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Thermal impact assessment with hydrodynamics and transport modeling

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ABSTRACT

While the number of installed geothermal heat pump systems is rising legislation is not prepared to address the issues concerning thermal impact. The aim of this paper is to model the effects of geothermal heat pump systems installed to shallow geothermal reservoirs in sedimentary formation based on the results of a real system in order to show the magnitude of the thermal affected zone.

The system examined is a standalone geothermal heat pump with a production and an injection well-being able to produce a maximum of 3.4 m^3/h groundwater. The thermal impact determined by simulation was 35 m for the standalone system. Two scenarios were considered to define the impact of two neighboring open-loop systems on each other. The results show that if two systems are to be installed on the same reservoir the minimum distance should be 55 m. That indicates that in case of designing systems installed to similar hydrogeological environment should consider the change in the water table and increased thermally affected zone if other groundwater heat pumps are in the area.

1. Introduction

The use of low temperature geothermal energy is considered to be an environmental friendly technology utilizing renewable resources and most suitable for residential use. The renewable nature of geothermal resources is a function of scale [1]. The side-effects of such systems should also not be neglected. Such adverse effect can be the impact on ecosystem due to changes of temperature [2]. Change in flow patterns [3] might occur. In case of inappropriate planning temperature anomalies and thermal breakthrough [4] might be of risk.

A special geological feature of Hungary is the contiguous aquifer systems of the Pannonian Basin [5] due to the sedimentary nature of the geological formations as opposed to magmatic or metamorphic types. Surrounded by the Alpine, Carpathian and Dinaric mountain belts the runoff of groundwater and thus the mobilization of the pollutant are somewhat limited. Beside that the average thickness of the continental crust is 25–28 km while the geothermal gradient is extremely high (about 5–6 °C/100 m) [6] due to the thinning of the lithosphere. The latter characteristics are advantageous in case of medium- and high-enthalpy geothermal systems while the former makes the aquifers susceptible to pollution originating from for example of geothermal heat pump systems.

Open-loop ground water heat pumps carry the highest risk of all shallow geothermal systems. The water demand for the heating system is provided from a production well and the energetically used cooler water is discharged into water bodies or re-injected to the aquifer by a well or tile field. Beside the risk of polluting the groundwater the installation is likely to change the course of flow. In addition to the hydrodynamic effect, these systems have a thermal impact, too.

The increasing popularity of geothermal heat pump systems (GHPS) is clear [7]. As Rizz et al. [8] point out this trend is expected to continue therefore the need to define minimum distances for such systems is urging. A survey with 60 countries revealed that there are only a few countries that have implemented such restrictions for minimum distances and temperature action values [9]. These existing regulations show diversity in the defined minimum distances. Table 1 shows examples of minimum distances defined in different countries.

In Sweden and Finland several criteria are established concerning different objects that have to be taken into consideration. In other countries the distance is defined usually from the nearest building or property line. An exception is China where only the neighboring borehole is considered. Criteria for open-loop systems are determined only in the Czech Republic, Greece and Sweden.

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Nomenclature

GHPS	geothermal heat pump systems	D_m	molecular diffusivity (m^2/s)
GSHPS	ground source heat pump systems	α	dispersivity (m)
GWHPS	groundwater heat pump systems	v_a	seepage velocity (m/s)
TAZ	thermally affected zone	q_s	source or sink of fluid ($m^3/s/m^3$)
asl	above sea level	C_s	source/sink concentration (g/m^3)
SWL	static water level	ρ_m	density of the porous medium (g/m^3)
3D	three dimensional	c_m	specific heat capacity of the porous medium (J/g/°C)
ρ_b	dry bulk density of the solid material (g/m^3)	ρ_w	density of water (g/m^3)
K_d	distribution coefficient (m^3/g)	c_w	specific heat capacity of water (J/g/°C)
n	porosity (–)	T	temperature (°C)
C	concentration of the examined soluble compound (g/m^3)	λ_m	effective thermal conductivity of the porous media (W/m/°C)
t	time (s)	q_h	heat injection/extraction (W/m^3)

The distances vary from 2.5 m to 300 m; the latter is in Denmark and only if there is a drinking well in the area [9].

As regards the change in groundwater temperature, some countries have action values but these show great variability. For example, the numbers for relative temperature difference vary from 3 °C to 11 °C [10].

In Hungary geothermal systems are the subjects of legislation, installation and operation license is needed. In case of open-loop systems the water has to be injected into the same media according to the Act on Water Management (No. 57/1995). Despite of that currently the Hungarian legal system does not define a minimum distance to avoid detrimental environmental impact in either hydrodynamic or thermal aspect. From a practical point of view the sustainability of the system is an important aspect in the planning stage to which design guidelines exist [11] but the Hungarian Inspectorate of Environmental Protection does not take the fact of the thermal penetration into consideration when issuing a water license. Previous practice was to allow systems with a relative temperature difference of 4 °C but nowadays well-doublets operating with 5–6 °C difference were granted permission.

The regulations at present lack the scientific arguments to confirm the proposed limit values. As Hähnlein et al. [12] pointed out static regulations such as fixed and absolute temperature thresholds are not recommended due to the local differences in geology and hydrogeology. Because of the heterogeneous nature of groundwater the minimum distance to avoid hydrodynamic and/or thermal effects of a GHPS may be determined only based on extensive research. Measurement results of numerous systems have to be collected and calculations have to be made to find correlation between the influencing parameters such as the heating capacity and the water demand of the system and the characteristics of the ground water media.

Several studies on GHP systems are already available but the main concern is usually the efficiency of the system. One pointed out that in case of closed-loop ground source heat pump systems (GSHPS) the efficiency depends greatly on the spacing of heat exchangers in the ground [13]. Koohi-Fayegh and Rosen [14] in their work proved that the wall-temperature of one borehole affects the temperature of the neighboring boreholes. The changes in performance per unit length throughout the heating season [15] should also be considered. It was also proved the axial effects mainly depend on the groundwater velocity in the aquifer and the length of the borehole heat exchanger [16]. Considering open-loop groundwater heat pump systems (GWHPS) it was found that the condition of groundwater flow and the position of the wells play a great role in the performance in case of a single well-doublet [17]. Similar results were received in case of applying well groups [18]. Thermal breakthrough was also found to be a great risk of such systems [19]. In many cases optimization of such a system leads environmental benefits, too but it is important to address the environmental issues in themselves to mitigate the effects. A good example to that is the research of Lo Russo et al. [20] in which the thermally affected zone (TAZ) development was studied. The TAZ of an open loop system is highly influenced by the hydraulic conductivity and the gradient of the given area [21]. It was proven that the thermal anomaly developed around the injection well moved downstream even after deactivation of the system [20].

2. Methods and materials

The purpose of the work presented in this paper is to model the effects of a ground water heat pump system installed to shallow geothermal reservoirs based on measurement results. The model territory is located in a suburban area with newly build detached houses. The two-story building with an energy performance certificate in band A has a net floor space of 126 m^2 but only the first

Table 1
Examples of minimum distances based on the collection of Hähnlein et al. [9].

Country	Minimum distance (m)	Object from where the distance should be kept	Open/closed systems	Legal status
Austria	2.5	Property line	Closed	Recommended
Czech Republic	5	Property line	Open/closed	Legally binding
Finland	30	Wastewater	Closed	Recommended
	20	Dug or energy well	Closed	Recommended
	3	Next building	Closed	Recommended
Sweden	10	Property line	Open/closed	Recommended
	20	Next installation	Open/closed	Recommended
	30	Drinking water well	Open/closed	Recommended
Greece	5	Building	Open	Legally binding
China	3–6	Next borehole	closed	Recommended