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Hydrogeochemical Properties of Geothermal Fluids in Afyon-Akşehir Graben (Akarcay Basin) and the Sustainability of Ömer-Gecek Area

*Can Başaran, *Ahmet Yıldız, **Yusuf Ulutürk and *Metin Bağcı

*Afyon Kocatepe University, Engineering Faculty, Afyonkarahisar/Turkey

**AFJET (Afyon Geothermal Facility Tourism, Industry and Trade Joint Stock Company, Afyonkarahisar/Turkey

cbasaran@aku.edu.tr

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ABSTRACT

In West Anatolia, there is a 3-30 km wide and 500 km long, NW-SE-trending normal fault system surfaces. This large seismogenic zone is called as Akşehir Simav Fault System (ASFS). With a length of 130 km and a width of 4-20 km, Afyon-Akşehir Graben is one of the most important graben and geothermal system in ASFS. The graben has a WNW–ESE trending structure bounded by normal fault systems. Ömer-Gecek, Gazlıgöl, Sandıklı and Heybeli areas are the most important geothermal areas associated with Afyon-Akşehir Graben faults. Hot and mineralized waters in the region are used generally for purposes of district heating, greenhouse and thermal tourism. In Omer-Gecek basin, existing outside the old well points, the new hot spots are being discovered and geothermal area are still being developed. Maximum temperature was measured at 125°C. It is planned to generate electricity, washing and drying from new wells from these new hot points.

Depending on their depths, reservoir rocks and temperatures, thermal waters have different electrical conductivity ranging from 350-7820 µs/cm and compositions are quite diverse, whereas Omer-Gecek waters types are Na-Cl-HCO_3, Sandıklı waters have Na-SO_4-HCO_3 type, Gazlıgöl waters have Na-HCO_3 type and the Heybeli waters have Na-Ca-HCO_3-SO_4 type. The cold groundwaters are mostly dominated by Ca and HCO_3 ions. According to Giggenbach diagram, while Omer-Gecek waters are both partially equilibrated and immature, Sandıklı-Heybeli and Gazlıgöl waters are immature. The silica geothermometer models suggest a reservoir temperature max.149°C for Omer-Gecek, max. 115°C for Heybeli, 123 °C for Sandıklı and 119°C for Gazlıgöl waters.

1. INTRODUCTION

Turkey is located on an active tectonic belt with many tectonic structures such as faults, grabens and overthrusts and most of the geothermal areas are located in western part of Turkey. Apart from Denizli, Aydın, Kütahya, İzmir and Manisa, Afyonkarahisar is also one of the most impartant geothermal field. There are 4 important geothermal fields associated with Afyon-Akşehir graben (AAG) faults. While low and medium enthalpy geothermal fields (Omer-Gecek, Gazlıgöl and Heybeli) are situated in the AAG, Sandıklı geothermal field is located in southwest of AAG. (Figure 1). The geothermal waters in the Afyonkarahisar province are generally used for district and greenhouse heating, thermal bath and health spas. By using the geothermal waters, approximately 23000 houses and 910.000 m^2 greenhouse are heated and the tourism facilities with a capacity of 29.000 beds are operated. This paper is focused on assessment of geothermal fields of Afyonkarahisar province and the development in the Omer-Gecek field.

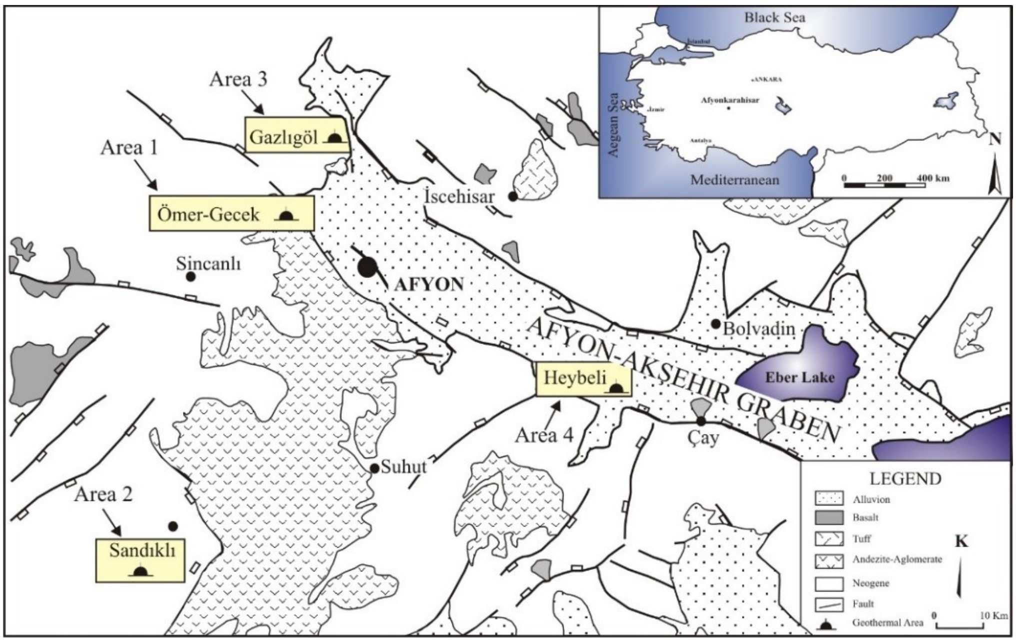

Figure 1: Geothermal areas in the Afyon-Akşehir graben system (modified from Gürsoy at al. 2003).

2. GEOLOGICAL SETTINGS

Turkey forms part of the Alpine-Himalayan orogenic belt and is a region of great tectonic complexity. Northwest Turkey encompasses two major tectonic units, the Pontides and the Torid-Anatolides, separated by the Izmir-Erzincan suture (Okay et al.

1996). The Anatolides, the metamorphosed northern extension of the Taurides, consist of several zones and the Afyon zone is one of them (Figure 2a). Afyon zone generally consists of low-grade greenschist facies metamorphic rocks and covers large areas in Central Anatolia and extends as far east as the Bolkardag region; to the west it forms the cover of the Menderes Massif (Tolluoğlu et al. 1997). The metamorphic rocks at and around Afyonkarahisar completed their evolution before Mesozoic and they are defined as Afyon Metamorphics. Having predominantly sedimentary origin, Afyon metamorphics were affected by multiple regional metamorphism and deformation. These metamorphic rocks are overlain by Anatolian carbonate platform. The succession which consists of Afyon metamorphics and Anatolian Carbonate platform is called as Afyon metasedimentary group. This group is overlien by the Triassic-Jurassic carbonates and Neogene aged volcanic and volcano-sedimentary units covers all these units (Figure 2b), (Tolluoğlu et al. 1997).As known, the extensional tectonic regime occurred by westward movement of the Anatolian plate is the characteristic feature of the Aegean region. There is a 3-30 km wide and 500 km long, NW-SE-trending normal fault system surface. This large seismogenic zone is called as Akşehir Simav Fault System (ASFS) which is one of the highest seismicity zone in Afyon Zone (Koçyiğit and Deveci, 2007). With a length of 130 km and a width of 4-20 km, Afyon-Akşehir Graben is one of the most important graben and geothermal systems in ASFS. The graben has a WNW–ESE trending structure bounded by normal fault systems and and the subsidence plant of the graben is called as Akarcay basin. Depending upon on these faults there are several geothermal fields (Figure 1).

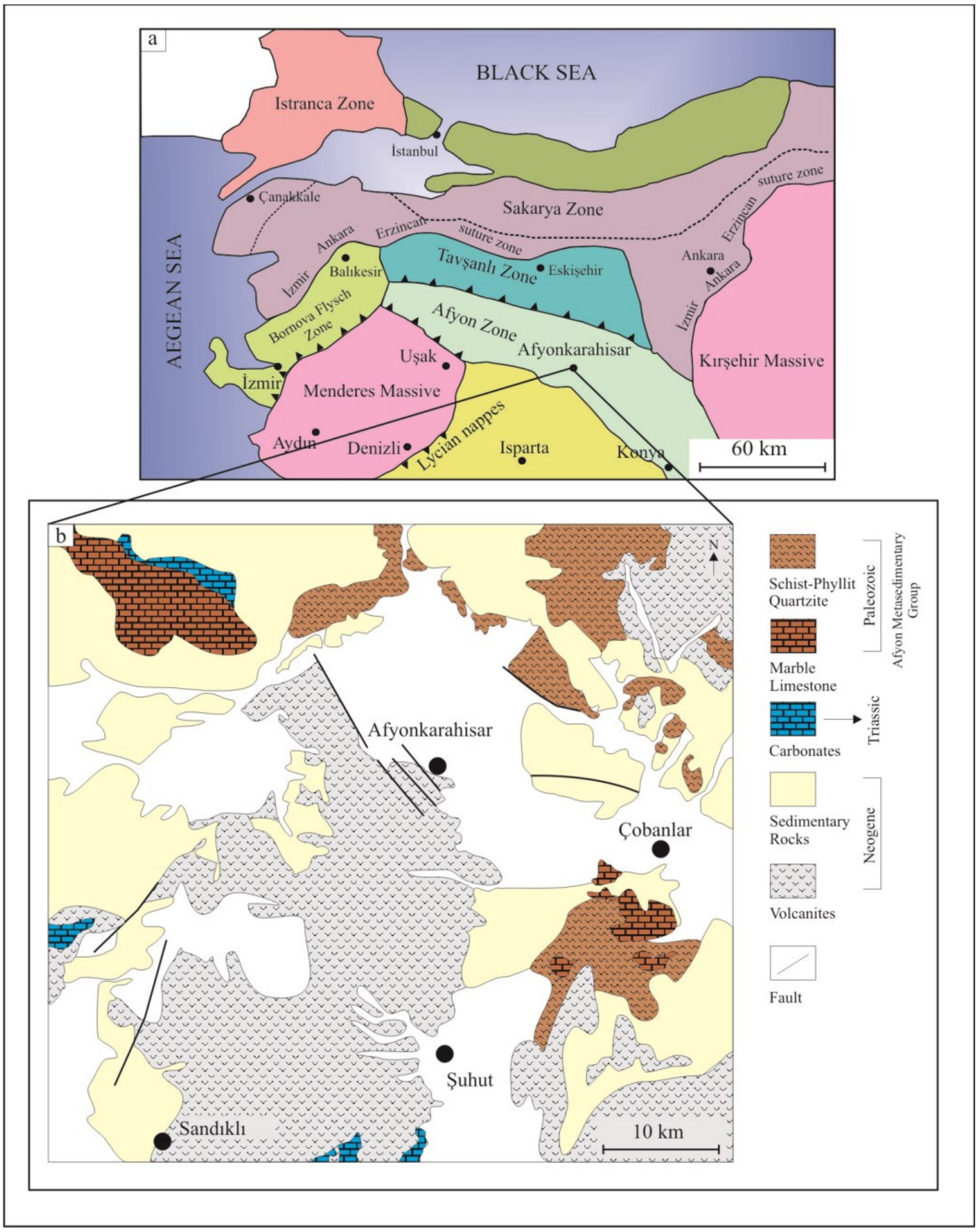

Figure 2: A: Paleotectonic map of west anatolia (simplified from Göncüoğlu et al. 1996), B: Geological map of Afyonkarahisar (simplified from Turhan 2002).

3. MATERIALS AND METHOD

To determine the hydrogeochemical properties of these geothermal fields, waters samples were collected from Omer-Gecek, Gazlıgöl and Heybeli areas and Sandıklı waters were evaluated according to Memiş (2010). In-situ (EC, pH, T) parameters were measured in the field and hydrochemical analyses were realized at the laboratories in Pamukkale and Süleyman Demirel Universities. Analysis results were utilized using Scholeer, Piper and Giggenbach diagrams.

4. GEOTHERMAL AREAS

Afyonkarahisar is one of the most important geothermal field in Western Anatolia and there are 3 important geothermal fields (Omer-Gecek, Gazlıgöl, Heybeli) located in Akarcay Basin and 1 (Sandıklı) geothermal field is located 50 km southwest of the basin but it is considered as if it is located in Akarçay basin. The effects of geological structure and fault lines have an impact on the development of geothermal resources. In general, the locations and geological properties of geothermal areas are similar to each other. Magma chambers forming Miocene aged volcanic rocks and the high geothermal gradiant are the heat source for geothermal waters. Impermeable phyllite-schist units of Afyon metamorphics are the basement rocks; marbles, re-crysitallized limestones and quartzites are the reservoir rocks and the impermeable Neogene sedimentary units are the cap rocks for the geothermal systems. Geothermal resources in the basin are reaching to the surface through the fault segments belonging to Afyon-Akşehir graben system (Başaran et al. 2012, Memiş 2010, Mutlu 1996, Mutlu and Güleç 2005, Ulutürk 2009)

In Afyonkarahisar province there are low and medium enthalpy geothermal fields with a temperature of 30-125 ^oC. Depending on their depths, reservoir rocks and temperatures, thermal waters have different physical and chemical properties. The physical properties of these four geothermal fields are given in next table.

Table 1: Physical properties of geothermal fields.

	Omer-Gecek	Sandıklı	Gazlıgöl	Heybeli
Reservoir Rock	Marble	Quartzite-Limestone	Quartzite	Recrystallized limestone
Number of drillings	30	26	56	10
Depts of drillings (m)	100-1100	49-1200	50-800	200-650
Temperatures (^oC)	45-125	65-85	43-86	30-55
Total Flow rate (l/s)	450	100	260	200
EC (µs/cm)	2700-7820	350-2300	2770-4070	580-3600
pH	7,1-7,9	6,4-7,9	6,92-8,10	6,4-7,83

3.1. Hydrogeochemical Properties

Schoeller diagram of thermal water samples is given in Fig. 3a. This diagram indicates that geothermal fields originated from the same reservoir within each other. In general, depending on the increase of drilling depths and sample temperatures, mineral concentrations are also increasing. Hot springs' relations with the lithology, hydrogeochemical exchange processes that occurred throughout the circulatory system was tried to be explained using Piper diagram (Fig 3b). Most of the hot water samples gathered in the same area except for some samples show that the samples have same origin within each other. According to the diagram Omer-gecek, Sandıklı, Heybeli and Gazlıgöl waters are of the Na-Cl-HCO_3, Na-SO_4-HCO_3, Na-Ca-HCO_3-SO_4, Na-HCO_3 types respectively. It seems in the Piper diagram that, Omer-Gecek water samples are quite close to Na and Cl corners. Sandıklı waters are dominated by Na and SO_4 ions, Gazlıgöl waters are very rich in terms of Na and HCO_3, Heybeli waters are located in no dominant cation area and close to HCO_3 corner.

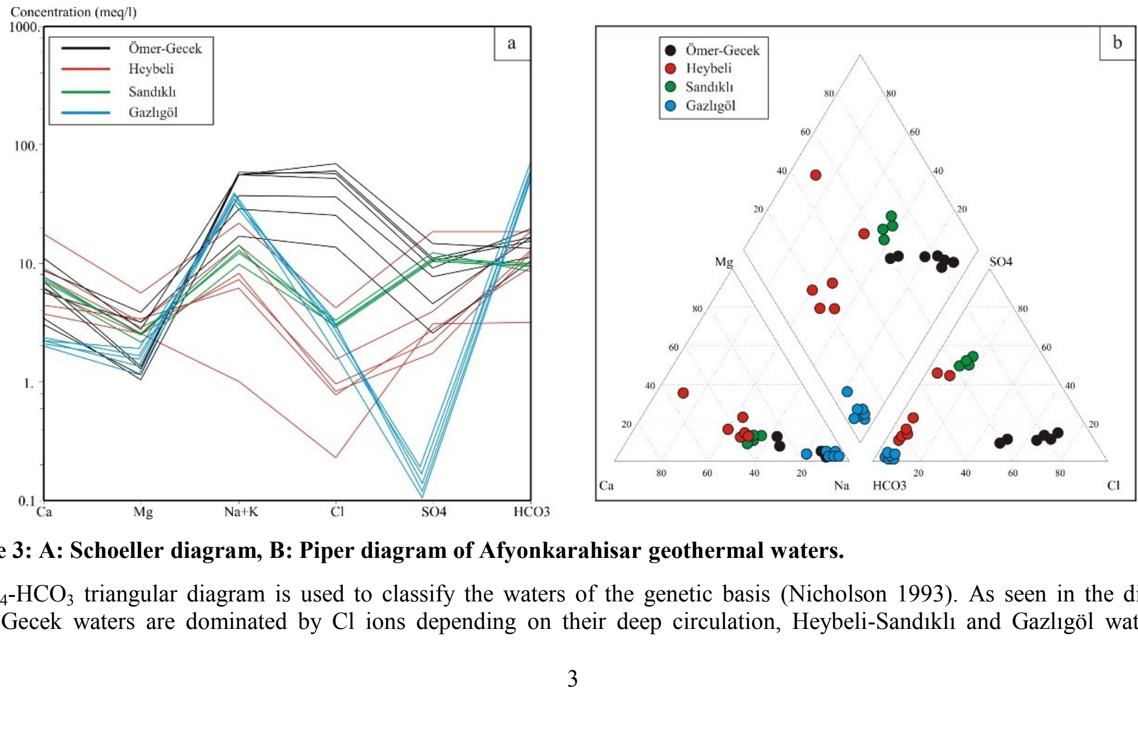

Figure 3: A: Schoeller diagram, B: Piper diagram of Afyonkarahisar geothermal waters.

Cl-SO_4-HCO_3 triangular diagram is used to classify the waters of the genetic basis (Nicholson 1993). As seen in the diagram, Omer-Gecek waters are dominated by Cl ions depending on their deep circulation, Heybeli-Sandıklı and Gazlıgöl waters are located in bicarbonate rich waters area. Sandıklı and some Heybeli water samples are close to sulfate rich waters area, these sulfate enrichment in Sandıklı and Heybeli areas is explained by mixing sulphate rich cold surface waters and pyrite content of reservoir rock respectively (Memiş, 2010) (Figure 4a).

Na-K-Mg triangular diagram is used for determining the origin of geothermal waters, to control the balance situation and in the selection of appropriate geothermometer (Giggenbach 1988). In Giggenbach diagram Omer-Gecek and Gazlıgöl waters are close to partially equilibrated area while Sandıklı and Heybeli waters are immature (Figure 4b). The waters are all immature/partially equilibrated and the cation geotermometers gives results that are not realistic, therefore, silica geothermometers were applied to the samples instead of cation geothermometers. The silica geothermometer models suggest a reservoir temperature max.149°C for Omer-Gecek, max. 115°C for Heybeli, 123 °C for Sandıklı and 119°C for Gazlıgöl waters (Table 2).

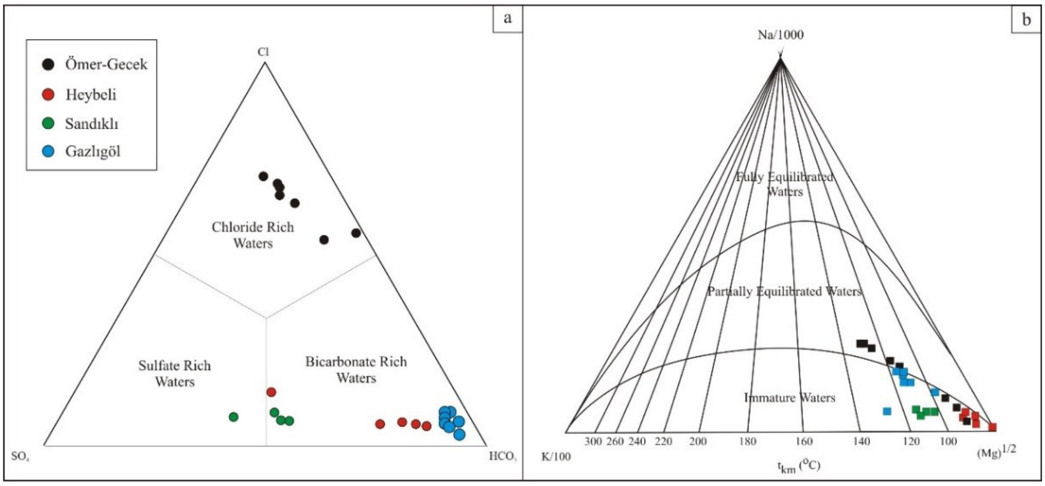

Figure 4: A: Cl-SO_4-HCO_3 diagram, B: Giggenbach diagram of Afyonkarahisar geothermal waters.

5. SUSTAINABILITY AND DEVELOPMENT OF OMER-GECEK FIELD

Omer-Gecek geothermal field, which is the most important geothermal field in the region, is located 15 km north-west to Afyonkarahisar. The temperatures of the thermal waters range from 45-125 ^{o}C. Thermal waters obtained from the region are used for district and greenhouse heating, thermal tourism and physiotherapy. By using the geothermal waters, approximately 13000 houses and 150.000 m^2 greenhouse are heated, the tourism facilities with a capacity of 10.000 beds and Afyon Kocatepe University Hospital for physiotherapy are operated.

For the last 4 years, under the leadership of AFJET (Afyon Geothermal Facility Tourism, Industry and Trade Joint Stock Company), depending on the increasing interest in geothermal energy and the intended of sustainable management, the geothermal field has been greatly improved. The primary aim of the company is to ensure the controlled and efficient use of geothermal waters. To achieve this aim, the company carries out some projects to use the geotermal energy in multiple scopes and reinject them with a minimal loss. To respond the growing needs and to ensure an efficient use, renovation and development studies have been initiated. Within the scope of these studies; water pipelines were replaced, old wells were made available for pumping, reinjection and monitoring wells were activated, the geothermal field was developed in the northwest, to the southeast direction and new wells were drilled (Figure 5, 6).

Figure 5: New production, reinjection and monitoring wells and new pumps-pipelines from Omer-Gecek field.

Table 2. The gothermometer resuts of water samples.

	Omer-Gecek							**Heybeli**					**Sandıklı**				**Gazlıgöl**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**References**
1-SiO_2 (amorphous silica)	-86	10	11	17	26	23	27	-10	-12	-18	-2	-34	-3	-1	-1	4	-7	-6	-12	-9	-1	-22	1	Fournier 1977
2-SiO_2 (alpha cristobalite)	-33	79	80	87	96	93	98	56	54	47	65	28	64	67	66	72	59	60	54	57	66	43	68	Fournier 1977
3-SiO_2 (beta-cristobalite)	-73	30	32	38	47	45	49	9	7	0	17	-17	16	19	19	24	12	13	7	10	18	-3	21	Fournier 1977
4-SiO_2 (chalcedony)	-20	102	104	110	121	118	123	77	74	67	86	46	85	89	88	95	80	82	74	79	88	62	90	Fournier 1977
5-SiO_2 (quartz)	13	129	131	137	147	144	**149**	107	104	97	**115**	78	114	117	117	**123**	109	111	104	108	117	93	**119**	Fournier 1977
6-SiO_2 (steam loss)	23	126	128	133	141	138	142	107	105	99	114	82	113	116	116	121	109	110	104	108	115	95	117	Fournier 1977
7-SiO_2 (chalcedony, con. cooling)	-14	101	103	109	119	116	121	78	75	68	87	49	86	89	88	94	81	82	75	79	88	64	90	Arnorsson vd. , 1983
8-SiO_2 (quartz, steam loss)	-4	102	103	109	117	115	119	81	79	73	89	55	88	91	91	96	84	85	79	82	90	69	92	Arnorsson vd. , 1983
9-SiO_2 (quartz, steam loss)	-23	98	100	106	117	114	119	73	71	63	83	43	82	85	84	91	76	78	71	75	84	59	87	Arnorsson vd. , 1983
10-SiO_2 (quartz, steam loss)	-2	120	122	128	139	136	141	96	93	86	105	65	104	107	107	113	99	100	93	97	106	81	109	Arnorsson vd. , 1983
11-SiO_2 (quartz, steam loss)	21	125	127	132	140	137	142	105	103	97	113	80	112	115	114	120	108	109	103	107	114	93	116	Arnorsson vd. , 1983
12-SiO_2 (chalcedony mmol)	-16	100	102	108	118	115	120	77	74	67	86	48	85	88	87	94	80	81	74	78	87	63	89	Arnorsson vd. , 1983
13-Na/K	208	172	170	171	186	184	183	216	214	221	228	142	274	306	287	295	182	182	183	177	190	185	193	Arnorsson vd., 1983
14-Na/K	215	188	186	187	198	197	196	220	219	224	228	164	261	282	269	275	196	196	196	192	201	197	203	Arnorsson vd., 1983
15-Na/K	182	144	142	143	159	157	156	191	189	196	203	112	255	291	269	278	155	155	156	150	163	158	166	Fournier & Truesdell 1973
16-Na/K	186	150	148	150	164	163	162	194	192	199	206	121	252	284	266	273	161	161	162	156	168	163	171	Truesdell, 1976
17-Na/K	216	187	185	186	198	197	196	222	220	226	231	161	267	290	276	282	195	195	196	191	201	197	204	Fournier 1979
18-Na/K	203	174	172	174	185	184	183	209	207	213	218	150	252	275	262	267	183	183	183	179	188	185	191	Nieva ve Nieva, 1987
19-Na/K	231	204	202	203	215	213	213	237	236	241	245	180	278	299	287	292	212	212	213	208	217	214	220	Giggenbach vd., 1983
20-K/Mg	114	131	133	128	124	121	125	85	81	72	72	70	89	99	93	94	116	115	116	112	118	114	111	Giggenbach vd., 1983

Figure 6. Drilling locations in Ömer-Gecek basin.

As a consequence of field development studies, apart from the old well points, new and higher temperature hot spots are being discovered and drilled. Until 2010 while production wells were 5 units, in 2013 this number was increased to 18. 3 reinjection and 4 monitoring wells were activated between the years of 2010-2013. From the point of production, the output of 600 m^3/h until 2010 is now 1600 m^3/h and 95 percent of this production is reinjected.

With these field development studies, water-pipeline renovations were carried out and automation system was activated. 130 km distribution line has been replaced with PPR 80 isolated pipes to prevent heat loss and leakage (Figure 7a). City distribution line was designed with Tichelmann (for automation) system for efficient heating. The automation made district heating circulation continues in a closed cycle. The geothermal waters produced from production wells are firstly deposited in to the storage pools and mains water is heated with them in the main heating center. Then the temperature of geothermal waters is reduced to 55 ^oC and then it is reinjected. The heated mains water in 90-degree temperatures is pumped to the interm heating centers. Then a second mains water is heated and pumped to the houses. Finally the mains waters returning from district heating return to the heating center at 45 ^oC and is heated again. (Figure 8).On the other hand, by installing thermostatic valve, calorimeter and temperature measuring systems to the houses payment as spent was provided for the users. (Figure 7b). On the other hand Omer-Gecek water distribution project is the only project that supplies heating and utilization waters along a 18-kilometer line from single authority to the thermal facilities with a capacity of 10.000 beds. Now with the 150 km long pipelines, district and thermal hotel heating are realized.

Figure 7: Isolated pipes, B: Calorimeters.

Using the recently drilled wells with temperatures up to about 125 ^oC, and a 3 MWe power plant for domestic use which will cover the firm's own demand, and to open a washing-drying facility with a capacity of 20.000 kg/d is planned. Finally, the firm will generate its own electricity, then with an amount of cooled water will be used for district and greenhouse heating and thermal spas and their washing and drying. These new plans will provide new dimensions to the geothermal waters' sustainability and efficient usage in Afyonkarahisar.

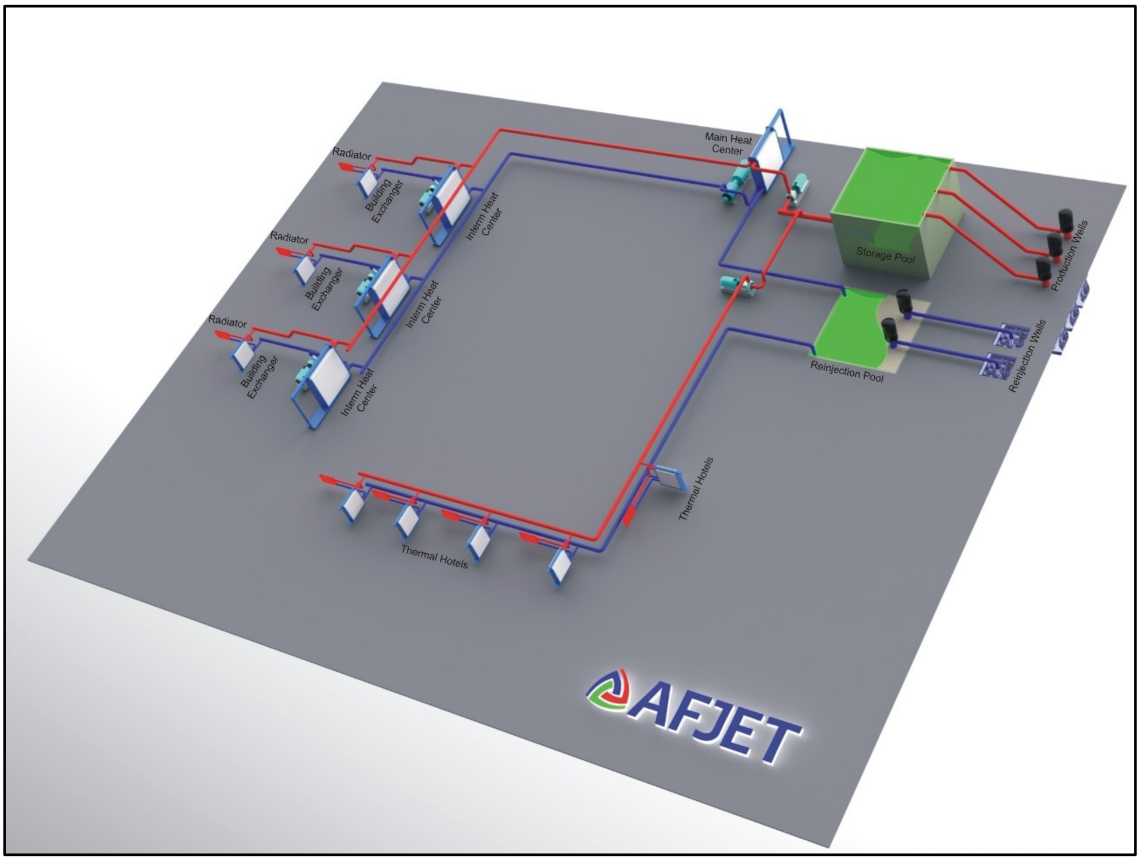

Figure 8: District and thermal facilities pipeline project.

6. RESULTS

Ömer-Gecek, Gazlıgöl, Sandıklı and Heybeli areas are the most important geothermal areas associated with Afyon-Akşehir Graben faults. By using the geothermal waters, approximately 23000 houses and 910.000 m^2 greenhouse are heated and the tourism facilities with a capacity of 29.000 beds are operated.

Water temperatures and electrical conductivities vary between 30-125 ^{o}C and 350-7820 µs/cm respectively. In general impermeable phyllite-schist units of Afyon metamorphics are the basement rocks; marbles-re-crysitallized limestones and quartzites are the reservoir rocks and the impermeable Neogene sedimentary units are the cap rocks for all the geothermal areas. It seems in the Piper and Scholler diagrams that Omer-Gecek, Sandıklı, Gazlıgöl and Heybeli waters are of the Na-Cl-HCO_3, Na-SO_4-HCO_3, Na-HCO_3 and Na-Ca-HCO_3-SO_4 types respectively. The silica geothermometers give a reservoir temperatures max.149°C for Omer-Gecek, max. 115°C for Heybeli, 123 °C for Sandıklı and 119°C for Gazlıgöl waters.

In Omer-Gecek region; approximately 13000 houses and 150.000 m^2 greenhouse are heated, the tourism facilities with a capacity of 10.000 beds and Afyon Kocatepe University Hospital for physiotherapy are operated. For the last 4 years, under the leadership of AFJET (Afyon Geothermal Facility Tourism, Industry and Trade Joint Stock Company), the geothermal field has been greatly improved. Water pipelines were replaced, old wells were made available for pumping, reinjection and monitoring wells were drilled, the geothermal field was developed from the north to the southeast direction and new wells were drilled. Using the recently opened wells with a temperature of 125 ^{o}C, it is planned to generate 3 megawatts of electricity which will cover the company's own demand, and to open a washing-drying facility with a capacity of 20.000 kg/d. These new plans will provide new dimensions to the geothermal waters' sustainability and efficient usage in Afyonkarahisar.

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