Modeling of Geothermal Heat Exchangers

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ABSTRACT

Heat pumps (HP) attain higher efficiencies and save energy when they are coupled to ground heat exchangers (GHEs). For this reason we compare, by modeling, the efficiency of the vertical and horizontal GHEs which are two basic types. The modeling of the vertical heat exchanger is represented by two tube lines of 100 m in length, embedded in four different types of ground with an additional bottom base. The horizontal heat exchanger consists of four tube lines, 50 m in length each, embedded in three ground layers. The simulation results of the vertical GHE are validated by comparison to a measured set of data showing very good agreement. Further simulations with the vertical GHE show, as expected, that when the initial ground temperature rises the mean temperature of the heat exchanger fluid increases as well in a linear relationship. For a 50-hour continuous operation, the inlet and outlet fluid temperatures are computed for certain ground temperatures. Comparisons between the horizontal and vertical GHEs reveal that under the same operating conditions and center-to-center distances of the tubes, the vertical heat exchanger keeps a much lower mean temperature because the initial ground temperature at the buried tube depth is always higher than that of the vertical GHE. Because of this observation one would assume that the vertical GHE is more efficient than the horizontal. Instead, in a proper design, one could increase the distance between the tube centres and in this way decrease the mean temperature of the tube fluid. Simulations, for a 50-hour continuous operation and 24°C initial ground temperature, show that the mean fluid temperature can stay below that of the vertical GHE if the center-to-center distance of the tubes increases to 1 m.

KEY WORDS: Earth heat exchangers, ground thermal properties, modeling, convection-diffusion equation.

INTRODUCTION

Ground can be used in energy systems both for energy storage and as an energy sink. In order to efficiently use the ground in this kind of systems its thermal properties and characteristics should be known. Many studies over the last decades have shown that the ground can be separated into three layers according to the variation of the ground temperature. At surface (depth of 1–5 m) the ground temperature is affected both by diurnal and seasonal variations. As the depth increases (between 5–20 m) the ground temperature is only affected by seasonal variation and at deeper layers (over 20 m) it remains constant throughout the year. The ground temperature at the deeper layers is most commonly higher than that of the ambient air during winter months and lower during summer months (Michalakakou et al., 1994; Hepbasli et al., 2003).

Thus, in order to exploit the thermal capacity of the ground special devices, the so called Ground Heat Exchangers (GHEs), are implemented. Due to the temperature difference between the ground and the ambient air, GHEs are using the ground as an energy sink during cooling mode operation and for energy storage during heating mode operation. For the efficient transfer of heat to or from the ground several heat transfer mediums, such as air, water or water and antifreeze mixture are used. GHEs usually consist of one or more arrays of pipes installed into the ground horizontally or vertically. The horizontal GHEs are characterized by the fact that they require a large area of land in order to be applied. As a result in applications where the land area is confined, the aforementioned type of GHEs cannot be used and the only option is to use the vertical GHEs or borehole heat exchangers. The vertical GHEs, not only have the advantage of being able to be applied in applications with confined areas, but also because they make use of the ground temperature of deeper layers which, as mentioned above, remains constant through all seasons. In vertical GHEs the pipes installed are usually made of polyethylene or polypropylene, while the remaining space in the hole is filled (grouted) with a pumpable material such as bentonite (Sanner, 2001). GHEs are mainly used as part of a central air conditioning system, for domestic water heating and also for the improvement of the efficiency of a heat pump (Pouloupatis et al., 2008).

Geothermal Heat Pumps (GHPs) or Ground Coupled Heat Pumps (GCHPs) are systems where a GHE is combined with a heat pump in order to improve the efficiency of the latter. These systems are divided into ground coupled system (closed loop) and groundwater system (open loop). The suitability of each type depends on several site parameters, such as the thermal characteristics of the ground, the available land area, the ground water availability, and temperature (Lund et al., 2004).

During the last years many studies have been carried out concerning the use of high efficiency GHPs in domestic applications. Some of the main issues investigated are the theoretical and experimental evaluation of different strategies on load adjustment of GHPs (Zhao et al., 2003; Lee, 2010; Pardo et al., 2011; Boait et al., 2010), the use of several environmental-friendly substances as heat transfer mediums (refrigerants) (Stene, 2005; Zhang et al., 2010), and the experimental evaluation of GHPs under specific climate conditions (Inalli and Esen, 2000).