PROCEEDINGS, Thirty-Ninth Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 24-26, 2014
SGP-TR-202

Methodology for Determining Geothermal Potential

Elemer Bobok, Aniko N. Toth, Peter Szucs and Zoltan Fejes

University of Miskolc, Miskolc-Egyetemváros 3515 Hungary

E-mail:toth.aniko@uni-miskolc.hu

Keywords: Define geothermal potential, thermal power, amount of geothermal output

ABSTRACT

There are different ways to define geothermal potential. At its simplest, geothermal potential is the yearly amount of recoverable geothermal energy. Another more specific definition limits geothermal potential to the recoverable energy produced by existing facilities operating continuously during a year. Yet another definition views geothermal potential as the thermal power which could be produced from the proven resources of a given region if the necessary wells and surface facilities exist. This definition is based on proven resources and an operation's assumed lifetime, which means that the range of potential geothermal output could differ through time by several orders of magnitude. Finally, one can define geothermal potential as the amount of geothermal output likely to be consumed by an operation's proven geothermal resources. All these definitions are illustrated by examples taken from Hungarian geothermal operations.

1. INTRODUCTION

Because of fossil energy's limited and ever decreasing supply, because of its regularly multiplying cost and because of the environmental damages associated with fossil energy, modern industrial societies are now being forced to fulfill their energy requirements through geothermal energy, which has a lower specific energy content. Before we can integrate geothermal energy into the mix of energy sources, we must know how to realistically estimate the amount of available geothermal energy, and recognize where and how it can be efficiently used. When estimating geothermal energy stocks, the biggest problem is that different estimates discuss different phenomena and use different units of measurement, creating a large deviation.

2. ESTIMATES OF GEOTHERMAL POTENTIAL

According to the International Geothermal Association (IGA), geothermal potential is defined as the amount of geothermal energy that can be produced in one year, or basically the mean power for a one-year period. Different authors have given estimates which vary by orders of magnitude. Table 1 illustrates the different estimates of recognized geothermal experts. These data were collected by Muffler and Cataldi (1977), Stefansson (1998), IGA News No. 53. (2003), Bertani (2009, 2010), Lund (2010), Rybach (2010), Williams et al. (2011)

What all these estimates have in common is that they investigate power generation and direct use separately. They all take a global approach: they assess geothermal potential on a world-wide basis.

	Electricity			Direct use		
	GW_e	TWh/y	EJ/y	GW_{th}	TWh/y	EJ/y
Actual World Energy Consumption 1996		12,000	43		112,000	400
Actual World Energy Consumption 2009			420			
Extrapolation 2020	42	300	1.1	40	140	0.50
Expected 2050 by Bertani 2009	140-280					
Actual Consumption WGC2000	8	49	0.18	15	53	0.19
Actual Consumption WGC2005	8.9	55.18	0.21	27.8	72.6	0.26
Actual Consumption WGC2010	10.7	67.2	0.24	50.5	121.7	0.43
Cataldi 1999	46	330	1.2	190	670	2.4
Gawell 1999	140	1,000	3.6			
Fridleifsson 1999	1,700	12,000	43	480,000,000	170,000,000	600,000
Stefansson 2000	3,100	22,000	79	160,000	>560,000	>2,000
Stefansson 2002	5,900	42,000	150	28,000	98,000	350
Stefansson 2005	50-2,000	438-17,520	1.6-63,1	1000-44,000	8,760-385,4400	

Table 1: Integrated data for expected world geothermal potential and actual production

From Table 1 one can draw some obvious conclusions.

- The different estimates vary by an order of magnitude
- In 2000 an extrapolation was made for 2020; this estimate was already surpassed in 2010
- Geothermal energy alone is not capable of satisfying the world's energy needs
- The minimum estimate of geothermal potential for power generation is 330 TWh/year (Cataldi, 1999), the maximum is 42,000 TWh/year (Stefansson, 2002)
- The minimum estimate of geothermal potential for direct use is 670 TWh/year (Cataldi, 1999), the maximum is 170 million TWh/year (Fridleifsson, 1999)

The contradictions between the data presented in Table 1 seem irreconcilable: Stefansson (2002) gives an estimate of geothermal potential for power generation of 42,000 TWh/y, whereas Cataldi (1999) gives an estimate of 330 TWh/y – or 127 times less. When estimating geothermal potential for direct use, the discrepancy is even greater between Fridleifsson (1999), who gives an estimate of $170 \cdot 10^6$ TWh/y, and Cataldi, whose estimate is only 670 TWh/y – or 253,731 times less.

A discrepancy this huge makes it hard to consider the data objectively or use that data as the basis for a long-term energy strategy. There are two possible reasons for this big difference: first, the different estimates use different methodology and have different starting points; secondly, the results are distorted by the unreliability of the global data.

3. ANOTHER METHOD FOR DETERMINING GEOTHERMAL POTENTIAL

First, let's clearly define and agree upon what we mean by the annual exploitable geothermal energy. The simplest objective data is the actually generated amount of energy in the current year. This is characterized by the actual performance ofthe geothermal industry, whether considered globally or by region..

We can accept the data of every World Geothermal Congress, based on each country's self-assessment,. Accordingly, as per 2010 WGC data, world geothermal power generation was 10,715 MW_e or 67,246 TWh/y. This means power production was 207 PJ/y. Direct utilization was 50,583 MW_t or 438,071 GWh/y. This means thermal power production was 1,347 PJ/y.

Another method for determing geothermal potential is to examine the amount of exploitable geothermal energy for one year. Instead of merely considering the average annual production from full use of the existing production capacities, we can divide the amount of existing exploitable geothermal energy by the assumed production lifetime, to get an accurate estimate for annual power production. This metric also has a power dimension and can serve as the basis for long-term prognoses.

Assuming that there is enough reliable data, we can accurately predict how much economically exploitable geothermal energy can be produced.

3.1 Geothermal Potential in Hungary

Natural conditions in Hungary are very favorable for geothermal energy production and utilization. Between the two World Wars, while prospecting for oil, huge thermal water reservoirs were discovered. During the 50's and 60's hundreds of geothermal wells were drilled, mainly for agricultural utilization. The peak of geothermal activity was the late 70's: a total of 525 geothermal wells were registered, and the 30 best wells had a production temperature of more than 90^oC. These wells yielded very reliable data. Using that data and his own exploration results, Boldizsár (1944, 1956) identified the high terrestrial heat flux and geothermal gradient in the Pannonian Basin. The anomalously high terrestrial heat flow (~0.09 W/m^2), the high geothermal gradient (~0.05 $^oC/m$), and the vast expanses of deep aquifers form an important geothermal resource.

Hungary's economically exploitable geothermal energy stock is estimated at 343,000 PJ/y by Lorberer (2004) is and estimated at 435,000 PJ/y by Bobok (1987). Other estimates are not too different.. This energy estimate is based on both reservoir rocks and thermal fluid. These are the in-situ energy resources of the reservoir. The exploitable energy resource depends on the respective production technology. In other words, the extraction yield is determined by the technology-dependent factor.

If we assume free up-flowing water production, calculate the elastic expansion of the water body, and use only the thermal and gas-lift, the recovery factor is only 0.4%. In this case, Hungary's e exploitable geothermal energy is 1,740 PJ.

If the well contains a submersible pump, the recovery factor can multiplied. If the structures allow for submersible pumps below 300m, the recovery factor reaches 4.2%, which means 18,270 PJ/.

For production-injection well pairs, assuming a full injection amount, and cooled to 20 C above the average reservoir temperature, the recovery factor could be as much as 28.8%. That would mean the geothermal energy produced in Hungary could be 125,280PJ.

If we arbitrarily assume a production lifespan of 300 years, geothermal potential from technology-dependent values are: 5.8 PJ/y for free up-flowing water production, 60.9 PJ/y with a submersible pump using, and 417.6 PJ/y with injection technology.

For long-term production, obviously we have to consider the latest.

Itis useful to compare Hungary's general energy source-side data with the energy demand from geothermal sources. It is known that our country's current primary energy consumption is 1,088 PJ/y, of which 435 PJ/y is direct heat demand. The main part of this is consumed by poorly insulated houses with outdated heating systems. It does not seem too bold a prediction to say that housing modernization will soon yield a significantly higher figure.

A comparison of supply-side and demand-side data shows that low-enthalpy geothermal resources should be able to satisfy the direct-heat energy demand for a long time.

The long-term potential of geothermal-energy use is also characterized by an alternative measure. If we know the geothermal potential and the market's yearly demand, we can get the production lifespan. If we divide the amount of exploitable geothermal energy by the yearly average direct heat utilization, we can get a time dimension number. Using water-reinjection technology, this yields a value of 288 years for Hungary.

The amount of economically exploitable geothermal energy will obviously increase over time due to technological advances, even though heating demand is falling. We can therefore conclude that in Hungary, resources for geothermal-based heating and cooling systems should suffice for at least another 300 years old.

Starting from the country's geothermal potential, we wish to define specific potential per unit area, using the measurement PJ/y km^{2}",creating a distribution function for the entire country.

Within the framework of the TÁMOP-4.2.2.A-11/1/KONV-2012-0049 EU project named KUTFO, we have begun work on creating a geothermal atlas for Zemplén County, in northeastern Hungary. This region has no heavy industry, but is noteworthy for a few charmingsmall towns and the historic Tokaj wine district. The region has no special geothermal activity or significant underground water resources. Geologically, the Tokaj region is characterized by clay or loess soils.overlaying a volcanic subsoil. Because the region has no large underground water reservoirs, the most practical way to use geothermal energy seems to be through the use of ground-source heat pumps. After weighing the Tokaj's geological conditions against. the region's heating-cooling demands, we've recommended a way for this region to best exploit its natural geothermal resources..

4. CONCLUSION

There are different ways to define geothermal potential. One is to define it as the yearly amount of recoverable geothermal energy. Another definition views geothermal potential as the thermal power which could be produced from the proven resources of a given region, if the necessary wells and surface facilities already exist. This definition is based on proven resources and an operation's assumed lifetime, which means that the range of potential geothermal output could differ through time by several orders of magnitude.

Instead of merely considering the average annual production from full use of the existing production capacities, we have used a method which divides the amount of existing exploitable geothermal energy by the assumed production lifetime, to get an accurate estimate for annual power production. This metric also has a power dimension, and can serve as the basis for long-term prognoses.

If we know the geothermal potential and the market's yearly demand, we can calculate the production lifespan, and in certain cases more accurately assess the relevant long-term geothermal potential. If we divide the amount of exploitable geothermal energy by the yearly average direct heat utilization, we can get a time dimension number.

Finally, one can define geothermal potential as the amount of geothermal output likely to be consumed by an operation's proven geothermal resources. All these definitions are illustrated by examples taken from Hungarian geothermal operations.

REFERENCES

Barelli A., Calamai A., Cataldi R.: Estimation of the geothermal potential of the pre-Apennine belt of central-southern Italy. *2nd U.N. Symposium,* San Francisco (1975)

Bobok, E.: Geotermikus energiatermelés, Tankönyvkiadó, Hungary (1987)

Bodvarsson, G.: An estimate of the natural heat resources in a thermal area in Iceland *Geothermics, Special Issue 2, Vol. 2.* (1970), 1289-1293.

Bodvarsson, G.: Geothermal resource energetics. *Geothermics Vol.3.* (1974), 83-92.

Boldizsár, T.: Terrestrial heat and geothermal resources in Hungary. *Bull. Volcanologique XXX.* (1967), 221-227.

Boyd, Tonya "Toni :Communitites with Geothermal Resource Development Potential, *Bulletin Geo-Heat Center, Oregon Institute of Technology,* (2008):

Cataldi, R., Muffler, P.: Methods for regional assessment of geothermal resources. *Proc. ENEL-ERDA Workshop Larderello* (1976), 131-207.

Cataldi, R.: Geothermal energy development in Europe to year 2020: prospects or hopes? *Technica Poszukiwan Geologiczncyhc, 4-5,* (1999), 48-59.

Fridleifsson, I.B.: Worldwide prospects for geothermal energy in 21st century. *Technica Poszukiwan Geologiczncyhc, 4-5.* (1999), , 28-34.

Fridleifsson, I.B.: Geothermal energy for the benefit of the people. *Renewable and Sustainable Energy Reviews, 5,* (2001), 299-312.

Gawell, K., Reed, M. and Wright, P.M.: Geothermal energy: the potential for clean power from the earth, *GEA Website,* (1999)

Long, J.C.S.: The potential of geothermal energy. *Mackay School of Mines, Reno*. (2001)

Lund J. at al. World-Wide Direct Uses of Geothermal Energy 2005. World Geothermal Congress, Antalya, Turkey. (2005):

Lund, J. – Boyd, T.: Oregon Institute of Technology Geothermal Uses and Projects - Past, Present and Future, 34th Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, CA (2009):

Muffler, P. and Cataldi, R.: Methods for regional assessment of geothermal resources, Geothermics, 7, 1978, 53-89.

Rybach, L. Muffler, L.: Geothermal Systems. *Wiley*, New York, (1981):

Stefansson, V.: The renewability of geothermal energy. *Proc. World Geothermal Energy,* Japan, 2000.

Stefansson, V.: Global perspective on geothermal energy. *Submitted to IEEE*, 2002.

Tester, J. et. al.: The future of geothermal energy. *Massathuettes Institute of Technology*, (2006)

Tóth A.: Hungarian Country Update 2005-2009, *World Geothermal Congress*, Bali, (2010)

The described work was carried out as part of the TÁMOP-4.2.1.B-10/2/KONV-2010-0001 project in the framework of the New Hungarian Development Plan. The realizationof this project is supported by the European Union, co-financed by the European Social Fund."

Special thank for D.K.Fenerty for reviewing our paper.