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Practical Experiences about Reservoir Monitoring in Alaşehir Geothermal Field

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ABSTRACT

Alaşehir geothermal area that is located in southern part of the Alaşehir Graben is one the important geothermal areas in Turkey. Currently, more than 6 operators are exploiting this field on a strictly competitive, and largely confidential, basis without significant exchange of resource information among them. This paper discusses monitoring of the response of part of Alaşehir geothermal system to large scale exploitation. In this regard, temperature and pressure of the reservoir, steam flowrate, brine flowrate, inflow performance relation curve of production wells, non-condensable gas content, chloride and silica content of produced fluid will be reported. Significant decrease of non-condensable gas will be discussed. Some practical experiences about reservoir monitoring will be shared. Finally, evaluation of the aforementioned parameters will be discussed.

1. INTRODUCTION

In geothermal reservoir monitoring, there are three important parameters which are temperature, pressure and flow rate. As a field is put on production, it is quite normal to experience decline in any of these parameters due to the nature of the reservoir. Decline of these parameters should be carefully monitored to keep in the acceptable ranges for a sustainable geothermal production. Several techniques have been used to understand the reservoir behavior during the production. The most convenient techniques are tracer testing, pressure transient testing, geochemical production monitoring and geophysical methods. Geophysical methods are usually conducted for geothermal exploration purposes; however, it can also be used to monitor geothermal activity during production with reasonable amount of uncertainty. To illustrate, MT (magneto telluric) data was recorded in Paralana, South Australia to monitor changes as electrically conductive fluids are introduced into the EGS reservoir (Thiel, et al., 2010). Similarly, seismic activity is monitored to trace reinjected waste water, which enables to identify the orientation of reinjected brine paths in Salavatli geothermal field, in Turkey (Gurbuz, et al., 2011). Traditionally, tracer tests are used to establish the degree of connectivity between wells. However, in the case of wells that are weakly connected, the test may need to be conducted over long periods of time using huge amounts of tracer. As a result, tracer testing can be too costly and impractical (Sullera and Horne, 1999). In addition, the flow paths that become important during the production phase of the project may differ (because of differences in pressure fields) from the paths shown in tracer tests before the production (Horne and Szucs, 2007). Concentration of chemical components of geothermal fluids is directly affected by reservoir/aquifer temperature. These components are known to be reactive and tend to equilibrate with minerals in reservoir hosting rocks. Examples of constituents that are generally tightly controlled by temperature are SiO_2, Na, K. Cooling will be reflected as decreased SiO_2 concentration and increased Na/K ratio (Padilla and Escalante, 2016). CO_2 mass content is also controlled by mineral solution equilibria at least in reservoirs located in western Turkey and it is monitored to estimate reinjected fluid paths. Another group of chemical constituents of geothermal fluids are considered to be non-reactive or conservative. They do not tend to equilibrate with geothermal minerals and their concentration is not controlled by reservoir temperature. These components are used as tracers and provide information on the source of the fluid. Examples of this type of components are Cl and B (Arnorsson, 2000). Well testing is a direct method to measure temperature and pressure in the well. In this regard, it can be considered as a verification tool as the actual temperature and pressure values are obtained. For example, if geochemical analysis indicates decreasing temperature in the reservoir, it has to be verified with temperature data. Pressure transient well testing (drawdown, buildup or interference test) is used to quantify well and reservoir properties including productivity, injectivity, permeability-thickness product (k*h) and reservoir storativity. Pressure transient test may also detect presence of a boundary if there exists one.

2. ALAŞEHIR GEOTHERMAL RESERVOIR

The stratigraphy of the Alaşehir geothermal reservoir is mainly represented by metamorphic rocks of the Menderes Massif and synextensional Salihli Granitoid as basement rocks, which are tectonically overlain by Neogene-Quaternary aged sedimentary rocks. These rocks are cut by detachment faults, which are also cut by younger various high angle normal faults (Iztan et al, 1991; Seyitoğlu et al, 1994; Seyitoğlu and Scott, 1996; Yazman, 1995; Yazman et al, 1998; Yılmaz and Gelişli, 2003). Basement is composed of carbonates of Menderes Massif rocks. They are highly fractured and karstified so that they are important to be geothermal aquifer. Menderes massif rocks are schists, quartzite, phyllites and marbles (Akin, 2017). The high temperature (> 190°C) geothermal reservoir in the upper section of the Paleozoic basement feeds from zones in the carbonaceous metamorphic at approximately 1150 m and 1600 m depths (Figure-2). The reservoir has good permeability-thickness probably from intersecting fractures. The southern part of the reservoir is liquid dominated with 2% to 4% CO_2 by weight. Well depths reach to more than 3000 m near the center of the graben. In this part, the highest recorded bottom hole temperature is 251°C (Figure-1) at a depth of 3011 m. The average flow rate is 300 ton/hr suggesting a similar permeability-thickness that has been observed in the southern part (Akin, 2017).

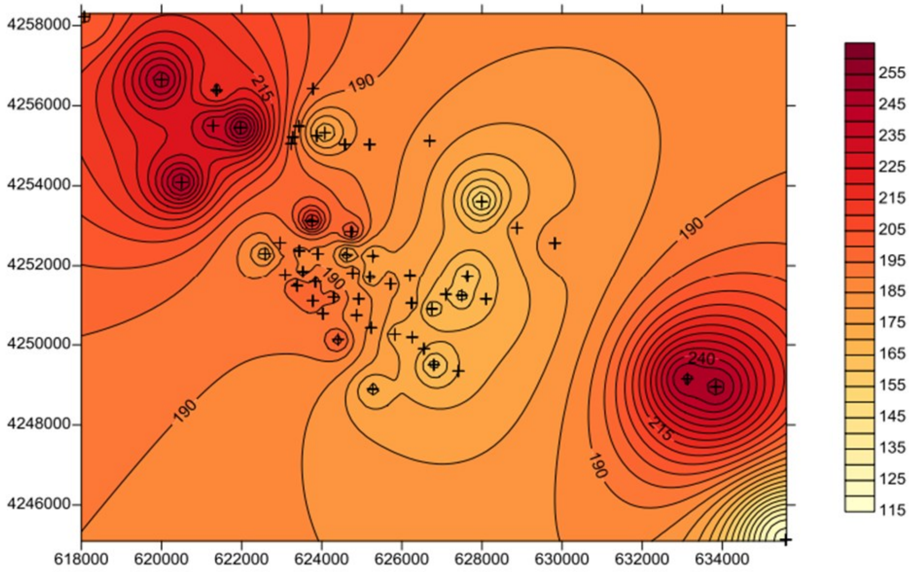

Figure 1: Bottom hole Temperature of Wells (^{o} C) (Source: Akin, 2017)

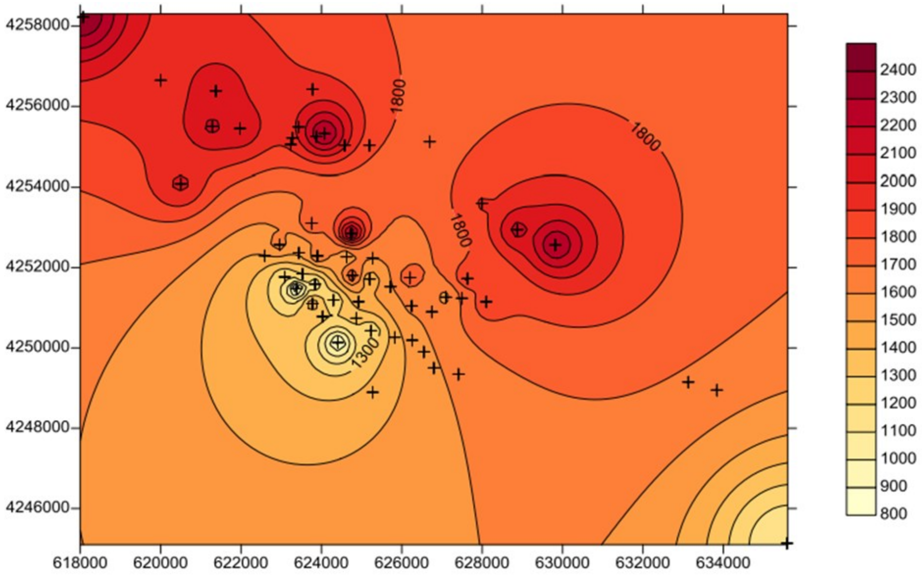

Figure 2: Reservoir Depths (meters) (Source: Akin, 2017)

3. GEOCHEMICAL EVALUATION

3.1 Chloride Concentration

Chloride (Cl) is a conservative and non-reacting component, which is present only in the liquid phase and its concentration is not controlled by reservoir temperature. In Alaşehir geothermal reservoir, chloride concentration initially changed between 150 ppm and 200 ppm. It has been observed that chloride concentration slightly increased to 250 ppm and 300ppm in the first year of production. However, as the new reinjection wells introduced in the field, the rate of change of chloride concentration in all production wells increased. Thus, it is concluded that all the production wells are recharged with colder reinjection fluid. However, change of chloride concentration in some production wells are larger than others (Figure-3) which means that these wells withdraw larger amount of reinjected colder brine compare to others. Spatial distribution of Cl concentration of wells (Figure-4 and 5) as a function of time are used to identify cold reinjection water paths in the reservoir. It is observed that the reinjection brine travels through the conductive faults that was previously identified by a seismic study. Wells, which are drilled into these conductive faults accept large amounts of reinjection fluid, which probably accelerate cooling effect.

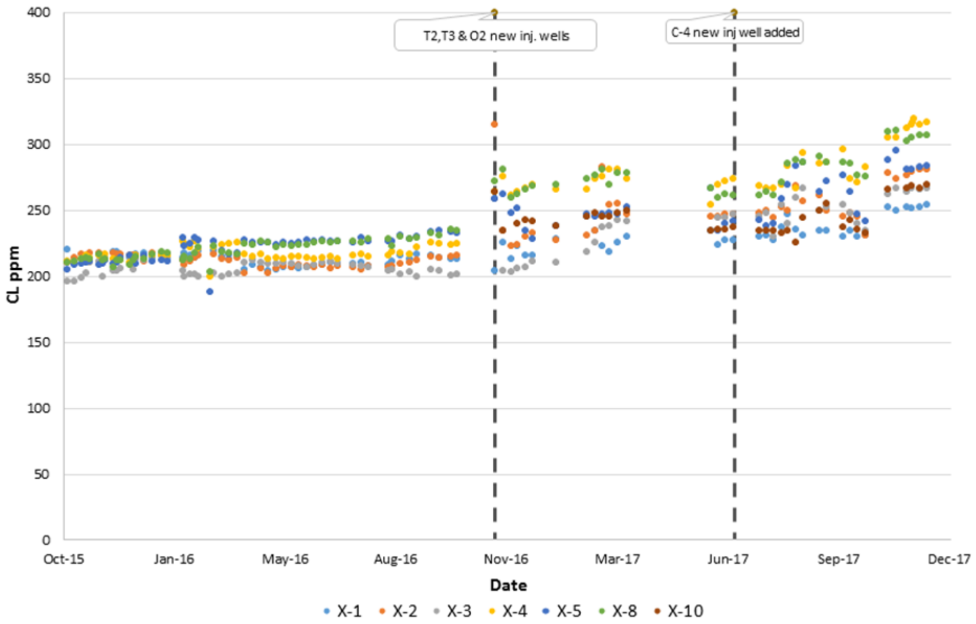

Figure 3: Change of Chloride Concentration

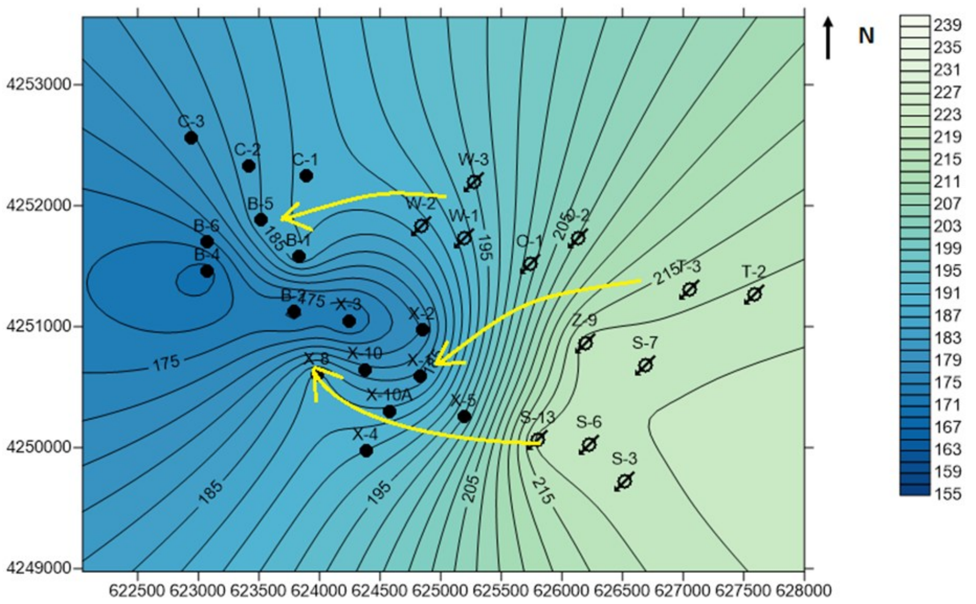

Figure 4: Spatial Distribution of Chloride @ Nov.15

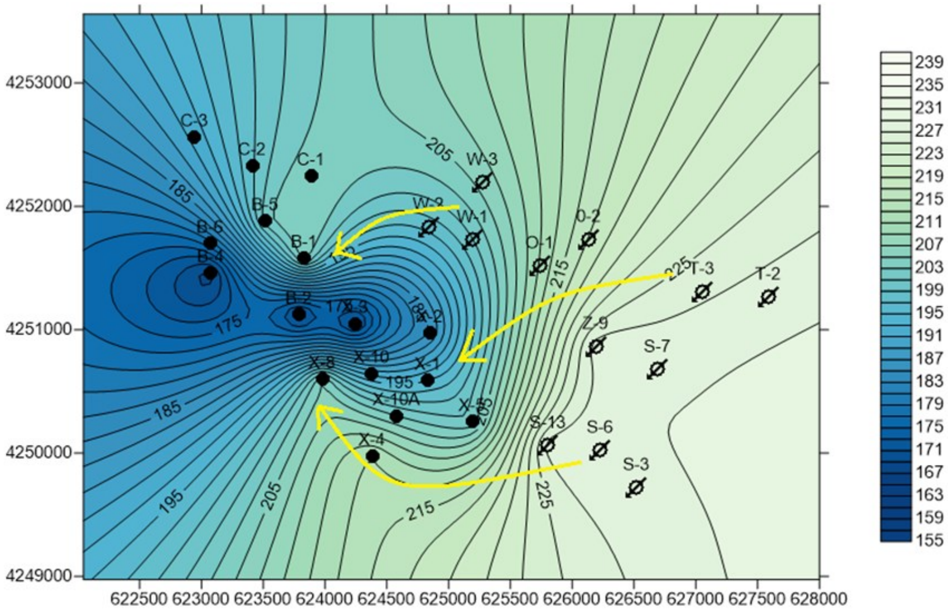

Figure 5: Spatial Distribution of Chloride @ May.16

3.2 Silica Concentration

Silica (SiO_2) is a reactive mineral that tends to equilibrate with minerals in reservoir rocks. It is tightly controlled by reservoir temperature (Padila, 2016). SiO_2 tends to be less soluble in relatively cooler water systems. Thus, decreasing silica concentration in produced water (Figure-6) can be considered as an indication of temperature decline, which is in accord with increasing chloride concentration as a result of recirculation of colder injectate. In order to confirm this claim, average steam fraction (SF) at the separator of gathering system is monitored to calculate the decline of average enthalpy at the top of slotted liner (TOSL). It is assumed that the fluid is in the liquid phase at the TOSL and that there is no further fluid entry to the wellbore apart from this level. To eliminate the effect of carbon dioxide (CO_2) in steam fraction calculation, the rate of CO_2 is subtracted from total steam rate. By knowing the SF, steam temperature and brine temperature at the separator, it is possible to calculate the enthalpy of liquid phase in the wellbore (Hirtz, 1993). It was observed that average liquid enthalpy has been decreased about 35 kj/kg (Figure-7). Temperature drop was confirmed with temperature measurements conducted in some of the production wells as well (Figure 8).

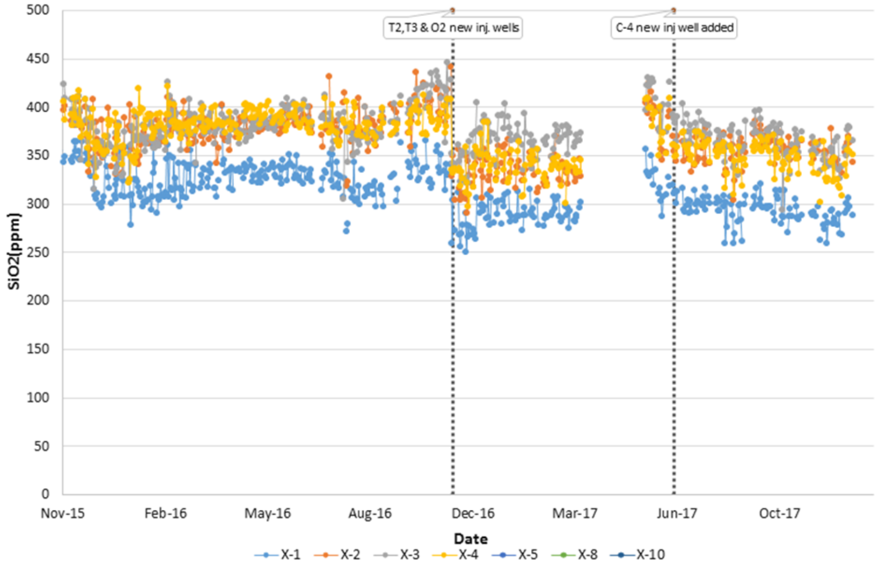

Figure 6: Change of Silica Concentration

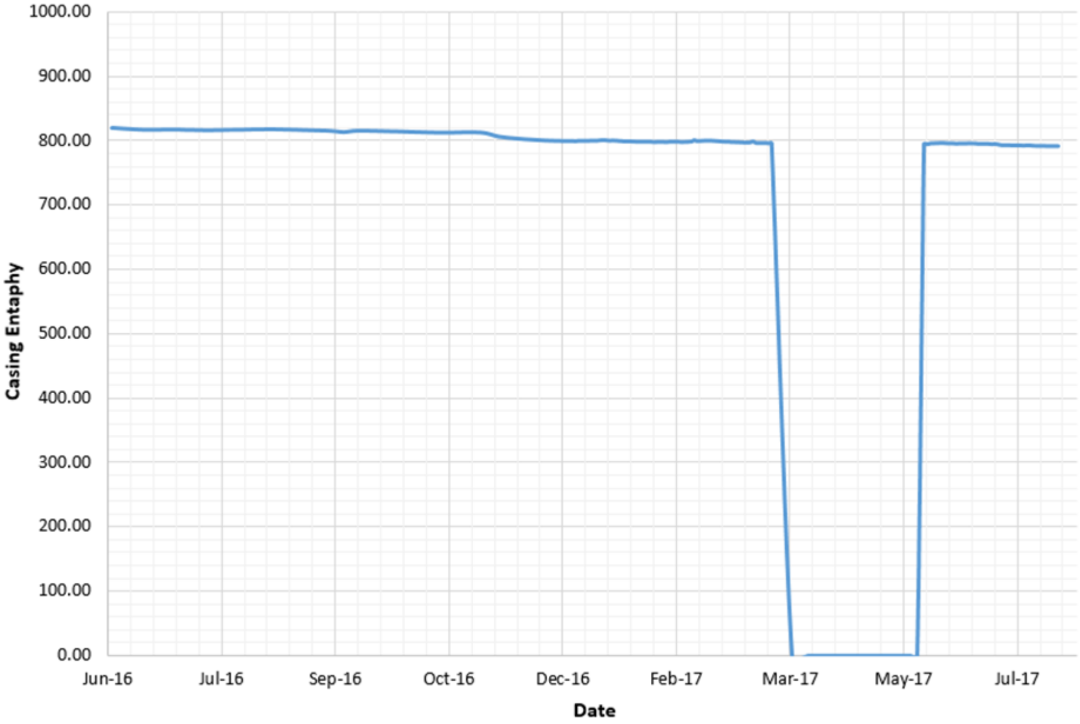

Figure 7: Average Liquid Enthalpy at TOSL

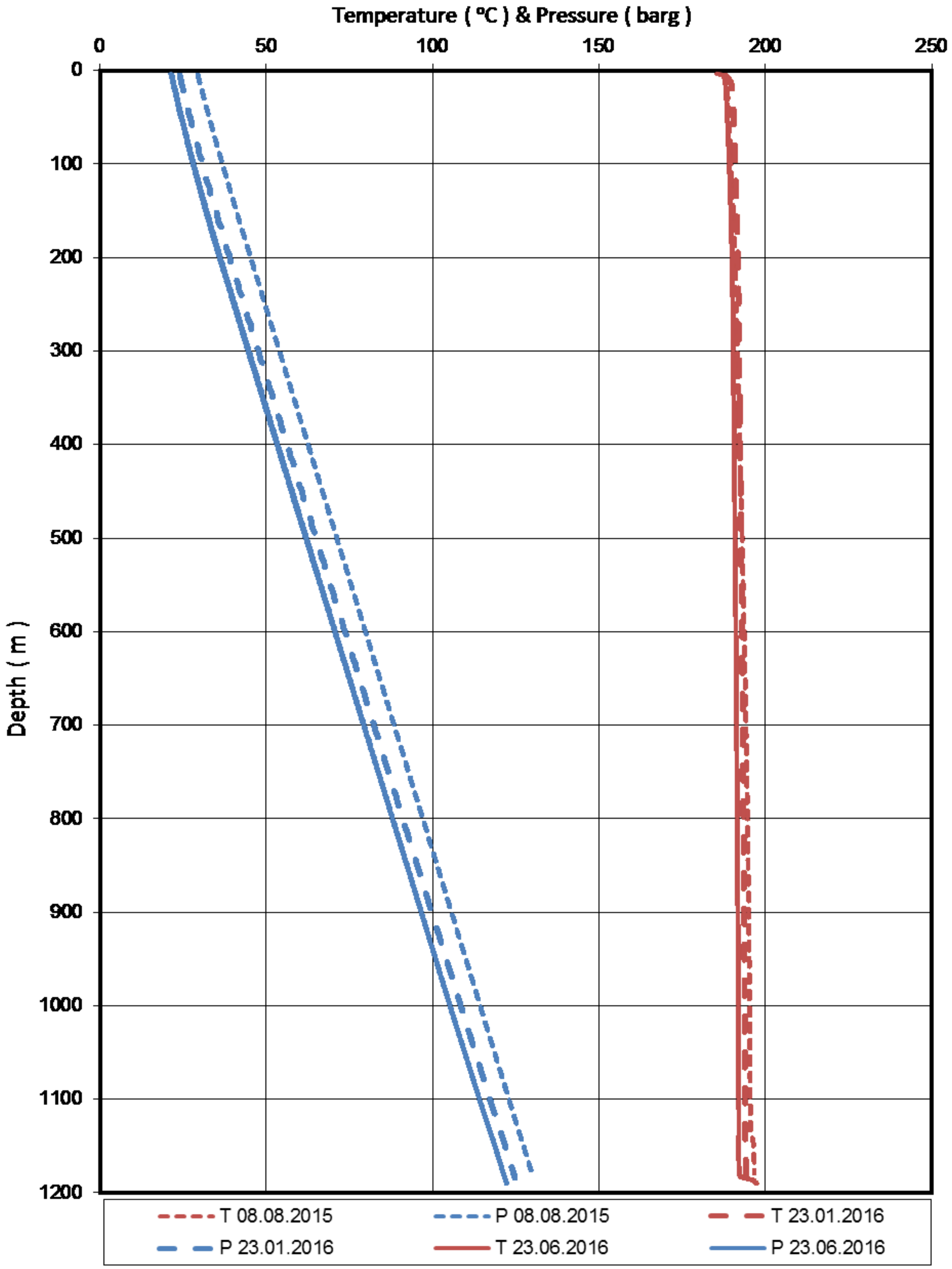

Figure 8: Dynamic T, P Profile of Well X-3

3.3 CO_2 Decline

All of the liquid dominated geothermal systems located in Western Turkey have relatively high (>1% by weight) concentrations of non-condensable gas in reservoir fluids. The gas contains typically 96% to 98% or greater carbon dioxide (CO_2) dissolved in the moderate to high temperature (200°C ± 50°C) liquid-dominated geothermal reservoirs. Carbonate-dominated metamorphic rocks including marbles, dolomitic marbles and calc-schists dominate reservoir rocks. The calcite in these rocks provides a large potential source of CO_2 when the calcite equilibrates with water (Haizlip et al., 2016). Henry's law states that the CO_2 solubility is controlled by temperature, pH and salinity of the liquid. 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 basic between 8 and 9. 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. It is observed that CO_2 production has been decreased by more than 60% in 2 years of production from Alaşehir geothermal reservoir. The sharp decline of CO_2 (Figure 9) indicates a strong connection between production and injection wells. Spatial distribution of CO_2 concentration by weight is in accord with chloride change, which may indicate the intrusion of colder injection fluid. The largest CO_2 decline is observed in wells that have higher Chloride concentration. Carbon dioxide production has decreased to a level changing between 0.5% and 0.8% by weight. This reduction corresponds to a pressure drop between 6 barg and 8 barg in the reservoir. This pressure drop is verified by conducting a short term flow testing by keeping the same flowrate. NCG decline has affected inflow performance of production wells negatively. IPR curves shifted to left and performances of wells decreased by 10% to 20 % (Figure 10).

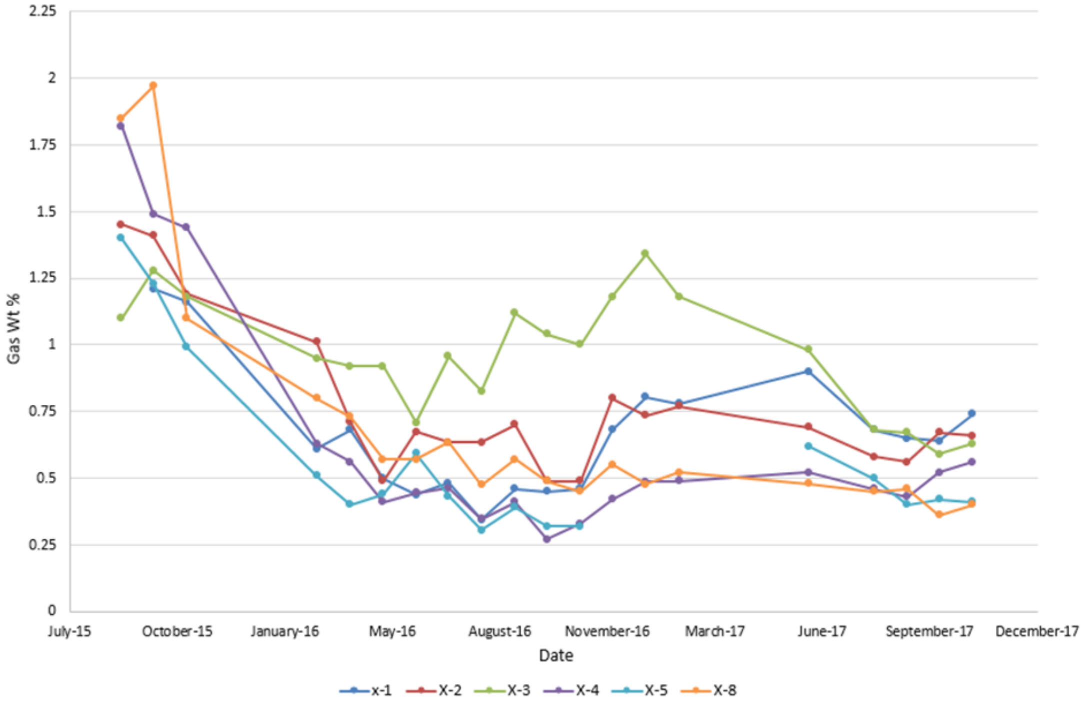

Figure 9: CO_2 Decline of Wells

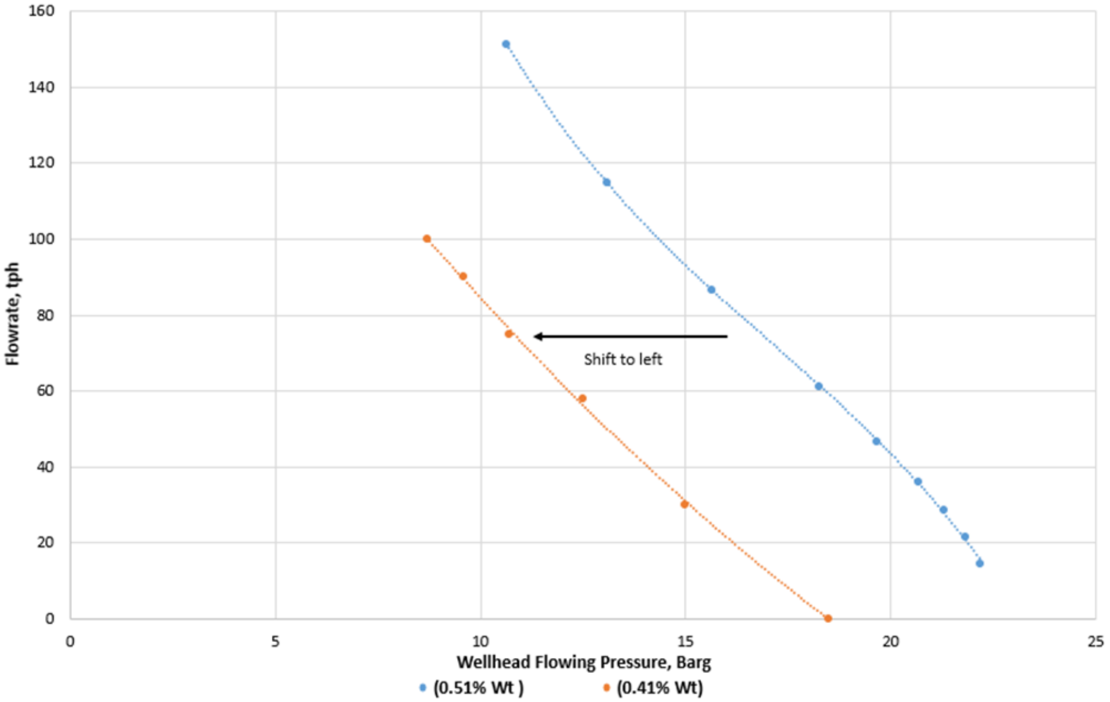

Figure 10: IPR of a Well with different CO_2 Content

3. CONCLUSION

Alaşehir geothermal reservoir is under development by 6 operators. Geochemical analysis and observations in the field indicates that all production and injection wells are connected through conductive intersected fractures. Strong connection between injection and production wells may cause significant temperature reduction in near future. By monitoring silica, chloride and carbon dioxide concentrations in produced water injection fluid flow paths are identified. Northeast-Southwest fault and Northwest-Southeast faults control the flow direction in the reservoir. Sharp decline of CO_2 accelerated reservoir pressure drop and it affected IPR performance of wells negatively. Geochemical analysis indicates decreasing temperature, which is monitored as a reduction of steam fraction at the separator of gathering system. By conducting short term flow tests, pressure and temperature reductions were verified.

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