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DETERMINING THE AMOUNT OF EXPLOITABLE THERMAL WATER IN HUNGARY'S HÓDMEZŐVÁSÁRHELY GEOTHERMAL RESERVOIR

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INTRODUCTION

Hódmezővásárhely was built above a geothermal resource that has long provided heating for homes, spas and agriculture. The city has the largest geothermal heating system in Hungary. In 1967, the first thermal well was drilled as an individual system, to help heat the local hospital. In 1993, the local government began developing an integrated geothermal heating system. At that time, 2,800 residences received geothermal heating.

Starting in 1998, the cooled water was injected into the sandy, sandstone geothermal reservoir. Ten years later, the city looked into how it might add more geothermal customers. To figure out how best to exploit the geothermal resource, current usage and existing-well potential was studied, along with the reservoir's potential. This meant determining the system's condition, the percentage of available capacity being used, the reservoir's heating capacity, and how much further expansion would be possible.

GEOLOGICAL BACKGROUND

Natural conditions in Hungary are very favorable for geothermal energy production and use. The terrestrial heat flow is rather high (~0.09 W/m^2) and the geothermal gradient is higher than the continental average (~0.05 ^{o}C/m).

Pannonian sediments are multilayered, composed of sandy, shaly, and silty beds. The lower Pannonian sediments are mostly impermeable; the upper Pannonian and Quaternary formations contain vast porous, permeable sand and sandstone beds. Their individual sandy layers are up to 30 m thick. They don't extend very far horizontally, but their sand lenses connect to form 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, although local recharge or discharge can slightly modify this pattern.

The Hódmezővásárhely geothermal reservoir

As shown in Figure 1, the Hódmezővásárhely reservoir is in South-Eastern Hungary, near the Tisza river. The basement rock contains a deep, extensive geological trench.

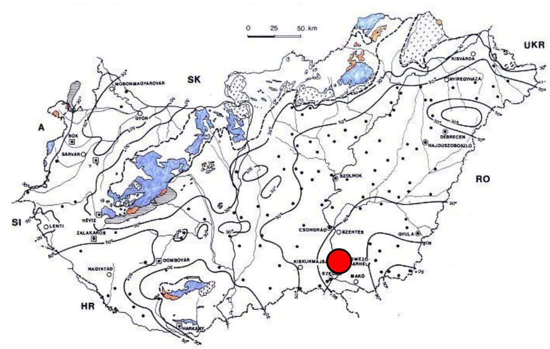

Figure 1: Regional distribution of accessible wellhead temperatures.

These relatively young sedimentary layers have a total thickness of about 7,000 m. Hence the geothermal gradient -- 0.0385 ^{o}C/m -- is slightly lower than the Hungarian average. The terrestrial heat flow is 0.077 W/m^2 at the surface and the pressure distribution is hydrostatic in all the aquifers.

Hódmezővásárhely's reservoir system has three basic parts. The first upper layer of the reservoir has very good permeability and a rather low TDS. As its temperature is about 30-35 ^{o}C, it is not used for energy production, but only for drinking water. With a heat pump, this upper layer could be used for energy production, as is done in Milan, Italy, under similar conditions. The second or

Levante layer is less permeable, but its TDS is almost the same and its temperature is higher.

The most valuable layer is the Upper-Pannonian, which has diverse properties. It can be divided into three different parts: III/a, III/b and III/c (see Table 1). Temperature and TDS increase linearly with increasing depth. The Upper-Pannonian is the part of the reservoir which produces the most fluid. Table 1 shows all the reservoir's layers, from the surface downwards.

Table 1: The reservoir layers and features

Layer	Depth [m]	Permeability [mD]	Temp [°C]	TDS [mg/l]
I.	550-700	1.500	30-35	300
II.	700-1,200	500	35-40	500
III/a	1,200-1,600	500	45-65	700-1,400
III/b	1,600-2,000	500	65-80	1,000-1,600
III/c	2,000-2,500	500	80-86	1,700-2,500

THE EXISTING WELLS AND PARAMETERS

This reservoir is quite well known. Table 2 displays the most valuable data regarding its existing, operating thermal wells.

Table 2: Existing wells and parameters

Wells	Year Drilled	Depth [m]	Temp [°C]	Flowrate [m^3/h]
B-107	1954	1,096.9	42	60
B-913	1967	2,002	65	20
K-271	1971	1,800	100	20
B-1077 pumped	1984	2,293	88	60
B-1090 pumped	1994	1,106	40	60
B-1092 pumped	1995	2,013.1	75	60
B-1093 pumped	1997	1,273.4	50	60
Déli pumped	2007	2,400	88	60
B-1094 I. injection	1998	1,685.5	-	-
B-1003 II. injection	2007	1,702	-	-

The first thermal well was drilled in 1954, but only to provide water for a therapeutic spa. In 1967, a hospital had another well drilled for both therapeutic and heating purposes. Since then, every well was drilled primarily for heating.

2,800 residences are currently heated with geothermal energy, totaling more than $10MW_t$ and producing 0.31PJ/year. This saves more than 5M m^3 of natural gas.

RECOVERABLE GEOTHERMAL WATER RESOURCE

Hódmezővásárhely has an area of 483 km^2, all of it above the multilayered sedimentary reservoir. The 1 km^2 unit seems most appropriate when using the total area as a multiplier to calculate the total amount of recoverable thermal water underneath.

The exploitable fluid volume by the elastic expansion of the water body is:

$$V_w = \phi V_{res} \beta (p_1 - p_2) \quad (1)$$

where

V_w = exploitable water volume [m^3],
ϕ = effective porosity of the reservoir [-],
V_{res} = volume of the reservoir [m^3],
β = isothermal volumetric expansion coefficient [m^2/N],
p_1 = initial pressure of the reservoir [N/m^2],
p_2 = final pressure at the end of the production [N/m^2].

The energy content of the recoverable thermal water over the energy level is related to the surface temperature. The exploitable energy per 1 km^2 unit is marked by E_1.

$$E_1 = V_w \rho_w (T_{wh} - T_s) \quad (2)$$

where

E_1 = exploitable energy [kJ],
ρ = the density of the water [kg/m^3],
T_{wh} = the wellhead temperature [°C],
T_s = the surface temperature [°C].

Since there is no energy production from the uppermost layer, a determination was made by examining only the capacity of the II. and the three

III. layers. Each of the four dominant layers was examined separately. Summarizing data from existing wells, the geothermal water production is $1.60\cdot10^6$ m^3/year. The injection is $352\cdot10^5$ m^3/year. It is obvious that drilling new wells can produce more geothermal water.

It is easy to calculate that the amount of the water use from the reservoir is $1.253\cdot10^6$ m^3/year. If the production is by submersible pump and the depression is 10 bar, the exploitable geothermal water per 1 km^2 unit area is $5.309\cdot10^6$ m^3/year. Given current water demands, this amount is enough for 4.24 years. Multiplying by 10 km^2 yields an estimate of 42.4 years, and multiplying by 20 km^2 yields 84.74 years.

It is important to avoid depleting the reservoir's reserves. Currently, all the geothermal water drawn out is injected into the same reservoir, a practice which can sustain the resource. Of course, if cooled thermal water is injected into the reservoir, the reservoir's temperature is lowered. If the temperature of the reservoir is decreased by ΔT, the exploitable energy from the unit 1 km^2 is:

$$E_2 = \delta\psi\left[\phi\rho_w c_w + (1-\phi)\rho_r c_r\right]\Delta T \qquad (3)$$

where

E_2 = exploitable energy [kJ],
δ = reservoir layer thickness [m],
ψ = rate of the sandy layer and the whole reservoir thickness [-],
ϕ = porosity [-],
ρ_w = water density [kg/m^3],
ρ_r = sandstone rock density 2,400 [kg/m^3],
c_w = heat capacity of the water 4,187 [J/kg ^oC],
c_r = heat capacity of the sandstone 870 [J/kg ^oC].

Table 3 summarizes the exploitable energy production, with submersible pump by 10 bar depression using the 1km ^{2} unit, without injection E_1, and with injection E_2 if the reservoir cooling is 10 ^oC.

Table 3: Exploitable geothermal energy per 1 km^2 unit of area

Layer	Temp [^oC]	V_w [m^3/km^2]	E_1 [TJ/km^2]	E_2 [TJ/km^2]	$\frac{E_2}{E_1}$
II.	48	$1.58\cdot10^6$	248	3,892	15.69
III./a	64	$1.35\cdot10^6$	299	3,140	10.50
III./b	79	$0.89\cdot10^6$	250	2,465	9.86
III./c	96	$1.49\cdot10^6$	514	3,860	9.51

We can easily see that the recoverable energy E_2 produced by injection is substantially greater than E_1 produced by elastic expansion of the water body from the same reservoir. Thus, the ratio of the investigated reservoir $\frac{E_2}{E_1}$ can be determined.

CONCLUSION

The main benefits of injection technology are the greater recovery factor and the sustained reservoir pressure. Salty water should be kept from intruding at the surface, but that is a relatively minor issue. Neither can we neglect the drilling and completion costs of the injection well, along with the performance costs of the injection pump. Still, it should be noted that these auxiliary costs are substantially lower than the value of the multiplied recovered energy.

SUMMARY

Hódmezővásárhely's geothermal heating system is the largest in Hungary, and plans exist to further develop the heating network, based on the proven existence of a huge geothermal reservoir extending throughout the city's subterranean region. Only eight production and two injection wells operate presently, but with increasing acceptance of the new injection technology's benefits, additional production and injection wells are surely on their way.

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