Evaluation of Heat Exchange Rate for Different Types of Ground Heat Exchangers

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ABSTRACT
This paper presents experimental results on the evaluation of thermal performance of U, W, 2U and coil type ground heat exchangers (GHEs). These GHEs were installed partially saturated landfill ground which was composed of silt and clay in the runway area of Incheon International airport. Thermal performance tests (TPTs) were conducted for 100 hours under the continuous operation condition. Heat exchange rates of individual GHEs are evaluated from TPT results, and the optimized GHE was suggested based on the thermal performance and construction cost as well, especially in the vertical ground source heat pump system (GSHP).

KEY WORDS:  Ground Heat Exchanger; Thermal Performance Test; Heat Exchange Rate; Installation Cost

NOMENCLATURE

\[ A \] area \((m^2)\)
\[ c \] specific heat capacity \((J \text{ kg}^{-1} \text{ K}^{-1})\)
\[ L \] borehole length \((m)\)
\[ m \] flow rate \((\text{kg} \text{s}^{-1})\)
\[ Q \] heat rate \((W)\)
\[ q_i \] heat rate per length of borehole \((W \text{ m}^{-1})\)
\[ R \] thermal resistance \((m \text{ K} W^{-1})\)
\[ r \] radius \((m)\)
\[ T \] temperature \((K)\)
\[ t \] time \((s)\)

Greek letters
\[ \alpha \] thermal diffusivity \((m^2 \text{s}^{-1})\)
\[ \lambda \] thermal conductivity \((W \text{ m}^{-1} \text{ K}^{-1})\)
\[ \rho \] density \((\text{kg} \text{ m}^{-3})\)
\[ \gamma \] Euler constant \((0.5772)\)

Subscripts
\[ b \] borehole
\[ f \] fluid
\[ g \] ground
\[ i \] fluid inlet
\[ o \] fluid outlet
\[ p \] pipe

INTRODUCTION

Because of its economic benefit and environment-friendly advantages, ground source heat pump (GSHP) system has been used these days. It is known that GSHP system is one of the most efficient systems for cooling and heating of buildings. Geothermal energy is often called ubiquitous energy because it can be used at any time at anywhere. Geothermal energy can be used through the GHEs for exchanging heat with the ground. With geothermal cooling/heating systems, heat energy is fed into and withdrawn from the ground via GHEs. Generally, U or W type ground heat exchangers (GHEs) are used to exchange heat with the ground in the vertical GSHP system.

However, conventional vertical GSHP system leads to high initial cost for drilling. As an alternative, many researches have been done to enhance the thermal efficiency. Heat transfer through the GHE can be affected by many factors such as grout thermal properties, GHE configuration, GHE type, pipe properties, and so on (Cui et al, 2011; Jun et al, 2009; Park et al, 2012). Recently, a coil shaped GHE is being used to ensure better efficiency of heat exchange rate, especially in the energy pile system.

This research presents experimental results of thermal performance using U, W, 2U and coil type GHEs. GHEs were installed partially saturated landfill ground which is composed of silt, clay, weathered granite soil and rock in the runway area of Incheon International airport. TPTs were conducted for 100 hours continuously, and heat exchange rates were analyzed for different kinds of GHEs. Besides, this paper suggested an optimal GHE considering the initial construction cost based on the experimental results.

HEAT TRANSFER MECHANISM

In the GHEs system, heat is extracted from or released to the surrounding ground through the fluid circulating in a GHE embedded in the borehole. The heat transfer mechanism of a GHE is quite complex and conjugated because of the various heat transfer mechanisms involved inside and outside GHEs. Soil is a multiple phase system involving complex heat transfer mechanisms, but heat transfer in soils occurs mainly by conduction (Brandl, 2006).

According to Fourier’s law, the heat flux through an arbitrary area during time \(t\), that is, the heat flux density can be written as