FINAL REPORT

INTERNATIONAL RESEARCH COLLABORATION

AND SCIENTIFIC PUBLICATION

DEVELOPMENT OF A NEW SPIRAL-TUBE GROUND HEAT EXCHANGER FOR AIR CONDITIONING SYSTEM

Chief researcher

Dr. Eng. Jalaluddin, ST, MT (NIDN: 0025087201)

Member of researcher

Dr. Rustan Tarakka, ST, MT (NIDN: 0027087504)

International partner

Prof. Akio Miyara (Saga University Japan)

HASANUDDIN UNIVERSITY

2018

HALAMAN PENGESAHAN
SBK RISET DASAR

Tittle of Research	:	DEVELOPMENT OF A NEW SPIRAL-TUBE GROUND HEAT EXCHANGER FOR AIR CONDITIONING SYSTEM.
Focus interest	:	Energi dan Energi terbarukan
Code/Name of field of science	:	431/Teknik Mesin (dan Ilmu Permesinan Lain)
Principal researcher	:	
a. Full name	:	Dr Jalaluddin S.T, M.T
b. NIDN	:	0025087201
c. Academic rank	:	Lektor Kepala
d. Study program	:	Teknik Mesin
e. Mobile phone/Email	:	082192267077/ jalaluddin_had@yahoo.com
Member of researcher (1)		
a. Full name	:	Dr Rustan Tarakka S.T, M.T
b. NIDN	:	0027087504
c. University	:	Hasanuddin University
International partner		
a. Full name	:	Prof. Akio Miyara
b. Name of institution	:	Saga University Japan
c. Address of institution	:	1 Honjomachi, Honjo, Saga, 840-8502, Japan
Length of research period	:	3 years
Year of research	:	3
Total research funds	:	Rp118,500,000.00
Research funds of current year	:	
- proposed to DRPM	:	Rp118,500,000.00
- approved by DRPM	:	Rp90,000,000.00
- Internal Univ. fund	:	Rp0
- Others	:	Rp0/in kind, please mention
Additional output Fund	:	Rp 0.00

Acknowledged,
Vice Dean for Academic Affairs of
Engineering Faculty

(Prof. Baharuddin, ST, M. Arch., Ph.D)
NIP/NIK 196903081995121001

Kota Makassar, 16-11-2018
Principal researcher,

(Dr JALALUDDIN S.T, M.T)
NIP/NIK 197208252000031001

Approved,
Head of LP2M Hasanuddin University

(Prof. Dr. Andi Alimuddin, M.Si)
NIP/NIK 19620818198702100l

RINGKASAN

Ground Source Heat Pump (GSHP) System merupakan sistem permesinan yang digunakan untuk pemanasan dan pendinginan dengan aplikasi yang sangat luas antara lain : pengkondisian udara pada bangunan, suplai air panas dan aplikasi pada pertanian. Aplikasi yang paling banyak digunakan dari sistem ini adalah untuk pengkondisian udara (pendinginan dan pemanasan) pada bangunan perumahan dan komersial.

Pengembangan beberapa tipe dari *Ground Heat Exchanger (GHE)* yang merupakan bagian dari sistem GSHP dan modifikasinya telah membantu dalam mengembangkan pemahaman tentang GHE untuk sistem pengkondisian udara yang dikenal dengan *Ground Source Cooling System.* Sekarang ini GHE tipe spiral-tube mendapatkan perhatian yang luas terkait dengan tingginya pertukaran panas dari GHE dengan tanah sekitaarnya. Penelitian ini bertujuan untuk mengembangkan sebuah GHE tipe spiral yang baru dan mempelajari performancenya selama 3 (tiga) tahun periode penelitian.

Pelaksanaan penelitian tahun ke-3 dari periode penelitian selama 3 (tahun) untuk mengembangan sebuah GHE tipe spiral yang baru telah dilakukan di Laboratorium Energi Terbarukan Prodi Teknik Mesin Universitas Hasanuddin. Kegiatan penelitian yang telah dilakukan meliputi: 1) Studi eksperimental tentang kondisi termal tanah, 2) Evaluasi unjuk kerja dan distribusi temperatur pada GHE tipe spiral dengan kedalam 3 m dengan variasi temperatur air masuk, 3) Evaluasi unjuk kerja GHE tipe spiral yang dipasang pada kondisi seri dan parallel, 4) Evaluasi berbagai faktor yang berpengaruh terhadap GHE tipe vertikal dengan simulasi numeric, 5) Menyusun rekomendasi desain untuk GHE tipe vertical. Adapun kegiatan terkait kerjasama internasional meliputi: 1) Kunjungan Prof. Miyara (Intrnational Partner) ke Laboratorium Energi Terbarukan, 2) Diskusi Kerjasama Penelitian & Kelas Internasional di Departemen Teknik Mesin Universitas Hasanuddin, 3) Kuliah Tamu / Visiting Lecture oleh Prof. Miyara, 4) Kerjasama dengan ACK Group Japan, 5) Kunjungan Perusahaan Japan (Asano Taiseikiso Engineering Co., Ltd.), 6) Kuliah Tamu oleh Dr. Eng. Arif Widiatmojo. Selanjutnya, diskusi dengan international partner (Prof. Miyara) dilakukan di Malang, Indonesia pada tanggal 29 s/d 31 Agustus 2018.

Beberapa hasil penelitian telah dihasilkan seperti Thermal performance of shallow spiral-tube ground heat exchanger for ground-source cooling system & Experimental Performance Analysis of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations telah dipresentasikan dan dipublish pada prosiding terindeks Scopus, The 5th International Symposium on Material, Mechatronics and Energy (ISMME) 2018 dan International Conference on Automative, Manufacturing and Mechanical Engineering (IC-AMME) 2018.

Desain dan rekomendasi untuk model baru spiral-tube GHEs pada aplikasi engineering telah dibuat.

DAFTAR ISI

BAB I PENDAHULUAN

Sekarang ini, penggunaan sumber energi yang ramah lingkungan dan terbarukan merupakan suatu tantangan untuk membuatnya menjadi teknologi yang attraktif dengan biaya yang efektif. Penggunaan energi geotermal telah dikenal sebagai solusi untuk mengurangi emisi gas rumah kaca seperti karbon dioksida (CO_2), sulphur dioksida (SO_2), dan Nitrogen Oksida (NO_x) di atmosfir. Sumber energi ini berdasarkan ASHRAE (2011) dikategorikan antara lain: 1) Temperatur tinggi (> 150 ^oC), untuk pembangkit listrik ; 2) Temperatur rendah dan menengah (< 150 ^oC), untuk pemanfaatan langsung ; dan 3) Temperatur < 32 ^oC, untuk aplikasi sistem pompa kalor yang berbasis tanah yang secara internasional dikenal dengan sistem *ground-source heat pump* (GSHP).

Aplikasi yang paling dikenal sekarang ini adalah untuk pemanasan dan pendinginan ruangan pada perumahan dan bangunan komersial dengan menggunakan sistem GSHP. Sistem ini memberikan efisiensi yang tinggi dibanding dengan sistem pompa kalor yang berbasis udara yang secara internasional dikenal dengan sistem *air source heat pump* (ASHP). Ground Heat Exchanger (GHE) digunakan pada sistem GSHP sebagai alat penukar kalor antara air sirkulasi dengan tanah sekeliling. Tiga parameter penting dalam mempelajari kinerja alat penukar kalor ini adalah konduktivitas termal, tahanan termal dari borehole dan temperatur tanah sekeliling.

Untuk pengembangan GHE tipe spiral yang baru diperlukan studi yang mendalam. Beberapa faktor seperti geometri optimum dari GHE tipe spiral dan kondisi operasi pada aplikasi sangat dibutuhkan dalam membuat guideline desain. Studi numerik dan eksperimental dibutuhkan untuk menggambarkan karakteristik dari faktor tersebut diatas. Pengembangan Ground-source Cooling System di Indonesia membutuhkan studi yang komprehensif terkait sifat-sifat termal tanah dan desain GHE tipe spiral serta konfigurasinya dalam aplikasi. Studi ini akan membandingkan data-data dari berbagai tipe GHE untuk mengetahui karakteristik GHE berdasarkan data di Japan dan Indonesia.

Tujuan Penelitian

Tujuan utama dari penelitian ini adalah untuk mengembangkan GHE tipe spiral yang baru untuk sistem pengkondisian udara. Target final yang diharapkan adalah rekomendasi desain dari GHE tipe spiral yang baru sekaligus membangun jaringan kerjasama penelitian internasional.

Tujuan penelitian dapat diuraikan sebagai berikut :

1. Mempelajari sifat termal dan karakteristik tanah di Makassar, Indonesia
2. Mempelajari berbagai faktor terkait untuk mengembangkan GHE tipe spiral yang baru untuk Ground-source cooling system.
3. Mengembangkan dan memasang GHE tipe spiral
4. Mempelajari peformansi GHE berdasarkan data eksperimental
5. Menganalisis energi dan exergi dari Ground-source cooling system

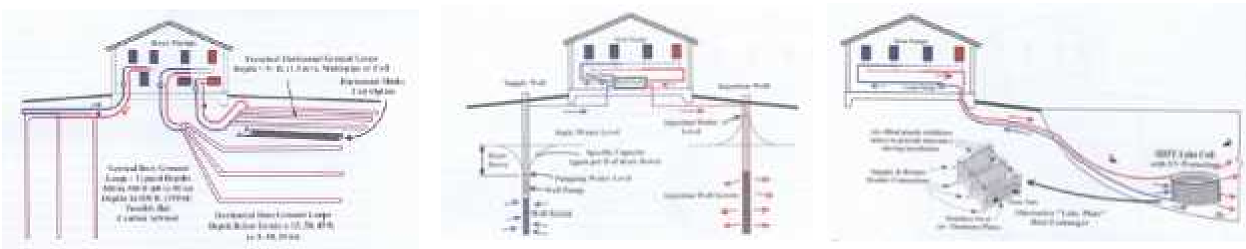
Output Penelitian

Target utama dari penelitian ini adalah mengembangkan GHE tipe baru dari modifikasinya untuk Ground-source cooling sistem. Hasil dari penelitian dipublish pada prosiding konferensi internasional dan jurnal ilmiah internasional setiap tahunnya.

BAB II TINJAUAN PUSTAKA

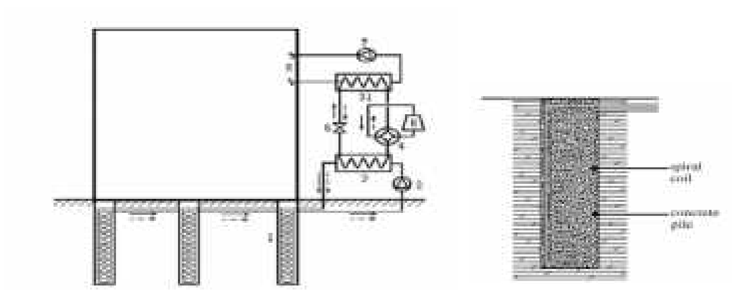
Sistem GSHP digunakan secara luas dalam aplikasi sebagai pemanas dan pendingin ruangan, suplai air panas dan aplikasi pada bidang pertanian. Pemanfaatan yang paling banyak dikenal adalah aplikasi sebagai pendingin dan pemanas ruangan pada bangunan perumahan dan komersial.

Beberapa penelitian telah dilakukan untuk mempelajari sistem GSHP ini. Pengembangan baru yang inovatif telah dilakukan oleh peneliti-peneliti internasional dan hasil penelitian mereka telah dipublish secara internasional. GHE yang digunakan dalam sistem GSHP dapat dibagi menjadi GHE yang dipasang secara horizontal dan vertikal seperti yang ditunjukkan pada gambar 1.



Gambar 1. GHE dipasang secara horizontal dan vertikal (Kavanaugh and Rafferty, 2014)

Diagram sekamtik GHE tipe spiral yang digunakan dalam sistem GSHP ditunjukkan pada gambar 2. GHE tipe ini mempunyai kenerja yang tinggi dibandingkan tipe konvensional. Walaupun demikian, kinerja yang tinggi dari GHE ini hanya dapat diperoleh pada kondisi-kondisi tertentu seperti kedalaman borehole, sistem operasi dan konfigurasi bentuk spiralnya.



Gambar 2. Diagram skematik dari GHE tipe spiral oleh Man et al. (2010) and Cui et al. (2011)

Persoalan mendasar pada GHE adalah biaya instalasi dan borehole untuk tipe vertikal dan keterbatasan area tanah yang tersedia untuk tipe horizontal. Penelitian ini akan mengembangkan GHE tipe spiral dengan kedalaman rendah dari borehole untuk mengatasi persoalan tersebut. Untuk mencapai maksud tersebut, tahapan penelitian telah disusun dan pelaksanaan penelitian telah dan sedang dilakukan. Beberapa hasil penelitian telah diperoleh untuk mendukung pengembangan GHE tipe spiral ini.

BAB III. METODE PENELITIAN

Penelitian dilakukan untuk mengembangkan GHE tipe spiral yang baru untuk Ground-source Cooling System. Studi numerical dan eksperimental sedang dilakukan di Laboratorium Energi Terbarukan Prodi Teknik Mesin Universitas Hasanuddin berkolabarasi dengan Laboratorium Termal Saga University Japan.

Indikator Kemajuan dari penelitian ini dapat dilihat dari output penelitian sebagai berikut:

(1) Diskusi Ilmiah dan Publikasi pada Prosiding konferensi Internasional (tahun ke-1, 2 dan 3)

(2) Publikasi Ilmiah pada Jurnal Internasional (tahun ke-1, 2 dan 3)

(3) Guideline rekomendasi desain

BAB IV. PELAKSANAAN PENELITIAN

Penelitian tentang pengembangan sebuah GHE tipe spiral yang baru sedang dilakukan di laboratorium Energi Terbarukan Prodi Teknik Mesin Universitas Hasanuddin.

Kegiatan penelitian yang dilakukan antara lain:

1) Studi eksperimental tentang kondisi termal tanah
2) Evaluasi unjuk kerja dan distribusi temperatur pada GHE tipe spiral dengan kedalam 3 m dengan variasi temperatur air masuk
3) Evaluasi unjuk kerja GHE tipe spiral yang dipasang pada kondisi seri dan parallel
4) Evaluasi berbagai faktor yang berpengaruh terhadap GHE tipe vertikal dengan simulasi numerik
5) Menyusun rekomendasi desain untuk GHE tipe vertikal

A. Experimental Set-up

Expeimental set-up dilakukan dengan membuat 3 buah GHE tipe spiral dipasang pada tanah dengan kedalaman 3 meter.

Experimental Set-up

B. Studi eksperimental tentang kondisi termal tanah

Temperatur tanah lokal (pada Fakultas Teknik Gowa, Universitas Hasanuddin) diukur sampai kedalaman 7 m. Hasil pengukuran ditunjukkan pada gambar 1.

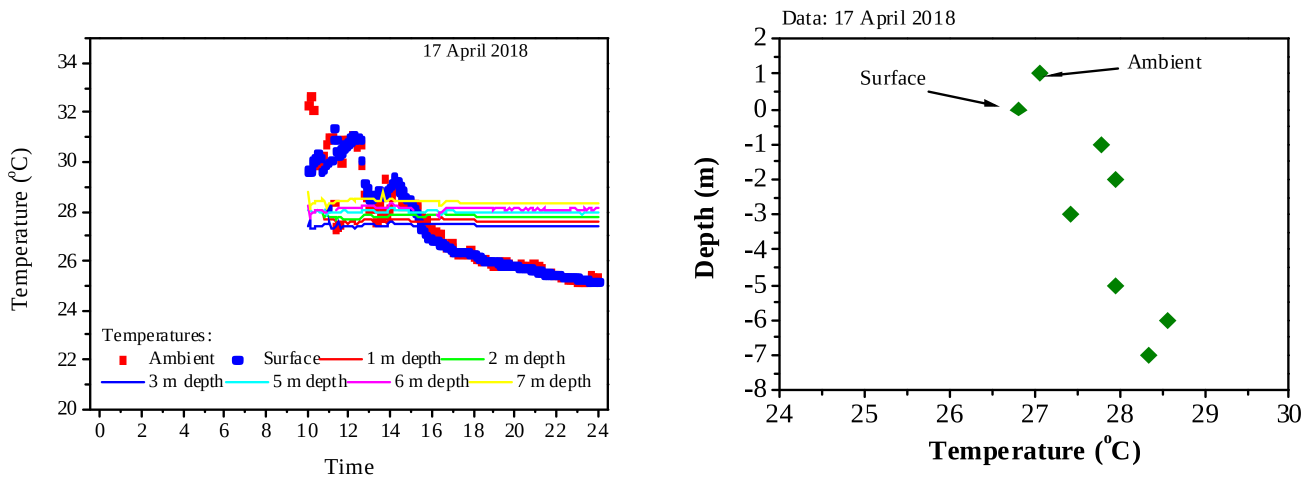


Fig. 1. The local ground temperature at Engineering Faculty of UNHAS Gowa campus

Profil tanah lokal (pada Fakultas Teknik Gowa, Universitas Hasanuddin) ditunjukkan pada gambar 2, sebagai berikut:

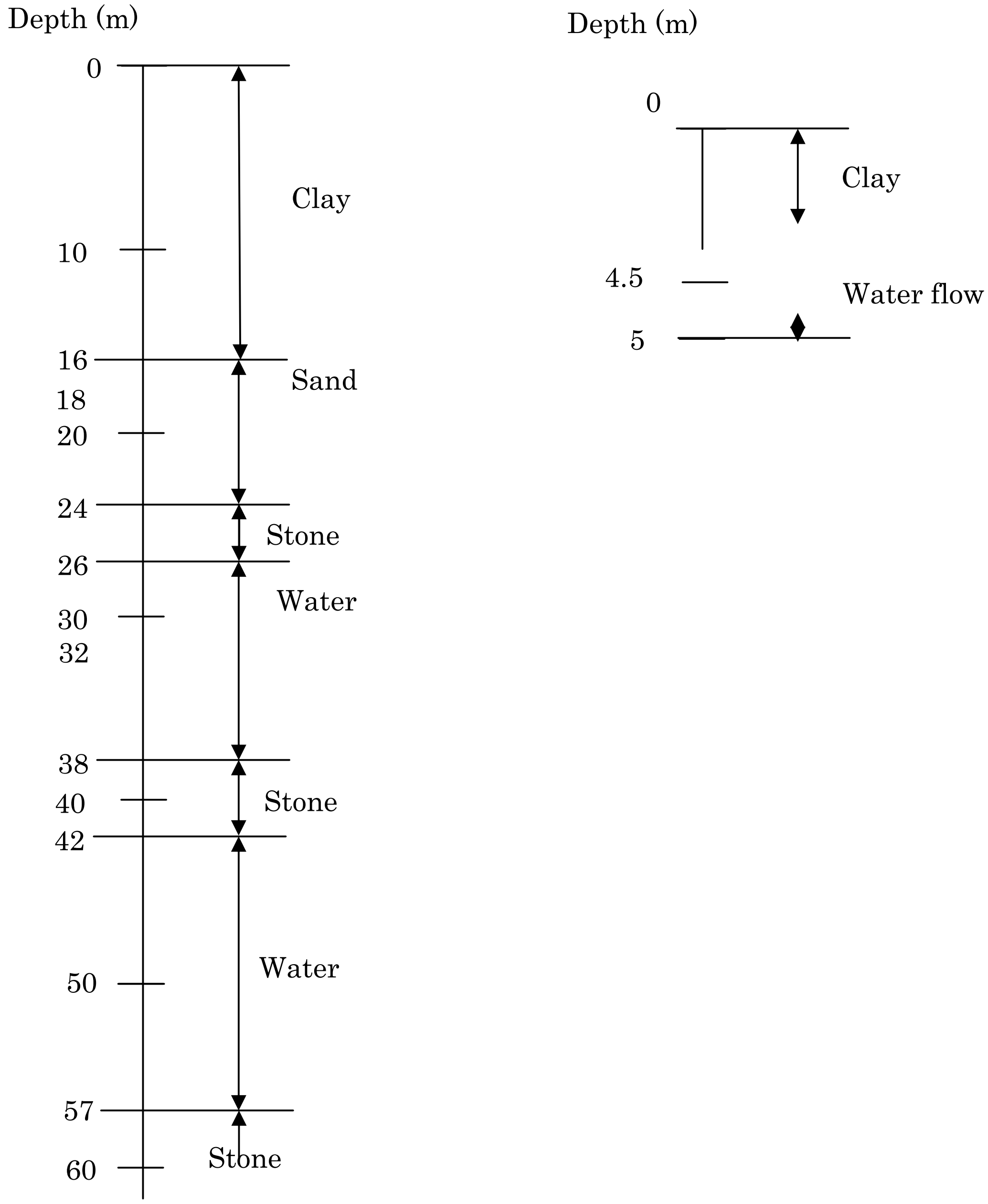


Fig. 2 Ground Profile at Engineering Faculty of UNHAS Gowa campus

C. Evaluasi unjuk kerja dan distribusi temperatur pada GHE tipe spiral dengan kedalaman 3 m dengan variasi temperatur air masuk

Thermal performance of shallow spiral-tube ground heat exchanger for ground-source cooling system

Jalaluddin [1, *], *Akio* Miyara[2], *Rustan* Tarakka[1], *Andi Amijoyo* Mochtar[1], *Muhammad* Anis IR[1]

[1] Department of Mechanical Engineering, Hasanuddin University, Tamalanrea, Makassar, 90245, Indonesia
[2] Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi, 840-8502, Japan

Abstract. This study present an investigation of thermal performance of spiral-tube ground heat exchanger (GHE) buried in shallow depth of borehole. The spiral-tube GHE consisting of spiral pipe installed in the borehole provides a better performance in application of ground-source cooling system. Experimental study was carried-out by circulating water through the spiral-tube GHE which is buried in the ground of 3 m depth. Temperatures of inlet and outlet water in the GHE were measured and recorded periodically. The thermal performance of the GHE was calculated with different inlet water temperatures. Heat exchange rate for different inlet water temperature of the spiral-tube GHEs are 44 W/m (35 ^{o}C), 126 W/m (40 ^{o}C) and 110 W/m (45 ^{o}C). The results show that the utilization of shallow borehole of spiral-tube GHE is appropriated for application in ground-source cooling system especially for the hot climate like Indonesia.

Key words: Ground heat exchanger, spiral-tube GHE, ground-source cooling system, thermal performance

1 Introduction

The ground source cooling system shows potential technology in engineering application for air conditioning system in the building. Ground heat exchanger (GHE) is used in this system for exchanging heat with the ground. Thermal performances of a number type of GHEs installed vertically and horizontally have been investigated. The performances of U-tube, double-tube and multi-tube types show that the heat exchange rate of the double-tube has the highest [1]. Operation modes of the GHEs including short-time period, discontinuous and continuous operations affected their heat exchange rates [2, 3]. Pipe thermal interferences, inlet water temperature and borehole depth also affected the heat exchange rate of the GHEs [4]. Recently, a spiral tube GHE is gaining interest due to its better thermal performance. In the spiral tube GHE, a spiral pipe is installed in the borehole or building foundation pile. Some studies have been carried-out to investigate the thermal performance of types of GHE. Analytical solutions for spiral coil type of GHE have been developed by Man et al. [5], Cui et al. [6], Man et al. [7] and Li and Lai [8]. In addition, comparison study of helical GHE with double U-tube and triple U-tube models have been presented by Zarella et al. [9, 10]. It is found that the helical GHE performance is better than others. The performance and pressure drop along the pipes of spiral tube GHE is a significant parameter in the GHE design [11]. Large investment cost is required to install a deep borehole of spiral-tube GHE. Several parameters should be considered in the design of spiral-tube GHE such as pumping power due to pressure drop and ineffective of outlet pipe due to thermal interference. In order to provide the possibility for reducing a borehole depth, a shallow spiral-tube GHE is taking interest. Dehghan et al. studied the performance and distance between shallow spiral-tube GHEs [12].

The heat transfer rate of shallow spiral-tube GHE becomes an important issue in application. However, there is a limited number on performance investigation of shallow spiral-tube GHEs. This study presents an experimental investigation of thermal performance of shallow spiral-tube GHE in order to study the possibility of application. The thermal performance of the GHE was calculated with different inlet water temperatures.

2 Experimental study

2.1 Spiral-tube ground heat exchanger

Spiral-tube GHE consists of a spiral pipe used as inlet tube and a straight pipe used as outlet pipe is shown in figure 1. Inlet and outlet pipes of the spiral-tube GHE are PEX-AL-PEX which is a multi-layered composite tubing consisting of an interior aluminum tubing lined with inner and outer layers of crosslinked polyethylene tubing with an inner diameter of 12 mm. The geometric parameter and material thermal properties of the spiral-tube GHE is shown in Table 1.

.

Fig. 1. Spiral-tube GHE.

Table 1. The geometric parameter and material thermal properties of the spiral-tube GHE.

Parameters	Value	Unit
Outer diameter, d_o	0.016	m
Inner diameter, d_i	0.012	m
Thermal conductivy, k_{pipe}	0.45	W/m K
Spiral diameter, D	0,25	m
Pitch (Spiral distance), p	0.2	m

2.2 Experimental set-up

The spiral-tube GHE is installed in the borehole of 3 m depth. The schematic diagram of experimental set-up is shown in figure 2. The spiral-tube GHE is placed 1 m depth from the ground level to protect from the effect of ambient climate. The experiment was carried-out by circulating water through the spiral-tube GHE with different inlet water temperatures. Inlet and outlet temperatures of circulated water and ambient air temperature were periodically recorded. Water was circulated into the spiral-tube GHE. Different inlet temperatures were applied of 35, 40 and 45 ^{o}C in the experiments. The flow rate of circulated water was set to be constant of 3.6 L/min.

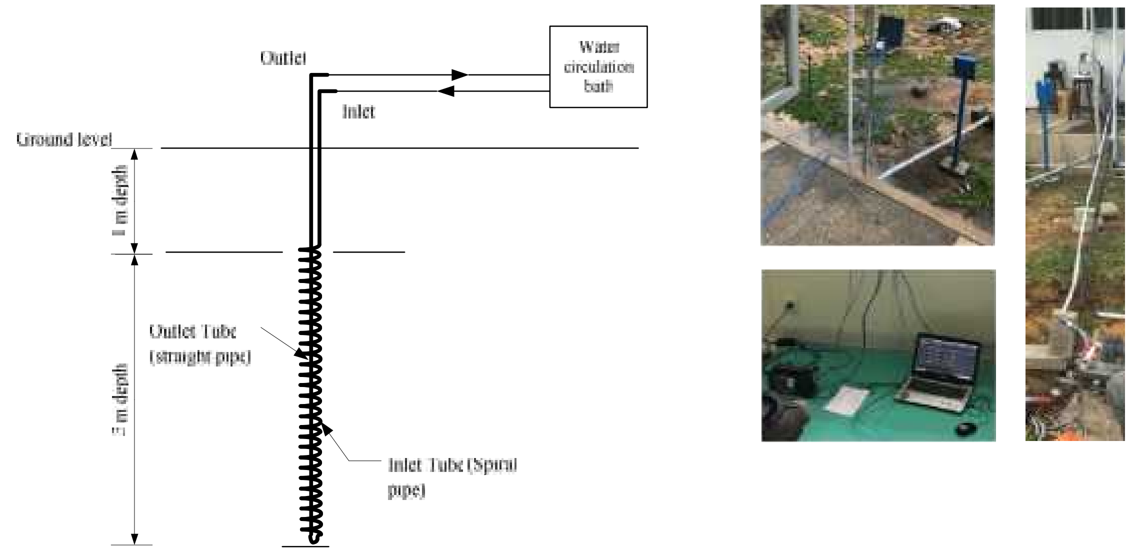


Fig. 2. The Schematic Diagram of Experimental Set-up.

3 Results and discussion

3.1 Temperature distributions

The temperatures of inlet and outlet water of the spiral-tube GHE, ground and ambient air were measured periodically as shown in figure 3. Local ground temperature at Hasanuddin University Gowa campus (119^o 30’ 06.1” E and 05^o 13' 52.4" S) was measured at 3 m depth. This ground temperature is also shown in figure 3. The initial ground temperature surrounding the borehole is 27-28 ^{o}C. Water was circulated through the spiral-tube GHE. The temperature of water decreased gradually along the spiral pipe. The average temperature differences of inlet and outlet water are 0.5 °C for inlet water temperature of 35 °C; 1.3 °C for inlet water temperature of 40 °C and 1.1°C for inlet water temperature of 45 °C.

3.2 Heat exchange rate

The thermal performance of the spiral-tube GHE is evaluated by calculating its heat exchange rate. The heat exchange rate, Q, is calculated by the following equation:

$$Q = \dot{m} c_p \Delta T \, , \quad (1)$$

where $\dot{m}$ is flow rate, c_p is specific heat, and ΔT is the temperature difference of inlet and outlet water.

For simplicity, the heat exchange rate per meter of borehole depth, $\overline{Q}$, is defined as

$$\overline{Q} = Q / L \, , \quad (2)$$

where L is borehole depth of spiral-tube GHE.

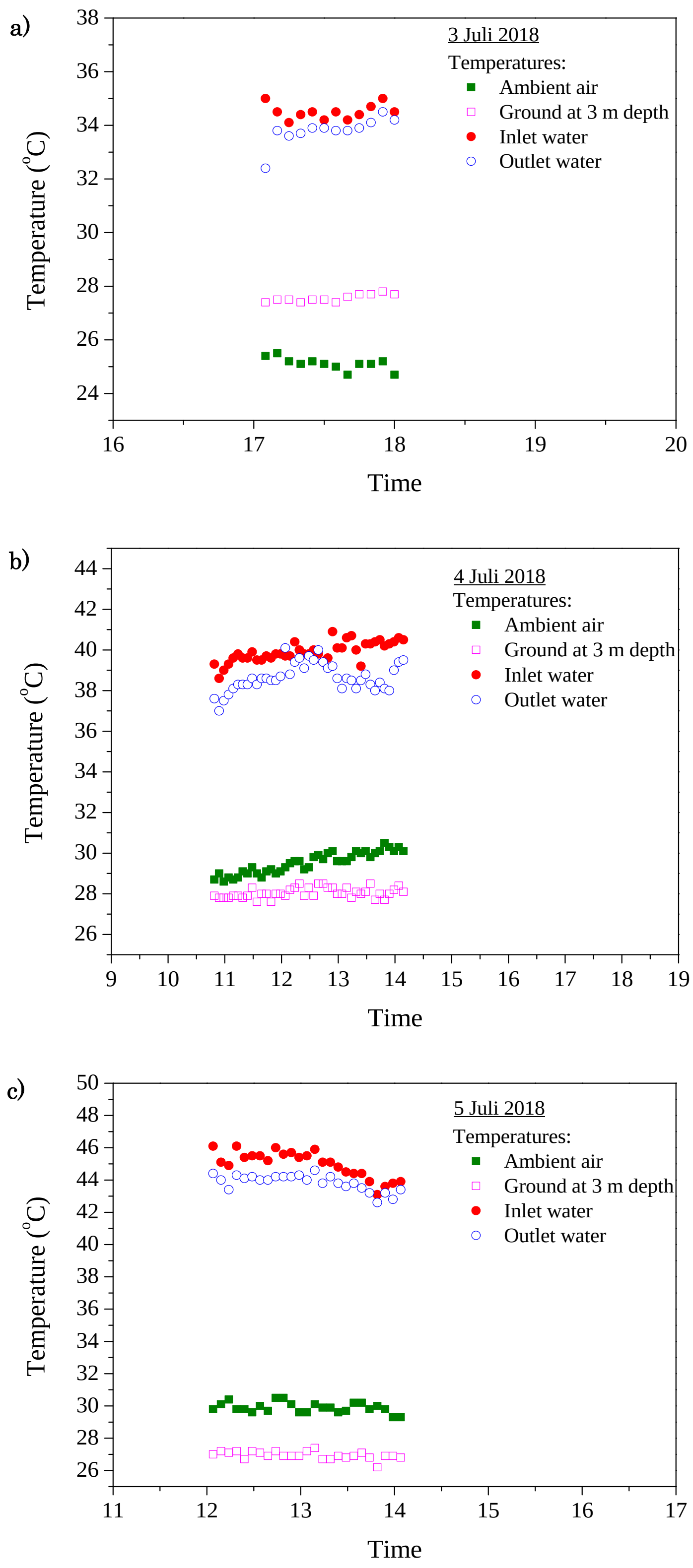


Fig. 3. Temperatures Distribution of Spiral-tube GHE.

The heat exchange rates of the spiral-tube GHE with different inlet temperatures are shown in figure 4. Heat is rejected to the ground surrounding the borehole through water flowing in the spiral-tube GHE. The high rejected heat to the ground will increase the performance of the GHE. The thermal performance of the GHE was calculated with the different inlet water temperature. Heat exchange rate for different inlet water temperature of the spiral tube GHEs are 44 W/m (35 ^{o}C), 126 W/m (40 ^{o}C) and 110 W/m (45 ^{o}C). The high heat exchange rate of the shallow spiral-tube GHE indicates that this GHE is appropriated for application in ground-source cooling system especially for the hot climate like Indonesia.

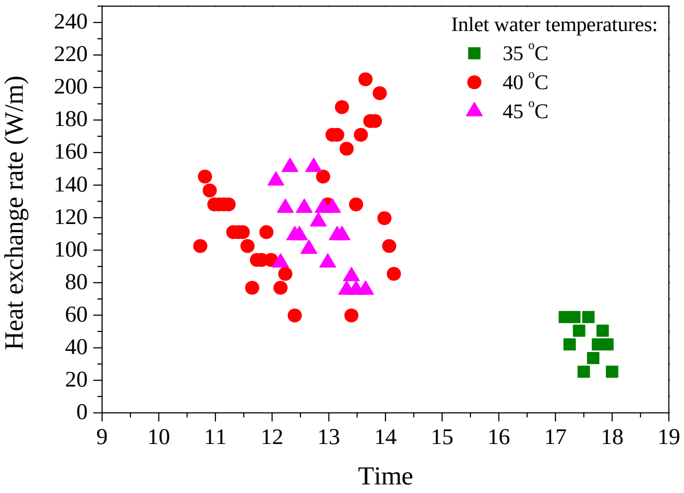


Fig. 4. Heat Exchange Rate of the Spiral-tube GHE.

4 Conclusions

The experimental study of shallow spiral-tube GHE which was buried in the ground of 3 m depth has been carried-out. The thermal performance of the GHE was evaluated by calculating its heat exchange rate. Based on the results of this study, the following conclusions are drawn:

1) The average temperature differences of inlet and outlet water are 0.5 °C for inlet water temperature of 35 °C; 1.3 °C for inlet water temperature of 40 °C and 1.1°C for inlet water temperature of 45 °C.
2) Heat exchange rate for different inlet water temperature of the spiral tube GHEs are 44 W/m (35 ^{o}C), 126 W/m (40 ^{o}C) and 110 W/m (45 ^{o}C).
3) The high heat exchange rate of the shallow spiral-tube GHE shows that the utilization of this type of GHE can be applied in ground-source cooling system especially for the hot climate like Indonesia.

Acknowledgment

This study was supported by LP2M Hasanuddin University and financed by grant of DIKTI (Directorate General of Higher Education of Indonesia).

References

1. Jalaluddin, A. Miyara, K. Tsubaki, S. Inoue, K. Yoshida, Ren. Energy, 36:764-771 (2011).
2. Jalaluddin, A. Miyara, K. Tsubaki, K. Yoshida, *Thermal performance of three types of ground heat exchangers in short-time period of operation*, Proceedings of the 13th International Refrigeration and Air Conditioning Conference at Purdue, West Lafayette, USA (2010).
3. Jalaluddin and A. Miyara, ATE, 33-34:167–174 (2012).
4. Jalaluddin and A. Miyara, 2016, JESTEC, 11 (12): 1771-1783 (2016).
5. Y. Man, H. Yang, N. Diao, J. Liu, Z. Fang, Int. J. Heat Mass Transfer, 53:2593–2601 (2010).

6. P. Cui, X. Li, Y. Man, Z. Fang, APEN, 88:4113–4119 (2011).
7. Y. Man, H. Yang, N. Diao, P. Cui, L. Lu, Z. Fang, HVAC&R Research, 17 (6):1075–1088 (2011).
8. M. Li and A.C.K. Lai, APEN, 96:451–458 (2012).
9. A.Zarrella, A. Capozza, M. De Carli, APEN, 112:358–370 (2013).
10. A. Zarrella, M. De Carli, A. Galgaro, 2013, ATE, 61:301-310 (2013).
11. Jalaluddin and A. Miyara, ATE, 90:630-637 (2015).
12. B. Dehghan, A. Sisman, M. Aydin, ENB, 127:999–1007 (2016).

D. Evaluasi unjuk kerja GHE tipe spiral yang dipasang pada kondisi seri dan parallel

Experimental Performance Analysis of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations

Jalaluddin [1,*], *Akio* Miyara[2], *Rustan* Tarakka[1], *Muhammad* Anis IR[1]

[1] Department of Mechanical Engineering, Hasanuddin University, Bontomarannu, Gowa, 92171, Indonesia
[2] Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi, 840-8502, Japan

Abstract. Ground source cooling system (GSCS) uses a ground heat exchanger (GHE) for exchanging heat with the ground. A spiral-tube GHE is gaining interest in recent year. This study presents an experimental analysis of thermal performance of shallow spiral-tube ground heat exchanger (GHE) installed in the ground at 3 m depth in series and parallel configurations. These GHE configurations offer a compromise between the conventional vertical and horizontal GHEs. The spiral-tube GHE which is consist of spiral pipe installed in the borehole provides a better performance in application of GSCS. The thermal performances of spiral-tube GHE in series and parallel configurations were investigated under actual condition. Inlet and outlet temperatures of the both configurations were measured and periodically recorded. The average heat exchange rates of the GHEs are 122.4 W/m in parallel configuration and 86.2 W/m in series configuration. Heat exchange rate of the spiral-tube GHEs in parallel configuration provides a better performance than that of in series configuration. The spiral-tube GHE in shallow depth can be applied in the GSCS.

Key words: Shallow spiral-tube GHE, series and parallel configurations, thermal performance

1 Introduction

The ground source heat pump system (GSHP) has been widely used for space heating and cooling system in the building. The GSHP system used for cooling system is also known as ground source cooling system (GSCS). A ground heat exchanger (GHE) which is used for exchanging heat with the ground in the GSHP system consists of vertical and horizontal types. The horizontal types of GHE such as horizontal slinky and spiral coil have been investigated for application in the GSHP system [1-6]. In the vertical types, a number types of pipe configuration installed in the vertical borehole are applied [7-12]. The spiral-tube GHE which is consist of spiral pipe installed in the vertical borehole is gaining interest in recent years [13-18]. The spiral-tube GHE provides a better thermal performance than others. Some studies have been carried-out to investigate the thermal performance of this type of GHEs. Analytical solutions have been developed for spiral coil type of GHE by man et al. [13], Cui et al. [14], Man et al. [15] and Li and Lai [16]. Characteristics of spiral-tube GHE including outlet pipe position and spiral pitch were discussed [17]. The performance of shallow borehole of spiral tube GHE has been investigated. Using this type of GHE can reduce the borehole depth compared with using the conventional U-tube GHE [18]. Zarella et al. [19, 20] presented a comparison study of helical GHE with double u-tube and triple U-tube models. The result confirmed that the performance of helical GHE is better than others. In addition, the groundwater flow affected the thermal performance of spiral coil GHE [21-23]. In the GHE design, the performance and pressure drop along the pipes of spiral pipe is a significant parameter [24]. Also, several parameters should be considered in the design of spiral-tube GHE such as pumping power due to pressure drop and ineffective of outlet pipe due to thermal interference in the deep borehole. Moch et al. [25] investigated helical heat exchangers buried in the subsoil between 1 and 4 m depth. Dehghan et al. [26] investigated the performance and the effect of distance between shallow spiral-tube GHEs. The performance of a conic helicoidal GHE for greenhouse heating buried in 3 m depth have been investigated by Boughanmi et al. [27].

In Horizontal GHE type, the large available land area is needed to install the GHE. Unfortunately, the large area is no longer available in urban areas. In addition, installing a deep borehole requires a large investment cost in vertical GHE type. In order to install the GHE in small land area and to reduce the borehole depth, a shallow spiral-tube GHE is taking interest to apply in engineering application. A number of shallow spiral-tube GHEs can be installed together in series and parallel configurations to meet the cooling demand of building. Furthermore, the performances of the shallow spiral-tube GHEs in both configurations are needed as a important parameter in application.

This work presents an experimental analysis of thermal performance of shallow spiral-tube GHE in series and parallel configurations under actual condition. Inlet and outlet temperatures of the both configurations were recorded periodically. The thermal performance of the GHE was evaluated by calculating its heat exchange rate.

2 Experimental set-up

Three shallow spiral-tube GHEs applied in the experimental study are shown in Figure 1. The spiral-tube GHE consists of a spiral pipe used as inlet tube and a straight pipe as outlet tube. Inlet and outlet pipes of the spiral-tube GHE are PEX-AL-PEX which is a multi-layered composite tubing consisting of an interior aluminum tubing lined with inner and outer layers of crosslinked polyethylene tubing with an inner diameter of 12 mm. Table 1 shows the parameter and thermal properties of the spiral-tube GHE.

Fig. 1. Three Spiral-tube GHEs.

Table 1. The parameter and thermal properties of the spiral-tube GHE.

Parameters	Value	Unit
Outer diameter of pipe, d_o	0.016	m
Inner diameter of pipe, d_i	0.012	m
Thermal conductivity, k_{pipe}	0.45	W/m K
Spiral / borehole diameter, D	0.25	m
Pitch (Spiral distance), p	0.2	m

The three spiral-tube GHEs namely SGHE#1, SGHE#2 and SGHE#3 were installed in the borehole of 3 m depth. The schematic diagram of experimental set-up is shown in Figure 2. The three spiral-tube GHE is placed 1 m depth from the ground level to protect from the effect of ambient climate. Distance between each the GHEs is 5 m. The experiments were carried-out by circulating water through the three spiral-tube GHE in series and parallel configurations. In the series configuration, water was circulated through the SGHE#1, SGHE#2 and SGHE#3. Circulated water flowed to the inlet pipes of each GHE in the parallel configuration. Inlet water temperatures were approximately 40-42 ^{o}C in the experiments for the both configurations. Inlet and outlet temperatures of circulated water and ambient air temperature were periodically recorded. The flowrate of circulated water was 3.6-3.8 L/min.

The thermal performance of the spiral-tube GHE is evaluated by calculating its heat exchange rate, Q.

$$Q = \dot{m} c_p \Delta T \quad (1)$$

where $\dot{m}$ is flowrate, c_p is specific heat, and ΔT is the temperature difference of inlet and outlet water.

The heat exchange rate per meter of borehole depth, $\overline{Q}$, is defined as

$$\overline{Q} = Q / L \quad (2)$$

where L is borehole depth of spiral-tube GHE.

3 Results and discussion

3.1 Temperature distributions

Temperature distributions including ambient air, inlet and outlet water were measured and recorded periodically as shown in Figure 3. Local ground temperature at Hasanuddin University Gowa campus (119° 30' 06.1" E and 05° 13' 52.4" S) was measured at 3 m depth. The average ground temperature at 3 m depth approximately 27-28 °C. In the series configuration, water was circulated through the SGHE#1, SGHE#2 and SGHE#3. The average temperatures of inlet water in SGHE#1 were 40 °C and outlet water in SGHE#3 were 35.6 °C as shown in Figure 3(a). Circulated water flowed to the inlet pipes of each GHE in the parallel configuration. The average temperatures in total of inlet and outlet water are 41 and 37 °C respectively as shown in Figure 3(b). The inlet and outlet water temperatures of each GHE are shown in Figure 3(c).

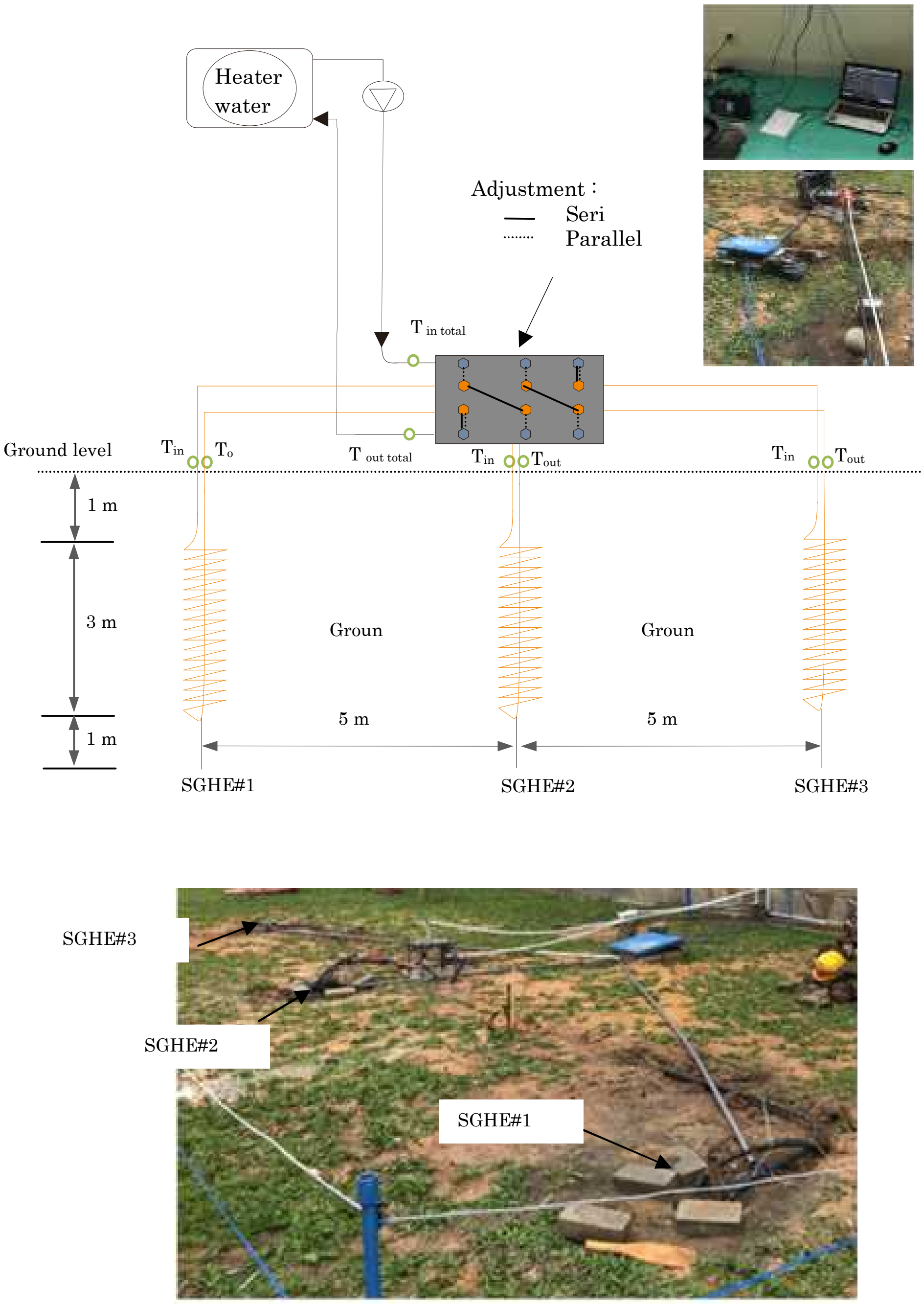


Fig. 2. The Schematic Diagram of Experimental Set-up.

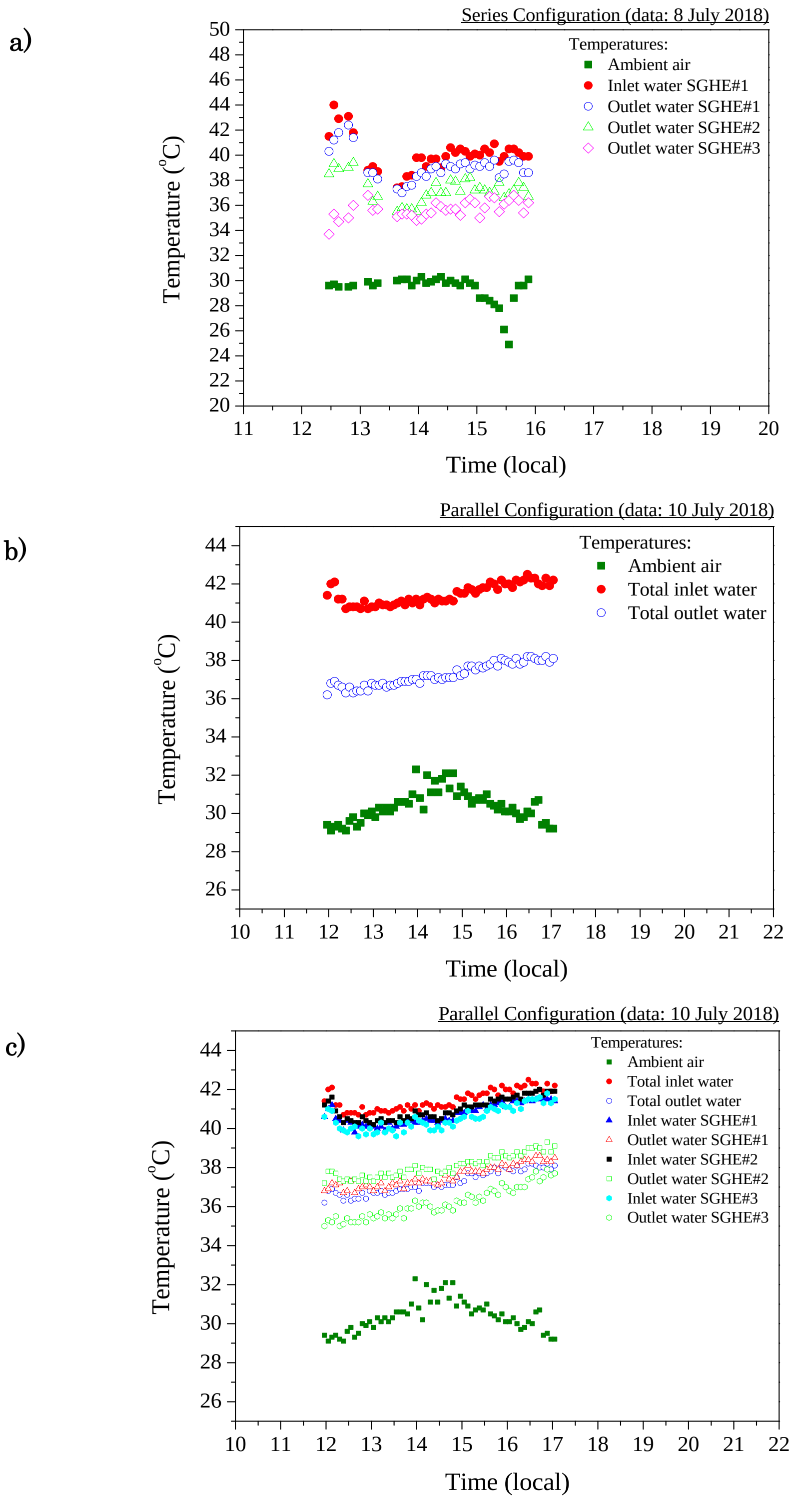
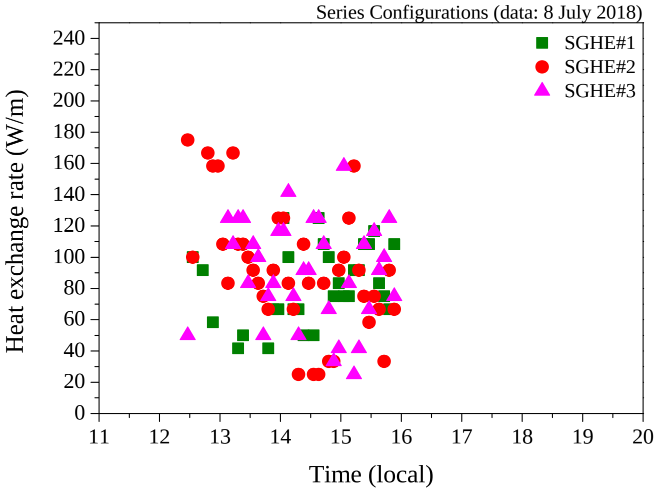


Fig. 3. Temperature Distributions of Spiral-tube GHE.

3.2 Heat exchange rate

The heat exchange rates of each spiral-tube GHEs in series configurations are shown in Figure 4 (a). Heat is rejected to the ground around the borehole through water flowing in the spiral-tube GHE. The performance of the GHE is affected by rejected heat to the ground. The thermal performance of the GHE was calculated based on the flowrate and temperature different between inlet and outlet water. In series configuration, the heat exchange rates are 79.9 W/m for SGHE#1, 92.3 W/m for SGHE#2 and 76.4 W/m for SGHE#3. The heat exchange rate in parallel configuration was calculated based on the temperature difference between inlet and outlet of the three GHEs. Finally, the heat exchange rates in average are 122.4 W/m in parallel configuration and 86.2 W/m in series configuration as shown in Figure 4 (b). This result confirms that the shallow spiral-tube GHE for the both configurations can be applied in the GSCS. The GHEs in parallel configuration provide a better performance than that of in series configuration. Inlet water temperature for each spiral-tube GHE in parallel configuration is similar. It also contributes to the high heat exchange rate in this configuration.

a)



b)

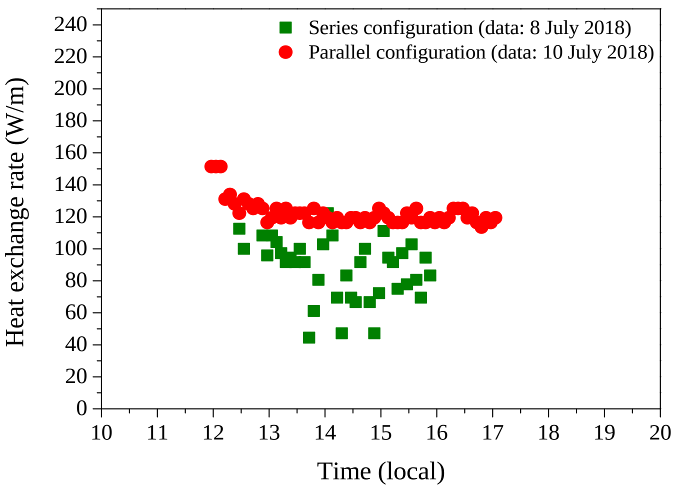


Fig. 4. Heat Exchange Rate of the Spiral-tube GHE.

4 Conclusions

The experimental study of three shallow spiral-tube GHEs in series and parallel configurations has been carried-out. The GHE performance was evaluated by calculating its heat exchange rate. The conclusions of this study are drawn as following:

1) The heat exchange rates are 79.9 W/m for SGHE#1, 92.3 W/m for SGHE#2 and 76.4 W/m for SGHE#3 in series configuration. In parallel configuration, the heat exchange rate is calculated based on the temperature difference between inlet and outlet of the three GHEs.

2) The heat exchange rates in average are 122.4 W/m in parallel configuration and 86.2 W/m in series configuration. The shallow spiral-tube GHE can be applied in engineering application of the GSCS in series and parallel configurations.
3) Finally, the GHEs in parallel configuration provide a better performance than that of in series configuration.

Acknowledgment

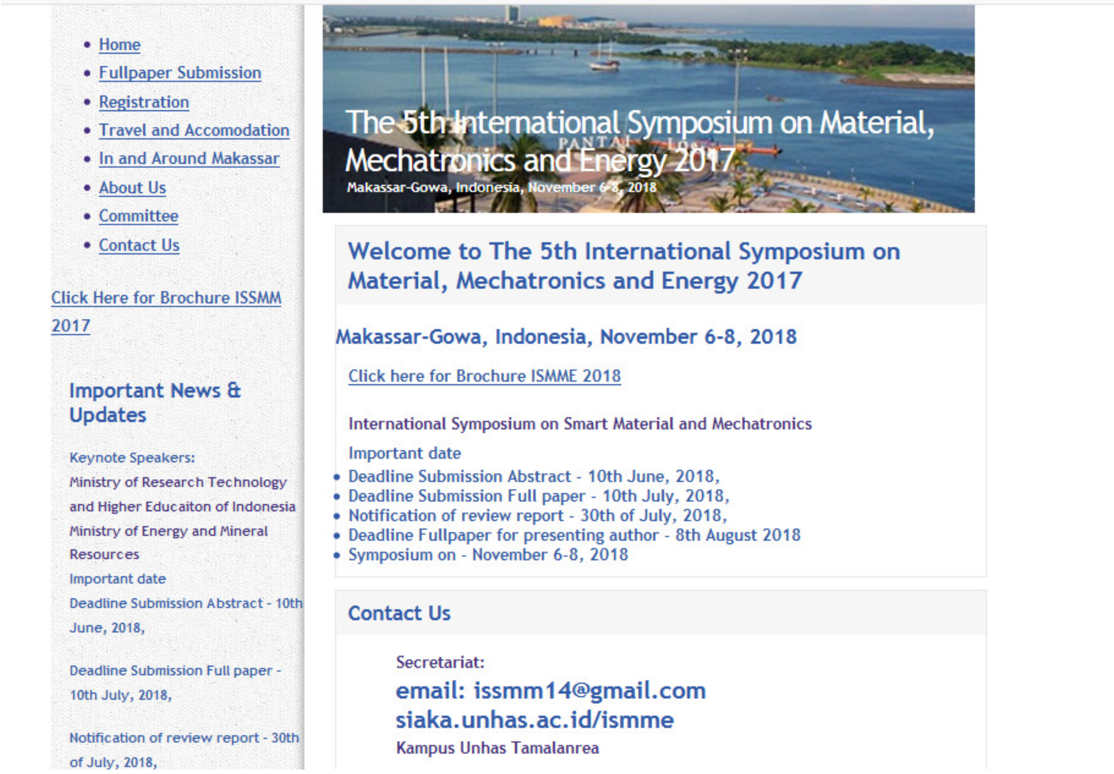
This study was supported by LP2M Hasanuddin University and financed by grant of DIKTI (Directorate General of Higher Education of Indonesia).

References

1. P. M. Congedo, G. Colangelo, G. Starace, J. Applthermaleng, 33-34:24-32 (2012).
2. S. Yoon, S. R. Lee, G. H. Go, J. Enbuild, 105:100–105 (2015).
3. Z. Xiong, D. E. Fisher, J. D. Spitler, J. Apenergy, 141:57–69 (2015).
4. S. Selamat, A. Miyara, K. Kariya, J. Renene, 95: 561-573 (2016).
5. J. S. Jeon, S. R. Lee, M. J. Kim, J. Energy, 152:732-743 (2018).
6. M. J. Kim, S. R. Lee, S. Yoon, J. S. Jeon, J. Geothermics, 72:338–347 (2018).
7. Jalaluddin, A. Miyara, K. Tsubaki, K. Yoshida, *Thermal performance of three types of ground heat exchangers in short-time period of operation*, Proceedings of the 13th International Refrigeration and Air Conditioning Conference at Purdue, West Lafayette, USA (2010).
8. Jalaluddin, A. Miyara, K. Tsubaki, S. Inoue, K. Yoshida, J. Renene, 36:764-771 (2011).
9. Jalaluddin and A. Miyara, J. Applthermaleng, 33-34:167–174 (2012).
10. Jalaluddin and A. Miyara, JESTEC, 11 (12):1771-1783 (2016).
11. X. Y. Li, T. Y. Li, D. Q. Qu, J. W. Yu, J. Geothermics, 65:72–80 (2017).
12. S. K. Fayegh, M. A. Rosen, J. Geothermics, 75: 15–25, (2018).
13. Y. Man, H. Yang, N. Diao, J. Liu, Z. Fang, Int. J. Heat Mass Transfer, 53:2593–2601 (2010).
14. P. Cui, X. Li, Y. Man, Z. Fang, J. Apenergy, 88:4113–4119 (2011).
15. Y. Man, H. Yang, N. Diao, P. Cui, L. Lu, Z. Fang, HVAC&R Research, 17 (6):1075–1088 (2011).
16. M. Li and A.C.K. Lai, J. Apenergy, 96:451–458 (2012).
17. Jalaluddin, A. Miyara, *Thermal performance and characteristics of spiral-tube ground heat exchanger for ground source heat pump*, The 15th International Heat Transfer Conference, ihtc digital library, Begell House (Kyoto Japan, August 10 – 15, 2014).
18. Jalaluddin, A. Miyara, R. Tarakka, JMeche, 15:2 (2018).
19. A. Zarrella, A. Capozza, M. De Carli, J. Apenergy, 112:358–370 (2013).
20. A. Zarrella, M. De Carli, A. Galgaro, 2013, J. Applthermaleng, 61:301-310 (2013).
21. W. Zhang, H. Yang, L. Lu, P. Cui, Z. Fang, J. Enbuild, 71:115–128 (2014).
22. G. H. Go, S. R. Lee, H. B. Kang, S. Yoon, M. J. Kim, J. Applthermaleng, 78:196-208 (2015).
23. W. Zhang, H. Yang, P. Cui, L. Lu, N. Diao, Z. Fang, Int. J. Heat Mass Transfer, 84: 119–129 (2015).
24. Jalaluddin and A. Miyara, J. Applthermaleng, 90:630-637 (2015).
25. X. Moch, M. Palomares, F. Claudon, B. Souyri, B. Stutz, J. Applthermaleng, 73:691-698 (2014).
26. B. Dehghan, A. Sisman, M. Aydin, J. Enbuild, 127:999–1007 (2016).
27. H. Boughanmi, M. Lazaar, A. Guizani, J. Solener, 171:343–353 (2018).

E. Submit Paper

1) ISMME 2018



Thermal performance of shallow spiral-tube ground heat exchanger for ground-source cooling system

Jalaluddin [1, *], *Akio* Miyara[2], *Rustan* Tarakka[1], *Andi Amijoyo* Mochtar[1], *Muhammad* Anis IR[1]

[1] Department of Mechanical Engineering, Hasanuddin University, Tamalanrea, Makassar, 90245, Indonesia
[2] Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi, 840-8502, Japan

Abstract. This study present an investigation of thermal performance of spiral-tube ground heat exchanger (GHE) buried in shallow depth of borehole. The spiral-tube GHE consisting of spiral pipe installed in the borehole provides a better performance in application of ground-source cooling system. Experimental study was carried-out by circulating water through the spiral-tube GHE which is buried in the ground of 3 m depth. Temperatures of inlet and outlet water in the GHE were measured and recorded periodically. The thermal performance of the GHE was calculated with different inlet water temperatures. Heat exchange rate for different inlet water temperature of the spiral-tube GHEs are 44 W/m (35 °C), 126 W/m (40 °C) and 110 W/m (45 °C). The results show that the utilization of shallow borehole of spiral-tube GHE is appropriated for application in ground-source cooling system especially for the hot climate like Indonesia.

Key words: Ground heat exchanger, spiral-tube GHE, ground-source cooling system, thermal performance

1 Introduction

The ground source cooling system shows potential technology in engineering application for air conditioning system in the building. Ground heat exchanger (GHE) is used in this system for exchanging heat with the ground. Thermal performances of a number type of GHEs installed vertically and horizontally have been investigated. The performances of U-tube, double-tube and multi-tube types show that the heat exchange rate of the double-tube has the highest [1]. Operation modes of the GHEs including short-time period, discontinuous and continuous operations affected their heat exchange rates [2, 3]. Pipe thermal interferences, inlet water

2) IC-AMME 2018

HOME | CALL FOR PAPER | KEYNOTE SPEECHES | COMMITTEE | REGISTRATION FEE | SUBMISSION | SCHEDULE | VENUE INFO

Home » Welcome to IC-AMME 2018

Welcome to IC-AMME 2018

International Conference on Automotive, Manufacturing, and Mechanical Engineering. This conference is a part of CIRAE (International Multi Conference on Innovative Research and Applied Engineering), more information available at cirae.petra.ac.id. The conference will be held in :

Bali, Indonesia on 26-28 Sept 2018.

Location : Holiday Inn Resort Baruna Bali, Kuta, Bali, Indonesia

Organized by : Mechanical Engineering Dept and Continuing Education Center, Petra Christian University

Important Dates

Extended Abstract :
~~11 May 2018~~

Acceptance
~~25 May 2018~~

Early Bird :
25 May - 6 Aug 2018

Paper Deadline :
~~11 Jul 2018~~ 25 Jul 2018

Paper Decision :
10 Aug 2018

Conference :
26-28 Sept 2018

Publication

All accepted papers will be published in :
Matec web of conferences (Scopus-indexed proceedings)

Experimental Performance Analysis of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations

Jalaluddin [1,*], *Akio* Miyara[2], *Rustan* Tarakka[1], *Muhammad* Anis IR[1]

[1] Department of Mechanical Engineering, Hasanuddin University, Bontomarannu, Gowa, 92171, Indonesia
[2] Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi, 840-8502, Japan

Abstract. This study presents an experimental analysis of thermal performance of shallow spiral-tube ground heat exchanger (GHE) installed in the ground at 3 m depth in series and parallel configurations. These GHE configurations offer a compromise between the conventional vertical and horizontal GHEs. The spiral-tube GHE consisting of spiral pipe installed in the borehole or in the building foundation pile provides a better performance in application of ground source cooling system. The thermal performances of spiral-tube GHE in series and parallel configurations were investigated under actual condition. Inlet and outlet temperatures of the both configurations were measured and periodically recorded. The average heat exchange rates of the GHEs are 122.4 W/m in parallel configuration and 86.2 W/m in series configuration. Heat exchange rate of the spiral-tube GHEs in parallel configuration provided a better performance than that of in series configuration. The spiral-tube GHE in shallow depth can be applied in the ground source cooling system.

Key words: Shallow spiral-tube GHE, series and parallel configurations, thermal performance

1 Introduction

The ground source heat pump system (GSHP) has been widely used for space heating and cooling system in the building. The GSHP system used for cooling system is also known as ground source cooling system (GSCS). A ground heat exchanger (GHE) which is used for

F. International Conferences

1) IC-AMME 2018

International Conference on Automotive, Manufacturing, and Mechanical Engineering (IC-AMME 2018) dilaksanakan di Holiday Inn Resort Baruna Bali, Kuta, Bali, Indonesia. 26 – 28 September 2018. Konferensi internasional ini dilaksanakan oleh Universitas Kristen Petra Surabaya. Prosiding dari konferensi ini akan dipublikasikan pada Matec web of conferences (prosiding terindeks Scopus).

2) ISMME 2018

International Symposium on Material, Mechatronics and Energy 2018 (ISMME2018) dilaksanakan pada tanggal 7 November 2018 di Gowa, Sulawesi Selatan – Indonesia.
Konferensi internasional ini dilaksanakan oleh Fakultas Teknik Universitas Hasanuddin. Prosiding dari konferensi ini akan dipublikasikan pada IOP Publishing (prosiding terindeks Scopus).

BAB V. KERJASAMA INTERNASIONAL

1) **Kunjungan Prof. Miyara (Intrnational Partner) ke Laboratorium Energi Terbarukan**



2) **Diskusi Kerjasama Penelitian & Kelas Internasional di Departemen Teknik Mesin Universitas Hasanuddin**


3) Kuliah Tamu / Visiting Lecture oleh Prof. Miyara

4) **Kerjasama dengan ACK Group Japan**

MOU antara FT-UH dgn ACK Group

5) **Kunjungan Perusahaan Japan (Asano Taiseikiso Engineering Co., Ltd.)**

6) Kuliah Tamu oleh Dr. Eng. Arif Widiatmojo

Shallow Geothermal and Hydrogeology Research Group

Fukushima Renewable Energy Research Center

National Institute of Advanced Industrial Science and Technology (AIST)

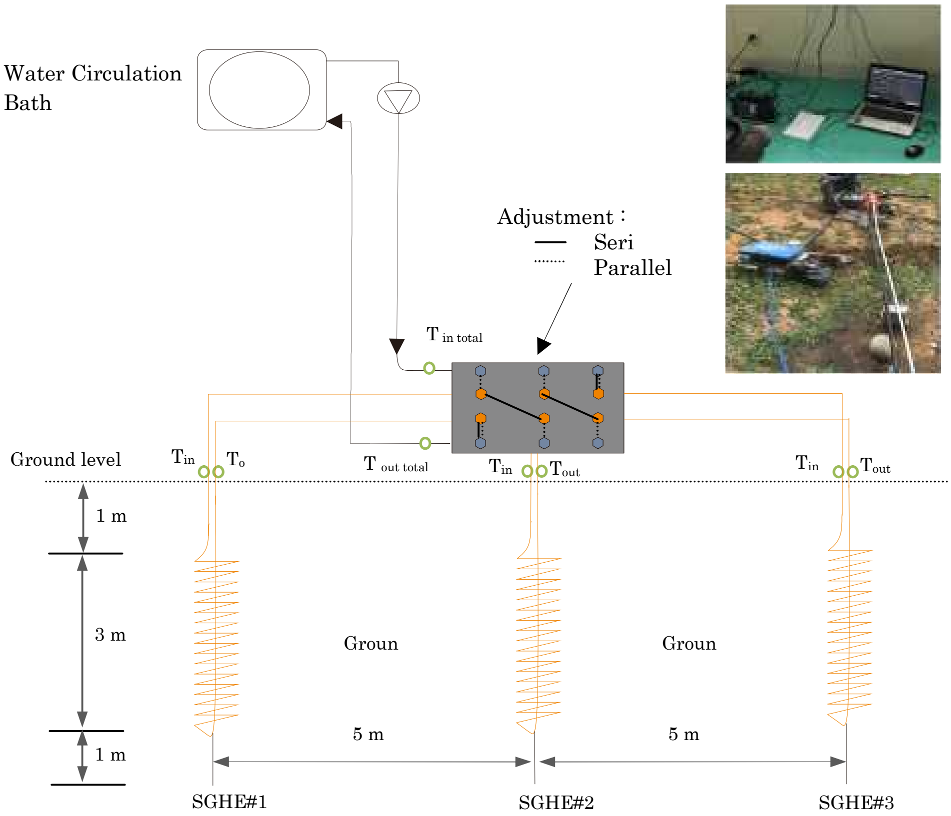
BAB VI. DESAIN & REKOMENDASI

Ground heat exchanger (GHE) tipe baru yaitu pipa spiral dan modifikasinya telah dibuat untuk diaplikasikan pada sistem pendinginan ruangan yang dikenal dengan nama Ground-source cooling sistem (GSCS).

Pada tipe GHE Horizontal, dibutuhkan ketersediaan lahan terbuka yang luas untuk memasang tipe GHE horizontal. Namun demikian, lahan terbuka yang luas sudah tidak tersedia di daerah perkotaan. Selain itu, memasang tipe GHE vertikal pada lubang bor yang dalam membutuhkan biaya yang sangat besar. Untuk memasang GHE pada lahan yang sempit dan dalam upaya mengurangi kedalaman lubang bor untuk menghemat biaya maka GHE tipe baru pada kedalaman dangkal menjadi solusi dalam aplikasi engineering. Dari hasil penelitian ini maka beberapa poin penting dapat disebutkan sebagai berikut:

1) Berdasarkan perbandingan dengan beberapa tipe GHE, spiral-tube GHE memberikan performansi yang baik.
2) Presure drop perlu diperhitungkan pada GHE tipe spiral
3) Tipe baru GHE yaitu pipa spiral yang dipasang pada kedalaman dangkal menjadi solusi dari keterbatasan tipe horizontal dan vertical.
4) Untuk memenuhi kebutuhan pendinginan pada ruangan digunakan beberapa GHE tipe spiral yang dapat dipasang seri dan vetikal.
5) GHE tipe spiral yang dipasang pada kedalaman dangkal yang dipasang secara parallel memberikan performansi yang lebih baik dibandingkan dengan yang dipasang secara seri.

Metode Pengujian:



BAB VII. KESIMPULAN

Pelaksanaan penelitian tahun ke-3 dari periode penelitian selama 3 (tahun) untuk mengembangan sebuah GHE tipe spiral yang baru telah dilakukan di Laboratorium Energi Terbarukan Prodi Teknik Mesin Universitas Hasanuddin. Kegiatan penelitian yang telah dilakukan meliputi: 1) Studi eksperimental tentang kondisi termal tanah, 2) Evaluasi unjuk kerja dan distribusi temperatur pada GHE tipe spiral dengan kedalam 3 m dengan variasi temperatur air masuk, 3) Evaluasi unjuk kerja GHE tipe spiral yang dipasang pada kondisi seri dan parallel, 4) Evaluasi berbagai faktor yang berpengaruh terhadap GHE tipe vertikal dengan simulasi numeric, 5) Menyusun rekomendasi desain untuk GHE tipe vertical. Adapun kegiatan terkait kerjasama internasional meliputi: 1) Kunjungan Prof. Miyara (Intrnational Partner) ke Laboratorium Energi Terbarukan, 2) Diskusi Kerjasama Penelitian & Kelas Internasional di Departemen Teknik Mesin Universitas Hasanuddin, 3) Kuliah Tamu / Visiting Lecture oleh Prof. Miyara, 4) Kerjasama dengan ACK Group Japan, 5) Kunjungan Perusahaan Japan (Asano Taiseikiso Engineering Co., Ltd.), 6) Kuliah Tamu oleh Dr. Eng. Arif Widiatmojo. Selanjutnya, diskusi dengan international partner (Prof. Miyara) dilakukan di Malang, Indonesia pada tanggal 29 s/d 31 Agustus 2018.

Beberapa hasil penelitian telah dihasilkan seperti Thermal performance of shallow spiral-tube ground heat exchanger for ground-source cooling system & Experimental Performance Analysis of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations telah dipresentasikan dan dipublish pada prosiding terindeks Scopus, The 5th International Symposium on Material, Mechatronics and Energy (ISMME) 2018 dan International Conference on Automative, Manufacturing and Mechanical Engineering (IC-AMME) 2018.

Desain dan rekomendasi untuk model baru spiral-tube GHEs pada aplikasi engineering telah dibuat.