# EFFECT OF GROUNDWATER FLOW ON A GROUND HEAT EXCHANGER

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Summary Multiple layer underground and the flow of ground water in some layers have an important effect on the heating of vertical heat columns and heat exchangers (HE). This paper investigates the important implication on the design of the Ground HE with regard to their heating effect. For this reason a thermal model is constructed in Comsol Multiphysics software and the effect of various parameters such as thermal conductivity of the ground and the groundwater flow velocity is considered. The model parameters are set to present actual (known) parameters of an installed column and validated against experimental values. Although the key for an overall capital cost reduction is the borehole length, the results indicate that by using the groundwater available, construction of shallow Ground Source Heat Pump systems can be achieved with an increase of the coefficient of performance (COP).

## INTRODUCTION

Ground Source Heat Pump (GSHP) systems constitute an evolving technology that has been given significant attention in recent years. GSHP systems have higher energy efficiency and lower environmental impact than regular ones [1]. Geothermal energy, although developed for many years, has not reached a stable and popular state to be widely used. This is due to the high manufacturing and installation cost of Ground Heat Exchangers (GHE) compared to similar, albeit not so effective systems. The capital cost of an air-to-air heat exchanger Heat Pump system is lower than that of a GSHP one, but the operation cost is higher compared to the GSHP system. Only recently the GSHP systems have gained more recognition due to energy shortage uses. It is noted that GSHP installations have increased dramatically in recent years (after 2010) with a rate of 10–30% annually [2].

The closed loop system, either vertical or horizontal, is the most common of the configurations. Pipes can be buried by drilling either vertical boreholes or horizontal trenches. Alternatively, if the building has access to an aquifer, pipes can run all the way down to utilize this natural underground water source. The effect of an aquifer with groundwater flow is examined in this paper through the use of the computational modeling. The model was constructed using the COMSOL v.5.1, which is a computational modeling software package allowing the use of general equations, but also adding and editing equations manually.

## MATHEMATICAL MODEL

The three dimensional conservation of the transient heat equation for an incompressible fluid used is given as

$$\rho c_p \frac{\partial T}{\partial t} + \rho_w c_{pw} u \nabla T + \nabla \cdot \mathbf{q} = Q, \qquad (1)$$

where $T$ is the temperature, $t$ is time, $\rho$ is the density of the borehole/soil material, $c_p$ is the specific heat capacity of the borehole/soil material at constant pressure, $\rho_w$ is the density of the ground water, $c_{pw}$ is the specific heat capacity of the ground water at constant pressure, $u$ is the velocity of the groundwater (seepage velocity is being used), $Q$ is the heat source and $q$ is given by the Fourier's law of heat conduction that describes the relationship between the heat flux vector field and the temperature gradient.

## COMPUTATIONAL MODELING

The geometry includes five layers of ground with different thickness and thermal properties. Two cylinders represent the boreholes with a total depth of 100 m and a distance between them of 10 m. The geometry and the properties of the ground can be found in Florides et al. [3]. The multilayer ground was constructed with different material properties in order to achieve realistic results and the general model was scaled down on the $z$-axis. The groundwater velocity was set using the seepage velocity, where the hydraulic conductivity minimum and maximum values were taken from typical data presented in Domenico and Schwartz [4]. The boreholes were set as a heat source with an overall $Q = -40$ W m$^{-1}$. For presenting a nearly realistic model a pulse function was also applied, by equating the heat source term to 1 (on) for 12 hours and to zero (off) for the next 12 hours, for 7 consecutive days.

## RESULTS AND DISCUSSION

By analyzing the borehole results at different regions (Figure 1), it is observed that the temperature decreases with time except in the region of the groundwater flow. This is due to the fact that heat is carried away from the borehole section

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where groundwater is present, while in the other sections heat is accumulated and maintained in the region. In addition, 7 lower peak points are noticeable due to the pulse function applied. The temperature reaches its lower peak point each day in the middle of the day after the 12 hours of continuous heat injection.

By plotting only the minimum temperature points in each borehole (Figure 2), it can be observed that by increasing the groundwater velocity the average surface temperature on the groundwater region increases. The results show that where the minimum hydraulic conductivity is applied (lower seepage velocity) there is not enough groundwater velocity to cool down the boreholes, whereas in the maximum hydraulic conductivity regime the boreholes response with lower average temperature and, in addition, they are reaching steady state in a shorter time. It is also noticeable that in the case of the first borehole, the average temperature reaches a steady state from the first day peak point, whereas on the second borehole (on the downstream) there is an increase in temperature before it reaches steady state again. Further on the heat carried away from the first borehole interferes with the second borehole (on the downstream) when the groundwater velocity is high enough, like in the case of the maximum seepage velocity (vS = $10^{-5}$ m $s^{-1}$).

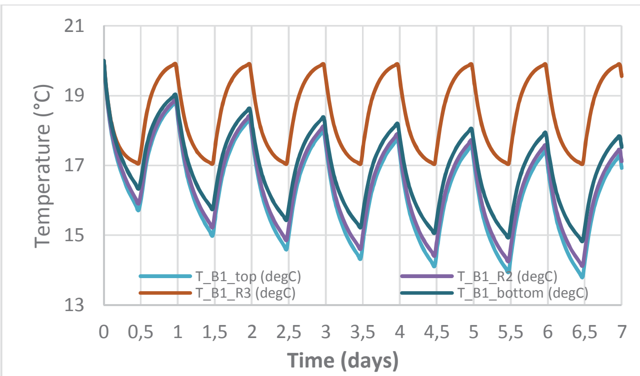


Figure 1. Temperature profiles versus time on the first borehole (B1) for a seepage velocity of vS = $10^{-5}$ m $s^{-1}$.

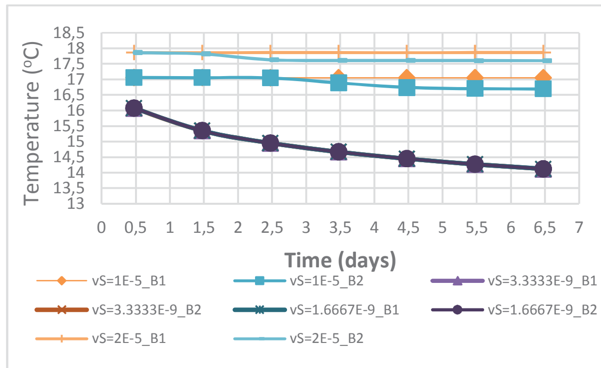


Figure 2. Average Temperature peak points versus time in the region of water flow for various values of seepage velocity (vS).

## CONCLUSIONS

In this paper the effect of the groundwater flow on a GHE in heating mode is examined using the Comsol computational modeling. The average borehole surface temperature on every ground layer was calculated with lower and higher seepage velocities. The results indicate that groundwater flow has an effect on the temperature of the ground water flow region. It is also noticeable that in this region steady state is reached much sooner than in the other regions. Additionally, the two boreholes interfere with each other when the groundwater flow velocity is high influencing the downstream borehole temperature.

**References**


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