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POSSIBLE REDUCTION OF ENVIRONMENTAL IMPACTS OF GEOTHERMAL ENERGY EXTRACTION IN A THEORETICAL SPA

TAMÁS BUDAY[1]

[1]University of Debrecen, Department of Mineralogy and Geology, Debrecen, 4032, Egyetem tér 1.
E-mail: buday.tamas@science.unideb.hu

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Abstract

Sustainable thermal water production involves the protection of the used reservoirs, as well as the minimizing of the environmental impact (caused by heat, gas and dissolved solid). Four water extraction models are discussed in which the water and heat demand of the theoretical spa are supplied using different sources. The most environmental friendly variation contains three wells with different depths of screening. In this case the dissolved gas and solid content became the lowest, as well as the radius of influence based on drawdown calculations. Beyond the environmental impact the owner have to consider other economic aspects, such as the number of wells, the possibility of independence from gas services, which force the owner to choose not the most environment friendly way. Optimizing the various factors, thermal water extraction for medical and wellness purposes could be feasible and appropriate for sustainable operation.

Keywords: thermal water, energy content of extracted water, environmental impact, drawdown, GHG emission

1. Introduction

Intensive thermal water extraction could lead to pressure drop, temperature changes, porosity reduction and other significant processes in the porous aquifer (Bobok and Tóth, 2000, Szanyi and Kovács, 2010, Szűcs, 2012). Larger spas use numerous wells to provide the water demand for filling outdoor and indoor pools, units of medical treatment. Construction of thermal wells is expensive, consequently owners are willing to use the wells and the reservoirs for a long time.

Beside the subsurface impacts, the surface impacts are also important. Used thermal water should be managed; if it is drained to the sewage system the supplier quotes the price of wastewater treatment. Drainage to a surface recipient is more difficult (Szűcs et al., 2009), however, in some places this is the sole possibility. If the temperature of the fluids is higher than 30°C, the fluids have to be cooled down in natural or artificial lakes. The cooled water can be drained to rivers via irrigation canals only from autumn to spring since they are used for irrigation in summer. The costs of the draining process are paid by the owner. If any parameter exceeds the limit, the authority may penalize the emitter.

The aim of the paper is to point out that different technological solutions of thermal water production from a typical Hungarian geothermal reservoir (Kozák and Mikó, 2003) will lead to different environmental impacts. The owner should procure information about the opportunities to avoid over-production and uneconomic operation, moreover, to minimize the environmental impacts before the appropriate solution is chosen from the several heat and water extraction methods.

2. Methods

Based on real data, the water and heat demand of a theoretical spa with three pools is calculated. The indoor medical pool is 100 m^2 in area, while its depth is 1.0 m. The water temperature is 35°C, a fill-and-drain system is used, it is completely drained, cleaned and refilled each day and there is continuous filling in operation (medical water demand: 100 m^3/day for refilling and 350 m^3/day for continuous filling).

The outdoor thermal pool is similar to the medical pool (100 m^2 area, 1.0 m depth, 35 °C water temperature, fill-and-drain system) with the exception of water quality, since medical effect is not required. The outdoor swimming pool operates only in summer, it has an area of 100 m^2 and depth of 2.0 m, its water temperature is between 20 and 25°C. Its recirculation system requires only 10 m^3/day water supply. The spa could use the thermal water for heating and sanitary hot water (SHW) production, however, gas appliances are also used when the heat content of extracted water is not enough for ensuring the indoor heat demand, estimated to be 40 kW (heating, ventilation and air conditioning) and the temperature control of the outdoor pool in winter (0.2 MW). The required 200 m^3/day water discharge for SHW originates from the cold water well, the heat demand for the heating of which is 0.4 MW. Further 100 m^3/day of cold water is needed for other purposes.

The calculations detailed in the next paragraphs determined the origin of the heat and water, described the CO_2, CH_4, salt and heat emission of the spa in each model, subsequently the underground movement of waters was determined by PMWIN (Chiang, 2006). The main parameters (e.g. model geometry, hydraulic conductivity values, boundary conditions) were received from a subregional model of the Hajdúszoboszló–Debrecen area (Buday, 2011, Kozák et al., 2011, Bódi and Buday, 2012). The original grid distance was 200 m, which has been refined for 100 m and 50 m in the surroundings of the wells.

In the hydrogeological model three production wells are located near the spa (Table 1). Well-1 produces from the lower Pleistocene coarse sandy reservoir (3rd layer), well-2 produces from the Pliocene (or upper Pannonian) silty-sandy reservoir deposited in fluviolacustric-lacustric facies (5th layer), while well-3 produces from the delta front sediments deposited in the upper Pannonian (7th layer). The wells are located in one square formed by four grids.

Table 1. Main character of the wells and water production in the models

	well-1	well-2	well-3
type	cold water	warm water	medical water
depth of the aquifer (m)	160	600	1000
temperature (°C)	18	39	60
top–bottom of the layer below the surface (m)	114.2–182.1	484.1–691.4	976.6–1232.7
horizontal hydraulic conductivity (m/d)	7.1	1.7	2.7
dissolved solids (mg/dm^3)	500	1000	5000
dissolved CH_4 (m^3/m^3)	0.00	0.18	0.20
dissolved CO_2 (m^3/m^3)	0.00	0.20	0.30
water production (m^3/d)			
model-1	310	–	900
model-2	535	–	675
model-3	310	450	450
model-4	310	450	450

The studied reservoirs contain lenticular aquitard/aquiclude zones, sand bodies that have hydraulic connection (Tóth and Almási, 2001, Buday and Püspöki, 2011), consequently the water movement is modelled in the entire layer instead of the separate sand bodies. Both well-2 and -3 produce thermal water.

Model-1: The whole amount of thermal water is produced from well-3, during the cooling there is no energetic utilization of the thermal water, all of the heat demand is supplied using natural gas. The cold water is produced from well-1 (Table 1).

Model-2: The indoor pool receives the water from the medical water well, the water of the outdoor pool is mixed from the water of well-1 and well-3. Heating and SHW system receive the heat from well-1, in addition when it is necessary natural gas is used.

Model-3: The indoor pool receives the water from the medical water well, the water of the outdoor pool is extracted through well-2. Heating and SHW producing utilizes the heat from well-3 and the gas system, in addition cold water is extracted from well-1.

Model-4: All of the heat required for heating and SHW warming is extracted from the produced water, without gas appliances. In this case a re-injection well is necessary.

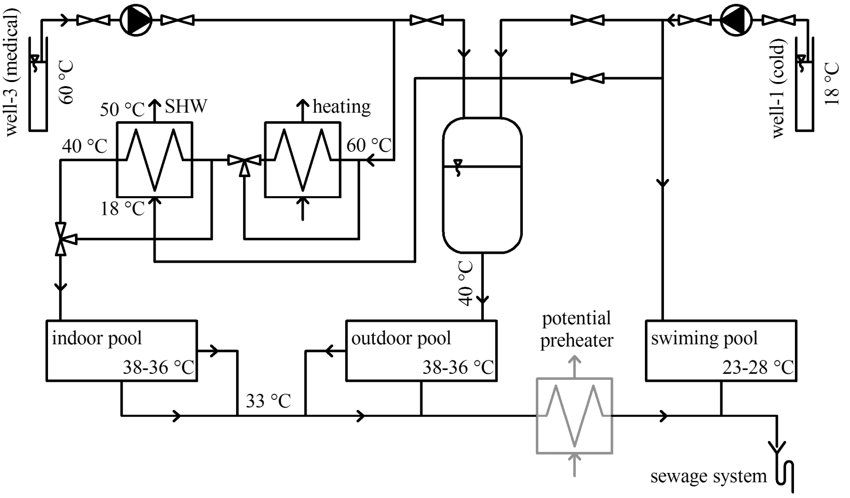

Fig. 1. Simplified scheme for model-2 (based on Halász and Barna, 2010)

3. Results

The heat content of the medical water with temperatures between 60°C to 40°C is determined to 0.88 MW in model-1, 0.66 MW in model-2, and 0.44 MW in model-3. This amount of heat is enough for warming up the SHW, therefore a well-designed building engineering system would be able to cover the heat demand. Consequently in the models, except model-1, the energy provided by the gas system might be excluded.

The steady state hydrodynamic models describe the permanent hydraulic head and drawdown. In the cold water reservoir the effects are less characteristic in model-1, -3 and -4 than in the other cases due to the relatively good transmissivity of the layer and the small yield (Fig. 2). The drawdown is more than 0.2 m inside a circle with a radius of 2 km around the well. In model-2 the amount of produced water from the cold water reservoir is higher, consequently more significant drawdown occurs than in the rest of the models.

The amount of water extracted from the medical water reservoir is larger than that from the other layers. In model-1 the radius of the area with drawdown greater than 0.2 m is approximately 8 km, in model-2 and -3 this value is lower. Well-2 is used only in model-3 and -4, the drawdown is also significant.

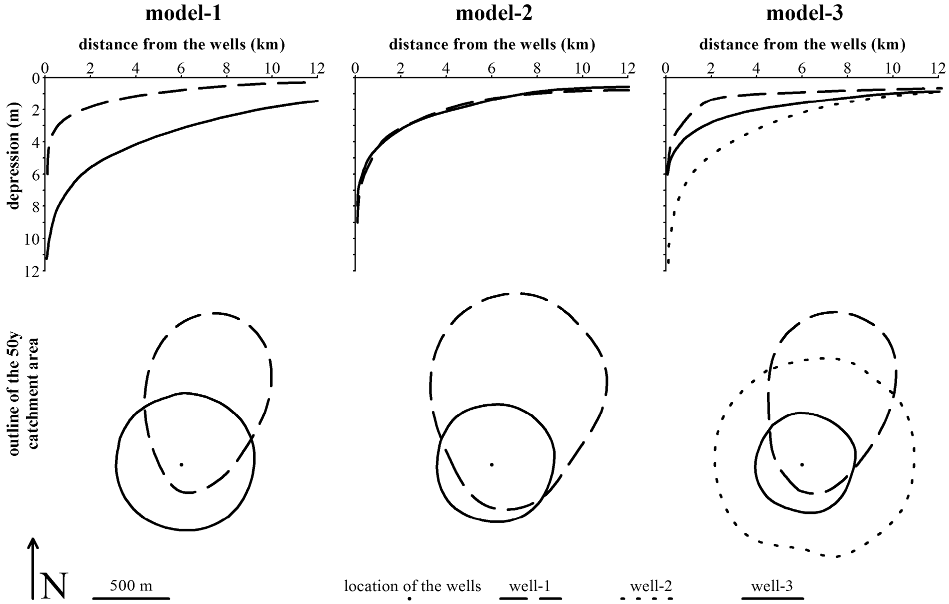

Fig. 2. Drawdown functions in the steady-state variations and estimated water protection zones around the wells of model-1 to -3

The particle tracking module (PMPATH) of the PMWIN determines the subsurface zone from which the particles will reach the well in 50 years. This time frame defines the hydrogeological "B" protection zone of the water base around the wells. Before the production the horizontal hydraulic gradient in the lower Pleistocene layer is high, consequently the direction of water movement after the production does not alter significantly. In the two lower layers the original water movement is slow with SW direction therefore the drawdown has a significant influence on the direction of water movement. The radii of protection zones are between 225 and 1500 m. The lower hydraulic conductivity and porosity values may cause significant drawdown and higher radius of protection zone in the reservoir of well-2. The environmental effects on medical water reservoir are reduced significantly as the amount of extracted water decreases.

Water produced from the deeper layer contains dissolved CO_2 and CH_4. In the surface facilities degassing occurred, in addition the CH_4 has to be combusted to avoid explosion. Depending on the dissolved gas content of the reservoirs the greenhouse gas (GHG) emissivity could be significant (Table 2), however, not so high as the GHG emissivity from model-1. Salt production is between 1000–1700 t/year in the discussed models, most part of the salt remains dissolved, and concentrations decrease by attenuation or fall-out. In some cases the used and contaminated thermal water is drained to the sewerage system, which could be the most environmental friendly treatment of the waste-water.

Scaling in the pipes and plate heat exchangers could be an important problem as well. It reduces the efficiency of the heat exchangers, however, raises the heat loss and pressure drop in the pipes (Kalmár, 2011, Csáki and Kalmár, 2011). The least amount of scale is formed in the pipes in model-3, since the water from well-2 flows through only pipes, in addition the least amount of water is produced from well-3 in the models. In all cases scale should be removed from the pipes and plate heat exchangers regularly.

Table 2
GHG and salt emission of the calculated models

model	CO_2 from heating (t/y)	dissolved gas from wells		CH_4 combustion		salt production (t/y)
		CO_2 (t/y)	CH_4 (t/y)	CO_2 (t/y)	heat (MW)	
model-1	740.86	174.93	42.46	116.62	0.071	1699.08
model-2	0.00	131.19	31.84	87.46	0.053	1329.51
model-3	0.00	145.77	40.33	110.79	0.067	1042.08
model-4	0.00	145.77	40.33	110.79	0.067	1042.08

4. Discussion

Each discussed system is appropriate to supply the water and heat demand in a spa. Model-1 is the least economic and has the greatest environmental impact. Numerous baths operate systems similar to that described in model-1 as the heritage of the last decades. Although the most moderate subsurface environmental impact appears in model-3, drilling a new well is not feasible in the case of most of the spas.

The energetic independency is presented in model-4 where only electricity is required for pumps. In this case the system does not require a gas system. To ensure the heat supply a heat exchanger or a heat pump is recommended to extract the heat of the waste pool water before it leaves the spa. These methods become more-and-more important in the modernization of spas (e.g. Fodor and Komlósi, 2012), since they could rise the extracted energy by 25–50 %, if the cold water is preheated in this way.

Higher energy demand forces the owner to drill a re-injection well. Its costs are similar to the costs of the production well, and its capacity is usually lower. The most part of the water flows through the pools, the re-injection of this amount of water is prohibited. According to the Hungarian law, re-injection of the remaining part is compulsory. This also implies that the energy extraction of post-pool phase and energetic modernization should be developed instead of water production only for energetic utilization.

The GHG emission of energy extraction from geothermal reservoirs can also be significant (Buday and Osváth, 2008). If regional regulation obligates the degassing and burning of CH_4, the energy of the combustion can be utilized for heating or for generating electricity that could also be used in the spa, and the negative environmental effects could decrease.

The drawdown and particle movement values depend strongly on the applied (adapted) geological model. It is also important to understand the stratigraphic aspect, the main water movement processes in a basin, and the slow filtration between the used aquifers (Szűcs, 2012, Bódi, 2012). This could give the basis of modern stratigraphic based modelling.

5. Conclusion

Possibilities of modernization in spas are growing due to the support of national and international tenders. The economic rationalization and the environmental impact reduction require similar projects that can assist to increase the role of renewable sources in primary energy production, decrease the import dependence of Hungary in the energy sector, in addition it could generate subregional economic growing.

The sustainable thermal water extraction requires avoiding the deterioration of reservoirs. It could happen by re-injection or multi-well, multi-layer production with taking the exact three dimensional geological model into consideration. The increasing computational capacity would support the determination of the main directions of water movement and the location of the recharge area, which is the base of the permission of water rights.

The energetic utilization of thermal water is not subsidized in Hungary; since the water use fee of medical water in the case of non-medical use is five times higher than that of in medical use, and the fee of energetic use is higher or energetic use is not allowed, in addition thermal water utilization has similar regulations. Despite this fact, the “pre-pool” and “post-pool” energetic utilization and the uniform distribution of wells could lead to optimal geothermal energy extraction in the thermal water based sector of it.

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