Proceedings World Geothermal Congress 2020+1
Reykjavik, Iceland, April - October 2021

The Carbon Dioxide Behavior of the Kizildere Geothermal Field

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Keywords: Kizildere geothermal field, carbon dioxide

ABSTRACT

The Kizildere Geothermal Field is located in Western Anatolia in the Agean region close to the town of Denizli. It sits on the Buyuk Menderes Graben where most of Turkey's power producing geothermal activity is. Power production in the Kızıldere field has started in 1984 with an installed capacity of 15 MW_e, however, over the past ten years, there has been a significant increase which has led to a current installed capacity of 260 MW_e through 4 separate power plants.

There are two factors that provide assistance in production. The first is the carbon dioxide in the produced geothermal fluid. The carbon dioxide acts to provide higher wellhead flowing pressures because of its high partial pressure. The carbon dioxide content of the Kizildere Geothermal Field varies depending on the depths of the production wells where an increase with depth is observed. The other factor that aids production is the reinjection operations carried out in the field. The role of reinjection is basically to maintain the pressure of the reservoir.

It has been observed that the carbon dioxide contents of the production wells and of the overall Kızıldere reservoir have been decreasing considerably due to the reinjection operations. In this study we provide an analysis of the decline trend of the carbon dioxide content in the Kızıldere geothermal Field. The study first considers the overall performance of the carbon dioxide behavior in the field. Then the behavior is analyzed this time considering the locations of the production and reinjection wells. Results show that the carbon dioxide content of the reservoir will continue to decline based on the reinjection ratio.

1. INTRODUCTION

Turkey is endowed with vast geothermal resources up to about 250 ^oC reservoir temperature that are thus suitable for various utilization technologies. While government-sponsored research and exploration in Turkey began in the 1960's, particularly most of the commercial development of geothermal power has occurred in the last 14 years. This has led to the installation of power plants with an installed capacity of1 347 MW_e (as of end of Nov. 2018), all in the western part of the country. In addition, Turkey is now one of the leading countries of the world in geothermal direct-use applications, having more than 3 400 MW_t of direct-use installed capacity.

Geothermal fluids in Turkey are characterized by unusually high carbon dioxide (CO_2) contents since carbonate rocks are commonly the dominant host rock type. Almost all of the reservoir waters in Turkey contain considerable amounts of dissolved carbon dioxide..

Despite the high initial CO_2 content of the produced water, the geothermal production wells have experienced gradual decline of CO_2 content with time. The declining CO_2 content of the produced water is linked to degassed brine that is reinjected into the reservoirs. Production of the mixture of the increasing ratio of reinjected brine w/o CO_2 to original reservoir water yields declines in CO_2 concentration in discharge from production wells. Declining CO_2 content of the produced fluid affects well productivity over time. 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.

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 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. 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. Zorlu Energy developed the field further and extended the total power capacity up to 260 MW_e with the addition of the third power plant (KZD-3, U-1 & U-2) in March 2018.

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 As compared to well locations in 2017 (Satman et al., 2017) some wells on the western region of the field were converted to be reinjection wells in order to supply pressure support for the nearby production wells. Such a configuration with reinjection wells on the eastern and western flanks is believed to work more efficiently based on our reservoir modeling and 3-D subsurface temperature distribution studies indicating the natural recharge entry from the southern-deeper part of the reservoir.

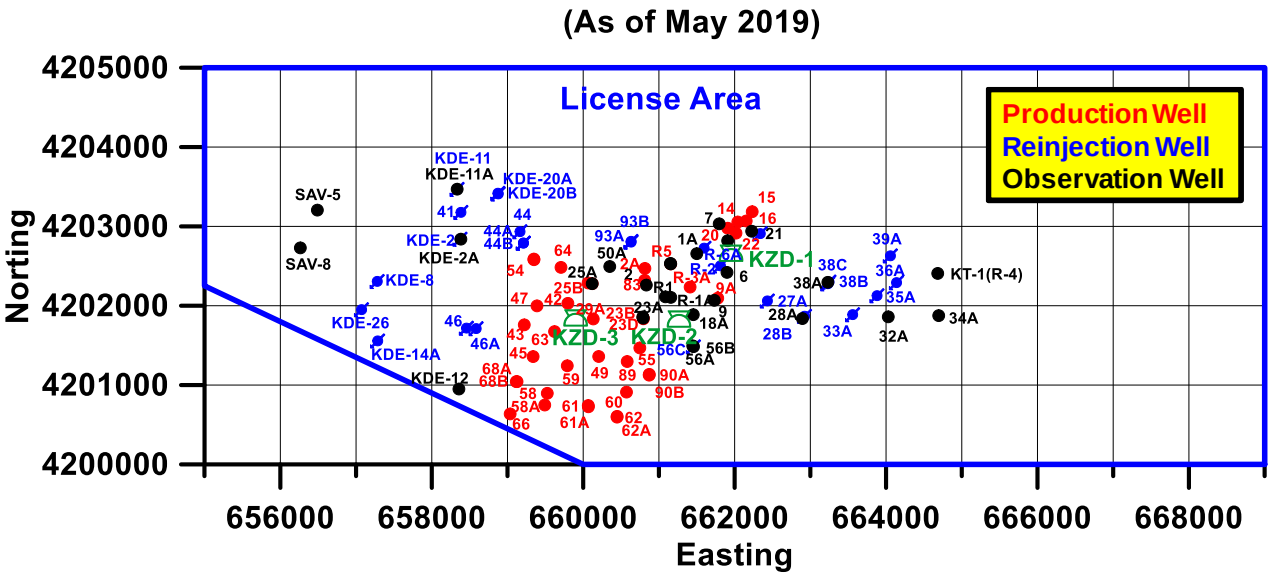

Figure 1: The locations of the wells in the Kizildere geothermal field.

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. New deep wells have been drilled up to depths of 3.5 km in the field.

Although the Kızıldere resource has a reasonably high temperature between 200 and 245 ºC, 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 1-10 % range by weight.

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. The carbon dioxide content of the water varies depending on the depths of the production wells where an increase with depth is observed This is followed by the discussion of the decline of CO_2 content of the produced brine due the reinjection effects.

2. THE CARBON DIOXIDE BEHAVIOR OF THE FIELD

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. 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 initial CO_2 contents for various wells. The CO_2 contents in Figure 2, x_{CO2}, represent the initial wellhead values measured just after the completion of wells if available. If such a measurement is not available, then the estimated value is obtained by analyzing the pressure and temperature properties of first ever static test and the inflow depth observed from the dynamic test. Whichever larger is assumed to be the initial value. The initial values range between 0.011 and 0.10 (fraction, kg CO_2/kg brine).

It is known that CO_2 is highly soluble in water and its solubility is highly sensitive to changes in pressure and temperature. Both theoretical and field data show that, at any given temperature, increasing pressure will increase solubility. At moderate temperatures between 150 and 200 ºC solubility seems to be less sensitive to temperature changes. So, for higher pressure, moderate temperature reservoirs such as the Kizildere reservoir, higher CO_2 solubility may be expected. The CO_2 gas comes out of solution as soon as the pressure is lowered to the flashing point pressure during the upward flow in the production wellbore and the resulting gas becomes the potential CO_2 emission from the power plant.

The increase in the CO_2 content is expected for the deeper and higher pressure wells drilled at the recent development stages. The CO_2 content increases as the depth (or bottom hole static pressure) of the well increases. The wells to the right of Figure 2 represent the wells with gradually increasing depths. The CO_2 contents of the old and shallow wells, about 800 to 1000 m deep, produced for KZD-1 plant as shown on the left of Figure 2 are relatively low, to be in the 1-2 weight % range. The recently drilled deep and hot wells showed CO_2 contents between 0.04 and 0.10. Some wells (with depths in between 3300 and 3500 m) have outstanding CO_2 contents close to 0.10. Although some necessary geological and other supporting evidences are still lacking, the analysis of the temperature and pressure profiles of static and dynamic tests indicates that the flow for some of these 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 monitored and measured periodically. 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 3 illustrates the CO_2 content decline history for Well KD-90A. The theoretical and original CO_2 content for KD-90A in Figure 3 corresponds to the initial CO_2 content. This value is estimated from the solubility-temperature-pressure relationship provided by Duan et al. (2003 and 2005) and Pistone et al. (2011). The pressure and temperature values used (262 barg and 230 ºC) are taken from the static test for the inflow depth of 3134 m. As demonstrated in Figure 3 the initial CO_2 content obtained for those pressure

and temperature values is 0.088 (or 8.8%). Figure 3 also shows the decrease in the CO_2 content by time. The decrease in the CO_2 content from 0.088 to 0.018 is due to the mixing of high CO_2 reservoir water and the reinjection water without or negligible CO_2 content after the breakthrough of the reinjection water. It is a reasonable and expected result.

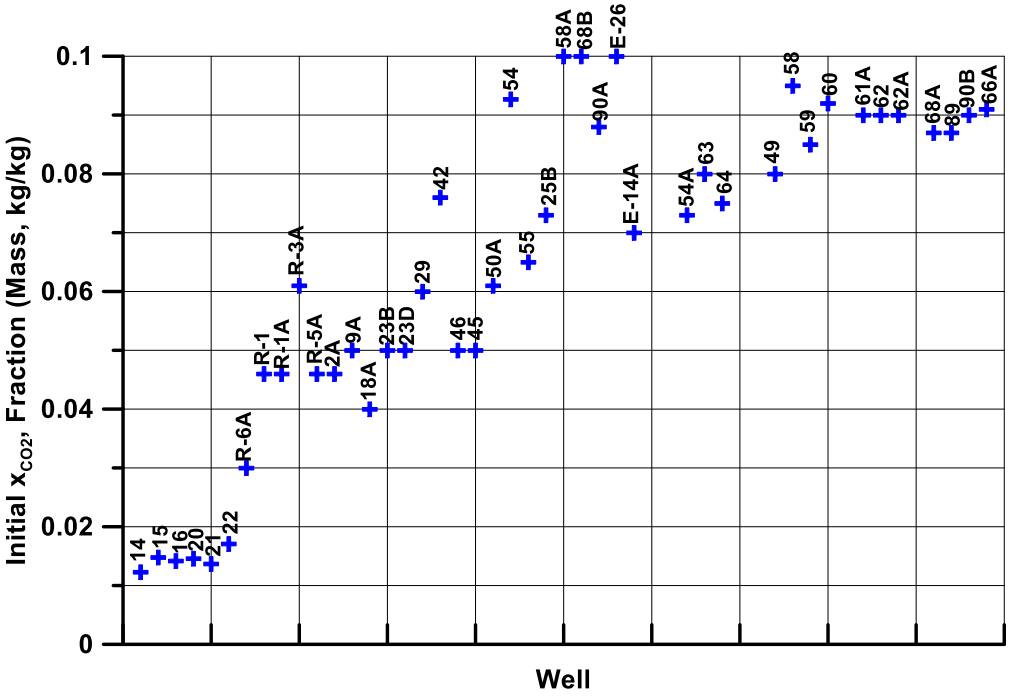

Figure 2: The initial CO_2 contents for wells in the Kizildere Geothermal Field.

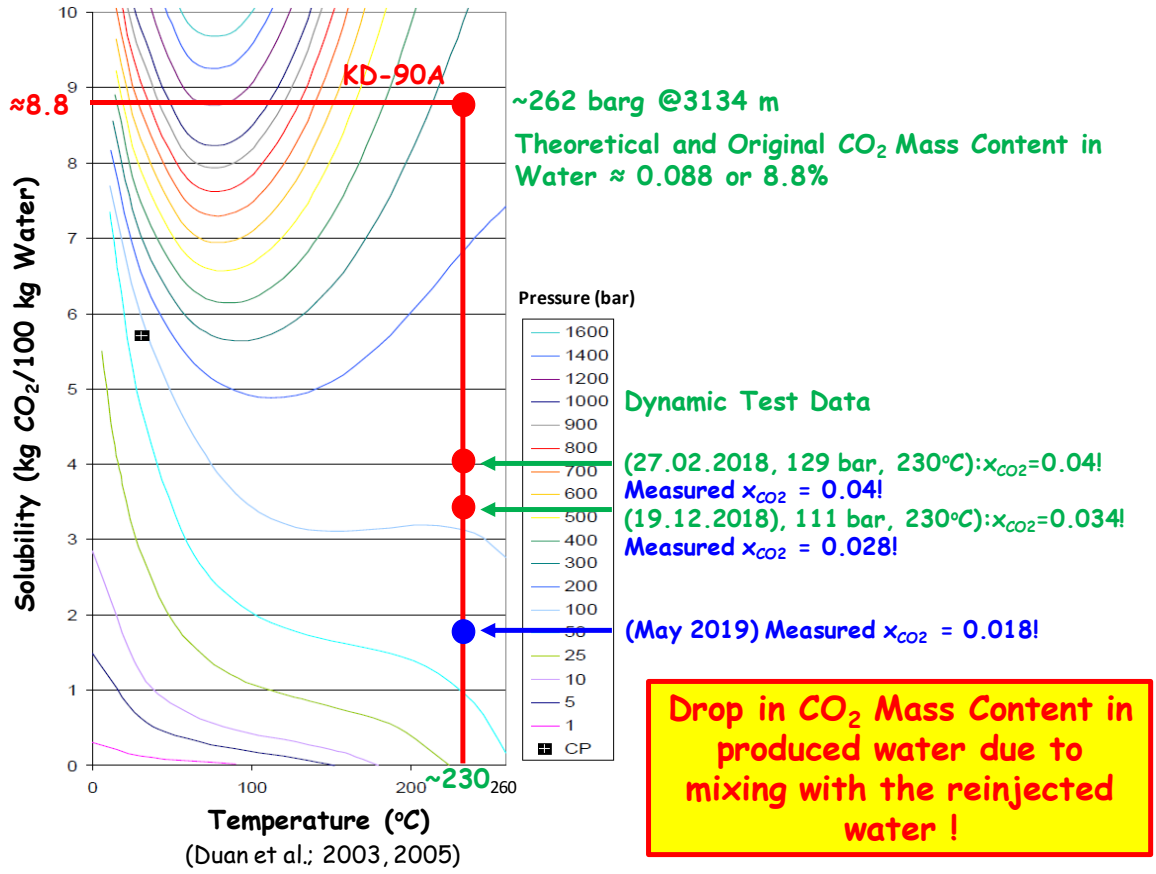

Figure 3: The CO_2 content decline history for Well KD-90A.

Figure 4 shows the changes of CO_2 contents of wells with time. The initial CO_2 contents and as well as the ones measured at various times are given for wells. Data points for an individual well correspond to x_{CO2} values measured (or estimated from dynamic test analysis) at various time intervals. All wells exhibit declines in CO_2 content values with time. Wells with sharp declines are the wells closer to the reinjection region.

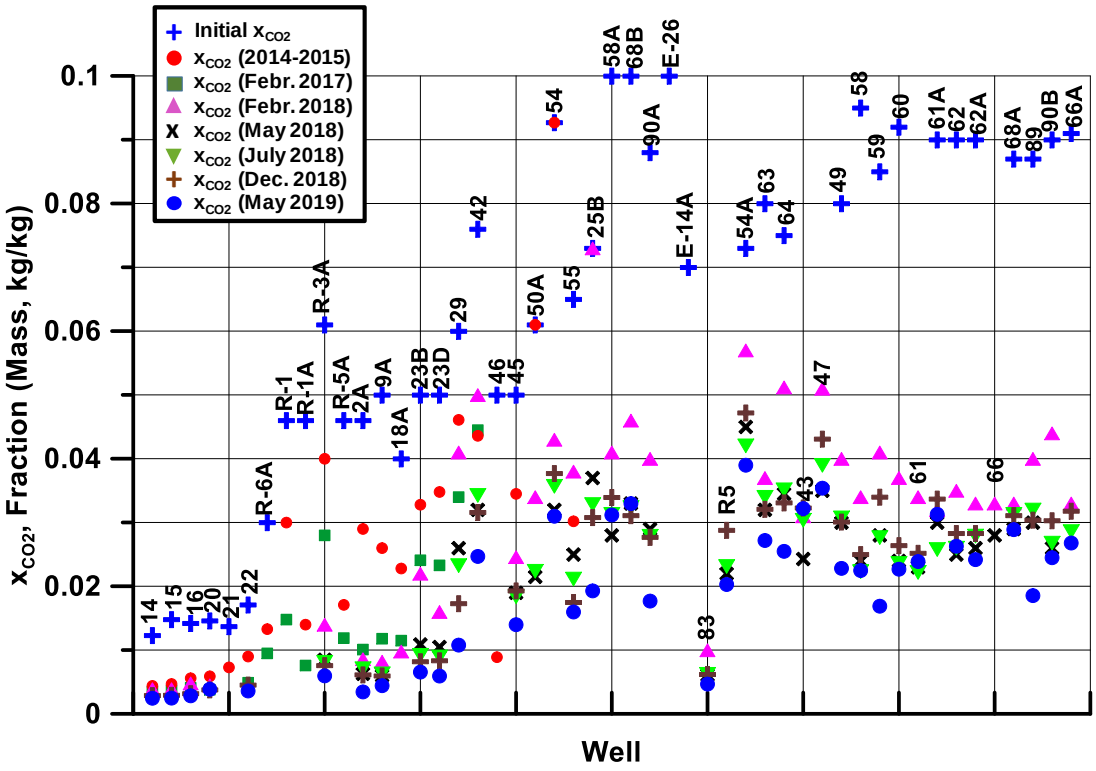

Figure 4: The change of CO_2 contents of wells with time.

The change of reservoir CO_2 content during the production period of a liquid dominated geothermal field containing considerable amount of CO_2 is discussed by Hosgor et al. (2016). Field results show that the carbon dioxide content of the production wells (and of course of the reservoir) continues to decline based on the reinjection ratio. However there is a limit for this decline if the volumetric average value of the reservoir CO_2 content is considered.

The following relationship exists in between $x_{CO2(Final)}/x_{CO2(Initial)}$ and Reinjection Ratio ($RR = w_{inj}/w_p$) where w_{inj} and w_p represent the total reinjection rate and the total production rate, respectively, at steady state conditions:

$$\frac{x_{CO2(Final)}}{x_{CO2(Initial)}} = \frac{(x_{CO2})_{ss}}{(x_{CO2})_{re}} = 1 - RR \qquad (1)$$

where $(x_{CO2})_{re}$ is the mass fraction of CO_2 in recharge water. Practically, it is the average reservoir value of the initial x_{CO2}. Thus the limiting value of the volumetric average of the reservoir CO_2 content can be estimated from Equation 1.

Figure 5 illustrates the change of $x_{CO2(Final)}/x_{CO2(Initial)}$ for wells with time. The x_{CO2} values measured for wells at various dates as given in Figure 4 are used to determine $x_{CO2(Final)}/x_{CO2(Initial)}$ for wells at corresponding dates. As of the end of May 2019, RR is 0.76 which means 76% of the produced fluid is reinjected. Then the value of $x_{CO2(Final)}/x_{CO2(Initial)}$ is expected to reach to 1-0.76=0.24, which represents a field average, as the limit for the steady state conditions. As observed in Figure 5 wells exhibit this characteristic. Wells closer to the reinjection wells have already reached this steady state limit, even some wells are more affected by reinjection and have values lower than the field average of 0.24. The $x_{CO2(Final)}/x_{CO2(Initial)}$ ratio of the wells further away from the reinjection region still continue to decline.

As of May 2019, the total production rate from the field is 6900 t/hr, the total reinjection rate 5300 t/hr, the reinjection ratio 0.76, and the CO_2 content in the produced fluid (the flow rate weighted average CO_2 content) is 0.02 (or 2.0%). An average initial x_{CO2} value for the field can be determined to be 0.083 by using Equation 1. This calculated value is consistent with an average of the initial x_{CO2} values of the respected production wells given in Figure 2, considering that the majority of these production wells are the relatively deep wells located on the right side of Figure 2.

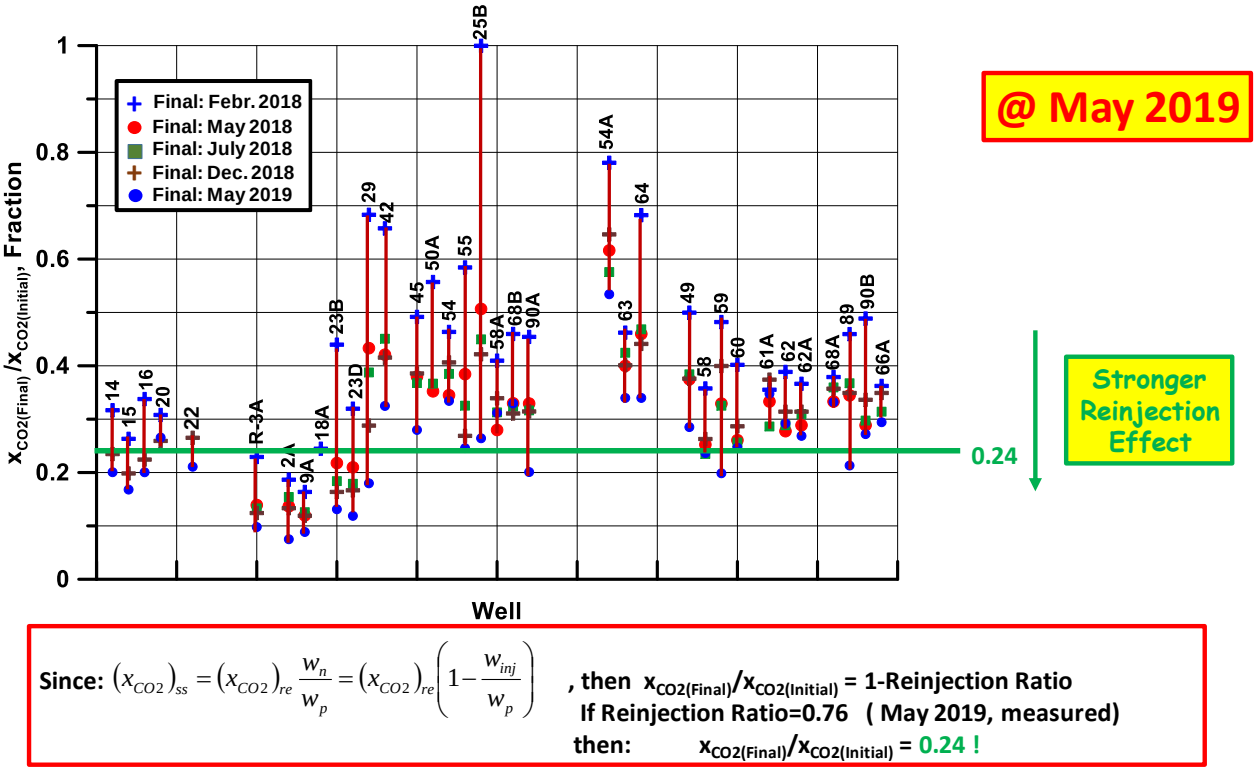

Figure 5: The change of $x_{CO2(Final)}/x_{CO2(Initial)}$ for wells with time.

One of the detrimental effects of the CO_2 content drop in produced water occurs on the dynamic pressure profile in the wellbore. An in-house wellbore simulator was utilized to study the effects of reservoir pressure drop and change of x_{CO2} on wellhead flowing pressure, p_{whf}. The schematic illustrations of the effects of the reservoir pressure drop and the CO_2 content drop of the production well on the wellhead flowing pressure are given in Figure 6. Figure 6 (a) shows how p_{whf} and w (production mass flow rate) are affected by the drop in reservoir pressure assuming brine production at a constant x_{CO2}. The Δp value corresponds to reservoir pressure drop and the results in Figure 6 are given for Δp of 11, 21, 31, and 41 bars. Assuming the bottom hole flowing pressure stays constant, five profiles are shown in Figure (b), for mass fractions (x_{CO2}) of 0.01, 0.02, 0.025, 0.0324 and 0.045. 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.

Based on the results obtained from the modeling study given in Figure 6, the following conclusions are valid: (1) drop in reservoir pressure (or increase in Δp) causes decline in wellhead flowing pressure for constant x_{CO2}, (2) drop in x_{CO2} causes decline in p_{whf} for constant reservoir pressure, and (3) simultaneous drops both in reservoir pressure and x_{CO2} cause greater declines in p_{whf}.

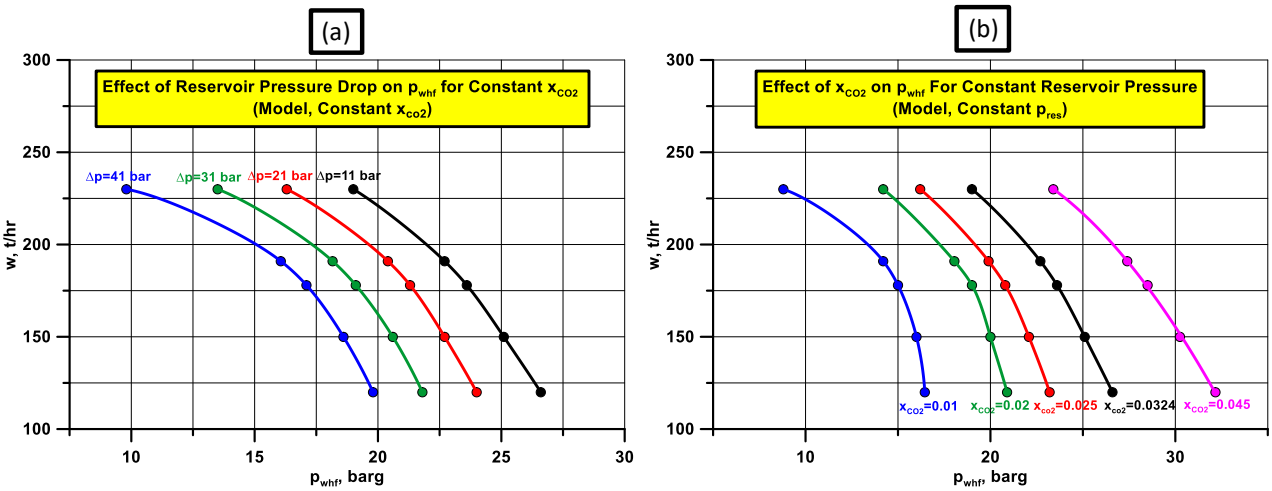

Figure 6: The effects of reservoir pressure drop and x_{CO2} drop on wellhead production performance.

3. CONCLUSIONS

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

- An overall drop in the average CO_2 mass fraction of the reservoir is expected in the long term. This is caused mainly by the reinjection water and the limiting value of this drop is determined by the reinjection ratio (RR).
- CO_2 data obtained from wells show that the CO_2 mass fraction content of the produced fluid increases as the wells get deeper.
- This is an expected result since as new wells are drilled, the wells are targeted towards deeper zones with greater reservoir pressure in the Kızıldere field. This results in higher initial mass fractions of CO_2.
- In production wells that are located closer to the reinjection wells, considerable drops in CO_2 mass fractions have been observed by time. The drops in CO_2 content coincide with the breakthrough time of the reinjection water. This suggests that the reinjection water which contains no CO_2 has managed to reach these wells and as a result causes a decrease in CO_2 mass fraction due to the mixing.
- The CO_2 content of the produced water 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.

ACKNOWLEDGEMENTS

The authors would like to thank ZORLU Energy for allowing to publish this work and for the opportunity to work in the project. Particularly cooperation with Ali Kındap, Abdurrahman Yasar and Erdinc Senturk are highly appreciated.

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