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Performance Study of Ground Heat Exchanger Based on Thermal Conductivity of Hybrid Soil

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ABSTRACT

The need for renewable energy sources has grown as the world has significantly changed, and fossil fuels have been used extensively in global perspective. As a result, renewable energy has replaced fossil fuels in many places around the world because it is better for the environment. Geothermal energy is the most efficient way to heat and cool space from all renewable energy sources. Geothermal renewable energy, in particular from ground heat exchangers (GHE), has enormous potential for use in construction (building). In order for the GHE to function appropriately (efficiently), it is critical (better) to have sufficient quantities of backfilling material. This material is used to fill the gap between the soil surrounding. The heat transfer rate from the air to the soil, which is controlled by thermal characteristics of the soil near the GHE pipe, determines the thermal performance of the GHE. Using some backfilling materials that have been thermally improved, the thermal properties of the soil around the GHE pipe can be improved as well. Therefore, the current study examines the impact of hybrid soils without moisture on the GHE performance. The hybrid soils comprise of two components: native soil and bentonite. A thermal property analyzer was used to measure the thermal conductivity of the hybrid soil. According to the study, compared to other grain sizes, native soil with a grain size of 2.0 to 2.5mm has the highest thermal conductivity value at 20% bentonite, which is 0.331 W/m.K. The effectiveness of the GHE system was assessed using a mathematical model, demonstrating that the GHE has significantly reduces temperatures along pipes with length of 0 to 16m. In a nutshell, once the thermal conductivity of hybrid soil increases, the performance of GHE will improve.

1. Introduction

The demand for building heating and cooling energy is rising daily because of an expanding in population and high living standards. The amount of energy required to heat and cool the world's buildings accounts for approximately one-third of the total demand for energy across the globe. Traditional building heating and cooling systems, known as Heating, Ventilation, and Air Conditioning (HVAC), are known for their high energy consumption and negative impact on the natural

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environment. HVAC systems in buildings improve indoor air quality and thermal comfort to provide thermal comfort to occupants [1]. Most of the world's energy comes from fossil fuels owned by a few countries whose prices change and damage the environment [2]. As a result, it is necessary to utilise HVAC systems that are friendly to the environment while also being efficient in their energy use [3]. Renewable energy is a vital source of clean energy that has been widely used in a variety of fields around the world [4, 5]. Geothermal energy-based HVAC systems have attracted a lot of attention recently. Ground thermal energy has good capability which is it can heat and cool buildings effectively [6, 7]. The temperature of the soil is equal to the mean annual ambient temperature of that location at a depth of 3 to 4m below the ground surface, where it is almost constant throughout the year [8, 9]. Compared to the surrounding air, the constant temperature of the underground soil is significantly higher in the winter and lower in the summer [10,11]. Therefore, soil can be used as a heat sink during the summer, and during the winter it can be used as a heat source [12]. In recent years, the GHE development and technology have been used in modern countries, particularly in Europe, due to its ability to provide cooling and heating during the summer and winter [13]. GHE is a promising application for cooling and heating spaces [14-16]. A blower is used to force air from the surrounding environment through pipes that are buried in the GHE. Air flows through these pipes, exchanging heat with the soil nearby and becoming heated or cooled based on the surrounding environment [3]. As a result, the GHE-conditioned air can be used for both cooling and heating purposes. Figure 1 depicts a typical GHE system that can be used for summer cooling.

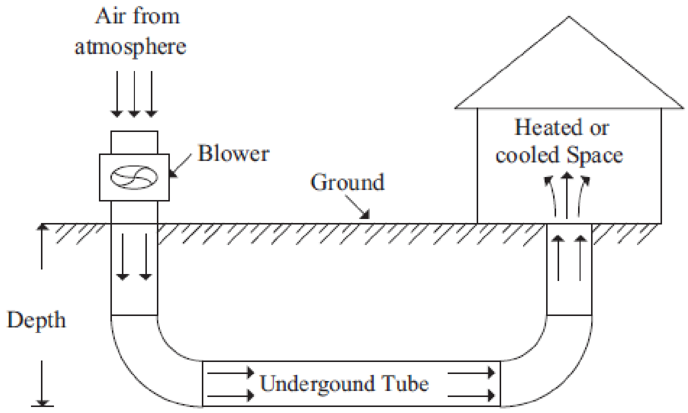

Fig. 1. Basic principle for open system GHE [17]

Although the GHE is an excellent passive heating and cooling method for buildings, the end-user faces significant installation cost challenges. This is because the longer pipes are needed for GHE to achieve a significant heat transfer, a long trench must be dug to install the pipes, which tends to raise the initial investment. In addition, a sizable piece of land is required for the trench, which is a major issue in urban areas. Around 30% of the total cost of GHE is spent on trench excavation, while 40% is spent on pipes [8]. The price of piping and trench excavation must be decreased for the GHE system to be economically viable. From the perspective of thermal conductivity, the grouts between the GHE and the backfill materials must be improved. Since it is less expensive and has high thermal conductivity, sand is typically used to fill boreholes [18]. Other important backfill material characteristics include an excellent sealing capacity and a sufficiently low permeability [19,20], good strength to avoid failure due to thermal stress [21,22], and good workability [23] that ensures the pumpability of the mixture during the grout pouring in the borehole.

Numerous researchers have studied the GHE system in depth and discovered that the system's efficiency is significantly influenced by the heat transfer rate between the air and the soil. The heat transfer between air and soil gives impacts to the initial cost needed to install a GHE system. Since the length of the pipe determines the amount of soil that needs to be excavated, it is estimated based on the heat transfer rate between air and soil. Thermal characteristics of the soil play a significant role in the heat transfer rate between air and soil. Therefore, using soil with high thermal conductivity close to buried pipes can significantly reduce the length of pipe needed for GHE systems [8]. Adding certain additives, such as bentonite, quartz, and metal particles may also improve the soil's thermal conductivity. Up to a certain length of the pipe, these materials may be placed all around it in a standalone layer of a predetermined thickness or mixed with the soil or sand in the proper proportion. The remaining space may then be backfilled with natural soil. Since the fine particles of additive materials like bentonite are much smaller than the soil or sand particles, they also fill up the air voids when combined with the sand or soil, just like water does. As a result, the native soil's air voids are filled with additives, which enhance the soil's thermal properties [3]. Backfilling a borehole made for a closed-loop GHE system has frequently been done with bentonite, which has a high swelling potential and low hydraulic conductivity [24,25]. As backfill materials in GHE systems, sand mixtures are enhanced with bentonite, which has high thermal conductivity, high strength, low compressibility, and very low hydraulic conductivity [26]. Through a series of geological engineering tests, Akgün*, et al.,* [27] concluded that a bentonite content of about 20% had satisfied the minimum regulatory hydraulic conductivity requirement.

The performance of the GHE is also heavily influenced by the properties of the backfill materials, such as their thermal conductivity, thermal diffusivity, and heat capacity [28]. To determine the impact of thermally enhanced backfilling material on the rate of heat transfer of the horizontal GHE system, Di Sipio and Bertermann [29] conducted a field test. Five trenches were used, each with a different backfilling material, which included natural material and commercial products. It was discovered that pure sand with coarse and fine particles has the lowest thermal conductivity, less than 1.3W/m-K, and sandy clay material has the highest, more than 2.0W/m-K. Meanwhile, the thermal conductivity of bentonite with 15% mixed sand is around 1.48W/m-K. When compared to standard sand-clay material, Wang*, et al.,* [30] found that the mixture of sand and bentonite used as a backfill material increased the heat transfer rate by up to 31%. Compared to a typical sand-clay material, Omer [31] found that using a sand-bentonite with 10–12% bentonite by weight as backfilling material in a borehole heat exchanger, it has increased the heat extraction and injection rates by 22.2 and 31.1%, respectively. For various sections of the buried GHE pipe, Cuny*, et al.,* [32] considered three types of coating soils: in-situ earth, sand, and a mixture of sand-bentonite. The authors observed that the GHE system's performance was highest with the sand-bentonite coating. According to Saeidi*, et al.,* [33], the increase in the thermal conductivity of the backfill material from 0.5 to 2.0W/m.K causes an approximately 40% increase in the heat transfer rate of a 10m vertical spiral tube GHE. The GHE outlet temperature decreases as the specific heat capacity of the backfill material increases from 500 to 3000J/kg.K. Guo*, et al.,* [34] also mentioned that the soil's thermal conductivity and heat capacity influence the thermal performance of the GHE in the soil. According to Yu*, et al.,* [35] and Zhang*, et al.,* [36], the sand/kaolin blend has a higher thermal conductivity than pure sand, which is related to the fact that the kaolin additive acts as a binder between sand particles, increasing the physical contact point between them. The above literature review shows that using soil with high thermal conductivity near GHE pipes improves their thermal performance and lowers the cost of installation.

To the best of authors knowledge, the main thing that affects how well GHE works is the thermal properties of the soil. Because of this, it's important to use soil with good thermal properties. Basically, the thermal conductivity of the soil and pipe materials has been correlated with GHE performance. However, the performance of the GHE system is not significantly impacted by pipe materials [37, 38]. By placing backfilling material that has been thermally enhanced close to the GHE pipe, the thermal properties of the soil around the pipe can be improved. The previous studies on the thermal conductivity of soil for GHE application did not thoroughly cover the performance increment and how it was related to the soil's thermal conductivity. Consequently, this study has examined hybrid soil consisting of native soil and bentonite. The hybrid soil is evaluated in a dry environment at room temperature. This experiment has four distinct native soil grain size ranges: 0.6-1.0mm, 1.0-1.6mm, 1.6-2.0mm, and 2.0-2.5mm. As a result, the hybrid soil's highest thermal conductivity was discovered, and the performance of the GHE was examined using a mathematical model simulation.

2. Methodology

This investigation aimed to determine how the presence of hybrid soil affects the performance of GHE. The thermal conductivity of the soil in the area surrounding the GHE pipe is a primary factor that determines the efficiency and performance of the GHE. As a result, research on the hybrid soil was conducted to enhance thermal conductivity. Both native soil and bentonite were used to create the hybrid soil in this investigation. The native soil was used as the primary soil, and the bentonite was used as the backfilling material due to its properties. Even though bentonite has a low thermal conductivity, it is an excellent backfilling material that can improve thermal conductivity [31]. The properties of bentonite include the ability to fill up the pores surrounded by native soil, thereby influencing the heat conduction capability of the entire mixture and increasing its thermal conductivity. Nevertheless, during this investigation, both native soil and bentonite were tested under dry conditions and at room temperature. The native soil contains various grain sizes, and the sieve method has been applied to categorise the grain sizes into four ranges. In this experiment, there are four grains sizes of native soil ranging from 0.6-1.0mm, 1.0-1.6mm, 1.6-2.0mm, and 2.0-2.5mm. In this stage, five sieves of various sizes were used to classify the grain sizes of native soil: 0.6mm, 1.0mm, 1.6mm, 2.0mm and 2.5mm, as shown in Figure 2.

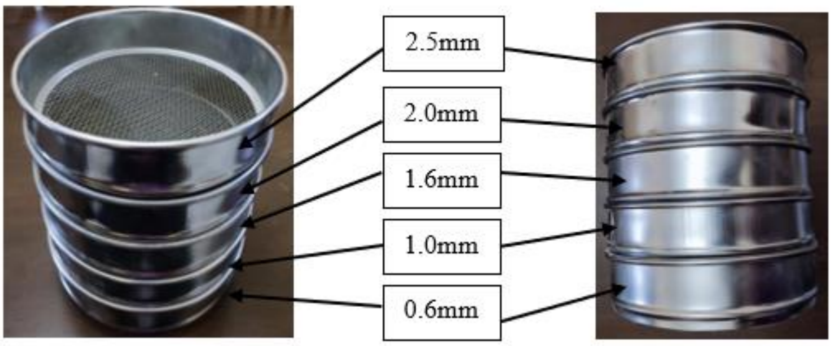

Fig. 2. Sieve in four different ranges

Table 1 shows the relation between the size of the sieve and the grain sizes of native soil. The grain sizes 0.6-1.0mm were obtained by using a sieve with a size of 0.6mm and 1.0mm; grain sizes of 1.0-1.6mm were obtained using a sieve with a size of 1.0mm and 1.6mm; grain sizes of 1.6-2.0mm were obtained using a sieve with size 1.6 and 2.0mm, and grain sizes of 2.0-2.5mm were obtained using a sieve with size 2.0mm and 2.5mm. Figure 3 shows the four grain sizes of the native soil and bentonite used in this study. Then, each range of grain sizes was combined with bentonite at a composition ratio of 0 to 100% by mass with increments of 10% as shown in Table 2.

Table 1
Grain sizes of native soil obtained from the sieve method

Sizes of sieve used (mm)	Range sizes of native soil (mm)
0.6 and 1.0	0.6-1.0
1.0 and 1.6	1.0-1.6
1.6 and 2.0	1.6-2.0
2.0 and 2.5	2.0-2.5

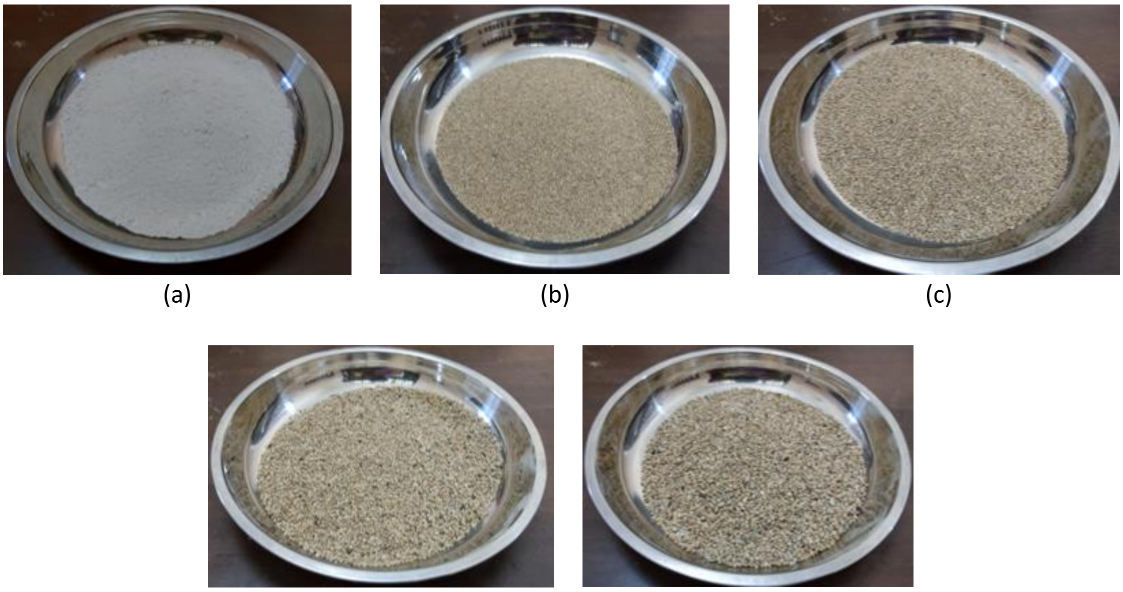
(a) (b) (c) (d) (e)

Fig. 3. Elements that used in this study which are (a) bentonite and four grain sizes of native soil: (b) 0.6-1.0mm, (c) 1.0-1.6mm, (d) 1.6-2.0mm and (e)2.0-2.5mm

Table 2
Composition ratio between bentonite and four grain sizes of native soil

Bentonite (%)	Native soil (%)			
	Grain size 0.6-1.0mm	Grain size 1.0-1.6mm	Grain size 1.6-2.0mm	Grain size 2.0-2.5mm
0	100	100	100	100
10	90	90	90	90
20	80	80	80	80
30	70	70	70	70
40	60	60	60	60
50	50	50	50	50
60	40	40	40	40
70	30	30	30	30
80	20	20	20	20
90	10	10	10	10
100	0	0	0	0

The preparation of hybrid soil, which consists of native soil with grain sizes ranging from 0.6-1.0mm and bentonite mixtures, began by placing both the native soil and the bentonite into a tray, as shown in Figure 4. Then, the mixture was placed into an oven that was set to 105°C. This was done to prepare hybrid soil for grain sizes 0.6-1.0mm of native soil and bentonite. Both native soil and bentonite were allowed to cool to room temperature after being dried for 12 hours [30]. After that, the native soil was combined with the bentonite in a variety of percentages, including 0%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 100% with 10% increments as shown in Table 2. Every sample of hybrid soil was placed into a bottle with a capacity of 60g in total mass. A sample of hybrid soil, consisting of grain size 0.6-1.0mm of native soil and bentonite, can be seen in Figure 5.

(a) (b)

Fig. 4. Getting ready to put in the oven: (a) native soil and (b) bentonite

Fig. 5. Samples of hybrid soil that is a mix of native soil grain size 0.6-1.0mm and bentonite

After that, the thermal conductivity value for each sample was measured using a KD2 Pro Thermal Properties Analyzer, as seen in Figure 5. In order to obtain the thermal conductivity value, the KD2 Pro Thermal Properties Analyzer needle was dipped into the hybrid soil and left for approximately two minutes in the vertical position, as shown in Figure 6. This process will be carried out for each sample three times to determine the average thermal conductivity value. Since the needles are so delicate and sensitive, precautions must be taken throughout the process. As some samples have a large grain size, the needles should be dipped slowly into the hybrid soils until they are completely covered. This is because the large grain size has the potential to damage the needles. Then, the same process was carried out for the other three grain sizes of native soil ranging from 1.0-1.6mm, 1.6-2.0mm and 2.0-2.5mm.

Fig. 6. The KD2 Pro Thermal Property Analyzer is used to measure thermal conductivity

The mathematical model simulation is used to carry out the investigation in determining how hybrid soil thermal conductivity influences the performance of the GHE. The simulation of the GHE system is an interesting technique for predicting and analysing the performance of the GHE based on the data and input parameters that are currently available. The system's performance can be analysed in a shorter period of time, and the process can be repeated using various input settings. Figure 7 is a schematic diagram that can analyse the mathematical heat transfer model from the air inside the GHE pipe to the surrounding ground [39].

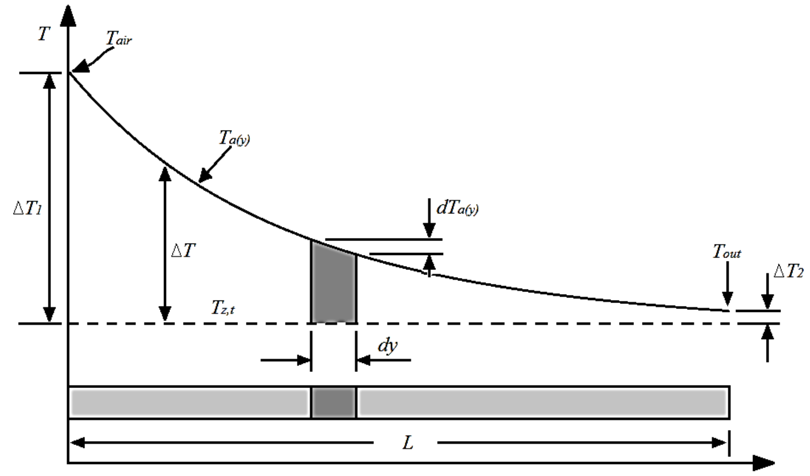

Fig. 7. Diagram of the heat transfer process within a GHE pipe [39]

The air will flow within the pipe at a constant ground temperature, and the figure shows the temperature of the air (T_{air}) entering the pipe, and heat will be transferred to the surrounding ground ($T_{z,t}$). In this scenario, a few assumptions have been made, including: (i) the soil in the area surrounding the pipe has an infinite heat capacity rate or is considered to be a thermal reservoir; and (ii) the presence of a pipe in the area surrounding in the soil does not has any impact on the temperature profile. As a result, the temperature at the pipe's surface is constant in the *y* direction, the pipe's cross sectional area is uniform, an air convection flow develops inside the pipe both hydrodynamically and thermally, and the ground around the pipe has uniform thermal properties and a constant thermal conductivity [40,41]. With increasing pipe distance from the inlet (*y*), the hot ambient air entering the pipe at T_{air} decreases as the pipe length, *y* increase which resulted temperature of air at distance y as $T_{a(y)}$. The temperature at which the hot air exits the pipe is indicated as T_{out}, which is slightly higher than the temperature of the ground ($T_{z,t}$). As a result, Eq. (1) should be utilised to express the rate of heat transfer that is received by the ground for any given length in the differential section of *dy*

$$dQ = U\pi D\left[T_{air(y)} - T_{z,t}\right]dy \tag{1}$$

On the other side of the heat transfer equation, Eq. (2) shows the heat rate that the air inside the pipe transmits in the differential section of the *dy* [10]

$$dQ = -\dot{m}_{air}c_p\left[dT_{air(y)}\right] \tag{2}$$

Because the change in temperature of the air is a quantity with a negative sign, it follows that the temperature will decrease as the length of the pipe increases. Thus, Eq. (2) receives a negative sign. As a result, it produces a positive result for the heat transfer rate. Theoretically, the rate of heat transferred from the ground to the air inside the pipe is the same amount of heat lost as the air moves through the pipe. As a consequence of this, Eq. (1) and Eq. (2) are equalised to produce Eq. (3), which is

$$U\pi D\left[T_{air(y)} - T_{z,t}\right]dy = -\dot{m}_{air}c_p\left[dT_{air(y)}\right] \tag{3}$$

Integrating both sides and rearranging Eq. (3) to solve for $T_{a(y)}$ gives the following results

$$T_{air(y),L} = T_{z,t} + \left(T_{air(y),0} - T_{z,t}\right)\left(e^{-UA_{sur}/\dot{m}_{air}c_p}\right) \quad (4)$$

As a result, Eq. (4) can be expressed as Eq. (5) for *y = L*.

$$T_{air.out} = T_{z,t} + \left(T_{air.in} - T_{z,t}\right)\left(e^{-UA_{sur}/\dot{m}_{air}c_p}\right) \quad (5)$$

where $T_{air.out}$ is the temperature of the air coming out of the outlet, $T_{z,t}$ is the temperature of the ground at depth *z* and time *t*, $T_{air.in}$ is the temperature of the air coming in through the inlet, *U* is the overall heat transfer coefficient, *y* is the length of the pipe, *cp* is the specific heat of air, and ṁ is the mass flowrate. By definition

$$NTU = \frac{UA_{sur}}{\dot{m}_{air}c_p} \quad (6)$$

As a consequence of this, Eq. (5) can be rewritten as a function of *NTU*, as shown in Eq. (7)

$$T_{air.out} = T_{z,t} + \left(T_{air.in} - T_{z,t}\right)e^{-NTU} \quad (7)$$

In order to investigate the impact of the thermal conductivity of the hybrid soil consisting of native soil and bentonite on GHE performance, the conditions of the pipe and its surroundings are tabulated in Table 3 for the simulation's input. The simulation used polyvinyl chloride (PVC) pipe with a thermal conductivity of 0.18W/m.K. The ground temperature is based on a depth of 2m below the ground surface [42-44]. In addition, the simulation is set up with constant values for the pipe's outer and inner diameters, pipe length, air velocity, flow rate, thermal diffusivity, ground temperature, and air inlet temperature.

Table 3
Conditions of the pipe and its surroundings for simulation input

Input name	Value	Units
Thermal conductivity of PVC pipe, k_p	0.18	W/m.K
Outer diameter of pipe, OD	114.3	mm
Inner diameter, ID	101.8	mm
Pipe length, L	25	m/s
Velocity of air, V	10.73	m/s
Flowrate, ṁ	0.1	kg/s
Thermal diffusivity, α	0.046	m^2/day
Ground temperature, $T_{z,t}$	24	°C
Air inlet temperature, $T_{air.in}$	35	°C

3. Results and Discussion

Four different grain sizes of native soil, which are 0.6-1.0mm, 1.0-1.6mm, 1.6-2.0mm, and 2.0-2.5mm was combined with bentonite. After that, each grain size of native soil and bentonite was thoroughly mixed with varying percentages of bentonite by mass. These percentages ranged from 0% to 100% with increments of 10%. The thermal conductivity value for each sample was measured using KD2 Pro Thermal Analyzer. The thermal conductivity values of hybrid soil are illustrated in Figure 8 for all grain sizes of native soil with varying percentages of bentonite. Based on the figure, the value of thermal conductivity for hybrid soil with native soil grain size 0.6-1.0mm and bentonite at 0% concentration is 0.191W/m.K. The addition of 20% bentonite increased the thermal conductivity value of the hybrid soil, reaching 0.269W/m.K. The increment in thermal conductivity value of hybrid soil with bentonite from 0% to 20% is approximately 40.84%. Meanwhile, the thermal conductivity value of hybrid soil dropped from 0.269W/m.K to 0.119W/m.K when the percentage of bentonite was increased from 20% to 100%. This reduction in thermal conductivity was due to the increasing presence of bentonite. It can be concluded that bentonite is effective as backfilling material. According to this graph, the hybrid soil with the addition of 20% bentonite to the native soil grain size of 0.6-1.0mm can increase thermal conductivity.

In the meantime, the thermal conductivity value for hybrid soil with native soil grain size 1.0-1.6mm and 0% bentonite is 0.198W/m.K. This value is relatively close to the thermal conductivity value of hybrid soil with native soil grain size 0.6-1.0mm and 0% bentonite present. The thermal conductivity value of the hybrid soil increased steadily when bentonite was added from 0% to 20%, with thermal conductivity of 0.278W/m.K, which is greater than the thermal conductivity value of hybrid soil with native soil grain size 0.6-1.0mm and 20% bentonite. The increment of thermal conductivity value with bentonite from 0% to 20% is about 40.4%. From the graph, the thermal conductivity value of the hybrid soil starts to decrease from 20% to 100% of bentonite, which is from 0.278W/m.K to 0.119W/m.K.

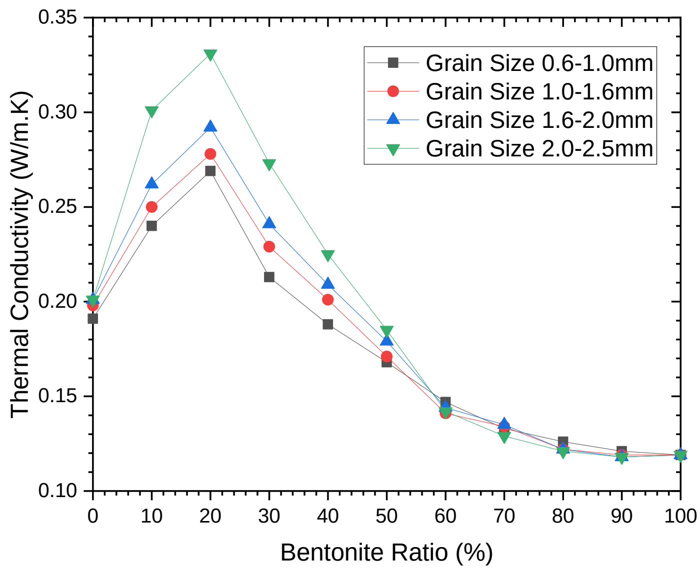

Fig. 8. Thermal Conductivity of hybrid soil for 0.6-1.0mm, 1.0-1.6mm, 1.6-2.0mm and 2.0-2.5mm grain size of native soil

Besides that, the graph also shows that the thermal conductivity value of hybrid soil for native soil grain sizes ranging from 1.6-2.0mm and bentonite at 0% is 0.201W/m.K, which is almost the same as the thermal conductivity value of hybrid soil at 0% bentonite for native soil grain sizes 0.6-1.0mm and 1.0-1.6mm. The value of thermal conductivity then increases steadily about 45.27% from 0.201W/m.K to 0.292W/m.K when the 20% of bentonite was added, which is greater than the thermal conductivity value of hybrid soil with native soil grain 0.6-1.0mm and 1.0-1.6mm at 20% bentonite. After that, the thermal conductivity value decreased from 0.292W/m.K to 0.119W/m.K when the bentonite increased from 20% to 100%. Finally, the graph also shows that the thermal conductivity value of hybrid soil with native soil grain size 2.0-2.5mm and 0% bentonite is 0.201W/m.K. The thermal conductivity value is almost the same as the thermal conductivity value of hybrid soil at 0% bentonite for native soil grain sizes 0.6-1.0mm, 1.0-1.6mm and 1.6-2.0mm. The thermal conductivity value then steadily increases about 64.68% from 0.201W/m.K to 0.331W/m.K when the presence of 20% bentonite. This increment is higher than other hybrid soil at 20% bentonite. After that, the thermal conductivity value decreased from 0.331W/m.K to 0.119W/m.K when the percentage of bentonite increased from 20% to 100%. In short, the presence of bentonite as a backfilling material at certain percentage in native soil could increase the thermal conductivity value. At 20% of bentonite mixture, it would produce the highest thermal conductivity at any grain size.

In a comparison of thermal conductivity values for all hybrid soil, there is a significant difference in thermal conductivity value. Furthermore, the thermal conductivity value for all hybrid soil follows the same trend with the presence of bentonite. This trend has occurred because when the proportion of bentonite increases, the amount of native soil decreases, and most native soil grains are surrounded by bentonite, which has a low thermal conductivity and thus weakens heat conduction between solid grains. From the analysis, for all hybrid soil, the thermal conductivity value increase when the percentage of bentonite increase from 0% to 20% and decrease when the percentage of bentonite increase from 20% to 100%. Besides, all hybrid soil has a higher thermal conductivity value when the percentage of bentonite is 20%. However, hybrid soil with native soil grain size 2.0-2.5mm has a higher thermal conductivity value than other hybrid soil as shown in Figure 9. Therefore, the increase in the range value of native soil grain size increases the value of thermal conductivity. The highest thermal conductivity value for all hybrid soil was used to investigate the effect on the GHE performance, which were 0.269W/m.K, 0.278W/m.K, 0.292W/m.K and 0.331W/m.K.

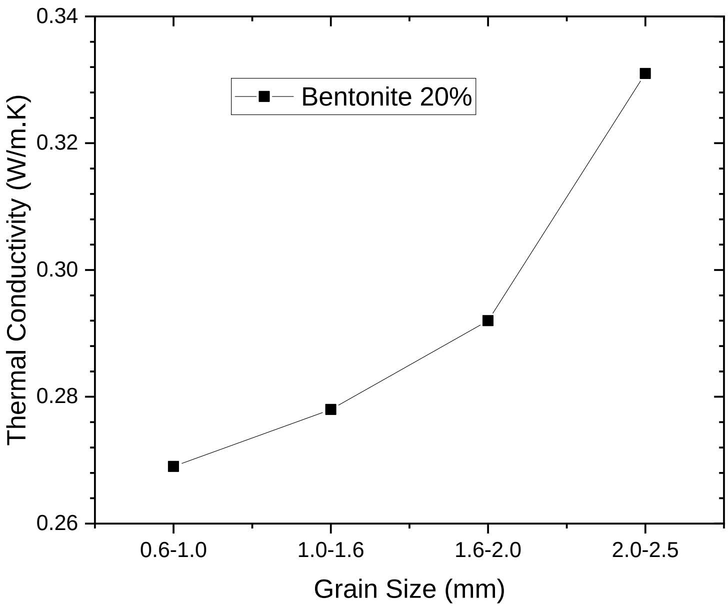

Fig. 9. The thermal conductivity value of hybrid soils with four native soil grain sizes at 20% bentonite

Simulation to analyse the performance of the GHE was conducted by analysing the air temperature inside the pipe by implementing the value of thermal conductivity without hybrid, which is 0.201W/m.K and four different thermal conductivity values for hybrid soil: 0.269W/m.K, 0.278W/m.K, 0.292W/m.K and 0.331W/m.K. The air temperature was simulated from 0 to 25m of pipe length using Eq. (7) and plotted in a graph as shown in Figure 10.

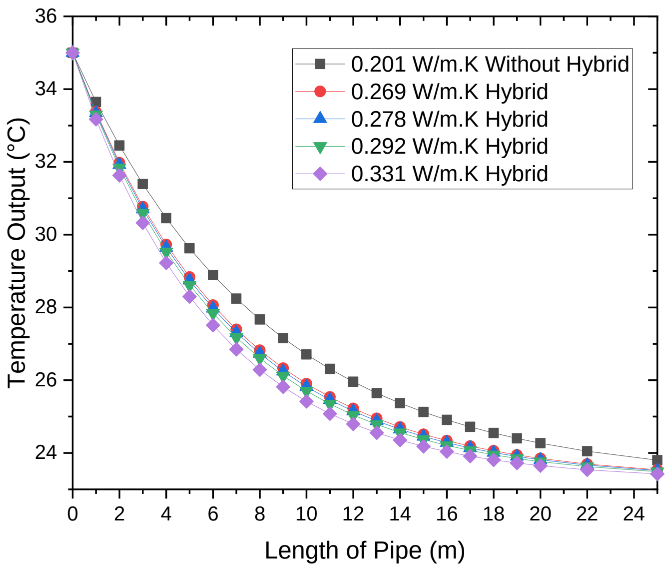

Fig. 10. Length of the pipe against air temperature for five thermal conductivity values

The graph indicates that the thermal conductivity value without hybrid and four thermal conductivity values of hybrid soil follow the same trend. The graph demonstrates that the temperature output gradually decreases from 0-16m length of pipe with an air inlet temperature of 35°C to 24.91°C, 24.34°C, 24.28°C, 24.21°C and 24.04°C of 0.201W/m.K, 0.269W/m.K, 0.278W/m.K, 0.292W/m.K and 0.331W/m.K respectively. Then, it remains nearly constant between 16-25m pipe length for all thermal conductivity values. The thermal conductivity of 0.331W/m.K has a better exit temperature, which is at 24.04°C compared to exit air temperature of thermal conductivity value 0.201W/m.K, 0.269W/m.K, 0.278W/m.K and 0.292W/m.K. Therefore, the thermal conductivity value of 0.331W/m.K has a better effect on the GHE performance than others. Thus, it can be concluded that the highest the thermal conductivity value of hybrid soil, the greater the impact on air temperature. In addition, bentonite is suitable for use as backfilling material at a certain amount to enhance the thermal conductivity value.

4. Conclusions

The hybrid soil was used in this study to investigate the performance of the GHE system using simulation. The hybrid soil comprises two components: native soil as the primary soil and bentonite as the backfilling material. There are four native soil grain sizes, which are 0.6-1.0mm, 1.0-1.6mm, 1.6-2.0mm, and 2.0-2.5mm. All four grain sizes of native soil were thoroughly mixed with a percentage of bentonite ranging from 0% to 100% by mass with a 10% increment. Besides, all hybrid soil has a higher thermal conductivity value when the percentage of bentonite is 20%. However, hybrid soil with native soil grain size 2.0-2.5mm has a higher thermal conductivity value than other hybrid soil. A simulation was performed using a mathematical model to investigate the effect of hybrid soil thermal conductivity value on the performance of the GHE system. The result shows that the thermal conductivity value of 0.331W/m.K has a more significant effect than 0.201W/m.K, 0.269W/m.K, 0.278W/m.K, 0.292W/m.K. Therefore, it is possible to conclude that increasing the soil's thermal conductivity can improve the GHE system's performance.

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