SUITABLE GEOTHERMAL AREAS FOR BINARY CYCLE SYSTEM IN TURKEY

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Geothermal, binary cycle, field

ABSTRACT

The quantity and quality of the produced fluids which in turns determines the current energy unit price are the most favorable circumstances in binary electricity generation from geothermal fluids. From enthalpy point of view there are eleven geothermal fields in Turkey which are apparently available for such purposes. Namely, they are Kizildere, Tekkehamam, Aydın-Germencik, Salavatlı, Seferihisar, Balcova, Yılmazkoy, Canakkale-Tuzla, Simav, Manisa-Caferbeyli and Manisa-Gobekli.The temperatures of the prospective fields are in the range of 100 to 242 ^{o}C. The expected potential from those fields will be evaluated.
The chemical nature of the geothermal areas generally poses some technical constraints to developments. The fluids produced from the geothermal areas subjected to this presentation contain various quantities of soluble species and dissolved gases. The most common geothermal gas in moderate geothermal fields is CO_2. Chemical analysis of the geothermal fluid both water and gases can give valuable information for the design of geothermal binary cycles. The scaling of calcite and silica minerals is often associated with the utilization of geothermal fluid.
The objective of this paper is to put down the potential and problems associated with the utilization and offer a general description of the geothermal fields for future binary cycle utilization developments in Turkey.

1. INTRODUCTION

Prior to discussing the specifics of geothermal power generation, it is useful to examine the nature of the source of the energy on which the systems depend. Turkey has a high geothermal potential as a result of its suitable geological situation: the presence of young volcanism, extensional tectonics (horst-graben systems) and hydrothermal altered areas.
There are approximately a total of 1000 thermal and mineral water spring groups throughout the country [1]. Geothermal resources in Turkey vary in temperature from 30-242 ^{o}C, and are either in the form of a mixture of steam and water or just liquid water. The high (<220 ^{o}C) and moderate-low geothermal fields are found in the western part of the country (Figure 1).



Figure 1. Distribution of high and moderate geothermal fields in Turkey

The high temperature geothermal areas of western Anatolia lie mainly along the following grabens [2]: Büyük Menderes, Gediz and Edremit Grabens. Especially, potentially promising ones lie along Büyük Menderes Graben. The highest reservoir temperatures measured in these graben are Denizli-Kizildere (242 ^{o}C), Tekkehamam (168 ^{o}C), Aydın-Germencik (231 ^{o}C), Salavatli (172 ^{o}C), Yilmazkoy (140 ^{o}C), Seferihisar (137 ^{o}C) and Izmir-Balcova (140 ^{o}C) (Figure 2). Canakkale-Tuzla (174 ^{o}C) is located in Edremit Graben;), Kutahya-Simav (162 ^{o}C), Manisa-Caferbeyli (150 ^{o}C) and Manisa-Gobekli (182 ^{o}C) fields lie along Gediz Graben.

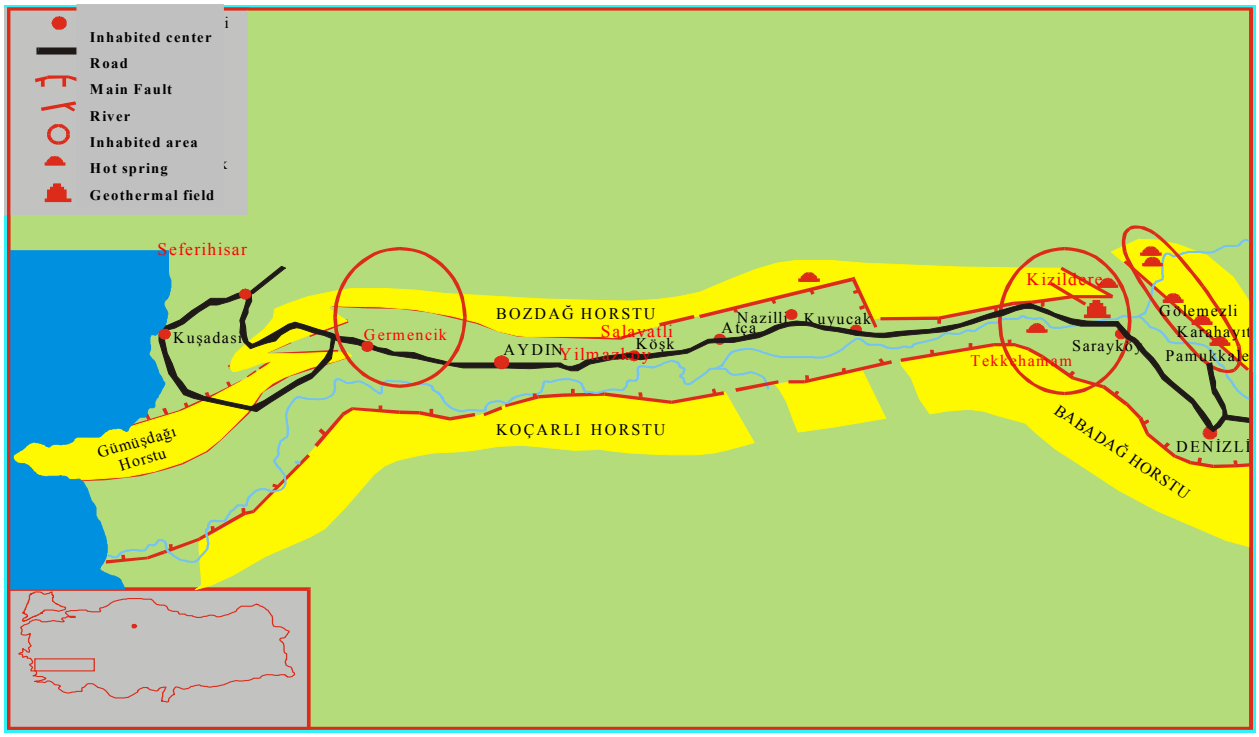


Figure 2. Location of high and moderate geothermal fields along Buyuk Menderes Graben[3]

2. IMPORTANT GEOTHERMAL FIELDS IN TURKEY

2.1 Denizli –Kizildere Geothermal Field

It is the first geothermal field suitable for electricity generation situated on the eastern part of Menderes Graben in western Anatolia. The depth and temperature of the reservoir change between 450-1100 m and 196 ^{o}C – 242 ^{o}C respectively. The ratio of steam is 10-18 %. The first geothermal power plant of 20.4 MW of Turkey was installed in this field 1984.

2.2 Aydin –Germencik Geothermal field

It is situated in western part of Menderes Graben and 110 km far from the Kizildere Geothermal Field. Depth and temperature of the reservoirs change between 285-1500 m and 200 ^{o}C -231 ^{o}C respectively in this field. The ratio of steam is 13-20 %. This field has important potential for electricity production.

2.3 Canakkale-Tuzla Geothermal Field

It is situated 80 km south west of Canakkale, 5 km inland in the North western Anatolia. The first hole was drilled down to 814 m in 1982. 130 ton/h steam and hot water with a temperature of 174 ^{o}C was tapped from a volcanic reservoir at the depth of 333- 553 m. Canakkale –Tuzla Geothermal area also is suitable for integrated uses of geothermal energy.

2.4 Izmir-Seferihisar Geothermal Field

It is situated 40 km southwest of Izmir, close to the Aegean Sea. The reservoir temperature is 153 ^{o}C. The studies have shown that existing drill holes can produce totally 8.17 x 10^{6} Kcal/ hour thermal energy. This is enough to heat greenhouses of 117 000 m^{2} and produce 0.5 MWe by binary cycle system.

2.5 Aydin-Salavatli Geothermal Field

This field also located in Menderes Graben halfway between the Kizildere and Germencik fields. The reservoir temperature changing between 162-172 ^{o}C. It is suitable for uses of electricity generation by binary cycle system.

2.6 Aydin-Yilmazköy Geothermal Field

It is situated in the vicinity of Aydin province, in Menderes Graben. By drilling to 1500 m, 140 ^{o}C reservoir temperatures was caught in this field.

2.7 Kutahya-Simav Geothermal Field

The field is situated north of Simav city. Reservoir temperature of the field is reaching to 162 ^{o}C. It is suitable for generation electricity by binary cycle system.

2.8 Izmir-Balcova Geothermal Field

It is situated in the vicinity of Izmir. The field was discovered in 1963 but first drill hole was filled up by intense deposition of the water. The reservoir temperature reaches to 140 ^{o}C in this field. This temperature of the fluid is also suitable for electricity generation by binary cycle system.

2.9 Manisa-Gobekli and Manisa Salihli Geothermal Fields

Both fields are situated in Gediz Graben. Salihli geothermal is approximately 100 km, Gobekli geothermal field is 130 km far from Izmir. 182 ^{o}C reservoir temperature in Gobekli and 150 ^{o}C reservoir temperature in Salihli geothermal fields were confirmed by drilling to 1500 m depth in both fields. The two fields are suitable for electricity production by binary cycle system.

3. PRESENT SITUATION AND PROSPECT USES

83 wells have been drilled in the above mentioned geothermal fields. The utilization of geothermal energy in the form of electricity generation started in February 1984 as a consequence of studies that have been carried out since 1962. The total potential of those fields suitable for electricity generation is approximately is 1610 MWt (Table 1).
High temperature geothermal reservoirs containing water or steam can provide steam to directly drive steam turbines and electrical generation plant. More recently developed binary power plant technologies enables more of the heat from the resource to be utilized for power generation [4]. A combination of conventional flash and binary cycle technology is becoming increasingly popular. In flash power plant, the steam and water is separated in a pressure separator, with the steam piped to the power station where it drives one or more steam turbines to produce electric power. The separated geothermal water can be utilized in a binary cycle type plant to produce more power. Aydin-Germencik and Kizildere Geothermal fields are two geothermal fields in Turkey which can be used in combination of conventional flash and binary cycle technology. A single flash power plant with 20.4 MWe installed capacity has been working since 1984 in the Kizildere geothermal field. 1000 kg/s waste water with temperature of 147 ^{o}C is being disposed from the power plant. This amount of water can be utilized efficiently to produce more power from the field. Another high temperature geothermal field, Aydin- Germencik which has 231 ^{o}C reservoirs temperature can also be used in combination way. The other eight moderate-low temperature geothermal fields can be utilized only in binary and/or hybrid cycle systems.

Table 1. Measured Temperature, Present Flow Rate and Total Thermal Potential of The Fields

Name of Fields	Number of Wells	Depth of Wells (m)	Temperature Range (^{o}C)	Total Flow Rate (kg/s)	Total Potential (MWt)
DENIZLI-KIZILDERE	10	510-2261	190-242	666.20	485.15
DENIZLI-TEKKEHAMAM	2	615,5-2001	116-162	26.60	11.55
AYDIN-GERMENCIK	9	285-2000	203-231	907.90	699.11
AYDIN-SALAVATLI	2	960-1500	167-172	185.40	104.36
AYDIN-YILMAZKOY	1	1501.00	142	30.00	13.44
IZMIR-BALCOVA	27	100-1000	91-140	297.75	116.48
IZMIR-SEFERIHISAR	3	1232-2009	56-145	10.15	4.61
MANISA-ALASEHIR-GOBEKLI	1	1447.1	182	15.00	9.23
MANISA-CAFERBEYLI	1	1189.00	150	2.00	0.96
KUTAHYA-SIMAV	12	65,80-958	51-162	354.13	126.44
CANAKKALE	2	81-814	90-174	101.70	38.47
Total	73			2596.8	1609.8

The temperature of the resource is a major determinant of the type of technologies required to extract the heat and the uses to which it can be put to. The table below lists [4] the basic technologies normally utilized according to resource temperature (Table 2).

Table 2. Utilization Technologies According to Resource Temperature

Reservoir Temperature	Reservoir Fluid	Common Use	Technology commonly chosen
High Temperature >220°C	Water or Steam	Power Generation Direct Use	• Flash Steam • Combined (Flash and Binary) Cycle • Direct Fluid Use • Heat Exchangers
Intermediate Temperature 100-220°C	Water	Power Generation Direct Use	• Binary Cycle • Direct Fluid Use • Heat Exchangers
Low Temperature 50-100°C	Water	Direct Use	• Direct Fluid Use • Heat Exchangers

As it mentioned in the previous section, there are two geothermal fields in Turkey that can provide steam to directly drive steam turbines and electrical generation plant. The plant that work with this condition is called single flash power plant (Figure 3). The discharged water from this type of plants can be utilized for more power in binary cycle systems. Figure 4 illustrates the single flash power plant of Kizildere. The amount of discharged water up to 147 °C from this power plant is 1293 tons/h (Figure 4) [3]. Up to previous year this amount of the waste water has been disposed to Büyük Menderes River. Typically, flash condensing geothermal power plants vary in size from 5 MWe to over 100 MWe. The present installed capacity of Kizildere is 20.4 MWe with. Depending on its steam characteristics, gas content, pressures, and power plant design, 10 tons of steam each hour is required to produce each MW of electrical power from the Kizildere power plant.

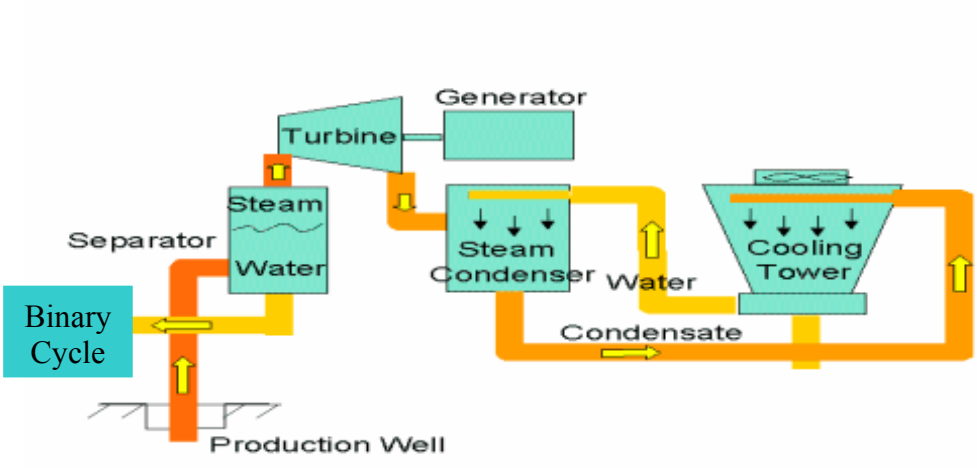


Figure 3. Single Flash Power plant [4].

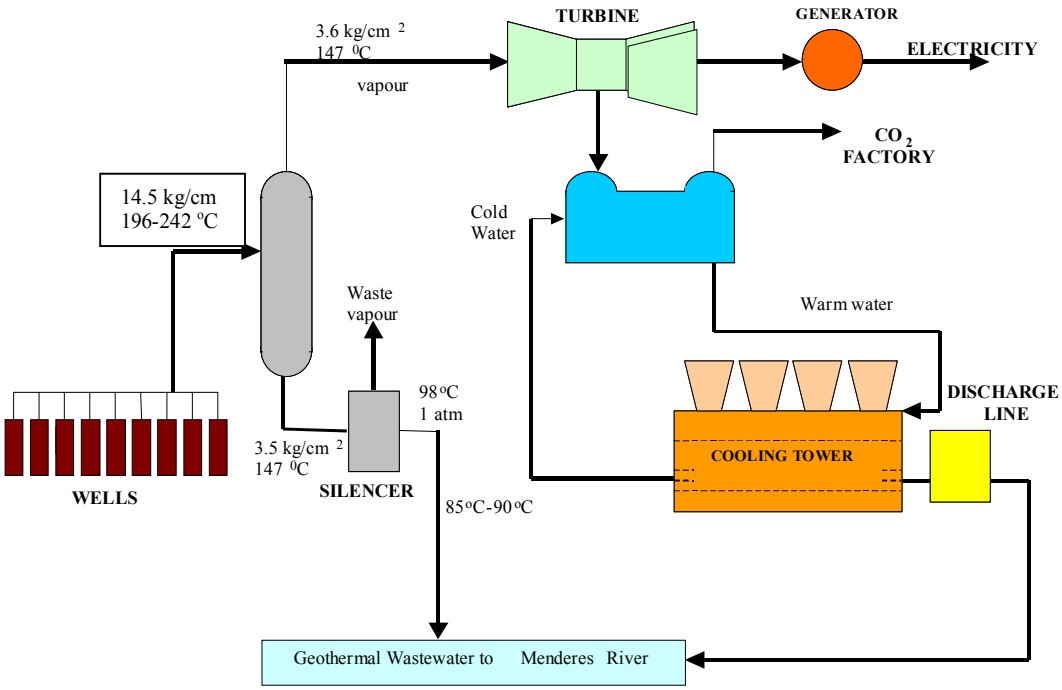


Figure 4. Flowsheet of Kizildere geothermal power plant for electricity production

4. POSSIBLE BINARY CYCLE POTENTIAL OF TURKEY

In reservoirs where temperatures are typically less than 220 °C, but greater than 100 °C, binary cycle plants are often utilised. The illustration below shows the principal elements of this type of plant (Figure 5).The reservoir fluid (either steam or water or both) is passed through a heat exchanger which heats a secondary working fluid which has a boiling point lower than 100°C. These are typically organic hydrocarbon fluids such as isobutene, isopentane or isopropane, which are vaporized and are used to drive the turbine [4][5].

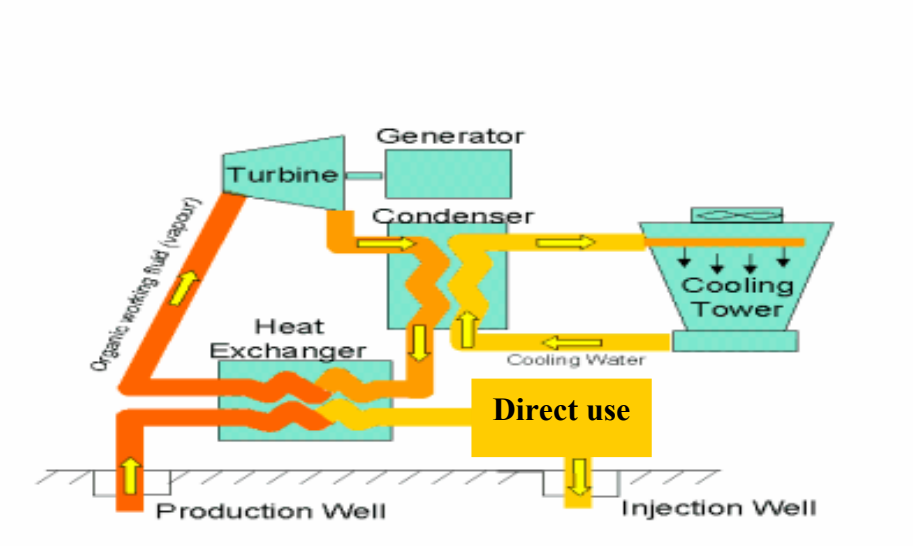


Figure 5. Binary Cycle Power Plant [4] [5].

As discussed in the previous section, there are only two geothermal fields in Turkey that can be used to generate electricity by direct drive steam turbines. From these, Kizildere has been in utilization since 1984, with 20.0 MWe single flash installed capacities. Since separation pressure of the steam is 4.5 kg/cm, the outlet of discharged waste water from the separators of Kizildere is 147 ^{o}C. The steam ratio of the fluid at this separation pressure is changeable between 10 % to 18 % depending on inlet pressure and temperature. In average, 85 tons/h of waste water with 147 ^{o}C temperature is discharged from separators to produce each hour MW of electrical power. The present operational capacity of the Kizildere power plant is 14 MWe. The discharged water which corresponding to this power generation capacity are approximately, 1293 tons/hour. When this amount of disposed water is used in binary cycle power plant, at least, 16 MWe additional electricity can be produced from the field. The estimated capacity of the Aydın-Germencik Geothermal field is 55 MWe within flash power. It has not yet been any power plant installed on this field. Supposing that Aydin-Germencik is also operated with the same condition as in Kizildere, the amount of the electricity that can be generated by binary system from the Germencik will be approximately 21 MWe.
The curves below give an indication of the electrical power output from the binary plant systems over a range of flows and geothermal reservoir temperatures of the moderate geothermal fields in Turkey (Figure 6).

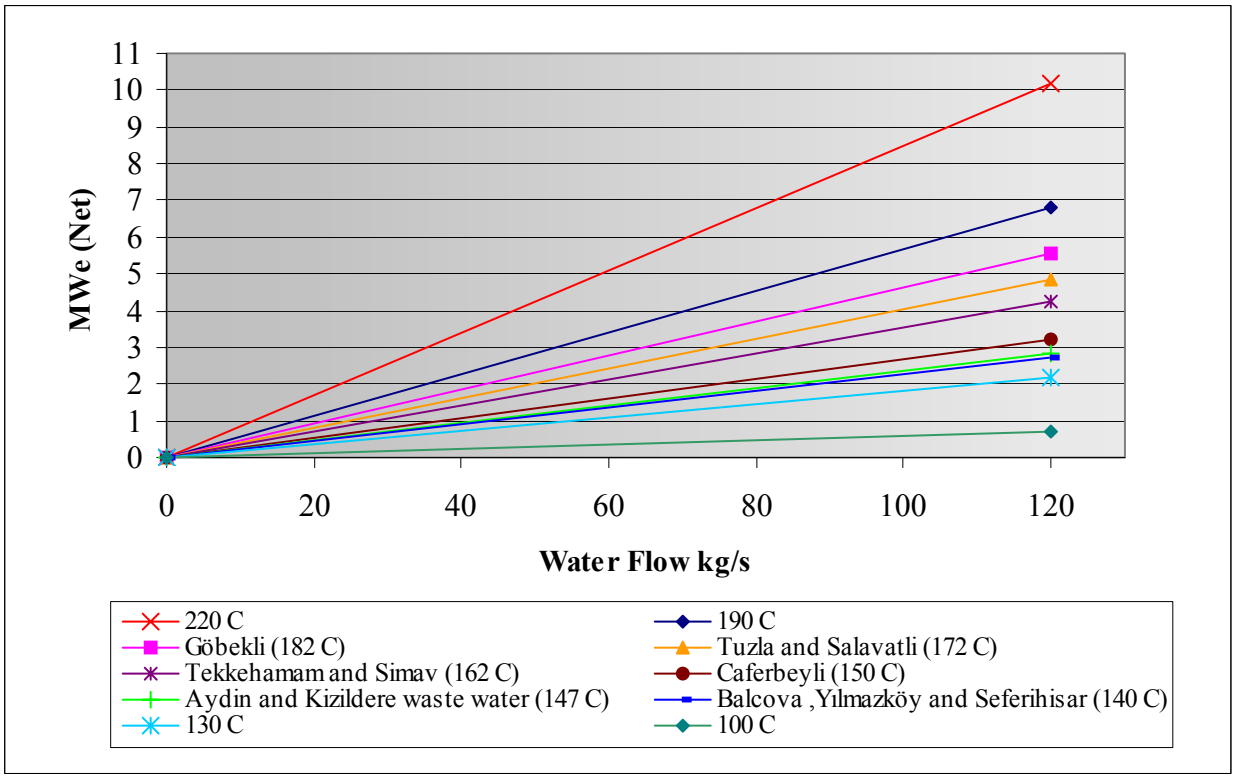


Figure 6. Net Power Versus Flow Rate From Known Temperature Geothermal Fluids

Prospective total "Binary Cycle " electricity production capacity in Turkey from the Kizildere and Aydin-Germencik fields with single flash power plants discharges and in addition with of the other moderate- low geothermal fields potential, according to above curves (Figure 6), is shown in the Table 3. Binary cycle type plants are usually between 7 and 12 % efficient depending on the temperature of the primary (geothermal) fluid. The higher the temperature of the fluid becomes, the more efficiently the electricity can be generated.

Table 3. Available Electrical Power Production by Binary Cycle Plant

Name of Fields	Number of Wells	Depth of Wells (m)	Temperature Range (°C)	Total Flow Rate (kg/s)	Possible Binary Cycle Potential (MWe)
DENIZLI-KIZILDERE	10	510-2261	190-242/147*	666.20	16
DENIZLI-TEKKEHAMAM	2	615,5-2001	162	26.60	1.0
AYDIN-GERMENCIK	9	285-2000	203-231/147*	907.90	21
AYDIN-SALAVATLI	2	960-1500	167-172	185.40	7.5
AYDIN-YILMAZKOY	1	1501.00	142	30.00	0.7
IZMIR-BALCOVA	27	100-1000	140	297.75	6.7
IZMIR-SEFERIHISAR	3	1232-2009	145	10.15	0.5
MANISA-ALASEHIR-GOBEKLI	1	1447.1	182	15.00	1
MANISA-CAFERBEYLI	1	1189.00	150	2.00	0.2
KUTAHYA-SIMAV	12	65,80-958	162	354.13	12.5
CANAKKALE	2	81-814	174	101.70	4.0
Total	73			2596.8	71

*waste water from single flash power plant

5. FLUID CHEMISTRY AND CALCULATED RESERVOIR TEMPERATURES

The main analyses results of the selected fields for binary cycle uses are illustrated in (Table 4). Water in the most fields is a dilute solution, containing mostly sodium, potassium, lithium, bicarbonate, sulfate, chloride, borate and silica.

Four primary types of water were identified for the fields [6]. In particular, except as in Canakkale Tuzla and Izmir-Seferihisar field waters which are of Na-Cl type, the end member of water tapped from the geothermal wells of remained fields is of Na-HCO_3 type. Mixing phenomena between this end member and shallow (which is of Ca-HCO_3 and Ca-SO_4) are found in some places. The silica content and rate sodium to potassium are dependent on temperature in the geothermal reservoirs. The maximum inferred temperatures from geothermometres for the fields are as follows:

Fields Name	**Temperature Range**
Denizli- Kizildere	220-240 °C
Denizli-Tekkehamam	150-220 °C
Aydin-Germencik	220-250 °C
Aydin-Salavatli	170- 200 °C
Aydin- Yilmazkoy	140-175 °C
Izmir Balcova	120-150 °C
Izmir- Seferihisar	120 175 °C
Kutahya-Simav	130 175 °C
Manisa -Gobekli	180-220 °C
Manisa-Caferbeyli	140-170 °C

5.1 The Constraints Chemical Characteristics and Solution Alternatives

The most frequent non-condensable gases that emitted along with geothermal vapor of the studied fields are CO_2, H_2S, CH_4, N_2 and H_2. The percentage of the CO_2 among these gases almost reaches to % 99. Despite the fact that carbon dioxide forms a greater portion compared to other gases, it does not create negative environmental effects. But, during the up-flow of the water in the well-bores, fluid pressure decreases, CO_2 separates from the liquid phase and pH increases. Consequently, $CaCO_3$ deposition occurs inside the well-bores and in surface equipments and separators.
Considering the chemical analyses of the fluids from candidate fields for the binary cycle uses in Turkey, the below result has obtained for scaling and corrosion tendencies of water according to "Langelier Saturation Index [6]

$$SI = pH(measured))-PHs(calculated) \quad (1)$$

$$pHs = p(Ca) + p(Alk) + C \quad (2)$$

Fields Name	pH	pHs	SI	Characteristics
Denizli- Kizildere	9.25	7.75	+ 1.50	Incrustative
Denizli-Tekkehamam	8.07	7.90	+ 0.17	Incrustative
Aydin-Germencik	8.3	7.3	+0.90	Incrustative
Aydin-Salavatli	7.71	6.75	+0.96	Incrustative
Aydin- Yilmazkoy	6.70	6.25	+0.40	Weak incrustative
Izmir Balcova	8.7	7.8	+1.10	Incrustative
Izmir- Seferihisar	6.8	6.8	±0.00	Neutral
Kutahya-Simav	8.7	8.1	+0.60	Weak incrustative
Manisa -Gobekli	8.6	7.25	+1.35	Incrustative
Manisa-Caferbeyli	7.25	7.0	+0.25	Weak incrustative

As can be seen above, all of the fluids that subjected to this study are incrustative. It means they are liable to cause $CaCO_3$ deposition during up-flow in the well-bores, in the separators and in the heat exchangers of the binary cycle plants. There are several methods in use to control $CaCO_3$ scale in geothermal applications. The most common measures are the proper design of the utilization plant and selection of operating conditions, such as pH adjustment, use of chemical additives and the removal of deposition by mechanical or chemical means [7]. The scale formation in the Kizildere well-bores has been removed by mechanical reaming. In the other utilizing fields the chemical additives (Inhibitor) have been in uses.

Table 3. Chemical Analyses of The Water Produced From The Fields

Place	Kizil dere	Tekke Ham.	Ger-mencik	Sal-vatli	Yil-maz-köy	Çanak-kale Tuzla	İzmir Balç-ova	İzmir Seferi-hisar	Simav Eynal	Manisa Göbekli	Manisa Cafer-beyli
Reserv.(^oC)	242	162	231	172	140	173	140	137	162	182	150
Sampling(^oC)	98	97.2	98	97	97	100	98	96	96	98	86
µS/25^{o}C	5500	4000	7100	4600	5150	70000	1518	33500	2075	5260	2025
pH/25^{o}C	9.25	8.07	8.3	7.67	6.7	7.0	8.7	6.8	8.7	8.6	7.25
Na	1400	750	1775	1100	1200	22250	395	6558	600	1520	320
K	138	75	170	90	105	2125	24	734	61	86	40
NH_4	14	17	4.8	0.67	3.7	2.6	1.5	3.9	0.1	<1.0	3.4
Ca	1.2	12	1.6	14	40	5715	27	1120	5.5	5.4	54
Mg	0.6	12	0.5	1.2	32	101	2.7	150	1.3	<0.1	25
As	0.72	0.28	0.9	<0.1	<0.1	-	<0.01	0.1	1.0	-	<0.1
B	26	12.1	68	42	67	35	13	20	5.4	116	30
Li	-	-	3.5	6.0	1.7	74	1.5	10.8	1.0	4.8	1.2
SiO_2	450	210	475	210	252	123	270	198	218	274	267
HCO_3	1342	446	1342	2831	1900	55	622	454	460	2723	1031
CO_3	720	-	0.0	0.0	0.0	0.0	0.0	0.0	130	698	0.0
SO_4	735	1350	74	170	98	176	143	606	483	27	98
Cl	136	76	1818	223	170	44140	176	11698	73	170	64
F	21.7	8.3	8.0	0.8	2.8	-	14	38.7	18	3.9	1.7
Geohemical Properties	Na-HCO_3	Na-HCO_3	Na-Cl	Na-HCO_3	Na-HCO_3	Na-Cl	Na-HCO_3	Na-Cl	Na-SO4	Na-HCO_3	Na-HCO_3

6. CONCLUSIONS

All the high and moderate-low temperature geothermal resources of Turkey lie along western part of the country. The most widespread application in Turkey is concentrated on the district heating. In district heating application moderate-low temperature geothermal fields fluid (<200) have to flash to atmosphere before introducing the heat exchanger. This means big energy loss for nowadays available binary cycle technologies. It is calculated that present prospective potential of the high and moderate-low geothermal fields is 75 MWe for single flash, 71 MWe for binary cycle and 1609 MWt for district heating applications. Of this potential only Izmir-Balcova potential in half capacity is being used in district heating. The amount of electricity that is being generated by single flash power plant is 14 MWe (Kizildere). This consists approximately only 1/5 of available capacity.

Unfortunately, binary cycle technology has not been yet put into practice on the potentially big Turkey's geothermal fields.

Financial lack, $CaCO_3$ scaling and environmental impact are only constraints to developments of geothermal energy utilization. Recently, carbonate scaling has overcome by means of chemical additives and environmental impact has been achieved by reinjection.

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