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# First in situ determination of the ground thermal conductivity for borehole heat exchanger applications in Saudi Arabia

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ABSTRACT

The paper deals with the in situ experimental determination of the thermal properties of the underground soil for use in the design of borehole heat exchangers (BHE). The approach is based on recording the unsteady thermal response of a BHE that has been installed for the first time in Saudi Arabia. In this approach, the temperature of the circulating fluid has been recorded at the inlet and outlet sections of the BHE with time following the start of its operation. Severe fluctuations in these temperatures occur at small times (up to 8 h) due to the transient effects inside the borehole and must be excluded. A method has been developed for estimating the time period characterized by these severe fluctuations. The recorded thermal responses together with the line source theory are used to determine the thermal conductivity, thermal diffusivity and the steady-state equivalent thermal resistance of the underground soil.



## 1. Introduction

The oil crisis of the 1970s stimulated increased funding in the western world for research and development of new and renewable energy technologies. The world now is vigorously searching for new sources of energy which should be environmental friendly and cheap because it is anticipated that humanity will face another crisis in the coming decades due to increasing energy demand and rapid depletion of non-renewable energy resources. In recent decades, there has been a shift towards efficient renewable energy sources as compared to conventional resources. Lately, geothermal energy (geo-exchange) systems have been receiving growing interest on a global basis. The utilization of such systems has broadened in many engineering applications and is now recognized as a cost effective standard for energy conservation.

In geo-exchange systems, a borehole heat exchanger (BHE) is used to exchange heat with the underground environment and to provide cooling and heating for an ever-increasing number of applications. Applications include space heating and cooling, water heating, crop drying and agricultural greenhouses. One of the well-known applications for the usage of BHE is the ground coupled heat pump (GCHP) systems. These systems provide high levels of comfort and have very low levels of maintenance requirements. In addition, the GCHP systems are found to be environmentally attractive and have gained international attention as proven means of energy saving. In vertical borehole heat exchangers, heat is extracted from or rejected to the ground by means of buried pipes, through which a heat carrier fluid is circulated in a closed circuit (see Fig. 1). The annular space between the U-shaped pipes and the borehole wall is usually grouted with a high thermal conductivity material which provides a strong bond between the pipes and the borehole. In addition, it improves heat transfer between the soil and the pipes.

To size or simulate the performance of a BHE, the thermal properties of ground at the vicinity of the BHE must be estimated. Such properties have a great effect on the number of boreholes required for any geo-exchange system [1]. The thermal response test is an effective method for the determination of the ground thermal properties. In this test, a known thermal load is applied to the BHE and accurate measurements of the inlet and outlet temperatures of the circulating fluid are recorded. The thermal response test was first presented by Mogensen [2] with a stationary test facility. Afterward, the mobile thermal response test facility appeared in Sweden [3], Canada, USA [4], Germany [5], Norway, Netherlands, England and Turkey [6], and Korea [7]. In Saudi Arabia, there are no studies undertaken so far related to the borehole heat exchanger systems and it is of interest to examine such systems in this environment. This is a starting point for a future development in the geothermal energy research in Saudi Arabia. In order to carry out technical and economical feasibility studies of utilizing

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**Nomenclature**

| | |
|---|---|
| $d$ | diameter (m) |
| $h$ | convective heat transfer coefficient (W m$^{-2}$ K$^{-1}$) |
| $k$ | thermal conductivity (W m$^{-1}$ K$^{-1}$) |
| $m^{\circ}$ | circulating fluid mass flow rate (kg s$^{-1}$) |
| $Q^{\circ}$ | heat transfer rate (W) |
| $R$ | thermal resistance (m K W$^{-1}$) |
| $t$ | time (s) |
| $T$ | temperature (°C) |
| $L$ | depth of the borehole heat exchanger (m) |
| SDR | standard dimension ratio (pipe outside diameter/pipe wall thickness) |
| *Dimensionless numbers* | |
| Pr | Prandtl number |
| Re | Reynolds number |
| *Greeks* | |
| $\alpha$ | thermal diffusivity (m$^2$ s$^{-1}$) |
| $\mu$ | viscosity (kg m$^{-1}$ s$^{-1}$) |
| *Subscripts* | |
| $B$ | borehole |
| $f$ | circulating fluid |
| $g$ | grout |
| $i$ | inside |
| $o$ | outside |
| $P$ | pipe |
| $s$ | soil |
| 2 | inlet to BHE |
| 3 | outlet from BHE |

geothermal systems, it is required to know the thermal properties of the ground formation in a given site. The work presented in this paper is the first step in that direction.

## 2. BHE installation

A survey was conducted on the contractors in Saudi Arabia in order to carry out the drilling and installation work. The survey revealed that experienced oil borehole drillers can profitably install a BHE with $300 per meter of borehole depth which is considered very expensive. Therefore a water well driller was contracted with a much lower cost and the drilling method used was the rotary drilling rig. The survey concluded that substantially lower costs (average of $50 per meter) are possible with a steady market to support competitive drillers with enough BHE installation work to develop their own productivity improvements.

The location chosen for the BHE installation was a house garden located at King Fahd University of Petroleum and Minerals (KFUPM) campus in Dhahran, Saudi Arabia. Two vertical boreholes separated by 1 m distance were drilled each of diameter $d_B = 20$ cm and depth $L = 80$ m. In the first borehole, a single U-shaped pipe was inserted and, subsequently, the annular space was grouted with a Bentonite–sand mixture. The pipes are of high density polyethylene (HDPE) material, 1 1/4″ diameter and SDR 11. The shank spacing (distance between BHE pipes) is 12 cm and it was kept constant all the way along the borehole by using rubber clips. The rubber clips were mounted every 1 m along the BHE depth. The second borehole was used as a monitoring borehole where six thermocouples of type T (Copper – Constantan) were mounted at depths of 0.1, 0.2, 0.3, 10, 30 and 50 m. After that, this borehole was grouted with the same drilling cut.

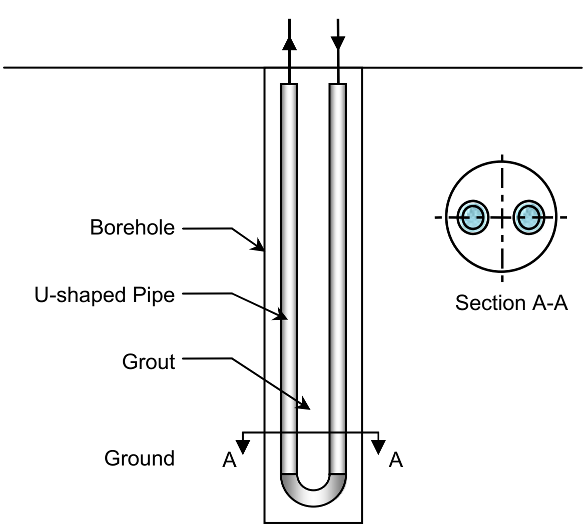


**Fig. 1.** Typical vertical BHE with a single U-shaped pipe.

The Dhahran area in the Eastern province of Saudi Arabia is formed geologically from relatively recent sediment. It is part of the Arabian shelf, which was submerged beneath sea water during the transgression and regression cycles during the geological history of the Arabian Gulf, including the late Pleistocene–Quaternary age (about 400,000 years before present) when the Arabian Gulf water stood at a level 150 m higher than its present mean. The soil at the site consists of five main layers as provided by Al-Shayea [8]. The lithology prevailing over the site of the borehole is represented by sandstone and marl. The geological formation and the measured density are shown in detail in Table 1. The groundwater level is at about 20 m depth and an analysis of the geological data gives a mean density of the undisturbed soil of about 1660 kg/m$^3$. The physical and thermal properties of the HDPE pipes and the Bentonite–sand mixture used in the BHE installation are shown in Table 2. The properties of the HDPE pipes were provided by the manufacturer while the thermal conductivity of the Bentonite–sand mixture was measured in the heat transfer laboratory of KFUPM using rapid, non-destructive thermal analysis equipment from Mathis Instrument Limited.

## 3. Experimental apparatus

The equipment of the experimental apparatus is set up on a small single-axle trailer (see Fig 2). The equipment consists of a 1 hp circulation pump, three water heater elements in the range of 5 kW, voltage regulator to stabilize the input voltage to the heaters, water supply/purge tank, water filter, well insulated pipes and valves. The apparatus has two flexible hoses on the exterior of the trailer to allow attachment of the two HDPE pipes which are protruding from the vertical BHE. All necessary instrumentation and data acquisition equipment are also contained within the trailer. The instrumentation equipment includes a flow meter, three thermistor probes of 0.1 °C accuracy and watt transducers. Temperatures at the inlet and outlet of the BHE and at various depths of the monitoring borehole as well as the flow rate and power input to the heating elements and the pump were recorded with a data logger type Fluke Hydra. Fig. 3 shows a layout of the