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Research Paper

Thermo-economic analysis of four different types of ground heat exchangers in energy piles

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HIGHLIGHTS

- Thermal efficiency of four types ground heat exchangers in energy piles is studied.
- Heating and cooling performance is analyzed by thermal performance tests.
- Double-U type heat exchanger performs the lowest thermal efficiency.
- Thermal efficiency is more important than pipe costs in practical application.

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ABSTRACT

In this paper, thermal efficiency of four different types of ground heat exchangers in energy piles is investigated (type: double-U, triple-U, double-W and spiral). Five thermal performance tests are conducted to analyze ground heat exchangers operation under an intermittent condition (7 days on for cooling, 26 days off, 7 days on for heating).

Results show that double-U type is with worst heating and cooling performance, accounting for 67–69% thermal efficiency than spiral and double-W types which are with similar thermal outputs. For technical problems, only heating performance of triple-U type is examined experimentally but the cooling performance is studied numerically. The findings show that tripe-U type performs highest thermal efficiency among all types. By examination of different pipe dimensions heat transfer rate of spiral type with 32 mm diameter is increased by 32% than that of 25 mm diameter.

In addition, cost-benefits evaluation shows that triple-U shaped ground heat exchanger has highest economic performance, followed by double-U, spiral and double-W type. However, pipe material is only a small consists of the total installation costs. Hence, thermal efficiency is a more important factor to consider than pipe costs in practical application.

1. Introduction

Low enthalpy geothermal systems have been developed rapidly as renewable and environmental friendly techniques for building's heating and cooling in recent decades [1]. The ground is used as heat source in winter or heat sink in summer to explore geothermal energy by circulating heat carrier fluid (e.g. water or anti-freeze solution) through the coupled ground heat exchangers (GHE) in geothermal systems [2]. Different types of GHEs such as horizontal coils and vertical U-shaped pipes in borehole are widely applied in current technologies. Thermal efficiency varies accordingly with the type of GHEs [3]. Among all these GHEs, energy pile system has been developed as a high thermal efficiency technology for ground source heat pump (GSHP) systems [4].

Within the energy pile systems, GHEs are embedded into piles of the foundations that are commonly grouted with concrete, as a diagram for a single W-type GHE shown in Fig. 1. This technology shows attractive performance due to the large heat exchanging area compared to conventional borehole heat exchangers (BHE) (e.g. energy pile is generally with drilling-hole diameter of 0.4–1.0 m, BHE is commonly with 10–20 cm borehole diameter) [5]. In additional, energy piles save drilling and grouting expenses

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Nomenclature

CNY	Chinese Yuan
GHE	ground heat exchanger
GSHP	ground source heat pump
SIR	saving to investments ratio (–)
T	temperature (°C)
H	length (m)
t	time (s or h)
$\dot{q}$	specific thermal rate (W/m)
W	volume of fluid (m^3/s)
h	water head (m)
B	benefits (CNY)
C	cost (CNY)
P	price (CNY)
L	pipe length (m)
s	flow distance (m)
K	hydraulic conductivity (m/s)
A	area (m^2)

Greek symbols

λ	thermal conductivity (W/m K)
ρc	volumetric specific heat (MJ/m^3 K)

Subscripts

in	inlet flow
out	outlet flow
f	fluid
e	electricity
p	pipe
h	heating
c	cooling
b	backfills
w	water

which are the main capital costs of GHE systems [6]. Therefore, energy pile systems have great advantages in reducing the installation costs with also remarkable thermal efficiency. However, the number of piles is designed according to the building's structure load. In general, thermal energy provided by energy piles cannot cover the total energy demand of buildings. Hence, the reach of possible highest thermal efficiency with limit installation capacity of energy piles is significant importance.

An optimal GSHP system design requires proper estimation of thermal performance of the GHEs. Many previous studies have been implemented to investigate the performance among different types of GHEs in energy piles [7–10]. Recently, Yoon et al. [11], reported an experimental and numerical study of the results of a thermal performance test using precast high-strength concrete (PHC) energy piles with W and coil-type GHEs. Thermal performance tests (TPTs) were conducted for four days under an intermittent operation condition. Furthermore, numerical study was conducted to compare with the four-day experimental results. Results showed that the heat exchange rate of the coil-type GHE showed 10–15% higher efficiency but with 200–250% expensive than the W-type. Gao et al. [12,13], investigated an energy piles system that was applied for an actual architectural complex in Shanghai, China. The results showed that W-shaped type GHE is preferred as the highest efficiency for the practical application in terms of thermal performance.

Recent studies indicated also that TPTs are useful and consolidated for estimation thermal performance of energy piles in order to provide the basic information for design and planning of GSHP system [14–16]. Franco et al. [17], presented a numerical study to reproduce the results of thermal response tests for synthetic energy pile systems with different material properties, dimensions and pipe configurations. Standard line heat source model is applied to evaluate the results of the numerical simulations and to highlight the magnitude of the errors. Results indicated that thermal conductivity obtained using the line heat source model can be misleading even in the absence of groundwater flow and soil heterogeneity.

Most previous studies [11,17,18–20] estimated performance of GHEs by the constant heat flux TPT method for simulating building's cooling scenario. A few studies have been implemented experimentally with considering GSHP systems operation under intermittent condition for both building's heating and cooling. In

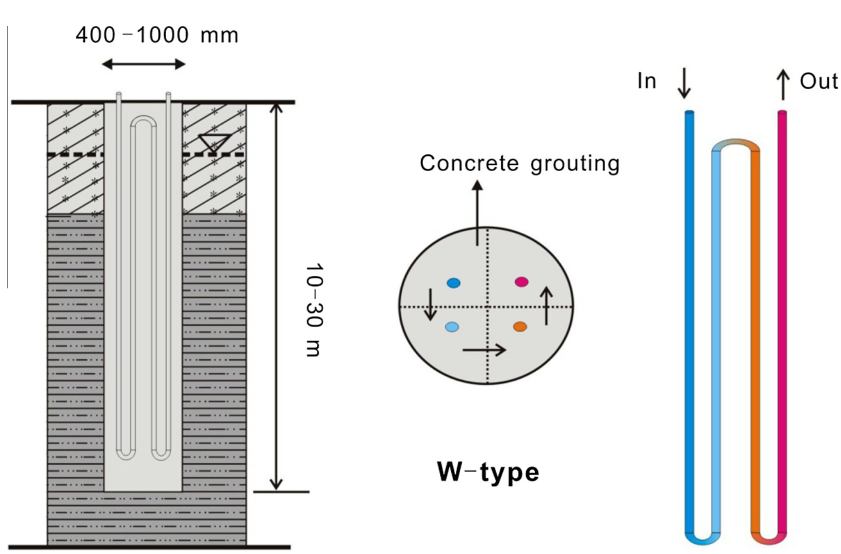

Fig. 1. Schematic diagram of a single W-type ground heat exchanger in energy piles.