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Performance Analysis of Gas Turbine Integrated Geothermal Power Plant in Turkey: The Proposed Kizildere Project

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ABSTRACT

To maintain performance improvement of Kızıldere single flash geothermal power plant and to increase geothermal based electricity power of Turkey, gas turbine integrated geothermal power plant is proposed. Nowadays in Turkey, to increase natural gas usage, a lot of new project related to natural gas are designed. Adding a gas turbine to existing single flash geothermal power plant appears very efficiently. In this project, leaving exhaust gases from gas turbine, enters a heat exchanger for transfer its heat energy to geothermal steam at saturated state. With this project, saturated steam will convert to superheated steam, so net power output of geothermal steam turbine will increase.

According to analysis, 43 % more power will be produce with new designed geothermal power plant. First law efficiency of the existing power plant rises from 4.556 % to 6.5 % and second law efficiency rises from 19.78 % to 28.4 %.

1. INTRODUCTION

Turkey is one of the richest countries in the world with the geothermal energy potential it posses. As well as Turkey is one of the leading countries in geothermal direct utilization, it is only the 16. country in geothermal electricity generation. Whereas, there are at least 10 geothermal fields that are suitable for electricity generation in the country (Table 1) (Dagdas, 2004). Especially Manisa-Salihli-Göbekli geothermal field have newly entered in literature. Among these fields, only in Denizli-Kızıldere 10 MW_e electricity generation is realized. This plant is the only geothermal power plant in the country. At present, power plant building is still going on in Aydın-Germencik and Aydın-Salavatlı. 100 MW_e installed capacity power plant in Aydın-Germencik and 5 MW_e installed capacity power plant in Aydın-Salavatlı are under construction. ORMAT company is conducting construction works of a binary power plant generating electricity from a largely liquid source in Salavatlı (Wolf, 2004).

Turkey, due to the geographical location, is very pretentious in being a natural energy corridor between Asia and Europe. In order to achieve this goal, important projects are being developed and executed. Baku-Tbilisi-Ceyhan pipeline is still under construction and it is estimated to be commissioned in May 2005. Kirkuk-Yumurtalık oil pipeline has been under service for long years. However, due to political instability in Iraq, interruptions in oil transfer on this pipeline occasionally occur. Turkey has problems, associated with foreign politics, going on for years with its neighbors. But, as a result of friendly relationships with neighbors in the few last years, in order to eliminate problems which would occur in the Bosporus's, studies connected with Transtrachia (İğneada-Saros) or Samsun-Ceyhan oil pipeline and natural gas pipeline constructions over Greece are still going on. Turkey will become an energy corridor that transfers Asian oil and natural gas to Europe when these pipelines are commissioned. This politics can speed up joining to European Union for Turkey.

Table 1: Suitable geothermal fields in Turkey to produce electricity from geothermal energy and its reservoir temperatures.

Geothermal Field	Reservoir Temp.
Denizli-Kızıldere	242 ^{0}C
Aydın-Germencik	232 ^{0}C
Manisa-Salihli-Göbekli	183 ^{0}C
Çanakkale-Tuzla	174 ^{0}C
Aydın-Salavatlı	171 ^{0}C
Kütahya-Simav	162 ^{0}C
İzmir-Seferihisar	153 ^{0}C
Manisa-Salihli-Caferbeyli	150 ^{0}C
Aydın-Yılmazköy	142 ^{0}C
İzmir-Dikili	130 ^{0}C

Table 2: The sectorel distribution of natural gas sales in Turkey (million cm^3)

Electricity	13,513	65 %
Residence	3 944	18 %
Industry	3 013	15 %
Fertilizer	469	2 %
Total	20,938	100 %

Natural gas gained an important role in meeting energy requirement of the country in the last years. In Table 2, sectoral distribution of natural gas utilization in Turkey is given. At present, Istanbul, Ankara, Bursa, Eskişehir and Izmit are the cities employing natural gas for district heating. Besides, 191 industrial facility and 46 power plants including autoproducer companies in Kırklareli, Tekirdağ, İstanbul, Kocaeli, Sakarya, Düzce, Bolu, Zonguldak, Bursa, Yalova, Balıkesir, Çanakkale, Bilecik, Eskişehir and Ankara employ natural gas. In 2005, natural gas consumption in Turkey is estimated to be 41 billion m^3/year and 60 cities are expected to be ready for natural gas utilization (Taskiran, 2004) (Kadioglu, 2004).

Denizli is an industry and tourism city located in southwest of Turkey. The industrial facilities in Denizli are well known in world wide and it is one of the locomotive cities in Turkey. When these features are considered, Denizli should be one of the prior cities in reaching natural gas. Natural gas is planned to be reaching Denizli at the end of 2004. Natural gas meets heating requirement very efficiently, cheaply and cleanly in both industrial plants and residents. Denizli is one of the most contaminated cities in the country at the present time. A steadily increasing contamination is taking place due to poor air circulation prevented by the high mountains surrounding the city and fossil fuel, like lignite, utilization in order to meet heating requirement. According to 2002-2003 heating season, Denizli is in the “first degree polluted cities” list. In this season, SO_2 presence in the air is 130 µg/m^3 and particulate in the air is 95 µg/m^3 (Kadioglu, 2004). It is an obvious fact that natural gas would improve air quality of Denizli.

Natural gas consumption of Turkey is estimated to be 40.7 billion m^3 in 2005. 65 % of this consumption occurs in power plants.

Table 3: The Natural gas fueled power plants in Turkey

Plant Name	Installed Power (MW_e)
Ambarlı combined cycle power plant	1350
Hamitabat combined cycle power plant	1200
Unimar combined cycle power plant	480
Marmara Ereğlisi combined cycle power plant	480
Bursa combined cycle power plant	1400
Esenyurt combined cycle and cogeneration power plant	180
Sakarya combined cycle power plant *	540
Gebze combined cycle power plant *	1540
Zonguldak Alaplı combined cycle power plant *	----
İzmir- Aliağa combined cycle power plant *	1520
Ankara-Polatlı combined cycle power plant *	770

* under construction

At present, 6 natural gas fired combined cycle power plants are operating in different regions of Turkey. Besides, 5 natural gas fired plants are under construction. Table 3 shows the natural gas fired power plants that are operating at the present and are still being constructed with their installed capacities (Kadioglu, 2004).

2. DENIZLI KIZILDERE GEOTHERMAL POWER PLANT

Denizli-Kızıldere power plant is in the borders of Sarayköy County which is located in 35 km west of Denizli. The geothermal plant employs a single flash system and was commissioned in 1984. The simplified layout of Kızıldere geothermal power plant can be seen in Figure 1. Plant capacity is 20.4 MW_e. However, due to scaling problems the actual generation is between 8-12 MW_e.

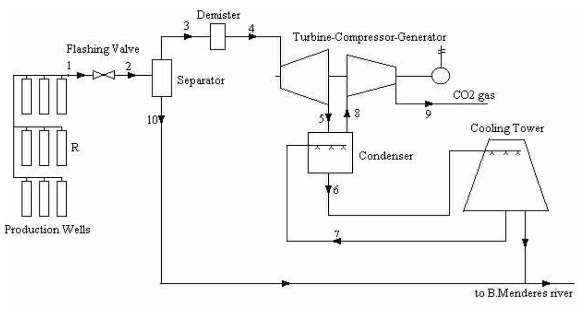

Figure 1: A simplified scheme of Denizli-Kızıldere Geothermal Power Plant.

There are 9 production wells in Kızıldere geothermal field. Geothermal fluid generated in every well is transformed into geothermal steam through flashing systems and separators that are located on top of the wells. Geothermal steam collected from separators, enters the steam turbine at saturated vapor conditions, 450 kPa and 147°C, and leaves the turbine at 10 kPa and 48°C. Waste steam leaving the turbine is condensed in a mixing type condenser. Cooling water is supplied from a cooling tower employing 4 forced draft fans. Two gas compressors coupled to turbine delivers the non-condensed CO_2 gas to a facility near the plant which generates dry ice and liquid CO_2. Liquid fluid dissociated in the separators was being directly sent to Büyük Menderes River formerly. But, with a new deal it is employed for residential heating of Sarayköy County which is 10 km away. For this purpose, geothermal liquid at 195 kg/s mass flow is delivered to Sarayköy through a pipeline and 1500 residences are heated. Geothermal liquid employed for heating is discharged to city sewer system instead of sending back to reservoir field. One of the most important problems of the reservoir field is the reinjection application which could not be made at desired level. This state is serious enough to lead rapid using up of the reservoir. Reinjection capacity of this well is 55-70 kg/s (Sarikurt, 2004).

According to the analysis made by Dagdas (2005), net power output of Kızıldere geothermal power plant is 9440 kW_e, first law efficiency is 4.556 % and second law efficiency is 19.78 % (Dagdas et. al., 2005). As much as these values are acceptable for geothermal plants, they are very low compared to classical fossil fuel fired systems. The reasons for that are the very low temperature and pressure values of the geothermal fluid.

Plant efficiency would be improved if the geothermal steam enters the turbine at superheated steam conditions. In order to accomplish this, building the natural gas fired power plant near Kızıldere geothermal field, which is planned to be build in the future as natural gas reaches Denizli by 2005, will improve the efficiency of the present geothermal power plant and meet electricity requirement of the region.

3. COMBINING KIZILDERE GEOTHERMAL PLANT WITH A GAS TURBINE PLANT

Temperature of the exhaust gases of gas turbine plants is generally between 400-600°C. Utilization of this high temperature waste energy will provide energy economy. There are a few successive examples like this in Italy (Bettocchi, 1993), (Bidini et.al., 1998) The purpose of this study is to determine the degree of the effect of superheating the geothermal steam entering to the turbine on the geothermal plant performance, by passing the exhaust gases of natural gas fired gas turbine plant through a heat exchanger. In order to reach this goal, Kızıldere geothermal plant has been considered as a base plant and construction of a gas turbine power plant has been proposed.

3.1 Operational Principals and Operational Conditions of the Proposed Combined Plant

Layout of the gas turbine system which will be integrated with Denizli-Kızıldere geothermal plant is shown in Figure 2. An analysis of the combined cycle plant is made with previously written software. According to this, standard air is taken into compressor at standard atmospheric conditions with a mass flow rate of 40 kg/s and compressed with a compressor pressure ratio of 10. Thus, temperature of the air rises to 315°C from 10°C. Air at high pressure and high temperature is burnt by natural gas in a combustion chamber and at the end of the combustion chamber air reaches 1100°C temperature and after expanding in the turbine section, leaves the gas turbine at 569.4°C. Exhaust gases at this temperature will be passed through a heat exchanger and transfer a portion of it's heat to the geothermal steam that is at saturated dry steam conditions (x=1), which enters the geothermal turbine. T-s diagram of the geothermal steam cycle is shown in Figure 3. Steam enters the turbine at state 4 and leaves the turbine at state 5 in the existing plant. Steam will be entering the turbine at state 4' and leaving the turbine at state 5' in the proposed system. Another advantage of superheating the steam is that, steam is still superheated when it leaves the turbine. Thus, deformation due to moisture formation in the last stages of the turbine will be prevented.

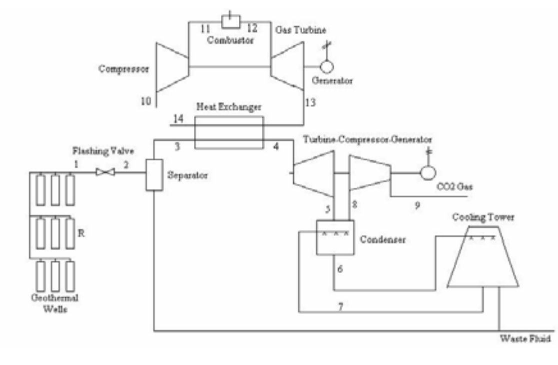

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Figure 2: A simplified scheme of the proposed combined gas turbine and geothermal power plants.

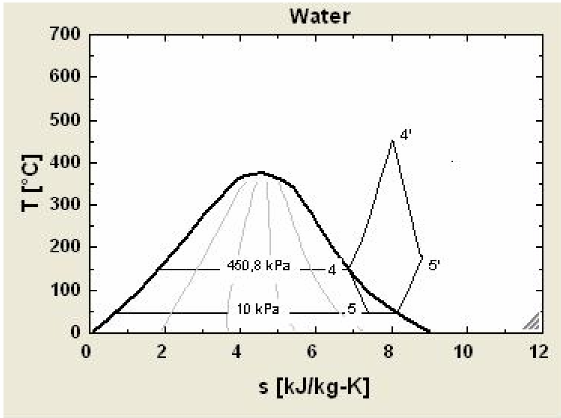

Figure 3: T-s diagram of geothermal steam cycle.

Output temperatures of the geothermal steam and exhaust gases have been used as parameters in the software analyses for heat exchanger. In this way, outlet conditions were determined depending on inlet conditions.

Selected values to analyze gas turbine plant are given Table 4. According to these values, properties of the basic points of the gas turbine section are given in Table 5.

Table 4: Selected values for gas turbine power plant analysis.

Air temperature at compressor inlet (T_{10})	10 ^{0}C
Air pressure at compressor inlet (P_{10})	101 kPa
Compressor pressure rate (P_{rc})	10
Turbine pressure rate (P_{rt})	9.45
Max. temperature of the cycle (T_{12})	1100 ^{0}C
Compressor isentropic efficiency	0.88
Turbine isentropic efficiency	0.90
Mass flow rate of air	40 kg/s

Table 5: Properties at basic points of the proposed gas turbine power plant.

State	Temp. T (^{0}C)	Press. P (kPa)	Mass Flowrate $\dot{m}$ (kg/s)	Enthlpy h (kJ/kg)	Entrpy s (kJ/kg K)	Energy Flowrat $\dot{E}_n$ (kW)	Exergy Flowrat. $\dot{E}_k$ (kW)
10	15	101	40	288.5	5.658	-40,26	172
11	315.3	1010	40	594.9	5.724	12217	11666
12	1100	1010	40	1483.0	6.674	47731	36202
13	569.4	101	40	869.0	6.772	23178	10521
14	150.8	101	40	425.6	6.048	5442	1151

Values employed for heat exchanger analyses are given in Table 6. Here, T_{13} is the temperature of the exhaust gases leaving the gas turbine plant. Outlet conditions for heat exchanger obtained from the analyses made by employing the values in Table 6, are seen in Table 7.

Table 6: The values of heat exchanger (HX).

Inlet temperature of geothermal steam (T_3)	148 ^{0}C
Inlet temperature of exhaust gases (T_{13})	569.4 ^{0}C
Mass flow rate of geofluid (m_{jeo})	28 kg/s
Heat transfer area (A)	1000 m^2
Heat transfer coefficient of HX (U)	0.25 kW/m^2 K

Table 7: The output values of heat exchanger

Outlet temperature of geothermal steam (T_4)	421.2 ^{0}C
Outlet temperature of exhaust gases (T_{14})	176.1 ^{0}C
Effectiveness of HX (ε)	0.9334
NTU	5.45

Temperature of the geothermal steam leaving the heat exchanger is 421°C, according to the analyses made by assuming 1000m^2 heat exchanger surface areas. In this case, geothermal steam enters the turbine at superheated steam conditions. Temperature of the exhaust gases leaving the heat exchanger is 176°C. It is possible to realize district heating or to back up the existing heating system in Sarayköy with the exhaust gases at these conditions, in order to heat a larger area.

Temperatures of both geothermal steam and exhaust gases will change within the heat exchanger surface area. These changes, depending on heat exchanger surface area, take place as shown in Figure 4. Heat exchanger efficiency and NTU values depending on heat transfer surface area can be seen in Figure 5.

Heat exchanger surface area also directly affects the net power output of the geothermal plant. This interaction can be clearly seen in Figure 6.

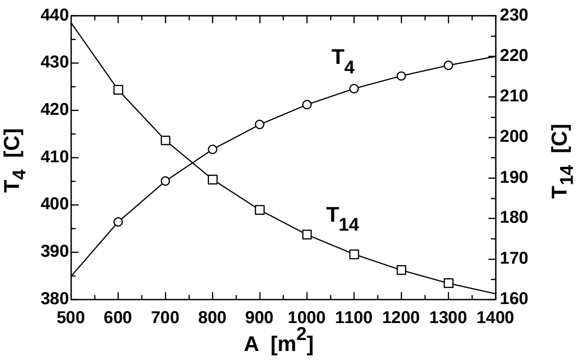

Figure 4: The variations of geothermal steam (T_4) and exhaust gases (T_{14}) temperatures at heat exchanger outlet by heat transfer area.

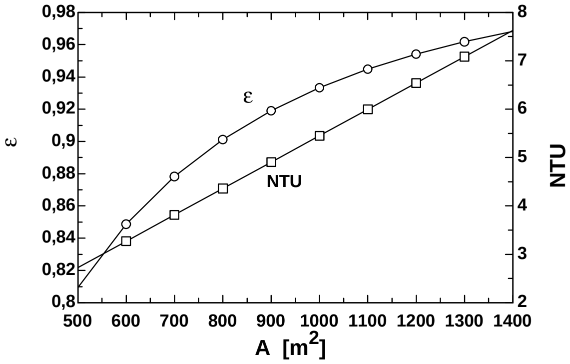

Figure 5: Heat exchanger effectiveness and NTU vs. heat transfer area.

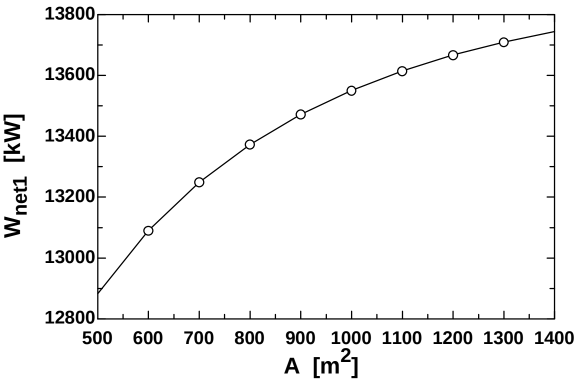

Figure 6: Net power output of geothermal power plant vs. heat transfer area.

Power output of the gas turbine operating at the conditions mentioned above is 24,345 kW and the power consumed in the compressor is 12,245 kW. In this case, net output of the gas turbine power plant which operates according to Brayton Cycle is 12,100 kW. Thermal efficiency of the gas turbine cycle is determined to be 34 %.

Net power output of the combined plant integrated with geothermal power plant is 25,561 kW_e. According to analyses, net power generated in the geothermal plant reaches 13,550 kW_e with the proposed enhancement method. The power augmentation of the geothermal plant is 4110 kW_e. This augmentation is 43.5% of the existing power plant power. First law efficiency of the geothermal power plant reaches 6.5% and second law efficiency reaches 28.4% according to reservoir conditions. As it can be seen in Table 8, enhancement in plant performance is very satisfying.

Table 8: The efficiency comparison between existing geothermal power plant and the proposed geothermal plant model with superheated steam.

	Existing plant	Superheated steam model
I. law efficiency	4.556%	6.5 %
II. law efficiency	19.78 %	28.4 %

Cost analyses have not been made in this study. By conducting cost analyses for combined system in further studies, economy of the obtained results can be seen.

4. RESULTS

In this study, a new model is proposed in order to improve efficiency and augment power output of the single flash type geothermal power plant operating in Denizli-Kızıldere. In this model, electric energy requirement of the region will be met and performance of the geothermal power plant will be up rated by building a gas turbine power plant near the existing plant. If proposed combined cycle power plant operates, power generated in the geothermal plant will increase 43.5 %. First law efficiency of the plant will increase to 6.5 % from 4.556 % and second law efficiency will increase to 28.4 % from 19.78 %. This increase is a power augmentation that can not be underrated. Besides, total power output of the combined cycle power plant is greater than the total output of the individual outputs of each system.

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