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Research Paper

Coupling short-term (B2G model) and long-term (g-function) models for ground source heat exchanger simulation in TRNSYS. Application in a real installation

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HIGHLIGHTS

- A novel dynamic borehole heat exchanger model is presented.
- The B2G dynamic model is coupled to the g-function steady state model.
- The complete GSHE model has been programmed in TRNSYS.
- Model performance has been validated against experimental data.

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ABSTRACT

Ground-source heat pump (GSHP) systems represent one of the most promising techniques for heating and cooling in buildings. These systems use the ground as a heat source/sink, allowing a better efficiency thanks to the low variations of the ground temperature along the seasons. The ground-source heat exchanger (GSHE) then becomes a key component for optimizing the overall performance of the system. Moreover, the short-term response related to the dynamic behaviour of the GSHE is a crucial aspect, especially from a regulation criteria perspective in on/off controlled GSHP systems. In this context, a novel numerical GSHE model has been developed at the *Instituto de Ingeniería Energética, Universitat Politècnica de València*. Based on the decoupling of the short-term and the long-term response of the GSHE, the novel model allows the use of faster and more precise models on both sides. In particular, the short-term model considered is the B2G model, developed and validated in previous research works conducted at the *Instituto de Ingeniería Energética*. For the long-term, the g-function model was selected, since it is a previously validated and widely used model, and presents some interesting features that are useful for its combination with the B2G model. The aim of the present paper is to describe the procedure of combining these two models in order to obtain a unique complete GSHE model for both short- and long-term simulation. The resulting model is then validated against experimental data from a real GSHP installation.

1. Introduction

Among the currently available options for heating and cooling systems, ground source heat pump (GSHP) systems are one of the most efficient and comfortable [1]. The main advantage of these systems consists of using the ground as a heat source/sink, depending on the operating mode, which provides a more stable temperature than air. Therefore, GSHP systems present a higher efficiency than the conventional air-to-water heat pump systems [2].

The heat exchange with the ground takes place in the ground source heat exchanger (GSHE), usually by means of a certain number of borehole heat exchangers (BHE) that are drilled in the ground. So, the GSHE becomes a key component of the system, and the focus of many research works aims at improving the system's energy performance [3,4].

In this context, an accurate model of the GSHE can be very useful in order to study the different configurations for this compo-

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Nomenclature

α	thermal diffusivity (m^2/s)
B	borehole spacing (m)
BHE	borehole heat exchanger
c	volumetric thermal capacity (J/m^3 K)
C	thermal capacitance (J/K)
D	diameter (m)
g	g-function (–)
GSHE	ground source heat exchanger
GSHP	ground source heat pump
H	active borehole length (m)
I	inactive upper part of the borehole (m)
k	conductivity (W/m K)
k_a	aggregation factor (–)
L	total borehole length (m)
$\dot{m}$	mass flow rate (kg/h)
m_a	aggregation margin (–)
n	number of nodes (–)
$\dot{q}$	thermal load (W/m)
r	radius (m)
R	thermal resistance (K/W)
R_{BHE}	borehole thermal resistance (m K/W)
R_{12}	fluid to fluid thermal resistance (m K/W)
t	time (s)
t_s	characteristic time (s)
T	temperature (°C)
v	velocity (m/s)
W	shank spacing (m)
Z	borehole depth coordinate (m)

Subscripts

1	downward pipe zone
2	upward pipe zone
b	borehole
bb	borehole node to borehole node
bw	borehole wall
eq	equivalent
f	fluid
g	ground
gp	ground penetration
in	inlet
p	pipe
pp	pipe node to pipe node
out	outlet
x	borehole node position

nent and how it affects the global thermal efficiency. There are several approaches that can be considered when modelling a GSHE. An accurate review of the different models currently available is presented in [5]. Among them, the ones discussed in the following will be focused on one of the most common BHE configurations: vertical boreholes with U tubes.

Many of the most widespread GSHE models are mainly focused on modelling the behaviour of the ground surrounding the boreholes for long-term time scales. The g-function model, proposed by Eskilson [6], is one of the most widely used. This model is based on the use of non-dimensional temperature response functions (g-functions) representing the evolution of the temperature at the BHE wall for a constant heat injection pulse. In [7], the original g-functions are extended to shorter time steps of one hour. This model has been used both in simulation and design software such as GLHEPRO [8] and EED [9]. Along the years, the g-function model has been continuously improved in different ways (e.g., [10,11]). In order to take into account the transient behaviour, Beier [12] developed an analytical model by coupling transient heat conduction equations for both grout and ground with the energy equations for the circulating fluid in each pipe. The transient solution, obtained by means of Laplace transform, gives an estimation of the ground thermal conductivity and borehole resistance with a reasonable accuracy.

Another of the most commonly used approaches for BHE modelling corresponds to the thermal network models. In this kind of models, the borehole and its surrounding are represented by a series of temperature nodes, connected by thermal resistances. It is possible to include the thermal inertia of the materials in the model by means of thermal capacitances connected to the temperature nodes. The standard delta network (Fig. 1, [13]) has been successively improved, usually adding more nodes to the network, as in [14–16] or depending on the borehole geometries [17]. With the thermal network model, it is possible to obtain a high accuracy on the simulation of the BHE behaviour, but it usually requires a high number of nodes in order to correctly represent the ground and the interaction between boreholes. This results in an increase in the number of differential equations to solve, which leads to a higher computational cost.

Finally, the finite elements model (FEM) is one of the most detailed models currently available [18–23]. This model uses a very fine discretization of the BHE, which produces the most accurate results, although having a very high computational cost. FEM models are usually used as a reference for validation of simpler models able to provide faster simulations, even if they are not so accurate.

Other numerical models have been developed in the recent years, adopting different approaches [24–27]. Usually, they can only be used for long-term calculations. However, the dynamic behaviour of the BHE in the short-term response can be a relevant issue, since the GSHEs are usually integrated in other systems (such as GSHP systems), where the short-term control algorithms have a high influence in the performance of the whole system.

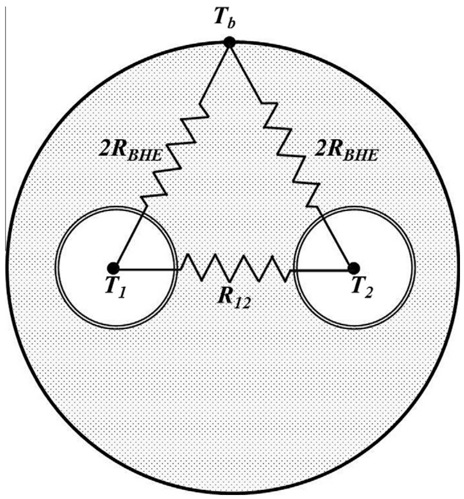

Fig. 1. Standard steady state delta network [13].