Simulation of Two Phase Fluid Flow With Various Kinds of Barriers Using Lattice Boltzmann Method

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Abstract. Multiphase fluid flow in a pore medium is a problem that is very interesting to be learned. In its flow, the fluid can experience a few of barriers / obstacles like the exsisting of things in the flow medium. The existence of the barriers can detain the rate speed of the fluid flow. The barries that its form is different will provide influence to the speed of of fluid flow that is different as well. To know the influence of barriers form twards the profile of fluid speed rate, is conducted by the simulation by using Lattice Boltzmann Methode (LBM). In this simulation, the barriers is varied in the form of circle, square, and ellips. From simulation that is conducted, to known the influence of barriers variations twards the fluid speed, ploted by the graph of the fluid speed relations along simulation time and plotted by the fluid speed vector in each posisition. From the simulation, it is obtained that the barriers with square formed produced the higest speed rate of the fluid flow, with the speed rate 0.26 lu/ts, then circle formed with the speed rate 0.24 lu/ts, and the last square formed with speed rate 0.24 lu/ts.

1. Introduction

The study of multiphase fluid flow in pore medium is interested and widely studied by the scientists. The knowledge of multiphase fluid flow can be utilized in various aspects of life, such as blood circulation modeling in human's body, groundwater flow modeling, fluid flow modeling in oil reservoirs, fluid flow modeling in geothermal reservoirs, and modeling for biomedical engineering. The scientists have been study about the properties of the multiphase fluid flow in pore medium and modeling with some numerical methods. The numerical methods used to model the fluid flow divided in to three groups, macroscopic modeling (FDM, NS, FEM), microscopic modeling (MD, DSMC), and mesoscopic modeling (LBM, LGA, SPH).

Mesoscopic modeling is a relatively new method to bridge the approach study between macroscopic and microscopic. Mesoscopic modeling (LBM) declared the behavior of group particles in a single unit, so in this method does not need to declare the behavior of each particle. The nature of group particle is then stated in distribution function that can represent a behavior from the particle group. The function of distribution that suitable to describe the behavior from the group particle is the function of Boltzmann distribution. The advantage of LBM in modeling the fluid is LBM only need small memory of calculations, can be used for modeling the fluid flow in complex geometry, and not to solve the Poisson equation in each iteration.

Some of multiphase fluid flow modeling has been carried out: LBM to determine the dashed permeability of fluid flow in the fiber [1], LBM to simulate the two-phase fluid flow in the rocky reservoir [2], LBM to simulate the two-phase fluid flow in porous media[3], and simulating the fluid flow through a certain obstacle pattern with LBM[4].

The aim of this modeling is to know the influence of barriers from twards the profil of fluid flow rate by using Lattice Boltzmann Method.

2. Metodology

In this modeling, it is implemented by SC LBM model [Shan and Chen, 1993.1994] on the system of two-phase fluid flow in porous medium, in an isothermal state[9]. In this model, the function of the particle distribution follows the Boltzmann distribution equation:

$$f_a(x+e_a\Delta t, t+\Delta t) = f_a(x,t) - \frac{\Delta t}{\tau}(f_a(x,t) - f_a^{eq}(x,t)) \tag{1}$$

Where the Boltzmann distribution function $f_a(x,t)$ that is used to calculate the density and field of speed, relaxation time τ which is correlated with fluid kinematic viscosity $v = c_s^2(\tau - 0.5\Delta t)$, $f_a(x+e_a\Delta t, t+\Delta t)$ the speed distribution function at $t+\Delta t$, the speed distribution function $f_a^{eq}(x,t)$ is at steady state.
The speed and momentum distribution model used two-dimensional model with nine directions (D2Q9) depend on hollow lattice [7]. The (D2Q9) lattice structure is:

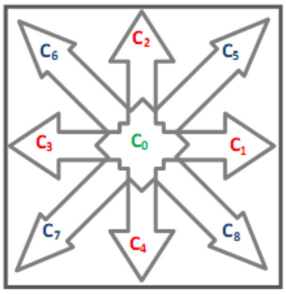


Figure 1. D2Q9 lattice structure [10]

According to those models, the value of e_a can be written as:

$$e_a = \begin{cases} (0,0) \rightarrow, a = 0 \\ \varphi_a c\left[\cos\frac{(a-1)\pi}{4}, \sin\frac{(a-1)\pi}{4}\right] \rightarrow, a \neq 0 \end{cases} \tag{2}$$

With φ_a,

$$\varphi_a \begin{cases} 1 \rightarrow, a = 1,2,3,4 \\ \sqrt{2} \rightarrow, a = 5,6,7,8 \end{cases} \tag{3}$$

The density of ρ and the speed of u define as:

$$\rho = \sum_a f_a u_i = \frac{1}{\rho}\sum_a f_a c_{ai} u_i \tag{4}$$

Equilibrium distribution function $f_a^{eq}(x,t)$ is written as:

$$f_a^{eq}(x,t) = w_a \rho \left[1 + \frac{e_a.u^{eq}}{c_s^2} + \frac{(e_a.u^{eq})^2}{2c_s^4} - \frac{(u^{eq})}{2c_s^2} \right] \quad (5)$$

With

$$\rho = \sum_a f_a^{eq}, u_i = \frac{1}{\rho} \sum_a c_{ai} f_a^{eq} \quad (6)$$

And

$$w_a = \begin{cases} \frac{4}{9}, a = 0 \\ \frac{1}{9}, a = 1,2,3,4 \\ \frac{1}{16}, a = 5,6,7,8 \end{cases} \quad (7)$$

Some boundary condition requirements that applied to this method are periodic boundary condition, bounce back boundary condition, and dirichlet boundary condition (Sukop, 2007). Periodic boundary condition caused the distribution function at the right end is considered the same as the particle distribution functions on the left end, so that the fluid flow will be connected continuously. Bounce back boundary condition is the most simple limitation requirement to create a solid barrier wall. This allows the particles to bounce without losing momentum when pounding the walls. Particles colliding the wall will be bounce back at a speed with an opposite direction to the initial speed direction (no-slip) (Wolf-Gladrow, 2006)[6]. Dirichlet boundary condition requirement was applied by describing the parameters of pressure at the domain limitation. Pressure parameters are associated with density variable.

The fluid flow performed by flowing it in a medium that has barrier with various form of circle, square, and ellipse. To distinguish barrier with the pore, the number granted barrier 1 and the number granted pore 0. The geometrical size of lattice on the vertical side is 150, and horizontal side size is 200.The limitation requirement applied periodically at the inlet and outlet sections. The reflection limitation requirement is used to simulate the fluid flow in a complex medium (Sukop, 2007). The other limitation requirement is reflection limitation (Zou and He 1997. In this simulation, there are two fluids of water with a density 1 in lattice unit and oil with a density 0.7 in lattice unit. The water is colored blue and oil is red.

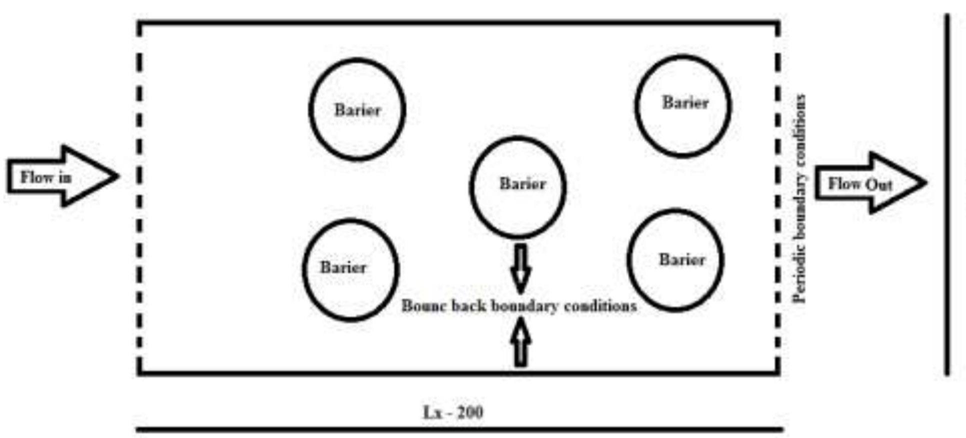
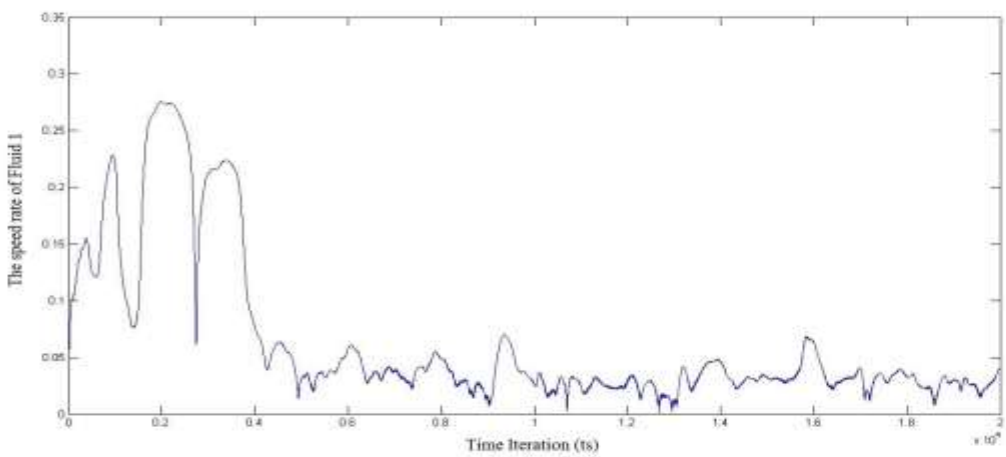


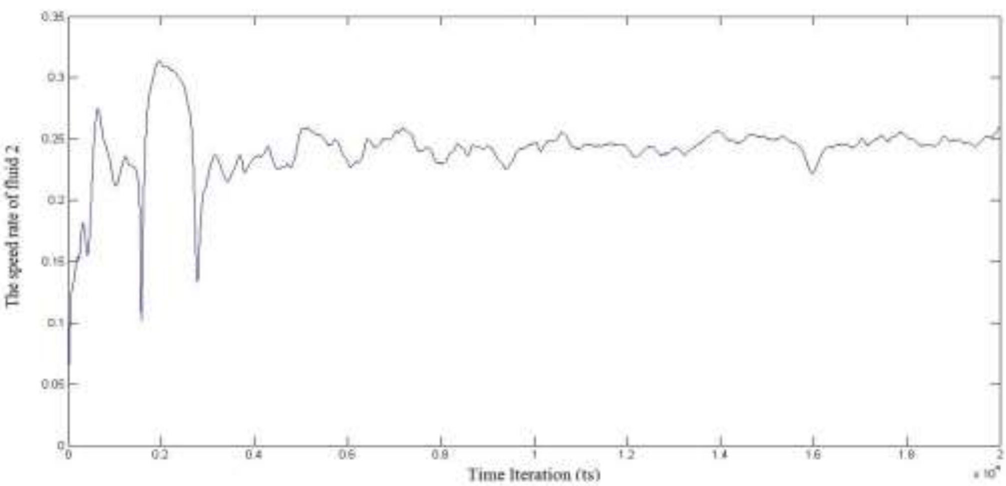
Figure 2. D2Q9 lattice structure(Sukop,2007)[8]

3. Results and Discussions

The simulation results of two phase fluid flow in porous media using the Lattice Boltzmann can be seen in the pictures below.

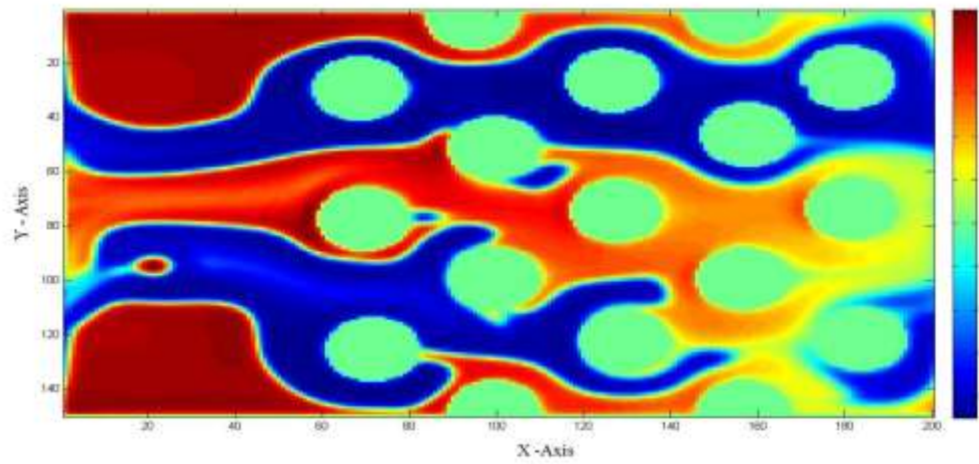


(a)



(b)

Journal of Physics: Conference Series **739** (2016) 012063 doi:10.1088/1742-6596/739/1/012063

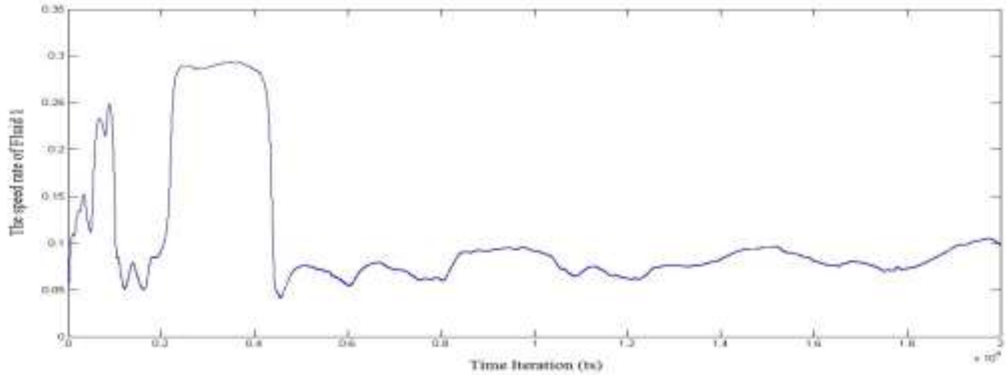


(c)

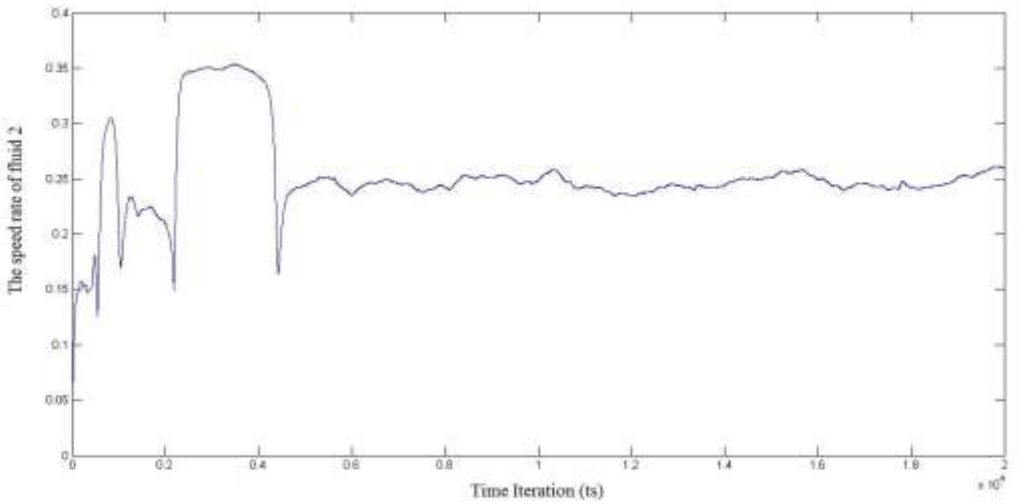
Figure 3. (a) graph of 1st fluid velocity in circular barrier, (b) graph of 2nd fluid velocity in circular barrier, (c) Visual of fluid flow in the system.

In the figure 3a, the highest speed at 0.27 lu / ts in the time iteration of 200 and the lowest speed at 0.05lu / ts in the time iteration of 1200. The maximum speed can be seen in the coordinates (25.70) and the spread amongst the gap of pores as shown in figure 3b. While the distribution of minimum speed at around outer part of pore. This phenomenon could happen because when fluid enters from the left side immediately fractionated by the circle formed pore, the circle has its form of degree of good unanimity, until the fluid flow tends to be convergent around pore row in front of intake flow fluid, the condition like this in accordance with the Poisuelle flow namely maximum speed fluid at the middle part of plane that is upright with the flow. The big amount of fluid that flows through mid plane, causes the flow in the edges owning low speed.

In figure 3a, the speed fluctuation shown at the range of 0-4000 time iteration, it explains that in that time range, the laminar flow of the fluid have not occurred yet. The Laminar of fluid flow is indicated by the speed when the fluid enters and goes out of owning the value that isalmost the same. In figure 3a, the laminar flow shown at the range of 500-20000 time iteration. Whereas in figure 3b, the speed fluctuation shown in the time iteration range of 0-3000, and the flow rate of fluid 2 is higher than the flow rate of the fluid 1, it is associated with the fluid density as the physical parameter. Fluid 1 is water and fluid 2 is oil. Water owns the value of density that is greater relative if we compare with oil, that water is more difficult relative to move compared with oil, therefore the time to achieve the stability of faster relative water flow, and owns the speed that is lower relative compared with oil.



(a)



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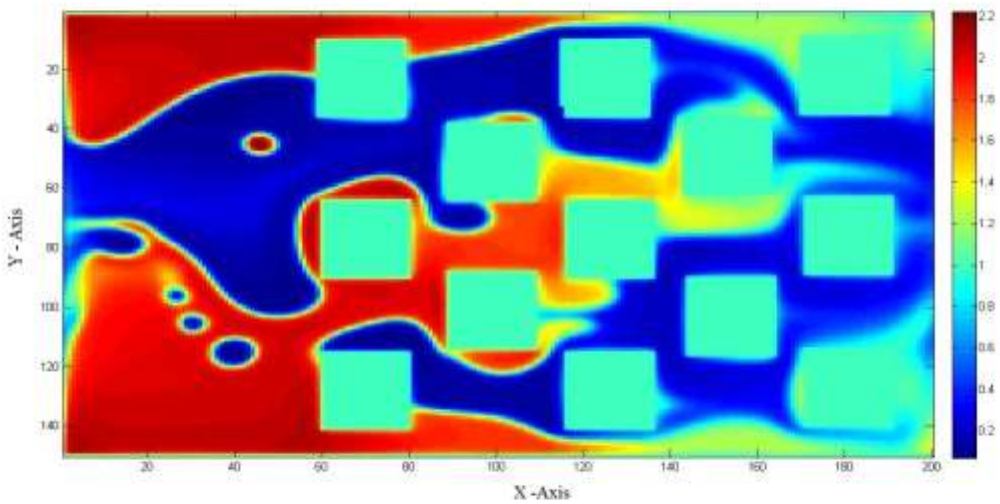


(c)

Figure 4. (a) graph of 1st fluid velocity in square-shaped barrier, (b)graph of 2nd fluid velocity in square-shaped barrier, (c) Visual of fluid flow in the system.

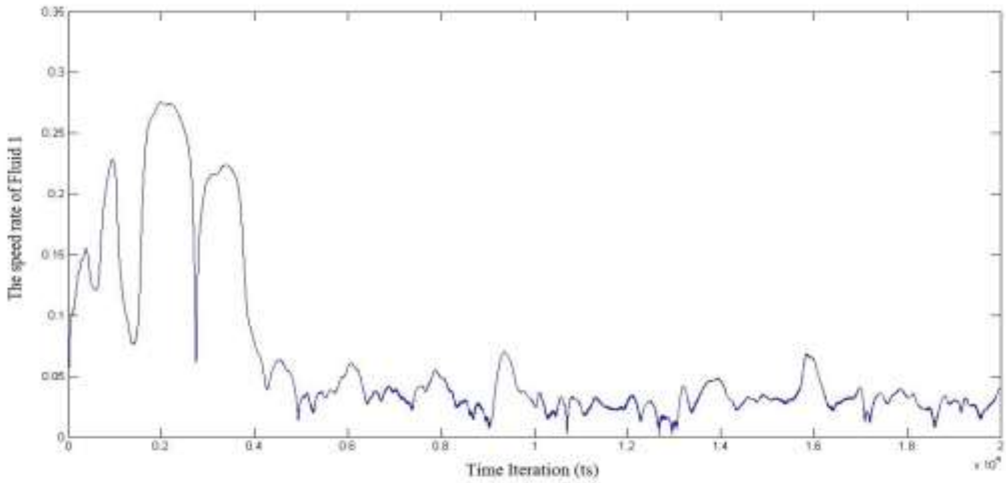
At the figure 4a, the higest speed at 0.3 lu / ts in the time iteration of 400 and the minimum speed of 0.05lu / ts in the time iteration 4200. The maximum speed can be seen the gap between the pores, and spread among the pores in the edge of the simulation plant, this thing caused by in the square formed barrier can split the fluid flow that enters to become two flows equally big towards pore edges, then the flow that have been cloven, split further by the barrier existing behind it, etc, until its speed spreads smoothly as shown in the Figure 4c.

The average value of the speed of a square formed barrier pores is lightly higher than of a circular barrier pores as shown in Figure 3a and Figure 4a. This was becaused in the circle formed pore of fluid flown dominated by oil flow that water is silent relative, while in the square formed pore, the oil flow spreads almost smoothly at the whole part due to be fractionated by pore, as the consequence of it, water tends to move more to follow the oil dynamics spread almost smoothly.

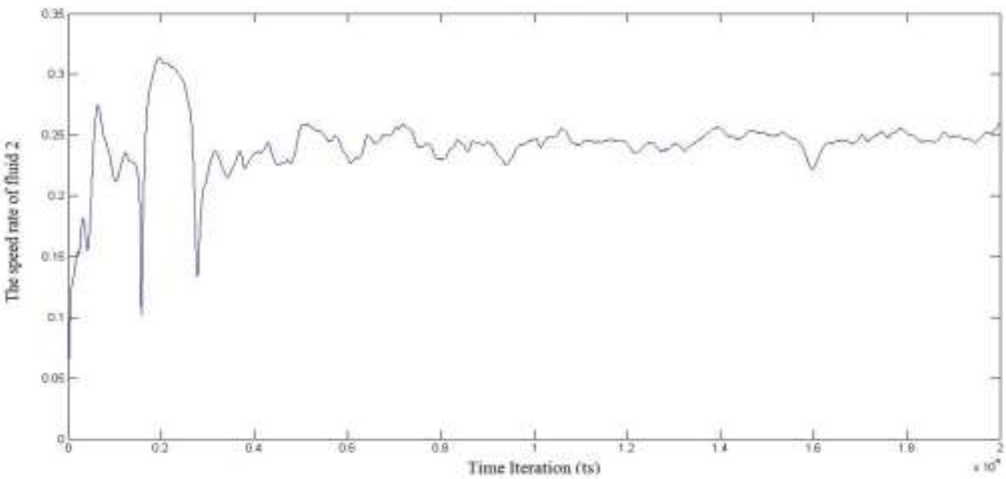
In the figure 4a, the speed fluctuation shown at the range of 0-4400 time iteration, this iteration time is relatively longer than the iteration time on fluid flow of a circular barrier. This means that the flow of water fluid in square

Journal of Physics: Conference Series **739** (2016) 012063 doi:10.1088/1742-6596/739/1/012063

formed are relatively more difficult to achieve laminar flow, so does the flow of oil fluid. The long time to achieve this laminar flowis due to the square barrier that continues to break the fluid flow to the right left side of the pore that only a little of fluid that can flow through the pore surface. It's different with the circle formed, the circular barrier pores can distraction of the fluid flow more smooth, so can achieve equilibrium faster.



(a)



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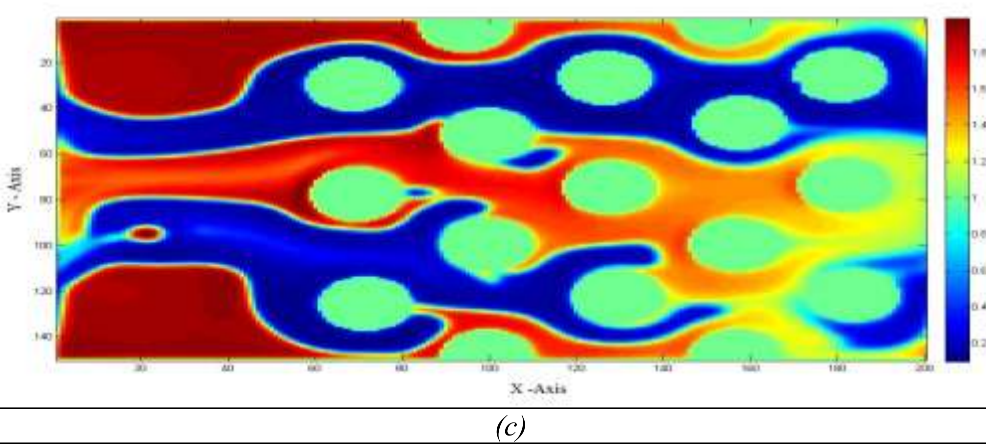

(c)

Figure 5. (a) graph of 1st fluid velocity in elliptical barrier, (b)graph of 2nd fluid velocity in elliptical barrier, (c) Visual of fluid flow in the system.

At the figure 5a, the maximum speed at 0.3 lu / ts in the time iteration of 1100 and the minimum speed of 0.05lu / ts in time iteration 1500. The maximum speed can be seen spread at the right and left gap of the pores as shown in figure 5c. While the distribution of minimum speed lies between the pore gap and behind the pore. This thing is due to ellipse formed owns the subtle rudeness and to be fluid dynamic, that it can break the fluid flow to the right and left part easily. The effect of the elliptical shape of the barrier extending to each side of barrier causing amount of fluid to flow backward through the barrier is relatively small. As a result, the number of fluid particles flowing through the gap pores is relatively slower.
In the figure5a,speed fluctuations shown at the range of 0-15000 time iteration, and in the figure 5b shown in the range of 0-12000, this time is the longest time if we compere with the time to achieve laminar flow in the square and circle formed barrier. This thing is due to the form is ellipse that widens and its end is fluid dynamic, that the fluid flow is always fractionated to left right part of pore and only a little fluid that can flow through the pore surface.

4. Conclusion

From the result of simulation that has been done, it was concluded that the barrier/pores square formed produces the profile of fluid flow is faster compared to the circle and ellipse formed barriers. In the viscous fluid, the fluid dynamic barrier will impede the flow of the fluid, this thing is due to the fluid in his flow will adhere in the pore surface, thatthe flow is slower.

Acknowledgement

The authors are thankful to Prodi FISIKA ITB which has given a grant to support this reaserch.

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