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

2017

HALAMAN PENGESAHAN

Judul	: DEVELOPMENT OF A NEW SPIRAL-TUBE GROUND HEAT EXCHANGER FOR AIR CONDITIONING SYSTEM
Peneliti/Pelaksana	
Nama Lengkap	: Dr JALALUDDIN, S.T, M.T
Perguruan Tinggi	: Universitas Hasanuddin
NIDN	: 0025087201
Jabatan Fungsional	: Lektor Kepala
Program Studi	: *Teknik Mesin*
Nomor HP	: 082192267077
Alamat surel (e-mail)	: jalaluddin_had@yahoo.com
Anggota (1)	
Nama Lengkap	: Dr RUSTAN TARAKKA S.T, M.T
NIDN	: *0027087504*
Perguruan Tinggi	: Universitas Hasanuddin
Institusi Mitra (jika ada)	
Nama Institusi Mitra	: Saga University JAPAN
Alamat	: 1 Honjo-machi, Saga, 840-8502 Japan
Penanggung Jawab	: Prof. Akio Miyara
Tahun Pelaksanaan	: Tahun ke 2 dari rencana 3 tahun
Biaya Tahun Berjalan	: Rp 95,472,000
Biaya Keseluruhan	: Rp 373,972,000

Mengetahui, Dekan Fakultas Teknik Unhas	Kota Makassar, 30 - 10 - 2017 Ketua,
(Dr. Ing. Ir. Wahyu H. Piarah, MSME) NIP/NIK 196003021986091001	(Dr JALALUDDIN, S.T, M.T) NIP/NIK 197208252000031001

Menyetujui,
Ketua LP2M Unhas

(Prof. Dr. Ir. Laode Asrul, MP)
NIP/NIK 196303071988121001

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 mendapatkan perhatian yang luas terkait dengan tingginya pertukaran panas dari GHE dengan tanah sekitarnya.

Penelitian ini bertujuan untuk mengembangkan sebuah GHE tipe spiral yang baru dan mempelajari unjuk kerjanya selama 3 (tiga) tahun periode penelitian yang diusulkan. Penelitian ini akan melalui studi numerikal dan eksperimental. Pada tahun kedua ini, studi tentang unjuk kerja GHE tipe spiral dengan kedalaman dangkal, 5 meter, diteliti. Perbandingan unjuk kerja GHE tipe spiral dengan dengan tipe konvensional dilakukan. Pengembangan GHE tipe spiral dengan kedalaman yang rendah dilakukan dengan berbagai variasi kondisi operasi dan konfigurasi. Selanjutnya, studi numerik tentang rangkaian GHE baik dalam kondisi seri maupun parallel dilakukan. Studi eksperimental tentang kondisi termal dari tanah juga dilakukan.

Simulasi tentang GHE tipe spiral pada berbagai kondisi dan perbandingan dengan tipe lainnya telah dilakukan. Beberapa hasil penelitian telah dihasilkan seperti analisis unjuk kerja GHE tipe spiral pada kedalaman dangkal telah diterima (accepted) pada jurnal terindeks Scopus, Journal of Mechanical Engineering (JMechE). Hasil-hasil penelitian dan rencana penelitian selanjutnya telah didiskusikan dengan international partner, Prof. Akio Miyara, di Saga University Japan. Selain itu, berpartisipasi pada JSRAE Annual Conference di Tamagawa University Tokyo Japan untuk melihat perkembangan terbaru terkait penelitian ini. Hasil-hasil lainnya telah didaftarkan pada konferensi internasional 4 tahunan bidang Heat Transfer, IHTC Beijing. Hasil penelitian ini juga telah ditambahkan kedalam draft buku ajar, Ground Heat Exchangers for Air Conditioning Applications.

Selanjutnya, beberapa pengujian eksperimental dan analisis unjuk kerja akan dilakukan pada rencana penelitian selanjutnya.

DAFTAR ISI

BAB I PENDAHULUAN

Penggunaan sumber energi yang ramah lingkungan dan terbarukan sekarang ini 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 *design guideline*. Studi numerikal 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*

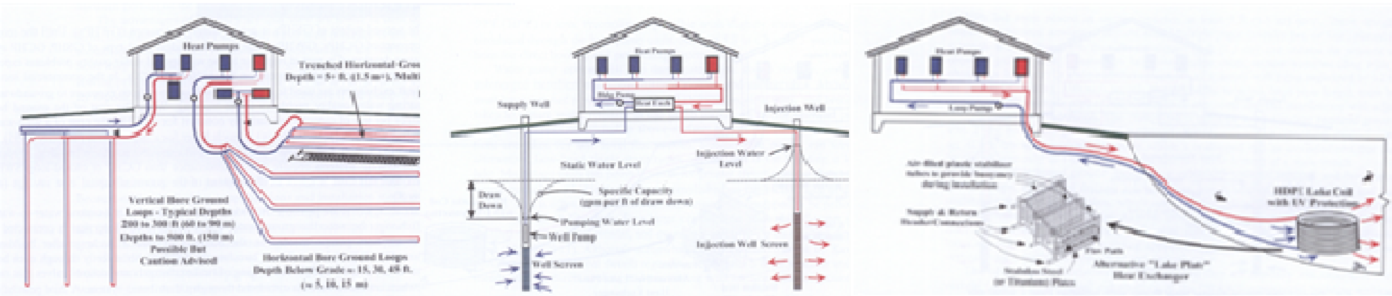
Output Penelitian

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

BAB II TINJAUAN PUSTAKA

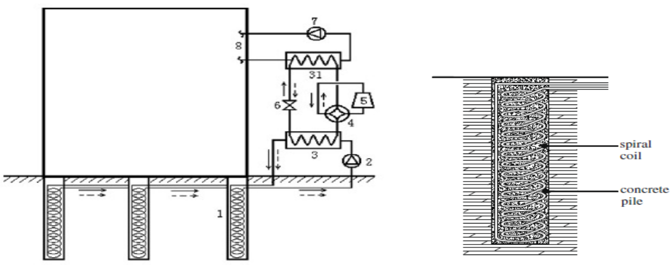
Sistem GSHP digunakan secara luas dalam aplikasi sebagai pemanas dan pendingin ruangan, suplai air panas dan aplikasi pada bidang pertanian. Pemanfaatan yang paling banyak dikenal adalah aplikasi sebagai pendingin dan pemanas ruangan pada bangunan perumahan dan komersial.

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 skematik 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 numerikal dan eksperimental sedang dilakukan di Laboratorium Energi Terbarukan Program Studi Teknik Mesin Universitas Hasanuddin berkolaborasi 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

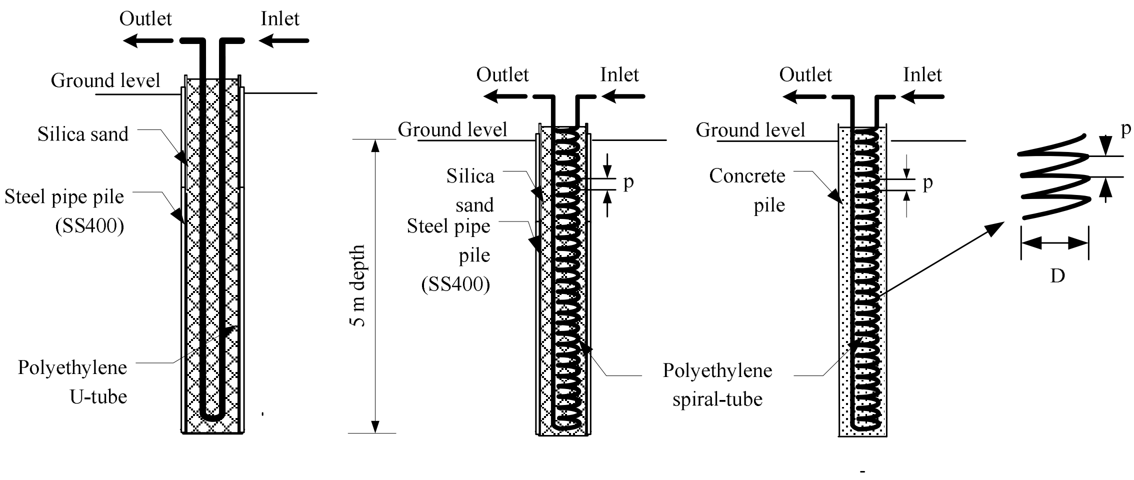
Penelitian tentang pengembangan sebuah GHE tipe spiral yang baru sedang dilakukan di laboratorium Energi Terbarukan Program Studi Teknik Mesin Universitas Hasanuddin.

Kegiatan penelitian yang dilakukan antara lain:

1) Analisis unjuk kerja GHE tipe spiral dengan kedalaman dangkal untuk mengetahui karakteristik GHE ini.
2) Analisis unjuk kerja GHE tipe spiral yang dipasang pada kondisi seri dan paralel dengan berbagai konfigurasi serta membandingkan dengan tipe lainnya.
3) Studi eksperimental tentang kondisi termal.

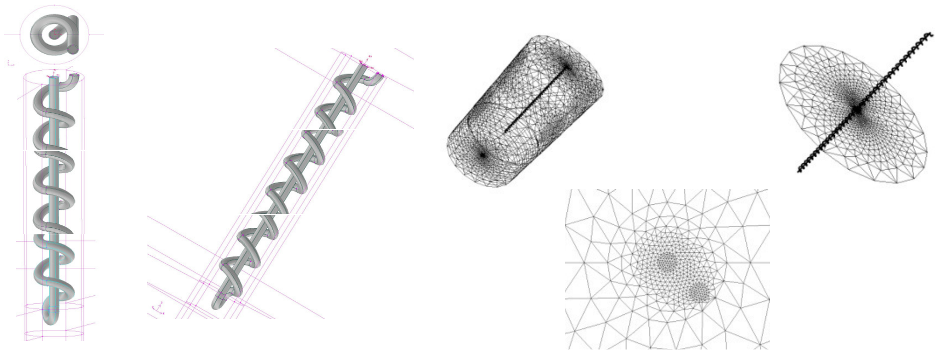
A. Unjuk kerja GHE tipe spiral pada kedalaman rendah

Skema dari GHE tipe U-tube dan spiral-tube ditunjukkan pada gambar 3. Kedua GHE dipasang pada kedalaman 5 m. Model tiga dimensi, grid dan meshing dari GHE tipe spiral-tube ditunjukkan pada gambar 4.



(a) GHE tipe U (b) GHE tipe Spiral

Gambar 3. Skema GHE tipe konvensional dan Spiral



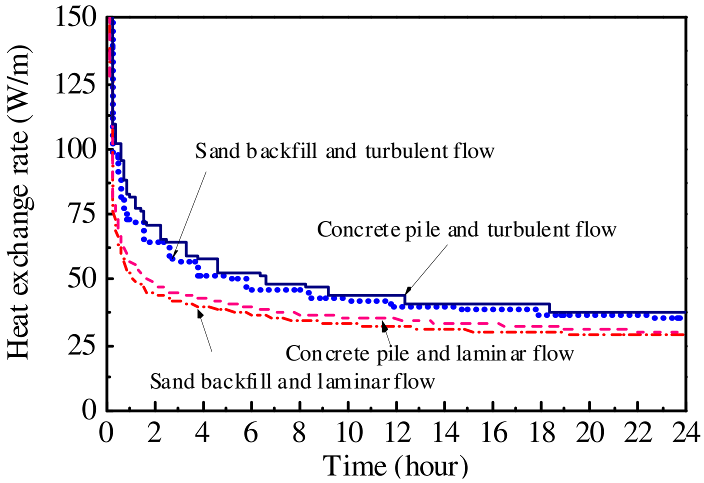
Gambar 4. Model tiga dimensi, grid dan meshing dari GHE tipe spiral

Karateristik perpindahan panas dari GHE tipe Spiral

Gambar 5 menunjukkan laju perpindahan panas dalam kondisi aliran laminar dan turbulen dari beberapa GHE dengan pengisi pasir Silika dan GHE dipasang pada tiang beton.

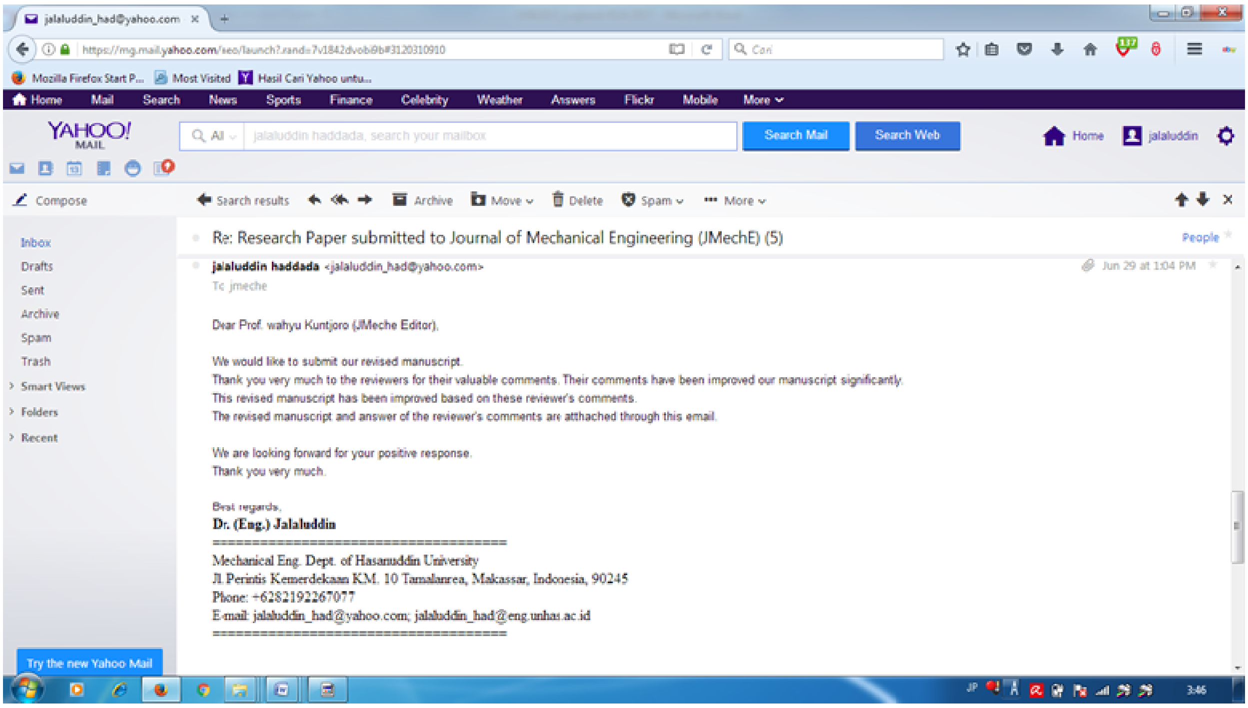
Laju perpindahan panas rata-rata dari GHE tipe spiral dengan pengisi pasir Silika adalah 46.9 W per meter borehole pada kondisi aliran laminar dan 64.6 W per meter borehole pada kondisi turbulen.

Laju perpindahan panas rata-rata dari GHE tipe spiral yang dipasang pada tiang beton adalah 49.6 dan 68.5 per meter borehole pada kondisi aliran laminar dan turbulen. Pemasangan GHE pada tiang beton menunjukkan sedikit peningkatan unjuk kerja dibandingkan dengan GHE dengan pengisi pasir Silika. Hal ini disebabkan karena perbedaan konduktivitas termal yaitu: 1.4 W/mK untuk pasir Silika dan 1.65 W/mK untuk tiang beton.

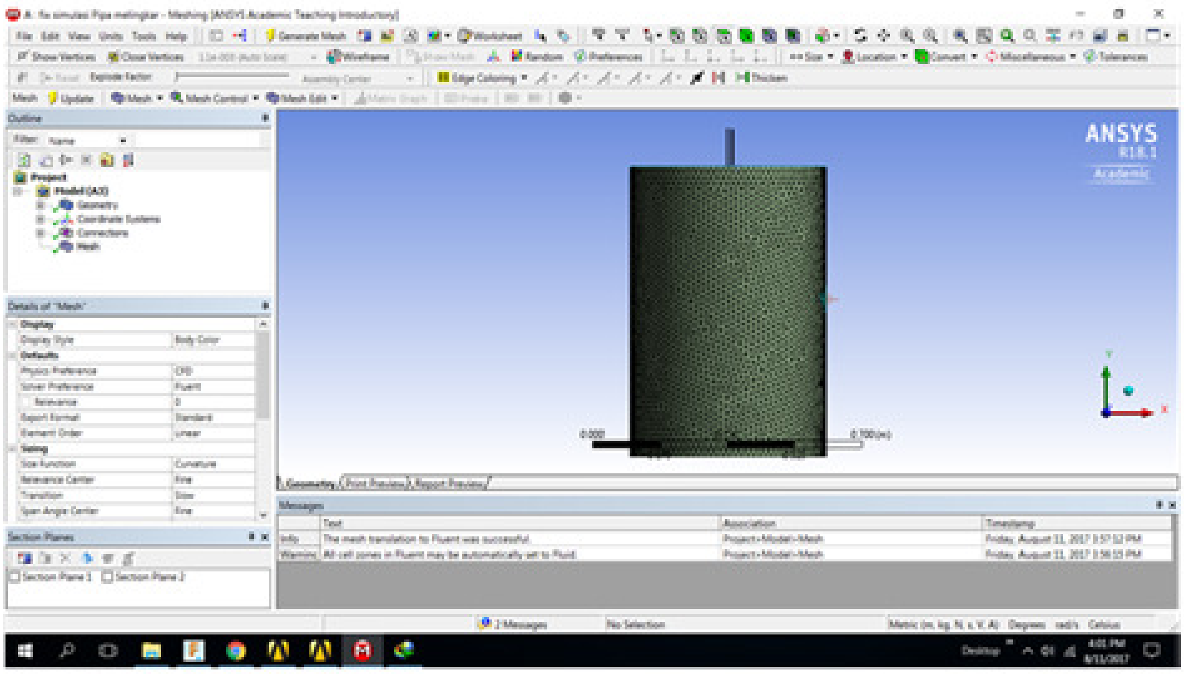


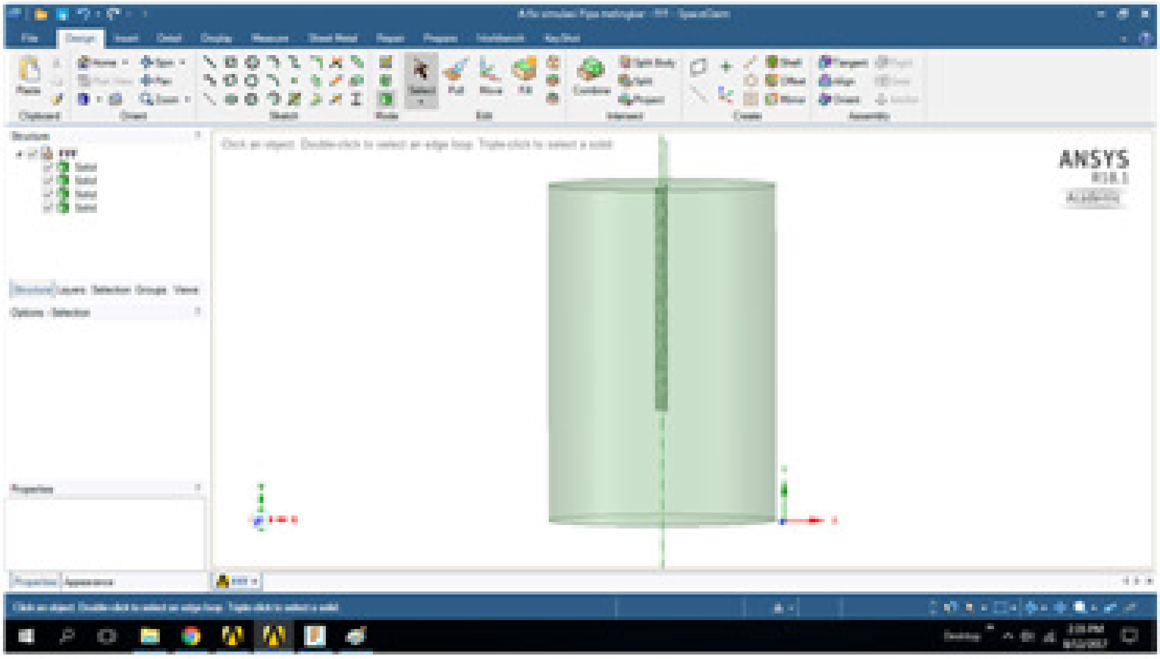
Gambar 5. Karakteristik perpindahan panas dari GHE tipe spiral

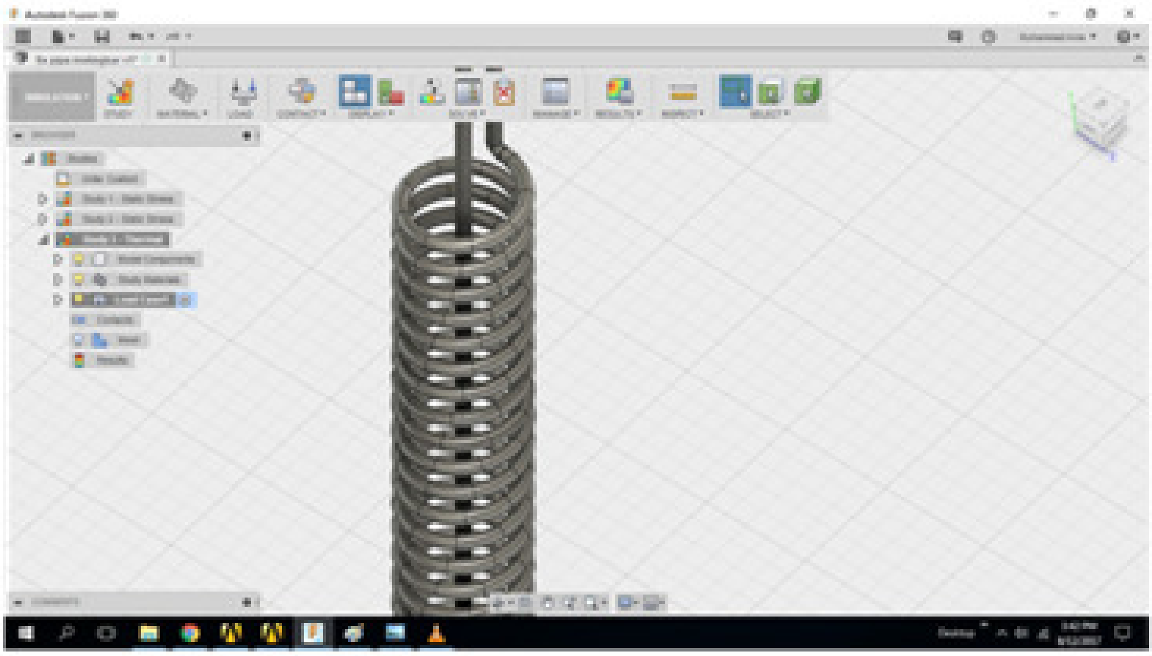
B. Submit Paper to Journal of Mechanical Engineering (JMechE)

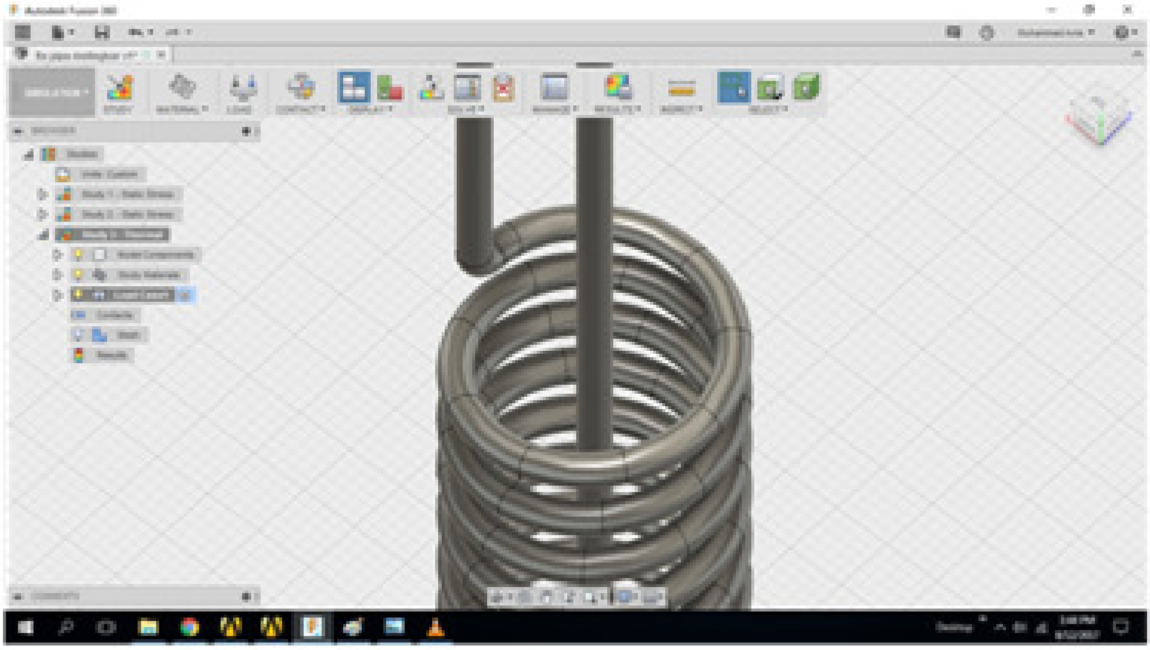


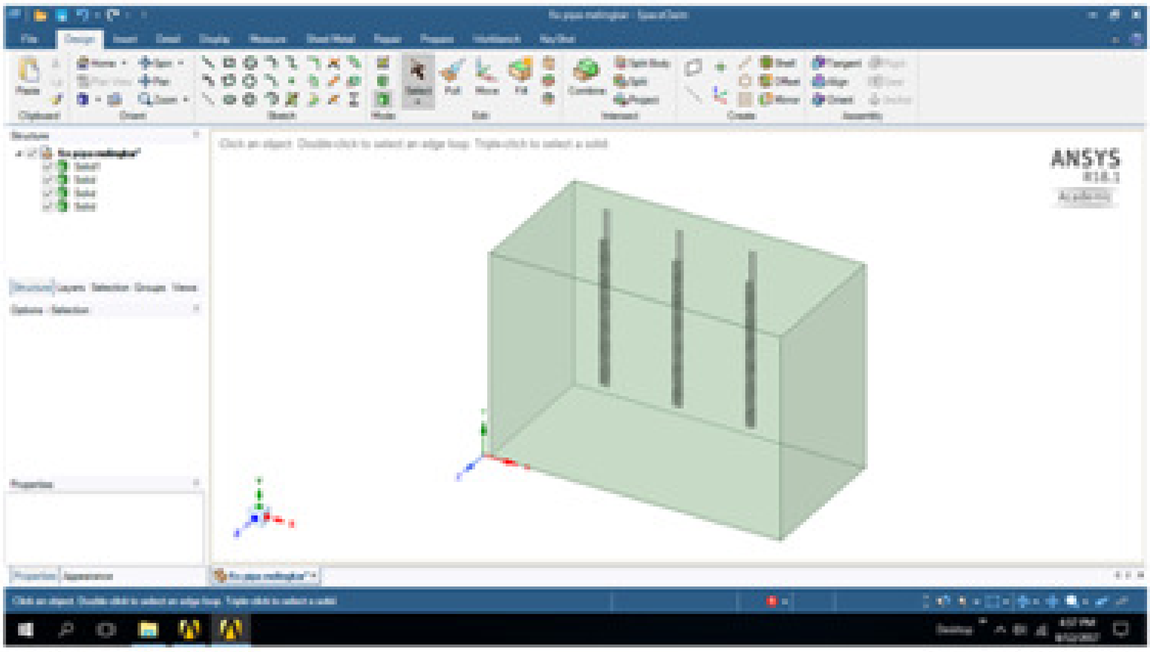
C. Rangkaian Simulasi Numerik untuk pengembangan Shallow Borehole Depth of GHE tipe Spiral pada kondisi seri dan parallel

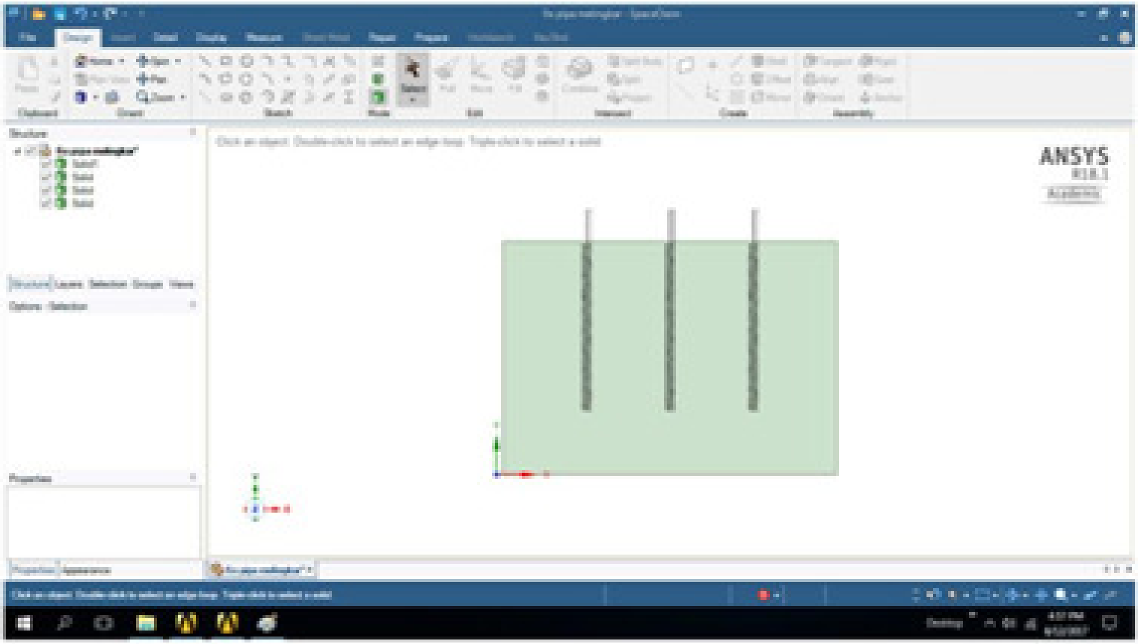


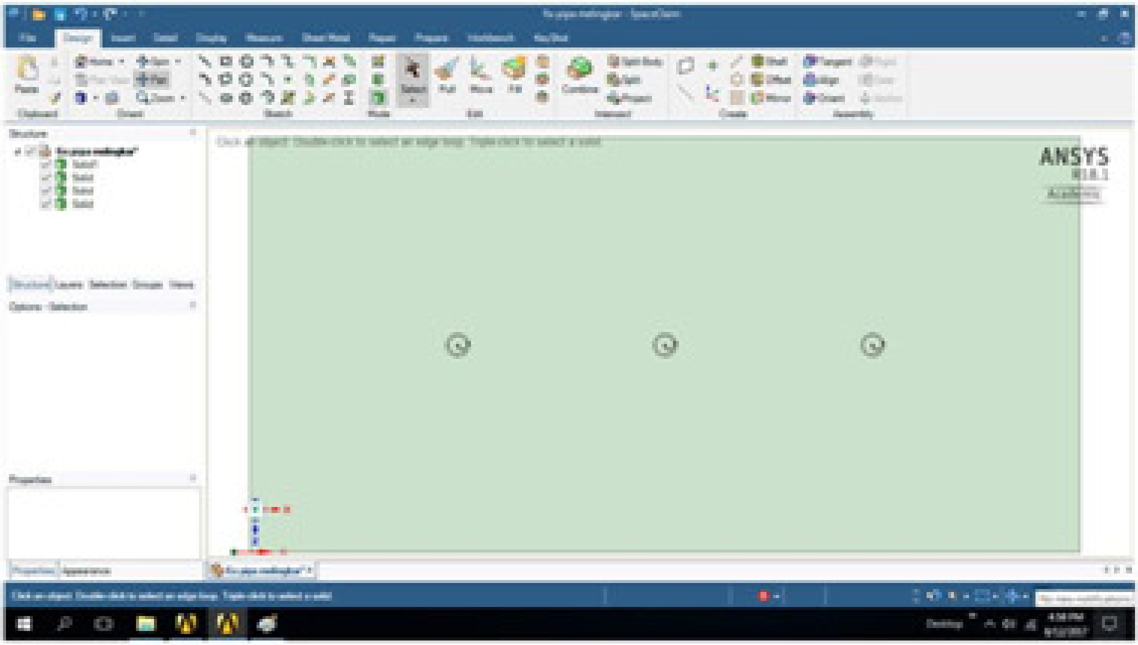

ANSYS

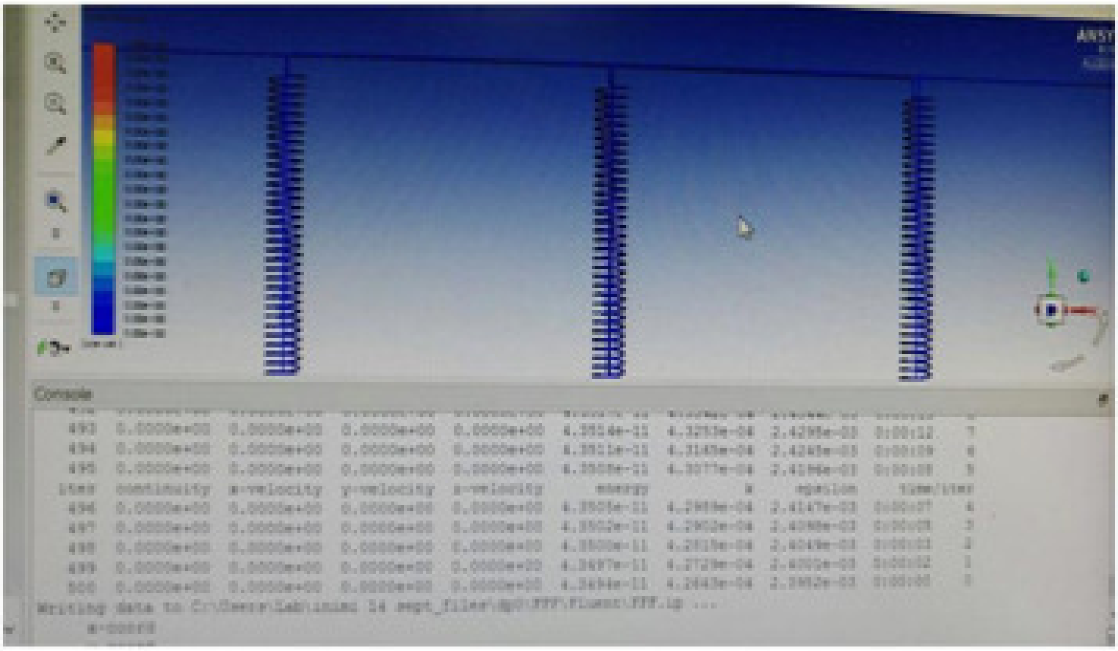





ANSYS
R18.1
Academic






Console

C. Peralatan untuk Studi Eksperimental

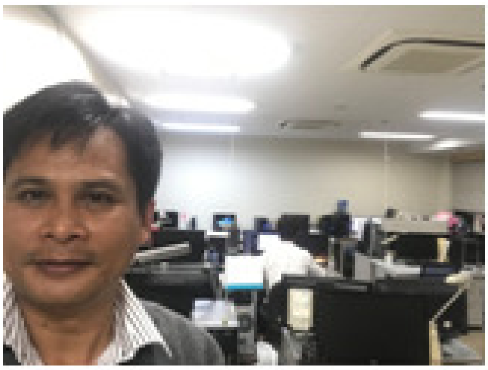
Instalasi Pengukuran Temperatur Tanah

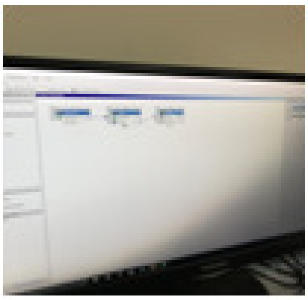
Research Discussions in Japan

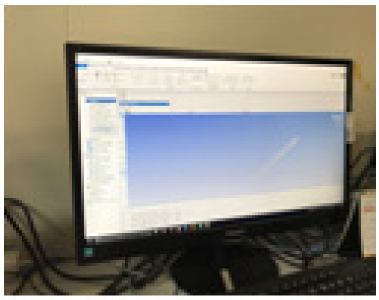
JSRAE Conference at Tamagawa University Tokyo Japan

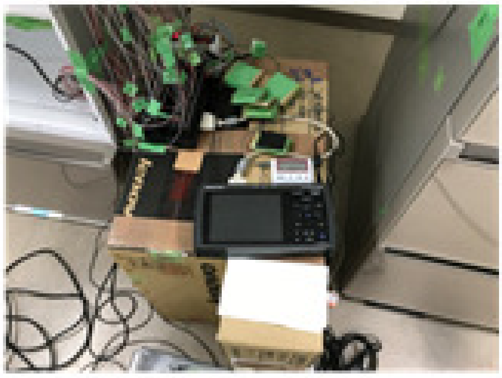
Saga University

Miyara Laboratory, Saga University









Prof. Miyara Office

BAB V. KESIMPULAN

Pelaksanaan penelitian tahun ke-2 dari periode penelitian selama 3 (tahun) untuk mengembangan sebuah GHE tipe spiral yang baru telah dilakukan di Laboratorium Energi Terbarukan Program Studi Teknik Mesin Universitas Hasanuddin. Studi tentang unjuk kerja GHE tipe spiral dengan kedalaman dangkal, 5 meter, diteliti. Perbandingan unjuk kerja GHE tipe spiral dengan dengan tipe konvensional dilakukan. Pengembangan GHE tipe spiral dengan kedalaman yang rendah dilakukan dengan berbagai variasi kondisi operasi dan konfigurasi. Selanjutnya, studi numerikal tentang rangkaian GHE baik dalam kondisi seri maupun parallel dilakukan. Studi eksperimental tentang kondisi termal dari tanah juga dilakukan.

Kegiatan penelitian yang dilakukan antara lain:

4) Analisis unjuk kerja GHE tipe spiral dengan kedalaman dangkal untuk mengetahui karakteristik dari tipe GHE ini.
5) Analisis unjuk kerja GHE tipe spiral yang dipasang pada kondisi seri dan paralel dengan berbagai konfigurasi serta membandingkan dengan tipe lainnya.
6) Studi eksperimental tentang kondisi termal.

Simulasi tentang GHE tipe spiral pada berbagai kondisi dan perbandingan dengan tipe lainnya telah dilakukan. Beberapa hasil penelitian telah dihasilkan seperti analisis unjuk kerja GHE tipe spiral pada kedalaman dangkal telah diterima (*accepted*) pada jurnal terindeks Scopus, Journal of Mechanical Engineering (JMechE). Hasil-hasil penelitian dan rencana penelitian selanjutnya telah didiskusikan dengan international partner, Prof. Akio Miyara, di Saga University Japan. Selain itu, berpartisipasi pada JSRAE Annual Conference di Tamagawa University Tokyo Japan untuk melihat perkembangan terbaru terkait penelitian ini. Hasil-hasil lainnya telah didaftarkan pada konferensi internasional 4 tahunan bidang Heat Transfer, IHTC Beijing. Hasil penelitian ini juga telah ditambahkan kedalam draft buku ajar, Ground Heat Exchangers for Air Conditioning Applications.

LAMPIRAN OUTPUT PENELITIAN

1. **Jurnal Paper accepted in Journal of Mechanical Engineering (JMechE) terindeks Scopus**
2. **Participated in JSRAE Conference, Tamagawa University Japan**
3. **Paper submitted to The 16th International Heat Transfer Conference (IHTC), International Conference 4 tahunan bidang Heat Transfer terindeks Scopus**
4. **Buku Ajar**
   Ground Heat Exchangers for Air Conditioning Applications

Jurnal Paper accepted in Journal of Mechanical Engineering (JMechE) terindeks Scopus

Home Mail Flickr Tumblr News Sports Finance Entertainment Lifestyle Answers Groups Mobile More

All | jalaluddin haddada, search your mailbox | Search Mail | Search Web | Home | jalaluddin

Compose

Search results | Archive | Move | Delete | Spam | More | Collapse All

Inbox
Drafts
Sent
Archive
Spam
Trash
Smart Views
Folders
Recent

MANUSCRIPT EVALUATION (2nd REVISION) - Minor (5)

People

jmeche With reference to the above matter, we would like to inform you that your research paper has been r — Aug 7 at 5:02 PM

jalaluddin haddada Dear Prof. wahyu Kuntjoro (JMeche Editor), Thank you very much for the reviewer's comi — Aug 14 at 9:47 PM

jmeche Dear Sir, Thanks for your reply. Before we issue acceptance letter for publication, please send us the p — Aug 25 at 1:03 PM

jalaluddin haddada Dear JMechE Publication Team, We have attached the revised paper follow the JMeche t — Aug 26 at 8:10 AM

jmeche <jmeche.int@gmail.com> — Oct 17 at 1:08 PM
To jalaluddin haddada

UNIVERSITI TEKNOLOGI MARA
FAKULTI KEJURUTERAAN MEKANIKAL
Publication Unit
40450 Shah Alam, Selangor Darul Ehsan, Malaysia
Tel: 03 – 5543 5135 / 5161 Fax: 03 – 5543 5160
E-mail: jmeche.int@gmail.com

Our Ref. : UP/JmechE/P16-26
Date : 24 October 2017

Dr. (Eng.) Jalaluddin
Mechanical Eng. Dept. of Hasanuddin University
Jl. Perintis Kemerdekaan KM. 10 Tamalanrea, Makassar, Indonesia, 90245.

Dear Dr. (Eng.) Jalaluddin,

ACCEPTANCE OF MANUSCRIPT FOR PUBLICATION

With reference to the above matter, we would like to inform you that your research paper **P16-26: Performance of Shallow Borehole of spiral-Tube Ground Heat Exchanger** has been accepted for publication in coming JMechE Journal.

Hereby, please complete the **transfer of copyright agreement** not later than **24 October 2017.**

We would like to take this opportunity to thank you for your contribution in JMechE.

Yours sincerely,

Prof. Wahyu Kuntjoro
JMechE Editor,
Publication Unit,
Faculty of Mechanical Engineering, UiTM

Show original message

Transfer o..doc

Home Mail Flickr Tumblr News Sports Finance Entertainment Lifestyle Answers Groups Mobile More

All jalaluddin haddada search your mailbox | Search Mail | Search Web | Home | jalaluddin

Compose

Inbox
Drafts
Sent
Archive
Spam
Trash
Smart Views
Folders
Recent

Search results Archive Move Delete Spam More Collapse All

MANUSCRIPT EVALUATION (2nd REVISION) Minor (6) People

jmeche	With reference to the above matter, we would like to inform you that your research paper has b	Aug 7 at 5:02 PM
jalaluddin haddada	Dear Prof. wahyu Kuntjoro (JMeche Editor), Thank you very much for the reviewer's	Aug 14 at 9:47 PM
jmeche	Dear Sir, Thanks for your reply. Before we issue acceptance letter for publication, please send u:	Aug 25 at 1:03 PM
jalaluddin haddada	Dear JMechE Publication Team, We have attached the revised paper follow the JM	Aug 26 at 8:10 AM
jmeche	UNIVERSITI TEKNOLOGI MARA FAKULTI KEJURUTERAAN MEKANIKAL Publication Unit 40450 SH	Oct 17 at 1:08 PM

jalaluddin haddada <jalaluddin_had@yahoo.com> Oct 20 at 9:46 AM
To jmeche

Dear Prof. wahyu Kuntjoro (JMeche Editor),

Thank you very much for acceptance of our manuscript for publishing in JMeche.
The transfer of copyright agreement is attached.

Yours sincerely,
Jalaluddin

Show original message

20102017....pdf

Performance of Shallow Borehole of spiral-Tube Ground Heat Exchanger

Jalaluddin

Rustan Tarakka

Department of Mechanical Engineering, Hasanuddin University, Tamalanrea, Makassar 90245, Indonesia

Email: jalaluddin_had@yahoo.com

Akio Miyara

Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi 840-8502, Japan

ABSTRACT

The use of geothermal energy has been recognized as a possible solution for reducing emissions. This energy source is an environmentally friendly energy source with wide range of applicability such air conditioning and hot water heating. A ground heat exchanger (GHE) is used in the air conditioning system to exchange heat with the ground. This study present an investigation of thermal performance of shallow spiral-tube GHE buried in the 5 m depth. The performance of this GHE is investigated by numerical method using CFD code. The performance of the spiral-tube GHE is 46.9 Watt per meter borehole depth in laminar flow and 64.6 Watt per meter borehole depth in turbulent flow. Comparison between the spiral-tube and the conventional U-tube GHEs shows the possibility to reduce borehole depth and installation cost. Using the spiral-tube GHE can reduce the borehole about a half compared with using the conventional U-tube GHE. Shallow spiral-tube GHEs can be arranged in series and parallel configurations to meet the needs in the application.

Keywords: *ground heat exchanger, shallow spiral-tube GHE, performance.*

Introduction

The ground source heat pump (GSHP) system is a promising technology for cooling and heating building in the world with wide range of applications such as for space heating and cooling, hot water supply and applications in the agricultural field. The well-known application of the GSHP system is for space heating and cooling in residential and commercial buildings. The heat exchange performance of the ground heat exchanger (GHE) is an important subject of GSHP system design. Operating the GHEs with different models and various conditions shows the different characteristic in their heat exchange rates. The performance of three types of GHEs namely U-tube, double-tube, and multi-tube GHEs have been investigated experimentally. The double-tube GHE has the highest heat exchange rate [1]. Operating the GHEs with different operation modes such as short-time period of operation, discontinuous and continuous operation shows the different characteristic in their heat exchange rates [2, 3]. The performances of multiple-tube GHEs with a number of pipes installed inside the borehole have been investigated. The result shows that thermal interferences between the pipes affect its performance [4]. The effect of different inlet water temperatures and borehole depths of the GHEs also affect its performance [5]. In the hot weather like Indonesia, the GSHP system is used for space cooling as an air conditioning system as known as ground-source cooling system. The hybrid GSHP system was applied for air conditioning system in hot weather condition such Hongkong [6]. Experimental test,energy and exergy analysis of the ground-source cooling system with horizontal GHE have been carried-out in Tunisia [7, 8].The utilization of GSHP is appropriated for cooling building in hot climate such Tunisia.

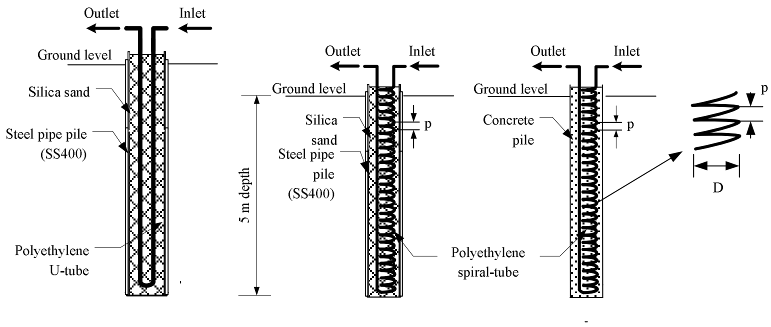
A GHE is used in the GSHP system to exchange heat with the ground. The spiral-tube GHE is gaining interest in recent years. Analytical solutions of spiral coil ground heat exchangers have developed by Man et al. [9], Cui et al. [10], Man et al, [11] and Li and Lai [12]. The classical approaches, i.e. the line heat source model and the "hollow" cylindrical heat source model, are no longer valid for thermal analysis and design of the GHE with spiral coils in foundation pile. A "solid" cylindrical source model has been developed considering the radial dimension and the heat capacity of the borehole or pile [9]. Cui et al. [10] developed the ring-coil source model taking into account the discontinuity of the heat source and the impact of the coil pitches. However, this model does not simulate the heat transfer of fluid circulating inside spiral coil pipe. A spiral heat source model has been developed for better thermal analysis by Man et al. [11]. Comparison study of helical GHE with triple U-tube [13] and double U-tube [14] GHEs were carried out. It is found that the helical GHE provided better thermal performance than others.

The spiral-tube GHEs have been proven by a number of studies that providing a better performance. Various models of spiral-tube GHEs installed in a borehole and concrete pile were simulated [15, 16]. Heat exchange rate and pressure drop along the pipe as an important parameter in design of the GSHP system are discussed [17]. For deep vertical spiral-tube GHE, large investment cost is needed. Pumping power due to pressure drop and ineffective of outlet pipe due to thermal interference should be considered. A shallow spiral-tube GHE is taking interest because of providing the possibility to reduce a borehole depth. Performance and distance between shallow spiral-tube GHEs have been studied [18]. Determining the distance between GHEs (spacing) and its effect on the heat transfer rate becomes as an important issue. However, there is a limited number of works on shallow spiral-tube GHEs. In addition, an optimum design of horizontal ground heat pump systems is also investigated for spiral-coil-loop heat exchangers [19]. Horizontal GHE usually needs a large of land area. If a large of land area is not available, using a number of shallow spiral-tube GHEs can be used as alternative solution.

In order to study the possibility to use shallow spiral-tube GHEs, this work present an investigation of thermal peformance of shallow spiral-tube GHE. Performance comparison of this GHE with the conventional U-tube GHE is also presented. Reducing the borehole depth is attractive economically due to reducing installation cost. The models of the U-tube and spiral-tube GHEs were built and simulated. The heat exchange rates of the GHEs are investigated.

Ground Heat Exchanger System

The schematic diagrams of the conventional U-tube and spiral-tube GHEs are shown in Figure 1. Polyethylene pipes were used as the tubes of the GHEs. A U-pipe is inserted in the borehole and buried in the ground at a depth of 20 m in the conventional U-tube GHE. In the spiral-tube GHE, a spiral pipe is used as the inlet tube of the GHE and a straight pipe is used as the outlet tube. The spiral-tube GHE is inserted and buried in the ground at a depth of 5 m. The boreholes were backfilled with silica-sand. In addition, the spiral tube was also installed using concrete pile foundation as shown in Figure 1(b).



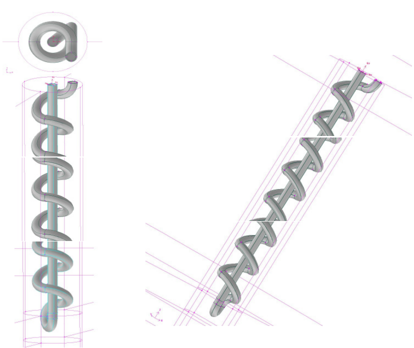
(a) U-tube (b) Spiral-tube

Fig. 1. The schematic diagrams of the conventional U-tube and spiral-tube GHEs

Simulation Set-Up

Three-dimensional model of GHE

Three-dimensional unsteady-state models were built and simulated using the CFD-code, FLUENT in order to investigate heat exchange from the GHEs system to the ground around the borehole. The software uses a finite volume method to convert the governing equations to numerically solvable algebraic equations. Figure 2 shows the three-dimensional model of spiral-tube GHE.



(a) U-tube (b) Spiral tube

Fig. 2. Three-dimensional model of spiral-tube

All the related geometric parameters and material thermal properties for the GHEs are listed in Table 1. The ground profiles around the borehole consist of Clay and its properties are presented in Table 2.

Table 1 Geometric parameters and material thermal properties of the GHEs

Parameters	Value	Unit
Inlet and outlet pipes of the GHEs, U-pipe and Spiral-pipe (material: Polyethylene)		
Outer diameter, d_o	0.033	m
Inner diameter, d_i	0.026	m
Thermal conductivity, k_{PE}	0.35	W/(m K)
Specific heat, c_P	2300	J/kg K
Density, ρ	920	kg/m^3
Leg spacing for U-Tube GHE, x	0.02	m
Pitch for Spiral-tube GHEs, p	0.1	m
Grout (material: Silica sand)		
Thermal conductivity, k_{grout}	1.4	W/(m K)
Specific heat, c_P	750	J/kg K
Density, ρ	2210	kg/m3
Concrete pile		
Density, ρ	2200	kg/m^3
Specific heat, c_P	1000	J/kg.K
Thermal conductivity, $k_{Concrete\text{-}pile}$	1.65	W/m.K

Table 2 The properties of the ground

Parameters	Value	Unit
Clay (temperature: 293 K; water content: 27.7%)		
Density, ρ	1700	kg/m^3
Specific heat, c_P	1800	J/kg.K
Thermal conductivity, k_{Clay}	1.2	W/m.K

A constant and uniform temperature was applied to the top and bottom surfaces of the model. Variation of ground temperature near the surface due to ambient climate effect is negligible. Initial ground temperature is assumed to be constant at 17.7 °C (290.85 K). The flow rate of circulated water was set to 2 l/min for laminar flow and 8 l/min for turbulent flow. The GHEs models were simulated in 24 h operation and inlet water temperature was set to be constant of 27 °C (300.15 K). For turbulence model, k-epsilon two equation models were applied in the FLUENT simulation set-up. Scaled residuals for turbulence models were monitored. Turbulence specification method is use turbulence intensity, $I=0.16(Re_{DH})^{-1/8}$.

Grid and meshing

Three-dimensional hybrid mesh generation was applied in the GHE model. Numerical mesh of the borehole and ground is shown in the Figure 3. The mid-view shown in the Figure 3 (b) is in the cross-section of 2.5 m depth of the borehole and ground. Meshing around the borehole is shown in the Figure 3 (d).

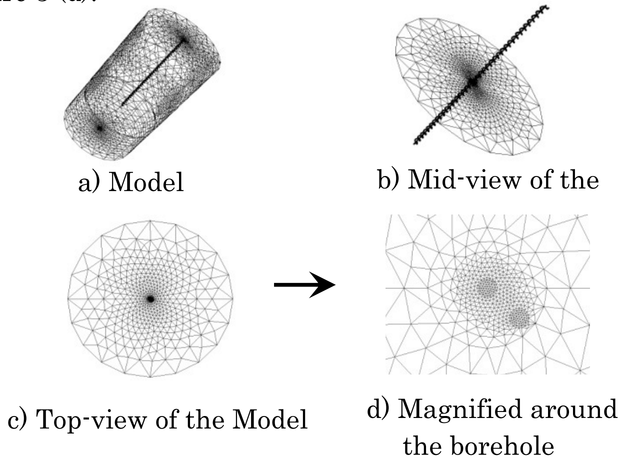


Fig. 3. Grid and meshing of the spiral-tube GHE

In order to validate the model of GHE, the grid for U-tube GHE was generated using gambit to perform grid independence test. The GHEs were simulated in 24 h continuous operation and its heat exchange rate was investigated. The cell number of the grid is shown in Table 3. The heat exchange rate of the grid 2 in which the total cell number of 197581 shows the same results as the finest grid 3 and 4 as shown in Figure 4. Then, the grid 2 was applied in the model.

The comparison of simulation result of the heat exchange rate of the GHE models with experimental result shows the reasonable agreement. Small differences between the numerical and experimental were caused by discrepancies of several uncertain factors such as local ground thermal properties, boundary and initial conditions, etc. The deviation of heat exchange rate between the experimental and simulated results is in the range of 2-18 %.

Table 3 The cell number of the Grid

GHE type	Grid 1	Grid 2	Grid 3	Grid 4
U-tube	46446	197581	438346	388681

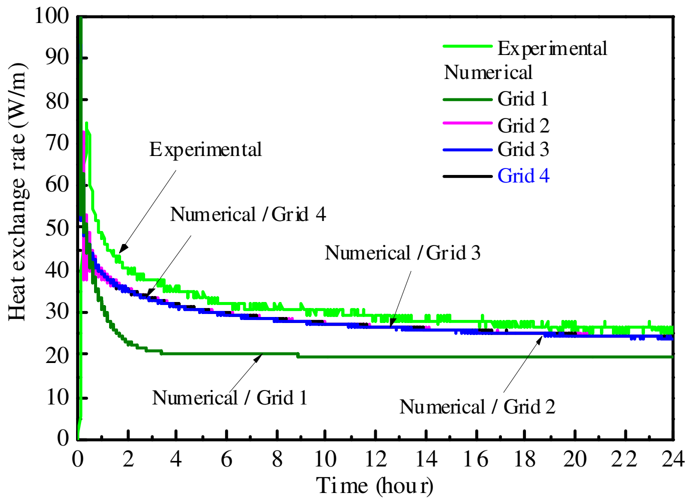


Fig. 4. Heat exchange rates of the U-tube GHE experimentally and numerically

A similar hybrid mesh is applied in the spiral-tube GHE as mention above for each component.

<u>Heat exchange rate</u>

The thermal performances of the spiral-tube GHEs were investigated by calculating their heat exchange rates through the water flow. The heat exchange rate 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 between the inlet and outlet tubes of circulated water.

The heat exchange rate per unit length of borehole depth is defined as the following equation and it is used to express the performance of each GHEs.

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

where L is the depth of each GHE.

Results and Discussions

<u>Temperature distribution</u>

Borehole temperature distribution

The heat buildup in the ground surrounding the borehole contributes to the thermal performance of GHEs. Figure 5 shows the borehole temperature distribution at x = 0.1 and 0.25 m (distance from borehole axis) and z = 2.5 m depth of spiral-tube GHE backfilled with silica sand in the laminar and turbulent flows. The borehole temperatures increase with operation time. It is due to the large of rejected heat to the ground and increasing temperature of the ground.

Water temperature distribution

Water temperatures of the spiral-tube GHEs through the depth with sand backfill and concrete pile in the laminar and turbulent flows are shown in the Figure 6. Inlet water temperatures for the GHEs were set to be constant of 27 °C (300.15 K). Water flows through the inlet and outlet pipes. The water temperature decreases in the flow direction due to heat. In the laminar flow, the high reduction in the water temperature in the spiral tube is due to the low flowrate of the water. The relatively small change in temperature in the outlet pipe is because of the thermal interference from the inlet pipe. In addition, the water temperature distribution is slight different between the GHE backfilled with silica sand and installed in the concrete pile due to their thermal conductivities.

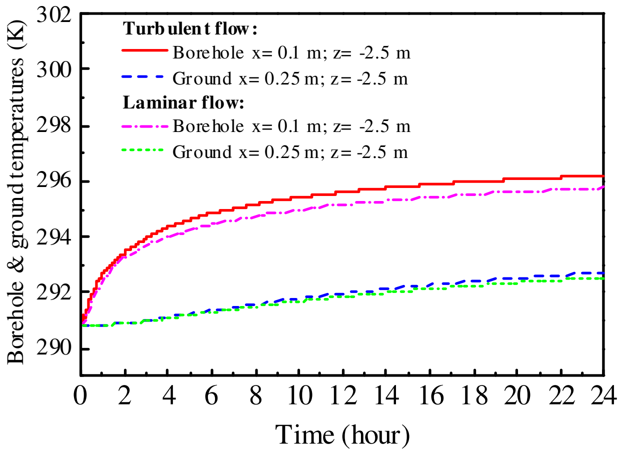


Fig. 5. Borehole and ground temperature

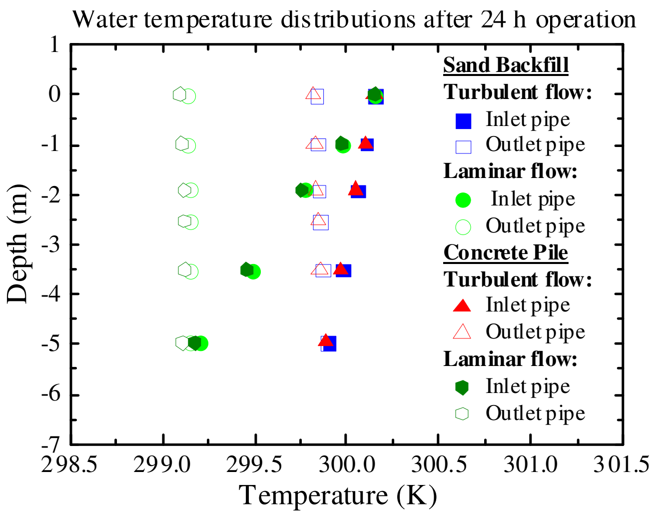


Fig. 6. Water temperature distribution of the

Heat exchange characteristics of spiral-tube GHEs

Figure 7 shows the heat exchange rate in the laminar and turbulent flows of the GHE backfilled with silica sand and installed in a concrete pile. Heat exchange rate of the spiral-tube GHE backfilled with silica sand in average is of 46.9 W per meter borehole depth in laminar flow. In turbulent flow, its performance in average is of 64.6 W per meter borehole depth. Heat exchange rate in average of spiral-tube GHE installed in a concrete pile are 49.6 and 68.5 W per meter borehole depth in laminar and turbulent flows respectively. Installing the GHE in the concrete pile increases slightly its performance compared with that of silica sand backfill. It is due to the high thermal conductivity of concrete pile compared with that of silica sand. Thermal conductivities of silica sand and concrete pile are 1.4 W/m K and 1.65 W/m K respectively.

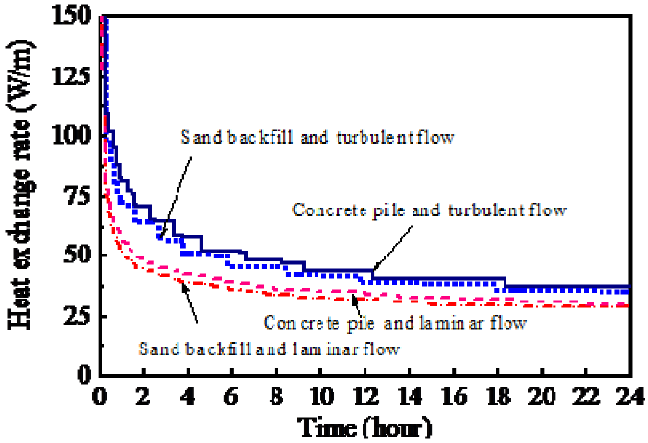
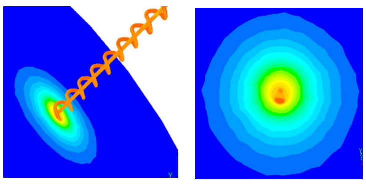
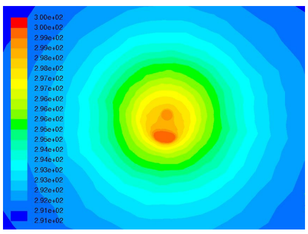


Fig. 7. Heat exchange rate of the GHEs

The cross-sectional temperature contours of the GHE backfilled with silica sand at 2.5 m depth for laminar and turbulent flows are shown in the Figures 8 and 9. The contours of the GHE installed in concrete pile at 2.5 m depth for laminar and turbulent flows are shown in the Figures 10 and 11. Heat rejected from the GHE to the ground is not uniform through the depth and cross-sectional. Water circulates through the spiral pipe and heat rejected to the ground. It causes non-uniform of temperature contours around the borehole.

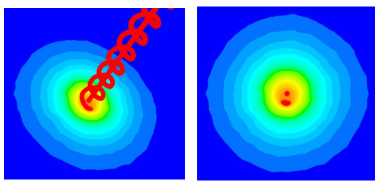


a) Isometric view b) Top-view

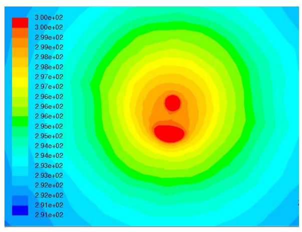


c) Magnified around the borehole

Fig. 8. The cross-sectional temperature contours at 2.5 m depth for laminar flow

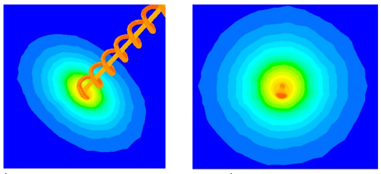


a) Isometric b) Top-view

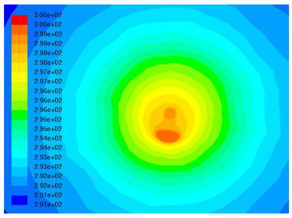


c) Magnified around the borehole

Fig. 9. The cross-sectional temperature contours at 2.5 m depth for turbulent flow

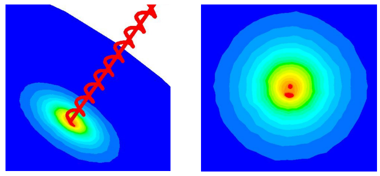


a) Isometric view b) Top-view

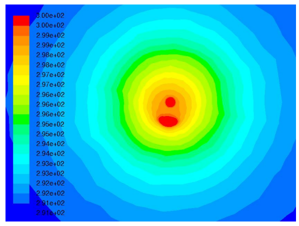


d) Magnified around the borehole

Fig. 10. The cross-sectional temperature contours at 2.5 m depth for laminar flow



a) Isometric view b) Top-view



e) Magnified around the borehole

Fig. 11. The cross-sectional temperature contours at 2.5 m depth for turbulent flow

<u>Comparison with the conventional U-tube GHE</u>

Performance comparison of the shallow spiral-tube GHE with the conventional U-tube GHE is discussed. Heat exchange rate of shallow spiral-tube GHE backfilled with silica sand is of 46.9 W per meter borehole depth in laminar flow and of 64.6 W per meter borehole depth in turbulent flow. This GHE is buried in the ground at a depth of 5 m. It means that rejected heat to the ground is 234.5 W in the laminar flow and 323 W in the turbulent flow. For performance comparison, the heat exchange rates of the conventional U-tube GHEs buried in the ground at a depth of 20 m are presented. Its heat exchange rate from experimental data [1] is 24.9 W per meter borehole in laminar flow and 31.5 W per meter borehole in turbulent flow. In addition, its heat exchange rate from simulation result is 20.1 W per meter borehole in laminar flow and 32.5 W per meter borehole in turbulent flow [16]. These results from simulation data show that rejected heat to the ground is 402 W in the the laminar flow and 650 W in the turbulent flow. Based on its amount of rejected heat to the ground, the rejected heat of 2 (two) shallow spiral-tube GHEs with 5 m depth is approximately same with that of 1 (one) conventional U-tube GHE. It will reduce the borehole depth about 10 m. This fact indicates that the borehole can be reduced about a half by using shallow spiral-tube GHE. Shallow spiral-tube GHEs can be arranged in series and parallel configurations to meet the needs in the application.

Conclusions

Performances of the shallow spiral-tube GHE are investigated by numerical method using CFD code. From the results of this study, the following conclusions are drawn:

1. The performances of spiral-tube GHE are 46.9 and 64.6 W per meter borehole depth in laminar and turbulent flows, respectively.
2. Installing the GHE in the concrete pile increases slightly its performance compared with that of silica sand backfill.
3. Based on the performance comparison, using the shallow spiral-tube GHE can reduce the borehole about a half compared with using the conventional U-tube GHE.

Acknowledgment

This work 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, and K. Yoshida, "Experimental study of several types of ground heat exchanger using a steel pile foundation," Renewable Energy, vol. 36, 764-771 (2011).

[2] Jalaluddin, A. Miyara, K. Tsubaki, and 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, July 12-15, 2010

[3] Jalaluddin and A. Miyara, "Thermal performance investigation of several types of vertical ground heat exchangers with different operation mode," Applied Thermal Engineering, vol. 33-34, 167–174 (2012).

[4] Jalaluddin and A. Miyara, Performance investigation of multiple-tube ground heat exchangers for ground-source heat pump, American Journal of Energy Engineering, vol. 2(5), 103-107 (2014).

[5] Jalaluddin and A. Miyara, Thermal Performances Of Vertical Ground Heat Exchangers In Different Conditions, Journal of Engineering Science and Technology, Vol. 11, No. 12, 1771-1783 (2016).

[6] Y. Man, H. Yang and J. Wang. "Study on hybrid ground-coupled heat pump system for air-conditioning in hot-weather areas like Hong Kong," Applied Energy, vol. 87, 2826–2833 (2010).

[7] N. Naili, M. Hazami, I. Attar and A. Farhat, "In-field performance analysis of ground source cooling system with horizontal ground heat exchanger in Tunisia," Energy, vol. 61, 319-331 (2013).

[8] N. Naili, M. Hazami, S. Kooli and A. Farhat, "Energy and exergy analysis of horizontal ground heat exchanger for hot climatic condition of northern Tunisia," Geothermics, vol. 53, 270–280 (2015).

[9] Y. Man, H. Yang, N. Diao, J. Liu and Z. Fang, "A new model and analytical solutions for borehole and pile ground heat exchangers," International Journal of Heat and Mass Transfer, vol. 53, 2593–2601 (2010).

[10] P. Cui, X. Li, Y. Man, and Z. Fang, "Heat transfer analysis of pile geothermal heat exchangers with spiral coils," Applied Energy, vol. 88, 4113–4119 (2011).

[11] Y. Man, H. Yang, N. Diao, P. Cui, L. Lu and Z. Fang, "Development of spiral heat source model for novel pile ground heat exchangers," HVAC&R Research, vol. 17(6), 1075–1088 (2011).

[12] M. Li, and A.C.K. Lai, "Heat-source solutions to heat conduction in anisotropic media with application to pile and borehole ground heat exchangers," Applied Energy, vol. 96, 451–458 (2012).

[13] Zarrella, A., Capozza, A., De Carli, M., "Analysis of short helical and double U-tube borehole heat exchangers: A simulation-based comparison", Applied Energy, 112, 358–370 (2013).

[14] Zarrella, A., De Carli, M., Galgaro, A., Thermal performance of two types of energy foundation pile: Helical pipe and triple U-tube, Applied Thermal Engineering, 61, 301-310 (2013).

[15] Jalaluddin and A. Miyara, Comparative performance of U-tube and spiral-tube ground heat exchanger for ground source heat pump, The 7th ACRA 2014 Conference SAREK Korea, May 18 - 21, 2014.

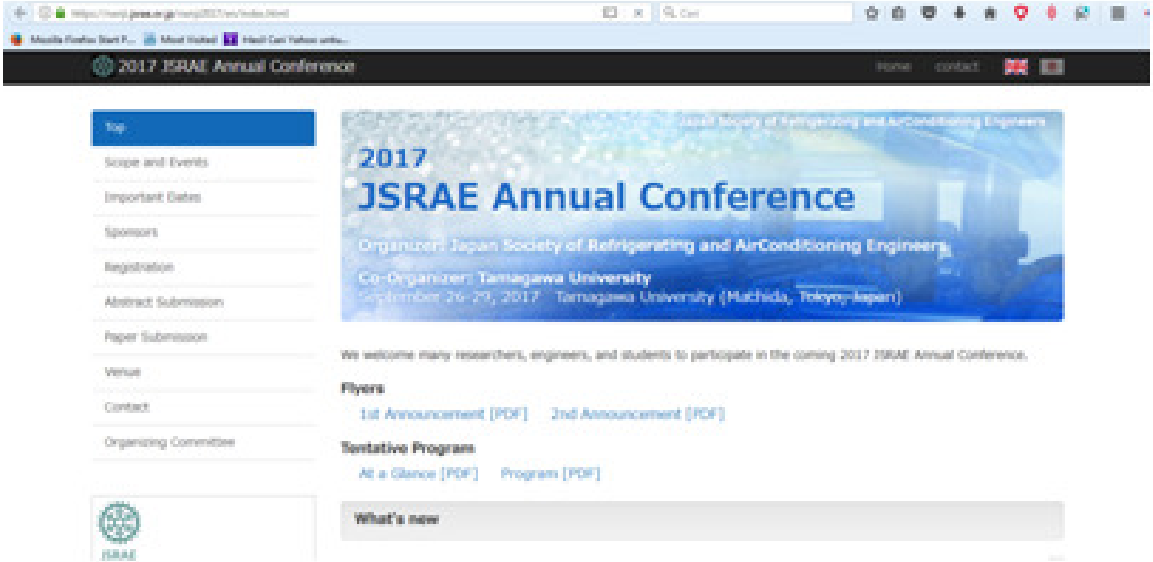
[16] Jalaluddin and A. Miyara, Thermal performance and characteristics of spiral-tube ground heat exchanger for ground source heat pump, The 15th International Heat Transfer Conference 2014 in Kyoto Japan, August 10 – 15, 2014.

[17] Jalaluddin and A. Miyara, Thermal performance and pressure drop of spiral-tube ground heat exchangers for ground-source heat pump, Applied Thermal Engineering, vol. 90, 630-637 (2015).

[18] B. Dehghan, A. Sisman and M. Aydin, "Parametric investigation of helical ground heat exchangers for heat pump applications," Energy and Buildings, vo. 127, 999–1007 (2016).

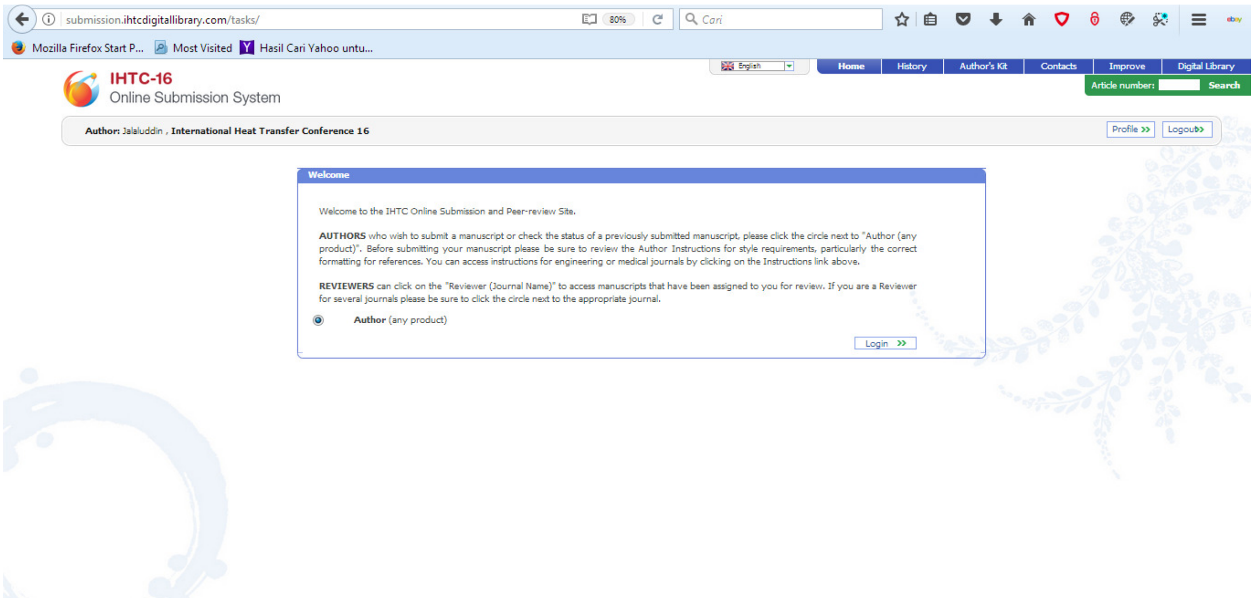
[19] G.H. Go, S.R. Lee, S. Yoon and M.J. Kim, "Optimum design of horizontal ground-coupled heat pump systems using spiral-coil-loop heat exchangers," Applied Energy, vol. 162, 330–345 (2016).

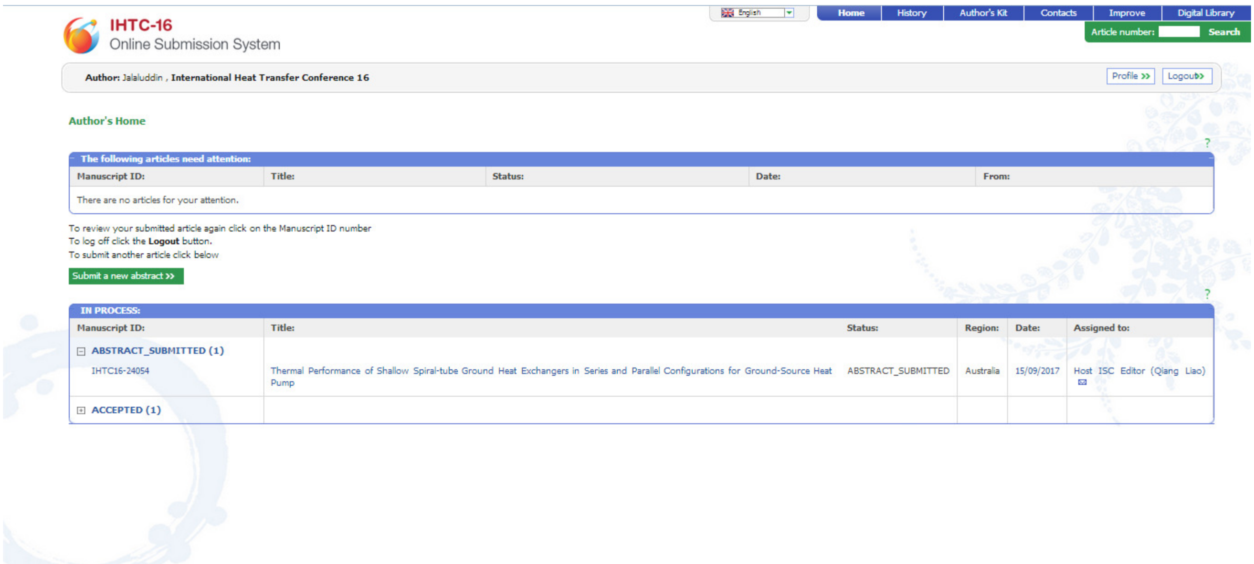
Participated in JSRAE Conference, Tamagawa University Japan

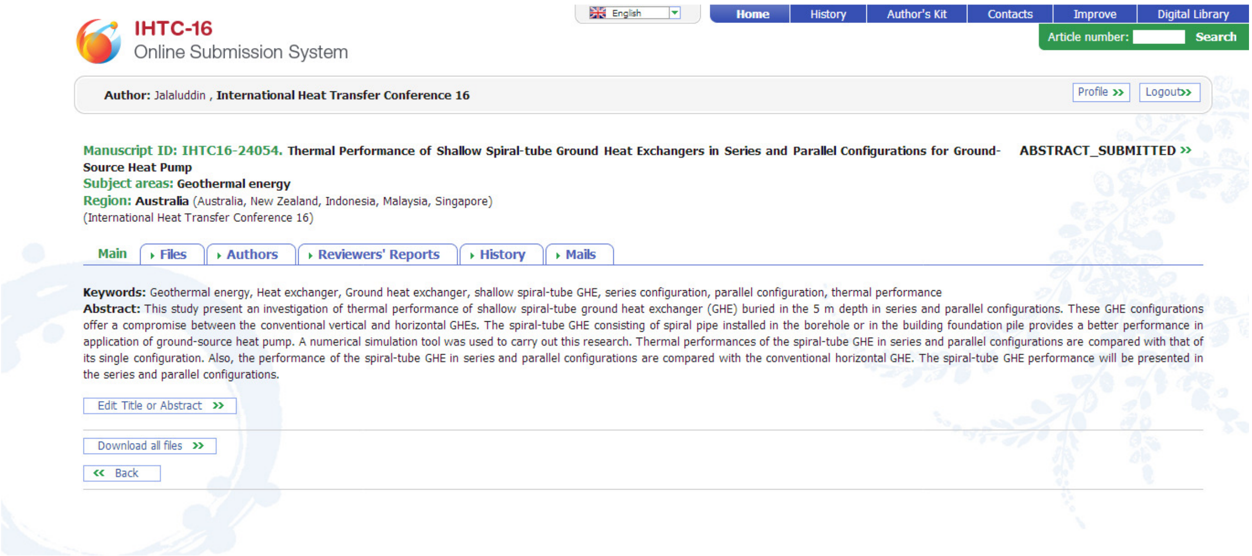

2017 JSRAE Annual Conference
Top
Scope and Events
Important Dates
Sponsors
Registration
Abstract Submission
Paper Submission
Venue
Contact
Organizing Committee
2017
JSRAE Annual Conference
Organizer: Japan Society of Refrigerating and AirConditioning Engineers
Co-Organizer: Tamagawa University
September 26-29, 2017 Tamagawa University (Machida, Tokyo, Japan)
We welcome many researchers, engineers, and students to participate in the coming 2017 JSRAE Annual Conference.
Flyers
1st Announcement [PDF] 2nd Announcement [PDF]
Tentative Program
At a Glance [PDF] Program [PDF]
What's new
JSRAE


日本冷凍空調学会
2017年度年次大会
2017年9月26日～29日
玉川大学 大学教育棟2014
JSRAE

Paper submitted to The 16th International Heat Transfer Conference (IHTC), International Conference 4 tahunan bidang Heat Transfer terindeks Scopus


submission.ihtcdigitallibrary.com/tasks/
Mozilla Firefox Start P...
Most Visited
Hasil Cari Yahoo untu...
IHTC-16
Online Submission System
English
Home
History
Author's Kit
Contacts
Improve
Digital Library
Article number:
Search
Author: Jalaluddin , International Heat Transfer Conference 16
Profile >>
Logout>>
Welcome
Welcome to the IHTC Online Submission and Peer-review Site.
AUTHORS who wish to submit a manuscript or check the status of a previously submitted manuscript, please click the circle next to "Author (any product)". Before submitting your manuscript please be sure to review the Author Instructions for style requirements, particularly the correct formatting for references. You can access instructions for engineering or medical journals by clicking on the Instructions link above.
REVIEWERS can click on the "Reviewer (Journal Name)" to access manuscripts that have been assigned to you for review. If you are a Reviewer for several journals please be sure to click the circle next to the appropriate journal.
Author (any product)
Login >>


IHTC-16
Online Submission System
English
Home
History
Author's Kit
Contacts
Improve
Digital Library
Article number:
Search
Author: Jalaluddin , International Heat Transfer Conference 16
Profile >>
Logout>>
Author's Home
The following articles need attention:
Manuscript ID:
Title:
Status:
Date:
From:
There are no articles for your attention.
To review your submitted article again click on the Manuscript ID number
To log off click the Logout button.
To submit another article click below
Submit a new abstract >>
IN PROCESS:
Manuscript ID:
Title:
Status:
Region:
Date:
Assigned to:
ABSTRACT_SUBMITTED (1)
IHTC16-24054
Thermal Performance of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations for Ground-Source Heat Pump
ABSTRACT_SUBMITTED
Australia
15/09/2017
Host ISC Editor (Qiang Liao)
ACCEPTED (1)



English | Home | History | Author's Kit | Contacts | Improve | Digital Library

IHTC-16
Online Submission System

Article number: Search

Author: Jalaluddin , **International Heat Transfer Conference 16**

Profile >> | Logout>>

Manuscript ID: IHTC16-24054. Thermal Performance of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations for Ground-Source Heat Pump **ABSTRACT_SUBMITTED >>**

Subject areas: Geothermal energy

Region: Australia (Australia, New Zealand, Indonesia, Malaysia, Singapore)

(International Heat Transfer Conference 16)

Main | Files | Authors | Reviewers' Reports | History | Mails

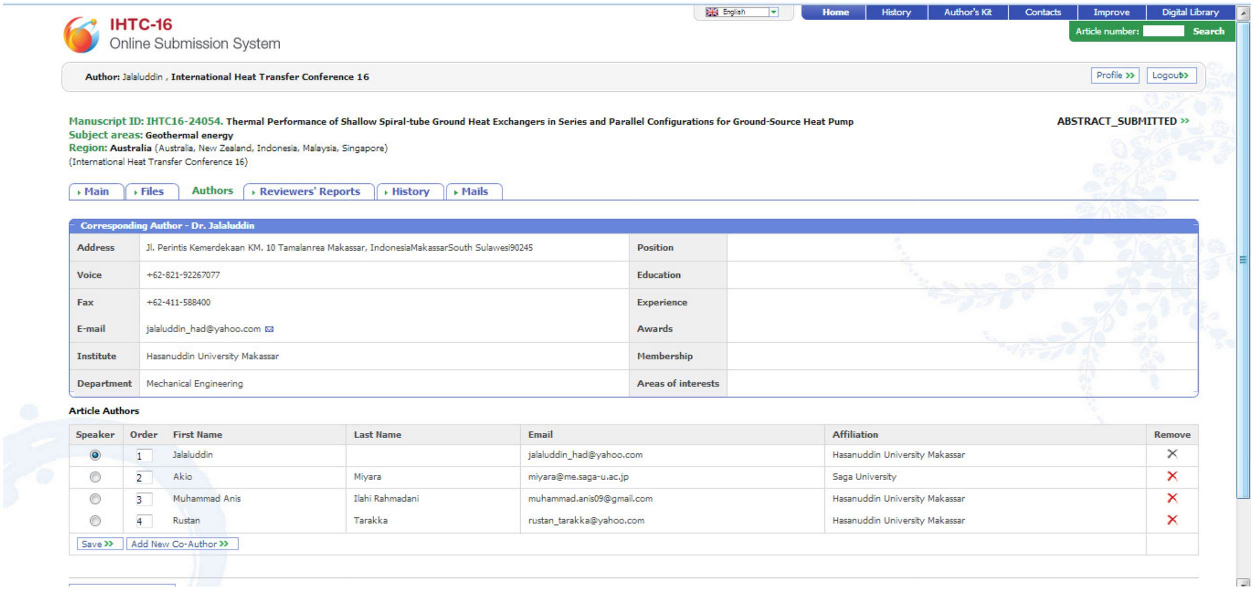
Keywords: Geothermal energy, Heat exchanger, Ground heat exchanger, shallow spiral-tube GHE, series configuration, parallel configuration, thermal performance

Abstract: This study present an investigation of thermal performance of shallow spiral-tube ground heat exchanger (GHE) buried in the 5 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 heat pump. A numerical simulation tool was used to carry out this research. Thermal performances of the spiral-tube GHE in series and parallel configurations are compared with that of its single configuration. Also, the performance of the spiral-tube GHE in series and parallel configurations are compared with the conventional horizontal GHE. The spiral-tube GHE performance will be presented in the series and parallel configurations.

Edit Title or Abstract >>

Download all files >>

<< Back



English | Home | History | Author's Kit | Contacts | Improve | Digital Library

IHTC-16
Online Submission System

Article number: Search

Author: Jalaluddin , **International Heat Transfer Conference 16**

Profile >> | Logout>>

Manuscript ID: IHTC16-24054. Thermal Performance of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations for Ground-Source Heat Pump **ABSTRACT_SUBMITTED >>**

Subject areas: Geothermal energy

Region: Australia (Australia, New Zealand, Indonesia, Malaysia, Singapore)

(International Heat Transfer Conference 16)

Main | Files | Authors | Reviewers' Reports | History | Mails

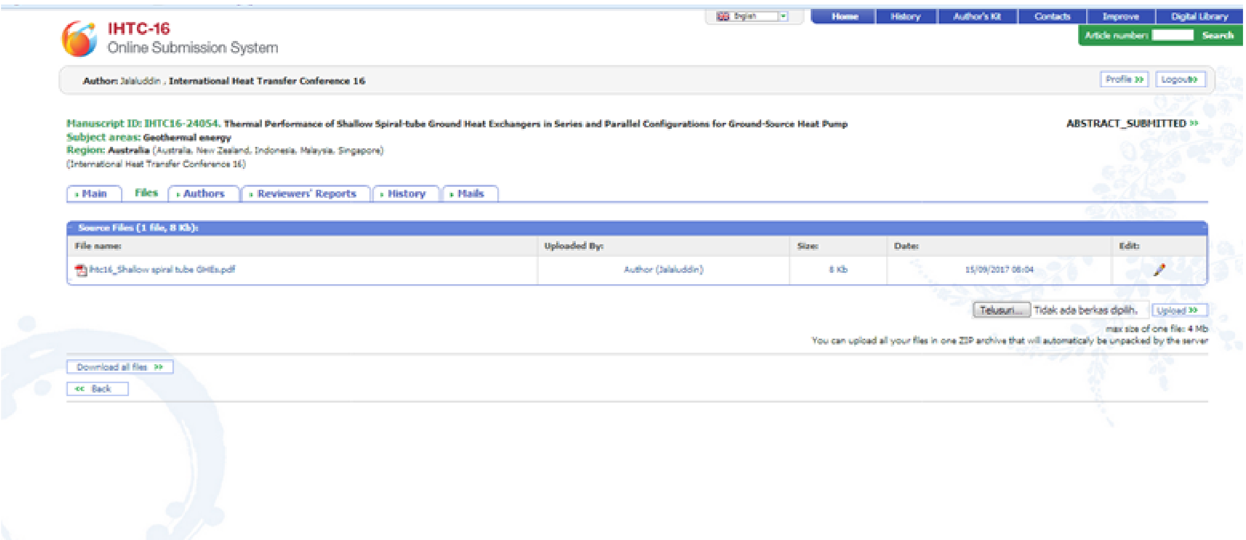
Corresponding Author - Dr. Jalaluddin

Address	Jl. Perintis Kemerdekaan KM. 10 Tamalanrea Makassar, IndonesiaMakassarSouth Sulawesi90245	**Position**	
Voice	+62-821-92267077	**Education**	
Fax	+62-411-588400	**Experience**	
E-mail	jalaluddin_had@yahoo.com	**Awards**	
Institute	Hasanuddin University Makassar	**Membership**	
Department	Mechanical Engineering	**Areas of interests**	

Article Authors

Speaker	Order	First Name	Last Name	Email	Affiliation	Remove
◉	1	Jalaluddin		jalaluddin_had@yahoo.com	Hasanuddin University Makassar	×
○	2	Akio	Miyara	miyara@me.saga-u.ac.jp	Saga University	×
○	3	Muhammad Anis	Ilahi Rahmadani	muhammad.anis09@gmail.com	Hasanuddin University Makassar	×
○	4	Rustan	Tarakka	rustan_tarakka@yahoo.com	Hasanuddin University Makassar	×

Save >> | Add New Co-Author >>


Home
History
Author's Kit
Contacts
Improve
Digital Library
Article number:
Search
IHTC-16
Online Submission System
Author: Jalaluddin , International Heat Transfer Conference 16
Profile >>
Logout>>
Manuscript ID: IHTC16-24054. Thermal Performance of Shallow Spiral-tube Ground Heat Exchangers in Series and Parallel Configurations for Ground-Source Heat Pump
ABSTRACT_SUBMITTED >>
Subject areas: Geothermal energy
Region: Australia (Australia, New Zealand, Indonesia, Malaysia, Singapore)
(International Heat Transfer Conference 16)
Main
Files
Authors
Reviewers' Reports
History
Mails
Source Files (1 file, 8 Kb):
File name:
Uploaded By:
Size:
Date:
Edit:
ihtc16_Shallow spiral tube GHEs.pdf
Author (Jalaluddin)
8 Kb
15/09/2017 08:04
Telusuri...
Tidak ada berkas dipilih.
Upload >>
max size of one file: 4 Mb
You can upload all your files in one ZIP archive that will automatically be unpacked by the server
Download all files >>
<< Back

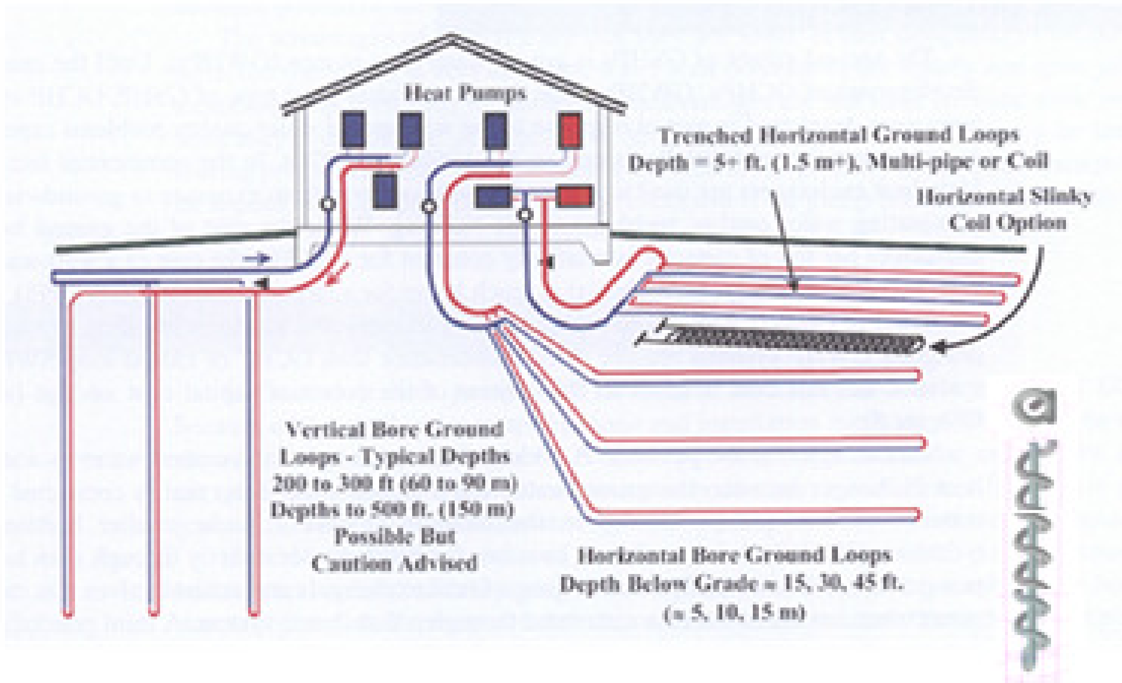
Buku Ajar

Ground Heat Exchangers for Air Conditioning Applications

Draft

GROUND HEAT EXCHANGER FOR SPACE AIR CONDITIONING SYSTEM

Dr. Eng. Jalaluddin, ST, MT



MECHANICAL ENGINEERING DEPARTEMENT
HASANUDDIN UNIVERSITY
2017

DAFTAR ISI

4. 5 Spiral Tube Ground Heat Exchangers

4.5.1 Performance of Shallow Borehole of spiral-Tube Ground Heat Exchanger

ABSTRACT

The use of geothermal energy has been recognized as a possible solution for reducing emissions. This energy source is an environmentally friendly energy source with wide range of applicability such air conditioning and hot water heating. A ground heat exchanger (GHE) is used in the air conditioning system to exchange heat with the ground. This study present an investigation of thermal performance of shallow spiral-tube GHE buried in the 5 m depth. The performance of this GHE is investigated by numerical method using CFD code. The performance of the spiral-tube GHE is 46.9 Watt per meter borehole depth in laminar flow and 64.6 Watt per meter borehole depth in turbulent flow. Comparison between the spiral-tube and the conventional U-tube GHEs shows the possibility to reduce borehole depth and installation cost. Using the spiral-tube GHE can reduce the borehole about a half compared with using the conventional U-tube GHE. Shallow spiral-tube GHEs can be arranged in series and parallel configurations to meet the needs in the application.

Keywords: *ground heat exchanger, shallow spiral-tube GHE, performance.*

Introduction

The ground source heat pump (GSHP) system is a promising technology for cooling and heating building in the world with wide range of applications such as for space heating and cooling, hot water supply and applications in the agricultural field. The well-known application of the GSHP system is for space heating and cooling in residential and commercial buildings. The heat exchange performance of the ground heat exchanger (GHE) is an important subject of GSHP system design. Operating the GHEs with different models and various conditions shows the different characteristic in their heat exchange rates. The performance of three types of GHEs namely U-tube, double-tube, and multi-tube GHEs have been investigated experimentally. The double-tube GHE has the highest heat exchange rate [1]. Operating the GHEs with different operation modes such as short-time period of operation, discontinuous and continuous operation shows the different characteristic in their heat exchange rates [2,3]. The performances of multiple-tube GHEs with a number of pipes installed inside the borehole have been investigated. The result shows that thermal interferences between the pipes affect its performance [4]. The effect of different inlet water temperatures and borehole depths of the GHEs also affect its performance [5]. In the hot weather like Indonesia, the GSHP system is used for space cooling as an air conditioning system as known as ground-source cooling system. The hybrid GSHP system was applied for air conditioning system in hot weather condition such Hongkong [6]. Experimental test, energy and exergy analysis of the ground-source cooling system with horizontal GHE have been carried-out in Tunisia [7,8]. The utilization of GSHP is appropriated for cooling building in hot climate such Tunisia.

A GHE is used in the GSHP system to exchange heat with the ground. The spiral-tube GHE is gaining interest in recent years. Analytical solutions of spiral coil ground heat exchangers have been developed by Man et al. [9], Cui et al. [10], Man et al, [11] and Li and Lai [12]. The classical approaches, i.e. the line heat source model and the "hollow" cylindrical heat source model, are no longer valid for thermal analysis and design of the GHE with spiral coils in foundation pile. A "solid" cylindrical source model has been developed