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Suggestion of a Load Sharing Ratio for the Design of Spiral Coil-type Horizontal Ground Heat Exchangers

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Abstract

As a primary component of the horizontal ground heat source pump (GSHP) system, spiral coil-type horizontal ground heat exchangers (HGHEs) have been widely used because of their superior heat transfer performance. To evaluate the ground temperature rise, many analytical solutions for spiral coil-type horizontal ground heat exchangers have been proposed. This study suggests a load sharing ratio, which is essential to consider the presence of an outlet pipe in the analytical solution to achieve more accurate prediction of ground temperature rise. This ratio enables the determination of the spiral coil heat exchange rate. Thus, a three-dimensional numerical model of the spiral coil-type ground heat exchanger was developed. Then, the effects of the factors influencing the load sharing ratio were investigated through a parametric study. Finally, the linear regression method was used to develop a load sharing ratio model. The load sharing ratio model may provide a more accurate prediction of ground temperature rise and help us design spiral coil-type HGHEs reliably.

Keywords: horizontal ground heat exchanger; Green's function; load sharing ratio

1. Introduction

As one source of renewable energy, ground source heat pumps (GSHP) systems have utilized geothermal energy for space heating and cooling for several decades. The ground source heat pump (GSHP) systems generally are divided into three components: the ground heat exchanger, heat pump unit and heat distribution system. The ground heat exchanger enables heat release to or absorption from the ground. Depending on the shape of the ground heat exchanger, various types of ground heat exchangers, such as straight line, slinky, spiral coil, etc., are widely used in the horizontal ground source heat pump systems. A number of research were conducted using numerical and experimental studies to investigate the heat transfer mechanisms for these heat exchangers [1, 2], and it was found that the spiral coil-type demonstrates higher heat transfer performance than the other types.

Recently, Wang et al. [3] have suggested a new analytical solution for the spiral coil-type horizontal ground heat exchanger (HGHE), with a similar concept proposed by Cui et al. [4], which simplified the spiral coil shape into

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several rings. Jeon et al. [5] also suggested a new analytical solution for a spiral coil-type HGHE, which enables the capture of the real geometry of spiral coil by modifying the analytical solution for a spiral coil-type vertical ground heat exchanger (VGHE) proposed by Park et al. [6]. However, the outlet pipe was not considered in these studies, and therefore, it is difficult to accurately predict the ground temperature rise. Accordingly, an investigation of the heat exchanger rate for the spiral coil should be performed to consider the outlet pipe.

This paper aims to provide a load sharing ratio that enables the determination of the spiral coil heat exchange rate. Based on a parametric study, the effects of the factors influencing the load sharing ratio were investigated. Consequently, a load sharing ratio model was proposed using the linear regression analysis.

Nomenclature

C_p	specific heat ($J / kg \cdot K$)
ρ	density (kg / m^3)
k	thermal conductivity ($W / m \cdot K$)
k_{wall}	thermal conductivity of the pipe wall ($W / m \cdot K$)
u	velocity field ($m / \sec$)
p	fluid pressure (Pa)
d_h	mean hydraulic diameter (m)
e	surface roughness (m)
F	volume force term
Q	general heat source
Q_{wall}	external heat exchange through the pipe wall
Re	Reynolds number
Pr	Prandtl number
e_t	unit tangent vector to the pipe axis
f_D	Darcy friction factor
h_{int}	heat transfer coefficient on the inside of pipe
p_c	pitch size of spiral coil (m)
r_c	radius of spiral coil (m)

2. Determination of the load sharing ratio

2.1. Numerical modelling

A commercial finite element code COMSOL Multiphysics was employed to construct the numerical modelling of heat transfer for the spiral coil-type horizontal ground heat exchanger. The generalized governing equations for a solid medium and an incompressible fluid flowing in a pipe are described as follows [7, 8]:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u \cdot \nabla T + \nabla \cdot q = Q \tag{1}$$

$$\frac{\partial A \rho_f}{\partial t} + \nabla_t \cdot \left(A \rho_t u e_t \right) = 0 \tag{2}$$

$$\rho_f \frac{\partial u}{\partial t} = -\nabla_t p \cdot e_t - \frac{1}{2} f_D \frac{\rho_f}{d_h} |u| u + F \cdot e_t \tag{3}$$

$$\rho_f A C_p \frac{\partial T}{\partial t} + \rho_f A C_p u e_t \cdot \nabla_t T = \nabla_t \cdot \left(A k \nabla_t T \right) + \frac{1}{2} f_D \frac{\rho_f A}{d_h} |u| u^2 + Q + Q_{wall} \tag{4}$$

To calculate the external heat exchange through the pipe wall, the Darcy friction factor and Nusselt number were obtained using the empirical equations proposed by Churchill [9] and Gnielinski [10], respectively.