PROCEEDINGS, 46th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 15-17, 2021
SGP-TR-218

Changing Casing-Design of New Geothermal Wells in Western Anatolia for Adapting to the Changes in Reservoir Conditions

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Keywords: Casing-design, ESPs, Geothermal, Alaşehir, Western Anatolia

ABSTRACT

The traditional casing-design of geothermal wells in Western Turkey is no longer cost-effective and shortening wells' production lifetime. The current reservoir conditions are much different from their initial values. Significant reduction of reservoir pressure and NCG (Non-condensable Gases) content have been observed in many geothermal fields in Western Turkey due to the construction of oversized power plants, aggressive production, and lack of unitized reservoir management. Thus, there is a need to adapt the casing-design of new production wells for the recent reservoir dynamics. A case study from the Alaşehir field, Western Turkey, is presented in this study. The proposed casing-design increases the performance and production lifetime of the artesian wells. It also enables the operators to use ESPs (Electrical Submersible Pumps) and LSPs (Line Shaft Pumps) with a large diameter for delivering large flowrates. With the new casing-design, we also aim to prevent casing-collapse due to poor cementing job between $9^{5/8}$" and $13^{3/8}$" casings. A set of codes written in Python was used to construct the new casing-design. The effect of the proposed design on the performance of artesian wells is studied using a wellbore simulation program, an academic version of PIPESIM. ESPs are proposed for the new and traditional casing program in the field. The proposed design will give a good insight into the development of the depleted geothermal reservoirs.

1. INTRODUCTION

Well integrity is crucial for oil, gas, water, and geothermal wells through the lifecycle of a well. The casing is one of the most critical components for well integrity, wellbore stability, and zonal isolation. Casing setting depths are important to avoid wellbore stability problems, especially during drilling. Pore pressure gradient, fracture pressure gradient, reservoir pressure & temperature, geothermal fluid properties (i.e., H_2S content, salinity, etc.), and geology are used to decide casing setting depths, the number of casing types, and casing size (Allahvirdizadeh, 2020; Sperber et al., 2010). The cost of casings is approximately 20 % of geothermal wells (Moumin, 2014), but the wrong casing design might cause the loss of the whole well. Thus, proper casing design is vital for the integrity and life of geothermal wells. In oil and gas wells, gas or oil production is provided along with tubing, and in some of these wells, a packer is set to allow fluid flow only along with the tubing. However, geothermal fluid is produced directly through casings in geothermal wells because of high flow rates, so casings are prone to negative effects of high saline and corrosive hot geothermal fluids (Lohne et al., 2016).

Generally, surface casing (20"), intermediate casing ($13^{3/8}$"), and production casing ($9^{5/8}$") are used in geothermal wells (Droessler et al., 2017; Kaldal et al., 2015; Teodoriu & Falcone, 2009). Compared to oil & gas production wells, a larger production casing size is essential for producing high volume and elevated enthalpy of geothermal fluids (Finger & Blankenship, 2010). In deep geothermal wells, the zonal isolation of deeper parts of the well with liner is advantageous to provide a larger casing inner diameter above the liner hanger (Sperber et al., 2010). Generally, the expected lifetime of geothermal wells is higher than this in hydrocarbon wells. Hence, casing integrity and cement integrity in geothermal wells are significant.

In geothermal fields, many casing failures occurred because of different reasons. To illustrate, according to a 15-year experience in the geothermal wells in Greece (mainly in the islands of Milos and Nisyros), the reasons for casing failures were investigated. In these fields, the self-sealing, overpressure, high temperature (more than 300^{o}C), and high-saline geothermal fluid make the casing design challenges. Thermal stress created during producing or cooling the well was the main reason for casing failures in the geothermal fields in Greece. In these wells, wellhead damage was also observed because of thermal expansion in surface casings and poor cementing (Chiotis & Vrellis, 1995).

Casing design with appropriate casing size & grade selection and slow preheating before production might avoid casing failures. Mainly, the surface casings of deep geothermal wells are prone to significant temperature change during drilling, which creates well integrity risk because of thermal stresses (Teodoriu & Falcone, 2009). To illustrate, the casing failure occurred in the production well (HCE229 in the water-dominated geothermal system with a temperature up to 330^{o}C and pressure up to 19.4 MPa) in the Dieng field, Indonesia. In this well, the actual loads and forces applied on casings were higher than those of casing catalog values (i.e., yield strength). Re-calculations for casing design showed that optimum casing set depth selection and casing design are crucial to avoid any casing failure (Marbun et al., 2020).

Approximately 40 deep geothermal wells were drilled in the Molasse Basin of Southern Germany. As well as high tectonic stresses and over-pressurized zones, the production of high-temperature (above 150^{o}C) geothermal fluids at high flow rates (above 100 l/s) along the casing string creates additional stresses. Thus, larger size casings were suggested to reduce friction along with the production casing for this field. In the Molasse Basin, $9^{5/8}$” casing collapsed within ten months of casing cementing. Annular pressure build-up (i.e., pressure increase by possible fluid trapped behind the casing during cementing) or buckling were considered as the potential reasons for $9^{5/8}$”-casing collapse (Lentsch et al., 2015).

The IDDP-1 well in the Krafla geothermal field of Northern Iceland was completed at a depth of 2072 m. The maximum temperature measured at the wellhead is 450^{o}C with a pressure of 142 bars. During long flow tests, several malfunctions were detected at the master valves of the wellhead, so flow tests were stopped. Then, it was a must to quench the well with cold water. This caused thermal changes in the casing, and then the casing collapsed at two parts below 600 m. The well was then abandoned. The problems encountered in the well were corrosion and extensive scale in the casing (Kruszewski & Wittig, 2018).

In oil & gas wells, the casing-casing interval is sometimes not cemented, and the only open hole-casing interval is cemented for economic reasons. However, for geothermal wells, casings should be cemented fully to prevent casing expansions in the high-temperature environment. The cementing operations are conducted for each casing for zonal isolation behind the casings. High temperature, the presence of corrosive components (i.e., CO_2), thick filter cake, and loss of circulation in fractured rocks reduce the quality of casing cementing (Allahvirdizadeh, 2020; Finger & Blankenship, 2010; Salim & Amani, 2013). Thus, poor casing cementing is commonly observed in geothermal wells. G Class cements with silica (~35%) are widely preferred in geothermal wells. Casing and cement are the most critical parameters affecting the lifetime of geothermal wells.

This study is organized as follows changes in the reservoir parameters of the Alaşehir field are overviewed, and the need for new-casing design is revealed. A new casing-design is constructed using a set of code in Python for a production well in the Alaşehir field. The effect of the proposed casing-design on the life-time of artesian production is studied by using the academic version of PIPESIM. Finally, ESPs are proposed for the new casing-design and the traditional casing-design to understand the importance of the new design for artificial lifting.

2. ALAŞEHİR FIELD

Alaşehir geothermal field has become the most attractive target for geothermal exploration activities and construction of geothermal power plants in the last decade. More than 100 wells have been drilled in the area by six different geothermal developers. There are six binary power plants and a combined flashing-binary power plant actively generating electricity from the field with a total installed capacity of 210 MWe. The reservoir is liquid dominated, and the Paleozoic aged reservoir rock consists of marble, mica-schist, calcschist, and quartz. The reservoir temperature ranges from 140°C to 250°C (Aydin and Akin, 2019). Significant pressure and NCG decline were reported due to the geothermal developers' aggressive production strategies (Aydin and Akin, 2020). Aydin et al. (2018) showed the NCG decline of geothermal wells in the Alaşehir field in figure 1.

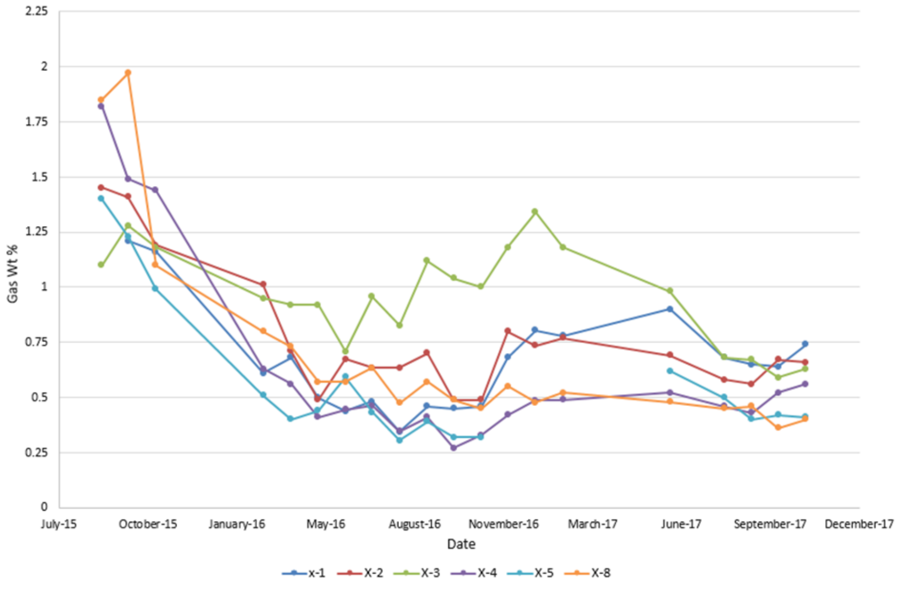

Figure 1: NCG Decline of geothermal wells in Alaşehir Field (Aydin et al. 2018)

High NCG content and reservoir pressure were the main issues to overcome during drilling when the field was untapped. A blowout occurred in the field due to wrong casing-design in 2012. Rabet et al. (2017) studied the blowout mechanism of the Alaşehir field. However, the field is exploited with an aggressive production by six different geothermal developers since 2014. The reservoir dynamics are now far different from their original values. The reservoir does not support the desired flowrates in some wells. Thus, production with

ESPs gains acceleration in the Alaşehir field. This means that a strict drilling fluid and casing program is no longer needed for the new wells in the field.

2.1 New Casing Design for Alaşehir Field

In geothermal wells, casings should be resistant to high temperature, corrosive fluid, thermal stresses, collapse resistance, burst strength, and axial loads (tensile strength) (Marbun et al., 2020; Moumin, 2014; Sperber et al., 2010). Casing failures (i.e., coupling failures and the collapse of the innermost casing) due to high load and thermal expansion are commonly observed in geothermal wells (Thorbjornsson, 2018). High thermal stresses appear due to large and quick thermal changes in high-temperature geothermal wells. According to a study, 3.6 % to 9.5 % of the geothermal wells in the South East Asia – Pacific region failed because of thermally-induced stresses (Droessler et al., 2017). Flexible couplings are suggested to prevent coupling failures with thermal expansions (Thorbjornsson et al., 2017). Optimum casing material selection, casing size selection, and casing design should be made to avoid casing failures. The most widely used casing grades in geothermal wells are J55, K55 for deep wells, N80, L80 in case of H2S presence, C95, T95, and rarely P110. For extreme conditions, 9 Chrome L-80 and 13 Chrome L-80, titanium (Beta-C Titanium) are used (Teodoriu & Falcone, 2009). As the casing grade increases, the cost of casings increases. The cost of drilling and well completions is more than half of the cost of whole geothermal projects. Thus, optimum casing design and cement design are essential for providing long-term geothermal fluid production. Casing failures observed in geothermal wells in literature are leakage, plugged or choked flow, Material degradation, including different types of corrosion, breakdown, bulge/collapse, spurious displacement/slippage, buckling due to thermal stresses and poor cementing, and annular pressure build-up (Allahvirdizadeh, 2020; Kaldal et al., 2015; Lohne et al., 2019).

In this study, a set of python codes was developed to make casing designs. In casing design, initially, casing sizes and setting depths are determined according to lithology, pore pressure gradient, and fracture pressure gradient. Then, for each casing, casing design estimations should be made. Casing size, casing setting depth, formation (reservoir) pressure, mud weight, and design safety margins are used as input parameters shown in figure 2.

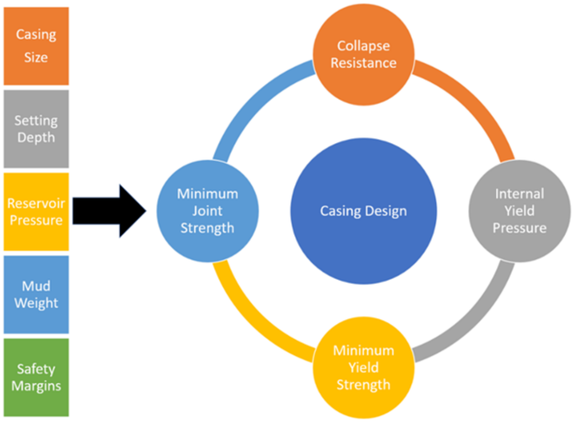

Figure 2: Input parameters and casing design scheme used in the study

From API casing catalogs, grade, nominal weight, internal yield pressure (P_i), collapse pressure (P_c), a constant for the dimensions and the material of construction of casing (K), minimum joint strength for standard API round-thread casings (short-F_{js}, long-F_{jl}), minimum yield strength (Y_m) and root thread area (A_j) for the selected casing size is listed (Bourgoyne et al., 1991; Mitchell et al., 2011). For instance, these parameters for $13^{3/8}$" casings and $9^{5/8}$" casings (API Spec 5CT) are listed in Table 1 and Table 2, respectively. From these tables, some of the casings are eliminated according to minimum P_i and P_c. Depending on F_{js}/F_{jl} and Y_m, the allowable length of the casing grade selected from the bottom of the well to the surface is estimated.

Table 1: API Casing Specification for $13^{3/8}$"

Grade	Nominal Weight, lb/ft	P_i, psia	P_c, psia	K, 1000 lb	F_{js}, 1000 lb	Y_m, psia	A_j, in^2
F25	48	1080	560	-	260	25000	10.546
H40	48	1730	740	1352	352	40000	10.546
J55	54.5	2730	1140	2017	545	55000	12.535
J55	61	3090	1670	2273	613	55000	14.508
J55	68	3450	2140	2528	695	55000	16.468
N80	72	5380	2880	3531	868	80000	17.791

Table 2: API Casing Specification for $9^{5/8}$"

Grade	Nominal Weight, lb/ft	P_i, psia	P_c, psia	K, 1000 lb	F_{jl}, 1000 lb	F_{js}, 1000 lb	Y_m, psia	A_j, in^2
H40	32.3	2270	1320	913	-	279	40000	6.99
H40	36	2560	1710	1025	-	318	40000	8.116
J55	36	3520	2220	1333	462	412	55000	8.116
J55	40	3950	2270	1489	521	477	55000	9.315
N80	40	5750	3530	1947	606	-	80000	9.315
N80	43.5	6330	4280	2135	670	-	80000	10.421
N80	47	6870	4900	2307	727	-	80000	11.434
N80	53.5	7930	6110	2643	841	-	80000	13.408
P110	43.5	8700	4760	3090	875	-	110000	10.421
P110	47	9440	6120	3339	952	-	110000	11.434
P110	53.5	109000	8830	3825	1100	-	110000	13.408

In Alasehir geothermal field, $13^{3/8}$" K-55, 68 lb/ft casing was set at 650 m in the previous well design. However, in the new casing program suggested in this study, $13^{3/8}$" casing is set at 800 m. Using the recent static pressure profile of the Alasehir geothermal field, the new casing design was made for $13^{3/8}$" at 800 m. The python code relying on figure 2 was used in this study for these estimations. The casings in Table 1 are suitable in terms of P_i except F25, 48 lb/ft. However, the casing grades above J55, 61 lb/ft have resistance to collapses. Thus, $13^{3/8}$" at 800 m, K55, 68 lb/ft was selected in this study. K55 has similar chemical properties and yield with J55, but K55 has higher minimum tensile strength, which can be advantageous for geothermal wells.

9 5/8", N80, 47 lb/ft was set at 1457 m in the previous casing program of the Alasehir geothermal field. However, for the new casing program suggested in this study, $9^{5/8}$" casing is planned to be set at 2724 m. However, this casing is planned to be hanged on $13^{3/8}$" casing as liners. Using the current pressure conditions and other properties of the Alasehir geothermal field, $9^{5/8}$" casing design was made using the python code relying on figure 2. In Table 2, $9^{5/8}$" casings are listed with their specifications. H40-32.3lb/ft, H40-36 lb/ft, and J55-36 lb/ft casings are not suitable in terms of P_i values. J55-40 lb/ft, N80-40 lb/ft, N80-43.5 lb/ft, and N80-47 lb/ft in Table 2 do not have enough resistance to collapses (P_c). Thus, N80, 53.5 lb/ft is appropriate to be set at 2724 m and hanged on $13^{3/8}$" casings as liners (figure 3).

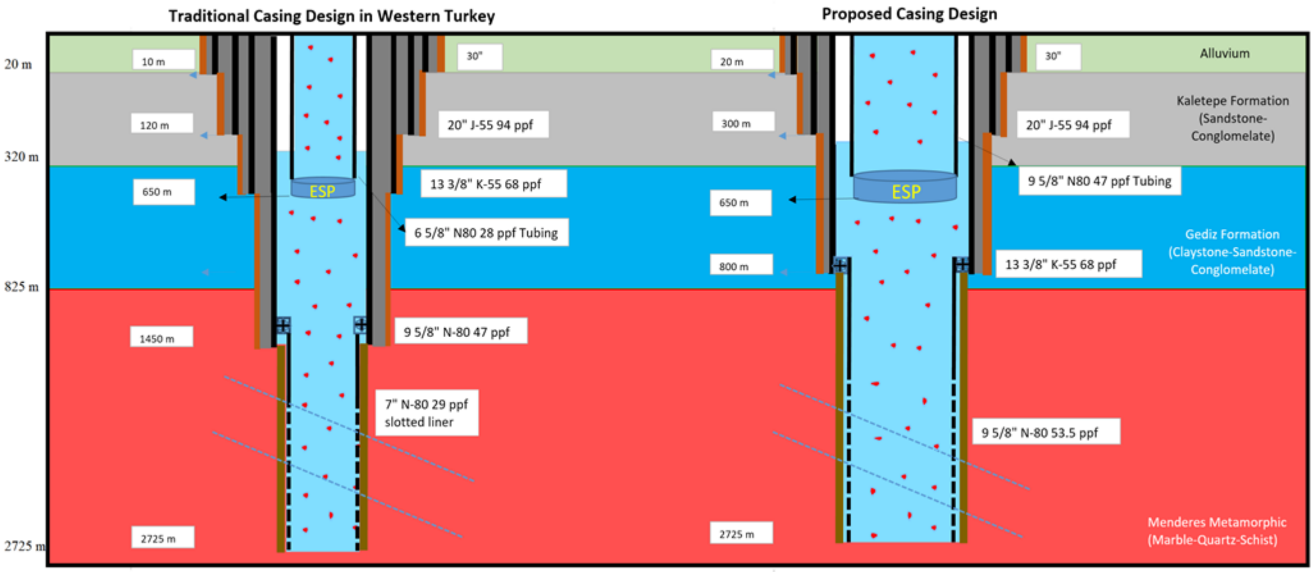

Figure 3: Traditional casing design (left) and the proposed casing design (right) for Alaşehir field

2.2 Effect of the proposed casing-design on the life-time of an artesian well

To understand the effect of new casing design on the life-time of an artesian well, we used the PIPESIM program for wellbore simulations. The simulations assumed that all the reservoir parameters remain constant, such as temperature, NCG, and productivity index except reservoir pressure. A flow rate of 216 tons/hour and 1 % NCG content by weight were used for all the simulations. Aydin and Akin (2020) performed numerical reservoir simulation of the field, and they reported a pressure decline of 3 to 4 bars per year in the Alaşehir field. In this study, we assumed 4 bars of pressure decline per year. The pressure drop in the reservoir is monitored on the wellhead flowing pressure for the traditional and new casing design. As seen in figure 4, the proposed casing design increases the lifetime of the artesian well by 3.5 years. As the depth of the well increases, the casing-size impact becomes more significant for the life-time of artesian wells.

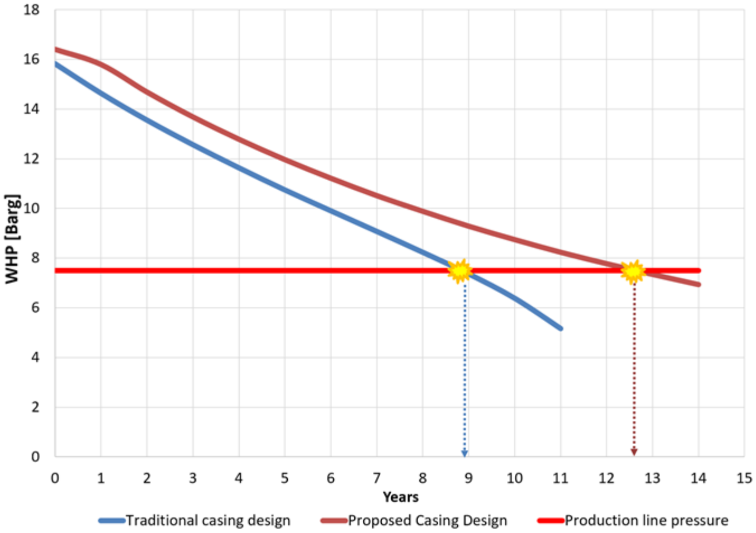

Figure 4: Lifetime of an artesian well with traditional and proposed casing design in Alaşehir field

2.3 Effect of the proposed casing-design on ESP performances

Due to the aggressive production and construction of oversized power plants, most of Turkey's geothermal power plants are operated far below their installed capacity. Aydin et al. (2020) evaluated the production capacity of geothermal power plants in Turkey, and they reported the production capacity as 65 %. To compensate for missing production, ESP is a widely used artificial lifting method, and ESP applications gain acceleration nowadays in the Alaşehir field. We used PIPESIM to design ESPs for the traditional and the new casing-design for the Alaşehir field. As shown in figure 3, a large diameter ESP can be installed in $13^{3/8''}$ casing for the new design. On the other hand, traditional casing design provide installing a moderate-size ESP. Besides, $9^{5/8''}$ production tubing can be used in the new casing program while the traditional casing program enables $6^{5/8''}$ tubing. In this study, we selected 10 inches-diameter, 9 stages, 3500 rpm, 60 Hz REDA N1400NA pump from REDA catalog for the new casing program as the most efficient ESP. For the traditional casing program, REDA H28000N was selected as the most efficient ESP from the REDA catalog. It has a 5.63-inch diameter, 20 stages, 3500 RPM, 60 Hz. The performance curves of the selected pumps are shown in figure 5. It was found that a traditional casing program can deliver a flow rate ranges from 150 tons/hour to 220 tons/hour with ESP. However, the new casing-design enables operators to use ESPs delivering 400 tons/hour to 500 tons/hour provided that the productivity index of the well is appropriate.

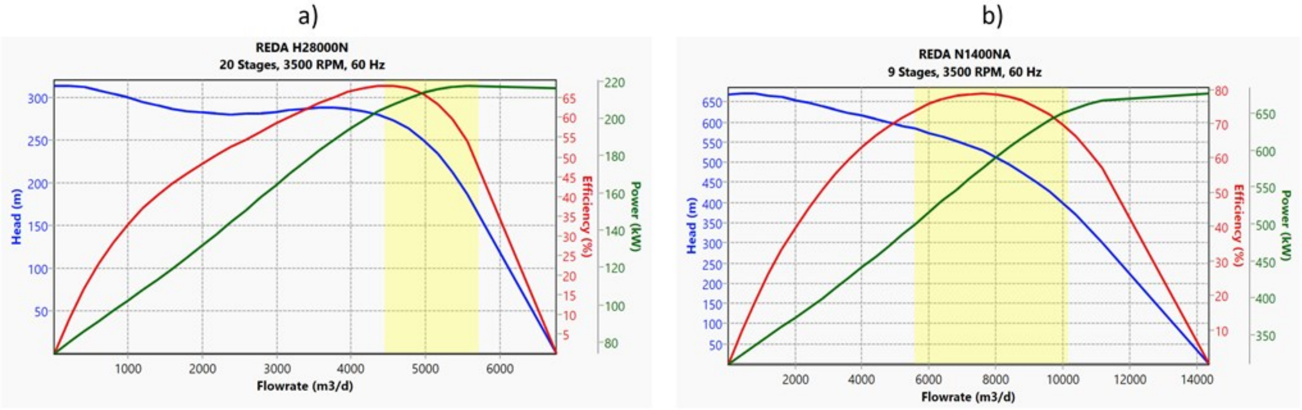

Figure 5: Performance curves of ESPs for traditional (a) and new casing program (b) in Alaşehir field

3. CONCLUSION

In this study, we propose a new casing-design for depleted geothermal wells found in Western Turkey. The study emphasized significant NCG decline and pressure reduction in the Alaşehir field. The need for a new casing design is stated with the production capacity of power plants, current reservoir dynamics, and wellbore simulations. The new casing design provides important benefits and decreases the risks of production loss. A set of codes written in Python was used to construct the casing-design. Casing sizes and setting depths are determined according to lithology, pore pressure gradient, and fracture pressure gradient. The effect of the new casing program on the lifetime of an artesian well is studied using wellbore simulations, and it was found that it increases the lifetime of the well by 3.5 years. ESP application for the traditional and new casing program is delineated, and significant flow rate improvements have been achieved with the new casing program. By hanging 9 $^{5/8"}$ casing in 13$^{3/8"}$ casing, poor cementing job that might cause casing collapse problem is prevented. The proposed design will give a good insight into the development of the depleted geothermal reservoirs.

ACKNOWLEDGEMENT

The authors thank Zorlu Energy and Schlumberger for providing the data and PIPESIM program to be used in this study.

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