

A Novel Solution based on the Lattice Boltzmann Method to Fluid Flow Problems

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Abstract — The Lattice Boltzmann Method (LBM) is a modern numerical technique, very efficient, flexible to simulate different flows within complex and varying geometries. Historically, it originated from lattice gas cellular automata, which simulate the dynamics of fluid particles on a microscopic level based on the Boltzmann equation in a discrete phase space using only a small number of velocities adapted to a regular grid in space. During the last two decades, the LBM has been developed as an alternative numerical scheme for solving the incompressible Navier-Stokes equations (NS). Phase separation is an important phenomenon in fluid dynamics, which has many important industrial applications. In this paper, we study Lattice Boltzmann model in two dimensions and nine directions. D2Q9 model used to study the phase separation in fluids flow. The results of simulations show that fluids flow in the cavity and the cylinder, simulation show phase separation of single component multiphase flow can observe bubble information by LBM.

Index Terms--Lattice Boltzmann Method, Fluid Flow, Navier-Stokes equations

I. INTRODUCTION

Many real life and engineering problems are complex. For instance, boiling and condensation take place in many industrial and power plant systems. Flows of oil–water–solid are very common in oil extracting process and oil–sand process, water treatment by macro- and micro-bubbles, combustion in furnaces, incineration or waste material, etc., the question is, how can we model and solve this kind of problems? The natural way is to incorporate complex physics in the source term. In fact, The Lattice Boltzmann Method (LBM) is more powerful to deal with multi-phase and multi-component flows that using continuum mechanics, Navier–Stokes equation (NS). The main reason for that is because, such problem involved thermodynamics, which can be naturally injected into LBM, while there is no simple means to combine the thermodynamics with NS. *

Lattice Boltzmann equations have been used already at the cradle *established* of lattice-gas cellular automata (LGCA) by Frisch et al. (1987) [1] to calculate the viscosity of LGCA. Lattice Boltzmann models as an independent numerical method for hydrodynamic simulations were introduced by McNamara and Zanetti in 1988. The main motivation for the transition from LGCA to LBM was the desire to get rid of the noise. The Boolean fields were replaced by continuous distributions over the FHP and FCHC lattices. Fermi-Dirac distributions were used as equilibrium functions. Linearized collision operator (Higuera and Jimenez, 1989). Boltzmann instead of Fermi-Dirac distributions. The collision operator, which is based on

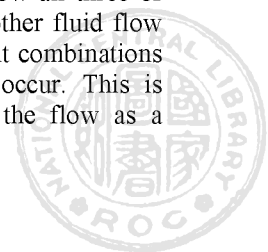
the collisions of a certain LGCA, has been replaced by the Bhatnagar-Gross-Krook (BGK) (also called single time relaxation) approximation by Koelman (1991), Qian et al. (1992) [2] and others. These lattice BGK models (LBGK) mark a new level of abstraction: collisions are not anymore defined explicitly. Multi-speed LBGK models are most popular today. However, more complex collision operators are still in use in models of multi-phase flows (Rothman and Zaleski, 1994). LBM can be considered as a simplified fictitious molecular dynamics model in which space, time, and particle velocities are all discrete.

Lattice Boltzmann methods (LBM) and Thermal Lattice Boltzmann methods (TLBM) are class of Computational Fluid Dynamics (CFD) methods for fluid simulation. Instead of solving the Navier–Stokes equations, the discrete Boltzmann equation is solved to simulate the flow of a Newtonian fluid with collision models such as BGK. By simulating streaming and collision processes across a limited number of particles, the intrinsic particle interactions evince a microcosm of viscous flow behaviour applicable across the greater mass. On the other hand, it has been shown that the LBM scheme can also be considered as a special discretized form of the continuous Boltzmann equation. From Chapman-Enskog theory, one can recover the governing continuity and Navier-Stokes equations from the LBM algorithm. In addition, the pressure field is also directly available from the density distributions and hence there is no extra Poisson equation to be solved as in traditional CFD methods.

Phase separation processes are the process used to separate area. Structures or elements there are different in that we will be interested if the substance density differs. Therefore, the phase separation process is important in the food, industry, beverage, pharmaceutical, dental procedures including drilling etc. In the past, people understood the phase separation of fluids just a little but in the current effort to update and explain the phase separation of Flux levels down to molecular level, where we use Lattice Boltzmann Equation to solve the problems of this phase separation process. Mathematically the problem is closed for given boundary and initial conditions. However there is no explicit equation for pressure.

Research solved problems in science and engineering. Techniques were introduced numerical into widespread use in fluid mechanics. In general, we distinguish behaviour of the flow into three main forms. Laminar flow, Transition flow and Turbulent flow. In addition, the flow all three of the foregoing, now there is a phenomenon other fluid flow more studies such as fluid flow with different combinations (Multicomponent) and flow, bubbles may occur. This is called a multiphase flow. We will model the flow as a

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Lattice. This model has many forms, such as in two dimensions, the general rule that D2QN, D2 stands for the two dimensional and QN is the number of velocity directions taken into account.

In this work we study the Lattice Boltzmann Equation, to explain behaviour of fluid flow the Lattice Boltzmann model, in two dimensions with a nine distribution (D2Q9) because it is easy to analyze the results accurate and close to reality. Study of phase separation of fluid flow used software packages, including development of mathematics to aid in the numerical and shows the results.

II. CONSERVATION EQUATIONS

2.1 The Navier-Stokes Equation

The flow of incompressible fluids can be described by the Navier-Stokes equation

$$\frac{\partial u}{\partial t} + (u \nabla) u = -\nabla P + \nu \nabla^2 u \quad (1)$$

together with the continuity equation

$$\nabla \cdot u = 0 \quad (2)$$

where u is the flow velocity, $P = p/\rho_0$ the kinematic pressure, p the pressure, ρ_0 the constant mass density and ν the kinematic shear viscosity. Incompressible flows of these fluids obey the same form of equation (Navier-Stokes) whereas their microscopic interactions are quite different (compare gases and liquids!). The Navier-Stokes equation is nonlinear in the velocity u which prohibits its analytical solution except for a few cases. Numerical methods are required to simulate the time evolution of flows.

2.2 Boltzmann Equation

The basic idea in the work of Boltzmann includes the idea that gas particle's interaction and can be explained by classical mechanics, since there is the number of particles considered many will need to use statistical methods to help in the estimation. This is why they said the course statistical mechanics become a simplified model to describe the equation Boltzmann kinetic theory of gases. Boltzmann is able to find the relationship of $f(\vec{x}, \vec{v}, t)$ in equations called the Boltzmann equation, which are integral-differential equation. For a single particle distribution function $f(\vec{x}, \vec{v}, t)$ is that

$$\partial_t f + \vec{v} \cdot \nabla_x f + \frac{\vec{K}}{m} \cdot \nabla_v f = Q(f, f) \quad (3)$$

where f is distribution function, \vec{K} is body force, m is a constant mass of the particle, $Q(f, f)$ is collision integral.

2.3 The Lattice Boltzmann Equation

The lattice Boltzmann Equation an idea from the Lattice Gas Cellular Automation (LGCA) that a patch invented by Frisch In 1987, the equation that describes the change in number n_i (Occupation number) the equation

$$n_i(\vec{x} + \vec{c}_i \Delta t, t + \Delta t) = n_i(\vec{x}, t) + \Delta_i \quad (4)$$

Subsequently be updated using the distribution function f instead n_i the equation is

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \nabla f = Q \quad (5)$$

In 1991 Koelman, and in 1992 Qian to estimate Q using the Bhatnagar, Gross and Krook method (BGK) by.

$$\frac{\partial f}{\partial t} + \vec{v} \cdot \nabla f = -\frac{1}{\tau} (f - f^{(eq)}) \quad (6)$$

When f^{eq} is equilibrium distribution function, τ is collision time

Renew the equation will be Lattice Boltzmann model

$$F_i(\vec{x} + \vec{c}_i \Delta t, t + \Delta t) - F_i(\vec{x}, t) = -\frac{1}{\tau} (F_i - F_i^{(eq)}) \quad (7)$$

Under the constraints of mass and momentum conservation laws [3] is that

$$F_i^{(eq)}(\rho, \vec{j}) = \frac{W_i}{\rho_0} \left\{ \rho + \frac{m}{k_B T} \vec{c}_i \cdot \vec{j} + \frac{m}{2\rho k_B T} \left[\frac{m}{k_B T} (\vec{c}_i \cdot \vec{j})^2 - |\vec{j}|^2 \right] \right\} \quad (8)$$

where W_i is distribution function of fluid in equilibrium, ρ_0 is mass density, m mass of the particle, k_B is Boltzmann constant, T is temperature and \vec{j} is momentum density. This is

$$\left. \begin{aligned} F_i^{(eq)} &= \frac{4}{9} \rho \left[1 - \frac{3}{2} \frac{|\vec{v}|^2}{c^2} \right], & i &= 0 \\ F_i^{(eq)} &= \frac{1}{9} \rho \left[1 - 3 \frac{\vec{c}_i \cdot \vec{v}}{c^2} + \frac{9}{2} \frac{(\vec{c}_i \cdot \vec{v})^2}{c^4} - \frac{3}{2} \frac{|\vec{v}|^2}{c^2} \right], & i &= 1, 2, 3, 4 \\ F_i^{(eq)} &= \frac{1}{36} \rho \left[1 - 3 \frac{\vec{c}_i \cdot \vec{v}}{c^2} + \frac{9}{2} \frac{(\vec{c}_i \cdot \vec{v})^2}{c^4} - \frac{3}{2} \frac{|\vec{v}|^2}{c^2} \right], & i &= 5, 6, 7, 8 \end{aligned} \right\} \quad (9)$$

Lattice Boltzmann model consist three parts, first is Lattice model D2Q9, second is Maxwell's equilibrium distribution function and third is kinetic equations that estimate by BGK.

2.4 The Lattice Boltzmann Model

Lattice Boltzmann models (LBMs) of the first generation are plagued by the same problems as the corresponding lattice-gas cellular automata except for the noise.

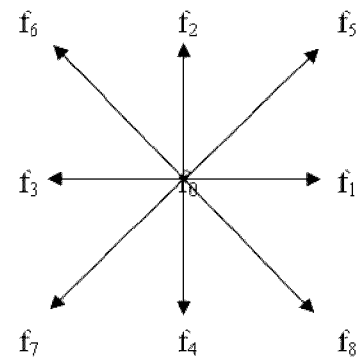
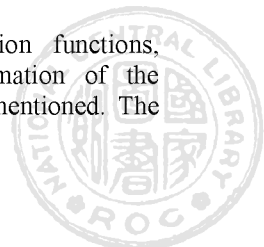


Fig. 1. The Lattice Boltzmann Model modern to Boltzmann distribution function.

Modern LBMs with Boltzmann distribution functions, several lattice speeds and BGK approximation of the collision operator are free of all problems mentioned. The



detailed discussion of such a model in 2D will be given. The derivations of the equilibrium distributions and the Navier-Stokes equation will be presented in full length. We will refer to this model as the D2Q9-LBM.

2.5 The Boundary Conditions

One of the important and crucial issues in LB simulation of flow is accurate modeling of the boundary conditions. Specifying boundary conditions for Navier-Stokes equations is somehow straightforward. This is not the case for LBM, where the inward distribution functions to the integration domain need to be determined at the boundaries. Therefore, we need to determine appropriate equations for calculating those distribution functions at the boundaries for a given boundary condition. In the literature different approaches are suggested and tested. In the following paragraphs, different boundary conditions are explained. The main idea is not to review different attempts, but to discuss, in our point of view, the simple and more robust methods.

2.5.1 Bounce Back

Bounce back is used to model solid stationary or moving boundary condition, nonslip condition, or flow-over obstacles. In the following sentences the bounce back method of stationary boundaries will be discussed. The method is quite simple and mainly implies that an incoming particle towards the solid boundary bounces back into flow domain. In the literature, a few versions of bounce back scheme have been suggested.

One of the best advantages in using lattice Boltzmann equation is the easy handling of boundary conditions. The boundary condition has been developed by Zou and He [4]. For D2Q9 model under boundary speed of $u_x, x + u_y, y$, the unknown particle distributions on the lattice at the north boundary are given by

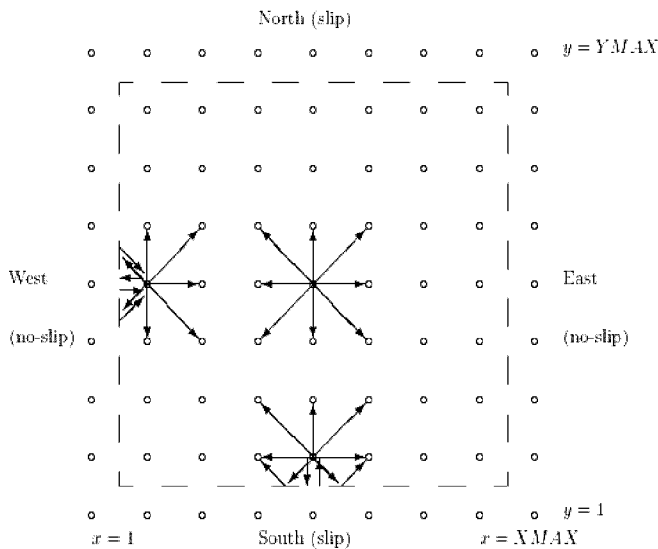


Fig. 2. Distribution functions at the boundaries of a domain North, South, East, West.

$$\rho = \frac{1}{1+u_y} [f_0 + f_1 + f_3 + 2(f_4 + f_7 + f_8)],$$

$$f_4 = f_2 - \frac{2}{3}\rho u_y,$$

$$f_7 = f_5 + \frac{1}{2}(f_1 - f_3) - \frac{1}{6}\rho u_y,$$

$$f_8 = f_6 + \frac{1}{2}(f_1 - f_3) - \frac{1}{6}\rho u_y.$$

The unknown particle distribution on the lattice at South boundary can be obtained by rotating with 180° .

III. SOLUTION OF FLUID FLOW

Lattice Boltzmann approaches model fluid dynamics by simulating the temporal evolution of one-particle distribution functions $f(x, v, t)$, where f represents the probability of finding a fluid particle at the point x , at time t , moving with velocity v . Knowing f , local values of the density and momentum are given by evaluating moments of f . The Lattice Boltzmann distribution function f_i is a discretized version of the continuous function f , where space is divided up into a regular lattice and the velocities are represented by a finite number of displacement vectors $\Delta t \cdot c_i$ to neighboring lattice sites, where $i = 0, \dots, b$, Δt is the time step, and b represents the total number of displacement directions. Resting particles are represented by a zero displacement vector c_0 .

In order to solve the macroscopic equations, we apply a multi-distribution function method (Palmer and Rector, 2000; Chatterjee and Chakraborty, 2006). Using a second distribution to model the energy density implies that we are following the passive-scalar approach which is based on the fact that the temperature satisfies the same evolution equation as a passive scalar if viscous heat dissipation and compression work are negligible (Shan, 1997).

This section, discusses Lattice Boltzmann model used to simulate single phase of fluid can be separated in several phases. The Phase separation in the Lattice Boltzmann model is able to apply by adding forces between particles. The inter-particle potential in the lattice Boltzmann scheme is defined as

$$V_{kl} = \wp W_{kl} \psi_k \psi_l \quad (11)$$

where k and l represent lattice positions. \wp is a signal function explained below. W_{kl} is the weight factor that depends on the relative position between position k and l .

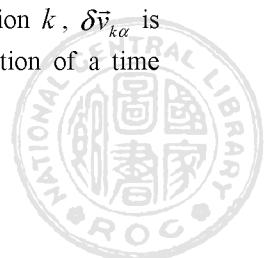
The reaction force acting on a particle at the position of the lattice k is

$$\vec{f}_k = -\sum_{l \neq k} \nabla V_{kl} \quad (12)$$

Reaction forces affecting the motion of the particles by changing the momentum of the particle

$$\rho_k \delta \vec{v}_{k\alpha} = \vec{f}_{k\alpha} \delta t \quad (13)$$

when ρ_k is density of particles at the location k , $\delta \vec{v}_{k\alpha}$ is corresponding speed change and δt is duration of a time step.



From the values of density and momentum at the lattice position k

$$\rho_k = \sum_{i=0}^b F_i \quad (14)$$

and

$$\rho_k \vec{v}_{k\alpha} = \sum_{i=0}^b F_i \vec{c}_{i\alpha} \quad (15)$$

where $\vec{c}_{i\alpha}$ is the speed vector of the Lattice Boltzmann model. We can calculate $F_i(\vec{x} + \vec{c}_i \Delta t, t + \Delta t)$, which is a new distribution function.

$$F_i(\vec{x} + \vec{c}_i \Delta t, t + \Delta t) = F_i(\vec{x}, t) - \frac{1}{\tau} (F_i - F_i^{(eq)}) \quad (16)$$

where $F_i(\vec{x}, t)$ and $F_i(\vec{x} + \vec{c}_i \Delta t, t + \Delta t)$ are the particle distribution functions before and after collision, $F_i^{(eq)}$ is the equilibrium particle distribution function and τ is collision time which is related to kinetic viscosity of the fluid in a two-dimensional model is D2Q9 relationship between ν and τ are

$$\nu = \frac{1}{3} \left(\tau - \frac{1}{2} \right) \quad (17)$$

and

$$F_i^{(eq)} = \rho W_i \left[1 + 3(\vec{c}_i \cdot \vec{v}^{(eq)}) + 4.5(\vec{c}_i \cdot \vec{v}^{(eq)})^2 - 1.5|\vec{v}^{(eq)}|^2 \right] \quad (18)$$

For the two-dimensional D2Q9 model, the velocity vectors c_i and the weights W_i are given by:

$$c_i = \begin{cases} (0, 0), & i = 0 \\ (\pm c, 0), (0, \pm c), & i = 1, 2, 3, 4 \\ (\pm c, \pm c), & i = 5, 6, 7, 8 \end{cases} \quad (19)$$

$$w_i = \begin{cases} 4/9, & i = 0 \\ 1/9, & i = 1, 2, 3, 4 \\ 1/36, & i = 5, 6, 7, 8 \end{cases} \quad (20)$$

The speed of sound is given by $c_s^2 = c^2/3$. For small Mach numbers $Ma = |u|/c_s \ll 1$, i.e. under the incompressible flow limit, the mass, momentum and energy equation can be derived through a Chapman–Enskog expansion (Palmer and Rector, 2000; Chatterjee and Chakraborty, 2006; Shi and Guo, 2009).

Eqs. (16) solved in a two-step procedure, i.e. collision and advection:

Collision:

$$F_i^{out}(\vec{x}, t) = F_i^{in}(\vec{x}, t) + \frac{1}{\tau} (F_i^{(eq)}(\vec{x}, t) - F_i^{in}(\vec{x}, t)) \quad (21)$$

Streaming:

$$F_i^{in}(\vec{x}, \vec{c}_i \Delta t, t + \Delta t) = F_i^{out}(\vec{x}, t) \quad (22)$$

where F_i^{out} and F_i^{in} denote the outgoing (i.e. after collision) and incoming (i.e. before collision) distribution functions, respectively. At equilibrium, the energy current is proportional to the mass current.

IV. SIMULATIONS AND RESULTS

The numerical simulations in the work are performed in the two-dimensional nine-direction regular Lattice Boltzmann scheme. To have a general concept of the length and time scales in the lattice Boltzmann model, it is supposed that the fluid with the kinetic viscosity, the Reynolds number, the relaxation parameter, the time step, the Dirichlet boundary condition and the boundary conditions of lid by Zou & He. In this section, the LBM is used to solve several test problems. Numerical simulations validate and illustrate how the LBM works for the symmetrical and asymmetrical. Moreover, the efficiency and stability of the LBM method to solved in many kind of fluids flow, in this work we will consider about the phase separation, the cylinder fluid flow and the cavity fluid flow.

4.1 Simulation LBM of phase separation.

This section will discuss results from simulation of the phase separation in fluid flow considered the present work is defined lattice particles in x-axis and y-axis equal 201×201 lattices, the relaxation parameter $\Omega = 1$, which is defined as the viscosity divided by the fluid density assumed to be constant with respect to the molecular density, the initial density $\rho = 1$ and $\Delta\rho = 0.001$ scheduled starting around 1000 loops is calculated to reproduce a $\Delta t = 1$, so $t = 1000$ means a repeating 1000 time step shown in Fig.3. Evolution of mass density distribution, which leads to the phase separation, has been performed for various time step and has been shown in Fig. 3 (a-f).

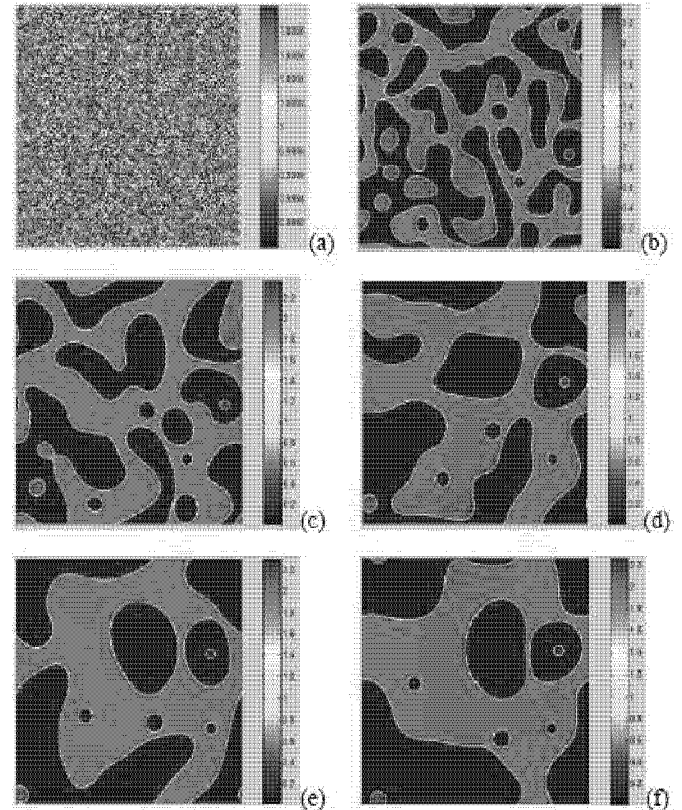
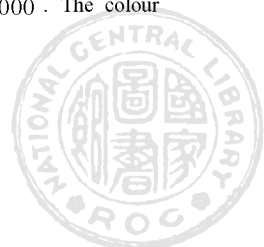


Fig. 3. The density profiles for different time step, (a) $t = 1$, (b) $t = 200$, (c) $t = 400$, (d) $t = 600$, (e) $t = 800$, (f) $t = 1000$. The colour bar indicated as the density of fluid.



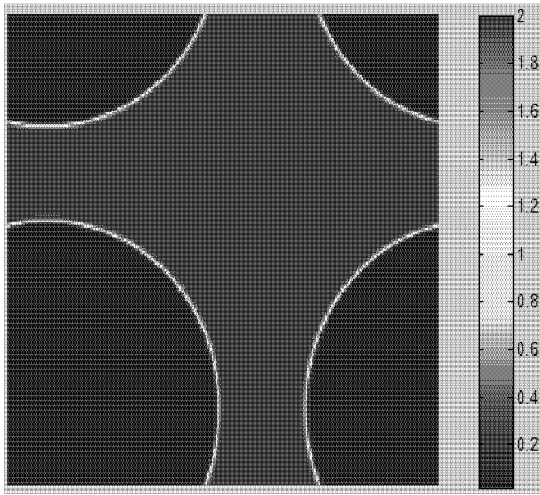


Fig. 4. Show the occurrence of phase separation for time step $t = 50,000$.

The red colour specifies an area with higher density and hence is identified as liquid while the blue area depicts the gas phase with a lower density. It can be observed that at the start, the phase separation is very quick but becomes slower due to the fact that a large amount of small bubbles start competing for those liquid particles which are in bubble phase. In the present case, phase separation leads to a single drop of liquid in a gas atmosphere. Whether liquid drops or bubbles are formed, as a result of phase separation process, depend on the initial density selected.

In Fig. 3 it can be seen that the smaller droplets are more unstable than the large droplets. This is due to the surface tension effect on the interface with a large curvature.

For simulation using lattice Boltzmann method in the case of a viscous fluid constant τ use simulating the single fluid phase separation. The phase separation occurs only when the density change, so we can take $t = 50,000$ loops.

The result is shown in Fig. 4. The lattice Boltzmann method has been used to simulate different fluid flow problems and phase separation process. The results obtained in all cases are in good agreement with the analytical results showing the validity of LBM for incompressible flows. LBM can be considered to be an efficient numerical method for simulation of fluid flow problems.

From the Fig. 4, to see a phase separation occurs. The red area is where the density is greater than the blue area. If define the density from the simulation showed that over time will occur the phase separation appears in this phase of the liquid and gas.

4.2 Simulation LBM of the cylinder fluid flow.

The flow around the cylinder groups has been extensively investigated by both experimental and numerical methods. In this part, we will observe and define the fluid flow simulation in current study are perform using a uniform rectangular mesh 400×100 , defined position of the cylinder in x-axis, y-axis and radius of the cylinder. Maximum velocity of Poiseuille in flow $u_{max} = 0.1$, the Reynolds number is 100, the kinematic viscosity

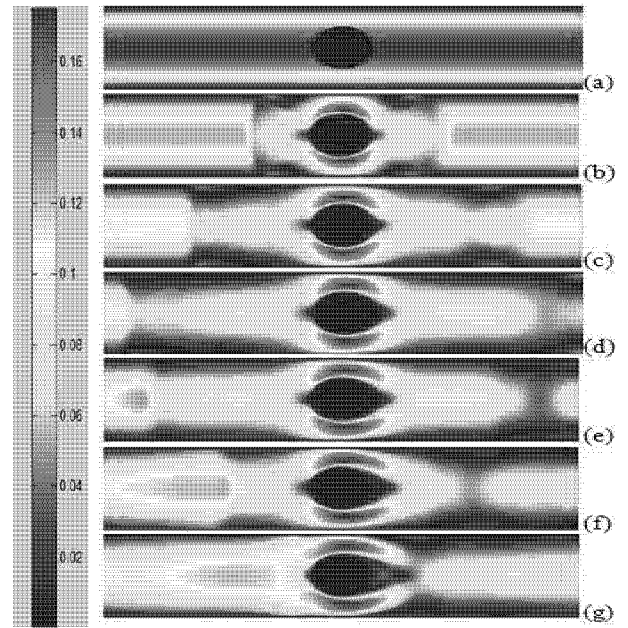


Fig. 5. The velocity of fluid flow in cylinder for different time step (a) $t = 1$, (b) $t = 100$, (c) $t = 200$, (d) $t = 300$, (e) $t = 400$, (f) $t = 500$, (g) $t = 600$. The colour bar indicated as the velocity of fluid flow.

$$\mu = \frac{(u_{max}) \times (2(\text{radius of the cylinder}))}{\text{Reynolds number}}, \text{ relaxation}$$

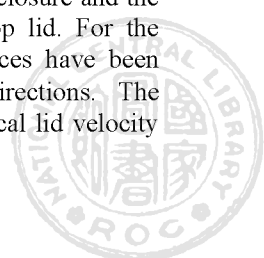
$$\text{parameter } \Omega = \frac{1}{(3\mu + 1/2)}. \text{ The result is shown in Fig. 5.}$$

In Fig. 5. Shows the velocity of fluid flow when a cylinder is inserted into the channel for different time step and had Bounce back boundary condition that right wall and left wall between time step (d) $t = 300$ and (e) $t = 400$. It is apparent that the introduction of the cylinder causes a narrowing of the main recirculation region as a result of the interruption within the flow. There also has a small recirculation zone behind the cylinder. The overall flow structure is in good agreement with that predicted intuitively.

The numerical results obtained for the velocity of fluid flow are in good agreement with the published experimental and numerical results. The simplified Lattice Boltzmann model applied in this part is easy to use and indeed an appropriate LBM for performing accurate simulations of fluid flows. The results have shown that inserting cylinder enhances the velocity of fluid flow as a result of flow interruption and Bounce back boundary.

4.3 Simulation LBM of the cavity fluid flow.

Lid-driven cavity flow has been studied extensively for more than three decades and is one of the most popular fluid problems in the computational fluid dynamics (CFD) field. This classical problem has attracted considerable attention because the flow configuration is relevant to a number of industrial applications. The lid driven cavity flow is always an important flow to check the validity of any numerical scheme because it has no analytical solution. An incompressible fluid is bounded by square enclosure and the flow is driven by uniform translation of top lid. For the square cavity, mesh grid size 128×128 lattices have been taken both in horizontal and vertical directions. The horizontal lid velocity is $u_{lid} = 0.05$, the vertical lid velocity



is $v_{lid} = 0$. The Reynolds number is 100, the kinematic viscosity was taken as

$$\mu = \text{horizontal lid velocity} / \text{Reynolds number}$$

the relaxation parameter was taken as

$$\Omega = \frac{1}{(3\mu + 1/2)}$$

The two top corners are singular points which are considered as part of moving lid in the simulations. The result is shown in Fig. 6.

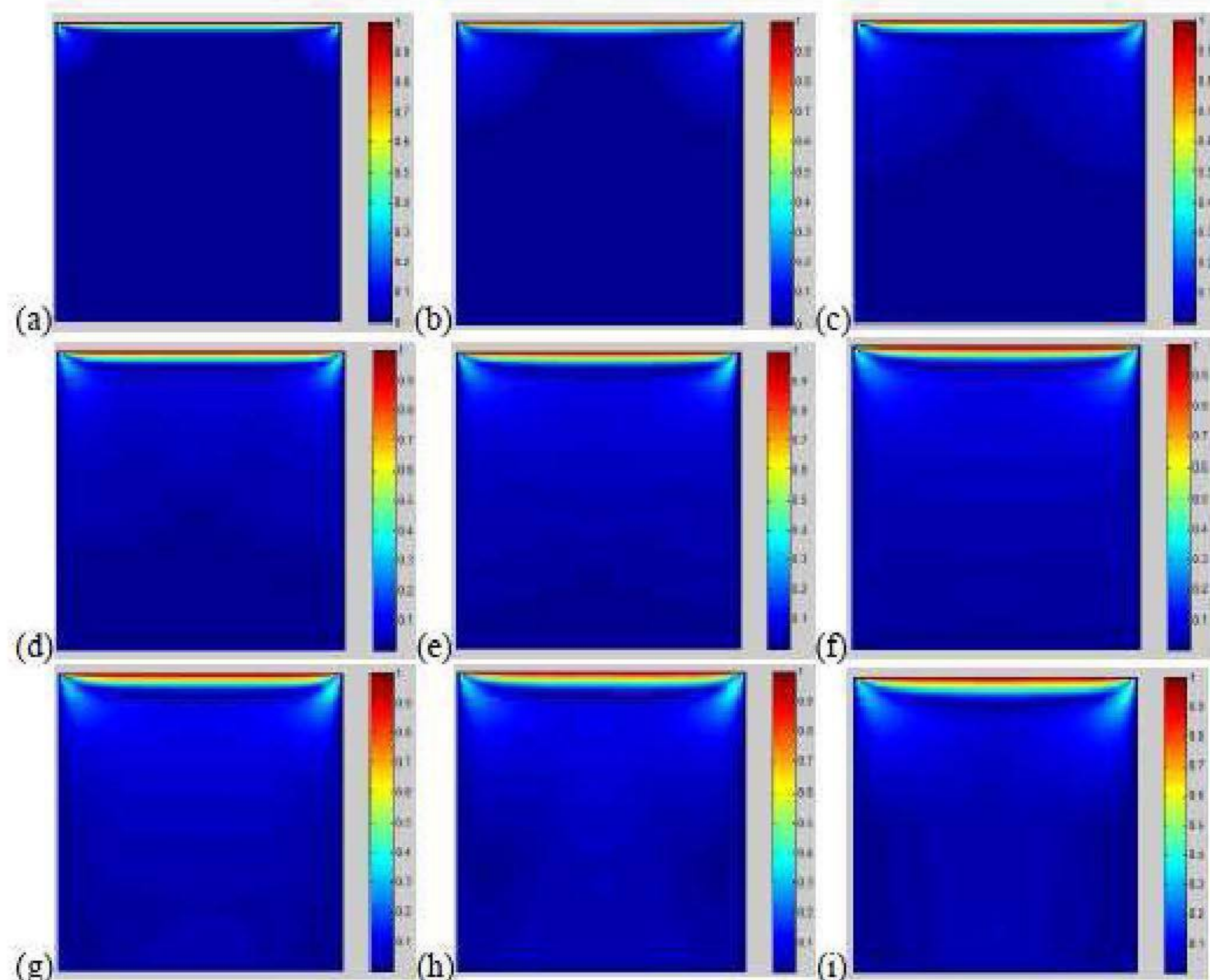


Fig. 6. Shows stream traces both of the top corner at different time step, (b) $t = 50$, (c) $t = 100$, (d) $t = 150$, (e) $t = 200$, (f) $t = 250$, (g) $t = 300$, (h) $t = 350$, (i) $t = 400$. The colour bar indicated as the velocity of fluid flow.

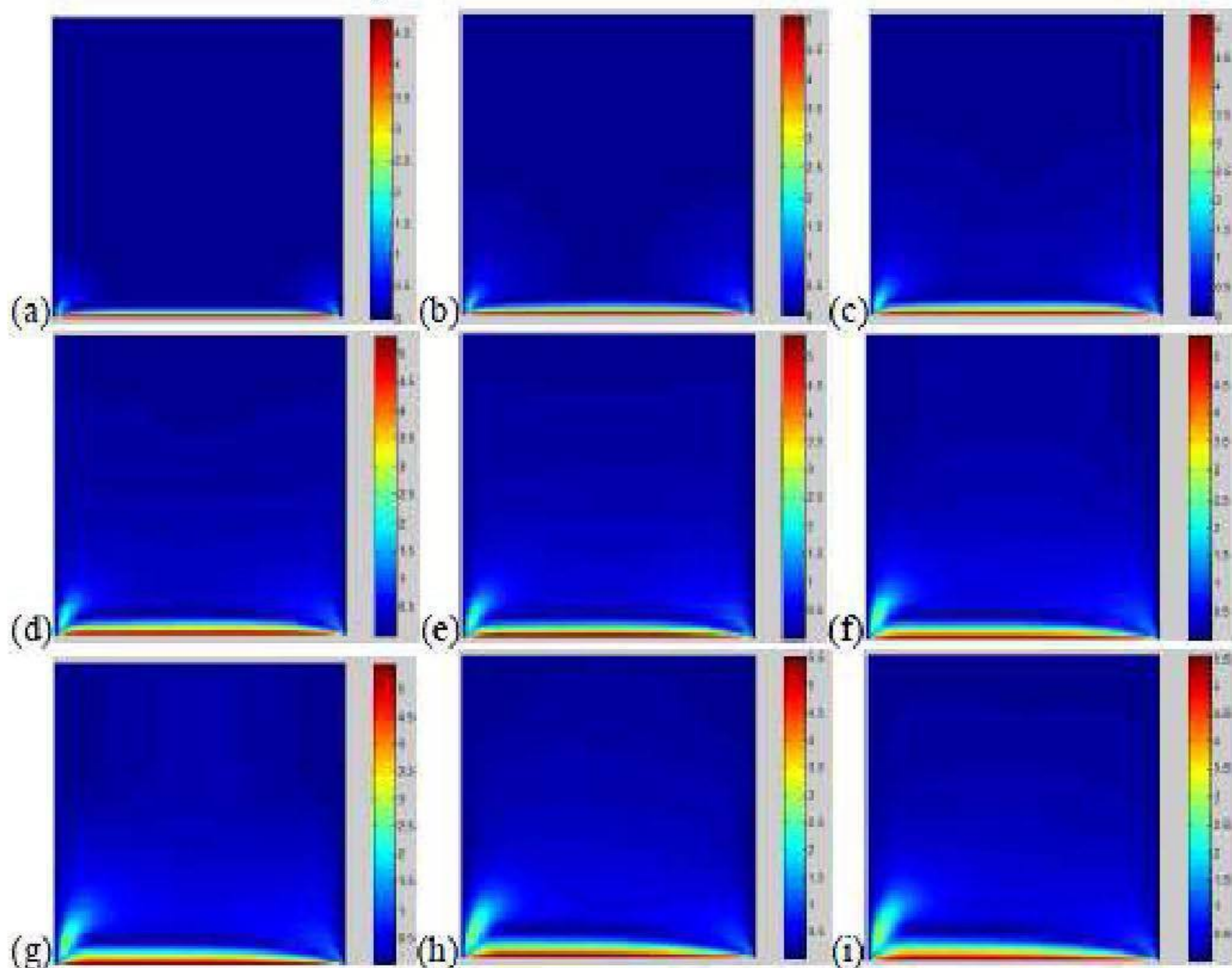


Fig. 7. Shows stream traces both of the below corner at different time step (a) $t = 1$, (b) $t = 50$, (c) $t = 100$, (d) $t = 150$, (e) $t = 200$, (f) $t = 250$, (g) $t = 300$, (h) $t = 350$, (i) $t = 400$. The colour bar indicated as the velocity of fluid flow.

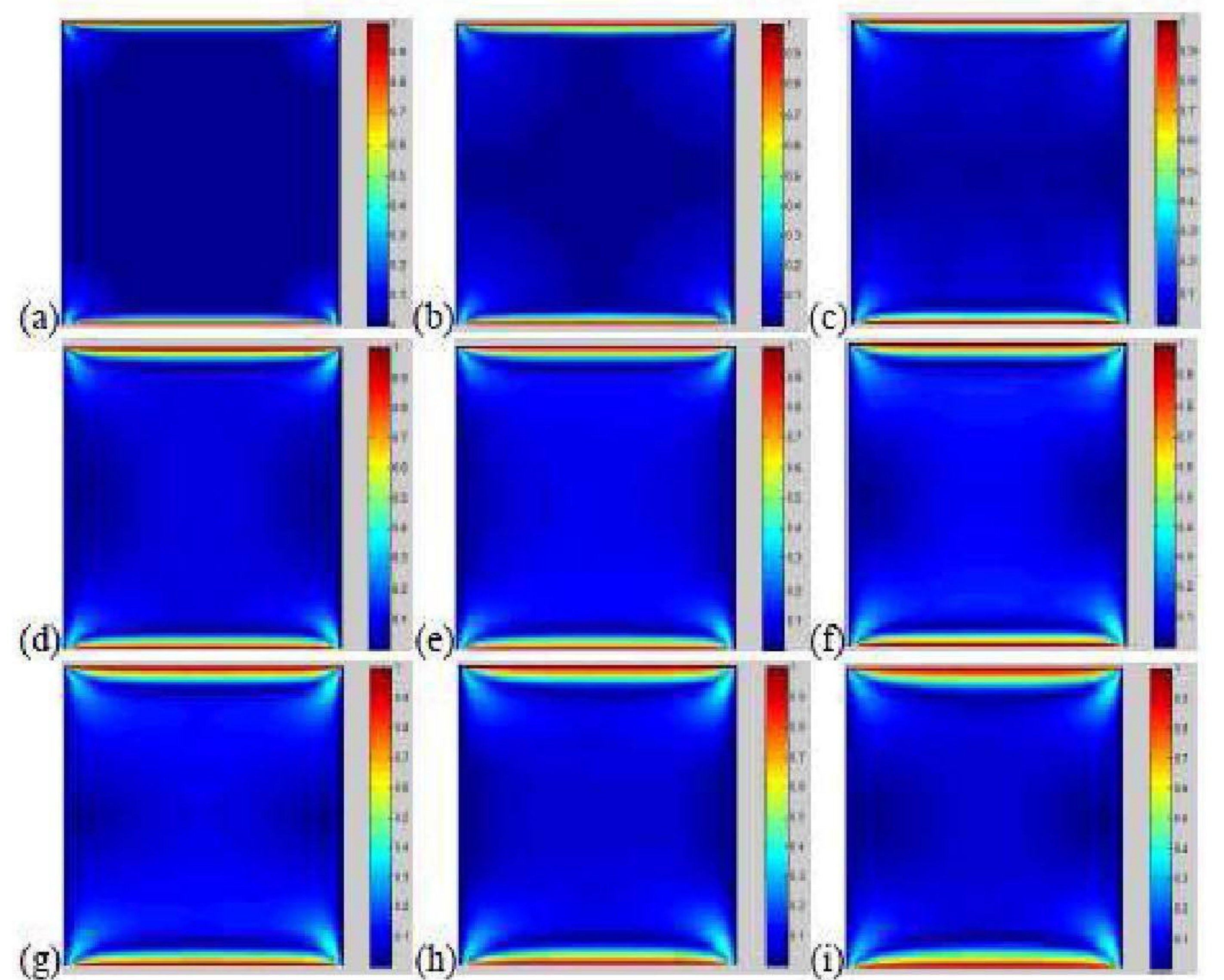


Fig. 8. Shows stream traces all of corner at different time step (a) $t = 1$, (b) $t = 50$, (c) $t = 100$, (d) $t = 150$, (e) $t = 200$, (f) $t = 250$, (g) $t = 300$, (h) $t = 350$, (i) $t = 400$. The colour bar indicated as the velocity of fluid flow.

In Fig. 6. Showed the velocity of the cavity fluid flow at two top corners at different time step and has Bounce back boundary condition. The stream traces indicated velocity of fluid flow in simulations. The two below corners are singular points which are considered as part of moving lid in the simulations. The result is shown in Fig. 7.

In Fig. 7. Showed the velocity of the cavity fluid flow at two below corners at different time step and has Bounce back boundary condition. The stream traces indicated velocity of fluid flow in simulations. The top and below four corners are singular points which are considered as part of moving lid in the simulations. The result is shown in Fig. 8.

In Fig. 8. Showed the velocity of the cavity fluid flow at four corners at different time step and has Bounce back boundary condition. The stream traces indicated velocity of fluid flow in simulations.

Results of lattice Boltzmann simulation of two-sided lid-driven on top and below flow, four-sided lid driven, inside rectangular cavity are presented in this article. The results obtained with LBM are in good agreement with the results available in the literature for two-sided lid driven rectangular cavity and four-sided lid driven rectangular cavity.

V. CONCLUSION

This paper shows the capability of LBM in simulating the multi-phase phenomenon. The simplest LBM models that can be implemented based on the concepts presented in the preceding discussion are the single component single phase models and the single component multi-phase models. These models are implemented for different fluid flow problems. Simulation of the Lattice Boltzmann model can learn how to use the software to develop models to simulate Lattice Boltzmann model in the future. The results of scientific experiments on fluid phase separation under fluid flow, this model may apply to adjust and compare the results to be close to reality. We have shown that the software has reached a reasonable level of reliability and performance. In future work, we will explore the performance of the presented hybrid solvers. Concerning the numerical methods used, we will examine their capabilities of being employed

in large-scale simulations associated with the forecast of tsunami waves in coastal regions or simulations in other situations of fluid dynamic system.

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