

Aplikasi Kisi Gas Automata Untuk Memperkirakan Efektifitas Porositas dan Model Penghalang Permeabilitas Pada Segitiga Dengan Variasi Ketinggian

Lattice Gas Automata Applications to Estimate Effective Porosity and Permeability Barrier Model of the Triangle with a Height Variation

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Penelitian ini bertujuan untuk menghitung porositas efektif (ϕ_{eff}) dan permeabilitas (k) menggunakan model segitiga dengan variasi tinggi yaitu 3, 4, 5, 6 dan 7 cm. Perhitungan porositas dan permeabilitas yang efektif dilakukan dengan menggunakan model *Lattice Gas Automata* (LGA), yang diimplementasikan dengan bahasa pemrograman Delphi 7.0. Untuk model segitiga penghalang dengan tinggi 3, 4, 5, 6 dan 7 cm, nilai porositas efektif dan permeabilitas, masing-masing: $\phi_{eff}(T_1) = 0,1690$, $k(T_1) = 0,001339 \text{ pixel}^2$; $\phi_{eff}(T_2) = 0,1841$, $k(T_2) = 0,001904 \text{ pixel}^2$; $\phi_{eff}(T_3) = 0,1885$, $k(T_3) = 0,001904 \text{ pixel}^2$; $\phi_{eff}(T_4) = 0,1938$, $k(T_4) = 0,001925 \text{ pixel}^2$; dan $\phi_{eff}(T_5) = 0,2053$, $k(T_5) = 0,002400 \text{ pixel}^2$. Dari hasil simulasi, diperoleh tinggi segitiga akan berpengaruh signifikan terhadap nilai porositas efektif dan permeabilitas. Pada segitiga lebih tinggi, menyebabkan tabrakan model aliran fluida LGA mengalami lebih banyak hambatan untuk penghalang, sehingga porositas efektif dan permeabilitas menurun. Sebaliknya, jika segitiga lebih rendah, menyebabkan tabrakan model aliran fluida LGA mengalami lebih sedikit hambatan untuk penghalang, sehingga porositas efektif dan permeabilitas meningkat.

This research purposed to calculate the effective porosity (ϕ_{eff}) and permeability (k) using the barrier model of the triangle with a high varying are 3, 4, 5, 6 and 7 cm. Effective porosity and permeability calculations performed using the model Lattice Gas Automata (LGA), which is implemented with Delphi 7.0 programming language. For model the barrier triangle with a high of 3, 4, 5, 6 and 7 cm, the value of effective porosity and permeability, respectively: $\phi_{eff}(T_1)=0,1690$, $k(T_1)=0,001339 \text{ pixel}^2$; $\phi_{eff}(T_2)=0,1841$, $k(T_2)=0,001904 \text{ pixel}^2$; $\phi_{eff}(T_3)=0,1885$, $k(T_3)=0,001904 \text{ pixel}^2$; $\phi_{eff}(T_4)=0,1938$, $k(T_4)=0,001925 \text{ pixel}^2$; and $\phi_{eff}(T_5)=0,2053$, $k(T_5)=0,002400 \text{ pixel}^2$. From the simulation results, obtained by the high of the triangle will be a significant effect on the value of effective porosity and permeability. If the triangle highest, causing the collision of fluid flow models LGA experience more obstacles to the barrier, so that the effective porosity and permeability decrease. Conversely, if the triangle lower, causing the collision of fluid flow models LGA experience less obstacles to the barrier, so that the effective porosity and permeability increases.

Keywords: Effective porosity, permeability, model triangle, model LGA

Introduction

There are two common ways the study of fluid. The first is to take a macroscopic viewpoint that describes the fluid as a continuum. The second uses microscopic point of view that illustrates the interaction between the particles in a fluid. Fluid has a characteristic length scale. On a macroscopic

scale, the characteristics associated with a channel width or diameter of obstacles or it can also measure the vortex. At the micro scale, these characteristics are determined by particle displacement distance before the collision, or the mean free path. On a micro scale, the mean free path for the liquid fluid is much smaller than gas (Bimo. BB, 2009). With the

advancement in the field of numerical computation, simulation of fluid flow have been done, although they found some difficulty in the number of lattice, and numerical stability (Koponen, 1998). Some relationships between reservoir parameters have been able to be explained by numerical modeling, one of which is a method of Lattice Gas Automata (LGA). LGA is a variation of cellular automata system, the lattice as a medium.

In this research, physical modeling done for validation mechanisms of fluid flow in porous medium. The purpose of this research is to get a comprehensive understanding of the mechanisms of fluid flow in porous medium with the actually. Permeability is a reservoir rock properties to be able to pass the liquid through the pore are interconnected, without destroying the particle forming or the rock frame work Henry Darcy has introduced a simple equation to calculate the velocity laminar flow of a viscous fluid in a porous medium written as:

$$q = \frac{k}{\eta} \frac{dp}{dx} \quad (1)$$

Where q is flow rate per cross-sectional area is expressed in centimeters per second, k is hydraulic permeability, η is viscosity of the fluid, and $\frac{dp}{dx}$ is gradient of pressure. Equation (1) in the discipline geohydrology can be modified to:

$$u = k_f \frac{\Delta h}{l} \quad (2)$$

Where k_f is coefficient of seepage, Δh is head height difference of head, and l is length of the medium. Thus it is clear that the permeability is k expressed in Darcy. Definitions API for 1 Darcy is a porous medium has a permeability of 1 Darcy, if the liquid-phase the viscosity 1 centipoise flowing at a speed of 1 cm/sec through the cross-sectional area of 1 cm² at a hydraulic gradient of the atmosphere (76.0 mm Hg) per centimeter and if the liquid is entirely filling the medium.

From the above definition does not explain the relationship between permeability and porosity. Actually there is no relationship between permeability and porosity. Always porous permeable rock, but on the contrary, the porous rock

is not necessarily permeable. This is because rock has a higher porosity of the pore is not necessarily related to each other. On the contrary it can be seen that the porosity is independent of particle size and permeability is a direct function of the grain size (Koesoemadinata, R.P, 1980).

The equation microdynamic and macrodynamic LGA
Rules and medium collisions in the LGA is a triangular lattice. The following is a mathematical formulation to describe fluid flow from the cellular system LGA method:

$$n_i(x + c_i, t + 1) = n_i(x, t) + \Delta[n_i(x, t)] \quad (3)$$

Particles moving in a hexagonal lattice as Boolean variable $n_i(x, t)$, the value will be equal to 1 if there is a particle and 0 if no particle moving from position x to position $x + c_i$. Operator delta (Δ) is the collision operator that describes changes in the value $n_i(x, t)$. These collisions can be valuable operator 0, 1 or -1. If there is no change in the number of particles i as a result of collision events, where the number of particles before and after the collision is equal to the value of $\Delta_i = 1$. The particles move from position x to position $x + c_i$, particles moving at a speed unit in the direction:

$$c_i = \left[\cos\left(\frac{2\pi i}{6}\right), \sin\left(\frac{2\pi i}{6}\right) \right] \quad (4)$$

where i are 1, 2, 3, ..., 6. The particles collisions in the medium and the gas grid must meet the law of conservation of mass, it's condition:

$$\sum_i \Delta_i(n) = 0 \quad (5)$$

and meet the law of conservation of momentum

$$\sum_i c_i \Delta_i(n) = 0 \quad (6)$$

using the relationship (6), the equation micro-dynamic for all directions i , conservation of mass becomes:

$$\sum_i n_i(x + c_i, t + 1) = \sum_i n_i(x, t) \quad (7)$$

Meanwhile, to get the equations of conservation of momentum is obtained by multiplying the equation (3) with c_i ,

$$\sum_i c_i n_i(x + c_i, t + 1) = \sum_i c_i n_i(x, t) \quad (8)$$

Equation (7) and (8) described the evolution of mass and momentum in Boolean terrain and can be considered as a mass and momentum balance equation of the lattice gas systems. LGA macro-dynamic equation obtained by looking at the case in Figure 1 which illustrates the evolution that occurs in the system. In the picture depicted a region A, of the lattice surrounded by the line S. Equation (8) can be written as:

$$\sum_{x \in A} \sum_i [n_i(x_i, t + 1) - n_i(x, t)] = - \left(\begin{array}{l} \text{flux netto mass coming} \\ \text{out of the } \alpha \text{ direction from S} \end{array} \right) \quad (9)$$

The left side of the equation is identical to equation finite difference and right sections are discrete statement of integral surface. By stating $\sum_i n_i$ as the average number of particles for all components i in one group and assumed $\langle n_i \rangle(x, t)$ changes slowly over space and time. Microscopic conservation of mass can be stated to be:

$$\frac{\partial}{\partial t} \sum_i \langle n_i \rangle(x, t) = 0 \quad (10)$$

so that the equation (10) can be written in the form:

$$\frac{\partial}{\partial t} \sum_i \langle n_i \rangle = - \frac{\partial}{\partial \beta} \sum_i \sum_i \langle n_i \rangle c_{i\alpha} \quad (11)$$

where α component of velocity c_i otherwise $c_{i\alpha}$. The above description also applies to the momentum flux, so the law of conservation of momentum equation can be written as:

$$\sum_{x \in A} \sum_i [n_i(x_i, t + 1) - n_i(x, t)] c_{i\alpha} = - \left(\begin{array}{l} \text{flux netto momentum coming out} \\ \text{of the } \alpha \text{ direction from S} \end{array} \right) \quad (12)$$

The above equation can be written in a simpler form to becomes:

$$\frac{\partial}{\partial t} \sum_i \langle n_i \rangle = - \frac{\partial}{\partial \beta} \sum_i \langle n_i \rangle c_{i\alpha} c_{i\beta} \quad (13)$$

To declare the equation (12) and (13), defined variable density physics:

$$\rho = \sum_i \langle n_i \rangle \quad (14)$$

and density of momentum:

$$\rho u_\alpha = \sum_i \langle n_i \rangle c_{i\alpha} \quad (15)$$

with substituting equation (12) and (13) to (11) obtained the continuity equation:

$$\frac{\partial}{\partial t} \rho = - \frac{\partial}{\partial \alpha} (\rho u_\alpha) \quad (16)$$

by defining the momentum flux tensor for the LGA as:

$$\Pi^{(0)}_{\alpha\beta} = \sum_i \langle n_i \rangle c_{i\alpha} c_{i\beta} \quad (17)$$

then the macroscopic momentum equation becomes:

$$\frac{\partial}{\partial t} (\rho u_\alpha) = - \frac{\partial}{\partial \beta} \Pi^{(0)}_{\alpha\beta} \quad (18)$$

In the case of a low speed, tensor $\Pi_{\alpha\beta}$ can be expanded becomes (Frisch U, dkk., 1986):

$$\Pi_{\alpha\beta} = p_0(\rho) \delta_{\alpha\beta} + \lambda_{\alpha\beta\gamma\delta}(\rho) u_\gamma u_\delta + O(u^4)$$

where $\lambda_{\alpha\beta\gamma\delta}$ is the elasticity tensor. Finally, from the equation (16) can be approached equation that approximates the shape of real, namely:

$$\frac{\partial}{\partial t} \rho u_\alpha + 2 \frac{\partial}{\partial \beta} B(\rho) u_{\alpha\beta} = - \frac{\partial}{\partial \alpha} [p_0(\rho) + A(\rho) u^2] \quad (19)$$

Equation (19) is similar to the Euler equations for the case of compressed streams. While A and B are two free elastic modules that can be obtained from the population of an average $\langle n_i \rangle$ (Frisch U, et al., 1986).

Equation permeability on the porosity of the rock cracks

An understanding of the pattern of fluid flow in the cracks is very important to do. In exploration and exploitation, whether it's oil or to search for ground water, information about the pattern of cracks can

give us a fluid movement. Thus it is possible to predict the position of the fluid is located. (Halaududin, 2003). Simple cracks pattern shown in Figure 1.

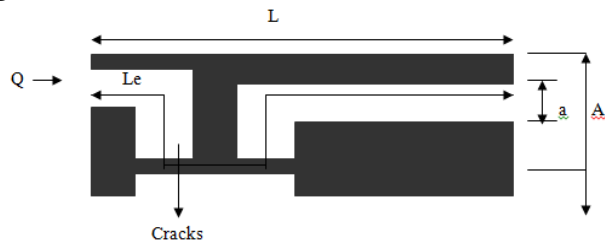


Figure 1 Illustration of simple cracks pattern

L_e is the effective channel length. The volume of fluid flow equations obtained from the above illustration is (Dullien, 1992):

$$Q = vA = v_p a \quad (20)$$

Porosity is obtained from equation (21) (Dullien, 1992):

$$\phi = \frac{aL_e}{AL} \quad (21)$$

Permeability is calculated by equation (22), (Koponen, et al, 1996):

$$k = \frac{\phi_{eff}^3}{cS^2} \quad (22)$$

Where ϕ_{eff} is effective porosity medium, c is coefficient Kozeny and S is specific surface area. S is calculated by an equation (23), (Dullien, 1992)

$$S = \frac{\phi}{R_0(1-\phi)} \quad (23)$$

With R_0 is the hydraulic radius.

Research Methodology

There are five pieces cracks with barrier model of the triangle to be simulated based on the high varying. These cracks are make based on the high varying are 3, 4, 5, 6 and 7 cm, but it,s of the triangle is fixed that is 4 cm. Profile of five such cracks are as shown in Figure 2.



Figure 2 Illustration of the cracks with barrier model of the triangle

Visualization of program

This model program consists of several programs and the overall program is created using programming language Borland Delphi 7.0, as well as visualization. The programs are:

1. Program inputs, where the program is used to select cracks, determine the direction of fluid flow in the cracks, determine the time-step of fluid flow as well as the command to execute (run) program.
2. The program calculates the amount of porosity cracks.
3. The program calculates the size of the crack permeability.
4. The program calculates the amount of porosity cracks.
5. Programs to display the graph between the porosity of the time-step.
6. Program to display the graph between the permeability of the time-step.
7. Program image (visualization) cracks after by passed fluid.

Table 1. Result of simulation

High triangle (cm)	Time-step	Total of porosity (ϕ_{tot})	Effective of porosity (ϕ_{eff})	Permeability (k) (pixel) ²
3	1000	0,9174	0,1690	0,001339
4	1000	0,9195	0,1841	0,001664
5	1000	0,9201	0,1885	0,001904
6	1000	0,9209	0,1938	0,001925
7	1000	0,9212	0,2053	0,002400

Results and Discussion

The simulation was performed with a program language Borland Delphi 7.0., with a time-step constant at 1000 time-step. Files saved with the extension (*.md3). There are several parameters directly known only after running the data, are:

1. In Notepad notes form the magnitude of total porosity and effective porosity and permeability values.
2. In the form of bmp.image, obtained a graph of porosity, a graph of permeability versus time-step, as well as illustrations of fluid flow

through cracks samples for each variation of the angle at the time before and after running data. While the permeability results LGA models shown detail in Table 1.

Calculating of porosity and permeability for cracks model with high barrier of the triangle for 3 cm, time-step of duration are 1000 shown in Fig. 3.



Figure 3 Result of LGA model for high barrier of the triangle for 3 cm

In Figure 4, showed magnitude of effective porosity value and permeability for 3 cm with high barrier of the triangle, with of value 0,1690 and 0,001339 pixel², respectively.

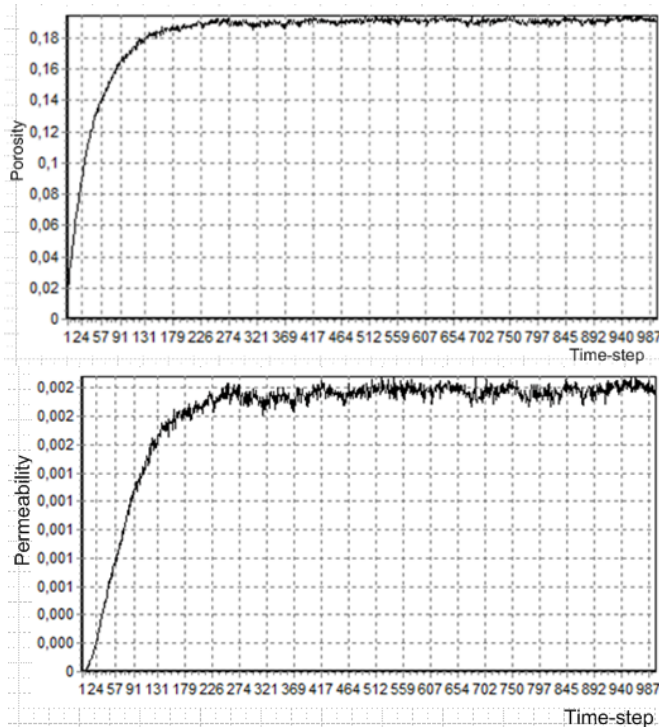


Figure 4 Graph of porosity and permeability based result of LGA model for 3 cm

Calculating of porosity and permeability for cracks model with high barrier of the triangle for 4 cm, time-step of duration are 1000 shown in Fig. 5.

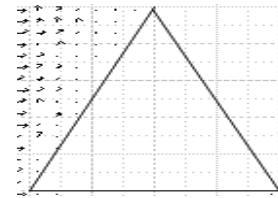


Figure 5 Result of LGA model for high barrier of the triangle for 4 cm

In Figure 6, showed magnitude of effective porosity value and permeability for 4 cm with high barrier of the triangle, with of value 0,1841 and 0,001664 pixel², respectively.

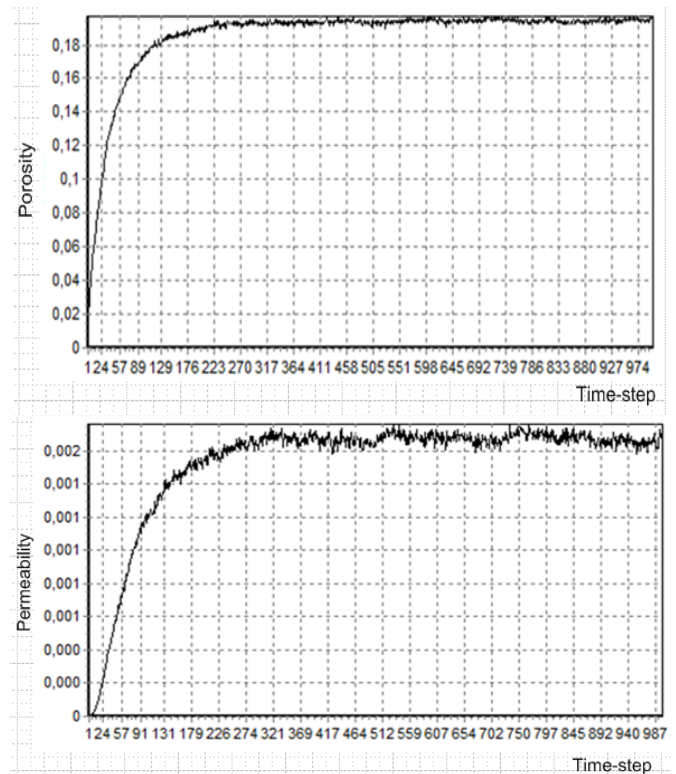


Figure 6 Graph of porosity and permeability based result of LGA model for 4 cm

Calculating of porosity and permeability for cracks model with high barrier of the triangle for 5 cm, time-step of duration are 1000 shown in Fig. 7.

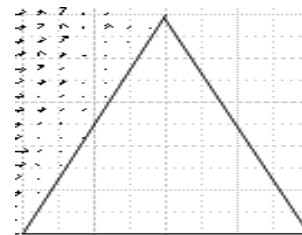


Figure 7 Result of LGA model for high barrier of the triangle for 5 cm

In Figure 8, showed magnitude of effective porosity value and permeability for 5 cm with high barrier of the triangle, with of value 0,1885 and 0,001904 pixel^2 , respectively.

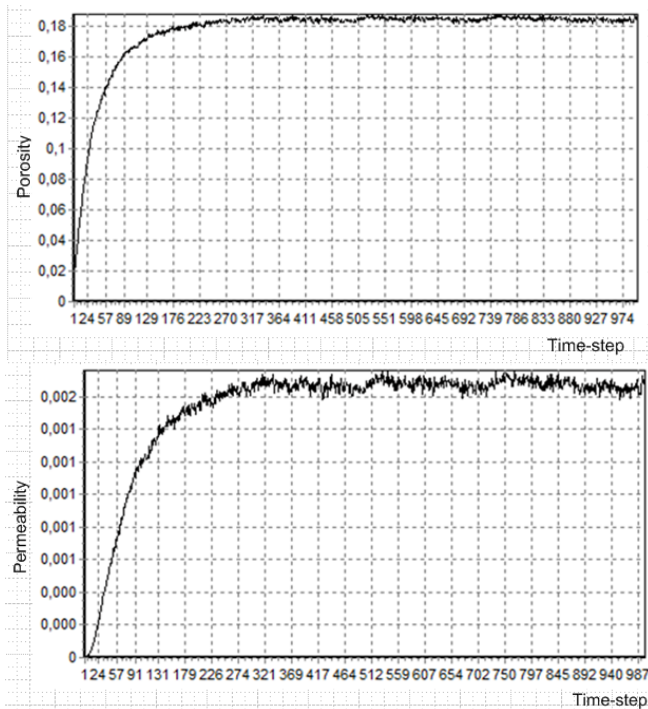


Figure 8 Graph of porosity and permeability based result of LGA model for 5 cm

Calculating of porosity and permeability for cracks model with high barrier of the triangle for 6 cm, time-step of duration are 1000 shown in Fig. 9.



Figure 9 Result of LGA model for high barrier of the triangle for 6 cm

In Figure 10, showed magnitude of effective porosity value and permeability for 6 cm with high barrier of the triangle, with of value 0,1938 and 0,001925 pixel^2 , respectively.

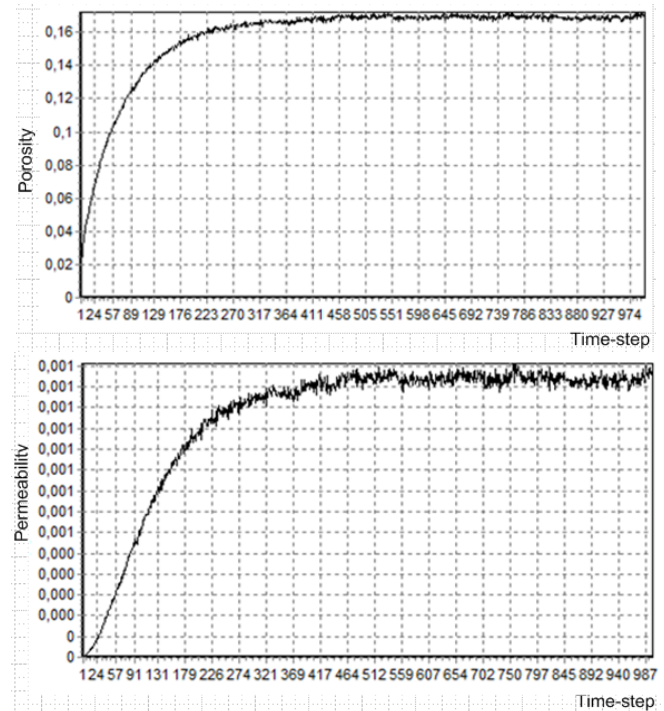


Figure 10 Graph of porosity and permeability based result of LGA model for 6 cm

Calculating of porosity and permeability for cracks model with high barrier of the triangle for 7 cm, time-step of duration are 1000 shown in Fig. 11.



Figure. 11 Result of LGA model for high barrier of the triangle for 7 cm

In Figure 12, showed magnitude of effective porosity value and permeability for 7 cm with high barrier of the triangle, with of value 0,2053 and 0,002400 pixel^2 , respectively. Based the process of running the data using a model of Lattice Gas Automata (LGA) at Figure 3; 5; 7; 9 and 11, showed that move of fluid have pattern of velocity are complex (laminar and turbulence). Time-step for every simulation are 1000. Time-step value are 100 fixed because can exactly for time-step 1000 proses of data running to calculate porosity and permeability had reach steady state

condition. Process of physics happened in LGA model can to proof something laminar and turbulence current. Based of hydrodynamic principle, if model as barrier of triangle is low, pattern of fluid current more dominant with laminar current, causing pattern of fluid according to turbulence current haven at side triangle only, causing permeability value increase. Conversely, if model as barrier of triangle is high, pattern of fluid current more dominant with turbulence current, causing pattern of fluid according to laminar current haven at middle triangle only, causing permeability value decrease.

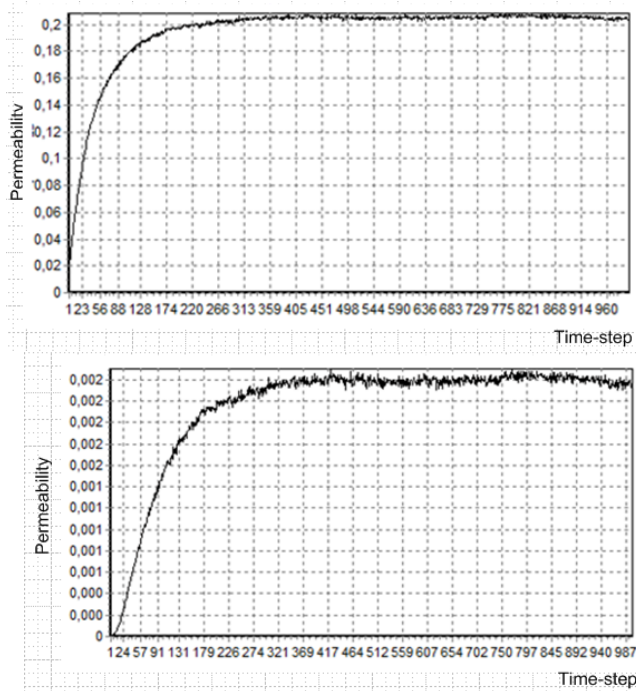


Figure 12 Graph of porosity and permeability based result of LGA model for 7 cm

Lattice Gas Automata (LGA) model can calculating total porosity value, effective porosity and permeability versus time-step using the barrier model of the triangle with a high varying. Total porosity value, effective porosity and permeability influenced by high barrier of the triangle. If barrier of the triangle high, influenced as linier towards to rise total porosity value, effective porosity and permeability. In case to caused that current of simulation fluid at running data just direction

as horizontal causing the collision fluid with model as barrier of triangle according to high barrier of the triangle model.

Conclusion

From the observation and discussion, we can make some conclusions, meanwhile Effective porosity value (ϕ_{eff}) and permeability (k) for five cracks barrier model of the triangle with a high varying are 3 cm; 4 cm; 5 cm; 6 cm; and 6 cm obtained, respectively: $\phi_{\text{eff}}(T_1)=0,1690$, $k(T_1)=0,001339 \text{ pixel}^2$; $\phi_{\text{eff}}(T_2)=0,1841$, $k(T_2)=0,001664 \text{ pixel}^2$; $\phi_{\text{eff}}(T_3)=0,1885$, $k(T_3)=0,001904 \text{ pixel}^2$; $\phi_{\text{eff}}(T_4)=0,1938$, $k(T_4)=0,001925 \text{ pixel}^2$; dan $\phi_{\text{eff}}(T_5)=0,2053$, $k(T_5)=0,002400 \text{ pixel}^2$. Lattice Gas Automata (LGA) model can used to estimate magnitude permeability cracks of rocks barrier model of the triangle with a high varying. Even if simulation pattern have dectet characteristic (move of fluid randomize characteristic), not same as current fluida actually, but this model can be recognise pattern of cracks to estimated permeability well.

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