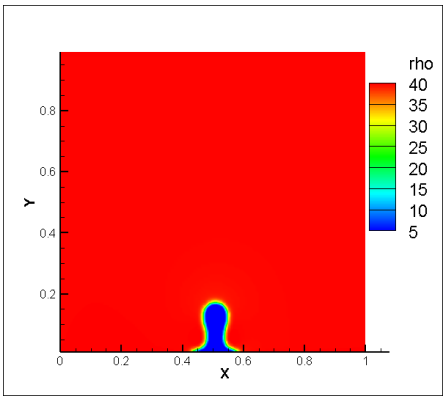
In order to investigate the effect of the gravity, the simulations of pool boiling for various values of gravitational accelerations are performed. Figure 4 shows the time evolution of the bubble shape with velocity vectors and temperature distributions for $g_{lbm} = 0.5$. It is seen that a bubble nucleation is formed at first, and then the bubble grows and leaves the wall, going up with deformation by the buoyancy. In addition, according to the evolution of temperature distribution in time, it can be seen that the heat is transmitted up with the rising bubble. Figure 5 shows the changes in the form of the bubble, depending on the time when $g_{lbm} = 0.08$. It is seen that the origin of the bubble of oval shape is formed at first. It was also investigated that the diameter of the bubble decreases with an increasing gravitational accelerations. When $g_{lbm} = 0.5$ requires a larger number of iterations than with $g_{lbm} = 0.08$ and the bubble form is different.

5 Conclusion

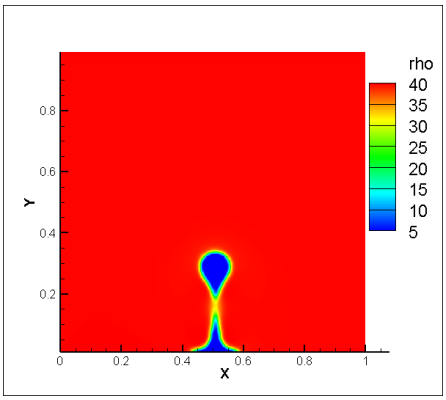
This paper proposed a two-dimensional thermal model LB for two-phase liquid and gas phases. The method was applied a two-dimensional simulations of nucleate pool boiling with a definitive heat source on a solid wall. In order to check the adequacy of the developed implementation model, a test task was solved. Numerical results have good agreement with the analytical solution. It was found that in preliminary calculations using this method, you can simulate pool bubble boiling for liquid-vapor systems at different temperatures.Finally, we obtained that the diameter of the bubble is proportional depend from the acceleration



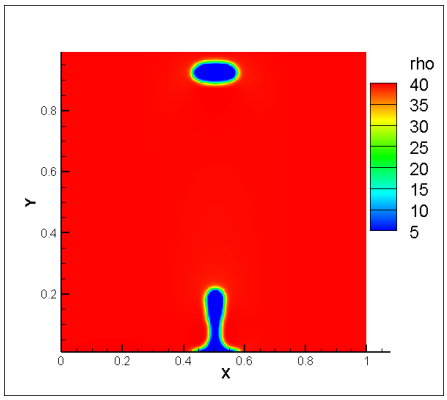
$t = 5000\Delta t$



$t = 10000\Delta t$

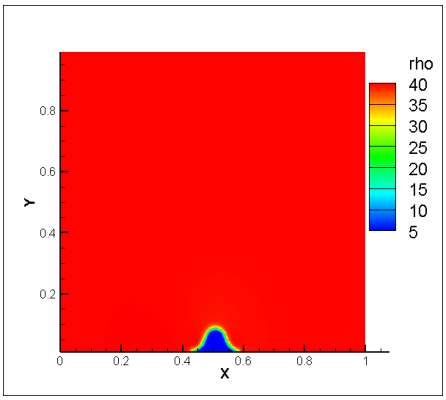


$t = 12000\Delta t$

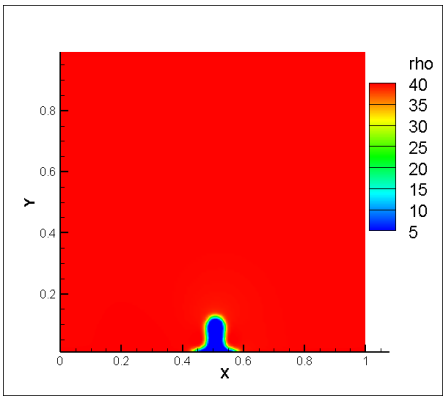


$t = 17000\Delta t$

Figure 4: The changes of bubble shapes during nucleate boiling at different time step for $g_{lbm} = 0.5$.

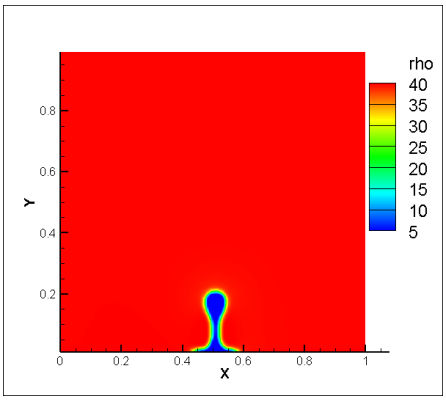


$t = 4000\Delta t$

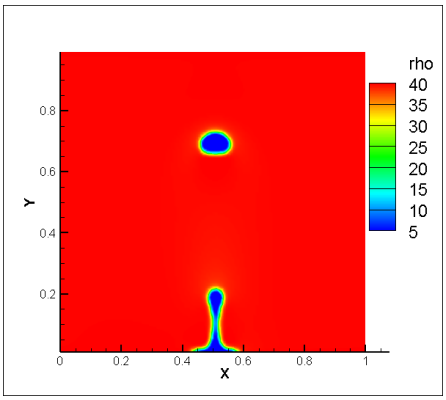


$t = 5000\Delta t$

g_{lbm}. The effects of the appearance of bubbles, breaking the interface of the phases under the action of temperature, the bubble floods at the expense of buoyancy forces. The dependence of the interface of the phases from the intensity of the heat flux, the surface tension and the buoyancy force are obtained. The velocity of vaporization is calculated.



$t = 6000\Delta t$



$t = 9000\Delta t$

Figure 5: The changes of bubble shapes during nucleate boiling at different time step for $g_{lbm} = 0.08$.

6 Acknowledgement

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