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Geothermal helical heat exchangers: Comparison and use of two-dimensional axisymmetric models

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HIGHLIGHTS

- A thermal model is given for the subsoil.
- 2D axisymmetric models of helical geothermal heat exchangers are compared.
- The necessity of taking into account the earth freezing is shown.
- A comparison between the model and experimental results is done.

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ABSTRACT

This study concerns near-surface geothermic heat pumps applied to the heating or the cooling of buildings, and more especially the modeling of new helical heat exchangers buried in the subsoil between 1 and 4 m depth. Two 2D axisymmetric models are considered for the exchangers: a horizontal rings model and an annular cylindrical conduit model. The models are described, and successfully compared with literature results applied to ground thermal energy storage. The 2 models give comparable results. The simulations run significantly faster when modeling the exchanger as an annular cylindrical conduit. The ability of the thermal model of the subsoil to simulate the earth freezing is validated by comparison to experimental results. The influence of the liquid fraction included into the ground on the thermal response of the geothermic heat pumps is analyzed. It has a significant impact on the return temperature from the geothermal heat exchangers because of the phase change phenomena and the increase of the conductivity due to the soil freezing.

1. Introduction

Several geothermal heat exchangers can be used for “low-enthalpy geothermal energy” installations. The most common are BHEs (borehole heat exchangers), pipes descending underground to a depth of 100 m: their performance is quite steady over a year, and they require little floor space [1]. The installation costs, in particular the vertical borefields, can slow their development. Moreover, such systems can create a thermal unload of the underground after several years. The average temperature in the underground can decrease by 2 K over 10 years [2], even when there is no interaction between exchangers.

An alternative method considered as “vertical” too are the pile geothermal heat exchangers, as presented in Ref. [3]. They are easy to include into the foundations of the buildings when piles are needed for mechanical reasons, so that the installation costs are reduced. Some countries like France are reticent about their use because of uncertainties on the ageing of mechanical piles having a thermal use, whereas they are quite widespread in other countries like Swiss.

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Nomenclature

Latin letters

a	thermal diffusivity (m^2 s^{-1})
c_p	specific heat (J kg^{-1} K^{-1})
E	thermal effusivity (J K^{-1} m^{-2} $s^{-1/2}$)
Fo	Fourier number (−)
H	height of the exchanger (m)
h	convective heat transfer (W m^{-2} K^{-1})
L	specific latent heat (J kg^{-1})
Nu	Nusselt number (−)
q_v	volumetric flow rate (m^3 s^{-1})
R	radius of the exchanger (m)
Re	Reynolds number (−)
R_{th}	thermal resistance (K/W)
r	radius (m)
T	temperature (K)
t	date (s)
z	depth (m)

Greek letters

α	first auxiliary coefficient (−)
β	second auxiliary coefficient (−)
ε	emissivity of the ground (−)
η	ratio of water at liquid state (−)
κ	volume fraction of water in the underground (−)
λ	thermal conductivity (W m^{-1} K^{-1})
ρ	mass density
σ	Stefan–Boltzmann constant (W m^{-2} K^{-4})
Φ	heat flux (W)
φ	heat flux density (W/m^2)
ω	annual pulse (rad/s)

Letters with special subscripts

h_{tot}	convective and radiative heat transfer (W m^{-2} K^{-1})
L_{tot}	helical length of the exchanger (m)
r_e	external radius of the pipe (m)
r_i	internal radius of the pipe (m)
T_{amp}	yearly amplitude of the ground-level temperature (K)
T_{ext}	ambient air temperature (K)
T_{mean}	mean ground temperature (K)
t_c	coldest day (s)

Subscripts

f	heat transfer fluid
flow	flow
ice	solid water
in	inlet
liq.wat	liquid water
low	lower part
mat	“Dry matrix” of the underground
mix	multi states
out	outlet
pipe	wall of the pipe
ring	ring (annular model)

Accentuation

$\tilde{}$	Undisturbed by the exchanger

Geothermal horizontal loops are buried pipes installed horizontally at a depth of around 1 m, covering a large area. In France, the number of such installations has increased over the last few years. The installation requires few specific tools so that it is not expansive: but it needs a large available area (typically between once and twice the heated area, [4]). These exchangers are sensitive to the outside temperature, and poor sizing can impact vegetation. Moreover, plants with deep roots have to be avoided since they may damage the exchanger.

Another kind of exchanger exists whose shape is helical [5], as shown in Fig. 1. They offer a compromise between the two previous geothermal exchangers. Several geometries are available: cylindrical or conical; their heights vary between 2 and 6 m and their diameters between 0.35 and 2 m. The upper part is generally placed 1 m below the ground level. They do not require such a large area as horizontal loops and are claimed to be cost-effective.

Various further uncommon exchangers have been reported in the literature, such as the double coil [6] and exchangers with fins that increase contact with the pipe [7].

BHEs and horizontal loops have been studied extensively, experimentally as well as theoretically. There are numerous validated BHE models. Simple ones mainly use three geometries: an infinite linear source, a finite linear source, and an infinite cylindrical source. The parameters which have the greatest influence on temperature recovery are ground thermal conductivity and heat capacity of the underground [8]. Porosity plays a major role, since it acts on both these parameters. The material for cementation is also important. Atmospheric temperature, wind, and solar radiation have a marginal influence, because they act on the heat exchanges

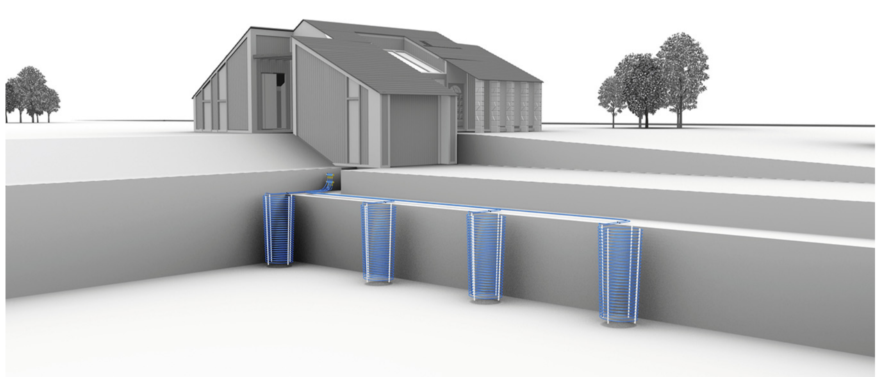

Fig. 1. A house with four spiral heat exchangers (courtesy of RYB-Terra).