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CO_2 Decline in Alaşehir (Turkey) Geothermal Reservoir

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ABSTRACT

Reinjection of gas free of brine into the peripheries of a geothermal reservoir may gradually decline non-condensable gas (NCG) concentration in the reservoir fluid during the operation of geothermal power plants. As a result, gradually decreasing gas emissions can be observed. In this study, we use separator data to calculate produced CO_2 amount in the reservoir fluid. The data used is from the Alaşehir geothermal area that is certainly not the one and only target for geothermal production in Turkey. Data obtained from 7 wells covering two years of production showed that reinjection of gas free brine into the peripheries of the geothermal reservoir declined CO_2 concentration in the reservoir fluid. It has also been observed that the commissioning of neighbor power plants has a significant effect on the produced CO_2 amount.

1. INTRODUCTION

Geothermal energy is considered as one of the renewable, environment friendly and base load energy resources. In the recent decades, investments in the geothermal industry have achieved great acceleration throughout the world. Especially, Turkey is one of the most active countries that has started to unlock its geothermal energy potential for electricity generation. The specific incentives provided by the Turkish government has played the main role in this achievement.

Low to moderate enthalpy of geothermal reservoirs are found in the Western Turkey. The initial non-condensable gas (NCG) concentration of these geothermal reservoirs is somewhat higher than that of the world's average value. Carbon isotope tests indicated that CO_2 originates from meteoric water-rock interaction instead of magmatic or sedimentary origin (Haizlip et al., 2016). However, as the fields were put into operation, it was observed that significant amount of NCG decline has been experienced due to the injection of gas free brine into the reservoir. Alaşehir geothermal field located 120 km east of İzmir (Figure 1) is one of the most important fields that shows the effect of reinjected brine on the decline of produced CO_2. These effects are studied in Aydin and Akin (2018) in detail. Carbon dioxide is monitored as a natural tracer to understand flow paths of reinjected brine. Aydin and Akin (2019) identified flow paths in the reservoir by using spatial distribution of CO_2 production from the wells in Alaşehir geothermal field.

Figure 1: Alaşehir geothermal field location.

Since NCG is one of the major components of geothermal fluid, it has important effects on reservoir modeling studies. In order to have a better reservoir evaluation, it is crucial to know the correct NCG concentration in the reservoir. In geothermal applications, NCG is measured in the surface lines by using flowmeters or the bubbling method. Then, it is recalculated to the reservoir conditions by using steam fraction at production line. The accurate way is to take downhole liquid samples below flashing depth and analyze them using appropriate laboratory equipment. However, downhole sampling and the corresponding laboratory measurements are not practical.

2. NCG MEASUREMENTS IN GEOTHERMAL RESERVOIRS

Liquid dominated geothermal fluid is found in the Alaşehir geothermal reservoir. As the geothermal water rises in the well, with the decrease of the pressure in the fluid, steam and dissolved gases like CO_2 pass into the gas phase. When the geothermal fluid reaches the surface, it consists of steam, water and non-condensable gas components under surface production conditions. In order to determine the characteristics of each phase, separators and condensers at the well heads are used. The most common methods of measuring NCG and steam ratio in gas phase are gas bubbling and gas flowmeter methods. These measurements are based on similar methodology. The method that we present here, is also based on ideal gas theory, but it is very simple and straight forward to measure the gas weight in the production wells.

2.1 Gas Bubbling Method

In this method, the gas coming from gas outlet of a mini separator and passing through a condenser is used. As the steam condenses through the condenser, the carbon dioxide and water (condensed steam) are separated. The water accumulates in the gas washing bottle whereas carbon dioxide gas passes to the graduated cylinder simultaneously (Figure 2-a). The volumetric flow rate of the gas phase is determined by counting the bubbles passing at a certain time. The amounts of accumulated water in the gas washing bottle and the amount of CO_2 determined from the graduated cylinder are in proportion to each other. This method is not accurate as it is usually affected by operator performance. This method does not provide consistent results, especially in wells with slug flow type.

2.2 Gas Flowmeter Method

The logic behind this method is similar to the bubbling method but instead of counting bubbles, a gas flowmeter is used to measure the gas amount (Figure 2-b). The common procedure is to sample the gas amount and steam condensate volume separately by using a condenser, a gas flowmeter and a steam sampling port, which is also used in the standard practice for gas sampling in two phase geothermal fluid flow (ASTM E1675 -95a). NCG flowmeters that operate based on heat transfer and first law of thermodynamics are used. The temperature difference between the two resistance temperature detectors is used to measure the gas volumetric flow. Due to temperature changes, this method is very sensitive to seasons. Since the temperature difference occurs because of heat carrier gas molecules, it is required to know the gas composition passing through the flowmeter. Thus, it may lead to inaccurate measurements from well to well because of changing gas compositions. Once the gas concentration in the steam phase is calculated (Equation 1), it is simply corrected to the gas weight at reservoir conditions by using steam fraction at the wellhead (Equation 2 and 3). The assumptions are as follows: (1) at the sampling conditions the amount of dissolved gas in brine is negligible compared to the total gas amount, (2) almost all of the gas is composed of CO_2 and (3) CO_2 exists only in the steam phase.

(a) (b)

Figure 2: CO_2-steam ratio measurement methods and related equipment, a) bubbling method and b) Flowmeter method.

$$X = \frac{n_{CO_2}}{n_{H_2O}} \tag{1}$$

$$SF = \frac{\mathrm{E}_{\mathrm{Casing}} - E_{Brine(L)}}{E_{Steam} - E_{Brine(L)}} \tag{2}$$

$$GW_{\mathrm{Re}servoir} = X * SF * 2.44 \tag{3}$$

Where X denotes mole fraction, SF represents steam fraction. E_{casing} , $E_{Brine(L)}$ and $E_{Steam(v)}$ stand for enthalpy of liquid at the top of feeding zones, enthalpy of brine and steam phases at sampling condition respectively. Overall, gas weight at reservoir condition ($GW_{Reservoir}$) is the product of X and SF.

These methods require tedious work and it takes a while to correctly measure gas concentration in geothermal wells. By using the theory of Dalton's Law, produced NCG can be continuously obtained.

2.3 Gas Weight Measurement by Using Dalton's Ideal Gas Law

In the geothermal power projects that have individual separators on production well pads, brine and steam are separated, and they flow through separate pipelines to the power plant. In such cases, it is easy to record pressure and temperature values of steam phase and brine separately. Thus, NCG-steam ratio of the well can be calculated continuously by using Dalton's Law, which is based on the relation of partial pressure ratio and mole fraction. Generally, instead of using an individual separator on a well pad, it is cost effective to construct a gathering system that collects all of the produced fluid in a central separator. In such a gathering system, steam, NCG and brine simultaneously flow in the same production line, which makes it difficult to have laminar flow conditions. In gathering systems, by using Dalton's Law, only the average value of the field can be obtained using data collected from the steam line, which is after the central separator. Thus, Dalton's Law may lead to wrong interpretations for individual wells in gathering systems, but it gives good results for obtaining field average value at the separation station.

The Dalton's Law states that the total pressure exerted by a mixture of gases is equal to the sum of the partial pressures of the gases in the mixture. From the partial pressure of a certain gas and the total pressure of a certain mixture, the mole ratio of gases can be found. The mole ratio describes the weight fraction of the mixture is a specific gas. The gas composition is required to calculate the partial pressure of each gas. In the geothermal steam line, the total exerted pressure is the summation of saturated steam pressure and NCG partial pressure (Equation 5). The total gas pressure is measured with a proper pressure transducer in production line. Saturated steam pressure can be calculated from an empirical formula, which is given in Equation 4 (Central Research Library, 1993). Steam does not behave as an ideal gas at high temperature and pressure. Thus, it should be corrected by using real gas equations such as Peng and Robinson (1976) or Redlich and Kwong-Soave (1949). It was observed that gas weights found by using ideal gas and real gas equations showed similar results. For simplicity, the ideal gas approach can be implemented. Partial pressure of NCG can be obtained simply by subtracting water pressure from the total exerted pressure (Equation 5). Thus, by using the relation of pressure ratio and mole fraction, gas weight can be found using Equation 6. Since the Alaşehir reservoir NCG content is 98% CO_2 (Table 1), NCG is assumed as pure CO_2 in the calculations.

Table 1: NCG Composition by Weight % in Alaşehir Geothermal Field.

Gas Type	Carbon dioxide	Hydrogen Sulfide	Nitrogen	Methane	Argon	Oxygen	Hydrogen	Helium
Dry Volume %	98.36	0.003	0.61	0.93	0.004	0.002	0.093	0.00002

$$P_{H_2O(v)} = \exp\left[\frac{A + CT + ET^2}{1 + BT + BT^2 + FT^3}\right] \tag{4}$$

Where;

A= -7.395489709, B= 4.884152*10^{-3}, C= 3.6337285x10^{-2}, D= 4.308960x10^{-6}, E= 2.651419x 10^{-5}, F= -4.14934x 10^{-9},

T= Temperature (^{o}C), $P_{H2O(g)}$ = (Mpa)

$$P_{Total} = P_{CO_2} + P_{H_2O(g)} \tag{5}$$

$$\frac{P_{CO_2}}{P_{H_2O}} = \frac{n_{CO_2}}{n_{H_2O}} \tag{6}$$

Once, saturated steam pressure is calculated using Equation 5, the partial pressure of NCG can be obtained by subtracting the steam pressure from the total gauge pressure. The next steps are the same as for the gas flowmeter meter method. It was observed that the initial gas weights of the production wells were in the range of 2% to 3% (Figure 3). It has been observed that the gas content of the produced stream remained almost constant before the injected gas free brine reached the production wells. This initial period is indicated by blue lines in Figure 3. After this period, injected gas free colder water diluted the reservoir brine and the CO_2 content of the produced stream started to decline as indicated by yellow solid lines, which show matches obtained by using the Arp's decline curve analysis models. Details of the Arp's model and the match procedure are described elsewhere (Aydin et al, 2020). Logarithmic decline was not as good as the Arp's model. Using Arp's model, it is possible to predict future CO_2 production provided that operational conditions, such as the wellhead pressure, do not change. The gas decline rates accelerated with commissioning of a double flash type power plant at September 2015, near the existing binary geothermal power plant (GPP). Further decrease has been observed when another binary geothermal power plant started production in September 2016. Commissioning of this binary GPP created oscillations in the produced CO_2, possibly due to the sudden decrease of reservoir pressure. A common reason of such oscillations is slug flow of CO_2 in horizontal pipes connecting the wells to separators. It has been observed that oscillatory behavior continues until now. Increase in the pressure difference between injection and production area has increased the velocity of recirculated brine in the reservoir. Thus, gas free brine reached production wells faster compared to the situation when the neighbor power plant was not operational. This resulted in a gradual NCG decline, which was monitored continuously by using steam line pressure and temperature data. Average gas weight of the field was also continuously monitored in the steam line of the central separator of the flash type power plant (Figure 4). It has been observed that gas flow meter measured, and calculated values are in good agreement with each other. Makeup wells drilled to compensate decreasing production showed faster NCG decline, suggesting that these wells are supported by reinjection. It should be noted that NCG production showed slug type fluctuations in some wells (i.e. See Figure 3 Ç-1).

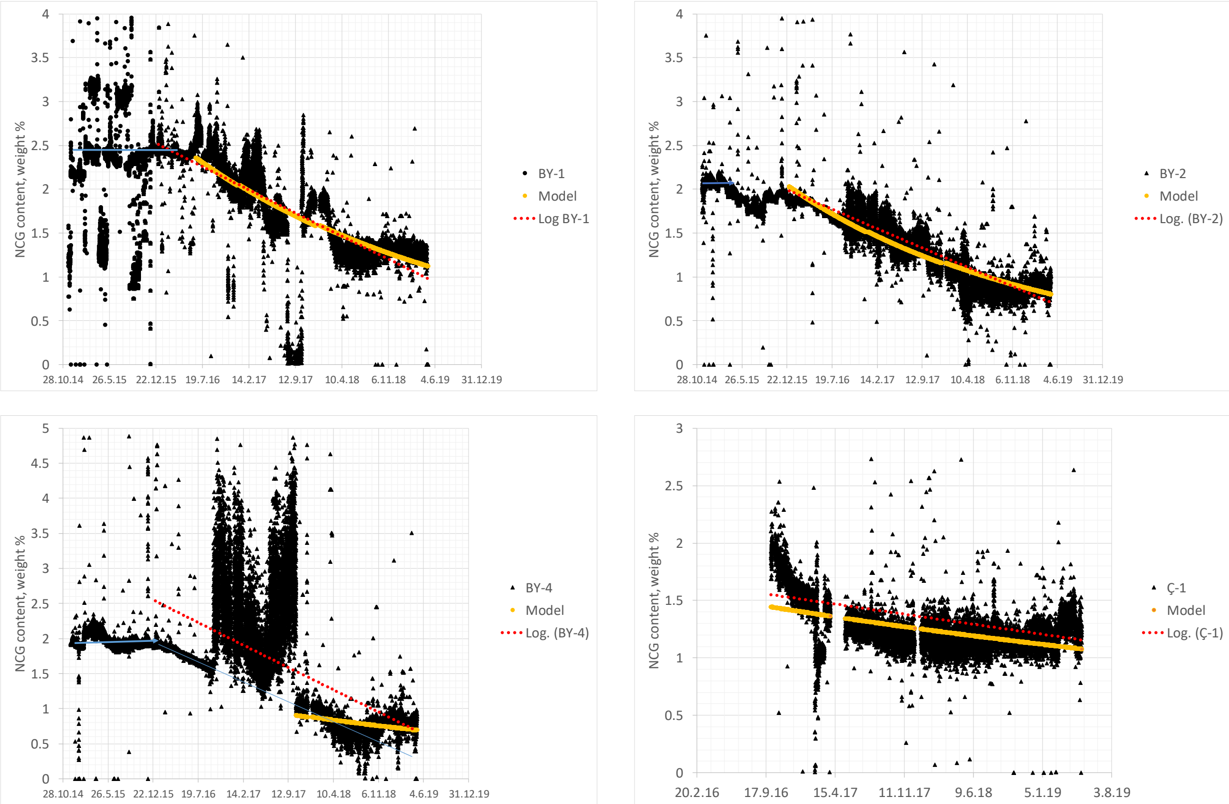

Figure 3: NCG Weight of Well BY-1, BY-2, BY-4 and Well Ç-1.

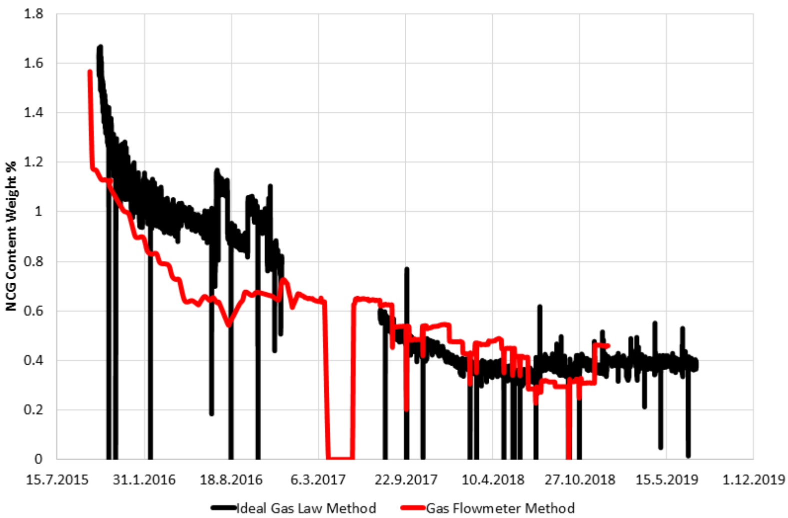

Figure 4: NCG Average Weight of the Field (Wells Supported by Reinjection Brine).

3. CONCLUSION AND DISCUSSIONS

In this study, we continuously calculated NCG weight percentage in the Alaşehir geothermal wells by using Dalton's ideal gas law. Although, saturated steam does not fully behave as an ideal gas, this method can still be used to obtain insight about the NCG behavior near production wells. The ideal gas approach needs only pressure and temperature recordings of gas phase. Thus, it is not affected by seasonal changes. It can be used to confirm gas flow meter measurements. Unlike the gas flow meter method, in the ideal gas approach less manpower is required, and it enables monitoring the well performance and reservoir evaluation online. Using this method, well and field NCG weight percentages were calculated. It has been observed that:

1) The initial gas weights of the production wells were in the range of 2% to 3%.
2) The NCG content of the produced stream remained almost constant before the injected gas free brine reached the production wells. After this period injected gas free colder water diluted the reservoir brine and the NCG content of the produced stream started to decline.

3) Average gas weight of the field obtained from gas flow meter measurements and calculated using steam line of the central separator of the flash type power plant are in good agreement with each other.
4) Gradual NCG decline rates can be monitored effectively by using steam line pressure and temperature recordings. This information can then be used to identify reinjection brine flow paths.

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