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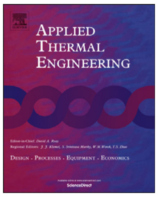

In-situ measurement of borehole thermal properties in Melbourne

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HIGHLIGHTS

- In-situ thermal response of borehole heat exchangers in Melbourne were analysed.
- Slope determination, two variable parameter fitting and the GPM model were applied.
- Three thermal conductivity values obtained were applied in TRNSYS simulations.
- The GPM model provides better agreement with measured temperatures from boreholes.

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ABSTRACT

The ability to quantify the ground thermal properties of a site is important for the appropriate sizing of ground heat exchangers. This paper presents the results of in-situ measurements of the thermal properties of two 40 m deep borehole thermal storage systems in Melbourne. The measurements from the tests were analysed using three methods: conventional slope determination, two variable parameter fitting technique and using Geothermal Properties Measurement (GPM) model. The values of effective thermal conductivities obtained from the three methods were applied in 12 TRNSYS simulations. The value from the GPM model was found to give relatively less error when the measured and simulated outlet temperatures were compared.

1. Introduction

The effective thermal conductivity of the soil and borehole thermal resistance are important parameters for sizing the borehole heat exchanger (BHE) of an inter-seasonal thermal storage system or a ground-coupled heat pump. These properties vary with the type of soil, local soil moisture content and particle size and hence are site-specific. Moreover, soil type variation within a borehole depth may also exist. It is therefore necessary to determine the thermal properties of the ground at each specific installation site. The effective ground thermal conductivity and effective borehole thermal resistance can be determined either by referring to existing literature relevant to the type of soil, conducting heat probe tests on soil samples or by performing an in-situ test [1–3].

For an estimation of the soil thermal conductivity based on the literature, the task is to identify the type of soil and its moisture content and refer to the existing data. As the soil type may vary along the length of the borehole, this estimate may not necessarily represent the true value as the estimate is confined to only one type of soil layer. The data on soil thermal conductivity is available for a range of soil types in the literature as shown in Table 1 [1,2,4–6]. Similarly, the volumetric heat capacity of the soil is also determined based on the type of soil.

Another method to determine the soil thermal conductivity is by a heat probe test [7–9]. The test is performed on a soil sample in a laboratory [1]. In this method, constant heat is supplied to the soil and the corresponding change in soil temperature is observed over a given time period. Based on the temperature change of the soil, the thermal conductivity can be determined by a parametric estimation. Because only a small sample of soil is tested, the value obtained may not be considered to be representative for the entire depth of the borehole. Since the borehole may have different types of soil along its length with different thermal properties, estimates from this method may also not be representative of the entire length of the borehole.

The third method of determining ground thermal properties is by an in-situ thermal response test (TRT) combined with a parametric estimation algorithm [2,3,10,11]. This method is a mimic of the BHE system. It was first proposed by Mogensen [12] and further

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Table 1
Thermal conductivity and volumetric heat capacity.

Material	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)	Volumetric heat capacity ($kJ\ m^{-3}\ K^{-1}$)
Gravel	2.0–3.3	2200–2700
Sand	1.5–2.5	2500–3000
Silt	1.4–2.0	2500–3100
Clay	0.9–1.8	2200–3200
Clay stone	2.6–3.1	2340–2350
Sandstone	3.1–4.3	2190–2200

studied and developed by Austin [3], Austin, Yavuzturk and Spitler [13] and Gehlin [14]. Since then several researchers [1,10,15–19] have used the TRT method to determine the BHE thermal conductivity based on the methodology described by the above authors. The principle of the TRT is based on constant heat injection from a source for 50–60 h by using the BHE. Austin [3] found that by conducting the test for a minimum of 50 h, the BHE thermal conductivity obtained would be within 2% of the value that would be obtained had the test been conducted for a longer duration. As the performance of the system is not only affected by the soil thermal properties but also by the properties of the grout, U-tube pipe and heat transfer fluid, the thermal conductivity obtained by this method is the effective thermal conductivity of the ground considering the BHE characteristics.

The value of measured effective thermal conductivity from the TRT is influenced by the duration of the test. The heat transfer during the initial few hours of the test is dominated by transient effects. Therefore, it is recommended to disregard the measured data during the initial 10–15 h [14]. This is mainly to avoid transient temperature gradients and using data which is significantly influenced by the grout thermal properties. Austin [3] found that best estimates were obtained when 12 h of initial data were disregarded and Gehlin [20] suggests discarding 12–20 h initial data when processing the experimental data. The number of hours to discard depends on when the temperature reaches a steady state. A further study conducted by Yu et al. [21] found that after 35 h of testing, the value of measured effective thermal conductivity became relatively constant.

The inconsistency in the value of soil thermal conductivity resulting from the different methods was reported by Witte, Gelder and Spitler [1]. They compared the values of soil thermal parameters by several methods. The types of soil while drilling a 35 m borehole were identified. The borehole comprised of 11 different soil types. Based on these, Witte, Gelder and Spitler [1] obtained the soil thermal conductivity for each layer from the literature. They estimated soil thermal conductivity for the borehole to vary from 1.2 to 3.4 $W\ m^{-1}\ K^{-1}$ with weighted average of 1.90 $W\ m^{-1}\ K^{-1}$. Next they determined soil thermal conductivity by performing the heat probe test on nine samples from different layers of soil from the same borehole. The measured thermal conductivity varied from 1.09 to 2.87 $W\ m^{-1}\ K^{-1}$ with a weighted average of 2.09 $W\ m^{-1}\ K^{-1}$. Finally, the effective soil thermal conductivity was determined by conducting an in-situ test on the same borehole. From the test they estimated the average effective soil thermal conductivity to be 2.10 $W\ m^{-1}\ K^{-1}$. While these estimates show that the soil thermal conductivity obtained by the laboratory and in-situ test are almost equal, the results may have been different had the laboratory test been conducted on only one soil sample.

Similar results were obtained in another test conducted by Witte [5] in Netherlands. The researcher estimated soil thermal conductivity to be 1.83 $W\ m^{-1}\ K^{-1}$ from the literature, 2.10 $W\ m^{-1}\ K^{-1}$ from a laboratory test and 2.13 from in-situ test. In both the studies, the authors observed that the average soil thermal conductivity estimate based on reference tables to be the lowest, followed by the laboratory test and the in-situ test. These comparisons suggest that the value obtained for the thermal conductivity of the soil varies with the method used to determine it. Furthermore, the literature also suggests that the most common and accepted method is the TRT. Since an estimation of effective thermal conductivity of soil of the borehole on site is essential, the TRT method was used to determine the effective soil thermal conductivity and borehole effective thermal resistance of boreholes to be used for an inter-seasonal underground thermal storage system which is located at the Burnley campus of the University of Melbourne. Thus, the aim of this paper is to determine the thermal conductivity and resistance of the boreholes used for inter-seasonal heat and coolth storage in Melbourne. The measurements from the tests were analysed using three methods: conventional slope determination, two variable parameter fitting technique and using Geothermal Properties Measurement (GPM) model.

2. TRT set up

Fig. 1 illustrates the TRT set up schematically. The TRT was performed on two 40 m deep boreholes, i.e. heat storage borehole (HSB) and coolth storage borehole (CSB), each borehole having two U-tubes. The two boreholes are 8 m apart centre-to-centre. The TRT set up consists of a 0.125 m^3 electric hot water tank rated at 4.8 kW, 0.2 m^3 buffer tank, water pump, flow meter, high density polyethylene (HDPE) pipes and temperature sensors. These pipes form the piping network from the tanks to the borehole heat exchanger headers. All the surface pipes and the water tank were insulated at the system, which detailed descriptions can be found in Lhendup, Aye and Fuller [22]. Fig. 2 illustrates the geometry and layout of the TRT boreholes. Additionally, there are temperature sensors inserted at 2, 21 and 40 m depths to monitor the temperature of the fluid along the borehole heat exchanger. Soil around the borehole was assumed to be homogeneous with a constant infinite line source at the centre of the borehole. A total of four TRTs, two on each

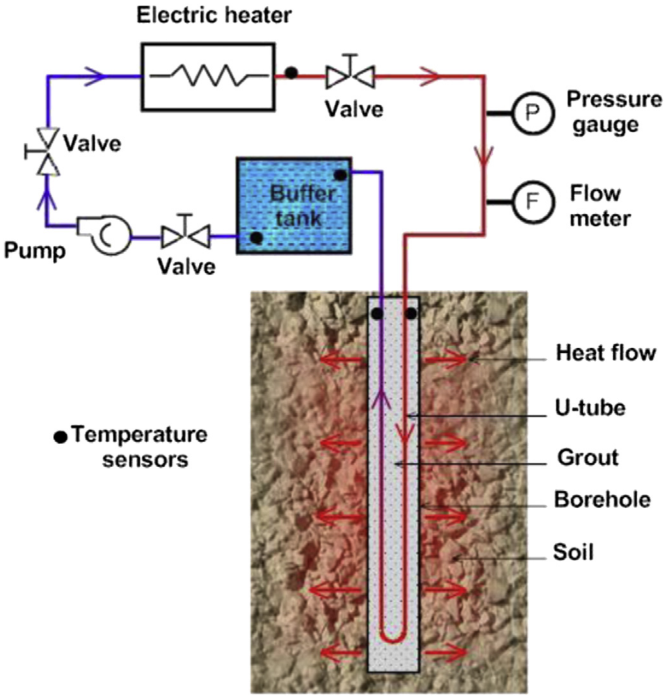

Fig. 1. Schematic of the TRT set-up.