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Mathematical Modeling of Geothermal CO_2 Production

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ABSTRACT

Turkey is perhaps the most active country in developing geothermal energy utilization for the last decade. Turkey's geothermal reservoirs include relatively higher NCG (Non-condensable Gases) compared to the word's average values. The majority content of non-condensable gases produced from Turkish geothermal reservoirs consists of mainly carbon dioxide (CO_2). The origin of CO_2 in these geothermal systems is usually meteoric and magmatic. In Turkey, the initial measurement of CO_2 in geothermal reservoirs is higher than weighted average of all geothermal fields in the world. However, as the fields were put on production, a gradual decline of CO_2 production has been observed in most of the fields because of reinjected brine. This study reports modeling of the decline of CO_2 production from selected geothermal fields in Turkey. It has been observed that CO_2 decline can be modeled using hyperbolic decline model. The reasons for the decline and the effects of decline on the fields' performance are also analyzed in this study.

1. INTRODUCTION

Non-condensable gases (NCG) found in geothermal systems can be originated from different sources. Sedimentary, magmatic and meteoric water-rock interactions are among the main sources of naturally occurring NCG. Carbon dioxide constitutes the major component of NCG in geothermal reservoirs in Turkey. It has been found that more than 98 % of NCG is CO_2, as obtained from carbon isotope tests. Haizlip et al. (2016) stated that carbon isotope tests in Alaşehir geothermal field showed that CO_2 is due to meteoric water-rock interaction rather than magmatic. They also emphasized that carbonate-dominated metamorphic rocks, including marbles, dolomitic marbles and calc-schists, dominate reservoir rocks. The calcite in these rocks provides an abundant potential source of CO_2 when the calcite equilibrates with water.

In the utilization of geothermal energy, carbon dioxide is separated from the geothermal fluid and it is released to the atmosphere. In Alaşehir geothermal power plant, the colder reinjection water has CO_2 concentration less than 0.2% by weight and the pH of this injectate is 9, which indicates a basic property. Reinjection fluid tends to solve less amount of $CaCO_3$; in other words, the amount of dissolved CO_2 decreases as it is recirculated in the reservoir. Thus, the pH values of production wells increased gradually (Figure-1). It was observed that CO_2 production had been decreased by more than 60% in 2 years of production from Alaşehir geothermal reservoir. The gradual decline of CO_2 is an indication of hydraulic connectivity between production and injection wells Aydin et al. (2018)

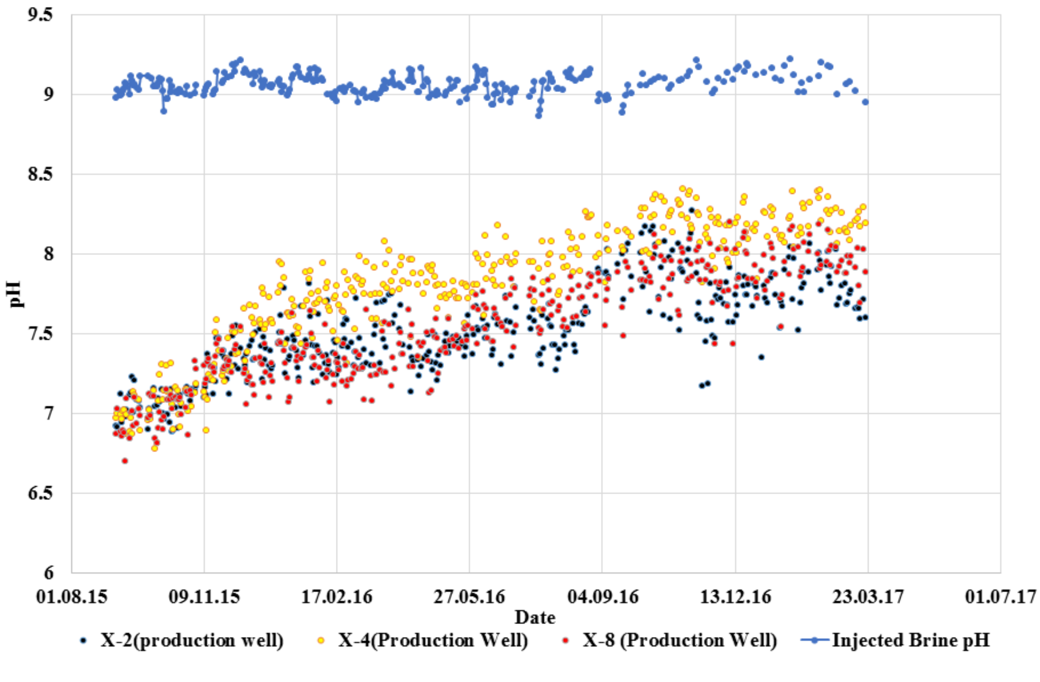

Figure 1: pH Values of Production Wells and Injected Brine

Decline curve analysis has been used widely for the prediction of a reservoir's performance and reserve estimation in the oil and gas industry. Several empirical and analytical methods have been studied to model production decline. Exponential, hyperbolic and harmonic equations introduced by Arps (1945). Fetkovich (1980), Fraim and Wattenbarger (1987) published type curves to describe the decline curve analysis in hydrocarbon reservoirs. Li and Horne (2001) proposed an analytical method derived from the relationship between production rate and reciprocal of the total production. Reyes et al. (2004) applied this relation to the Geysers for a new decline curve analysis method.

In this study, we used Arp's empirical equations to analyze the decline of CO_2 production in several geothermal wells in Alaşehir. A decline curve analysis model was developed based on the theory of fluid flow mechanisms with relative permeability and capillary pressure, as reported in Reyes et al. (2004). Since CO_2 is originated from meteoric water-rock interaction in carbonate reservoirs in Turkey, the pH of injected fluid, fracture surface area, and temperature are other properties that affect the decline of CO_2 production from geothermal reservoirs. Thus, rate of recovery of injected fluid has a direct effect on the decline of CO_2 production.

Arp's equations are useful for reserve estimation but they have some disadvantages. For example, underestimated results may be obtained by using exponential decline curves. Similarly, harmonic decline method may provide overestimated reserves. The mathematical equations for exponential decline, hyperbolic decline and harmonic decline are given in equation 1, equation 2 and equation 3 respectively Arps (1945).

$$\frac{q}{q_i} = \frac{1}{e^{D*t}} \tag{1}$$

$$\frac{q}{q_i} = \frac{1}{(1+b*t*D_i)^{\frac{1}{b}}} \tag{2}$$

$$q = \frac{q_i}{(1-D_i*t)} \tag{3}$$

Where q, q_i, D_i, t and b represents flowrate, initial flowrate, initial decline rate, time and an exponent that varies between 0 and 1.

Decline curve analysis should be applied only when the reservoir is under boundary dominated flow conditions. Typically, the decline rates are high at the transient flow period and it starts to stabilize when the boundaries are reached. In highly fractured geothermal reservoirs, because of high conductivity, the transient period is shorter than that of oil reservoirs. Thus, generally a few months of production is good enough to observe the boundary dominated flow. However, geochemical stabilization usually takes longer time than that of pressure.

2. CO_2 DECLINE FROM GEOTHERMAL WELLS

In this study, CO_2 decline in geothermal wells was analyzed by using Arp's equations. The study area, Alaşehir geothermal field is located in Western Turkey. The field has a high permeable reservoir with liquid dominated geothermal fluid, which included a significant amount of NCG at the beginning of the production. Akin (2017) stated that the southern part of the reservoir is liquid dominated with 2% to 4% CO_2 by weight. Because of strong hydraulic connectivity between injection and production wells, reasonable amount of decline has been observed within few months of production. There are several studies in the field area. Aydin and Akin (2019) proposed that there is no compartmentalization in the reservoir based on DFN (Discrete Fracture Network Model) modeling study supported by tracer test, geochemical components, and interference test results. Aydin et al. (2018) studied the effect of CO_2 decline on reservoir pressure drop and IPR performance of wells in the field. Currently, 7 license holders producing a total of 210 MWe from the field. The proximity of the license areas and small well spacing resulted in pressure interference and a sharp CO_2 decline was observed. A sharp flow rate decline (more than 60%) occurred in some production wells, which are somewhat away from re-injection area that stabilized after a year of production. However, the wells that are relatively far from injection area showed gradual decline rather than sharp decline.

CO_2 measurements were conducted with a gas flowmeter in Wells: X-2, X-4 and X-8. The CO_2 content of other wells was calculated by using ideal gas law. The decline rate analysis was conducted by using non-linear least square approximation. The decline curves showed the best matches with hyperbolic model (Figures 2 through 8). It was observed that in the transient time period, production wells showed different decline behaviors based on hydraulic connectivity and proximity to injections wells. However, once stabilization was reached, most of the wells showed hyperbolic decline with different exponents and initial decline rates.

Well ID	Decline Rate (Hours)	b, Exponent (Constant)
BY-1	0.0002	0.69
BY-2	0.000043	0.31
BY-4	0.00004	0.62
X-2	0.00237	0.82
X-4	0.005318	0.63
X-8	0.005276	0.81

Table 1: Hyperbolic Model Parameters

Semi-log analysis of CO_2 decline was used to determine the stabilization time for CO_2 decline in the production wells. The stabilization time changed between 500 hours and 900 hours. After 2 years of production, when a new power plant was commissioned, a very sharp CO_2 decline was observed in these wells.

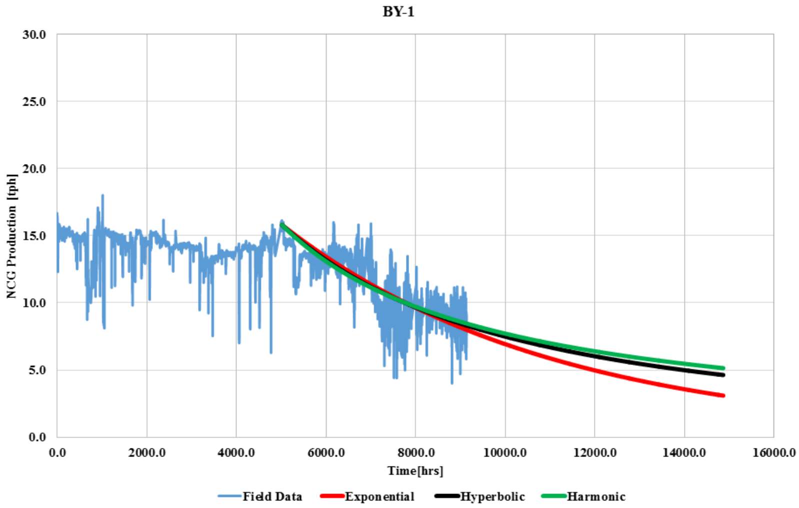

Figure 2: Decline Curve Analysis of Well BY-1

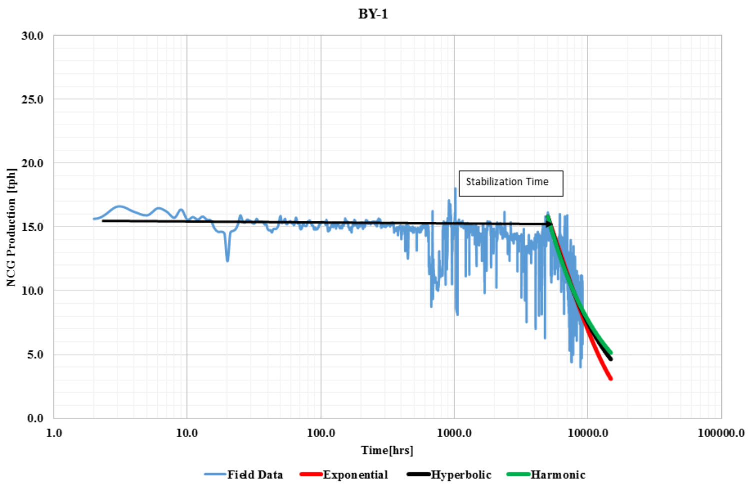

Figure 3: Semilog Analysis of Well BY-1

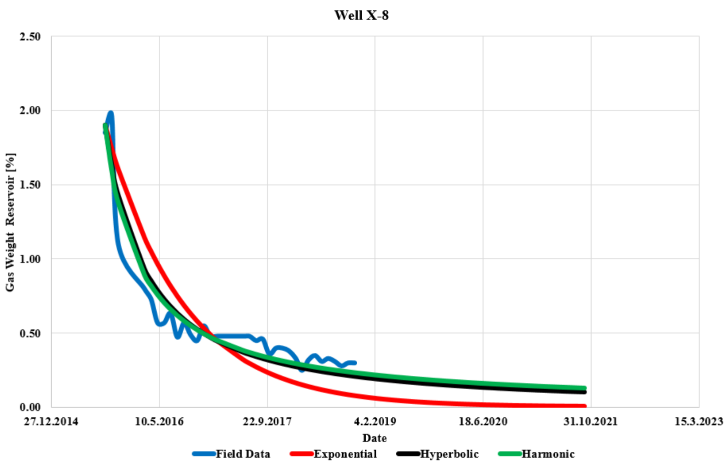

Figure 4: Decline Curve Analysis of Well X-8

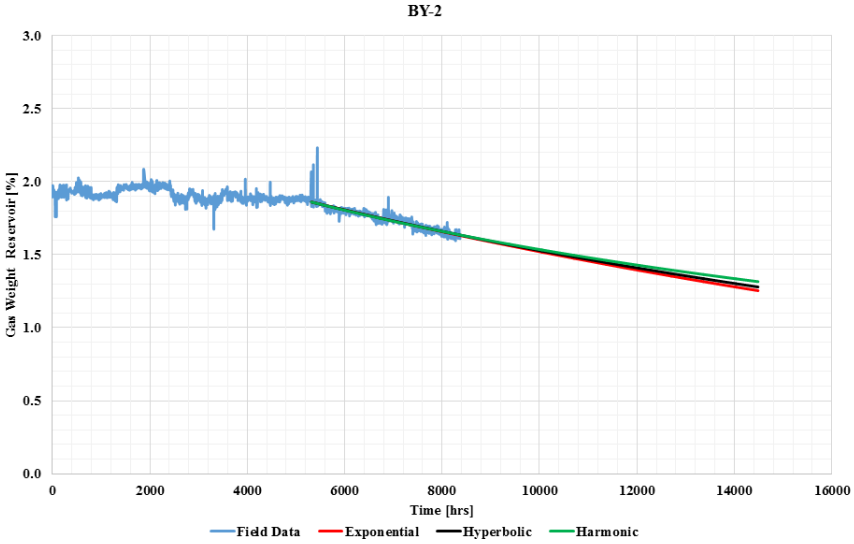

Figure 5: Decline Curve Analysis of Well BY-2

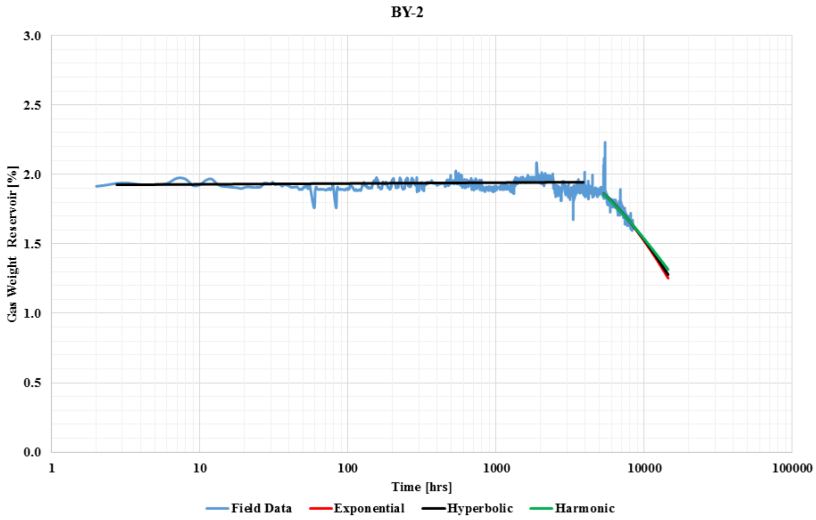

Figure 6: Semi-log Analysis of Well BY-2

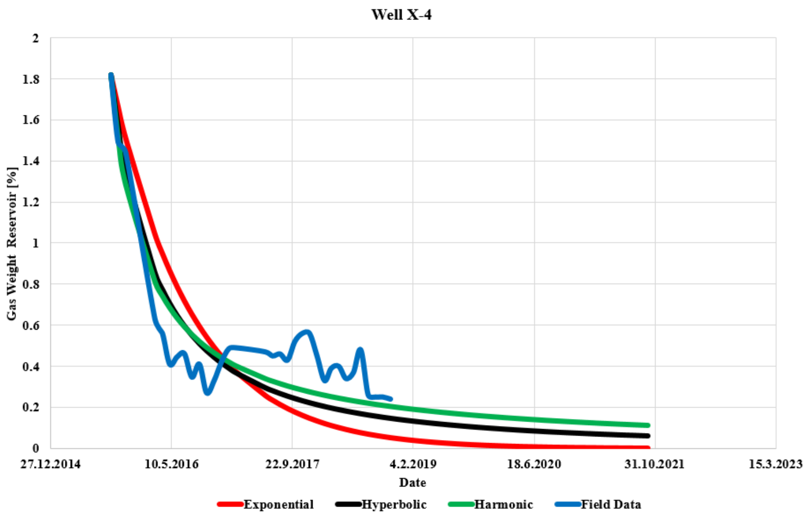

Figure 7: Decline Curve Analysis of Well X-4

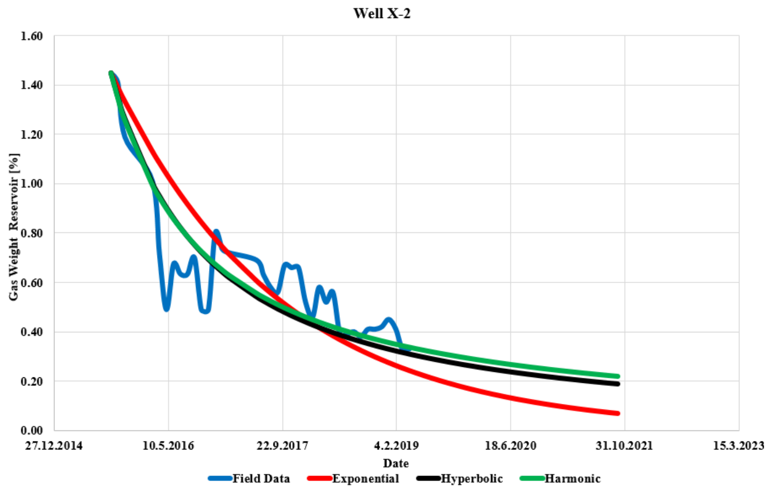

Figure 8: Decline Curve Analysis of Well X-2

CONCLUSION

The decline of CO_2 production from geothermal wells in the Alaşehir field was best matched with hyperbolic decline model. The exponential model showed underestimated results. In some wells, both harmonic and hyperbolic model matches were very similar. Based on hydraulic connectivity and proximity to the injections wells, a very sharp decline of CO_2 observed in some wells while it was gradual in other wells at the beginning of the production. The CO_2 contents were in the range of 2% - 3% in the beginning and it fell below 1% as a new power plant was put on production in the field. Extrapolation of hyperbolic model showed that CO_2 content of the wells in reservoir would stabilize in the range of 0.20 to 0.25% by weight, which is in accord with injection/production ratio in the field.

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