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Inner heat source model with heat and moisture transfer in soil around the underground heat exchanger

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Abstract

This paper presents an inner heat source model of underground heat exchanger based on the heat and mass transfer theory in soil. A number of factors such as moisture movement in soil, soil type, and soil property were taken into account in the model. The underground heat exchanger was simplified as the equivalent inner heat source term in the model. The software of Autough2 was used to conduct the numerical simulations. And the paper presents the analyses on the influences of different soil properties and different operation modes on the underground temperature field around the single U-vertical underground heat exchanger.

Keywords: Inner heat source; Heat and moisture transfer; Soil property; Underground heat exchanger; Underground temperature field

1. Introduction

In recent years, many works have been devoted to the research on ground-coupled heat pump (GCHP). The efforts have been largely focused on the interrelation between the underground heat exchangers and the surrounded soil. Since 1970s, the heat transfer of underground heat exchanger

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Nomenclature

C	volumetric specific heat (kJ/m^3 K)
c	specific heat (kJ/kg K)
D_θ	isothermal diffusivity (m^2/s)
D_T	thermal diffusivity (m^2/s)
D_{va}	molecular diffusivity of vapor–air
h	enthalpy (kJ/kg)
h_{lv}	latent heat of water (kJ/kg)
$\vec{j}$	mass flux, a vector (kg/s m^2)
q_v	inner heat source (W/m^3)
R_v	gas constant (kJ/kg K)
T	ground temperature (°C)
t	time (s)

Greek symbols

ρ	density (kg/m^3)
λ	thermal conductivity (W/m K)
μ	dynamic viscosity (kg/m s)
ε	porosity
ε_{sat}	saturated permeability of soil (m^2)
ε_{rl}	liquid relative permeability
θ	volumetric moisture content (m^3/m^3)
ϕ	relative humidity
ψ_m	soil moisture potential (kJ/kg)

Subscripts

a	air
l	refers to liquid
s	soil solid
v	refers to vapor
sat	saturated vapor
surf	surface
w	water (liquid + vapor)

has been researched extensively in Europe, America, etc., and the achievements can be found in the papers of Bose and Parker [1], Metz [2] and Mei [3].

There exist different types of soil, such as Sand, Clay, and Rock. They have different properties, and in turn have different effects on the performance of underground heat exchanger. Moreover, moisture movement induced convection heat transfer is also a factor to be taken into account [4–6]. Some of the works about the transient heat and mass transfer in soil focused on a monotonic increase in the soil temperature due to the presence of a heated source [7–9].