Geothermal energy production and its environmental impact in Hungary

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Abstract

The utilization of geothermal energy has a long tradition in Hungary. When the present economic recession in the country ends in the near future, geothermal energy will surely play an increasing role in the energy supply. The paper shortly reviews the history of geothermal power use and discusses the present state of geothermal energy production in the country. Present power statistics as well as future plans are detailed.

Keywords: *steam outburst, direct utilization, balneology, reinjection.*

1 Introduction

Natural conditions in Hungary are very favorable for geothermal energy production and utilization. The anomalously high terrestrial heat flow (~0.09 W/m^2), the high geothermal gradient (~0.05 °C/m), and the vast expanses of deep aquifers form an important low-enthalpy geothermal resource.

Surface manifestations have been known since ancient times: thermal springs of Budapest had been used in the Roman Empire and also later in the medieval Hungarian Kingdom. The artificial exploration of thermal waters began with the activities of V. Zsigmondy, the legendary drilling engineer, who in 1877 drilled Europe's deepest well (971 m) in Budapest. Between the two World Wars, while prospecting for oil, huge thermal water reservoirs were discovered. Based on data of this exploration, Boldizsár (1944, 1956) recognized the high heat flux and geothermal gradient in the Pannonian Basin Figure 1. (at the end of the paper). He also constructed the world's first regional heat flow map of Hungary, (Boldizsar, 1958).

During the 50's and 60's hundreds of geothermal wells were drilled, mainly for agricultural utilization. The peak of geothermal activity was at the late 70's: a total of 525 geothermal wells were registered, the best 30 of them had a production temperature of more than 90^{o}C. Total thermal power capacity of these wells was 1,540 MW, but utilization was seasonal and the efficiency was rather low.

Today the utilization of geothermal energy has decreased substantially while the technical level and the efficiency of utilization has increased.

2 Geological background

The Pannonian basin is encircled by the Carpathian Mountains. The Earth's crust here is relatively thin (~25 km) due to sub-crustal erosion. The thinned crust had sunk isostatically and tertiary sediments mostly fill the basin thus formed. Pannonian sediments are multilayered, composed of sandy, shaly, and silty beds. Lower Pannonian sediments are mostly impermeable; the upper Pannonian and Quaternary formations contain vast porous, permeable sand and sandstone beds. The latter formed the upper Pannonian aquifer, which is the most important thermal water resource in Hungary.

The individual sandy layers have various thicknesses between 1 and 30 m. Their horizontal extension is not too large, but the sand lenses are interconnected forming a hydraulically unified system. This upper Pannonian aquifer has an area of 40,000 km^2, an average thickness of 200-300 m, a bulk porosity of 20-30%, and a permeability of 500-1,500 mD. The hot water reservoir has an almost uniform hydrostatic pressure distribution; local recharge or discharge can slightly modify this pattern.

Carbonate rocks of Triassic age having a secondary porosity is another type of geothermal reservoirs. These can be fractured or karstified rock masses with continuous recharge and important convection. About 20% of the Hungarian geothermal wells produce from such carbonate rock formations (Bobok, et al., 1984).

The existence of high enthalpy reservoirs was proved by a dramatic outburst of steam from the well Fábiánsebestyén in the Southeast of Hungary in 1985.

From an exploratory borehole over-pressured steam had blown out at a pressure of 360 bars and a temperature of 170°C. The mass flow rate was approximately 80 kg/s. The reservoir is a fractured dolomite formation at the depth of 3,700 m. The duration of the blowout was 47 days, and the wellhead pressure as well as the flow rate remained constant. The well was finally killed and the borehole cemented. At the present, feasibility studies are going on to determine the dimensions and the geothermal potential of the reservoir. Existence of other deep, high-enthalpy reservoirs in the Southeastern part of Hungary seems to be possible.

3 Production and utilization

Most Hungarian geothermal wells produce hot water from the upper Pannonian reservoir system. A smaller part of them taps the deep karstic aquifer. Up to the present a total of 643 wells have been drilled that produce thermal water warmer than 40°C. Out of this number, 36 wells are abandoned and 103 are temporarily closed.

A typical geothermal well in Hungary might have a depth between 1,000 and 2,100 m. The well completion is typical. A 13 3/8 in (349 mm) conductor casing is set at a depth of 50 m, in a 17 ½ in (444.5 mm) hole. It is followed by a surface casing of 9 5/8 in (244.5 mm) at 500-1,800 m in a 12 ¼ in (311.1 mm) hole.

Finally a 7 in (177.8 mm) liner runs in a 8 ½ in (215.9 mm) hole to a depth of 1,000-2,100 m with its top at 30-50 m above the shoe of the surface casing. Each string is cemented in such a manner that the casing-hole annulus is totally filled.

Typical mass flow rates of the upper Pannonian wells can range between 20 and 30 kg/s. The production temperatures vary regionally as shown in Table 1 (at the end of the paper). Undoubtedly, the best area is in the Southeast of Hungary near the cities Szeged, Szentes and Hódmezővásárhely (Figure 1).

Most Hungarian geothermal wells operate without any artificial production method. Reservoirs are driven by both compaction and dissolved gas. Submersible pumps are installed in only a few wells, in which the reservoir pressure has been depleted substantially.

Balneology use was the earliest way to utilize thermal waters. Worldknown spas are in Budapest, Bük, Hajdúszoboszló, Harkány, Hévíz, Sárvár, Zalakaros and many other places. Altogether 214 thermal wells and 120 natural springs produce water for sport and therapeutically purposes (Ottlik, 1988).

Agricultural use is the most important branch of geothermal energy utilization in Hungary. Greenhouses of more than 500,000 m^2, plastic tunnels and soil heating is supplied with the heat of thermal water. Technical level of these geothermal heating systems can be very different. There are well-designed systems and ones with sophisticated controll, where a dozen of geothermal wells supply a cascade of sub-systems: greenhouses, plastic tunnels and soil heating are connected in series (e.g. Szentes). In other cases a single well provides thermal water directly to greenhouses, and the discharged, still relatively hot water causes a low efficiency and environmental problems sometimes.

Animal husbandries are heated by thermal water in more than 50 cases at chicken, turkey, calf and pig farms. Low-temperature released waters supply fishponds near Szentes and Győr. The estimated thermal power applied in the field of agricultural utilization is about 120 MW.

District and space heating by geothermal energy was started near balneology centers. The first examples are some apartment houses and the Budapest Zoo in between the two World Wars. In the late 50's district heating projects were started in Southeast Hungary e.g. Szeged, Szentes, Makó, Hódmezővásárhely. At the present, 9,000 flats in nine cities are heated by thermal water; the estimated total thermal power is more than 38.7 MW. Simultaneously, thermal water is used as domestic water in the same district. The thermal power of the domestic water supply is about 12 MW.

It is a little known fact that since 1969, thermal water is used in the secondary oil production technology in the Algyő oilfield. Presently 7,000 m^3/s of hot water is reinjected to the oil reservoir for oil displacement. The utilized geothermal power during this secondary oil recovery technology is 15 MW.

Another application is that gathering pipes are heated by thermal water in the heavy oil-producing oilfield Sávoly in the Southwest of Hungary.

There is an unusual utilization of geothermal energy in the oilfield Nagylengyel. An artificial gas cap is formed above the depleted part of the oil reservoir. Natural gas with a high content of CO_2 (~81%) is produced, transported and reinjected to develop a gas cap in the formation. The technology operates without compressors; compressor power is replaced by the thermal lift between the production and reinjection wells. The higher the extracted geothermal heat from the produced gas, the stronger the thermal lift and the higher the gas mass flow rate, while the extracted heat is utilized, too. In this case the fluid carrying the geothermal energy is the CO_2 gas.

Some important data of Hungarian geothermal wells are summarized in Table 1. Wells are grouped on the basis of utilization and the ranges of wellhead temperature. In order to estimate the total thermal capacities some practical approximations had to be made, as the flow rates of individual wells were not always measured. They were obtained from well completion measurements at different times thus their compatibility is questionable.

The estimated thermal capacity of any well was obtained from:

$$\mathbf{P} = \dot{\mathbf{m}}\mathbf{c}\left(\mathbf{T}_{\mathbf{wh}} - \mathbf{T}_{\mathbf{s}}\right) \qquad (1)$$

Where $\dot{m}$ is the mass flow rate, c is the heat capacity of the water, T_{wh} is the wellhead temperature, T_s the yearly average temperature at the surface of 10,5°C.

These values are summarized for several temperature ranges and types of utilization. Averages are obtained by dividing the total amount by the number of wells.

The total available thermal capacity of Hungarian geothermal wells was found to be approximately 1,201 MW. Since the utilized temperature difference is substantially lower than (T_{wh}-T_s), the effectively utilized thermal capacity can be estimated at a level of 325 MW only. This gives an assumed load factor of 27%.

4 Environmental impact of geothermal energy production

Any geothermal activity needs to deal with the significant impacts on the surrounding physical, biological and socio-economic environment. The major concerns are: reservoir pressure decrease, pollution of fresh groundwater and the waterways on the surface thermal effects, emission of dissolved gases, ground subsidence and noise.

Hungarian geothermal reservoirs may be sedimentary, sandy or karstified limestone aquifers. Reservoir pressure decreasing occurs mainly in the sandstone aquifers. Some fields have been exploited more than seventy years, thus the piesometric head of the reservoir has subsided almost 70 m in the Hajdúszoboszló field, the production can be sustained by artificial lifting methods only. The supply of the carbonate aquifers in Western Hungary seems to be unexhausted.

The freshwater aquifers are located above the geothermal reservoirs. Thus the drilling operations can be hazardous. During normal drilling situations downhole drilling fluids are usually the greatest potential threat to the environment. In the case of oil-based mud the cuttings also present a problem. There is a variety of chemicals that are toxic e.g. chromates. During the well completion operations acid jobs can be hazardous.

Nevertheless a blowout can be the greatest environmental hazard while drilling. The most serious blowout of a geothermal well occurred in Fabiánsebestyén, Eastern Hungary in 1985. The mass flow rate was 80 kg/s having an extreme high salinity and the small creek Kórógy lost all kinds of life. The noise level during the outburst reached the 125 dB.

The salinity of the Hungarian geothermal brines is comparable to that of seawater. The water of the upper Pannonian aquifer contains mainly sodium or calcium carbonate; the brine in the lower Pannonian formations contains mainly sodium chloride. The environmental impact of the released thermal waters can be serious. The wells of Bükkszék spa produce more than 1 m^3/min of very saline water; its solved solids are 24.000 mg/l. This means that 14.000 t/year are polluting the small Tarna River.

Thermal waters contain dissolved gases, mainly methane, nitrogen, carbon dioxide and hydrogen sulphide. Methane is separated from the water and utilized in auxiliary equipment. The H_2S is more harmful because of its acid, corrosive nature. This may lead to perforation of the casing and damaging of the cement sheet as well. Fortunately H_2S is present only in a few Hungarian geothermal wells (e.g. Mezőkövesd).

Most problems of environmental pollution can be avoided by means of reinjection of the heat-depleted thermal water to the aquifer. The reinjection is very useful for some other reasons too. The pressure support of the reservoir can be provided, the enthalpy of the rock matrix becomes exploitable and the surface ground subsidence can also be avoided.

Reinjection is a routine technology in the petroleum industry. It is relatively simple to inject hydraulically into karstic carbonate aquifers, but short-circuiting the injected fluid to the production wells introduces a serious risk. It is a more complex procedure into a sandstone reservoir as the necessary injection pressure can substantially increase within a relatively short time. The permeability is decreased because of formation damage. It can occur because of clay swelling, pore space blocking by fine particles or precipitation of dissolved solids due to the mixing of injected water and the formation water or due to temperature changes. There are many efforts ongoing to solve these problems: theoretical analyses, numerical simulation, in the laboratory and by in-situ experiments. Successful industrial experiments were carried out in the city

Hódmezővárhely. The most important experiences are: a suitable choice of place and depth of the injection well, correctly designed and completed well, good hydraulic performance, very slow transient performance processes (pressure, temperature, flow rate).

Some Hungarian thermal water contains toxic materials: arsenic, beryllium, chromium, organic materials (pesticides) and pathogenic organisms, bacteria. If released to the natural waterways, toxic materials and the relative warm wastewaters harm the wildlife of these waters.

5 Future Developments

The Hungarian economy is starting to develop after some years of stagnation. There is no question that geothermal energy will continue to be an important resource base of this process. Environmental advantages of geothermal energy seem to be especially important, because CO_2 emissions in Hungary must be decreased by 4 million metric tons per year (Kyoto Protocol?).

Since 1995, three important projects have been started.

Feasibility studies are in the making to determine the conditions of electric power generation in the Southeast of Hungary, at the Békés basin. This is the site where high enthalpy geopressurized water has been found in Fábiánsebestyén and Nagyszénás. There seem to be serious technical problems due to the high pressure (360 bars at the wellhead) and the strongly saline water.

Two small-scale electric power generation plants are being planned using the organic Rankine cycle with 100^{o}C water in the Southern and Southwestern parts of the country. These projects aim at a complex utilization: the small modular prefabricated power plant may be the attractive element of the system. Direct heat utilization for district heating and greenhouses can make the project economically viable.

Acknowledgments

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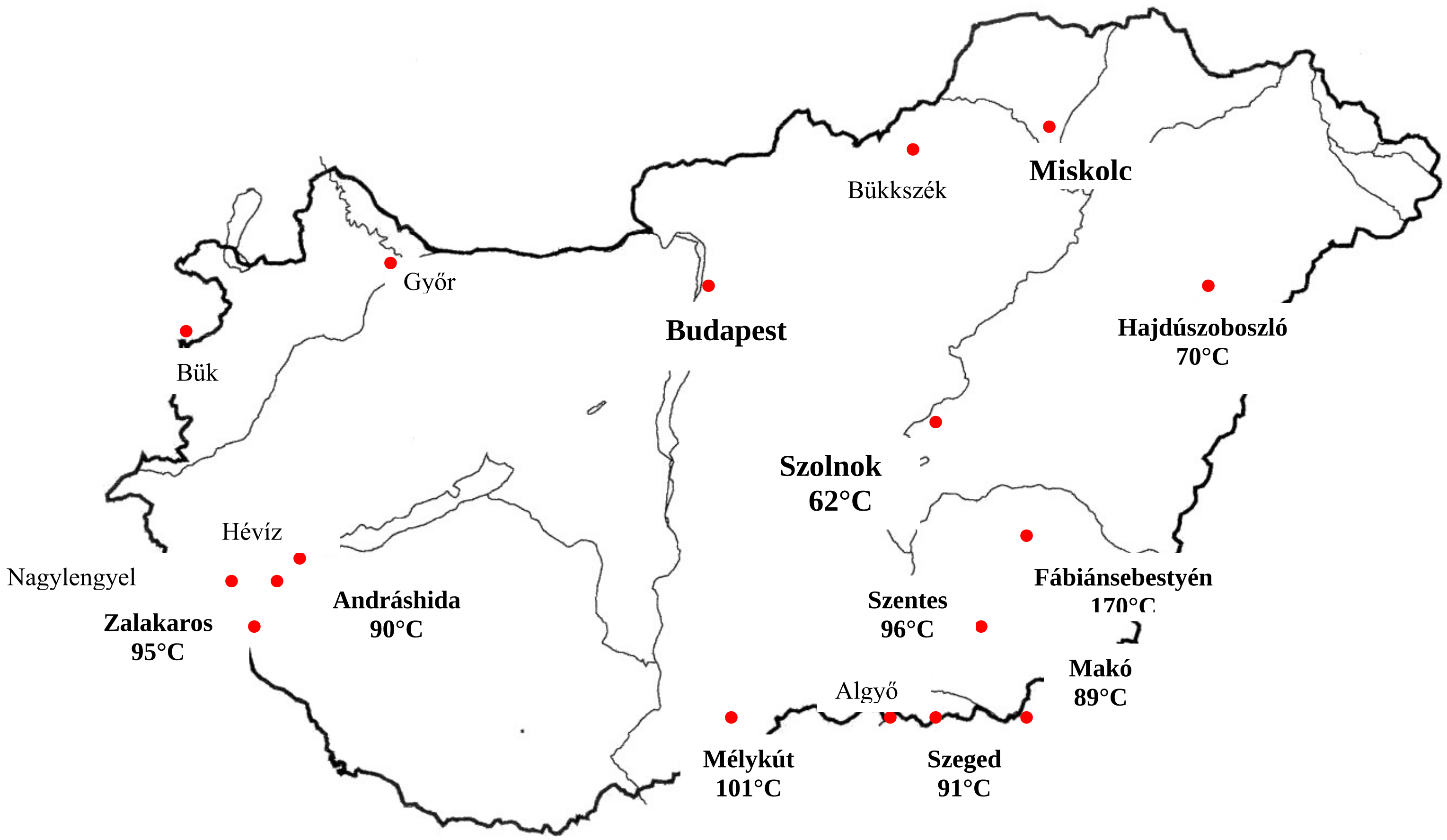

Figure 1:Wellhead temperature regions of Hungarian Upper Pannonian water wells.

Table 1: Hungarian geothermal well data.

Utilization		Temperature Range						
		40-50°C	50-60°C	60-70°C	70-80°C	80-90°C	90-100°C	>100°C
Number of Wells	Agricultural	14	14	15	18	28	20	1
	Industrial	13	14	14	4	3	1	0
	District Heating	2	2	1	3	1	5	1
	Multi Purpose	17	12	28	14	1	0	0
	Balneological	89	39	29	8	3	4	0
Total Mass Flow Rate, kg/s		659	665	955	841	696	811	62
Mass Flow Rate per Well, kg/s		14.32	15.83	16.47	21.56	21.09	23.85	31.00
Total Thermal Capacity, MW		95.19	125.90	219.92	228.88	215.65	292.03	23.62
Thermal Capacity per Well, MW		2.07	2.99	4.87	4.87	6.53	8.59	11.81