

# **Injection Rehabilitation at Kızıldere Geothermal Field: Use of Flow Rate Weighted Average Production Wellhead Pressure for Reservoir Management**

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**Keywords:** Injection Rehabilitation, Average Wellhead Pressure, Kızıldere, Pressure Decline

## **ABSTRACT**

By commissioning of Kızıldere-III geothermal power plant (GPP), an additional 165 Megawatt put on production, thus total installed power plants' capacity operating by Zorlu Energy reached 260 Megawatt in Kızıldere geothermal field, in 2018. Tripled production from the field created substantial changes in the reservoir dynamics. Although new production wells are located at the outer part of the existing production zone, such an increase in the total depletion rate needed to be treated accordingly. For this reason, before the commissioning of the Kızıldere-III GPP, several wells that are located at inner and outer parts of the planned production zone, used as observation wells to quantify the effects of the depletion created by new production wells. After a while of production, a gradual pressure decline was monitored at all the observation wells and wellhead producing pressures. To identify the exact reason for the decline, a comprehensive tracer test was designed and implemented for the new injection wells. The tracer test showed that pressure support from the existing injection wells to Kızıldere-III production wells would not be sufficient at the current operating conditions. With this diagnose, an injection rehabilitation plan was immediately adopted and implemented in the field. It was found that the new reinjection strategy provides good pressure support and the pressure decline rate is in the acceptable ranges. In this study, we present a practical approach that was used to identify new candidate wells for reinjection. Correlation of flow rate weighted average wellhead pressure with reservoir pressure was used to identify hydraulic connection between wells.

## **1. INTRODUCTION**

The Kızıldere geothermal field was discovered in 1968 by MTA (Mineral Research and Exploration Institute of Turkey). The first power plant was installed with a power capacity of 15 Megawatt in 1984. The field was initially utilized from the shallow depth wells which has an average vertical depth of 500 m. The field has been produced seasonally without reinjection from 1984 to 2002. A deep reinjection well was drilled in 1998. This new well was found as the discovery of a deeper reservoir section. The highest temperature of the field at that time was recorded as 243°C in the well-named as R-1. The license of the field was owned by Zorlu Energy in 2008 after the privatization of the field. The field was developed by drilling the new deep wells. The average vertical depth of these wells is 2500 meters. Guney et. al. (2011) made an overview about the intermediate reservoir section. In 2013, a double flash-binary combined power plant was installed with the capacity of 80 Megawatt. The last and the newest discovery was made at the deeper reservoir section which is ranging from 3000 to 4000-meter depth. The highest temperature recording of these wells is 246°C. The largest geothermal power plant of Turkey which has triple flash-binary combined and the capacity of 165 Megawatt was put on operation with two units in 2017 and 2018.

The new power plants required the withdrawn of a large volume of geothermal fluid from the field. This has created substantial changes in the field of dynamic behavior. The primary change was found as a greater local pressure decline compared to before observed at some of the production and observation wells within the production area. To understand the pressure support of new reinjection wells, a comprehensive tracer test was conducted in 2018. The test showed that the existent reinjection wells have no good interferences in the production area. The previous production scenario was that geothermal fluid was produced from the deep reservoir section and reinjection was done into shallower depths. This means that there is a vertical compartmentalization in the Kızıldere field. With this diagnosis, a new reinjection strategy was found to be planned and implemented urgently. In this study, a new methodology is used to determine the proper reinjection location of injection wells.

## **2. CHARACTERISTICS OF GEOTHERMAL FIELD**

Kızıldere geothermal field is located between Denizli and Aydın provinces, at the eastern part of the Büyük Menderes Graben, between the Buldan and Babadağ Horsts. The field is at the southern part of the Menderes Massifs, which is one of the largest (300x200 km) metamorphic massifs in Turkey (Bozkurt & Oberhänsli, 2001). Kızıldere Geothermal Field is in the eastern part of the Büyük Menderes Graben. Paleozoic metamorphic of Menderes Massifs and Pliocene and Quaternary sedimentary rocks form the general stratigraphy of the field (Şimşek et al., 2009). Menderes metamorphic form the basement rocks, which mainly consist of augen gneisses, schists, quartzite, mica schist and marbles (Karamandereci, 2013). The upper Pliocene and Quaternary sedimentary rocks have been divided into four lithological units (Şimşek, 1985a). These units, from bottom to top, are Kızılburun Formation, Sazak Formation, Kolankaya Formation, and Tosunlar Formation. The Kızılburun Formation consists of 13 well-consolidated 200 m thick red-brownish conglomerates, sandstones, and claystone. It behaves as a cap rock due to its impermeability and forms the boundary between the Paleozoic metamorphic and Pliocene sediments. Sazak Formation is the shallow reservoir section of the field and mainly consists of 100 - 250 m thick limestones, but gradations into marls and sandstones were observed, laterally and vertically, which makes a restriction for a continuous reservoir aspect (Kucuk, 2018). The interbedded marble-quartzite-schist section of the upper unit of the Menderes metamorphic are called İğdecik Formation, and

forms the intermediate level reservoir of the Kızıldere geothermal field, with a varying thickness of 100 - 300 m. A deeper, third reservoir section, which mainly consists of metamorphic schist and marble.

### 3. METHODOLOGY

The proper location of reinjection wells is crucial to maintain the material balance and pressure support in the reservoir. The use of the pressure data obtained from the observation wells is related to wellhead producing pressures by using flow rate weighted wellhead pressure. By incorporating the coordinates into the same formula, the center of the reinjection wells also determined for the previous and the new reinjection strategy.

$$\frac{\sum_{i=1}^{n_p} (Q_i * WHP_i)}{\sum_{i=1}^{n_p} (Q_t)} \tag{1}$$

$$\frac{\sum_{i=1}^{n_p} (Q * (X_i, Y_i, Z_i))}{\sum_{i=1}^{n_p} (Q_t)} \tag{2}$$

$$\frac{P_{current} - P_{min}}{P_{max} - P_{min}} \tag{3}$$

where Q, WHP, P and n are flow rate, wellhead flowing pressure, observation pressure and number of production wells respectively and X, Y, Z are the coordinates.

Flow rate weighted wellhead producing pressures are normalized by using the equation (3). The same process is carried out for the observation wells. The closer the behavior of normalized pressure curves means the more the interferences between wells.

### 4. DETERMINING CANDIDATE REINJECTION WELLS IN KIZILDERE

Based on the methodology described above, we used the equation (2) to determine the center of production and injection area (Figure 1). The distance between the production and injection area was around 1870 meters in 2013. In 2017, as the new production wells put on production, the distance increased to 2041 meters. The pressure data of observation wells and flow rate weighted average wellhead pressure data were normalized by using equation (3).

It should be noted that wasted geothermal fluid has been reinjected into shallow depth wells since 2002. In the tracer tests, it was observed that the deeper reservoir section was found not to be supported by the shallower reinjection. Normalization of pressure data from observation wells and production wells were used to confirm the existence of the vertical compartmentalization. Figure 2 illustrates the behavior of an observation well that was completed at shallow depth. Reinjection wells support the shallow depth reservoir section while normalized flow rate weighted wellhead flowing pressure continuously decreases. On the other hand, Figure 3 illustrates the behavior of deep observation well which has a very similar trend of pressure decline with average wellhead flowing pressure. In Figure 4, the pressure behavior of two different observation wells completed at the deep reservoir section is given. One of the observation well is located within the production area, named as infield well and the other observation well is located at the out of production area named as outfield well. The trend of normalized wellhead flowing pressure is similar to the two observation wells. This means that these wells are in good interference. The closer the trend behavior means the more the interferences of wells.

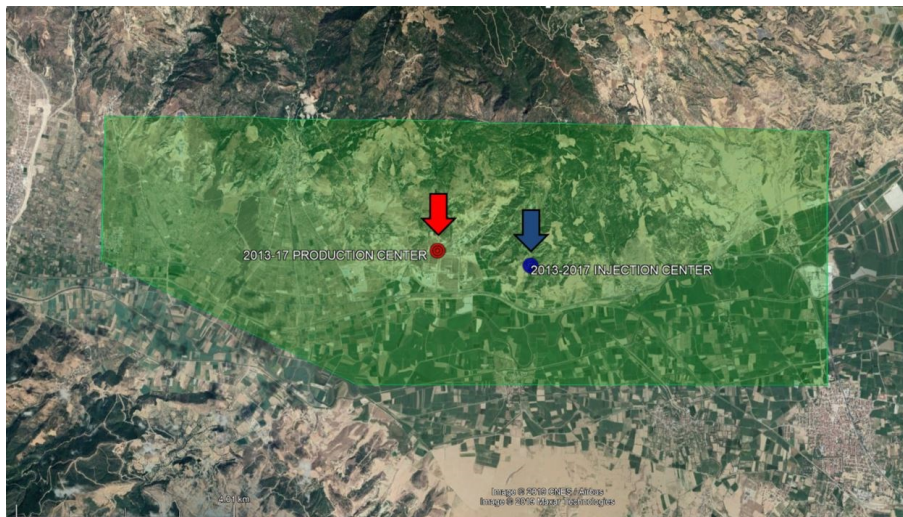
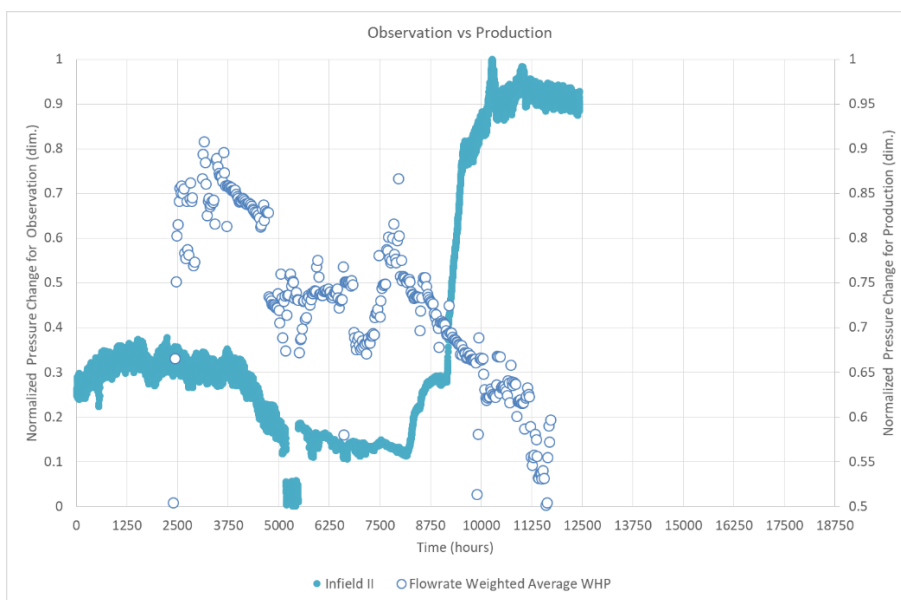
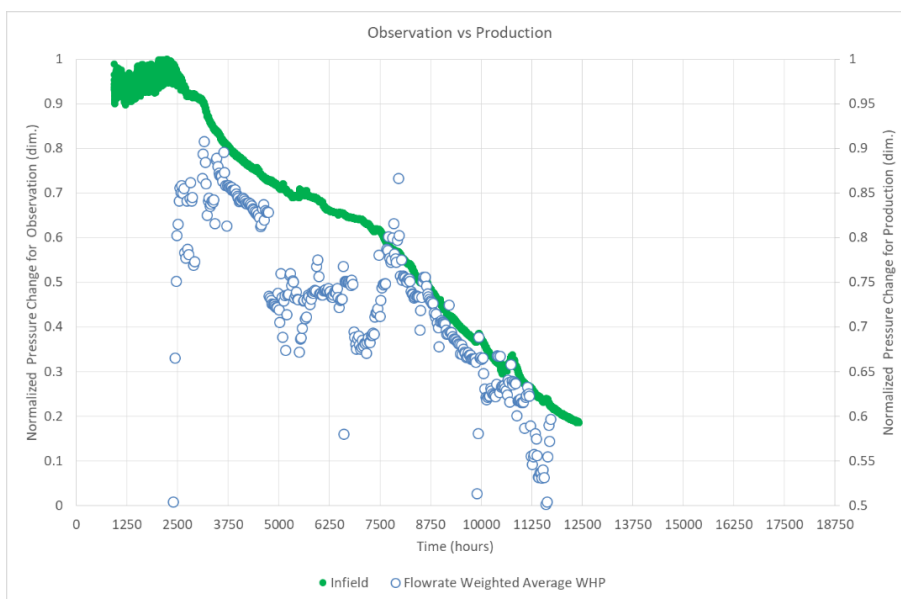


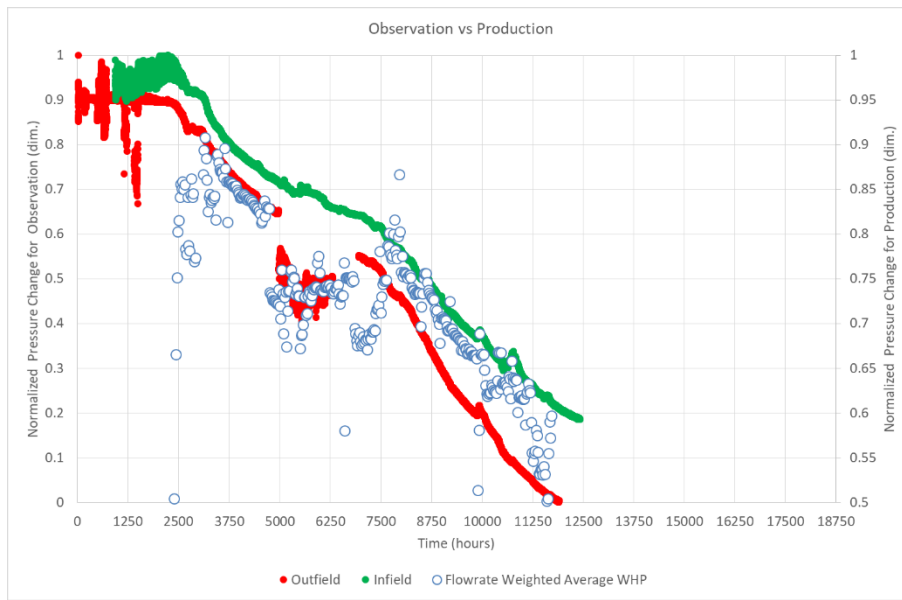
Figure 1: Production and injection center in the period of 2013 and 2017



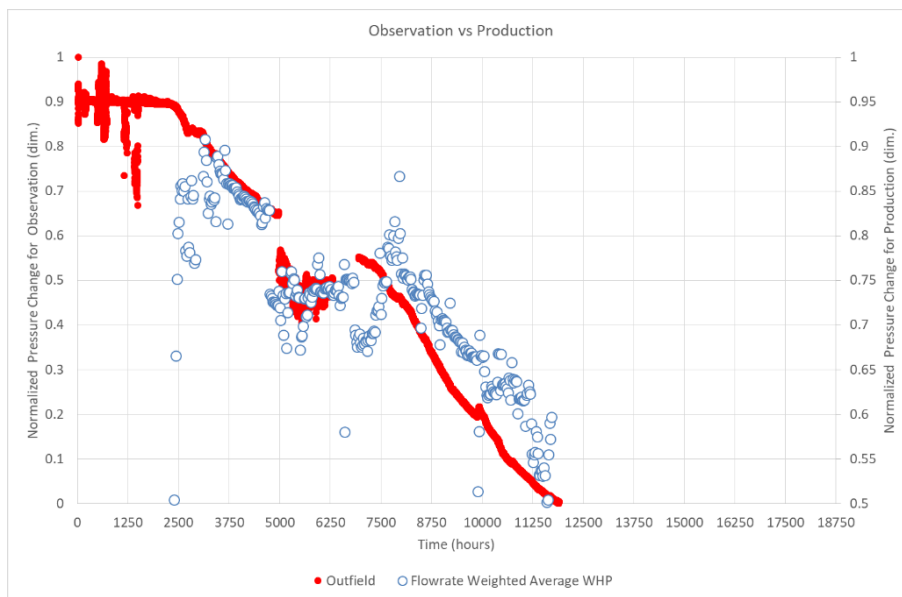
**Figure 2: Normalization of flow rate weighted wellhead pressure and a shallow observation well**



**Figure 3: Normalization of flow rate weighted wellhead flowing pressure and a deep observation well located within production area**

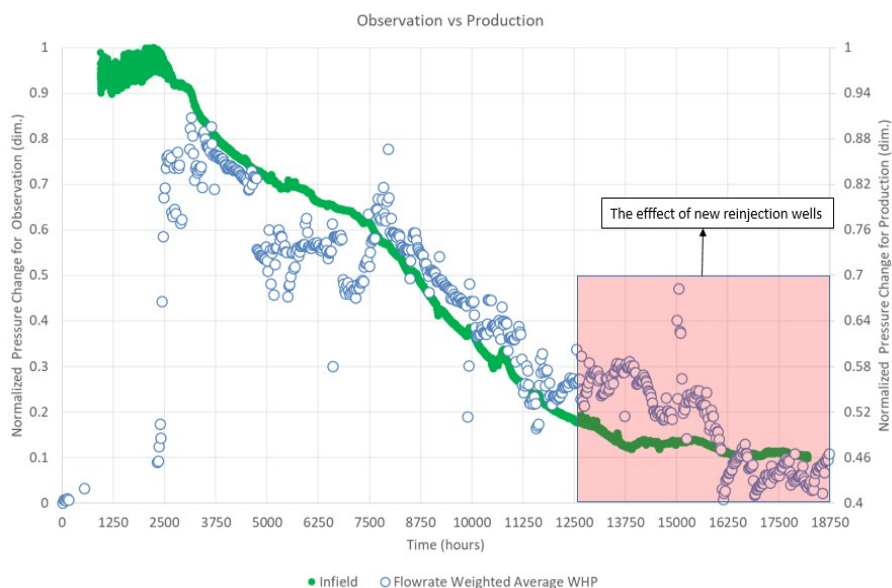


**Figure 4: Normalization of flow rate weighted wellhead flowing pressure and two deep observation wells at different locations**

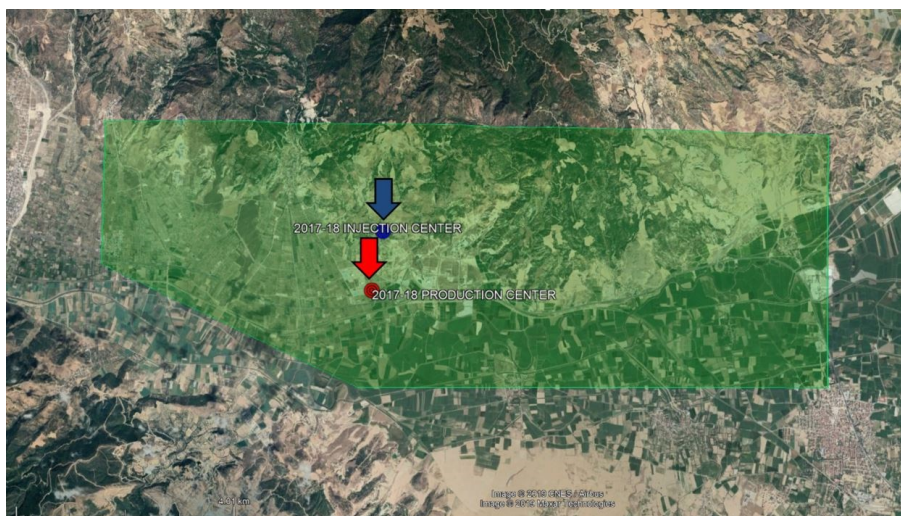


**Figure 5: Normalization of flow rate weighted wellhead flowing pressure and a deep observation well located out of production area**

Based on the evaluations of the tracer test, flow rate weighted wellhead flowing pressure and observation wells, it was decided to reinject into deep reservoir section at determined area. The effect of new reinjection wells were monitored from the deep observation wells and wellhead pressure of production wells. The slope of the pressure decline was decreased sharply with new reinjection wells. Thus, reservoir pressure decline is now within the acceptable ranges. After diverting 35 % of reinjection fluid into the deep reservoir section, the center of production and reinjection become closer at a distance of 1140 meter (Figure 7).



**Figure 6: Effect of the new reinjection wells on the normalized pressure data**



**Figure 7: Production and injection center in the period of 2017 and 2018**

## 5. CONCLUSION

The pressure behavior of observation wells and flow rate weighted wellhead producing pressure data are related by using the normalization phenomena. With this approach, the location of new candidate reinjection wells are determined and put on operation. Very promising results are obtained as the result of the new reinjection strategy in the Kızıldere geothermal field. The initial pressure drop has been stabilized and it has been kept within acceptable ranges. Thus, if the pressure data of observation wells and wellhead pressure of production wells converted into the same scale by eliminating the effect of flow rate and depth, it can be used to quantify the degree of connectivity between wells.

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