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Pressure Transient Analysis of Alaşehir Geothermal Reservoir

Hakki Aydin[1], Sukru Merey[2], and Serhat Akin[3]

Hakki.Aydin@zorlu.com ,

Zorlu Enerji, Denizli, Turkiye[1]

Batman University, Batman, Turkiye[2]

Middle East Technical University, Ankara, Turkiye[3]

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ABSTRACT

Pressure Transient Analysis (PTA) is a sophisticated method used to determine crucial reservoir parameters such as permeability, porosity, permeability-thickness, the radius of investigation, boundaries, and hydraulic connectivity between wells. The most widely applied pressure transient tests in geothermal wells are the pressure buildup, drawdown, fall off, and interference tests. This study characterizes Alaşehir geothermal reservoir using special interpretation techniques such as Bourdet pressure derivative analysis on a log-log scale and straight-line analysis (semi-log analysis and special lines). An academic version of the Kappa-Saphir module was used for the analyses. The pressure transient analyses suggested that geothermal wells produce from intersected fractures in the Alaşehir field. Double porosity behavior was found in most of the wells. High permeability-thickness products are in good agreement with the high production performance of the wells. A high skin factor was calculated in some wells, which might be related to the high content of solid particles used in the drilling fluid. No-flow boundary detected in the wells might suggest sealing faults, while constant pressure boundary might be due to injection supports in the nearby injection wells. Once the reservoir properties are obtained, the spatial distribution of the parameters is constructed for the reservoir characterization, giving good insight into the field development.

1. INTRODUCTION

Geothermal energy in Turkiye has become a crucial energy resource primarily since 2006, benefitting from several government support programs for geothermal companies. Subsequently, exploration and production wells were drilled extensively, mainly in the Western Anatolia Region of Turkiye. In 2006, the installed geothermal electricity production capacity was just 20 MWe. However, according to 2022 data, Turkiye's installed geothermal energy capacity had reached a significant 1688 MWe, as shown in Figure 1. Approximately 80% of geothermal fields in Turkiye are in the Western Anatolia. The temperature of geothermal fluids in this region ranges from 100°C to 285°C, with production wells typically tapping into fluids between 150°C and 240°C. To meet the demands of the installed geothermal capacity and capitalize on government incentive mechanisms, geothermal companies are increasingly drilling production and injection wells while employing artificial production methods (Aydin and Merey 2021).

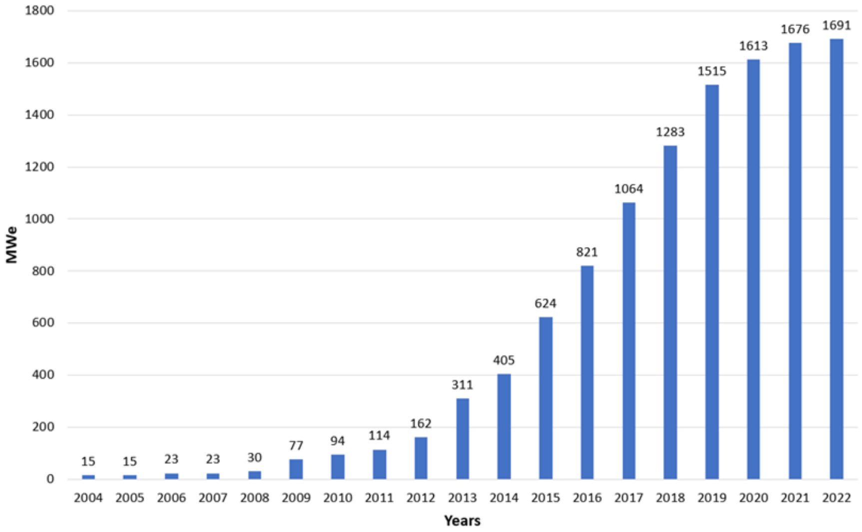


Figure 1: Turkiye's installed geothermal energy capacity (Ministry of Energy and Natural Resources, 2023)

The rapid pace of geothermal fluid production in Western Anatolia has necessitated a shift towards strategic reservoir management, emphasizing critical parameters like well connectivity, fluid mobility, pressure and temperature dynamics, and other key reservoir engineering aspects. In this context, pressure-transient analysis (PTA) emerges as a valuable tool, long established in the oil and gas industry, for characterizing reservoir properties and informing sound management decisions. PTA involves conducting controlled production and/or injection tests on one or more wells within the field. During these tests, accurate recording of flow rates/injection rates, pressure, and temperature data is essential. By analyzing the resulting pressure response through PTA, valuable reservoir parameters can be obtain (Zarrouk and McLean, 2019).

As in many geothermal fields, pressure buildup, pressure drawdown, fall-off, interference, and tracer tests are commonly applied in the geothermal fields of Turkiye (Serpen and Onur 2001). Axelsson (2013) described well testing types conducted at well completion, and production. The important reservoir and well parameters obtained from these tests are formation transmissivity, formation storage coefficient, skin factor, wellbore storage capacity, average reservoir pressure, initial reservoir pressure, and boundary properties such as faults, constant pressure sources and etc. Onur et al. (2003) investigated the pressure buildup test and interference test data to analyze the production/injection behavior in the Kızıldere Geothermal Field in Turkiye. In this way, it was possible to understand production rates, mobility, and the interaction between the wells. Similarly, Arkan et al. (2002) investigated the effects of calcite scaling on pressure transient of geothermal wells. Significant changes in skin, storativity, conductivity, and permeability thickness product were reported.

Similarly, two injection/fall tests and two pressure drawdown tests in the Balcova-Narlidere geothermal field, Turkiye by (Onur et al. 2005). The pressure transient analysis of these tests was useful for understanding well communication and conductivity in the field with faults. Tracer testing is also considered among the well tests that provide crucial information about reservoir properties. Multiwell tracer testing of Kızıldere geothermal field has been conducted using Naphthalene Sulfonates (Akin et al., 2016). Aydin and Akin (2020) presented a comprehensive tracer test in Alaşehir field, Turkiye. These tests reveal that geothermal fields in western Turkiye are dominated by intersecting faults.

In this study, the pressure transient analysis in the Alaşehir geothermal field located at Western Anatolia of Turkiye was made to predict mobility, porosity behavior in the reservoir, skin factor, boundary type, and other reservoir properties. This analysis was made by using Sapphire module of the academic version of Kappa software.

2. ALAŞEHİR GEOTHERMAL FIELD

Alaşehir geothermal field is one of the most actively producing geothermal fields in Turkiye. The field is located 130 km from Izmir, in the South-east of Gediz graben, in the West of Turkiye (Figure 2). Figure 2 shows the location and license areas of seven different companies in the Alaşehir geothermal reservoir. It is quite difficult to apply effective geothermal reservoir management if the companies apply different production/injection approaches in the same reservoir. The installed power capacity of the field is 310 MW in December 2020. There are 12 binary plants and a combined plant having double flashing and binary system. More than 100 wells have been drilled in the field. Strong connectivity between wells caused a sharp decline of NCG (non-condensable gas) content, reservoir pressure, and temperature in the production wells. The average reservoir pressure decreases by 3 bar/year, and significant temperature and NCG decline occur due to high connectivity between injection and production wells (Aydin and Akin 2021).

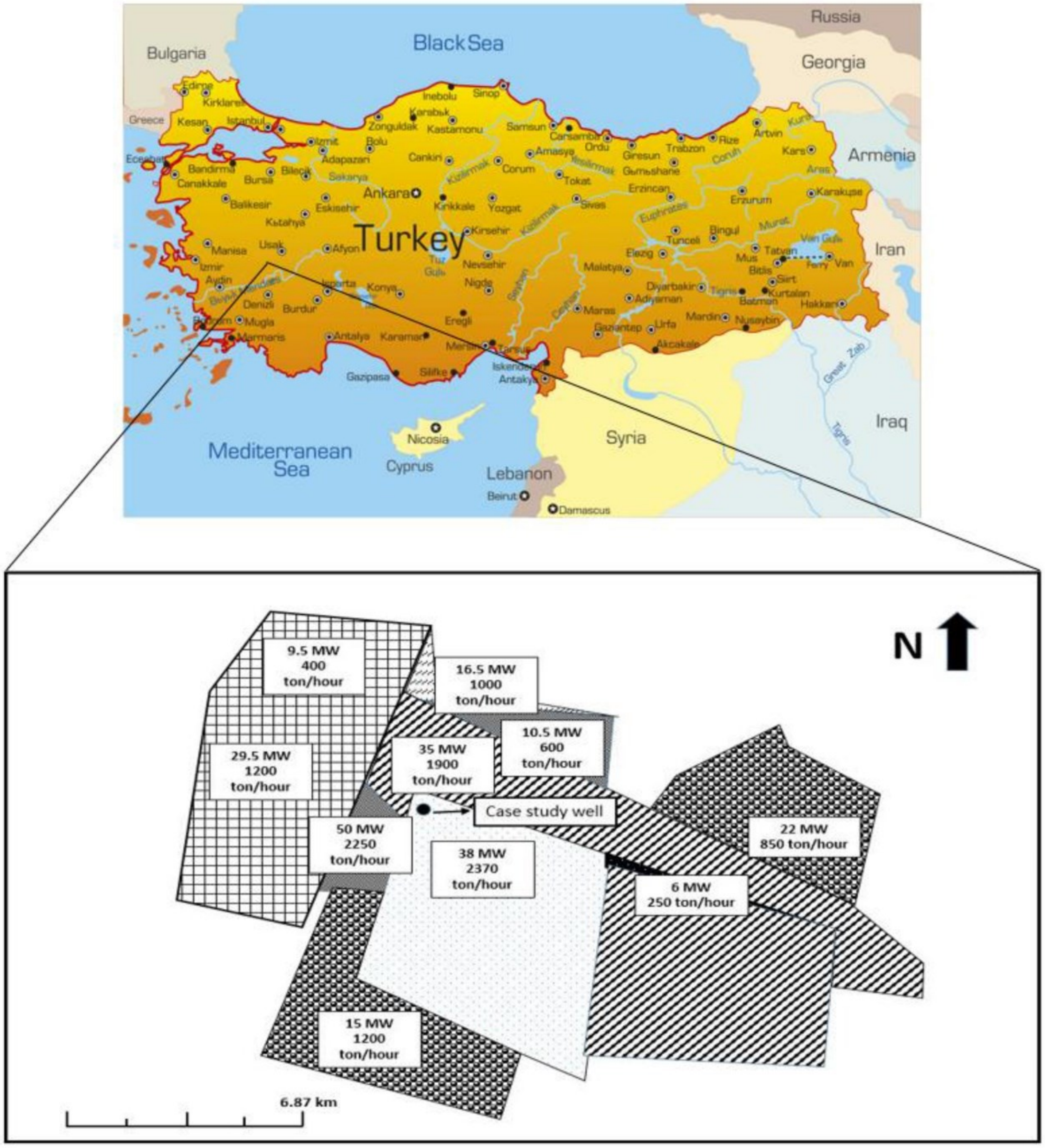


Figure 2: License areas and current (May 2020) power production of existing geothermal plants in Alasehir Field, West Anatolia, Turkiye (Aydin and Merey 2021)

3. MATERIALS & METHODS

In the pressure transient tests, a pressure disturbance signal is created by either shut-in a flowing well, initiating the well production, starting re-injection, or changing the well flow rate or injection rate. The created pressure disturbance moves from the wellbore towards reservoir sections laterally. The movement of the pressure signal is dominated by the rock and fluid characteristics.

Pressure and temperature values were recorded using the Kuster PT tool, PPS PT tool, and digital pressure transmitter on the wellhead. Flow rates were measured using the silencer-weirbox system in production wells and orifice flow meters in re-injection wells. Pressure buildup test and drawdown tests were conducted in production wells, while fall-off test was performed in re-injection wells.

A computer-aided PTA was performed to interpret the tests. Kappa software offers a suite of modules for PTA, decline curve analysis, and well test analysis (KAPPA 2022). These include modules like Sapphire, Topaz, Rubis, Emeraude, Citrine, and Azurite. In this study, the academic version of the Kappa-Saphir module was used for the analysis. Special interpretation techniques in the Sapphire module, such as Bourdet pressure derivative analysis on a log-log scale and straight-line analysis (semi-log and special lines), enable the identification of reservoir geometry and flow properties like permeability-thickness product, skin factor, porosity, and wellbore storage. The Saphir module offers automatic type curve matching for pressure derivative curves and some special straight-line techniques to estimate reservoir parameters with a specified confidence interval. The selection of a representative reservoir model and boundary conditions is crucial for obtaining the most accurate results.

4. RESULTS AND DISCUSSIONS

Alaşehir geothermal reservoir has a highly fractured reservoir with a considerable amount of void development associated with meteoric origin fluid circulation in the system. Therefore, it is expected to see a double porosity reservoir behavior in the analyses. Besides, high transmissivity values might be associated with the dense fractures created by fault mechanisms in the field area. The reservoir rock consists of marble, schist, and quartz minerals. Schist minerals deposited on the fault surfaces might act as impermeable boundaries.

We have used straight line analyses from semilog and horner plots to determine skin factor and transmissivity. Double porosity and reservoir boundary information was obtained by the log-log plot analysis. Table 2 shows the wells' and reservoir characteristics obtained from the buildup and fall-off tests in Alaşehir field. Log-log, semilog, and horner plot of the tests are shown in Figure 1 to Figure 11. A negative skin factor was obtained in most wells, meaning no need for acidizing operation or well cleaning flow. The double porosity reservoir model was found suitable to match with pressure data. Transmissivity of the wells changes in a wide range depending on the proximity to permeable faults. The wells with high transmissivity show high flow performances. The spatial distribution of transmissivity of wells is shown in Figure 12. The boundaries detected in the analyses are intersecting fractures, no flow boundary, and constant pressure fault. The structural geology of the Alaşehir field agrees with these findings. N-S trend faults are cut by E-W trending faults providing high transmissivity for geothermal wells. Besides, deposition of fine particles such as schist and clay on the permeable fault zone acts as impermeable layers, which is detected as the boundary in the pressure analysis tests. Aydın and Akın (2020) defined permeable and impermeable layers in a numerical reservoir model of the Alaşehir field. Akin (2015) designed a multi well interference test FOR Alaşehir field. However, the study found no hydrologic boundaries, which were believed to associate with rise in seasonal water level, masking the effects of boundary in the very late time data. High transmissivity of faults and low permeable zones are shown in the study based on field observations. High-pressure interference of wells was reported in Aydin et al. 2020, suggesting that the production performance of wells will impact each other in the long-term production. Permeability values are comparable with results obtained from (Akin, 2013) using mud loss data to estimate fracture permeability in Alaşehir field. The transient analysis of tests are in the same order of results obtained from Akin, 2013 and Akin, 2015.The reason for discrepancy is due to use of different wells.

Table 1: Pressure derivative analysis of buildup test and fall off tests

Well ID	Wellbore Storage, C (M^3/bar)	Skin Factor (Dimensionless)	Permeability*Thickness, kh, (Darcy*m)	Omega (Dimensionless)	Lambda (Dimensionless)
X-1	0.639	1.59	96.5	0.286	1.10E-07
X-2	0.171	1.27	35.5	0.00753	1.23E-07
X-3	0.436	1	278	0.00194	4.98E-08
X-4	0.1	3.07	570	0.011	3.98E-08
B-1	0.97	-3.6	34	0.0155	1.57E-05
K-3	0.3	-3.6	0.88	6.50E-05	4.80E-05

W-1	0.1	-17	0.57	6.50E-05	2.98E-04
W-2	0.1	-16	0.006	4.27E-04	0.00867
W-3	0.11	-7.4	1.66	8.62E-09	1.52E-6
W-4	5.52	-17.1	7.32	0.0265	0.00152
S-3	0.14	-6.3	0.405	-	-

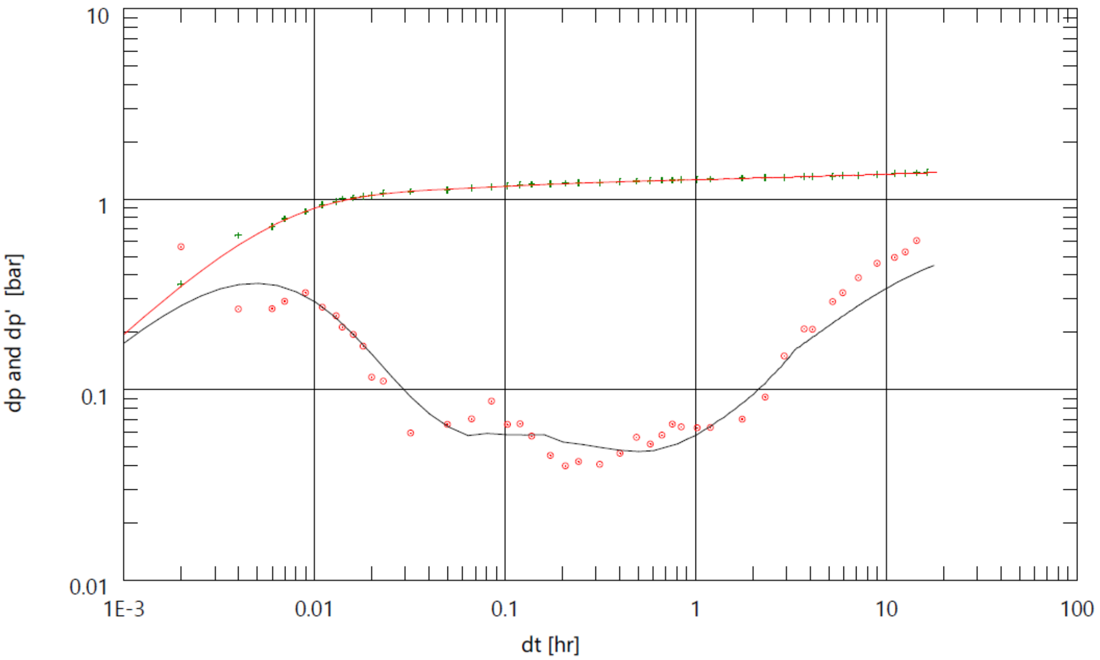


Figure 3: Log-log plot of pressure buildup test of well-X1

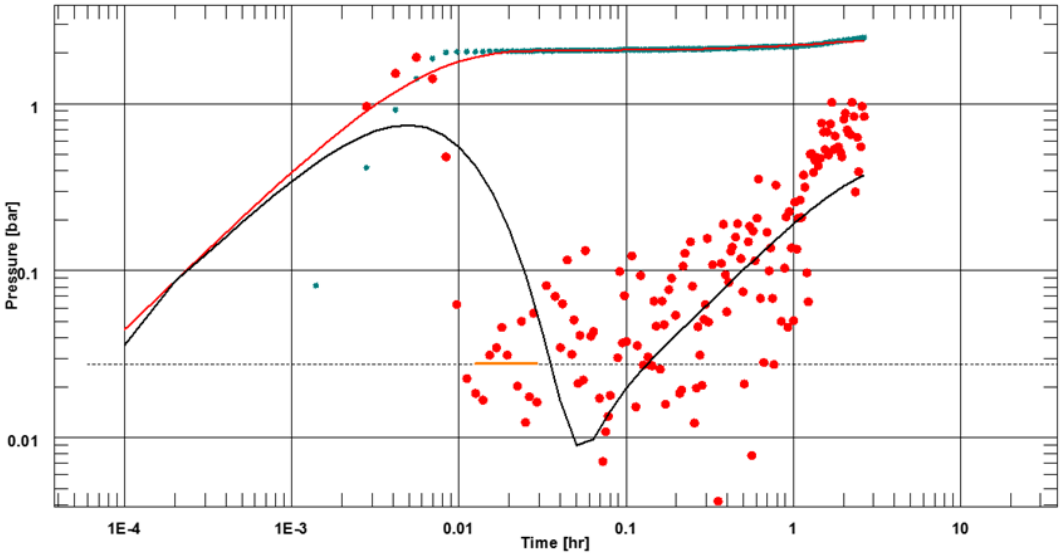


Figure 4: Log-log plot of pressure buildup of Well-X3

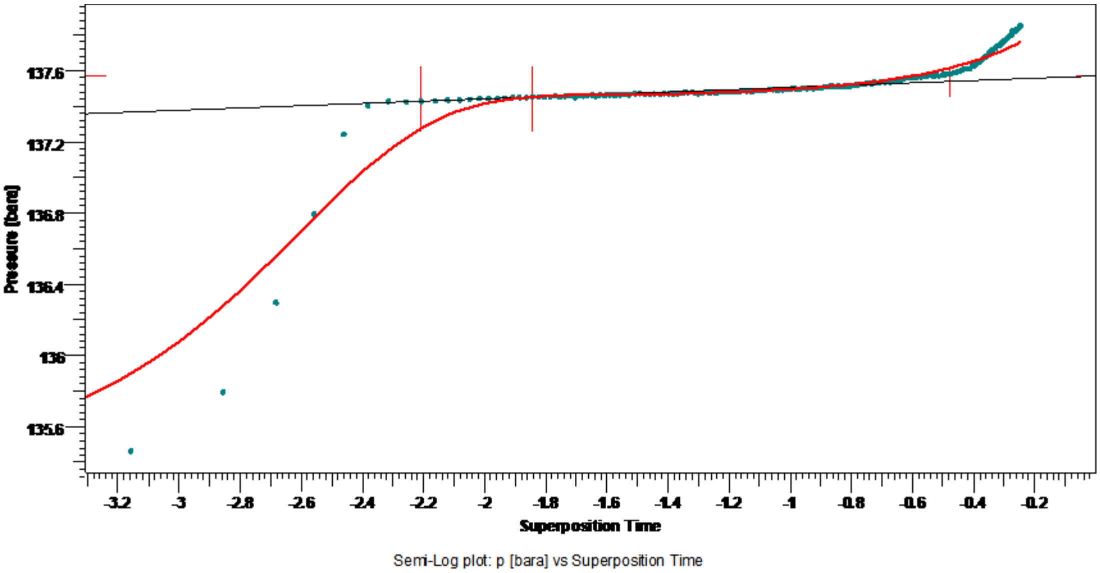


Figure 5: Semi-log plot of pressure buildup of Well-X3

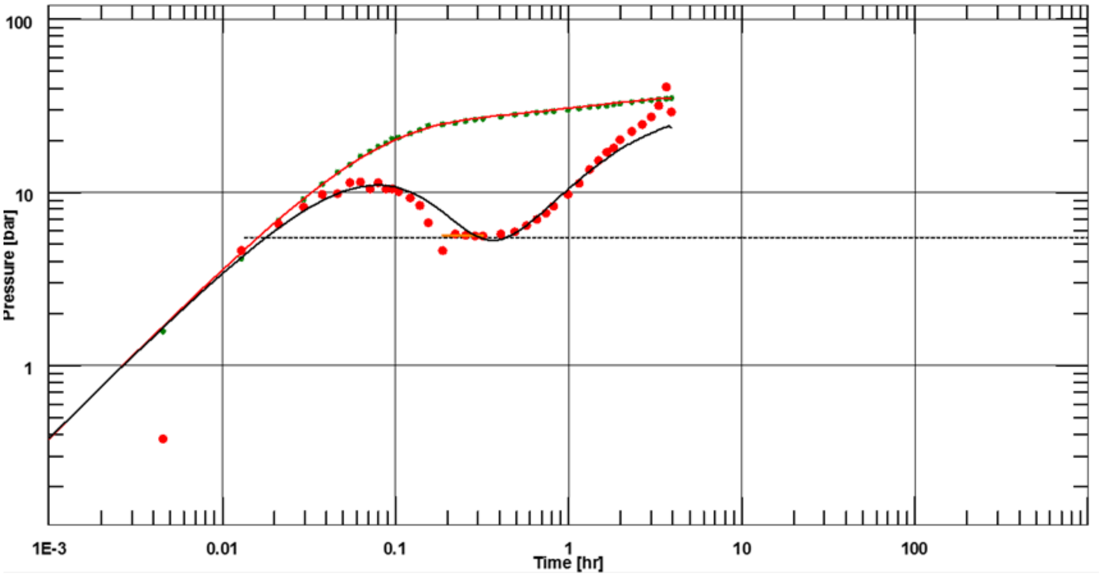
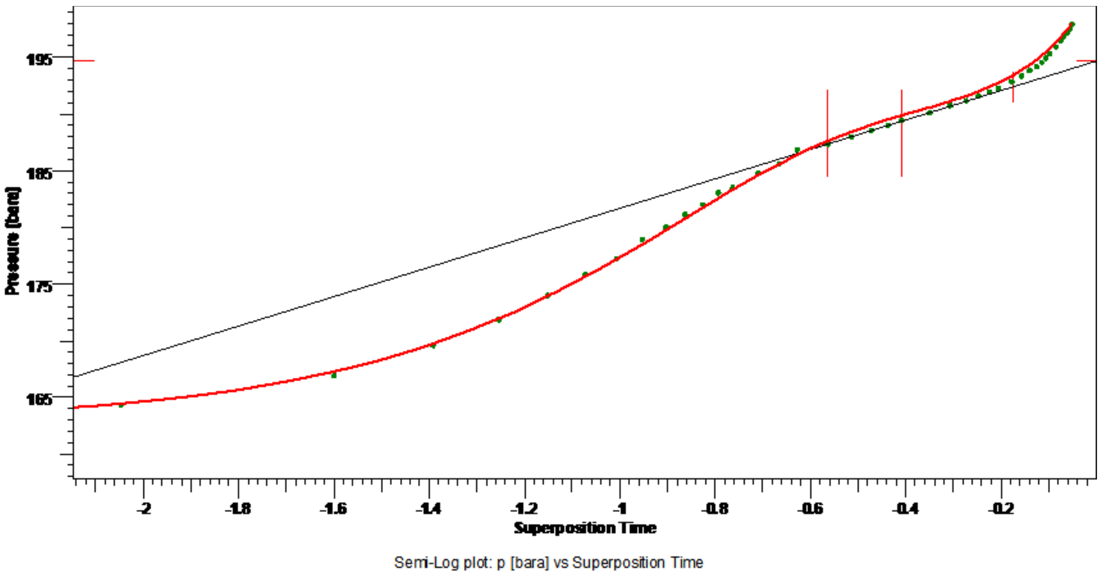


Figure 6: Log-log plot of pressure buildup of Well-B1



Semi-Log plot: p [bara] vs Superposition Time

Figure 7: Semi-log plot of pressure buildup of Well-B3

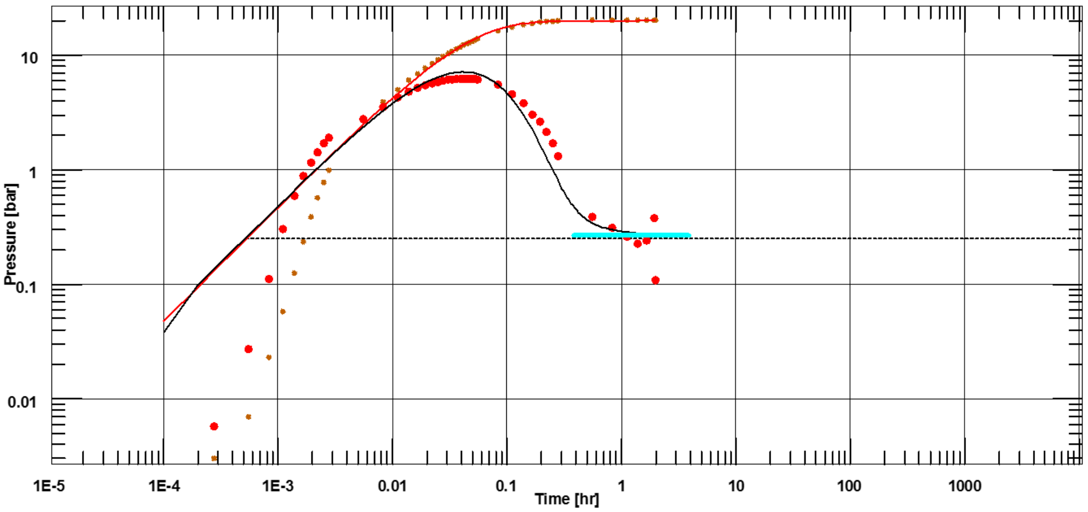


Figure 8: Log-log plot of pressure buildup of Well-C1

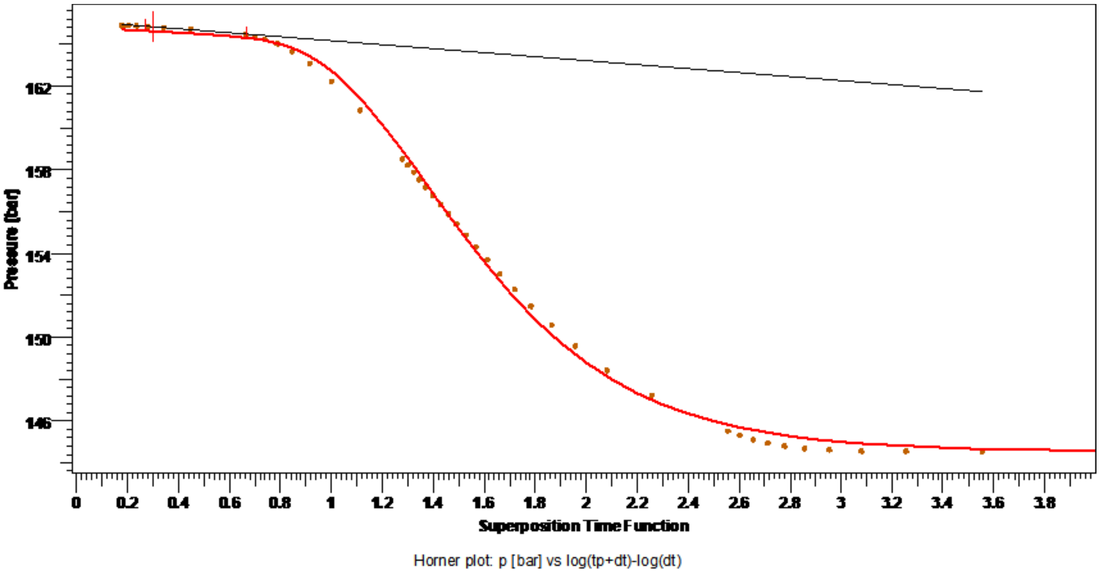


Figure 9: Horner plot of pressure buildup of Well-C1

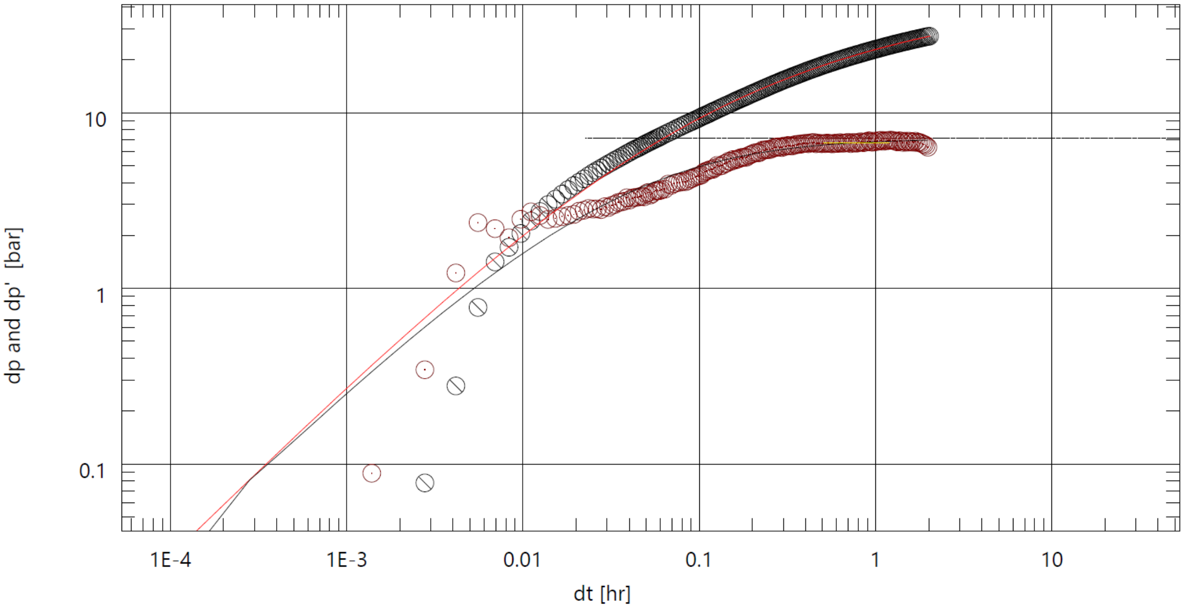


Figure 10: Log-log plot of fall-off test of Well-S3

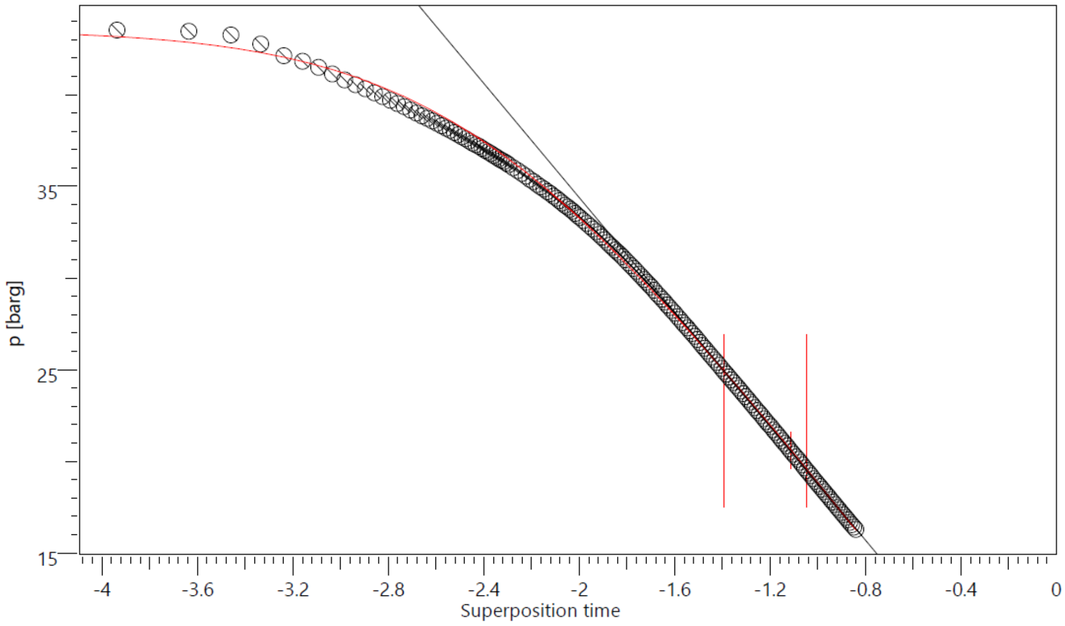


Figure 11: Horner plot of fall-off test of Well-S3

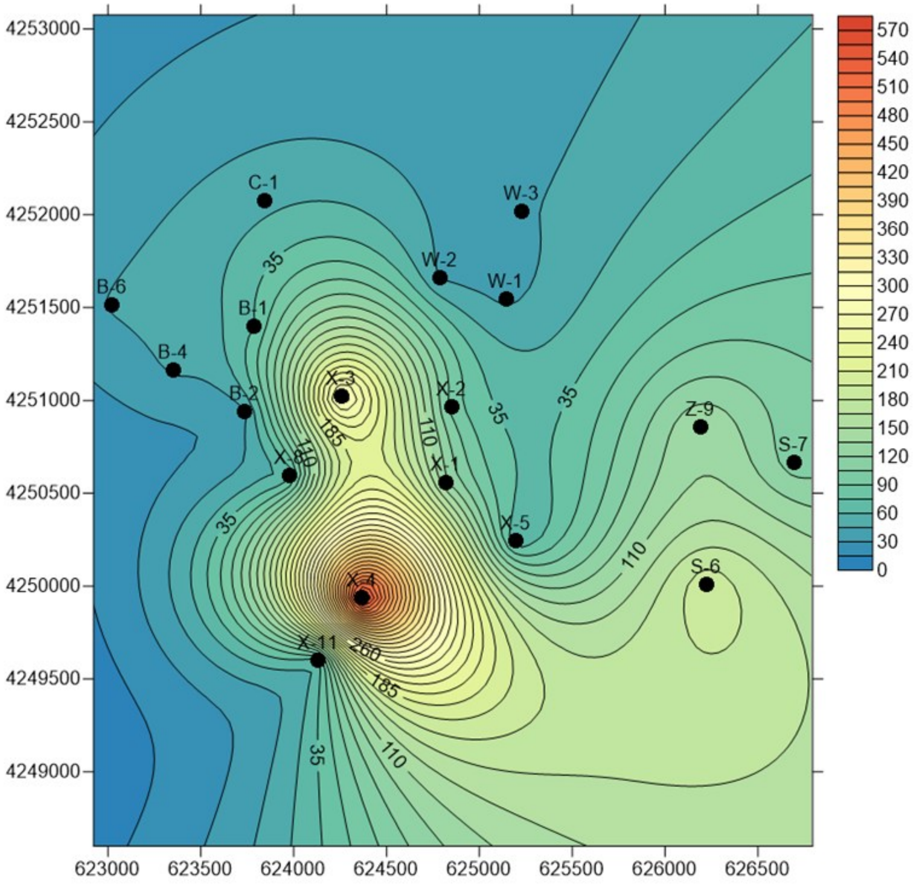


Figure 12: Spatial Distribution of Transmissivity (in Darcy*m) Alaşehir Field

4. CONCLUSION

Pressure transient analysis (PTA) is a strong tool for characterizing geological formations. It is essential to conduct pressure transient tests to obtain information about the characteristic properties of geothermal reservoirs in the beginning of a geothermal project. This study presented the analysis of pressure transient tests conducted in the Alaşehir geothermal reservoir in Turkiye. Straight line analysis and Bourdet pressure derivative analyses were performed using the academic version of Kappa software. In the initial time period of tests, a negative skin factor was observed in most of the wells, suggesting that there is no need for stimulation operations like acidizing. Analysis of the intermediate time period showed double porosity behavior, which might be associated with marble dissolution and the high number of fractures in the target zones. In the late time period, intersecting faults with sealing boundary and constant pressure boundary were detected. Test results suggested that the high heterogeneity of reservoir characteristics is controlled by tectonic mechanisms and depositional environments in the field area. The spatial distribution of reservoir properties is in good agreement with faults' traces.

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