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Geothermal Potential Assessment of Edremit Geothermal Field (NW Turkey)

Özgür AVŞAR[1], Nilgün GÜLEÇ[2], Mahmut PARLAKTUNA[3]

[1]Muğla Sıtkı Koçman University, Department of Geological Engineering, Muğla, Turkey

[2]Middle East Technical University, Department of Geological Engineering, Ankara, Turkey

[3]Middle East Technical University, Department of Petroleum and Natural Gas Engineering, Ankara, Turkey

[1]ozguravsar@mu.edu.tr; [2]nilgun@metu.edu.tr; [3]mahmut@metu.edu.tr

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ABSTRACT

Hot geothermal water from Edremit geothermal field is being used for district heating purposes since early 2000s. Geothermal water with an average wellhead temperature of 60 °C is produced from 12 wells located at a distance of 3 km SE of the city center. Although the field has been producing for several years there is no resource assessment study for the field. There are plans to extend the operation into new areas in spite of the signs of a shortage of energy for the installed capacity. This study aims to estimate the recoverable heat energy of Edremit geothermal field using the limited data obtained from the wells.

The method that was selected for resource estimation is the volumetric method which requires the numerical values of parameters within the volumetric method equation. Almost all parameters of the volume method exhibit uncertainties (especially reservoir volume, porosity and temperature) where a probabilistic approach is the common application to overcome these uncertainties. In this study, a Monte Carlo method was used to assign numerical values for each parameter within the given constraints as distribution functions (i.e. triangular, Gaussian, uniform). Geological and geophysical studies, drilling reports, and temperatures from geothermometer applications were the data sources to define the constraints of each parameter. In addition, parameters related to the recovery of heat and parameters specific to the project (recovery factor, transformation yield, load factor, total project life) were assigned from literature. Estimates of recoverable heat are 58.6 MW_t, 26.8 MW_t, and 9.1 MW_t for 10%, 50% and 90% probability, respectively. Those heat recoveries correspond to 1500, 4300 and 9400 Residence Equivalent (RE) heating application where 1 RE means 100 m^2 heated area. The municipality of Edremit has a target of 7500 RE heating which corresponds to heat energy with 19% probability.

1. INTRODUCTION

Hot geothermal water from the Edremit geothermal field is being used for district heating purposes since early 2000s. Geothermal water with an average wellhead temperature of 60 °C is produced from 12 wells located at a distance of 3 km SE of city center (Figure 1 and Table 1). Although the field has been producing for several years there is neither a resource assessment nor a numerical modeling study for the field. There are plans to extend the operation into new areas in spite of signs of a shortage of energy for the installed capacity. No reinjection has been applied in the area yet, but it will probably be considered in the future plans as an environmental issue and resource management concern. This study aims to estimate the recoverable heat energy of Edremit geothermal field using the limited data obtained from the wells.

2. ACCESSIBLE RESOURCE BASE CALCULATION

There are four major methods used in geothermal resource assessment: volume method, surface thermal flux, planar fracture and magmatic heat budget. Among these, volume method is reported, by Muffler and Cataldi (1978), as the most useful method for accessible resource base calculations. In the volume method heat energy is calculated by the following formula;

$$\begin{aligned} H_{Total} &= H_R + H_F \\ &= (1-\phi)c_R\rho_R V\left(T_R - T_U\right) + \phi c_F \rho_F V\left(T_F - T_U\right) \end{aligned} \tag{1}$$

where H, ϕ, c, ρ, V, T are heat energy (kJ), porosity (fraction), specific heat (kJ/kg-°C), density, hot rock volume (m^3), temperature (°C), respectively and subscripts R, F and U represent rock, fluid and utilized, respectively.

Many parameters of Equation 1 exhibit uncertainties (especially volume, porosity and temperature) where a probabilistic approach for the solution of problem is a common procedure. Among different probabilistic approaches Monte Carlo method was used to evaluate Edremit Geothermal Field by the help of the computer program @Risk. Monte Carlo is a statistical method which assigns distribution functions (triangular, normal etc.) rather than exact values for the parameters. Although various types of distributions can be used in the Monte Carlo method, triangular distribution (minimum, most likely, maximum values) is recommended by the literature (i.e. Newendrop, 1975) when the number of input data is limited. Except utilization temperature, for which the minimum value is taken as 42 °C (the lowest temperature -belonging to YAGCI well - utilized in Edremit geothermal district heating system), triangular distribution was used for all variables of Equation 1 (Table 2).

Avşar et al. (2013) made several geothermometer calculations for estimating reservoir temperature of Edremit geothermal field. The first approach was preparing graphs of the saturation index versus the temperature of the waters. Assuming that there is a temperature-dependent chemical equilibrium between mineral(s) and fluid in deep reservoir conditions, by using temperature versus saturation index (SI) graphics, the temperature values which make the saturation index of the mineral zero (SI=0) were recorded graphically and these temperatures were assumed to represent the reservoir temperatures. Curves generally intersect with the equilibrium line (SI=0) in the range of 60 and 150 °C. This range is consistent with the cation geothermometer results with a range of 58 to 154 °C and temperatures coming from silica-mixing (112 °C). Evaluating all these results together, the reservoir temperature of the Edremit geothermal field is found to be 110 °C. This information is used to estimate the maximum thickness of the geothermal reservoir by using the annual mean temperature and average geothermal gradient of Edremit region as 16 °C and 3 °C/100 meters, respectively. Those parameters require a depth of 3000 m to cover the temperature difference of 94 °C (110 – 16). The minimum and most likely values for the thickness of the accessible resource base are taken as 500 m (proven by drilling) and 1500 m, respectively.

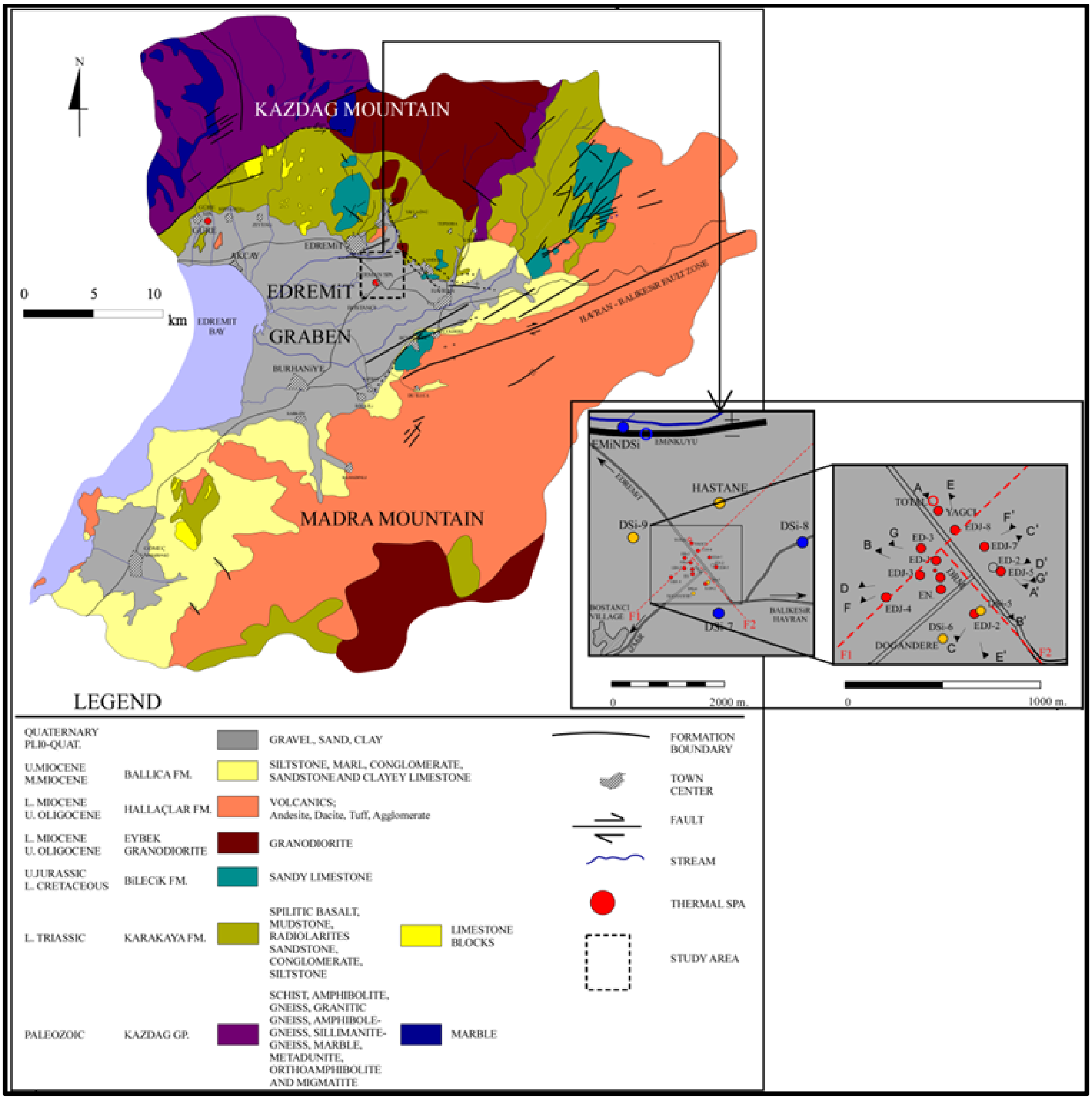

Figure 1: Geological map of the Edremit region. Inset maps showing locations of the wells. Taken from Avşar et al., (2013).

The assigned maximum thickness (3000 m) corresponds to the depth of granodiorite in the Edremit geothermal field. Therefore, the maximum, minimum and most likely values for the parameters such as porosity, density and specific heat, were selected from those reported in the literature as representative of magmatic lithologies (in the case of absence of a parameter for granodiorite in the literature, values of the other magmatic rocks (e.g. granite, diorite, basalt) are assigned for the parameters). In this respect, the assigned porosity values are 0.03 (lower limit for weathered granite in Goodman (1989)), 0.05 (upper limit for porosity of weathered granite in Goodman (1989)) and 0.10 (porosity of granite in Heath (1983)) for minimum, most likely and maximum values, respectively.

Goodman (1989) suggests densities of 2650 kg/m^3 and 2850 kg/m^3 for granite and diorite, respectively. Triangular distribution of the density of the rock units are assigned as 2650 kg/m^3 for minimum, 2850 kg/m^3 for maximum and - the average value of these two values - as 2750 kg/m^3 for most likely.

Using the data provided by Schärli and Rybach (2001), specific heat of the rock units are taken to range between 0.720 (granite) and 0.775 (diorite) kJ/kg-°C . 0.752 kJ/kg-°C (granodiorite) is accepted as the most likely value for the specific heat of rocks.

Again, triangular distribution is assumed for the areal extent of the geothermal field. For the minimum value, the area surrounded by 40 °C contour of upper aquifer (Figure 2) which is 546,000 m^2 is assigned. For the maximum value, the area defined by 20 ohm.m contour of 200 meter depth of Sarp et al. (1998) is assigned (1,414,000 m^2). The most likely value of the area is determined to be the area delineated by the location of the geothermal wells that penetrate the lower aquifer (Figure 1 and Table 1). This area is 900,000 m^2.

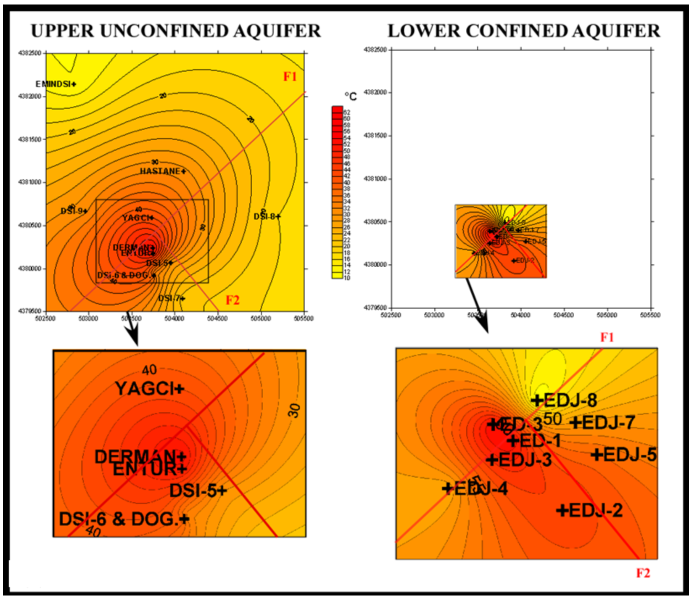

Figure 2: Contour map of temperature upper and lower aquifers. Taken from Avşar et al. (2013).

Table 1: Coordinates, depths and well-head water temperatures of wells in the Edremit geothermal field. There are two superimposed aquifers in the field, Upper and Lower and 2nd Column indicates the aquifer penetrated by each well. The wells 1-12 is used for geothermal purposes however 12-22 is used for irrigation.

Index	Aquifer	Well No	Drilling date	COORDINATE (UTM/EUROPEAN 1950)		Elev. (m)	Depth (m)	Dynamic well-head temperature (°C)	Static bottom-hole temperature
				E	N				
1	Lower	ED-3	2001	503639	4380394	22	495	62	50.1
2	Lower	ED-1	2000	503718	4380329	22	189	62	59
3	Lower	EDJ-3	2005	503634	4380252	21	266	59	50
4	Lower	EDJ-2	2008	503916	4380049	24	300	58	40
5	Lower	EDJ-5	2005	504054	4380273	23	216	55	57.7
6	Upper	DERMAN	-	503731	4380197	22	100	53	-
7	Upper	ENTUR	2000	503743	4380178	22	90	51	-
8	Lower	EDJ-7	2005	503968	4380402	23	246	51	49
9	Lower	EDJ-4	2005	503458	4380136	19	296	50	49
10	Lower	ED-2	2001	504014	4380293	23	496	47	51
11	Lower	EDJ-8	2007	503815	4380491	23	250	43	60
12	Upper	YAGCI	-	503729	4380591	23	100	42	-
13	Upper	DSI-6	1970	503753	4379919	24	95	39	-
14	Upper	TOTAL	-	503729	4380591	24	-	36	-
15	Upper	DOGANDERE	-	503753	4379919	24	30	32	-
16	Upper	DSI-9	1974	502958	4380668	20	122	32	-
17	Upper	HASTANE	1975	504099	4381130	28	90	31	-
18	Upper	DSI-5	1970	503949	4380066	24	91	30	-
19	Upper	DSI-7	1970	504088	4379653	22	132	21	-
20	Upper	DSI-8	1972	505195	4380605	26	83	18	-
21	Upper	EMINKUYU	-	503129	4382054	28	-	18	-
22	Upper	EMINDSI	1975	502824	4382144	24	100	12	-

The maximum temperature of the rock and the fluid (T_R and T_F) is selected as 110 °C which is the expected reservoir temperature as estimated from fluid-mineral equilibria calculations suggested by Avşar et al. (2013). The minimum value assigned for this parameter is 40 °C which is the lower limit of the discharge temperature of the wells that are used as geothermal wells (1-12 wells in Table 1). The most likely value is taken as 60 °C considering the down-hole temperature measurements (Table 1).

The maximum, minimum and most likely specific heat and density of the fluid (water) are taken from the literature (U.S. Department of Commerce, 2008; The Engineering Toolbox, 2010) for relevant temperatures (minimum: 40 °C, most likely: 60 °C and maximum: 110 °C) (Table 2).

According to the results obtained by running the @Risk program with 10,000 iterations, accessible resource base (H_t) is determined as 1.98×10^{14}, 9.73×10^{13} and 3.45×10^{13} kJ for 10%, 50% and 90% probability, respectively (Figure 2).

Table 2: Probability distribution for parameters for accessible resource base calculation.

Parameters	Mean	Type of Dist.	Min.	Most Likely	Max.
Porosity, ϕ (fraction)	0.06	Triangular	0.03	0.05	0.10
Specific Heat of Rock, c_R (kj/kg-°C)	0.749	Triangular	0.720	0.752	0.775
Density of Rock, ρ_R (kg/m^3)	2750	Triangular	2650	2750	2850
Area, A (m^2)	9.53E+05	Triangular	5.46E+05	9.00E+05	1.41E+06
Thickness, h(m)	2500	Triangular	500	1500	3000
Temperature of Rock and Fluid, T_R or T_F (°C)	83	Triangular	40	60	110
Atmospheric Temperature, T_U(°C)	42	Constant	42		
Specific Heat of Fluid, c_F (kj/kg-°C)	4.20	Triangular	4.179	4.190	4.233
Density of Fluid, ρ_F (kg/m^3)	973.8	Triangular	951	978	992

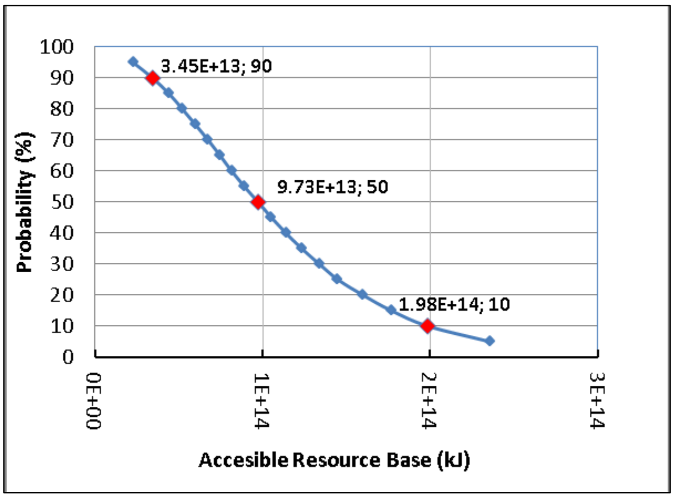

Figure 2: Accessible resource base vs. probability.

3. RECOVERABLE HEAT ENERGY CALCULATION

In low temperature geothermal fields, recoverable heat energy can be calculated by the following equation

$$H_{Recoverable} = \frac{[H_{Total} \times RF] \times Y}{LF \times t} \quad (2)$$

where $H_{Recoverable}$, H_{Total}, RF, Y, LF, t are recoverable heat energy (kW$_t$), accessible resource base (kJ), recovery factor for the given reservoir (fraction), transformation yield (fraction), load factor (fraction), and total project life (sec).

H_{total} is calculated in section 2. The most critical parameter in Equation 2 is the recovery factor (RF). This factor represents the amount of heat that is extracted from the rock by the fluid and taken to the surface. Considering relevant literature (White and Williams, 1975; Muffler and Cataldi, 1978; Sorey et al., 1982; Nathenson and Muffler, 1975; Williams, 2004; Williams, 2007; Williams et al. 2008) 0.07, 0.18 and 0.24 for the minimum, most likely and maximum values are selected, respectively, for the recovery factor (RF) (Table 3).

Total time in which the system is active in a year is determined by load factor. The geothermal energy is used only for district heating in Edremit and the system is almost idle during summer except for balneological use. A constant value of 0.5 is selected for load factor since the Edremit geothermal system is active for only half of the year (Table 3).

Transformation yield represents the ratio that accounts for the efficiency in heat transfer in the exchangers. Minimum, most likely and the maximum values assigned for the yield factor are 0.70, 0.85 and 0.93, respectively.

Total project life is determined to be 30 years ($9.46x10^8$ sec.) as a constant value (Table 3).

Running @Risk with 10,000 iterations resulted in recoverable heat energy as follows:

for 10% probability, 58.6 MW_t;

for 50% probability, 26.8 MW_t;

for 90% probability, 9.1 MW_t (Figure 3).

Table 3: Probability distribution for parameters of recoverable heat energy ($H_{recoverable}$).

Parameters	Mean	Type of Dist.	Min.	Most Likely	Max.
Recovery factor, RF (fraction)	0.16	Triangular	0.07	0.18	0.24
Project Life, t (sec)	9.46E+08	Constant	30 years		
Load Factor, LF (fraction)	0.5	Constant	4380 hours/year		
Transformation yield, Y(fraction)	0.83	Triangular	0.70	0.85	0.93

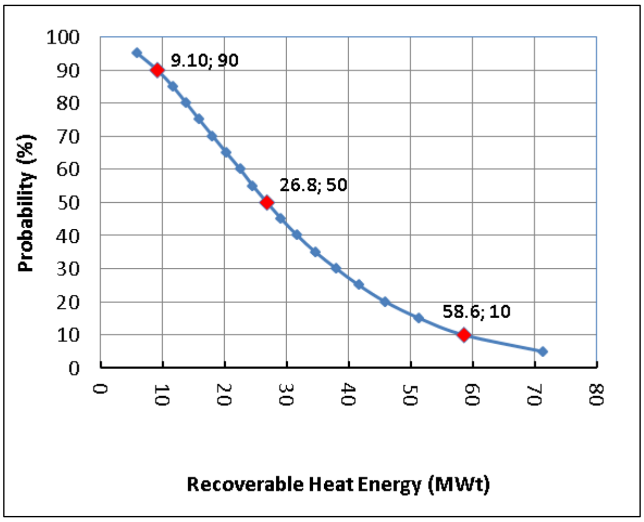

Figure 3: Recoverable heat energy vs. probability.

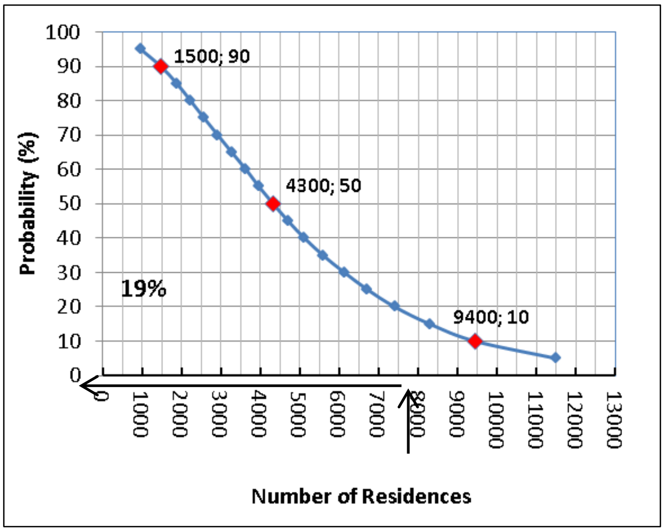

Figure 4: Number of residences vs. probability graph. 7500 is the target of Edremit municipality.

4. CONCLUSION

The method that was selected for resource estimation is the volumetric method which requires the numerical values of parameters within the volumetric method equation. Almost all parameters of the volume method exhibit uncertainties (especially reservoir volume, porosity and temperature) where a probabilistic approach is the common application to overcome these uncertainties. The Monte Carlo method was utilized to assign numerical values for each parameter within the given constraints as distribution functions (i.e. triangular, Gaussian, uniform). Geological and geophysical studies, drilling reports, and temperatures from geothermometer applications were the data sources to define the constraints of each parameter. In addition, parameters related to recovery of heat and specific to the project (recovery factor, transformation yield, load factor, total project life) were assigned from literature. Estimates of recoverable heat are 58.6 MW_t, 26.8 MW_t, and 9.1 MW_t for 10%, 50% and 90% probability, respectively. Those heat recoveries correspond to 1500, 4300 and 9400 Residence Equivalent (RE) heating application where 1 RE means 100 m^2 heated area. Municipality of Edremit has a target of 7500 RE heating which corresponds to a heat energy with 19% probability.

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