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Treating Carbon Dioxide Data as Tracer for Geothermal Reservoirs

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ABSTRACT

Good reservoir engineering practice is a must for making accurate future performance predictions in geothermal fields. Accurate performance predictions lead to good reservoir management. In almost all fields, a reservoir model is of necessity for providing good reservoir engineering practice. The model must be calibrated to all kind of data available. When future performance predictions are concerned, it becomes extremely important to integrate production data. Production data may consist of flow rates, wellbore pressures, wellhead pressures, average reservoir pressure and tracer data in geothermal reservoirs. Collecting wellbore pressures may not be possible at all times since a gauge needs to be lowered into the well. Wellhead pressures, although easy to obtain, may not be always be useful since they also contain all kinds of wellbore phenomena. Average reservoir pressures are very useful but is extremely hard to obtain and usually require observation wells to be used. Tracers give a good idea about inter-well connectivity but are applied seldom.

Carbon dioxide exists in most geothermal reservoirs, especially the ones in Turkey. Usually the concentration of carbon dioxide is a function of depth. The deeper the wells, the more carbon dioxide content there is. With production this carbon dioxide is also produced. However, the reinjection water on the other hand does not contain any carbon dioxide. Hence when this water is reinjected, the concentration of carbon dioxide is changed and decreases with time and space. Sooner or later, the water with the decreased carbon dioxide content reaches the production wells causing a decrease in the carbon dioxide content at the production wells. Measuring the carbon dioxide content at the production wells is a very easy process and can be repeated whenever necessary.

In this study, a model is constructed to simulate the behavior of the carbon dioxide content for geothermal reservoirs. Using the model, the carbon dioxide data is treated as if it were a tracer and leads to a better characterization of the reservoir. Furthermore, we also make use of existing models developed for tracers and for thermal applications for further characterization of a geothermal field. From the carbon dioxide data, connectivity between regions of injection wells and production wells can be quantified. However, at this point it is important to note that the models used in this study and the applications given are valid for liquid dominated geothermal reservoirs.

1. INTRODUCTION

Turkey has had a rapid development in the utilization of geothermal energy both for power and for direct use. Most of the geothermal fields are gathered in the Aegean region. There are two common features of the geothermal reservoirs in Turkey. The first is that almost all are liquid-dominated reservoirs. The second is that almost all contain some amount of carbon dioxide. The carbon dioxide found in Turkey's geothermal reservoirs is dissolved in the water and is not associated with a gas phase in the reservoir. During production, the carbon dioxide comes out of solution and forms a gas phase along with steam. This happens inside the well at flashing point depths. Above this depth, two-phase flow is usually experienced where water and gas flow together. The high partial pressure of carbon dioxide causes a high wellhead pressure and aids production. A decline in the carbon dioxide levels in the reservoir are associated with a decline in the well head pressure.

The initial levels of carbon dioxide vary from field to field. Furthermore, the carbon dioxide levels in any field can vary depending on the depths of the production wells. The initial carbon dioxide content of the Kızıldere field varied anywhere between 1% and 9% by mass depending on the depths of the wells (Satman et al., 2020). The Germencik field on the other hand had an initial average carbon dioxide content of 2.1% by mass (Tureyen et al., 2016).

The carbon dioxide content of a reservoir that is being exploited usually does not remain the same. During production, the utilized cold water is reinjected back into the reservoir mainly for pressure maintenance and for efficiently disposing of the water. However, the carbon dioxide content of the reinjected water is usually so small as to be neglected. Hence, the reinjection of water with negligible amounts of dissolved carbon dioxide causes a decrease in the carbon dioxide content of the reservoir. The decline trend of the carbon dioxide due to reinjection has been previously studied and the decline with time is given by Eq. 1 (Hosgor et al. 2016)

$$x(t) = x_0 e^{-\frac{w_p c_t}{\kappa}t} + \frac{w_{inj}\, x_{inj} + w_n x_{re}}{w_p} + \frac{w_n x_{re}}{w_p - \frac{\alpha}{c_t}} e^{-\frac{w_p c_t}{\kappa}t} - \frac{w_n x_{re}}{w_p - \frac{\alpha}{c_t}} e^{-\frac{\alpha}{\kappa}t} - \frac{w_{inj}\, x_{inj} + w_n x_{re}}{w_p} e^{-\frac{w_p c_t}{\kappa}t} \quad (1)$$

where x (fraction) represents the mass fraction of dissolved carbon dioxide in water, w (kg/s) represents the mass flow rate, α (kg/(bar.s)) represents the recharge index, c_t (1/bar) represents the total compressibility of the system and κ (kg/bar) represents the storage capacity of the reservoir. The subscript 0 represents the initial conditions, subscript p represents production, subscript inj represents injection, subscript n represents net and subscript re represents recharge. The w_n term in this case represents the net flow rate and is given by Eq. 2.

$$w_n = w_p - w_{inj} \tag{2}$$

The storage capacity κ is given with Eq. 3.

$$\kappa = V_b \rho_w \phi c_t \tag{3}$$

where, V (m^3) represents the bulk volume of the reservoir, ρ (kg/m^3) represents the density and ϕ (fraction) represents the porosity of the reservoir. The subscripts b and w stand for bulk and water respectively.

The reinjection of colder water with negligible amounts of carbon dioxide forms a region of altered carbon dioxide content first right around the reinjection well and then this region expands as reinjection continues. Naturally, the reinjected water with the negligible carbon dioxide content moves toward the production wells. Hence flow in the porous media is composed in this case of two separate regions of flow. These regions represent the two different concentrations of carbon dioxide. Measurements of carbon dioxide at the production wells (with a declining trend) should provide information regarding the flow characteristics in the reservoir.

In this study, the behavior of the change of carbon dioxide is modeled and explained through the use of a doublet system. Furthermore, field examples are also provided. However, at this point it is important to note that the methodology and the examples provided in this study are for a liquid-dominated reservoir. Two-phase systems and steam-dominated systems are not considered in this study.

2. BEHAVIOR OF CARBON DIOXIDE AS A TRACER

In this section the change of carbon dioxide content is modeled through a doublet system. The doublet system is illustrated in Figure 1. It consists of two wells; one injector and one producer in a rectangular reservoir. The width of the reservoir is taken to be D and the length is $2D$.

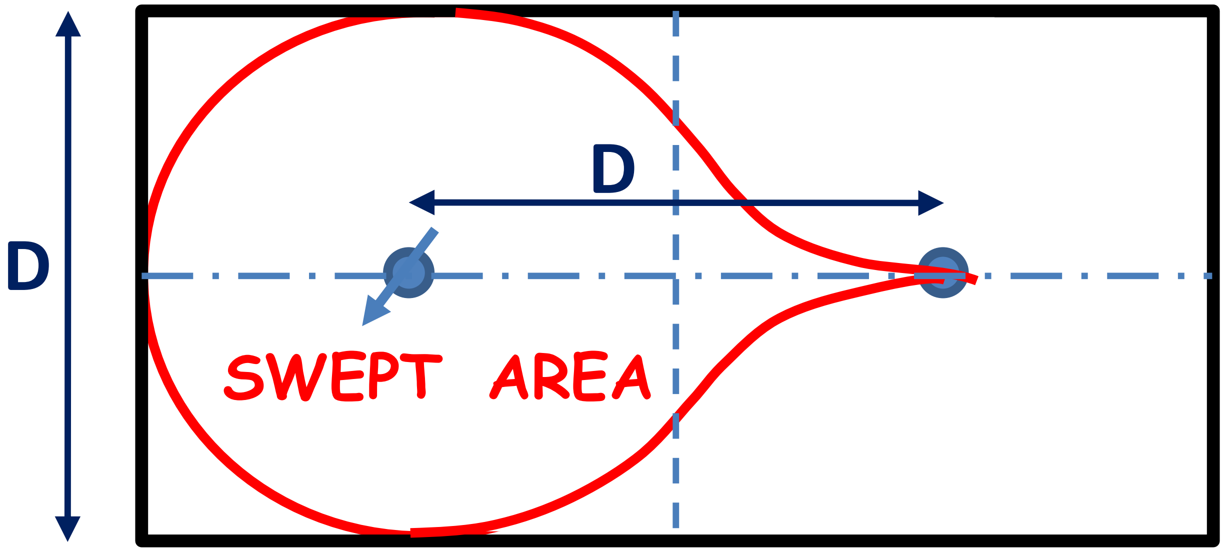

Figure 1: Illustration of a doublet system.

In modeling the behavior of the change of carbon dioxide, the reinjected water with the negligible carbon dioxide content is treated as if it were a tracer. In a traditional tracer application, water is reinjected with a certain concentration of a specific type of tracer. Then measurements are taken at the production wells. The breakthrough time and the concentration at which the tracer arrives at the producer gives information about the reservoir and flow characteristics. In a tracer application the reinjected water with the specific concentration of the tracer is reinjected only for a short period of time. Hence at the production well, it is received in a single pulse-like manner, where after the breakthrough of the tracer the concentration at the production well first increases and then decreases.

In the case of the reinjection of water with the negligible carbon dioxide content, the behavior at the production wells is different than that of a traditional tracer. The behavior is illustrated in Figure 2. Initially, the production well produces water with the initial carbon dioxide content of the reservoir at that particular depth. Then, the reinjected water reaches the production well (the time of breakthrough of the water which has negligible carbon dioxide content, we will refer to this as the hydraulic front) and the carbon dioxide content observed at the production well starts to decrease. The decrease is because the reinjected water contains negligible amounts of carbon dioxide. Because the reinjection of water with negligible carbon dioxide is a continuous process (unlike a traditional tracer where the tracer is injected for a short period of time), the decrease of the carbon dioxide content observed at the production well also has a continuous decline trend. It asymptotically declines to a value which may not necessarily be equal to zero (zero here represents the negligible amount of carbon dioxide in the reinjected water).

The value at which the carbon dioxide content stabilizes is a function of the injection rate to the production rate. The stabilized final value can be determined from the expression given in Eq. 4.

$$\frac{x_f}{x_i} = 1 - \frac{w_{inj}}{w_p} \qquad (4)$$

where the subscript *f* represents final and subscript *i* represents the initial. Eq. 4 can be obtained simply by taking the limit of Eq.1 as time goes to infinity and also treating x_{inj}=0 and taking x_{re}=x_i. As is clear from Eq.4, the higher the reinjection ratio, the lower the final carbon dioxide content.

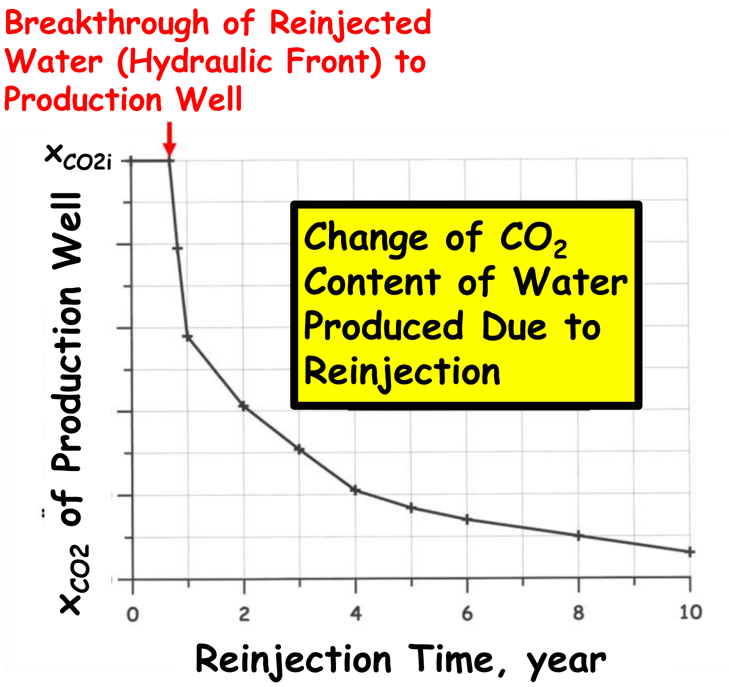

Figure 2: Typical behavior of carbon dioxide concentration at the production well.

Although the behavior shown in Figure 2 is a theoretical one, a similar behavior can also observed in the field. Figure 3 shows the carbon dioxide behaviors of the KD-14, KD-15 and KD-16 production wells in the Kizildere field (Satman et al., 2017).

As illustrated in Figure 3, the carbon dioxide behaviors from three of the production wells in the Kizildere field show a similar response. These three wells are shallow wells located in the northern part of the field and are wells that have supplied the KZD-1 power plant. The behavior here is such that initially there is somewhat a constant behavior followed by an increase that starts on the 18th of November 2012. The increase continues until February 2013. This is followed by a gradual decrease until the carbon dioxide levels become more or less stabilized at an average value of approximately 0.046 in February 2016. Before explaining the details of the carbon dioxide content behavior, other information regarding the reinjection operations in the field needs to be given.

Before 18th of November 2012, the three wells were under the influence of reinjection from the wells R-2, KD-1A and KD-8. On the 18th of November 2012, the reinjection operations of these wells stopped. This caused an increase in the carbon dioxide content behaviors of the three production wells KD-14, KD-15 and KD-16. The reason for the increase is that, once reinjection has stopped, the production wells are no longer partially supplied by the reinjection waters but are supplied from the surroundings of the wells which have a higher carbon dioxide content. On the 1st of December 2012, another reinjection operation started from the well KD-38C which is one of the blue wells given in Figure 3. The carbon dioxide content continues to increase until the reinjected water from the KD-38C well breaks through. Then the decline in carbon dioxide content starts. The stabilization is observed at an average value of 0.046 as mentioned before.

A similar behavior has also been observed in the R-1 well and is shown in Figure 4. Figure 4 illustrates the carbon dioxide content from the well R-1 and also the overall field production, injection and net mass flow rates. The point at which the field mass flow rates increase marks the point at which the KZD-2 power plant has been put into commission. Reinjection at this point has been performed mainly from the blue wells shown in Figure 3. Hence, a little while after reinjection has started, the reinjected water has broken through to the R-1 well and has caused a significant drop in the carbon dioxide content; from an average of 0.035 to an average of 0.017.

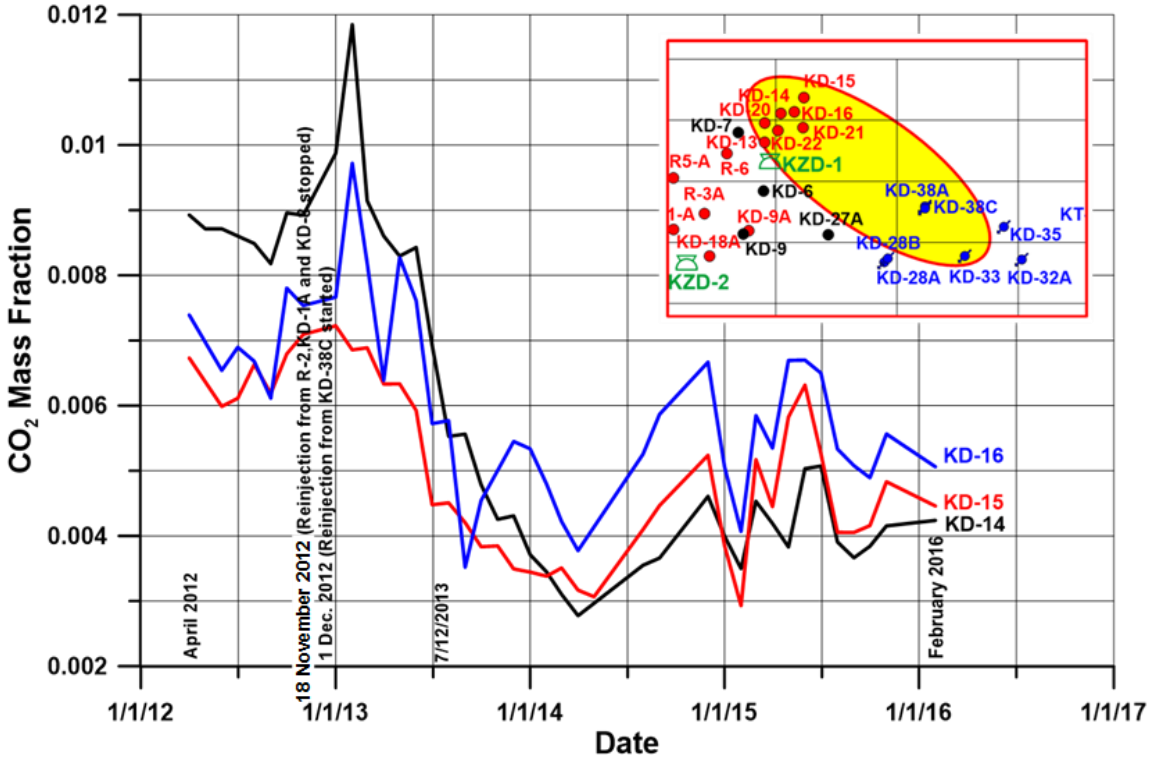

Figure 3: The carbon dioxide behavior of the KD-14, KD-15 and KD-16 wells from the Kizildere field (Satman et al., 2017).

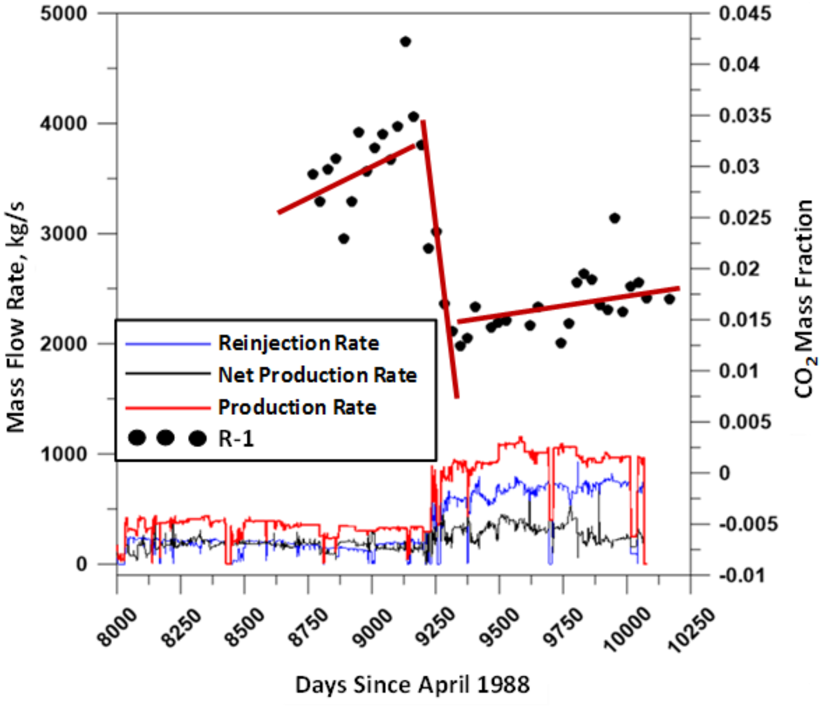

Figure 4: The carbon dioxide behavior of the R-1 well from the Kizildere field (Satman et al., 2017).

Figure 5 illustrates the temperature behavior at the production well. Because the reinjection water is colder than the reservoir water (because the water has been utilized and the temperature has decreased), a decline in the temperature is also observed after the breakthrough of the thermal front.

At this point it is important to recognize the difference between the breakthrough times of the hydraulic front and the thermal front. As it is clear from a comparison of Figures 2 and 5, the thermal breakthrough is achieved at much later times than that of the hydraulic breakthrough. This is expected because the reinjected water is heated as it travels through the reservoir towards the production well. Hence, even though hydraulic breakthrough is achieved, the temperature does not change for some time. Figure 6 provides a comparison between the hydraulic and thermal fronts in space for a snapshot in time.

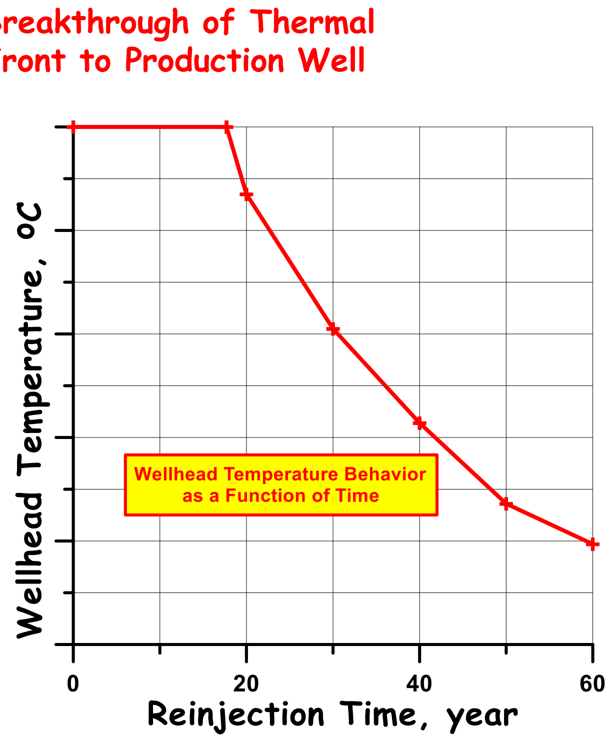

Figure 5: Typical behavior temperature at the production well.

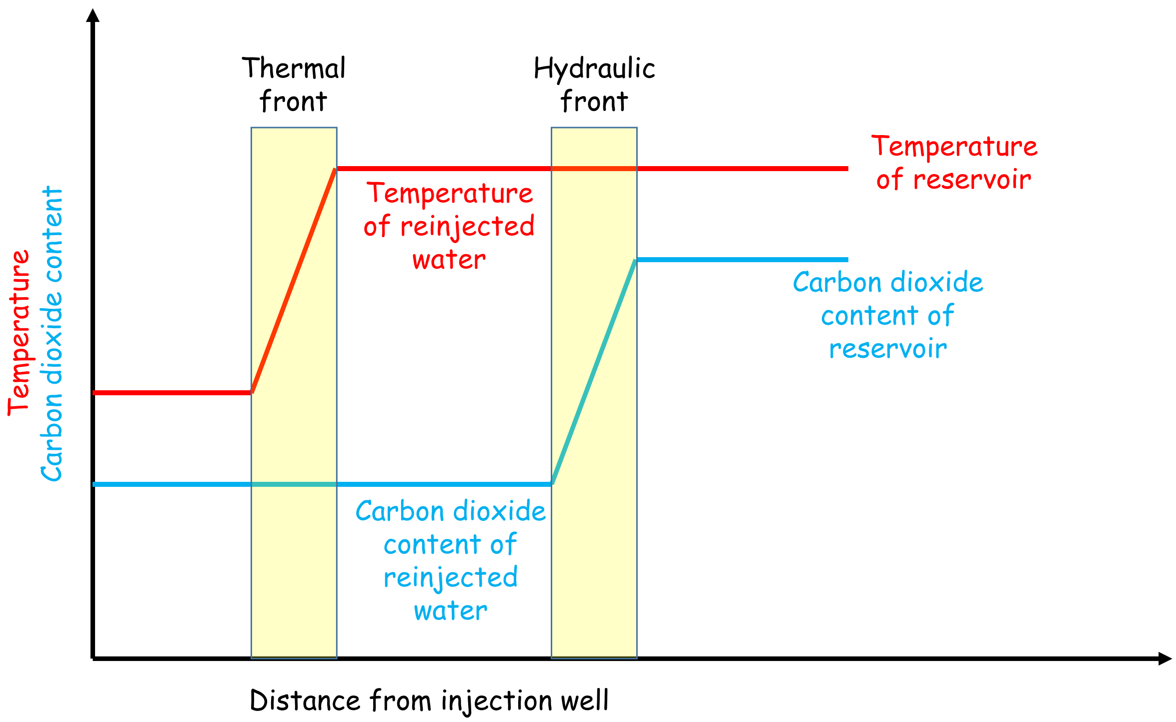

Figure 6: Comparison of the hydraulic and thermal fronts in space for a snapshot of time.

The thermal breakthrough time may be obtained with the relationship given in Eq. 5.

$$t_{TBT} = \frac{\rho_{av} C_{av}}{\rho_w C_w} \frac{hD^2}{q} \quad (5)$$

here C represents the specific heat capacity (J/(kg.°C)), h (m) represents the thickness and q (m^3/s) represents the volumetric flow rate. The subscript *av* represents the average and *TBT* represents thermal breakthrough.

The hydraulic breakthrough may be obtained by using Eq. 6.

$$t_{HBT} = t_{TBT} \frac{\emptyset \rho_w C_w}{\rho_{av} C_{av}} \tag{6}$$

where the subscript *HBT* represents hydraulic breakthrough.

The product of the average density and the average specific heat capacity may be obtained using Eq. 7.

$$\rho_{av} C_{av} = \emptyset \rho_w C_w + (1 - \emptyset) \rho_r C_r \tag{7}$$

where the subscript *r* represents the rock. Assuming a porosity of 5%, and using typical figures for the rock density, water density, rock specific heat capacity and rock density the relationship between the thermal breakthrough time and the hydraulic breakthrough time becomes t_{TBT}=13.5t_{HBT}. The volume reinjected for the doublet given in Figure 1 can then be determined from Eq. 8.

$$V_{ri} = q t_{HBT} = \frac{\pi \emptyset h D^2}{3} \tag{8}$$

The total swept area in this case becomes:

$$A_s = \frac{\pi}{6} A = \frac{\pi}{6} 2D^2 \tag{9}$$

where the subscript *s* refers to swept.

From the above equations, if the hydraulic breakthrough times are observed at the production wells, then it is possible to infer information regarding the average thickness of the flow path that the reinjected water follows towards the production well where it breaks through.

3. CONCLUSIONS

Most of the fields in Turkey are liquid-dominated and contain some amount of carbon dioxide. With production the carbon dioxide content of the field and of the individual wells decline due to reinjection operations because the reinjected water contains negligible amounts of carbon dioxide. Because of this reinjected water, a hydraulic front with negligible amounts of carbon dioxide move from the reinjection well to the production well. Because of the existence of regions of different concentrations of carbon dioxide, it is possible to treat the carbon dioxide data as if it acted as a tracer. In this study the behavior of the carbon dioxide content obtained from the production wells is analyzed and explained for liquid dominated geothermal reservoirs. The following conclusions are obtained:

- Declining trends of carbon dioxide at the production wells are caused by the reinjected water (with negligible amounts of carbon dioxide) breaking through.
- The decline of carbon dioxide becomes stabilized after some time and the stabilized value of the carbon dioxide content at the production wells is dominated by the ratio of the reinjection mass rate to the production mass rate.
- There is a difference between the velocities of the hydraulic front and the thermal front moving from the reinjection wells to the production wells. The difference in the velocities is dependent on the porosity of the system.
- From the records of breakthrough times at the production wells, information regarding the average thickness of the flow paths between the reinjection well and the production well can be inferred.
- Observation of carbon dioxide content decline show that there is connectivity between the reinjection wells and the production wells.

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