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Geothermal Power Plant Design of Double-Flash Type using EES Numerical Analysis

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Double-flash,
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Abstract: The need for energy is rapidly increasing due to the meteoric increase in the population as well as economic and social life. However, moving forward with non-renewable energy sources such as fossil fuels. The depleting characteristics of fossil fuels have increased the demand for clean, sustainable, and renewable sources. In this way, with the utilization of green energy sources, it would not only be possible to meet the further growing global demand for energy, but also alleviate global warming. Double-flash geothermal power plants can be considered an alternative approach to meet today's energy demand. In geothermal power plants, the electrical power is obtained by the high enthalpy content of hot water. Such power plants provide environmentally friendly and sustainable energy production by utilizing reserves found in various parts of the World. In this study, a 40 MW double-flash geothermal power plant was specially designed with the numerical calculations using the Engineering Equation Solver (EES) program. Initially, the design of the geothermal power plant was determined using various methods. Plus, the detailed analyses of the efficiency, power computations, and the power plant were carried out. Eventually, depending on the necessary computations, it was concluded that the designed geothermal power plant with the rated power of 40 MW may meet the needs of electricity for the half of a medium-sized city of Türkiye has a population of 100,000.

EES Yazılım Programı Kullanılarak Çift Flaşlı Jeotermal Enerji Santrali Tasarımı ve Sayısal Analizi

Anahtar Kelimeler
Jeotermal enerji tesisi,
Çift flaş,
Yenilenebilir güç,
EES sayısal analizi

Öz: Nüfusun ve ekonomik ve sosyal yaşamın meteorik artışı nedeniyle enerjiye olan ihtiyaç hızla artmaktadır. Ancak, fosil yakıtlar gibi yenilenemeyen enerji kaynaklarıyla ilerlemek artık mümkün değildir. Fosil yakıtların tükenen özellikleri, temiz, sürdürülebilir ve yenilenebilir kaynaklara olan talebin artmasına neden olmuştur. Bu şekilde, yeşil enerji kaynaklarının kullanımıyla, yalnızca daha da artan küresel enerji talebini karşılamak mümkün olmayacak, aynı zamanda küresel ısınma üzerinde de hafifletmeler elde edilebilecektir. Buna göre, çift flaşlı jeotermal enerji santralleri, günümüz enerji talebini karşılamak için alternatif bir yaklaşım olarak dikkate alınabilir. Jeotermal enerji santrallerinde, elektrik gücü sıcak suyun yüksek entalpi içeriğinden elde edilir. Bu tür santraller, dünyanın çeşitli yerlerinde bulunan rezervleri kullanarak çevre dostu ve sürdürülebilir enerji üretimi sağlar. Bu çalışmada, Engineering Equation Solver (EES) programı kullanılarak sayısal hesaplamalar yapılarak özel olarak 40 MW'lık çift flaşlı jeotermal enerji santrali tasarlanmıştır. Başlangıçta, jeotermal santralin tasarımı çeşitli yöntemler kullanılarak belirlenmiştir. Ayrıca, verimlilik, güç hesaplamaları ve santral üzerinde detaylı analizler yapılmıştır. Sonunda, gerekli hesaplamalara bağlı olarak, 40 MW nominal güce sahip tasarlanan jeotermal santralin, 100.000 nüfusa sahip

Türkiye'nin orta büyüklükteki bir şehrinin yarısının elektrik ihtiyacını karşılayabileceği sonucuna varılmıştır.

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1. Introduction

Exploiting from the geothermal energy has significantly increased recently, as the general trend of power applications includes shifting from fossil fuel-powered energy generation methods to the renewable ones. This type of energy production can be defined as power obtained from the heat naturally found within the earth's crust. It is therefore captured for useful electric generation, as well as considered for space heating else in industrial steam. It is naturally available everywhere under the earth's surface, however, the highest temperatures, therefore the most preferred resources are found in the exact or close places to active volcanoes or close to volcanoes of geologically young types [1]. Geothermal energy is a clean and renewable power source since the heat coming from the inner parts of the earth is substantially unlimited. Besides, geothermal energy sources obtained from deep inside the crust are available at all hours of the day as well as at all days of the year [2].

On the other hand, unlike the geothermal energy, solar and wind energy sources, in the opposite, are depending on lots of different factors, which include power fluctuations in a daily or seasonal manner, and as well as the power generations from those technologies also depend on the variations of the weather situations. For these reasons, the electric energy obtained from geothermal facilities is more consistently reliable, as soon as the resource is found and prepared for power exploitation, the facility will continue to generate useful power for years. Double-flash geothermal power plants are superior to single-flash systems in terms of energy efficiency and sustainability and are particularly preferred in areas with medium- to high-temperature geothermal resources. However, due to their higher investment costs and more complex infrastructure, various analyses should be conducted. Kulasekara and Seynulabdeen (2019) stated in their study that geothermal energy is a renewable energy source that can be effectively used for electricity generation. They also compared geothermal power with other renewable sources such as solar and wind energy, noting disadvantages such as higher initial costs and geographical dependency [3]. Özer (2018) provided detailed information on the application areas of double-flash geothermal power plants. This study examined in detail how double-flash cycles are utilized for electricity generation, especially from high-temperature geothermal resources, as well as their other applications. It was noted that such plants are used to meet the energy needs of industrial zones with high energy demands or densely populated cities [4].

The influence of the geothermal energy on the environment is significantly small and that is controllable, therefore it is regarded as an environmentally friendly renewable power source. Air emissions from such facilities are negligibly small. Besides, emission from the greenhouse gases including nitrous oxide, hydrogen sulfide, sulfur dioxide, ammonia, methane, particulate matter, as well as carbon dioxide are pretty low. Those are especially so low when compared to the emissions obtained from the fossil fuels. However, some toxic chemical elements may be found inside the water or the condensed steam of the geothermal power plants, such as arsenic, mercury, lead, zinc, boron as well as Sulphur may be found in those waters. And, their toxicity effects generally depend on the concentration of those substances [5]. DiPippo (2012) provides comprehensive information on the design and environmental impacts of geothermal power plants. It includes detailed analyses, particularly regarding the potential of double-flash systems to reduce carbon emissions. The study highlights that geothermal power plants have significantly lower CO_2 emissions compared to fossil fuel-based plants [6]. Bosnjakovic et al. (2019) focus on the advantages and environmental impacts of double-flash systems, emphasizing that geothermal power plants contribute to combating climate change by reducing carbon dioxide emissions [7]. Fridleifsson et al. (2008) state that geothermal power plants have lower greenhouse gas emissions throughout their lifecycle compared to fossil fuel power plants. This indicates that geothermal energy can play a crucial role in addressing climate change [8]. On the other hand, most portion of such elements remain in the water solution which is reinjected back into the same reservoir of the rock. This hot rock mainly serves as the source of extracting hot water or steam.

Some main elements are included in a geothermal system, which could be given as the heat source, reservoir, and the fluid that is the carrier needed for heat transfer from underground to the ground level. A recharge area and an impermeable cap rock are also found together with those elements to obtain the seal of the aquifer. The simplified presentation of such systems is given in Figure 1.

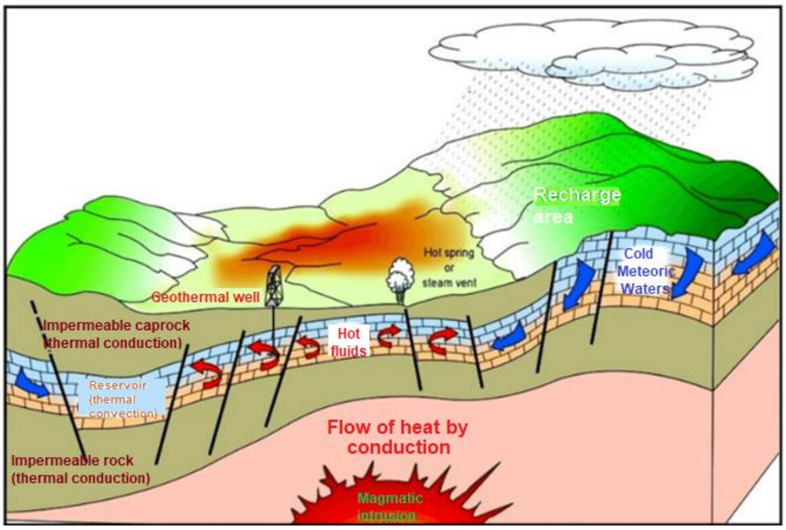

Figure 1. An ideal geothermal system

Fluid convection is the type of heat transfer mechanism responsible for conveying the heat between different locations in the geothermal systems. This heat transfer mechanism takes place due to the heating and consequent fluid thermal expansion in the gravity field. The heat that is provided at the circulation system base is the energy responsible for driving the system. As obeying the laws of physics, the fluid that is heated will have a lower density and it will rise, and will be replaced by the cold fluid having a high density, which comes from the system margins and will have the trend of sinking. Depending on the convection nature, temperatures in the upper system part have a tendency to increase, whereas, the temperatures in the lower system part tend to decrease [9].

The heated water by geothermal means is separated into hot water and steam in a surface vessel. This vessel is known to be the steam separator, whereas, the hot water is also referred to as the brine. Later, the produced steam is given to the steam turbine, and the turbine powers the generator. The low-energized fluid is then given back to the reservoir [10].

Especially, in higher-temperature geothermal locations, power facilities of the double-flash types can be operated with a high effectiveness and efficiency. Therefore, in the case of installing a double-flash system to a geothermal facility instead of installing a conventional geothermal system to the same facility, considering the same value of the temperature and the pressure, the double-flash type will generally produce a higher power output [11].

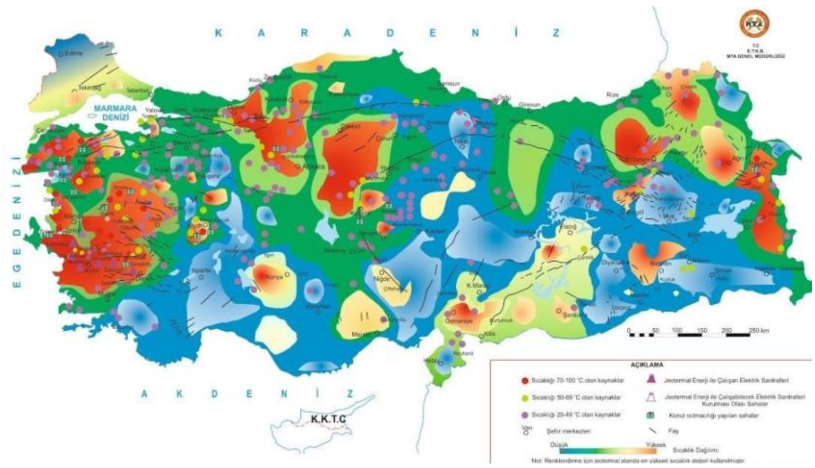

Figure 2. Map of Türkiye's Geothermal Resources and Applications [12]

In Figure 2, red regions represent high-temperature sources, while green and blue regions represent medium- and low-temperature sources, respectively. As shown on the map, Türkiye's known geothermal fields with high temperatures (average 70–100°C) and flow rates are located in the regions of Denizli (Pamukkale), Aydın (Germencik), and Manisa (Salihli). Türkiye's geothermal resources exhibit regional variations in terms of temperature and flow rates. While high-temperature sources are found in Western Anatolia, medium- and low-temperature sources are present in Central and Eastern Anatolia [13]. For example, a well drilled in 2016 in the Bozköy district of Niğde measured a bottom-hole temperature of 341°C at a depth of 3,845 meters [14]. Additionally, as of 2014, flash steam systems accounted for the majority of the world's installed geothermal power generation capacity, with approximately 42% for single-flash systems and 19% for double-flash systems [15]. These data reveal that Türkiye has significant geothermal energy potential with notable regional differences.

Recent studies have been reviewed. Zağralıoğlu (2020) examined different power plant types used for electricity generation from geothermal resources and stated that double-flash systems can generate 10-15% more energy compared to single-flash systems using the same amount of steam [16]. Ates (2016) conducted a comparison of various geothermal power plant types, highlighting that double-flash systems produce more electricity by utilizing a two-stage separation system and turbines with dual inlet pressures [17]. Yılmaz (2019) performed a lifecycle cost analysis of a hydrogen production system integrated with a combined flash-binary geothermal power plant. The study evaluates the economic and environmental performance of geothermal power plants [18]. Akbay and Yılmaz (2021) conducted a thermodynamic performance analysis of a flash-binary geothermal power plant using different working fluids (n-butane, isobutane, and isopentane). The results showed that when using n-butane, the total power generation was 3,624 kW, with the highest energy efficiency calculated at 13.49% [19].

2. Materials and Methods

Double-flash geothermal power plants are a technology used to achieve higher efficiency from geothermal energy resources. One significant advantage of these plants is their ability to provide high energy efficiency. They offer the possibility of generating more energy from the same geothermal resource, enabling a more effective utilization of resources. However, challenges such as high installation costs and their applicability only in specific geological regions are notable. Therefore, these systems must be designed with all these issues in mind. Details regarding their design and analysis are provided in this section.

In a geothermal system, hot water is captured from an underground reservoir of water-dominated. By the utilization of the production wells that are either constructed artificially or found naturally, the fluid rises to the surface. However, a production valve can be utilized to form isolation of the system underground part from the surface part.

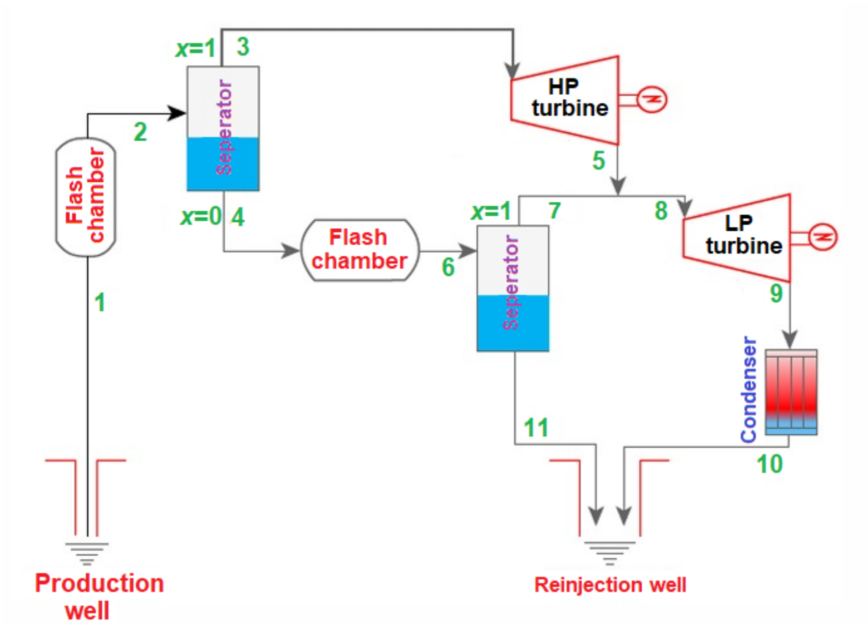

Figure 3. The double-flash type of geothermal power plant [20]

In the path from the production well towards the flash chamber, shown via 1, the hot water mixed with the high enthalpy steam that is captured from the geothermal reservoir is provided as a mixture to the flash chamber, before location 2. In this system referred as the double flash system, an initial separator is utilized to separate the high-pressure steam from the geothermal fluid. At location 2, the fluid is ready to be separated at the separator. The high-pressure steam at the exit of the separator having the quality value of 1 is now directed to the first turbine of high-pressure type. Namely, along with path 3, the steam of the high pressure is utilized for driving this first turbine, which is connected to the generator for output power generation. Due to the rotation of the turbine, the generator also rotates to produce useful power.

At the exit side of the separator having the quality value of 0, the geothermal fluid is found in the form of having high temperature, which is provided to the second separator, towards the path from 4 to 6. Here, separation of the water from the steam is again performed to be fed to the second turbine, referred to as a low-pressure turbine. At location 5, namely, along with the exit of the first high-pressure turbine, the high-pressure steam that was used to drive the first turbine now has relatively lower energy, mixed with the steam coming along path 7, to be given to the second low-pressure turbine, at location 8. Accordingly, the steam at the exit of the first turbine and the steam coming from the second separator with the quality of 1, pass respectively towards the directions of 5 to 8 and 7 to 8, to produce power in the low-pressure turbine, in the path of 8 to 9. The mechanical power captured at the mechanical blades of the second turbine is converted to electrical energy at its generator, to produce additional electrical energy.

Along with the path from 9 to 10, the steam of low pressure obtained from the second turbine is condensed to liquid water with the utilization of the condenser. The liquid water that is obtained in the separator exit having the quality of 0 at the location of 11 is given to the reinjection well together with the liquid water at the exit side of the condenser at the location of 10. Namely, this geothermal water is not wasted but reinjected back into the reservoir. During the reinjection process in geothermal power plants, certain challenges may arise. The geothermal fluid extracted from underground can contain high concentrations of dissolved minerals and metals. These substances may require proper treatment before reinjection. Additionally, mineral precipitation can lead to blockages in reinjection wells, which can reduce system efficiency. During reinjection, microseisms may be triggered depending on local geological conditions. This could increase seismic activity and raise concerns among residents in the area, making it another drawback. In some cases, the reinjection process may release carbon dioxide, methane, or other gases from underground, potentially increasing environmental impact. As potential solutions, filtration and treatment systems can be used prior to reinjection. Furthermore, continuous monitoring can help detect potential anomalies. Another solution involves controlling the reinjection rate, which could mitigate potential seismic effects.

In a geothermal power plant of double-flash type, the saturated liquid geothermal water found with the temperature of 260°C and the mass flow rate of 200 kg/s is flashed in an isentropic manner in the flash chamber with the pressure ratio of 2. In the vapor-liquid separator, its steam is separated from the liquid water, and then the stream is used. The isentropic efficiency of the steam turbine is assumed to be 85% in the power conversion. The geothermal water that is discharged from the turbine is later condensed to be given to the reinjection well. Under these circumstances, a 40 MW rated power geothermal power plant was designed with the utilization of the EES program.

In the system design of the double-flash geothermal power plant, initially, a cumulative of 11 numbers is used to indicate different locations of the system components, demonstrated in Figure 3. The same codes have been also taken into consideration in the EES program, during the design of this double-flash geothermal power plant. The codes utilized in the EES are presented in the appendix.

In state 1, information on the fluid that is captured from the geothermal production well has been entered into the EES program. On the other hand, at state 2, the outlet side of the flash chamber is introduced, namely before entering the first separator, to obtain fluids of zero and unity qualities. At state 3, the coding has been performed for the part where the fluid is now at a state having a complete vapor, referred to as the unity quality. Therefore, this vapor leaving the separator is now ready to enter the high-pressure turbine at the inlet side. Besides, at state 4, the fluid separated to the zero quality at the separator exit again enters the flash chamber, and the necessary coding for this state is also given in the appendix part. As also revealed from the codes provided in the appendix, at the state of 3 with full steam of unity quality, the temperature value at this point is the same as the source temperature of state 2. On the other hand, at the state of 4 with full liquid water of zero quality, the pressure value at this point is the same as the source pressure of state 2.

The code for state 5 has been written with the assumption of 85% efficiency of the high-pressure turbine at the outlet side of this turbine. At state 6, there is the connection of the outlet of the flash chamber to the separator inlet, and the related codes of EES are provided. At state 7, which is the outlet side of the second separator, quality of the fluid is x=1 with full vapor. At the inlet side of the low-pressure turbine, the codes for state 8 give the relevant information. Furthermore, the inlet side on the condenser of the low-pressure turbine is demonstrated with the path of 9. Similarly, related coding on the EES program for this state of 9 is indicated in the appendix section. At the condenser outlet, the phase of the liquid water is obtained from the initial water vapor phase found at the condenser inlet, therefore the fluid becomes ready to be injected back into the reinjection well along this path of 10. Similarly, the phase of liquid water is acquired along with the path of 11, to be ready for injection to the reinjection well together with the liquid water coming along the path of 10.

In a double-flash geothermal power plant, x (quality) represents the mass fraction of the vapor phase. When the quality value is equal to the value of 0, the system is referred to be found completely in the liquid phase. In this case, the generated power in the value of MW will be low, since there is no available steam for the power production. In this study, the quality value has been taken to be equal to the value of 0.

On the other hand, when the quality value has increased to the value of 0.1, the amount of the mass ratio regarding the vapor phase in the system will accordingly increase. This means more steam passes through the mechanical blades of the turbine, thus increasing the overall energy production. As a result, when the quality value increases, the power generation from the facility given in MW value also increases accordingly, and in this case, when the study is re-examined again, the power rating is found to correspond to 70 MW. This increase is occurring due to the higher energy-carrying capacity of the steam. Therefore, it is concluded that the higher the quality value of the steam is the higher the energy production will be.

3. Results and Discussions

The aim of the study includes the design of a 40 MW geothermal power plant in the form of double flash type, and accordingly, the required codes for each of the 11 states for this system shown in Figure 3, have been initially written. On the other hand, concerning the rated power assumption corresponding to 40 MW, the thermal efficiency (η_{th}) has been computed using the formula presented in Eq. (1):

$$\eta_{th} = \frac{\dot{m}_3(h_3 - h_9)}{\dot{m}_1 h_1 - (\dot{m}_{11} h_{11} + \dot{m}_{10} h_{10})} \qquad (1)$$

In Eq. (1), the designations $\dot{m}$, h, and η_{th} refer to the mass flow rate, enthalpy, and the thermal efficiency, respectively. In this regard, the thermal efficiency of the system is defined by the ratio of the difference of the enthalpies between states 3 and 9, which are respectively exit sides of the first separator and the exit side of the low-pressure turbine, that is multiplied by the mass flow rate of the vapor fluid with full unity, divided to the initial energy content of the water captured from the production well excluding the energy contents given to the sink without utilization at the locations 10 and 11, respectively standing for condenser exit and the exit of the second separator. In this respect, the thermal efficiency is computed as η_{th} =0.1499, which is approximately assumed to be 15%. This result accompanying the other outputs of the EES computation is exhibited in Figure 4. On the other hand, various thermodynamic parameters derived from the EES study have been indicated in Figure 5. These parameters are, respectively, *h*: Enthalpy, *hs*: Isentropic enthalpy, $\dot{m}$: Mass flow rate, *P*: Pressure, *s*: Entropy, *ss*: Isentropic Entropy, *T*: Temperature, *x*: Evaporation quality and it is used only in two-phase systems, expressing the vapor ratio. Here, the subscript of i stands for the instant state from 1 to 11. To support this result from the literature, Argün has concluded the cumulative thermodynamic efficiency of his studied geothermal power plant corresponded to the value of 12-13%; accordingly, that was demonstrated to be much lower than the result of the current study [21].

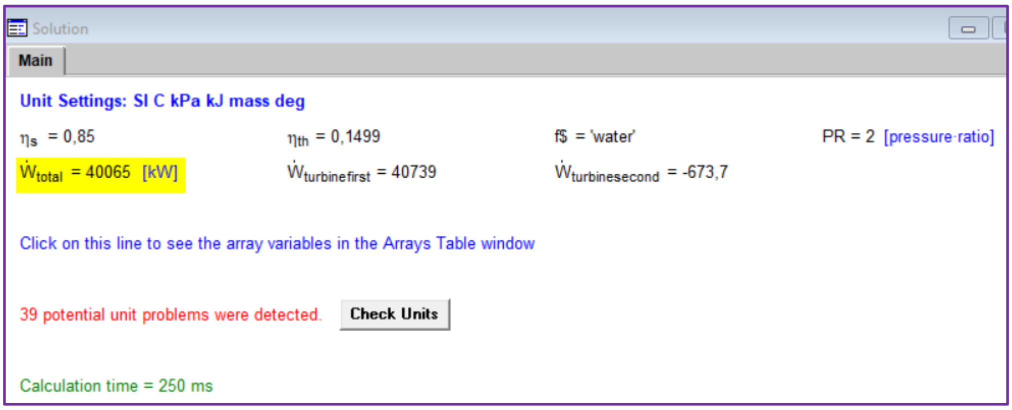

Figure 4. The analysis computation outcomes of the EES

Arrays Table

Main

Sort	h_i	hs_i	$\dot{m}_i$	P_i	s_i	ss_i	T_i	x_i
[1]	1135		200	4692	2,885		260	0
[2]	1135		200	2346	2,905		220,6	0,1016
[3]	2801		20,33	2346	6,28		220,6	1
[4]	946,3		179,7	2346	2,523		220,6	0
[5]	797,1	770,8	179,7	6	2,608	2,523	36,16	0,2673
[6]	946,3		179,7	1173	2,538		186,9	0,07668
[7]	2783		13,78	1173	6,53		186,9	1
[8]	2063	1936	13,78	3	6,957	6,53	24,08	0,803
[9]	2112	2121	13,78	5	4,885	6,957	32,87	0,8149
[10]	137,7		13,78	5	0,4762		32,87	0
[11]	793,8		165,9	1173	2,206		186,9	0

Figure 5. The analysis computation outcomes of the EES for the various parameters

Now, two turbines are available in the system that generate useful power and the power conversion on those turbines are indicated with the following relation of Eq. (2):

$$\dot{W}_{total} = \dot{m}_3\,(h_3 - h_5) + \dot{m}_8(h_8 - h_9) \quad (2)$$

Eq. (2) indicates the products of the rate of the mass flow of vapor entering both high-pressure and low-pressure turbines multiplied by the enthalpy dissipated from the high-energized vapor during the power conversion. The enthalpy dissipations responsible for power conversions that are multiplied by vapor flow rates for both turbines are then added with each other to give the total power generation, is exhibited in Eq. (2). In this context, the total power revealed with the thermodynamic unit of kW has been reported to correspond to 40,065 kW.

Along with the path from 1 to 2, at a mass flow rate of 200 kg/s at 260°C of geothermal water temperature, the isentropic flash has occurred in the flash chamber keeping the pressure ratio equal to 2. Then the flashed fluid found in the saturated state is further separated into vapor water and liquid water, where vapor water is used for power conversion. Later, the power is generated in the steam turbine at an isentropic efficiency of 85%. During the design of this geothermal power plant that has a power rating of 40 MW, the capacity factor for the assumed power plant was selected as 30%. The capacity factor refers to the actual amount of energy produced by a power plant over a specific period compared to the theoretical maximum energy it could generate. This factor typically depends on the quality of the resource used in geothermal plants, reservoir pressure, cycle technology (e.g., single flash, double flash, or binary cycle), and the plant's operating time. A 30% capacity factor is generally adopted for plants utilizing low-temperature resources or in cases where reservoir temperature and flow rate are inconsistent. The reason for this is that, although geothermal reservoirs are a sustainable energy source, they are limited by the renewal rate of the reservoir and the amount of geothermal fluid available. A 30% capacity factor is chosen as a precaution to ensure the long-term utilization of the reservoir. In short, a lower capacity factor is often preferred to minimize the risk of reservoir depletion and secure long-term energy production. This approach can be considered a strategy to extend the operational lifespan of the plant.

After completing the design stage of the power plant, the energy produced by this power plant in 1 year is calculated and presented in kWh. Similarly, the approximately 1-year energy need of a house is calculated and shown again in kWh. Ultimately, the total amount of houses that can be fed by the energy generated in this power plant is determined by dividing the annual energy generated from this power plant by the approximate energy need of a house. In the analysis, with the assumption of a city having a population of 100,000, where 4 people live in every house is assumed, will yield a total of 25,000 houses in total in this city. The computations demonstrated below will show that the power obtained from this power plant will meet the needs of 12,000 houses approximately. Consequently, it was determined that a designed 40kW power plant meets the electricity needs of half of a city with a population of 100,000. In an ordinary house, the following electrical appliances may be found, in which their amounts and rated powers and their daily power consumptions are exposed in Table 1.

Table 1. Electrical appliances used in an ordinary home

Appliance	Power (W)	Amount	Total power (W)	Hours/days use	Energy per day (Wh)
Television (1)	75	1	75	5	375
Refrigerator (2)	650	1	650	24	15,600
Dish washer (3)	870	1	870	0.67	582.9
Washing machine (4)	650	1	650	0.67	435.5
Furnace (5)	900	1	900	0.67	603
Toaster (6)	1,000	1	1,000	0.17	170
Vacuum cleaner (7)	600	1	600	0.33	198
Computer (8)	120	1	120	1	120
Modem (9)	10	1	10	24	240
Lamp (10)	30	10	300	5	1,500
Hair dryer (11)	2,100	1	2,100	0.02	42
Water heater (12)	7,000	1	7,000	0.5	3,500
Iron (13)	2,200	1	2,200	0.17	374

The approximate electricity consumption of an ordinary house is projected in Table 1. In this table, initially, the electrical devices in the house were identified, and then the number of each device in the house was projected and noted. Their rated power has been also plotted in this table, given in the thermodynamic unit of Watts. As demonstrated in this table, there are about 13 different types of electrical devices in total. Accordingly, they are numbered from 1 to 13. The total power for each appliance is determined again in Watts. Similarly, the number of hours that we benefit from those devices has been determined and shown in the same table. Finally, in the rightest column, the total energy dissipation in one day for each device given at a certain amount has been determined and revealed. The usage of devices numbered 1 and 2 are taken as 5 and 24 hours, respectively. Considering the device numbered with 3, i.e., referring to the dishwasher, if it is used for a total of 2 hours every three days, the daily usage of this device can be configured with the coefficient of 0.67. The same applies to devices 4 and 5. For device number 6, if it is used for a total of 1 hour every 6 days, the daily usage of this device can be configured as 0.17. For device number 7, if it is used for 1 hour every 3 days, the daily usage of the device is counted as 0.33 hours. Devices number 8, 9, and 10 have usage times of 1, 24, and 5 hours, respectively. For device number 11, if it is used for a total of 5 minutes in 3 days, approximately 0.02 hours per day is counted in the calculation. For device number 12, if it is used for a total of 1 hour in 2 days, it is taken as 0.5 hours in 1 day. Device number 13 is similar to device number 7. Necessary calculations are shown in Eq. (3)-(17):

$$75W\ x\ \frac{24h}{1\ day}x\frac{5h}{24h}=\frac{375Wh}{day} \tag{3}$$

$$650W\ x\ \frac{24h}{1\ day}x\frac{24h}{24h}=\frac{15{,}600Wh}{day} \tag{4}$$

$$870W\ x\ \frac{24h}{1\ day}x\frac{0.67h}{24h}=\frac{582.9Wh}{day} \tag{5}$$

$$650W\ x\ \frac{24h}{1\ day}x\frac{0.67h}{24h}=\frac{435.5Wh}{day} \tag{6}$$

$$900W\ x\ \frac{24h}{1\ day}x\frac{0.67h}{24h}=\frac{603Wh}{day} \tag{7}$$

$$1{,}000W\ x\ \frac{24h}{1\ day}x\frac{0.17h}{24h}=\frac{170Wh}{day} \tag{8}$$

$$600W\ x\ \frac{24h}{1\ day}x\frac{0.33h}{24h}=\frac{198Wh}{day} \tag{9}$$

$$120W\ x\ \frac{24h}{1\ day}x\frac{1h}{24h}=\frac{120Wh}{day} \tag{10}$$

$$10W\ x\ \frac{24h}{1\ day}x\frac{24h}{24h}=\frac{240Wh}{day} \tag{11}$$

$$30W\ x\ \frac{24h}{1\ day}x\frac{5h}{24h}=\frac{1{,}500Wh}{day} \tag{12}$$

$$2{,}100W\ x\ \frac{24h}{1\ day}\ x\ \frac{0.02h}{24h} = \frac{42Wh}{day} \quad (13)$$

$$7{,}000W\ x\ \frac{24h}{1\ day}\ x\ \frac{0.5h}{24h} = \frac{3500Wh}{day} \quad (14)$$

$$2{,}200W\ x\ \frac{24h}{1\ day}\ x\ \frac{0.17h}{24h} = \frac{374Wh}{day} \quad (15)$$

For all electrical appliances, the Wh/day data is collected, to find the cumulative, as provided in Eq. (16):

$$Total = \frac{23{,}740.4\ Wh}{day} \quad (16)$$

Finally, the unit of Watt-hour given in Eq. (16) has been converted to the unit of kilowatt-hour, as indicated in Eq. (17):

$$Total\text{: } 23{,}740.4\ \frac{Wh}{day}\ x\ \frac{1\ kWh}{1000\ Wh} \cong 24\ \frac{kWh}{day} \quad (17)$$

Therefore, the approximate daily energy consumption is calculated and exhibited as 24 kWh. Now, the annual energy consumption can be determined with Eq. (18):

$$Annual\ total = \frac{24\ kWh}{1\ day}\ x\ \frac{30\ day}{1\ month}\ x\ \frac{12\ month}{1\ year} = \frac{8{,}640\ kWh}{1\ year} \quad (18)$$

According to these derived data, the average energy consumption of an ordinary house annually can be found and demonstrated as 8,640 kWh, given in Eq. (18). As also indicated by [22], the annual electricity consumption of a house is reported to be around 5,000 kWh, in which the configured calculation in the current study is displayed to be compatible with this value [22].

In the case of integrating the 40 MW double flash type geothermal power plant to the city grid lines, the total annual energy generation of this power facility can be computed as provided in Eq. (19):

$$Annual\ generation = P_{rated} x capacity\ factor x total\ hours =$$

$$40MW x\ 0.30 x \frac{8{,}760h}{1\ year} = \frac{105{,}120\ MWh}{1\ year} \quad (19)$$

The kWh equivalence of Eq. (19) is indicated in Eq. (20):

$$Annual\ generation = 105{,}120\ MWh\ x\ \frac{10^3\ kWh}{1MWh} = \frac{105{,}120{,}000\ kWh}{1\ year} \quad (20)$$

Eventually, the number of houses that will be fed by this annual power generation can be determined and exhibited with Eq. (21):

$$\frac{105{,}120{,}000\ kWh}{8{,}640\ kWh} = 12{,}166.67\ houses \quad (21)$$

At this moment, the total energy value of the power generation of the geothermal power facility that has been obtained in Eq. (20), corresponding to the value of 105,120,000 kWh has been divided to the power need of a single house that has been acquired in Eq. (18), that corresponds to the value of 8,640 kWh gives the value of 12,166.67 houses that has been indicated in Eq. (21). In scientific interpretation this stands for meeting the energy need of approximately 12,167 houses, that is to be obtained from geothermal power plant. In the case of integrating this conclusion to the needs of a city, and in the case of assuming the population of a city to correspond to 100,000, as well as in the case of assuming that 4 family people live in a house; in line with these data, it can be roughly assumed that there will be approximately 25,000 houses in a province with a population of 100,000. Ultimately, Eq. (22) can be computed as follows:

$$100{,}000\ person\ x\ \frac{1\ house}{4\ person} = 25{,}000\ houses \quad (22)$$

Since Eq. (21) shows the electricity that is produced from this designed power plant could be sufficient for approximately 12,167 houses; and due to Eq. (22), it is assumed that approximately 25,000 houses are found in a city; in this case, it may be concluded that the energy needs of approximately half of the houses in the city can be met, by this geothermal power plant facility. In a similar approach, under the utilization of this 40 MW rated power plant geothermal facility, the energy requirements of half of a province with a population of 100,000 could be met using renewable power.

The outputs of the design trials obtained from the EES program have been presented in Figure 6. Accordingly, the power plant having the rated power of 40,000 kW at the pressure ratio of 2 was chosen. This situation is well shown in Figure 7, which exhibits the variation of the rated power in kW, depending on the pressure ratio, Pr of the dimensionless quantity.

Parametric Table

Table 1

1..10	1 PR [pressure ratio]	2 $\dot{W}_{total}$ [kW]
Run 1	1	0,0000198
Run 2	1,5	24869
Run 3	2	40065
Run 4	2,5	50761
Run 5	3	58902
Run 6	3,5	65415
Run 7	4	70808
Run 8	4,5	75388
Run 9	5	79354
Run 10	5,5	82842

Figure 6. Total power versus pressure ratio during design trials

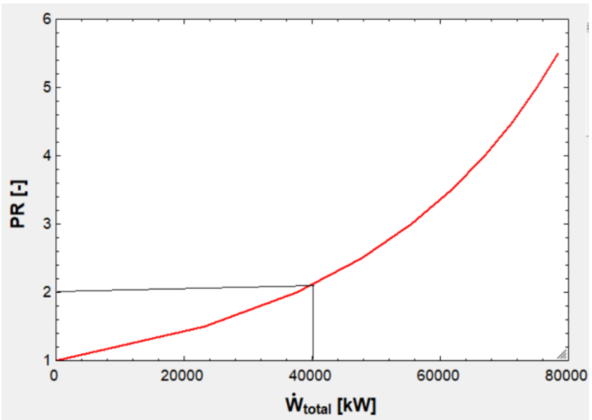

Figure 7. Total power functional variation against the pressure ratio

As depicted in Figures 6 and 7, the value of the pressure ratio is significantly important to obtain enhancements in both the system efficiency as well as the output energy. In this regard, the low-pressure ratio means the system is fairly inefficient. Namely, the pressure ratio value increase will provide more electricity production obtained from the geothermal power plant facility. In the analysis, the pressure ratio value was taken as 2. As can be seen, the total power value was found to be 40,065 kW, shown in Figure 6.

On the other hand, isentropic efficiency is a thermodynamic terminology often encountered in machines or thermodynamic systems, this is the case, especially in turbines. In geothermal power plants, the isentropic system of turbines and other energy conversion systems has a significant effect on the total system processes. In this frame, in the case of this value approaching 1, more system efficiency will be observed. Figure 8 shows the change in the total power due to the variation of isentropic efficiency. Besides, Figure 9 displays the functional relation of the total power in kW given to the thermal efficiency presented in percentage (%).

Parametric Table

Table 1 | Table 2

1..10	η_s	$\dot{W}_{total}$ [kW]
Run 1	0,2	38189
Run 2	0,2889	38443
Run 3	0,3778	38693
Run 4	0,4667	38939
Run 5	0,5556	39191
Run 6	0,6444	39449
Run 7	0,7333	39712
Run 8	0,8222	39980
Run 9	0,9111	40254
Run 10	1	40533

Figure 8. Total power versus the isentropic efficiency

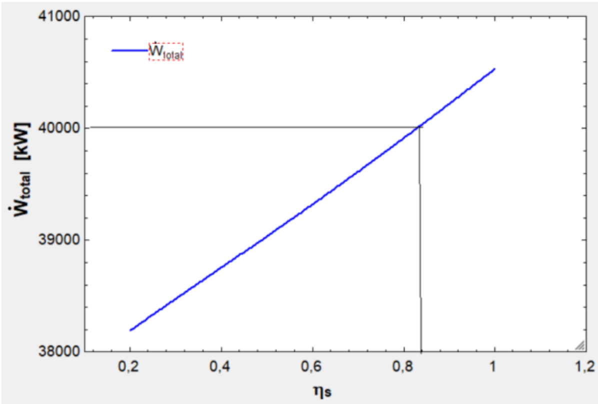

Figure 9. Total power functional variation against the thermal efficiency

In this study, the isentropic efficiency of the geothermal power plant was determined to correspond to 85%. As can be seen from the graph, as the efficiency increased, thus the value of the total power. In this respect, at the efficiency value of 85%, the cumulative power is reported and exposed to be 40,065 kW.

4. Conclusions

In the facilities of the geothermal power plants, the energy source is hot water, and considering the high enthalpy of this water, the thermal energy could be converted to useful electrical energy. To produce this useful energy, either the hot water is captured from naturally occurring wells or artificial wells are constructed to capture the hot water from them. These wells provide distribution of hot water and steam, sometimes only one of them, and sometimes a fluid that has the combination of both, at a certain value of thermal quality. In this analysis, a double-flash geothermal power plant was designed and examined. In this way, the hot water at a high pressure will evaporate at a low temperature. The resulting steam and the concentration of the steam that is increased at the separator will turn the mechanical blades of the geothermal turbine. Ultimately, the mechanical blade energy of the geothermal turbine will be transformed into useful electrical energy at the generator component of the turbine attached to the mechanical blades via the mechanical shaft. Cooling of the system will be performed using the cooling towers, however, the cooling towers are not considered in this analysis of the current study. Finally, electrical energy is transmitted to the regions through the electrical grid. Such power plants can meet the sustainable energy needs of a specific region or location for many years, with a high efficiency. Double-flash geothermal power plants have many advantages. For example, initially, their carbon emissions are significantly low, and in this way, the damage to the environment is minimized during the utilization of such systems. Besides, energy security is increased with those systems, because local resources of the country are used and the country's dependence on fossil fuels is reduced. Finally, it provides sustainable energy production, which offers economic and environmental benefits in the long term.

In the current study, a geothermal power plant designed in a double-flash type has been examined. The efficiency of the power plant, operating pressure, its rated power, annual output power generation, and the ability of the facility to feed the total number of houses are discussed. The EES program was used in numerical calculations to select this double-flash geothermal power plant having the capacity of 40 MW, and the other necessary thermodynamic parameters have been computed. As a result of the computations, it has been concluded that this power plant can produce significant amounts of electricity by operating at high efficiency. The computations were grounded depending on the projections of the annual electricity consumption of an ordinary house. Accordingly, it was demonstrated that the designed geothermal power plant can meet approximately half of the electricity needs of a city, whose population is selected to be 100,000. This study showed the effectiveness and the reliability of the geothermal energy source, by an applied study approach.

On the other hand, confidence in this technology will increase depending on the fact that a power plant having 40 MW power capacity meets the electricity needs of the half of the cited population. Besides, such a facility will contribute to local economic development, as well as during the installation and operation of the power plant, it will create employment and ultimately, as soon as the power plant operates, energy costs will decline. Furthermore, those types of power plants will contribute to diversifying the energy supply, and fossil fuel utilizations will be reduced. Therefore, it will play a significant role in fighting against climate change.

A 40 MW capacity double flash geothermal power plant can be proposed with this current study as a solution to the energy demand of medium-sized cities. Geothermal power plants have an important place among sustainable energy and meeting half the electricity requirements of a city with 100,000 population reveals how effective such power plants are. Environmental sustainability and economic advantages will pave the way for double-flash geothermal power plants to be used more widely in the future. This is a promising development in terms of increasing the integration of renewable energy sources and reducing the use of fossil fuels. Geothermal energy will continue to play a vital role in a sustainable future. With the encouragement and integration of such geothermal projects, cities can build a more sustainable and resilient future.

The results not only highlight the environmental sustainability of geothermal power plants, which provide high efficiency in energy production, but also reveal their contributions to local economies. Detailed analyses demonstrate the feasibility of this technology. Such power plants can play a critical role in reducing carbon emissions. Particularly in rural or medium-sized cities, promoting the use of these energy facilities can lower energy costs while strengthening regional energy independence. For future studies, energy generated from geothermal systems can be utilized not only for electricity production but also for secondary energy applications such as district heating or greenhouse operations. The economic and environmental impacts of such applications could be analyzed. Another example of future work could include designing power plants tailored to geothermal resources in different regions of Türkiye. These suggestions could enhance the scientific value of the study while paving the way for more comprehensive applications that would resonate widely in the energy sector and academia.

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Appendices

```
PR=2

// state 1

T[1]=260
x[1]=0
m_dot[1]=200
f$='water'
P[1]=pressure(f$;T=T[1]; x=x[1])
h[1]=enthalpy(f$;T=T[1]; x=x[1])
s[1]=entropy(f$;T=T[1]; x=x[1])

// state 2 - flash chamber outlet

h[2]=h[1]
P[2]=P[1]/PR
m_dot[2]=m_dot[1]
s[2]=entropy(f$;P=P[2]; h=h[2])
T[2]=temperature(f$;P=P[2]; h=h[2])
x[2]=quality(f$;P=P[2]; h=h[2])

// State 3 - turbine inlet

T[3]=T[2]
x[3]=1
s[3]=entropy(f$;T=T[3]; x=x[3])
h[3]=enthalpy(f$;T=T[3]; x=x[3])
P[3]=pressure(f$;T=T[3]; x=x[3])
m_dot[3]=m_dot[2]*x[2]


// State 4 - again flash chamber inlet

P[4]=P[2]
x[4]=0
s[4]=entropy(f$;P=P[4]; x=x[4])
h[4]=enthalpy(f$;P=P[4]; x=x[4])
T[4]=temperature(f$;P=P[4]; x=x[4])
m_dot[4]=m_dot[2]*(1-x[2])

// State 5 - HP turbine outlet

eta_s=0,85
P[5]=6
ss[5]=s[4]
hs[5]=enthalpy(f$;P=P[5];s=ss[5])
eta_s=(h[4]-h[5])/(h[4]-hs[5])
s[5]=entropy(f$;P=P[5];h=h[5])
T[5]=temperature(f$;P=P[5];h=h[5])
m_dot[5]=m_dot[4]
x[5]=quality(f$;P=P[5];h=h[5])

// State 6 - flash chamber outlet and seperator inlet

h[6]=h[4]
P[6]=P[4]/PR
m_dot[6]=m_dot[4]
s[6]=entropy(f$;P=P[6]; h=h[6])
T[6]=temperature(f$;P=P[6]; h=h[6])
```

```
x[6]=quality(f$;P=P[6]; h=h[6])

// State 7 - Seperator outlet

T[7]=T[6]
x[7]=1
s[7]=entropy(f$;T=T[7]; x=x[7])
h[7]=enthalpy(f$;T=T[7]; x=x[7])
P[7]=pressure(f$;T=T[7]; x=x[7])
m_dot[7]=m_dot[6]*x[6]

// State 8 - LP turbine

P[8]=3
ss[8]=s[7]
hs[8]=enthalpy(f$;P=P[8];s=ss[8])
eta_s=(h[7]-h[8])/(h[7]-hs[8])
s[8]=entropy(f$;P=P[8];h=h[8])
T[8]=temperature(f$;P=P[8];h=h[8])
m_dot[8]=m_dot[7]
x[8]=quality(f$;P=P[8];h=h[8])

// State 9 - LP turbine outlet

P[9]=5
ss[9]=s[8]
hs[9]=enthalpy(f$;P=P[9];s=ss[9])
eta_s=(h[8]-h[9])/(h[8]-hs[9])
s[9]=entropy(f$;P=P[4];h=h[9])
T[9]=temperature(f$;P=P[9];h=h[9])
m_dot[9]=m_dot[8]
x[9]=quality(f$;P=P[9];h=h[9])

// State 10 - condenser outlet

P[10]=P[9]
x[10]=0
s[10]=entropy(f$;P=P[10]; x=x[10])
h[10]=enthalpy(f$;P=P[10]; x=x[10])
T[10]=temperature(f$;P=P[10]; x=x[10])
m_dot[10]=m_dot[9]

// State 11 - seperator outlet

P[11]=P[6]
x[11]=0
s[11]=entropy(f$;P=P[11]; x=x[11])
h[11]=enthalpy(f$;P=P[11]; x=x[11])
T[11]=temperature(f$;P=P[11]; x=x[11])
m_dot[11]=m_dot[6]*(1-x[6])

eta_th=(m_dot[3]*(h[3]-h[9]))/(m_dot[1]*h[1]-(m_dot[11]*h[11]+m_dot[10]*h[10]))

W_dot_turbinefirst=m_dot[3]*(h[3]-h[5])
W_dot_turbinesecond=m_dot[8]*(h[8]-h[9])
W_dot_total=(m_dot[3]*(h[3]-h[5]))+(m_dot[8]*(h[8]-h[9]))
```