PROCEEDINGS, 42nd Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 13-15, 2017
SGP-TR-212

Effect of Carbon Dioxide Content on the Well and Reservoir Performances in the Kizildere Geothermal Field

Abdurrahman Satman*, Omer Inanc Tureyen*, Emine Didem Korkmaz Basel*, Aygun Guney**, Erdinc Senturk** and Ali Kindap**

* ITU Petroleum and Natural Gas Engineering Department

** Zorlu Energy

mdsatman@itu.edu.tr, inanct@itu.edu.tr, korkmazem@itu.edu.tr, aygun.guney@zorlu.com, erdinc.senturk@zorlu.com, ali.kindap@zorlu.com

Keywords: Kizildere geothermal field, carbon dioxide

ABSTRACT

The Kizildere geothermal field is located on the Buyuk Menderes Graben in the Denizli and Aydin Provinces of Aegean region, Turkey. The field was discovered in 1968 and production for power generation has started in 1984. Bottomhole temperatures as high as 245 °C have been recorded. The installed capacity of the initial power plant was 17 MW_e. In 2013, an additional 80 MW_e power plant was installed. Plans to expand the power generation capacity of the field to 260 MW_e are under way.

One of the main features of the Kizildere geothermal field is the carbon dioxide content which is measured at various wells to be between 1 to 3.5% by mass. Carbon dioxide in geothermal reservoirs can have a considerable effect on the production behavior. The main effect of carbon dioxide is that even small amounts dissolved in the geothermal water can raise the flashing point of water and subsequently affects the production well performance significantly.

In this study we present models for analyzing the production well behavior for geothermal reservoirs with dissolved carbon dioxide. Mixing of the reinjection water with the reservoir water causes drop in CO_2 content of the produced water and this leads to drop in wellhead flowing pressure and temperature. Some of the production wells nearby the reinjection region in the Kizildere geothermal field clearly showed this behavior.

This paper discusses the effect of CO_2 in production wells´ wellhead performance and presents the actual well data. We also assess the overall performance of the carbon dioxide behavior in the reservoir and present future predictions of how the dissolved amount of carbon dioxide changes in the field.

1. INTRODUCTION

The Kızıldere geothermal field is located in the Denizli and Aydın provinces of western Turkey at the western extreme of the Buyuk Menderes graben.

The Kızıldere geothermal field was discovered in 1968. It is identified as a water dominated hydrothermal system. It is the first explored geothermal field and one of the largest and most developed resources discovered in Turkey so far. In 1974, a 0.5 MW_e pilot turbine was installed. After the pilot test study, in 1984, a 15 MW_e steam turbine and generator unit flash plant (KZD-1) was constructed. Assuming that this power plant has operated with a capacity of about 11 MW_e, then with an average production rate of 800 t/hr, the field was being operated with a ratio of about 73 t/(hr-MW_e). At the end of 2008, after the privatization of Kızıldere Geothermal field, Zorlu Energy has drilled new production and reinjection wells, and a second power plant with an installed capacity of 80 MW_e (KZD-2), a 60 MW_e triple-flash power plant and another 20 MW_e binary plant, was put in use at the last quarter of 2013 and total installed capacity of the field has reached to 95 MW_e with the older plant. Considering that the field is producing with this capacity with an average production rate of 3500 t/hr, we can conclude that the field is currently being operated with a ratio of 37 t/(hr-MW_e). Considering the improvement from 73 t/(hr-MW_e) to 37 t/(hr-MW_e), Zorlu Eergy has managed to efficiently develop the field. The Zorlu Energy lease covers an area of about 65 km^2. Figure 1 gives the concession area along with the locations of the production, injection and observation wells (Satman et al., 2016).

Since the discovery in 1968, the field has been exploited to varying degrees ever since. It is a good quality geothermal resource, with some bottomhole temperatures exceeding 245 °C. Furthermore the evidence as results of recent ongoing geological, geophysical and drilling activities indicate that a deep, better quality reservoir with higher temperatures is available for exploitation. New deep wells have been drilled up to 3 km depth (some even deeper) in the field. Zorlu Energy intends to develop the field further and to extend the power capacity up to 260 MW_e in the near future.

Although the Kızıldere resource has a reasonably high enthalpy, it also presents a considerable challenge with respect to very high concentrations of non-condensable gases (NCG), mainly carbon dioxide (CO_2), in the reservoir. Production from the reservoir has demonstrated the CO_2 content in the produced water to be in the 2-3 weight % (even higher in some cases) range.

In this study we focus on the behavior of CO_2 in the reservoir and the effects it has on the performance of the Kızıldere geothermal field. Initially, the CO_2 data obtained from the wells are presented. This is followed by the demonstration of the effects of a decrease in the CO_2 level on the wellhead pressures. Then a mathematical model is presented for predicting the future CO_2 levels at the reservoir scale.

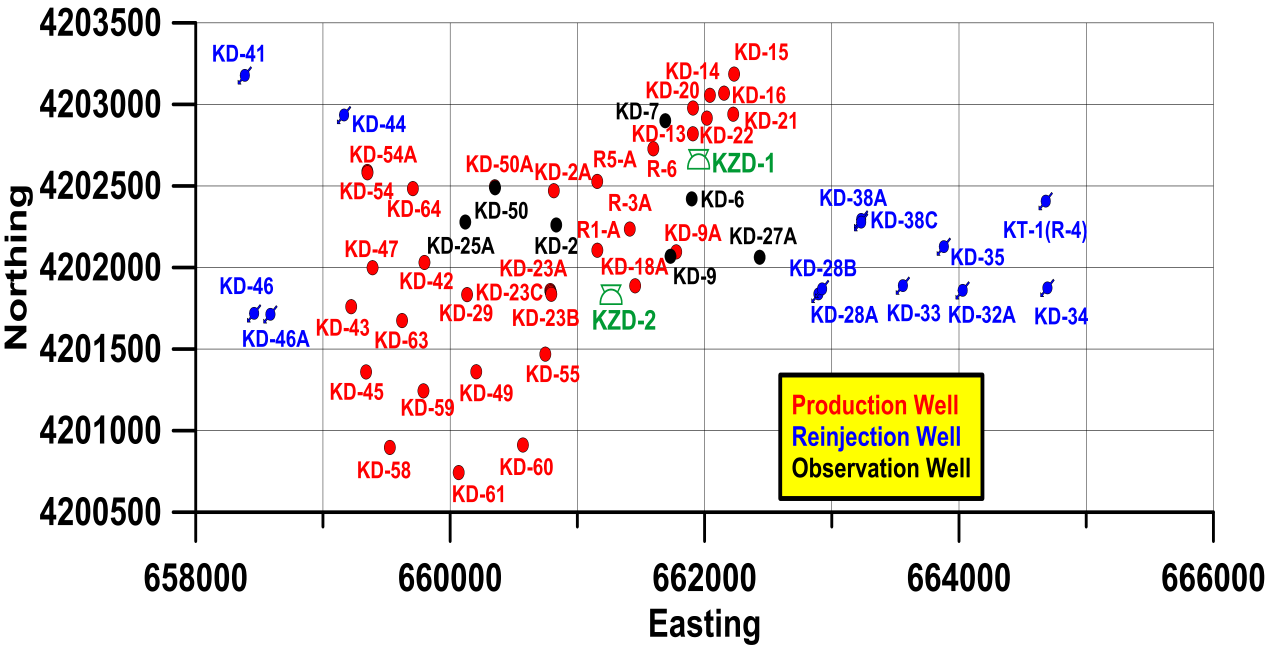

Figure 1: The locations of the wells in the Kızıldere field.

2. EFFECTS OF CARBON DIOXIDE ON PRODUCTION AND RESERVOIR PERFORMANCE

One of the features of the Kızıldere geothermal field is the high noncondensable gas (mainly CO_2) content. The CO_2 content of the geothermal water for each production well is measured using a mini-separator at the wellhead and also can be determined from the dynamic pressure profiles analyzed by the in-house wellbore simulator as discussed previously. The CO_2 contents obtained from the measured and the analyzed dynamic pressure profiles generally yield good comparison for all wells analyzed.

Figure 2 gives the CO_2 content in molar fraction (mol CO_2/kg water) versus bottom hole temperature relationships for various wells. The CO_2 contents in Figure 2 represent the wellhead values measured just after the completion of wells. The measured values range between 0.009 and 0.093 (weight fraction). The CO_2 content increases as the bottom hole temperature increases. The CO_2 contents of the old wells produced for KZD-1 plant and the wells drilled at the periphery of the field such as KD-46 are relatively low, close to about 0.01 (weight fraction) The recently drilled deep and hot wells showed an average CO_2 content between 0.03-0.04 (weight fraction). Two wells (KD-54 and KD-50A), however, have outstanding CO_2 contents greater than 0.06 (weight fraction, 0.09 and 0.06 respectively). Although some necessary geological and other supporting evidences are still lacking, it is believed that the flow for these two wells is originated from the deeper parts of the reservoir than the bottom hole possibly due to the existence of a vertical fracture below.

The CO_2 contents of the production wells are measured periodically. Figure 3 shows the change of the average of CO_2 contents (fraction, m_{CO2}/m_{water}) of production wells. The increase on the field average CO_2 content is due to the contribution of deeper and higher pressure wells at the recent development stages.

Generally speaking, the production wells not affected by the reinjected water show fairly stable and constant CO_2 values. However the wells closer to the reinjection region and affected by the reinjected water show a decreasing CO_2 content as soon as the reinjected water arrives to bottom hole. Figure 4 illustrates this behavior for the well R-1. The sharp decrease on the CO_2 content from 0.035 to 0.017 is due to the mixing of high CO_2 reservoir water and the reinjection water with negligible CO_2 content after the breakthrough of the reinjection water. It is a reasonable and expected result.

Figure 5 shows the effects of reinjection on the CO_2 content of the wells (KD-14, KD-15, and KD-16) supplying hot water to the KZD-1 plant. The inserted picture shows the locations of the wells and the nearby reinjection region. Reinjection from the reinjection region on the eastern flank of the field initially started from the well KD-38C. As Figure 5 indicates the CO_2 contents of water produced from nearby production wells decreased sharply in about a year from 0.008 to 0.004. In a way, the injected water acts as a tracer and we can conclude that the breakthrough has occurred at wells KD-14, KD-15, and KD-16.

One of the detrimental effects of the CO_2 content drop in produced water occurs on the dynamic pressure profile in the wellbore. The schematic illustration of the effects of the CO_2 content of the production well on the wellhead flowing pressure and the flashing depth is given in Figure 6. Assuming the bottom hole flowing pressure stays constant, three profiles are shown in the figure, for mass fractions

(x_{CO2}) of 0.021, 0.01, and 0.004. Drop at CO_2 content results in decreasing the flashing point pressure and therefore the flashing depth where the change from single phase to two-phase flow occurs closer to the wellhead. This causes a higher hydrostatic pressure drop in the single phase water column and thus results in a lower wellhead pressure and a considerable drop at wellhead flowing pressure. Although it is not shown in Figure 6, a slight temperature drop also occurs at the wellhead.

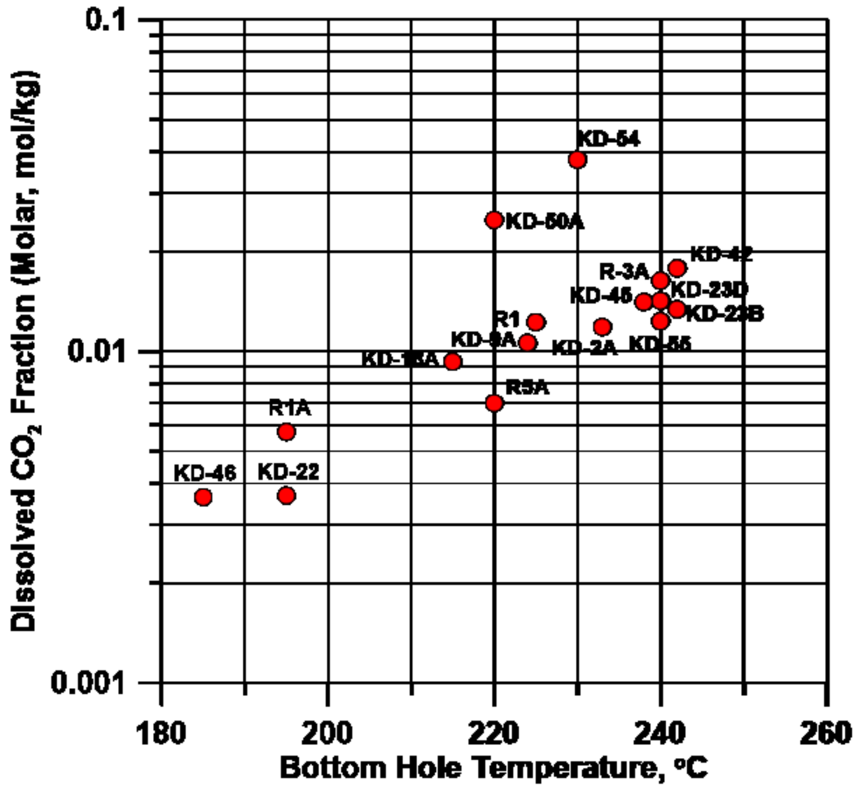

Figure 2: The CO_2 content versus bottom hole temperature relationships for various wells.

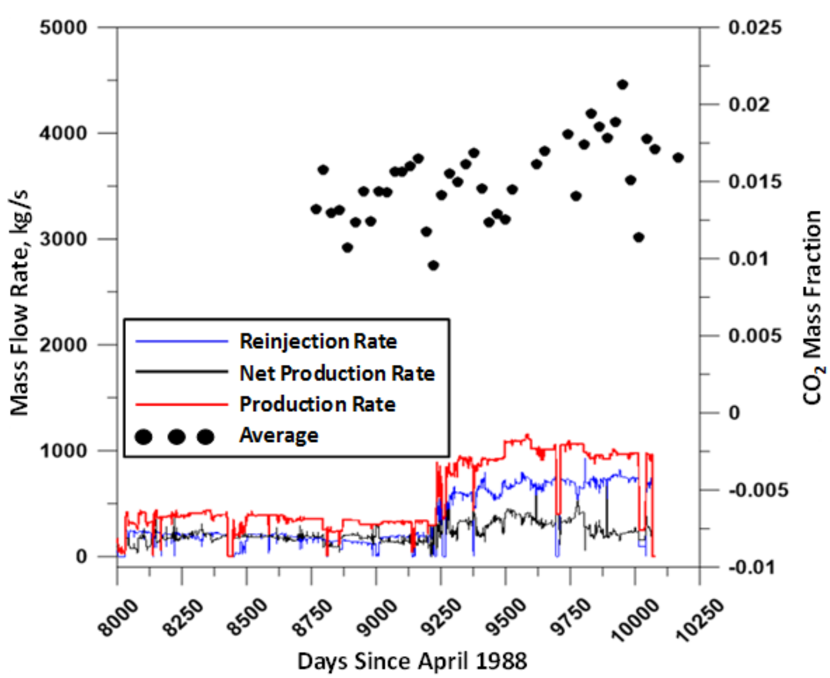

Figure 3: The change of the average of CO_2 contents of production wells.

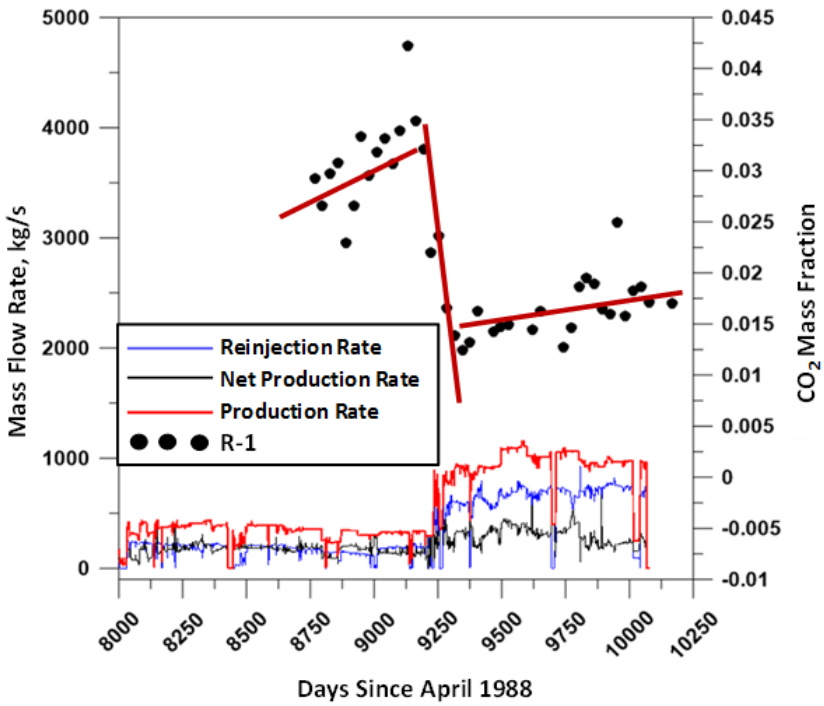

Figure 4: The effect of reinjection on the CO_2 content of the well R-1.

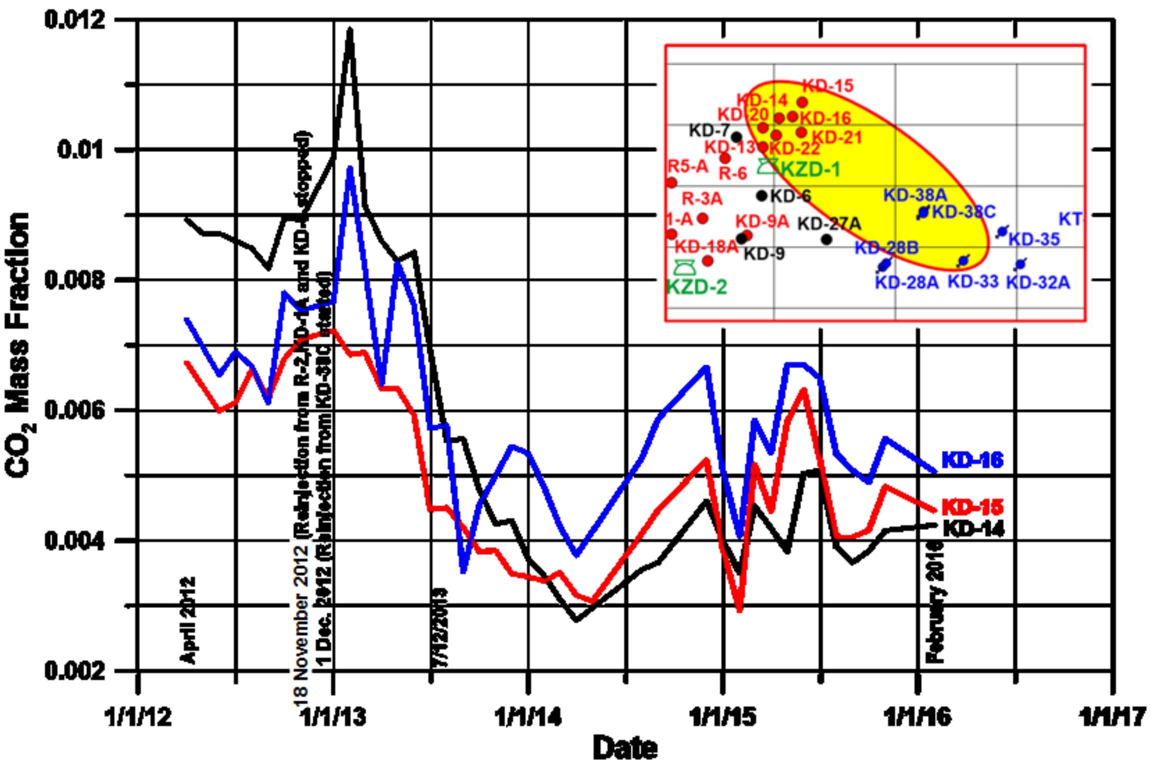

Figure 5: The effects of reinjection on the CO_2 content of the wells (KD-14, KD-15, and KD-16) supplying hot water to the KZD-1 plant. The inserted picture shows the locations of the wells and the nearby reinjection region.

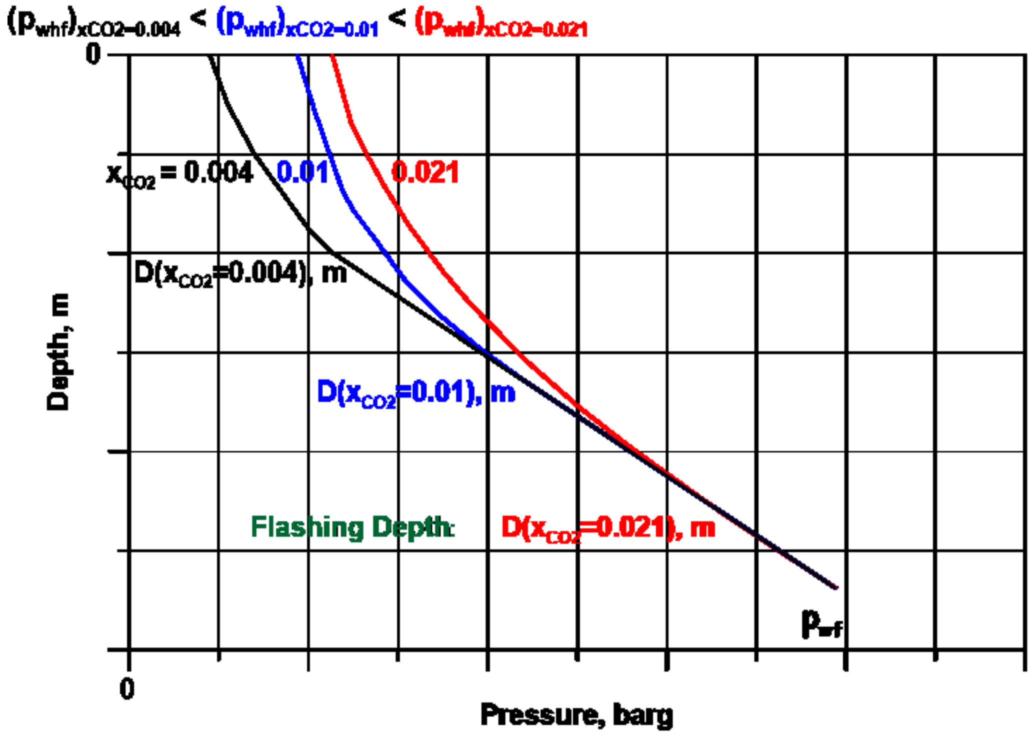

Figure 6: The schematic illustration of the effects of the CO_2 content of the production well on the wellhead flowing pressure and the flashing depth.

The drop in wellhead flowing pressure is critical from the turbine input pressure point of view. This should be avoided and delayed. High wellhead pressures are necessary for keeping power plants operational and maintaining high production flow rates. Wellhead pressures must remain above a certain threshold for power production since the fluid must be able to flow through a turbine. The design of the reinjection well locations and the safe distance to avoid early breakthrough of injection water between reinjection and production wells should consider this fact. The Zorlu Energy management is already aware of this and should take the necessary precautions.

Some of the present reinjection well locations are now questioned due to the observation of decline in CO_2 content of the produced water. This appears to be a result of the nature of the heavily explored parts of the geothermal system containing reinjection wells close to production wells, which causes the decline of CO_2 content in the water discharged from produced wells. In a compressed liquid reservoir such as Kızıldere, the net mass loss of the reservoir caused by exploitation is supplied by decompression of water and decline of the partial pressure of CO_2. The relocations of the reinjection wells are being discussed by the management.

Another aspect of the production performance of the Kızıldere geothermal field containing considerable amount of CO_2 is the change of reservoir CO_2 content. On determining the change of CO_2 at the reservoir scale the model of Hosgor et al. (2016). The following relationship is used:

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

where w is the mass flow rate (kg/s), x is the mass fraction of CO_2 (fraction), c is the compressibility (bar^{-1}), α is the recharge constant (kg/(bar.s)), κ is the expansion coefficient (kg/bar) and t is time (s). The recharge index and the expansion coefficient are the same as that used by Sarak et al. (2005). The subscripts have the following definitions; *0* represents the initial condition, *inj* represents the injection, *n* represents the net, *re* represents the recharge water, *p* represents the production and *t* represents total.

The flow rates used for the Kızıldere field have already been given in Figure 3. The recharge index and the expansion coefficient for the Kızıldere field have been determined from a history matching procedure to the pressure data obtained from observation wells and is not provided in this paper. The history matching is based on a trial and error procedure.

Two factors considered in change of CO_2 balance are the CO_2 contents of the natural recharge water and the reinjection water. Figure 7 shows the schematic illustration of the effects of the CO_2 content of the reinjection water and the existence of natural recharge on the reservoir water CO_2 content as a function of time. The model parameters α, κ and c_t for this schematic illustration are not provided here. The results given in Figure 7 should be used to understand the behavior of CO_2 change schematically. Our modeling study on the expected behavior of the Kızıldere geothermal field based on the actual field data is underway.

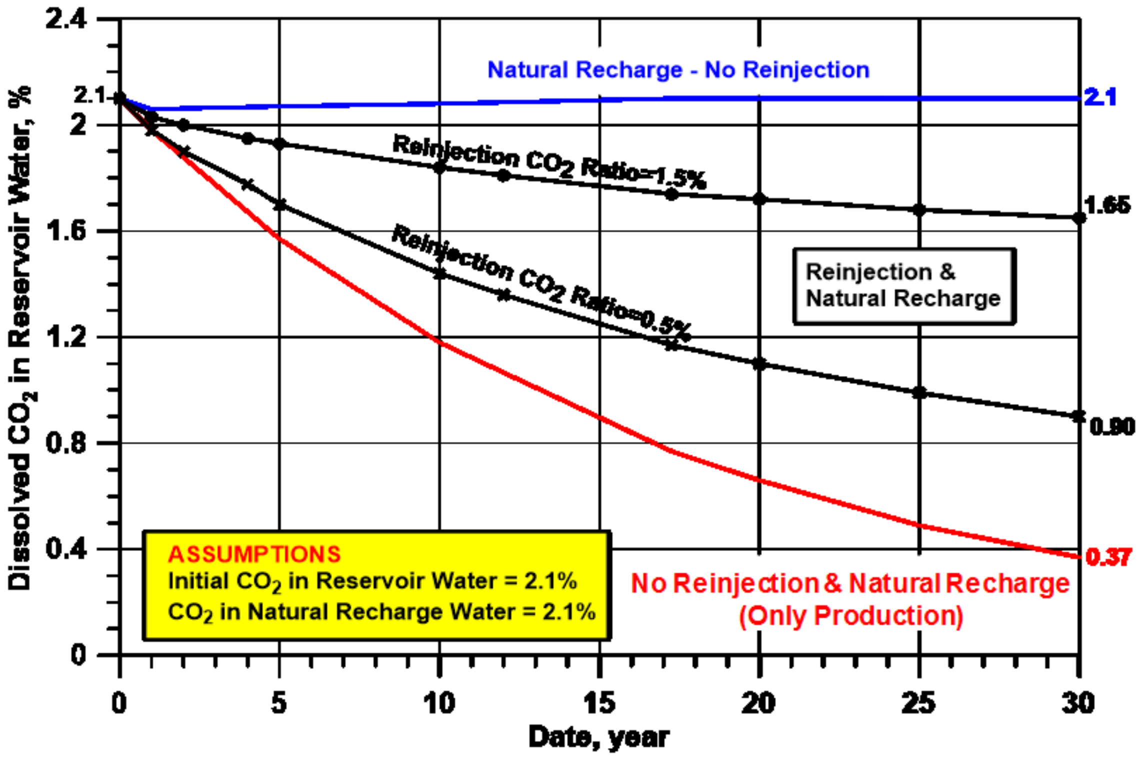

Figure 7: The schematic illustration of the effects of the CO_2 content of the reinjection water and the existence of natural recharge on the reservoir water CO_2 content as a function of time.

For the cases given in Figure 7, the initial mass fraction of CO_2 is assumed to be 0.021. Four cases are considered. Two cases (natural recharge-no reinjection and no reinjection & natural recharge) represent the extreme cases and their results are important only from the theoretical point of view. Other two cases considered represent the expected behavior of the Kızıldere field. For those two cases, the CO_2 content of the natural recharge water is assumed to be the same as the initial CO_2 content of the reservoir and stays the same throughout the operation of the field. The other two cases show the considerable effect of the CO_2 content of the reinjection water on the reservoir CO_2 change. The CO_2 contents of the reinjection water in these two cases are assumed to be 0.015 and 0.005, respectively. As it is clear from Figure 7, if the CO_2 content of the reinjection water is high, the reservoir CO_2 content is maintained and the sustainability success of the project increases. One of the goals for a sustainable management is to maintain the reservoir p ressure by reinjection. However this eventually causes a drop in the reservoir CO_2 content. As discussed previously, such a drop in CO_2 content of the produced water causes detrimental effects on the flashing point pressure and the wellhead flowing pressure. Hence it becomes very important to know the amount of CO_2 present in the reservoir at any time.

3. CONCLUSIONS

Zorlu Energy is the company that currently operates the Kızıldere geothermal field for power production. Zorlu Energy has managed to effectively develop the field in a sustainable manner so far. The study presents a portion of the initial results of an ongoing project to assess the Kızıldere field performance and to determine optimal strategies for a sustainable management for power generation. The ongoing project deals with various aspects of reservoir engineering and flow in the wells. However this study gives only the portion where the effects of carbon dioxide on the reservoir performance is given. The following conclusions are obtained:

- CO_2 data obtained from wells show that as the wells get deeper, the CO_2 mass fraction increases as well.

- The average CO_2 production is currently increasing with time. This is an expected result since as new wells are drilled, the wells are targeted towards deeper zones in the Kızıldere field. This results in higher mass fractions of CO_2.

- In some of the wells that are located close to the reinjection wells, considerable drops in CO_2 mass fractions have been observed. These sudden drops in CO_2 content coincide with the time as that of the reinjection operations started for the KZD-2 power plant. This suggests that the reinjection water which contains no CO_2 has managed to reach these wells and as a result cause a decrease in CO_2 mass fraction due to the mixing. The injected water acts in this case as if it were a tracer. Hence, it is possible to determine inter well connectivity by way of analyzing from which well breakthrough of the injected water occurs.

- The amount of CO_2 is extremely important when flow in wells is considered. It is the dominating factor for the flashing point depth and the wellhead pressure. High wellhead pressures are favored for power plants. A decrease in the CO_2 content will eventually cause a decrease in the wellhead pressure and hence must be accounted for in making future predictions.

- An overall decrease in the CO_2 mass fraction is expected in the long term. This is caused mainly by the reinjection water.

REFERENCES

Hosgor, F. B., Tureyen, O.I, Satman, A. (2016). Keeping inventory of carbon dioxide in liquid dominated geothermal reservoirs. *Geothermics*, **64**, 55-60.

Sarak, H., Onur, M., Satman, A. (2005). Lumped-parameter Models for Low Temperature Geothermal Reservoirs and Their Applications. *Geothermics*, **34**, 728-755.

Satman, A., Tureyen, O. I., and Korkmaz Başel, E. D., (2016). Modeling Study on the Production and Reservoir Performance of the Kizildere Geothermal Reservoir Denizli and Aydin Provinces, Turkey. *Unpublished Report*, Istanbul, Turkey

ACKNOWLEDGEMENTS

The authors would like to thank ZORLU Energy for allowing to publish this work and for the opportunity to work in the project.