Simulation of Production and Injection Process in Geothermal Reservoir Using Finite Difference Method

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Abstract— Thr geothermal energy is well known as a renewable and clean energy. A step to understand and to estimete the geothermal energy is by using a reservoir modeling development. In this study, a mathematical and numerical modeling are performed to simulate a geothermal reservoir with injection and production well attached in the reservoir. Mathematical modeling performed obeys a Darcy's law, mass balance, energy balance, and also applying the finite difference method to get the model for the entire reservoir system. Numerical modeling is also performed in this study for calculating the variables. The results that obtained in this study are the distribution of temperature, pressure, enthalpy and fluid flow direction in the reservoir. These results will provide many information in the future. We can hope that a reservoir is expected to be designed with an appropriate management system.

Key-words: Geothermal energy, numerical modeling, Darcy's law, mass balance, energy balance, finite difference method

1. INTRODUCTION

Geothermal energy is one of the prospect energy in the future. The geothermal is renewable and clear energy. So it is an important subject to study and to develop the geothertmal energy. Therefore clarifying the thermal processes in a geothermal reservoir is needed by using numerical simulation. There are some numerical simulation available, For example, Faust and Mercer (1979) presented the geothermal reservoir simulation for liquid and vapor dominated. However almost of them simulate the fluid condition for liquid and two phase state, in which the temperature is less or equal to the boiling point depth (BPD) temperature. In one occasion the higher temperature than BPD can be attained at the reservoir. This paper is presented to develop a simulator of numerical modeling for estimating the physical state of fluid in the reservoir.

2. Basic Mathematical Model

There are a lot of variables and formulation that has to be reviewed in Geothermal reservoir modelling. These formulations and variables are reviewed with physics and mathemathics formulation approach. These variables have relation one each other and coupled. In this paper, some formulation and variables are used that related to how fluid flow in the porous medium.

2.1 Darcy's Law

The movement of fluid through the permeable zone is assumed sufficiently slow. According to the assumption, the Darcy's equation can be used as simplified momentum balances in multiphase flow. The Darcy's equation for fluid movement in porous media can be expressed as follows (Singarimbun, 1996, 1997):

$$Q = \frac{kk_{rw}}{\nu}(\nabla P - \rho g \nabla D) \qquad (1a)$$

$$Q = \frac{kk_{rs}}{v}(\nabla P - \rho g \nabla D) \quad (1b)$$

where Q is the mass flux of fluid, k is the intrinsic permeability of porous media, k_r is the relative permeability, v is the kinematic viscosity, P is the pressure, ρ is the density of fluid, g is the gravity acceleration and D is the depth respectively. Subscripts w and s refer to liquid and steam state.

Darcy Law is a formula that describes about how fluid flow through a porous media. The Darcy's equation can be simplified by visualization in Figure 1. In Figure 1, the fluid flow in a simple porous pipe. According to Darcy's law, the fluid discharge in a pipe that has length L and sectional area A with a pressure difference ΔP. In the end both of the pipe, Q will depend on the variables that shown in the equation below:

$$Q = vA = -\frac{kA}{\mu}\Delta P \quad (2)$$

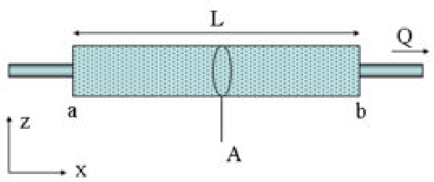

Figure 1. Pipe's model that describe a Darcy's Law (sourcer:http://en.wikipedia.org/wiki/Darcy%27s law)

In two phase fluid flow case, the k variables have to be defined as a $k = k_r k_f$ with k is a effective permeabillty, k_r is a relative permeabillity, and k_f is phase permeabillty (Corey, 1956). In multiphase flow the fluid permeabillity is not only depends on the porosity of the rocks but also depends on the other fluid.

2.2 Mass and Energy Equilibrium

The mass and energy equilibrium for the modelling is described by a box of square where the mass and energy that come to the box will be same with the mass and energy that comes out from the box as visualized in figure2.

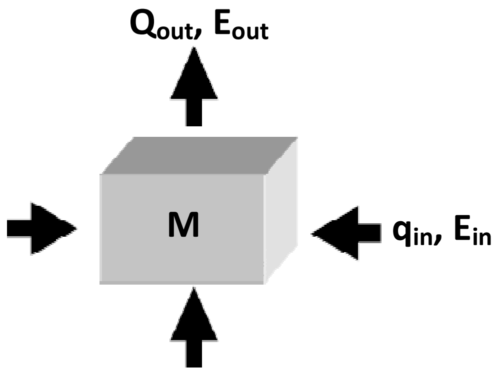

Figure 2. Mass and Energy equilibrium box

The Mass and energy equilibrium equation for this modelling is described as:

$$\frac{\partial M}{\partial t} = -\nabla q_{out} + q_{in} \quad (3)$$

$$\frac{\partial E}{\partial t} = -\nabla E_{out} + E_{in} \quad (4)$$

with M is the fluid total mass, q_{out} is the flux of mass production, q_{in} is replenishment mass flux, E is total energy in the reservoir, E_{out} is discharge energy flux, and E_{in} is replenishment energy flux. There are two general classification of hydrothermal fluid namely one phase and two phase. The difference beetwen this classification will affect the mass and energy definition in the above equation.

The mass and energy equation can be described with considering the Darcy's law, so the equation will describe as a mass and energy equation for the porous media as shown below (Holzbecher, 1998, 1984)

$$\frac{\partial(\phi\rho_f)}{\partial t} + \nabla\left(-\frac{\rho_f k}{\mu_f}\left(\nabla P - \rho_f g \nabla D\right)\right) = 0 \quad (5)$$

and then (Grant, 1982),

$$\nabla\rho_f\left[\frac{k}{\mu_f}\left(\nabla P-\rho g\right)\right]=C\frac{\partial P}{\partial t} \quad (6)$$

For the mass equlibrium in equation (5), $C=\rho(\alpha+\phi\kappa)$ is the compresibility coeficient, ρ is fluid density, ϕ is porosity and g is the gravity accelaration. The energy equilibrium equation is described as follows (Singarimbun, 1997, 2009):

$$\left[(1-\phi)\rho_m C_m+\phi\rho_f C_f S_f\right]\frac{\partial T}{\partial t} + \rho_f v_f C.\nabla T=-\nabla.K\nabla T \quad (7)$$

with T is temperature and K is thermal conductivity. The expression of the mass balance equation is as follows :

$$\frac{\partial}{\partial t}(\phi\rho_w S_w+\phi\rho_s S_s)+\nabla\bullet(Q_{mw} + Q_{ms})-q_m=0 \quad (8)$$

and the heat balance equation can be expressed as follows:

$$\frac{\partial}{\partial t}[\phi\rho_w S_w h_w+\phi\rho_s S_s h_s+(1-\phi)\rho_r h_r] +\nabla\bullet(Q_{mw}h_w+Q_{ms}h_s) -\nabla\bullet[K(\frac{\partial T}{\partial P})_h\nabla P +K(\frac{\partial T}{\partial h})_P\nabla h-q_e=0 \quad (9)$$

In equations (6), (7), (8) and (9), t is the time, ϕ is the porosity, S_w is the water saturation, S_s is the steam saturation, Q_{mw} and Q_{ms} are the mass flux of fluid for liquid and steam and q_m is the mass source term, respectively. In equation (9), h is the specific enthalpy, T is the temperature, P is the pressure, K is the thermal conductivity of medium, ρ_r is the rock density, h_r is the rock enthalpy and q_e is the energy source term respectively.

2.3 Reservoir's Presseure Decrease

One problem that always occurs in geothermal reservoir exploitation process is the pressure decrease that can affect another variable such as temperature and density in the reservoir. In this study we use the pressure decrease to describe reservoir condition in real condition. Therefore we still pass over in some variables to simplify the calculation. The pressure decrease in the reservoir formulation depends on three main variables that caused the decrease namely gravity, friction, and acceleration as shown below (Singarimbun, 2009):

$$\left(\frac{dP}{dz}\right)_{total}=\left(\frac{dP}{dz}\right)_a+\left(\frac{dP}{dz}\right)_f+\left(\frac{dP}{dz}\right)_g \quad (10)$$

In this study we ignore the pressure drop because of the friction and acceleration variables have the small value. The pressure drop only affected by the gravitation variables as shown below

$$P(h)=P_o+\rho_W\, g\, h \quad (11)$$

2.4 Finite Difference

The Finite Difference method is a numerical method that used to approximate the solution of some differential equation by divide its derivative problem into a square block with a specific interval (Desai, 1972).

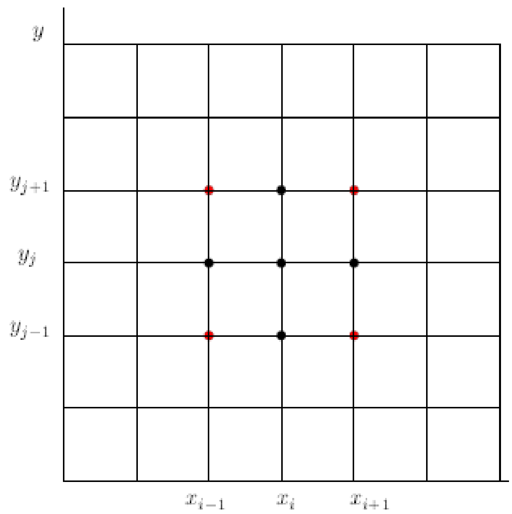

Figure 3. Finite difference grid system (source: http://www.mathematik.uni-dortmund.de/~kuzmin/cfdintro/lecture4.pdf)

The variables in finite difference problems is shown in a notation as below:

$$u_{i,j}=u\left(x_0,y_0\right) \quad (12)$$

$$u_{i\pm m,j\pm n}=u\left(x_o\pm m\,\Delta x, y_o\ \pm n\,\Delta y\right) \quad (13)$$

where $u_{i,j}$ is value of u in (x_0,y_0) coordinate, m and n are (-∞,.., -2, -1, 0, 1, 2, …,∞). Then by using Taylor series, we can get three main formulation for solving the derivative problems that known well as forward, backward, and centre differentiation (Golf-Racht, 1982)

$$\left(\frac{\partial u}{\partial x}\right)_{i,j} = \frac{u_{i+1,j} - u_{i,j}}{\Delta x} = \frac{u(x_o + \Delta x, y_o) - u(x_o, y_o)}{\Delta x} \quad (14)$$

$$\left(\frac{\partial u}{\partial x}\right)_{i,j} = \frac{u_{i,j} - u_{i-1,j}}{\Delta x} = \frac{u(x_0, y_0) - u(x_0 - \Delta x, y_0)}{\Delta x} \quad (15)$$

$$\left(\frac{\partial u}{\partial x}\right)_{i,j} = \frac{u_{i+1,j} - u_{i-1,j}}{2\Delta x} = \frac{u(x_0 + \Delta x, y_0) - u(x_0 - \Delta x, y_0)}{2\Delta x} \quad 16)$$

3. DISCRITATION AND MODELLING

The next step to the geothermal reservoir modeling is to form a discritització formula by using finite difference and applicate it to mass and energy equilibrium equation. The discrititation formula is needed in order to calculate and to know the value of parameter of physics distribution of the reservoir.

3.1 Mass and Energy Equilibirum Discrititation

The discrititation process using divergence theorem to get the final formulation can be calculated by the below equation:

$$\frac{k}{\mu_f} \sum_m \left(\rho_{f_{n,m}} \frac{P_m - P_n}{d} - \rho_{f_{n,m}}^{\ 2} g \eta \right) = C \frac{\Delta P_n}{\Delta t} d \quad (17)$$

For the mass formulation and the energy equation can be written as

$$\rho \frac{\Delta H_n}{\Delta t} d = \sum_m \left[\begin{array}{l} K(\mu_{JT} \frac{P_m - P_n}{d} + \frac{1}{C_p} \frac{H_m - H_n}{d}) \\ + \rho_{f_{n,m}} \frac{k}{\mu_f} \frac{P_m - P_n}{d} \left(\frac{H_m + H_n}{2} \right) \\ - \frac{k}{\mu_f} \rho_{f_{n,m}}^{\ 2} \bar{g} \left(\frac{H_m + H_n}{2} \right) \end{array} \right] \quad (18)$$

3.2 Numerical Solution

In this research, equations (2), (3) and (4) are the main equations as the basis of the numerical simulator with their variables are pressure (P) and enthalpy (h). To obtain the values of pressure and temperature, eq. (1a) and eq. (1b) can be substituted to eq. (5), and in FDM form, it can be described as follows:

$$\frac{1}{(\Delta X_i)^2} \Delta[k_{ii} \lambda_w (\Delta P + \rho_w g \Delta D) + k_{ii} \lambda_s (\Delta P + \rho_s g \Delta D) + q_m = \frac{1}{\Delta t} \Delta[\phi \rho_w S_w + \phi \rho_s S_s) \quad (19)$$

In eq. (19), k_{ii} is the permeability tensor in principal direction. Index i = 1,2 and 3 refer to x, y, and z axes, $\lambda_w = k_{rw}/v_w$ and $\lambda_s = k_{rs}/v_s$. Considering that V_b is the grid block volume of the fluid (*Fig 1*) with A as the sectional area perpendicular to the flow direction and l_i is the length increment in the flow direction (ΔX_i), then mass balances of eq. (17) becomes:

$$\Delta \left[\begin{array}{l} \frac{k_{ii} \lambda_w A}{l_1} (\Delta P + \rho_w g \Delta D) \\ + \frac{k_{ii} \lambda_s A}{l_i} (\Delta P + \rho_s g \Delta D) \end{array} \right] + V_b q_m = \frac{V_b}{\Delta t} (M^{n+1} - M^n) \quad (20)$$

where M is the mass term ($M = \phi \rho_w S_w + \phi \rho_s S_s$).
Similarly, by substituting eq. (1a) and (1b) to eq. (7), for heat balance in the FDM form can be written as follows (Singarimbun, 1997, Sumardi, 2003) :

$$\frac{1}{(\Delta X_i)^2} \Delta[k_{ii} \lambda_w h_w (\Delta P + \rho_w g \Delta D) + k_{ii} \lambda_s h_s (\Delta P + \rho_s g \Delta D) + K(\frac{\partial T}{\partial P})_h \nabla P + K(\frac{\partial T}{\partial h})_P \nabla h] + q_e = \frac{1}{\Delta t} \Delta[\phi \rho_w S_w h_w + \phi \rho_s S_s h_s + (1-\phi) \rho_r h_r \quad (21)$$

where H is the enthalpy of fluid respectively.

In a block volume of V_b, eq. (20) can be expressed as :

$$\Delta \left[\frac{k_{ii} \lambda_w A}{l_1} (\Delta P + \rho_w g \Delta D) + \frac{k_{ii} \lambda_s A}{l_i} (\Delta P + \rho_s g \Delta D) \right] + V_b q_m = \frac{V_b}{\Delta t} (M^{n+1} - M^n) \quad (22)$$

Furthermore, by the Taylor expansion, a set of linear equation in δP and δh can be obtained to solve eq. (21) and (22) numerically as follows:

a. for mass balance :

$$\phi c_w \rho_w \frac{P^{n+1}_{i,j}-P^{n}_{i,j}}{\Delta t}-\frac{k}{\upsilon}\left(\frac{P^{n}_{i+1,j}-2P^{n}_{i,j}+P^{n}_{i-1,j}}{\Delta x^2}\right)-\frac{k}{\upsilon}\left(\frac{P^{n}_{i,j+1}-2P^{n}_{i,j}+P^{n}_{i,j-1}}{\Delta z^2}\right)-q_{in}=0 \quad (23)$$

By Crank Nicholson technique, the mass balance can be expressed as (Singarimbun, 2010):

$$\phi c_w \rho_w \frac{P^{n+1}_{i,j}-P^{n}_{i,j}}{\Delta t}-\frac{k}{2\upsilon}\left(\frac{P^{n+1}_{i+1,j}-2P^{n+1}_{i,j}+P^{n+1}_{i-1,j}}{\Delta x^2}+\frac{P^{n}_{i+1,j}-2P^{n}_{i,j}+P^{n}_{i-1,j}}{\Delta x^2}\right)$$
$$-\frac{k}{2\upsilon}\left(\frac{P^{n+1}_{i,j+1}-2P^{n+1}_{i,j}+P^{n+1}_{i,j-1}}{\Delta z^2}+\frac{P^{n}_{i,j+1}-2P^{n}_{i,j}+P^{n}_{i,j-1}}{\Delta z^2}\right)-q_{in}=0 \quad (24)$$

or

$$P^{n+1}_{i,j}=P^{n}_{i,j}+\frac{k\Delta t}{2\upsilon\phi c_w\rho_w}\left(\frac{P^{n+1}_{i+1,j}-2P^{n+1}_{i,j}+P^{n+1}_{i-1,j}}{\Delta x^2}+\frac{P^{n}_{i+1,j}-2P^{n}_{i,j}+P^{n}_{i-1,j}}{\Delta x^2}\right)$$
$$+\frac{k\Delta t}{2\upsilon\phi c_w\rho_w}\left(\frac{P^{n+1}_{i,j+1}-2P^{n+1}_{i,j}+P^{n+1}_{i,j-1}}{\Delta z^2}+\frac{P^{n}_{i,j+1}-2P^{n}_{i,j}+P^{n}_{i,j-1}}{\Delta z^2}\right)+\frac{q_{in}\Delta t}{\phi c_w\rho_w} \quad (25)$$

for heat balance:

$$[(1-\phi)\rho_m+\phi\rho_w]\frac{\left(H^{n+1}_{i,j}-H^{n}_{i,j}\right)}{\Delta t}-$$
$$\frac{k}{\upsilon_w}\left(\frac{H^{n}_{i+1,j}-H^{n}_{i,j}}{\Delta x}\right)\left(\frac{P^{n}_{i+1,j}-P^{n}_{i,j}}{\Delta x}\right)-\frac{kH^{n}_{i,j}}{\upsilon_w}\left(\frac{P^{n}_{i+1,j}-2P^{n}_{i,j}+P^{n}_{i-1,j}}{\Delta x^2}\right)-$$
$$\frac{k}{\upsilon_w}\left(\frac{H^{n}_{i,j+1}-H^{n}_{i,j}}{\Delta z}\right)\left(\frac{P^{n}_{i,j+1}-P^{n}_{i,j}}{\Delta z}\right)-\frac{kH^{n}_{i,j}}{\upsilon_w}\left(\frac{P^{n}_{i,j+1}-2P^{n}_{i,j}+P^{n}_{i,j-1}}{\Delta z^2}\right)-$$
$$K\mu_{JT}\left(\frac{P^{n}_{i+1,j}-2P^{n}_{i,j}+P^{n}_{i-1,j}}{\Delta x^2}\right)-\frac{K}{C_P}\left(\frac{H^{n}_{i+1,j}-2H^{n}_{i,j}+H^{n}_{i-1,j}}{\Delta x^2}\right)-$$
$$K\mu_{JT}\left(\frac{P^{n}_{i,j+1}-2P^{n}_{i,j}+P^{n}_{i,j-1}}{\Delta z^2}\right)-\frac{K}{C_P}\left(\frac{H^{n}_{i,j+1}-2H^{n}_{i,j}+H^{n}_{i,j-1}}{\Delta z^2}\right)-E'''_{in}=0 \quad (26)$$

Similarly, by Crank Niholson technique (Dragondi, 2010), the mass balance can be expressed as:

$$((1-\phi)\rho_m+\phi\rho_w)\frac{H^{n+1}_{i,j}-H^{n}_{i,j}}{\Delta t}-\frac{k}{2\upsilon}\left(\frac{P^{n}_{i+1,j}-P^{n}_{i,j}}{\Delta x}\right)\left(\frac{H^{n+1}_{i+1,j}-H^{n+1}_{i-1,j}}{\Delta x}+\frac{H^{n}_{i+1,j}-H^{n}_{i-1,j}}{\Delta x}\right)$$
$$-\frac{k}{\upsilon}\left(\frac{P^{n}_{i+1,j}-2P^{n}_{i,j}+P^{n}_{i-1,j}}{\Delta x^2}\right)\left(\frac{H^{n+1}_{i,j}+H^{n}_{i,j}}{2}\right)-\frac{k}{2\upsilon}\left(\frac{P^{n}_{i,j+1}-P^{n}_{i,j}}{\Delta z}\right)\left(\frac{H^{n+1}_{i,j+1}-H^{n+1}_{i,j-1}}{\Delta z}+\frac{H^{n}_{i,j+1}-H^{n}_{i,j-1}}{\Delta z}\right) \quad (27)$$
$$-\frac{k}{\upsilon}\left(\frac{P^{n}_{i,j+1}-2P^{n}_{i,j}+P^{n}_{i,j-1}}{\Delta z^2}\right)\left(\frac{H^{n+1}_{i,j}+H^{n}_{i,j}}{2}\right)-K\mu_{JT}\left(\frac{P^{n}_{i+1,j}-2P^{n}_{i,j}+P^{n}_{i-1,j}}{\Delta x^2}\right)$$
$$-K\mu_{JT}\left(\frac{P^{n}_{i,j+1}-2P^{n}_{i,j}+P^{n}_{i,j-1}}{\Delta z^2}\right)-\frac{K}{2C_P}\left(\frac{H^{n+1}_{i+1,j}-2H^{n+1}_{i,j}+H^{n+1}_{i-1,j}}{\Delta x^2}+\frac{H^{n}_{i+1,j}-2H^{n}_{i,j}+H^{n}_{i-1,j}}{\Delta x^2}\right)$$
$$-\frac{K}{2C_P}\left(\frac{H^{n+1}_{i,j+1}-2H^{n+1}_{i,j}+H^{n+1}_{i,j-1}}{\Delta z^2}+\frac{H^{n}_{i,j+1}-2H^{n}_{i,j}+H^{n}_{i,j-1}}{\Delta z^2}\right)-E'''_{in}=0$$

3.3 Boundary Conditions

The modelling process is divided into two step. The first step is modelling of a new reservoir in its initial condition. The second step is modelling of the reservoir with production and injection well attached in the reservoir with the final state of the first modelling as a initial state in the second modelling process. In this study we made the reservoir model as a square box that located in 500 m underground with the caprock temperature is 100°C, and then the bedrock as a heat source of the reservoir is made 500°C. The reservoir dimension is 400m x 1000m and divided by grid that have a partition value is 20m x 20m. The porosity and density is made fixed in this modelling that is 10% and 910 kg/m^3. Another assumption is no mass and energy that comes in and out from the reservoir or the reservoir is a closed system. In the second modelling that is a reservoir modelling with injection and production well attached in the reservoir we pick the injection well 800 meters below the ground and the production well is 500 meters below the ground. The porosity of the well is assumed by 80%. The injection well is attached below the production well is intended to avoid the temperature decrease in the reservoir. The physical parameters that assumed in the reservoir modelling can be seen in the table 1 below.

Table 1. Physical Parameters

No.	Physical Parameters	Value
1	Intrinsict permeabillity (*m*^{2})	1x10^{-14}
2	Fluid dynamic viscosity (*kg/m s*)	0.0004
3	Vertical compresibillity in porous medium (*ms*^{2}*/kg*)	4x10^{-11}
4	Fluid compresibillity (*ms*^{2}*/kg*)	4.5x10^{-9}
5	Fluid thermal expansivity ($^0C^{-1}$)	5x10^{-4}
6	Rock thermal conductivity (*kg m/s*^{3} ^0C)	1.7
7	Rock density (*kg/m*^{3})	3000
8	Rock heat specific (*m*^{2}*/ s*^{20}*C*)	800
9	Fluid heat specific (*m*^{2}*/s*^{20}*C*)	3500
10	Gravity acceleration (*m/s*^{2})	9.8

The illustration of reservoir model for the first step modelling and second modelling with injection and production well attached is visualized in Figure 4 and Figure 5.

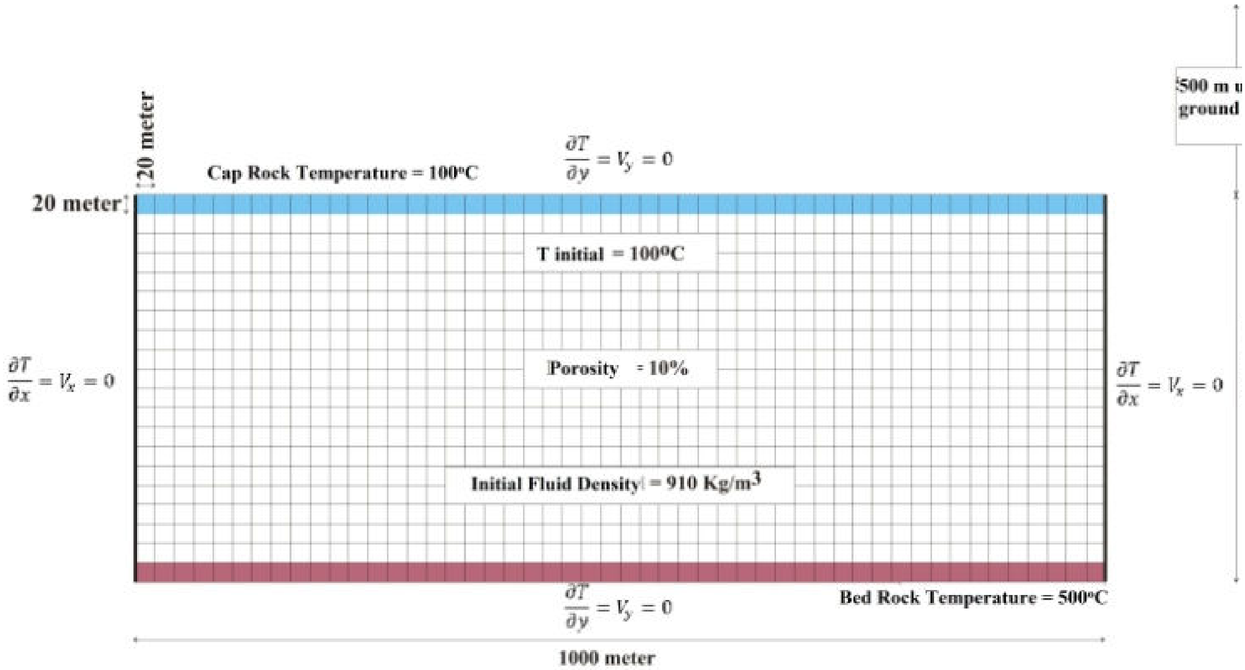

Figure 4. Geothermal reservoir with no injection and production well attached

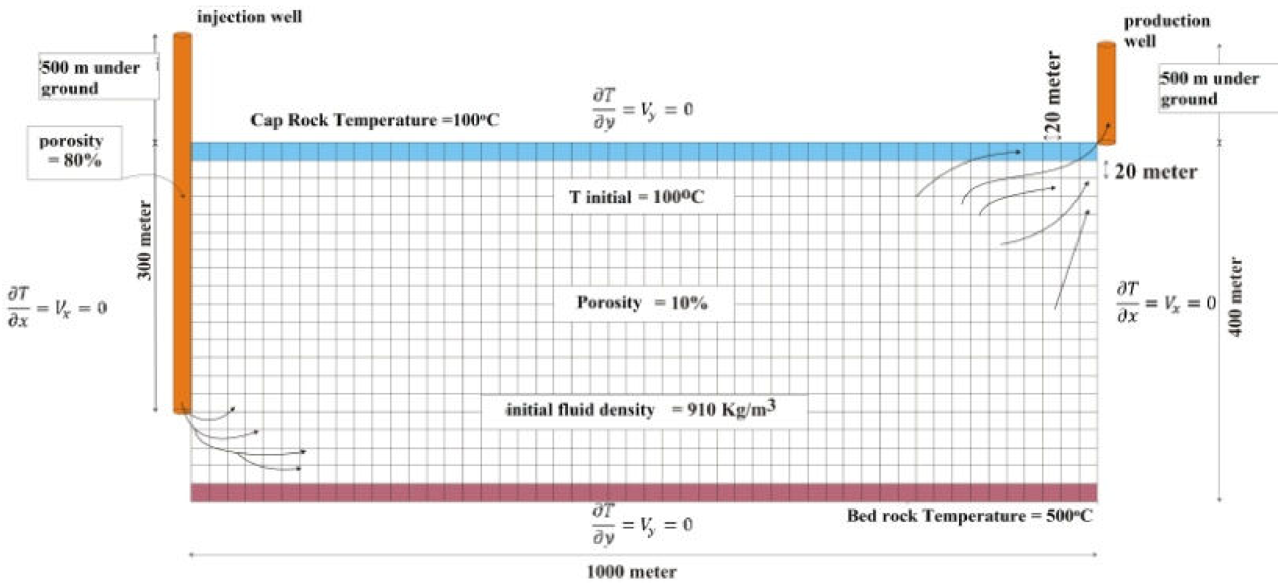

Figure 5. Geothermal reservoir with injection and production well attached

4. RESULT AND ANALYSIS

In this numerical sumulation model, 30 kg/m of magmatic water as energy comes from magma with its enthapy about 3500 kJ/kg (JSME STEAM TABLE, 1980). The downgoing meteoric water comes from the earth's surface and then it enters to the central part of the reservoir. As a result, the main physical parameters of the fluid reservoir cover pressure, temperature and enthalpy were obtained. These parameters represent the thermal state of the fluid in the reservoir. The estimated values of the parameters are clarified by using the Finite Difference Method based on the mass and heat balance equations.

The numerical modeling results show the fluid temperature in reservoir from the initial time to several years. The high temperature is shown at around of central of the reservoir due to two phase state fluid in this area. Based on this result and other supporting geophysical data, the geothermal energy can be exploited from the reservoir. The high temperature is at the bottom of the reservoir. It can be seen that the state of fluid is in two phase at arround of central part of the reservoir, especially at the bottom of the central of reservoir. The temperature at the top of the central of reservoir is about 200^{o} C. The development of temperature to be increase after 1000 years step of calculation (Figure 6). The flow direction of fluid can be seen in Figure 7. The enthalpies distribution pattern almost have same type with the temperature distribution (see Figure 11). This means that it is possible to exstract energy from the reservoir in this condition. This results can be used to estimate the heat discharged rate from reservoir as preliminary study about geothermal reservoir energy prospect.

4.1 Temperature Distribution

We observe the temperature distribution for the firs step of modelling in the reservoir model from the first day the reservoir is formed until the reservoir that we assumed is ready to be exploited. For the first time its formed we attached the temperature trigger in the reservoir to make some fluid convection flow so that for the next time the temperature will going up through the time.

The observation is stopped until the 1000th years step. It is because the temperature is already convergen and for the next years the temperatures change in the reservoir is small. Another factor that in the step of 1000th year we stopped the modelling because in the 1000th year we assumed that the reservoir is ready to be exploited because of the high temperature distribution that covered the whole reservoir and also the hig heat that located near the ground.

The second step of modelling with production and injection well attached using the final model of the first step modelling as its initial condition. The result showed that the temperature distribution is always changing and moving over time in the reservoir. This is because of the convection flow that made by injection and production well so that the fluid is always moving and there are no state condition in the reservoir model

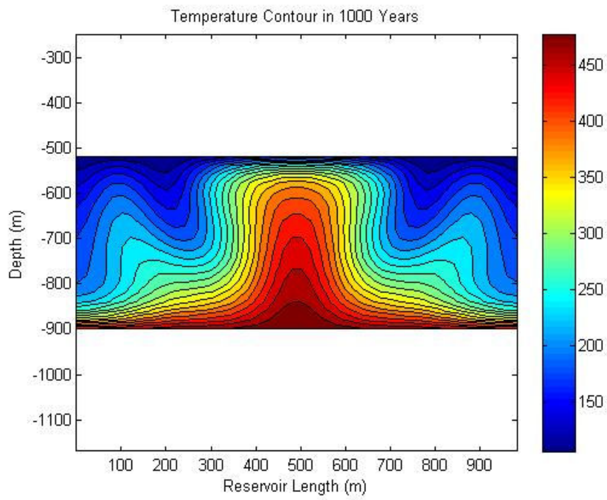

Figure 6. Temperature Distribution

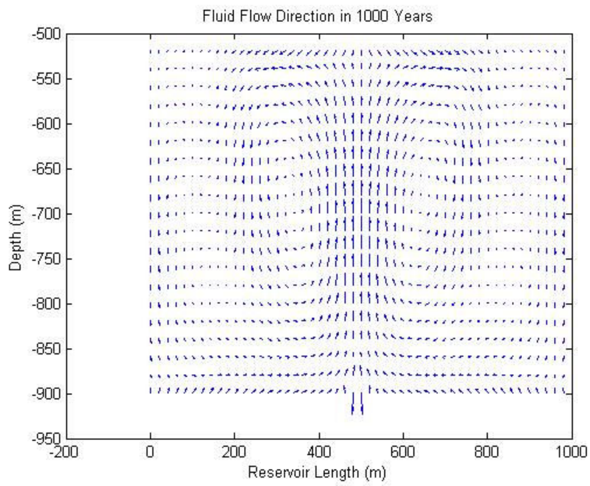

Figure 7. Fluid Flow Direction in reservoir

4.2 Pressure Distribution

The pressure distribution is also observed as a temperature distribution change. The data that we get shown that the pressure changes in the reservoir model is showed a little change over time. as shown in the figure below (Figure 8)

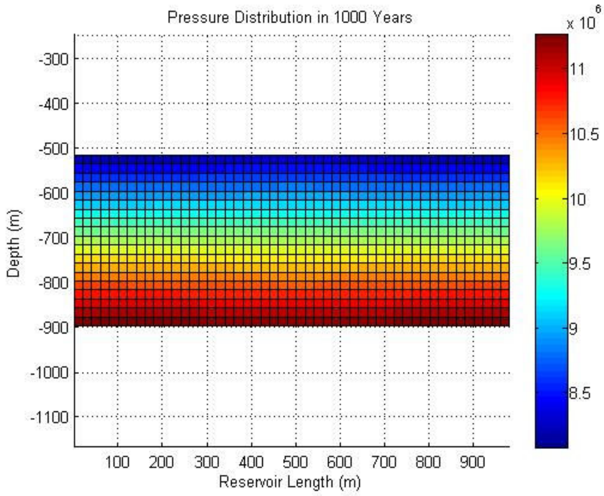

Figure 8. Pressure Distribution

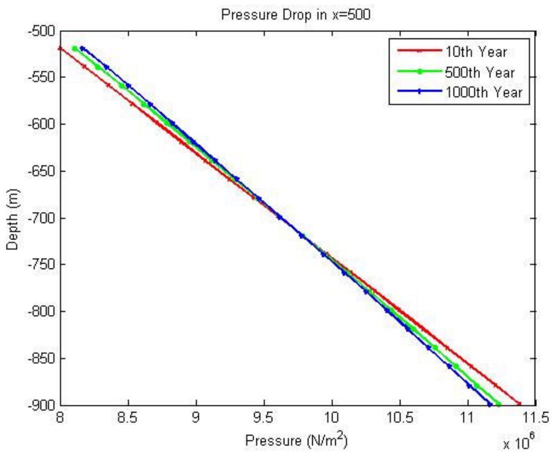

Figure 9 Pressure VS Depth plot for 1st step modelling

The slightly changes of prfessure caused because we made that there are no mass and energy that comes in and out from the reservoir. We also made a pressure vs depth plot to make sure that the pressure changes in the reservoir is really small. From the first step modelling we get the plot and for the second step modelling we also got that the pressure isslightly change by seeing the pressure vs depth plot

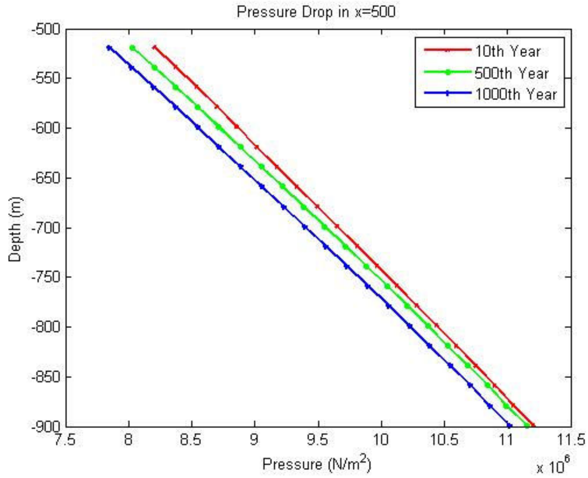

Figure 10. Pressure VS Depth plot for 2nd step modelling

4.3 Enthlpy Distribution

Variable that also we get is enthalpy distribution. Using the steam table and temperature and pressure value distribution di we can get the enthalpy value in th reservoir. The enthalpy distribution model will much look like the temperature distribution model as seen in figure below

The information that also contained in the enthalpy distribution is phase change in the reservoir. From the phase change curve below we can get the information that the fluid in the reservoir will change it phase when its enthalpy is above 2100 kJ/kg.

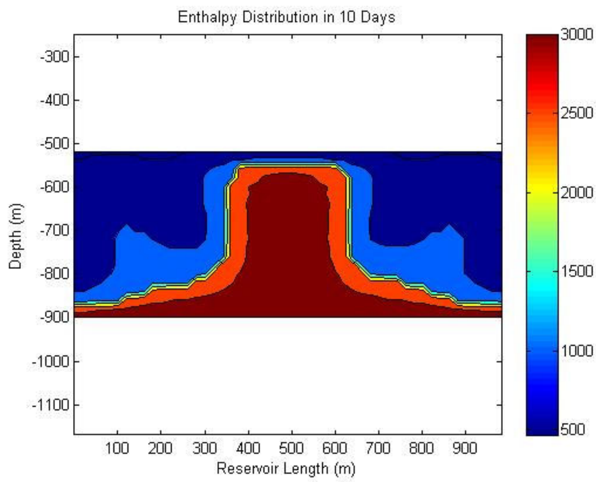

Figure 11. Enthalpy Distribution in 10 Days

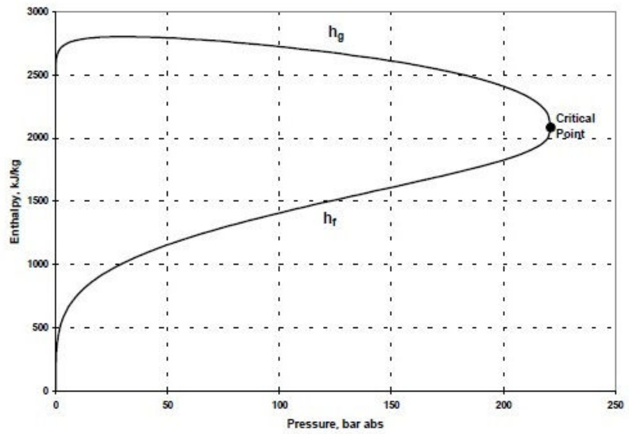

Figure 12. Phase Change Curve

5. CONCLUSION

From the modelling study we can get some conclusion. The reservoir model need a thousand years step until it reach its steady condition. Geothermal reservoir has some of hotspot. This hotspot is caused by the convection fluid flow in the reservoir. Geothermal reservoir is ready to be exploited when the temperature distribution condition is reach the 200^o C – 250^o C. The heat is spread evenly with temperature about 153^o C in the reservoir, and also the heat is near the ground so that it will be easy to exploit the heat.

From the second step of modelling the injection and production well that attached to the reservoir will caused the temperature distribution of the reservoir is increase over time with average temperature is about ± $244,64^o$C. It is important to know it, because from the data we can make a management system to increase the geothermal energy production such as to add more production well in the reservoir by increasing the debit of fluid in the injection well, etc.

The pressure distribution that we get in the modelling study showed a slightly decrease that is about ± 0.20 N/m^2 per-1000 years for the first step modelling and ± 0.15 N/m^2 per-500 days for the second step of modelling. It is because we assumed that the reservoir is a closed system so that there are no mass and energy that comes in and out from the reservoir. The modelling study also give an information about phase change by seeing the enthalpy value and enthalpy distribution in the reservoir model.

We can conclude that in the modelling study we found that there is a phase change. In the first step of model, the enthalpy data shown that the fluid phase is still in liquid form and then in the second step of modelling there is a phase change after 700th years. The data is also shown us that not all the fluid is change its form but there is a multiphase flow in the reservoir.

6. ACKNOWLEDGEMENT

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