Parametric Study of Reservoir Parameters on Tracer Tests using Ethanol in a Geothermal Reservoir

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Abstract - *Understanding the connectivity among wells in production and injection area is required for the characterization of a geothermal reservoir. Tracer test is a standard tool for this purpose. However interpretation of tracer data is very difficult due to many parameters affects the tracer return curve. Therefore, most of the interpretation of tracer test is based on qualitative analysis.*

This paper presents a study to investigate the influence of some reservoir parameters that could affect the tracer flow in the porous medium. Such parameters including porosity, permeability, wet heat conductivity and initial water saturation. TMVOC simulator was used to develop a linear flow of one-dimensional model. Typical rock properties encountered in geothermal reservoirs were applied.

This study is able to quantify the effects of some reservoir parameters on the tracer curve. This because we provided details of rock properties as input for the simulator as well as alcohol properties data.

Key Words: tracer test, ethanol, geothermal, TMVOC, simulation

1. INTRODUCTION

Tracer test is a standard method to examine the hydrogeological connection between injection and production well. The test is conducted by injecting tracer chemicals into an injection well. Condensate samples were then taken repeatedly for a certain time from the nearby production wells. Changes of tracer concentration in the condensate samples with time at the production well are used to characterize the connection among the wells.

Interpretation of a tracer test could be analyzed both qualitatively and quantitatively. In qualitative analysis, the connectivity between two wells is predicted from the existence of tracer returns. If there is no return, the injection well and the production well must be not hydrogeologically connected and vice versa.

Many attempts have been made in order to analyze tracer data quantitatively. Wu et al. [1] proposed a method to calculate swept pore volume and thermal breakthrough from tracer data. Shook [2] introduced a method for estimating flow geometry in single phase geothermal reservoirs. Shook [3] developed a mathematical method to estimate matrix-fracture surface area. His method relies on differences in mean travel time between a conservation and an absorbing tracer.

Tracer test could be categorized into two main types [4], i.e. conservative tracer test and partitioning tracer test. In conservative tracer test, the tracer remains in a single phase. Only the volume occupied by that volume is being interrogated via tracer tests. This test provides information relating to its reference phase, i.e. the phase in which it is soluble. In partitioning tracer test, the tracer partition into other phase that are present. The difference between partitioning tracer and conservative tracer could be used to determine the volume of other phases present.

Alcohol is one of the partitioning tracers that have been applied in several geothermal fields, such as Matsukawa, Darajat and Kakkonda. In Matsukawa, four types of alcohol (methanol, ethanol, i-propanol, and n-propanol) were injected in order to trace the injectate flow in the reservoir [5]. The tracer return curves were analyzed qualitatively.

In Darajat, alcohols were injected along with perfluorocarbons to trace the amount of of steam derived from the injected water [6]. In Kakkonda, a numerical simulation was carried out by incorporating liquid and two-phase tracers using TOUGH2-EOS7R [7]. The phase partitioning behavior of tracer (alcohols) were simplified by assigning Henry's law constant in the model.

This paper presents a numerical simulation of a synthetic tracer test in a geothermal reservoir. The aim of this paper was to investigate the effects of some reservoir parameters in the numerical simulation. Parameters that were examined include porosity, permeability, wet heat conductivity, and initial water saturation.

This study will be able to quantify the effects of those parameters on the simulation results. This because details of rock properties were used as input for the simulator as well as alcohol properties data.

2. TMVOC Simulator

TMVOC [8] is a simulation program for fluid- and heat flows of multiphase, multicomponent in porous and fractured media. The structure of TMVOC program is based on TOUGH2 [9]. The general form of mass- or energy balance equation which is solved in TMVOC can be written as follow:

$$\frac{d}{dt}\int_{V_n} M^{\kappa}\, dV_n = \int_{\Gamma_n} \boldsymbol{F}^{\kappa} \cdot \boldsymbol{n}\, d\Gamma_n + \int_{V_n} q^{\kappa}\, dV_n$$

M is the mass or energy per volume, F denotes mass or heat flux, and q denotes sink and sources. They are defined for an arbitrary volume Vn with closed surface Γn. Superscript $\kappa = 1, \ldots, NK$ denotes the mass component (water, NCGs, volatile organic chemicals), and $\kappa = NK + 1$ is the heat component. Symbol n stands for the normal vector on surface element dΓ, pointing inward into Vn.

Alcohols were assigned as volatile organic chemicals. We selected ethanol as alcohol to be examined in this study. The chemical and physical properties of ethanol were taken from Reid et al. [10]. We then used those data as an input for TMVOC.

3. BASE CASE MODEL

To simulate tracer test in a geothermal reservoir, a synthetic one-dimensional model of linear flow was developed [11]. The model dimension is 100 m long, 10 m wide and 10 m high (**Fig -1**). The size of each grid block is 1m x 10m x 10m. The distance between the injection well and the production well (red grids in **Fig -1**) is 60 m. The rock properties for the model are summarized in **Table -1**.

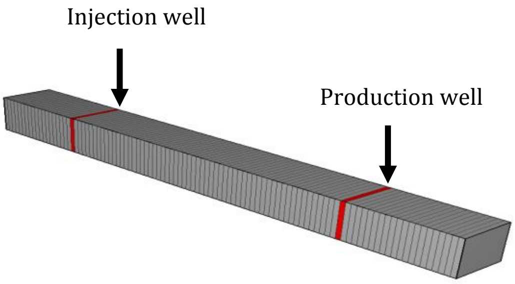

Fig -1: Model of production-injection in a geothermal reservoir

Initial condition was set up with water saturation of 0.01 and temperature of 200 °C. A total conductive heat input of 0.05 W/m2 was imposed for all grid blocks. At three months before tracer injection was carried out, water was injected continuously at a rate of 0.1 kg/s. The production well was produced with productivity index of 10^{-12} m^3 and flowing bottom-hole pressure of 5×10^5 Pa.

Table -1: Rock properties of the model

Parameter	Value	Unit
Density	2600	kg/m^3
Porosity	0.1	
Permeability	1×10^{-15}	m^2
Wet heat conductivity	2	W/(m.K)
Specific Heat	1000	J/(kg.K)
Relative permeability	Grant	
Residual liquid saturation	0.3	
Residual gas saturation	0.05	

Ethanol was injected after three months of continuous water injection at the injection well, followed by another continuous water injection (**Fig -2**). Since alcohol is flammable, it needs to be diluted into a solution. Alcohols that have been implemented in geothermal fields is low-carbon alcohols. Their properties is quite similar with water, thus it is expected that they will flow following the flow path of injected water. However, alcohols is flammable material, thus it was diluted into a solution up to 50 %.

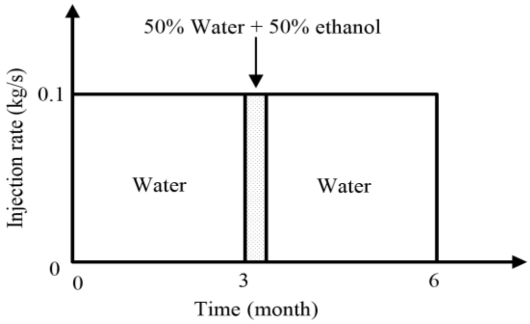

Fig -2: Condition of tracer injection

After three months of continuous water injection (a moment just before tracer injection), water saturation was distributed along the way between the injection well through the production well (**Fig -3a**). The gridblock where injection well is located, was filled with 100 % water at 58 °C (**Fig -3b**). The dryness of the produced fluid at the production well was about 70% at 158 °C. A pressure difference between the injection well and production well was about 2.5 x 105 Pa (**Fig -3c**).

At six months after tracer injection, most of the gridblocks were filled by water (**Fig -3d**). The vapor saturation at the production well was very small (Sv = 0.3). Temperature at the injection well approached the temperature of injected water, whereas only a slight decrease of temperature occurred at the production well (**Fig -3e**). This indicates water breakthrough was achieved more quickly rather than temperature breakthrough. Pressure at both the injection well and production well relatively stable. However, a little pressure changes occurred between the wells (**Fig -3f**).

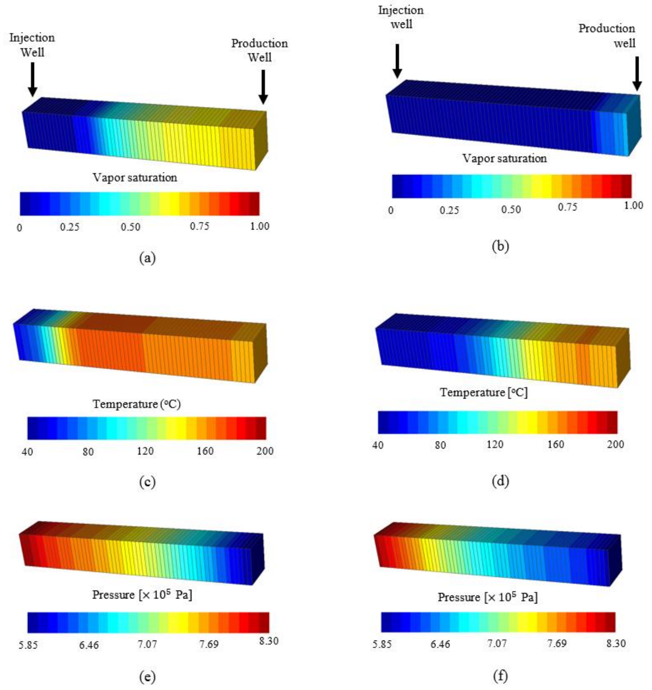

Fig -3: Distribution of vapor saturation, temperature and pressure before (left) and after 6 months (right) of tracer injection.

Tracer return was observed at the production well in both liquid phase and vapor phase (**Chart -1**). Peak concentration of both phases were achieved at the same time. However, the tracer recovery in the vapor phase was higher than in the liquid phase. This might because the vaporization rate of ethanol is higher than vaporization rate of water. Thus, mole fraction of ethanol in vapor phase is higher than in liquid phase.

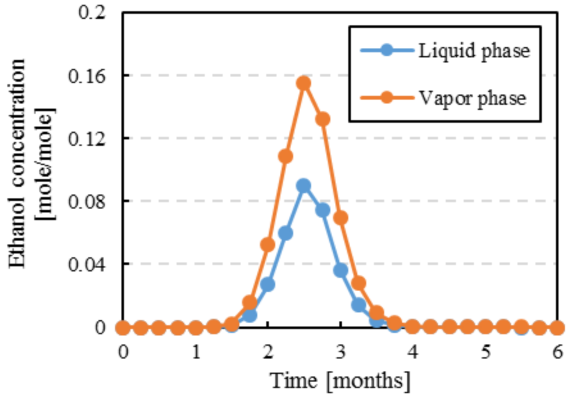

Chart -1: Tracer concentration at the production well

4. PARAMETRIC STUDY

4.1 Effect of porosity

Porosity is a parameter that measure how big the fluid storage in a porous medium. As the porosity increases, more fluids fills the open space of the rock. In a higher porosity the tracer would get more dispersed, thus the tracer reached the production well more slowly. In other words, small porosity yield a very quick arrival of tracer (**Chart -2**).

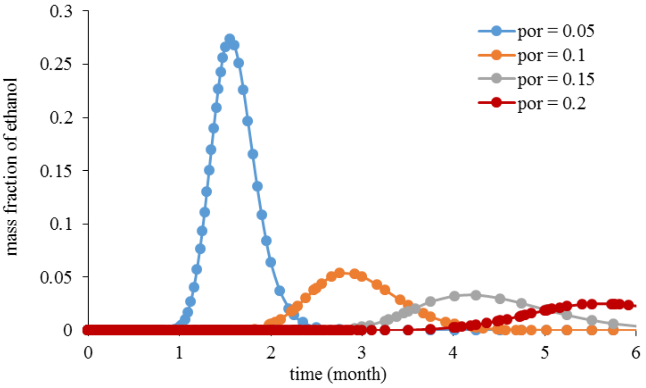

Chart -2: Effect of porosity on the tracer curve

4.2 Effect of permeability

The effect of permeability was captured on the tracer return curve (**Chart -3**). As the permeability increases, the return of tracer appeared earlier. This because the tracer flows in the porous medium in the higher speed. Also a higher permeability yields a higher peak concentration. We increased the permeability value from 10^{-15} m^2 to 10^{-12} m^2. The highest peak concentration and the earliest arrival time are found in the case with permeability of 10^{-12} m^2.

Little difference was shown by setting a permeability of 10^{-15} m^2 and of 10^{-14} m^2. The arrival time and peak concentration was relatively the same. However, the tracer curve changed drastically when we increased the permeability to the order of 10^{-13} m^2.

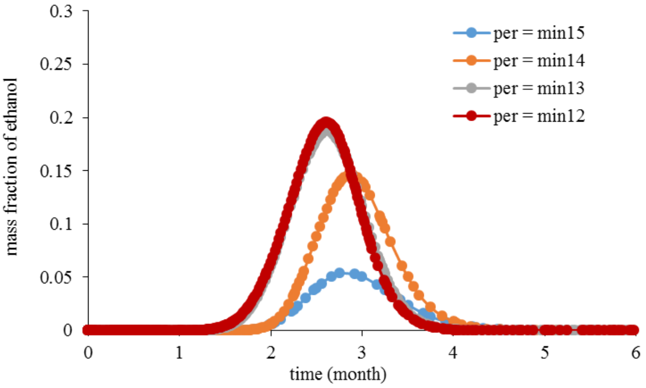

Chart -3: Effect of permeability on the tracer curve

4.3 Effect of wet heat conductivity

Wet heat conductivity is a parameter that shows the rock ability to conduct heat. We varied the conductivity value from 2 to 3.5 W/(m.K) and investigated its effect on tracer response. No significant effects was appeared. The highest peak concentration was achieved by setting a wet heat conductivity of 2 W/(m.K) (see **Chart -4**). This because the smallest the value of wet heat conductivity, the more difficult the rock to conduct the heat. Since we injected relatively cold water (40 °C) into the injection well, thus the higher temperature difference was achieved from the smallest wet heat conductivity.

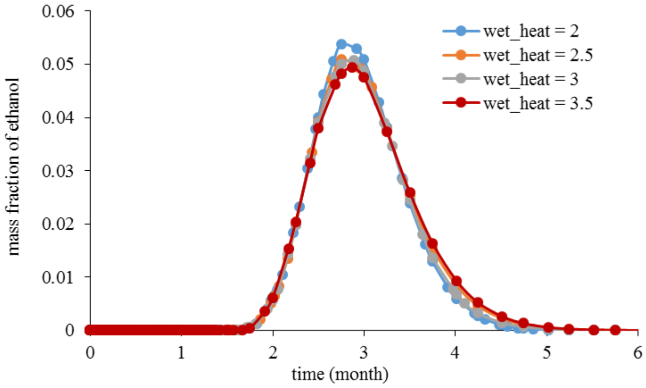

Chart -4: Effect of wet heat conductivity on the tracer curve

4.4 Effect of initial vapor saturation

In order to examine the effect of initial water saturation on the fluid flow of ethanol, we conducted three different cases with several distributions of initial water saturation (**Chart -5**). Case C is the base case. At the injection well and the cells nearby, liquid water filled all the pore spaces for all three cases.

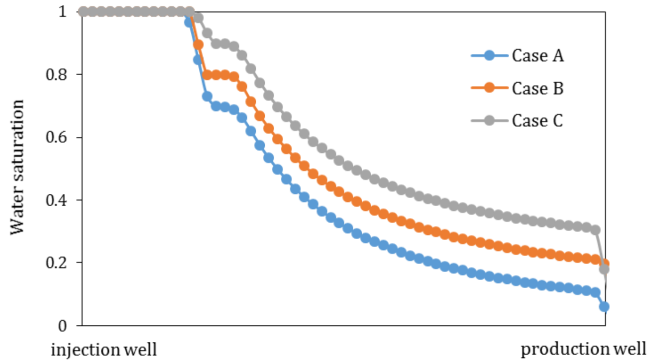

Chart -5: Three cases of different distribution of initial water saturation

The arrival time of each cases appeared in a relatively similar time. However, the peak concentration is little bit difference. Case A had the highest peak concentration among others (**Chart -6**).

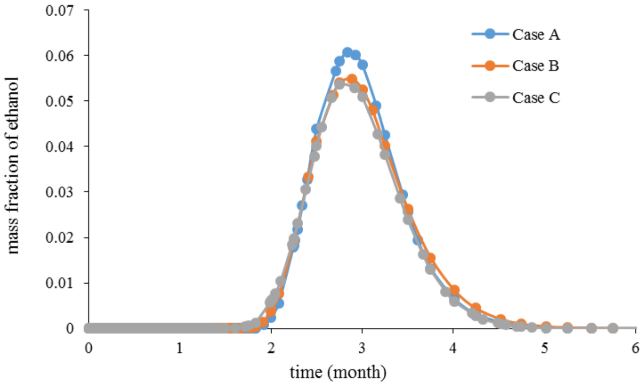

Chart -6: Effect of initial water saturation on the tracer curve

5. CONCLUSIONS

This paper has examined the influence of several reservoir parameters as well as initial distribution of water saturation. On the basis of this work, we draw the following conclusions:

- As the porosity increases, the injected tracer get more dispersed in the porous medium. This yields the tracer reached the production well more slowly.
- Permeability affects the velocity of the tracer flow. The higher the permeability, the higher its velocity.
- Wet heat conductivity does not affect the tracer response significantly. Only a little difference on peak concentration was shown in our case.
- Distribution of initial vapor saturation had the same effect as wet heat conductivity does. As the smaller initial water saturation in the reservoir yields a higher peak concentration.

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