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

2016

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
Program Studi : Teknik Mesin
Nomor HP : 082192267077
Alamat surel (e-mail) : jalaluddin_had@yahoo.com
Anggota (1)
Nama Lengkap : RUSTAN TARAKKA
NIDN : 0027087504
Perguruan Tinggi : Universitas Hasanuddin
Institusi Mitra (jika ada)
Nama Institusi Mitra : SAGA UNIVERSITY JAPAN
Alamat : 1, Honjomachi, Saga-shi, JAPAN, 840-8502
Penanggung Jawab : Professor Akio MIYARA
Tahun Pelaksanaan : Tahun ke 1 dari rencana 3 tahun
Biaya Tahun Berjalan : Rp 160.000.000,00
Biaya Keseluruhan : Rp 593.085.000,00

Mengetahui,
Dekan

(Dr. Ing. Ir. Wahyu H. Piarah, MSME)
NIP/NIK 19600302 198609 1 001

Makassar, 15 - 11 - 2016
Ketua,

(Dr. JALALUDDIN S.T, M.T)
NIP/NIK 19720825 200003 1 001

Menyetujui,
Ketua LPPM UNHAS

(Prof. Dr. Ir. Laode Asrul, MP)
NIP/NIK 19630307 198812 1 001

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 yang diusulkan. Penelitian ini akan melalui studi numerik dan eksperimental. Pada tahun pertama ini, studi tentang beberapa faktor terkait pendesainan GHE tipe spiral dibandingkan dengan beberapa tipe GHE dengan beberapa kondisi operasi seperti pengaruh temperatur inlet air dan kedalaman tanah. Selanjutnya, studi tentang perbandingan GHE tipe spiral dengan dengan tipe konvensional dilakukan. Pengembangan GHE tipe spiral dengan kedalaman yang rendah dilakukan dengan berbagai variasi kondisi operasi dan konfigurasi. Pada tahun kedua, GHE untuk sistem pengkondisian udara akan diuji secara eksperimental. Analisis energi dan exergi dari sistem akan dilakukan pada tahun ketiga. Target utama adalah rekomendasi desain dari aplikasi GHE tipe spiral dan modifikasinya untuk sistem pengkondisian udara serta membangun jaringan penelitian internasional secara komprehensif.

Simulasi tentang GHE tipe spiral pada berbagai kondisi dan perbandingan dengan tipe lainnya telah dilakukan. Beberapa peralatan pendukung telah disiapkan untuk mendukung penelitian ini. Beberapa kegiatan yang telah dilakukan terkait kerjasama penelitian dengan peneliti mitra sebagai output penelitian antara lain : peneliti mitra telah berpartisipasi sebagai keynote speaker pada ICESNANO 2016 Solo. Penulisan jurnal paper internasional telah di submit ke Journal of Engineering Science and Technology (JESTEC) terindeks Scopus. Hasil penelitian ini juga diseminarkan pada “The 3rd International Symposium on Smart Material and Mechatronic (ISSMM) 2016 dan internasional conference lainnya. Hasil penelitian tersebut yang didiskusikan pada ISSMM Conference 2016 akan ditingkatkan untuk disubmit ke Jurnal Internasional Scopus: Journal of Mechanical Engineering © 2016 Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), Malaysia. Selanjutnya, aktivitas penelitian internasional telah dilakukan pada tanggal 23 s/d 29 Oktober 2016 dengan diskusi hasil penelitian dengan *international partner* di Saga University Japan (Prof. Akio Miyara & Dr. K Kariya). Diskusi hasil penelitian dan eksperimental set-up untuk pengujian sistem GSHP di Saga University serta penyusunan skenario penelitian tahun 2017 telah dilakukan. Peneliti mitra juga telah sepakat untuk memberikan kuliah khusus dan menjadi pembicara kunci di Universitas Hasanuddin pada bulan November tahun 2017. Special lecture terkait perkembangan penelitian juga telah dilakukan pada tanggal 26 Oktober 2016 di Saga University Japan. Hasil penelitian yang telah dilakukan bersama dengan *international partner* dipresentasikan pada New Energy and Industrial Technology Development Organization (NEDO) Japan di Tokyo pada tanggal 28 Oktober 2016.

DAFTAR ISI

HALAMAN PENGESAHAN

RINGKASAN

DAFTAR ISI

LAMPIRAN-LAMPIRAN

BAB I PENDAHULUAN

Penggunaan sumber energi yang ramah lingkungan dan terbarukan sekarang ini merupakan suatu tantangan untuk membuatnya menjadi teknologi yang atraktif 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 yamg terjadi antara air sirkulasi pada alat penukar kalor tersebut 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*

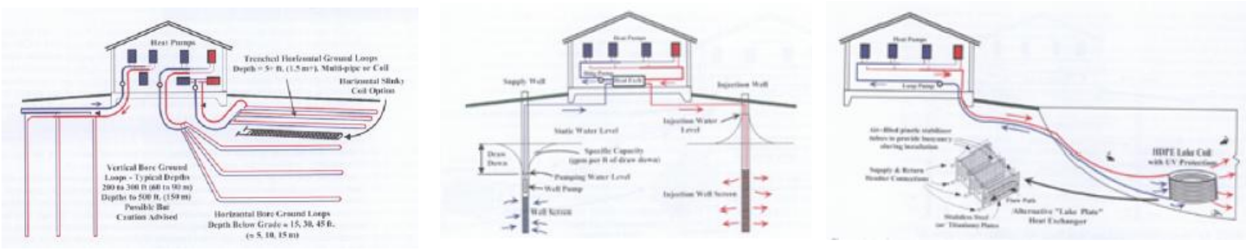
Output Penelitian

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

BAB II TINJAUAN PUSTAKA

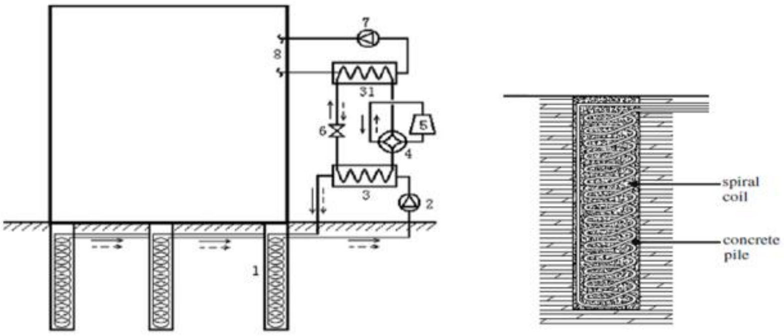
Sistem GSHP digunakan secara luas dalam aplikasi sebagai pemanas dan pendingin ruangan, suplai air panas dan aplikasi pada bidang pertanian. Pemanfaatan yang paling banyak dikenal adalah aplikasi sebagai pendingin dan pemanas ruangan pada bangunan perumahan dan komersial.

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.



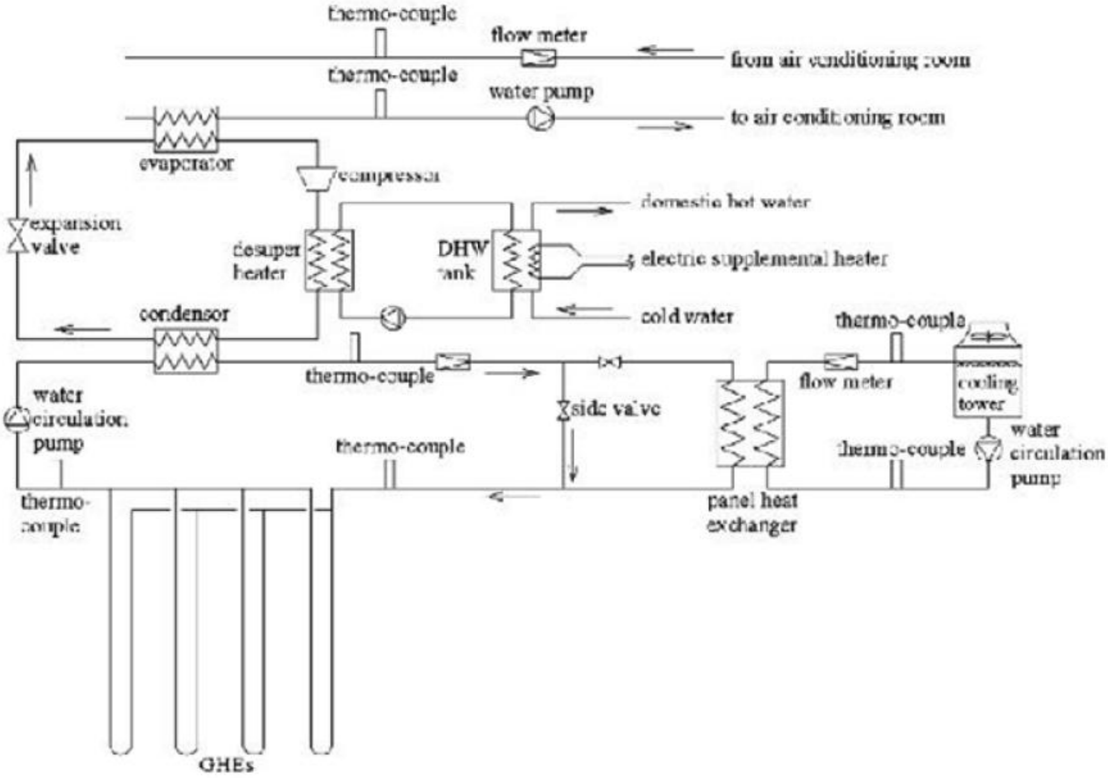
Gambar 1. GHE dipasang secara horizontal dan vertikal (Kavanaugh and Rafferty, 2014)

Diagram skematik dari 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.



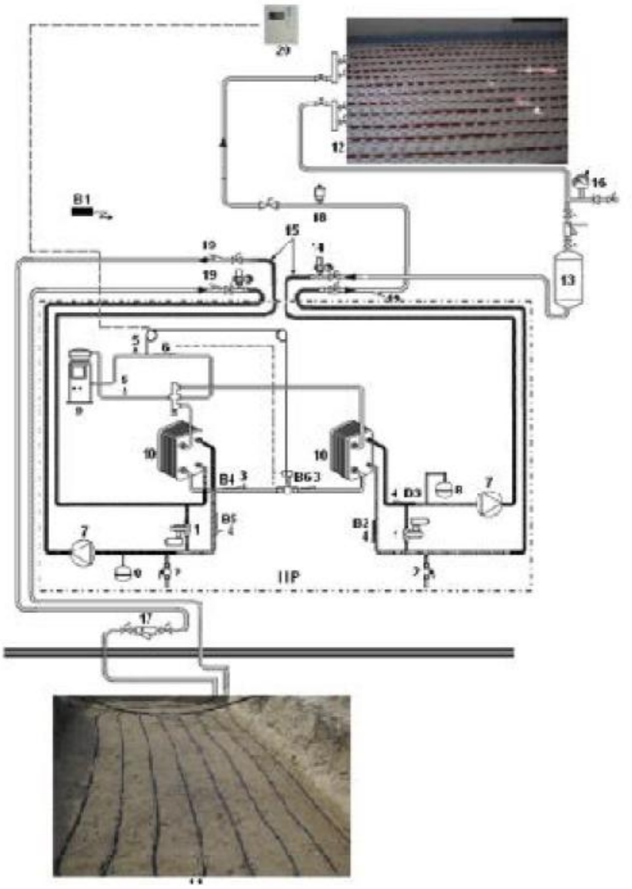
Gambar 2. Diagram skematik dari GHE tipe spiral oleh Man et al. (2010) and Cui et al. (2011)

Pada daerah bercuaca panas seperti Indonesia, sistem GSHP digunakan sebagai sistem pengkondisian udara yang dikenal dengan *ground source cooling system*. Sistem ini digunakan hanya untuk sistem pendinginan sehingga panas yang dibuang ke tanah akan terakumulasi di sekitar GHE. Untuk mengatasi hal tersebut, sistem hibrid GSHP telah dikembangkan secara luas (Man et al., 2010) dengan menggunakan *supplemental heat rejector* untuk mengurangi akumulasi panas di sekitar GHE seperti yang ditunjukkan pada gambar 3.



Gambar 3. Diagram skematik sistem hibrid GSHP

Studi eksperimental untuk mengevaluasi parameter optimal dari GHE yang digunakan untuk sistem pendinginan ruangan di Tunisia telah dilakukan seperti ditunjukkan pada gambar 4. Performansi dari GHE dengan konfigurasi horizontal telah dianalisis secara eksperimental dan analitik (Naili et al., 2013). Analisis energi dan exergi dari sistem ini untuk kondisi cuaca panas telah (Naili et al., 2015).



Gambar 4. Eksperimetal set-up dari *ground source cooling system*

Beberapa peneliti telah mengembangkan *ground source cooling system* untuk sistem pengkondisian udara pada perumahan dan bangunan komersial. Pengembangan *ground source cooling system* di Indonesia membutuhkan sebuah studi yang komprehensif tentang sifat termal tanah, desain dari GHE dan sistemnya secara keseluruhan. GHE tipe spiral mendapatkan perhatian yang besar karena besarnya kemampuan pertukaran panas dengan tanah disekitarnya. Pengetahuan tentang performansi dari GHE tipe spiral pada kondisi bervariasi sangat krusial dalam aplikasinya. Beberapa faktor seperti geometri optimum dan kondisi operasi untuk aplikasi masih sangat dibutuhkan untuk panduan desain.

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 numerik dan eksperimental sedang dilakukan di Laboratorium Energi Terbarukan Program studi Teknik Mesin Universitas Hasanuddin berkolaborasi dengan Laboratorium Termal Engineering 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

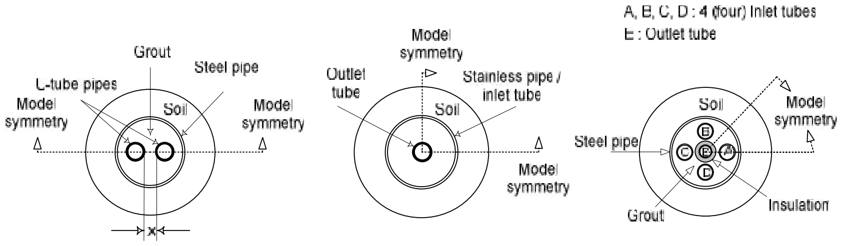
Penelitian tentang pengembangan sebuah GHE tipe spiral yang baru dilakukan di laboratorium Energi Terbarukan Prodi Teknik Mesin Universitas Hasanuddin.

Kegiatan penelitian yang dilakukan antara lain:

1) Analisis berbagai faktor yang berpengaruh terhadap GHE tipe vertikal dengan simulasi numerik untuk mengetahui pengaruh temperatur inlet air dan pengaruh kedalaman borehole.
2) Analisis performance GHE tipe spiral yang dipasang pada kedalam rendah dan menyusunnya dengan berbagai konfigurasi serta membandingkan dengan tipe konvesional.
3) Pembuatan dan persiapan studi eksperimental tentang kondisi termal tanah.

A. Beberapa faktor yang berpengaruh terhadap GHE tipe vertikal

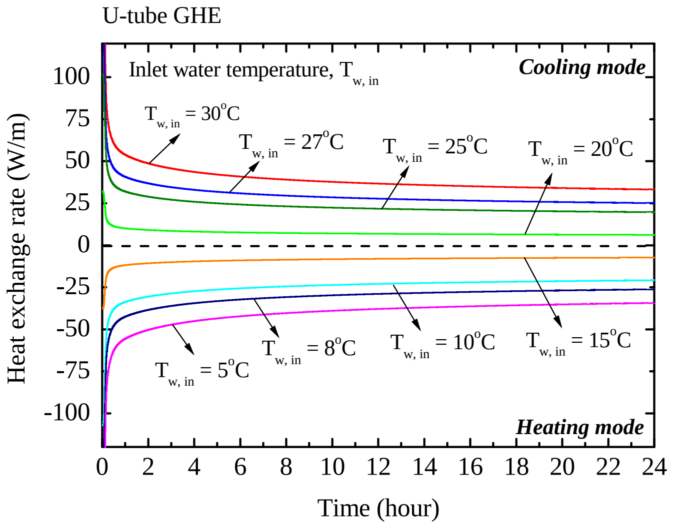
Simulasi numerik dilakukan untuk mengetahui pengaruh temperatur inlet air terhadap kinerja GHE. Beberapa tipe dari GHE meliputi U-tube, Double-tube dan Multi-tube dijadikan model acuan untuk pengembangan GHE tipe baru. Model dari GHE tersebut dapat dilihat pada gambar 5 dengan potongan melintang horizontal.



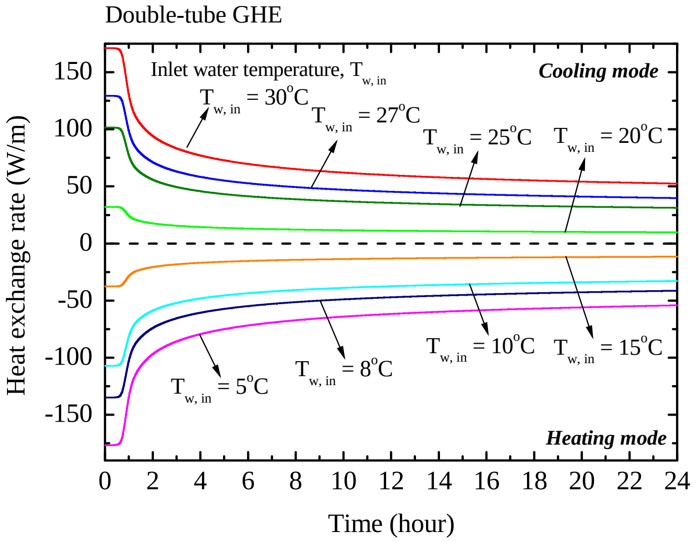
(a) U-tube (b) Double-tube (c) Multi-tube

Gambar 5. Model GHE dengan potongan melintang horizontal

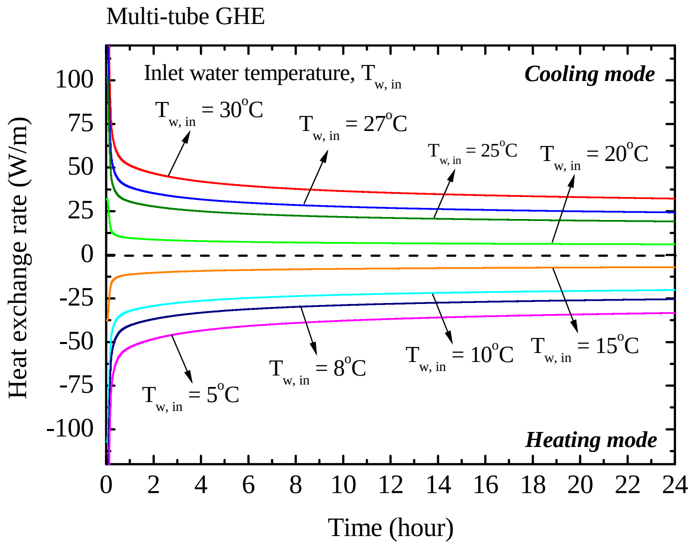
Kinerja dari ketiga model GHE tersebut diatas di uji dengan variasi temperatur inlet. Hal ini untuk melihat pengaruh delta temperatur antara air sirkulasi dengan temperatur tanah sekelilingnya. Hasil simulasi menunjukkan pengaruh temperatur inlet terhadap kinerja dari ketiga model GHE seperti terlihat pada gambar 6.



(a) U-tube



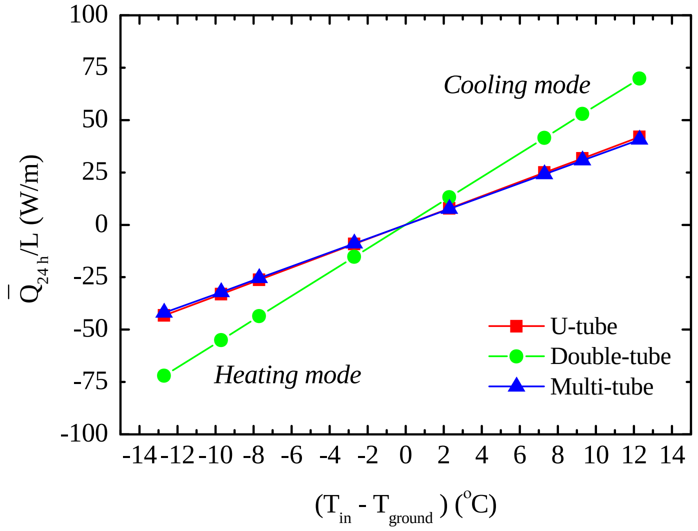
(b) Double-tube



(c) Multi-tube

Gambar 6. Kinerja GHE terhadap variasi temperatur inlet air sirkulasi

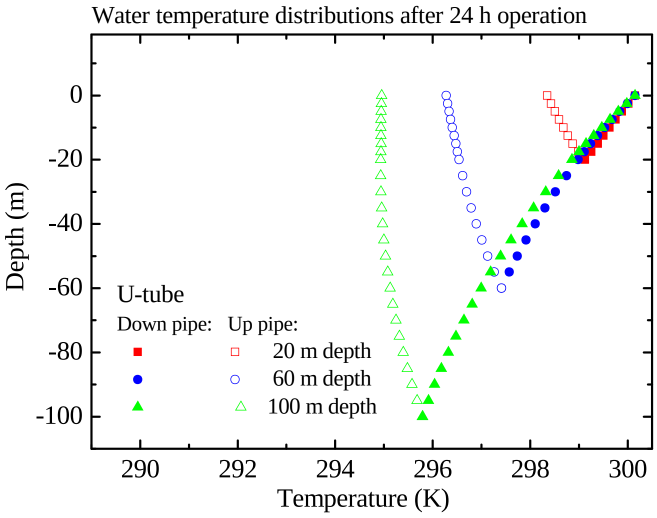
Nilai rata-rata kinerja GHE selama 24 jam pengoperasian dapat dilihat pada gambar 3. Kinerja GHE meningkat pada proses pendinginan dan menurun pada proses pemanasan sebasar 3.4 W/m untuk tipe U-tube, 5.7 W/m untuk tipe double-tube dan 3.3 W/m untuk tipe multi-tube dengan peningkatan 1 °C (K) terhadap perbedaan temperatur air masuk dan tanah sekeliling (T_{in}–T_{ground}).



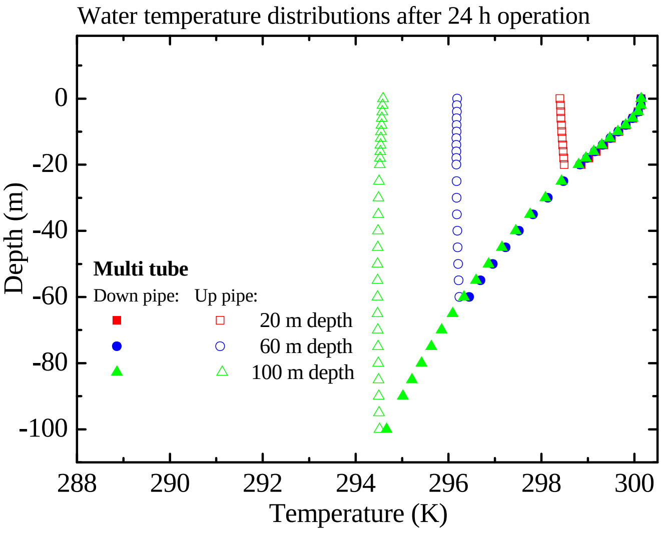
Gambar 7. Nilai rata-rata kinerja GHE selama 24 jam pengoperasian

Kinerja GHE terhadap perubahan kedalaman borehole juga dipelajari. Kedalaman borehole sangat berpengaruh terhadap biaya instalasi dari GHE. Karakteristik GHE meliputi distribusi temperatur serta pengaruh interperensi antara pipa inlet dan outlet dapat dilihat pada gambar 8.

Kinerja GHE rata-rata selama 24 jam pengoperasian terhadap perubahan kedalaman borehole 20 m, 40 m dan 100 m dapat dilihat pada gambar 9. Berdasarkan perbandingan dengan kinerja GHE pada kedalaman 20 m, diketahui bahwa kinerja per meter kedalaman menurun 32.5 % pada kedalaman 60 m, 47.9 % pada kedalaman 100 m untuk GHE tipe U-tube dan 29 % pada kedalaman 60 m, 42.7 % pada kedalaman 100 m untuk multi-tube.

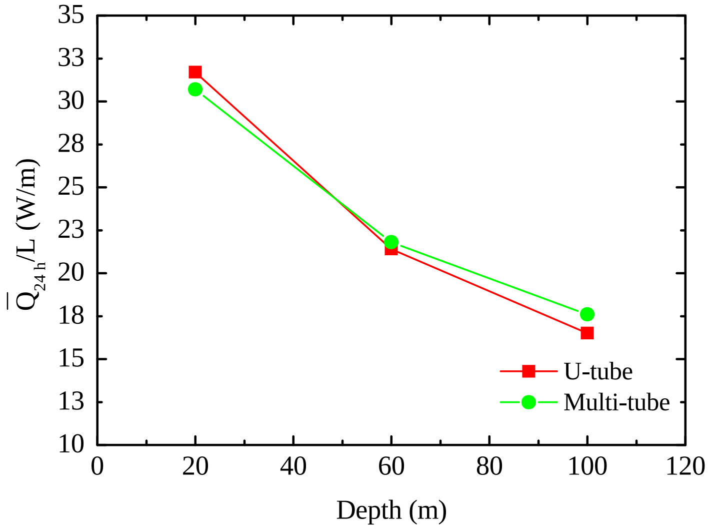


(a) U-tube



(b) Multi-tube

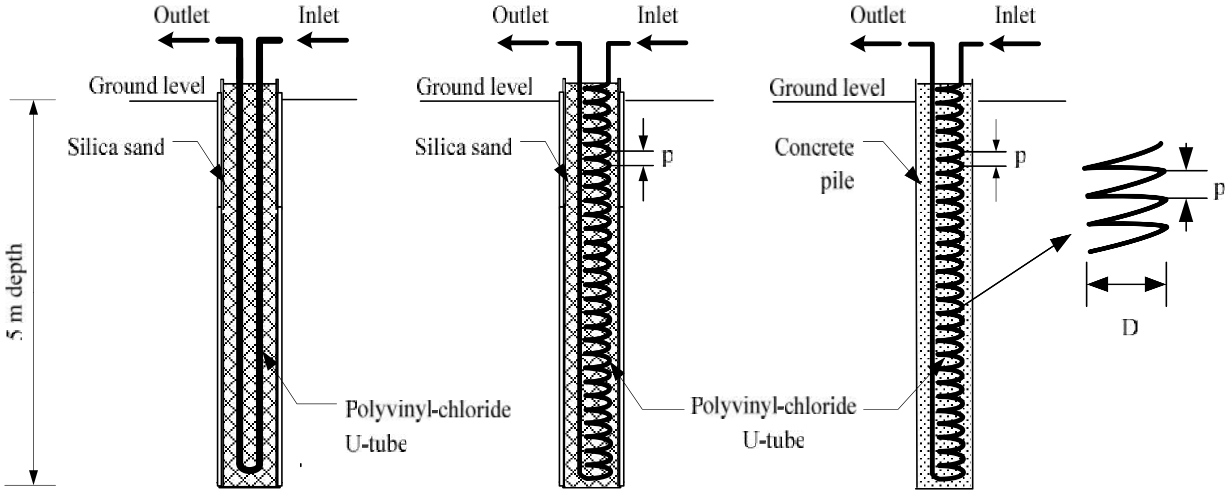
Gambar 8. Distribusi temperatur terhadap perubahan kedalaman borehole



Gambar 9. Kinerja GHE rata-rata selama 24 jam pengoperasian terhadap perubahan kedalaman

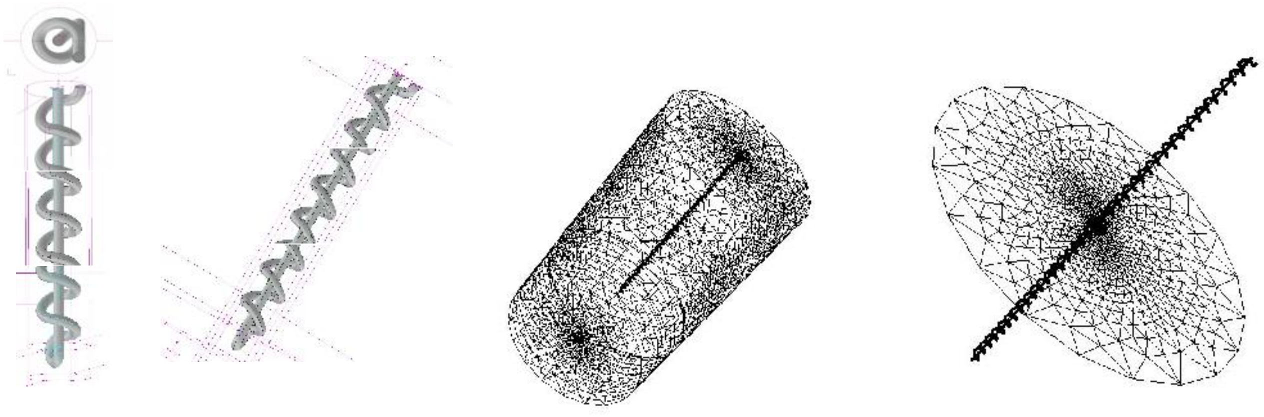
B. Performance GHE tipe spiral pada kedalaman rendah

Skema dari GHE tipe U-tube dan spiral-tube ditunjukkan pada gambar 10. Kedua GHE dipasang pada kedalaman 5 m. Model tiga dimensi, grid dan meshing dari GHE tipe spiral-tube ditunjukkan pada gambar 11.



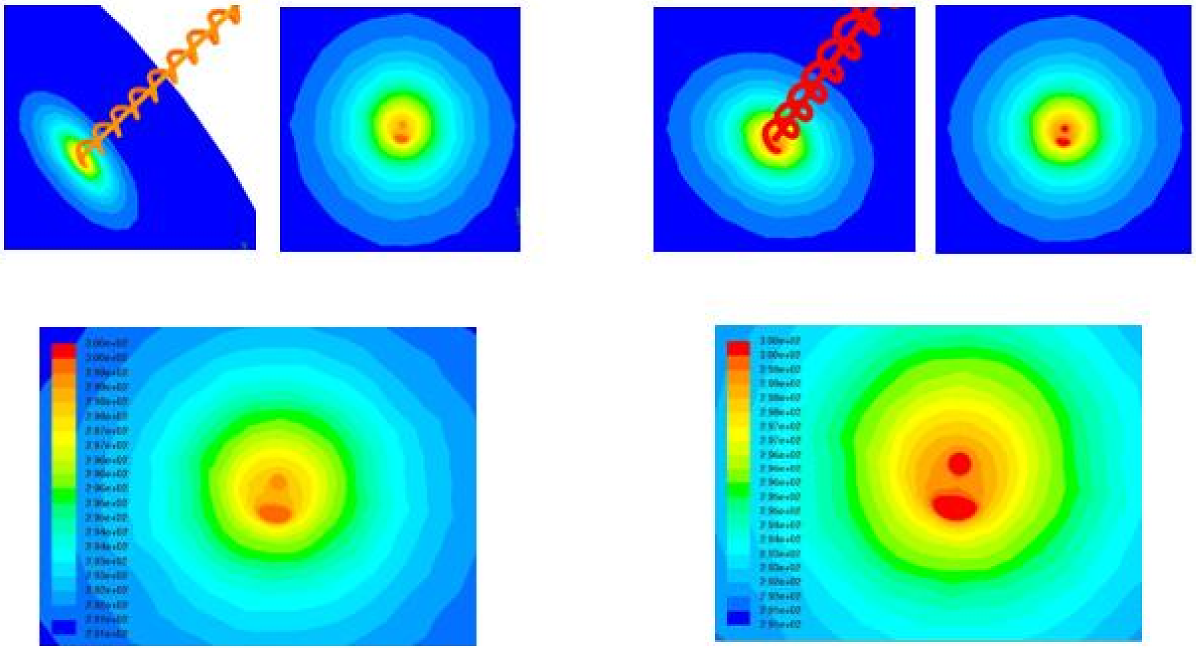
(a) (b) Spiral

Gambar 10. GHE tipe spiral dan tipe U-tube pada kedalaman rendah



Gambar 11. Model tiga dimensi, Grid dan meshing dari GHE tipe spiral

Salah satu hasil simulasi seperti pada gambar 12 menunjukkan kontur dari temperatur distribusi dari GHE dan tanah sekeliling pada kedalaman 2.5 m.



(a) Laminar Flow

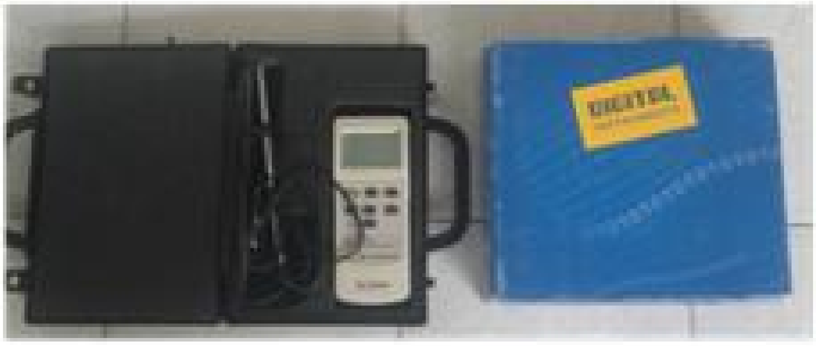
(b) Turbulent Flow

Gambar 12. Kontur temperatur dengan potongan melintang dari GHE tipe spiral pada kedalaman 2.5 m

C. Studi Eksperimental tentang kondisi termal tanah

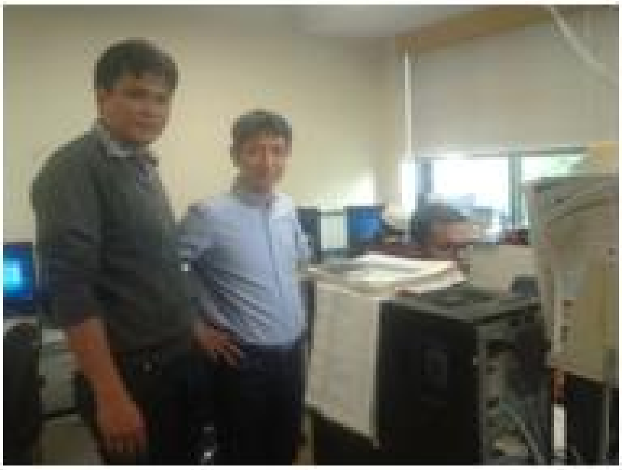
Peralatan pendukung untuk studi eksperimental dilakukan di laboratorium Energi Terbarukan Program studi Teknik Mesin Fakultas Teknik Unhas Gowa.

Peralatan dan Alat ukur sebagai berikut:




TES 1333
Solar Power Meter

D. Setting Peralatan Uji di Laboratorium Termal Saga University Japan



E. Special Lecture Saga University Japan

F. NEDO Conference in Tokyo Japan

平成28年度
NEDO新エネルギー成果報告会

③地中熱交換器の研究開発

[illegible]スパイラル型地中熱交換器の計算モデル

✓熱交換量 約2倍，圧力損失 約8倍
✓熱交換量の増加より，圧力損失の増加が大きい
✓スパイラル型地中熱交換器を使う効果は？
⇒システムCOPの観点から熱交換器を評価

BAB V. KESIMPULAN

Pelaksanaan penelitian tahun ke-1 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 beberapa faktor terkait pendesainan GHE tipe spiral dibandingkan dengan beberapa tipe GHE dengan beberapa kondisi operasi seperti pengaruh temperatur inlet air dan kedalaman tanah. Selanjutnya, pengembangan GHE tipe spiral dengan kedalaman yang rendah dilakukan dengan berbagai variasi kondisi operasi dan konfigurasi.

Tahapan penelitian yang telah dilakukan antara lain :

1) Analisis berbagai faktor yang berpengaruh terhadap GHE tipe vertikal dengan simulasi numerik untuk mengetahui pengaruh temperatur inlet air dan pengaruh kedalaman borehole.
2) Analisis performance GHE tipe spiral yang dipasang pada kedalam rendah dan menyusunnya dengan berbagai konfigurasi serta membandingkan dengan tipe konvesional.
3) Pembuatan dan persiapan studi eksperimental tentang kondisi termal tanah.

Simulasi tentang GHE tipe spiral pada berbagai kondisi dan perbandingan dengan tipe lainnya telah dilakukan. Beberapa peralatan pendukung telah disiapkan untuk mendukung penelitian ini. Beberapa kegiatan yang telah dilakukan terkait kerjasama penelitian dengan peneliti mitra sebagai output penelitian antara lain : peneliti mitra telah berpartisipasi sebagai keynote speaker pada ICESNANO 2016 Solo. Penulisan jurnal paper internasional telah di submit ke Journal of Engineering Science and Technology (JESTEC) terindeks Scopus. Hasil penelitian ini juga diseminarkan pada “The 3rd International Symposium on Smart Material and Mechatronic (ISSMM) 2016 dan internasional conference lainnya. Hasil penelitian tersebut yang didiskusikan pada ISSMM Conference 2016 akan ditingkatkan untuk disubmit ke Jurnal Internasional Scopus: Journal of Mechanical Engineering © 2016 Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), Malaysia. Selanjutnya, aktivitas penelitian internasional telah dilakukan pada tanggal 23 s/d 29 Oktober 2016 dengan diskusi hasil penelitian dengan *international partner* di Saga University Japan (Prof. Akio Miyara & Dr. K Kariya). Diskusi hasil penelitian dan eksperimental set-up untuk pengujian sistem GSHP di Saga University serta penyusunan skenario penelitian tahun 2017 telah dilakukan. Peneliti mitra juga telah sepakat untuk memberikan kuliah khusus dan menjadi pembicara kunci di Universitas Hasanuddin pada bulan November tahun 2017. Special lecture terkait perkembangan penelitian juga telah dilakukan pada tanggal 26 Oktober 2016 di Saga University Japan. Hasil penelitian yang telah dilakukan bersama dengan *international partner* dipresentasikan pada New Energy and Industrial Technology Development Organization (NEDO) Japan di Tokyo pada tanggal 28 Oktober 2016.

LAMPIRAN-LAMPIRAN

- OUTPUT PENELITIAN
- AKTIVITAS PENELITIAN INTERNASIONAL

OUTPUT PENELITIAN

1. Peneliti Mitra (Prof. Akio Miyara, SAGA University Japan) sebagai Keynote Speaker pada ICESNANO 2016

http://icesnano.ft.uns.ac.id/keynote-speakers

Keynote Speakers

Prof. Abdul Latif Ahmad (Universiti Sains Malaysia)
"Membrane Technology
"Membrane technology: borderless, innovative and creative separation technology"

Prof. Akio Miyara (Saga University)
"Thermal Energy Engineering
"Heat transfer characteristics of various kinds of ground heat exchangers for ground source heat pump system"

Assoc Prof. Takahiko Miyazaki (Kyushu University, Japan)
"Thermal Energy Conversion System
"Study toward high-performance thermally driven air-conditioning systems"

Heat transfer characteristics of various kinds of ground heat exchangers for ground sourse heat pump system

A. Miyara[1]*, K. Kariya[1], Md.H. Ali[1,2], S.B. Selamat[3], Jalaluddin[4]

[1]*Saga University, Saga-shi, Japan*
[2]*Khulna University of Engineering & Technology, Khuluna, Bangladesh*
[3]*Universiti Malaysia Perlis, Arau, Malaysia*
[4]*Hasanuddin University, Makassar, Indonesia*

*Corresponding author:
Email: miyara@me.saga-u.ac.jp
1 Honjo-machi, Saga-shi, 840-8502 Japan, tel. +81-952-28-8623, fax: +81-952-28-8587

Abstract

Three kinds of vertical-type ground heat exchangers, U-tube; double-tube; multi-tube, and two kinds of horizontal-type ground heat exchangers, standing Slinky; reclined Slinky, were experimentally and numerically investigated in order to clarify their heat transfer characteristics. Experiments and simulations were carried out under two operation conditions which are continuous operation mode and discontinuous operation mode and effects of temperature recovery and thermal storage on the heat transfer rate were shown. Differences of the heat transfer rate between standing Slinky and reclined Slinky were also indicated.

Keywords: Ground heat exchanger, Vertical, Horizontal, U-tube, Double-tube, Multi-tube, Slinky-tube

INTRODUCTION

Preserving the environment of human life is not only the surrounding problems of our living place. As well known, deceleration of the global warming is an urgent task to all over the world. Therefore, many kinds of measures are being conducted in all the different fields, such as industries, transportations, buildings, domestic houses, etc., to reduce emissions of carbon dioxide and the other greenhouse gases. In the field of air-conditionings, researches and developments for next-generation refrigerants which have low global warming potential are concentrately being conducted. And, high efficient systems are also actively investigated for energy saving. Ground source heat pump or ground-coupled air conditioning are getting attention because of their low energy consumption operations. Use of the ground source heat was mainly developed for heat pump in cold area because temperature of the underground is higher than that of ambient air. Recently, the use in warm area is also attracting attention. In the summer, the underground temperature is lower than the ambient temperature, and the energy consumption of air conditioner can be reduced. Expanding the use of underground thermal energy will be a promising measure to prevent the global warming.

A problem preventing the use expansion is the cost to install the ground heat exchanger. Unknowns of ground heat exchanger characteristics are still remained. And, improvement of the performance is desiered. In the present study , various kinds of ground heat exchangers are studied to clarify their characteristics and performance.

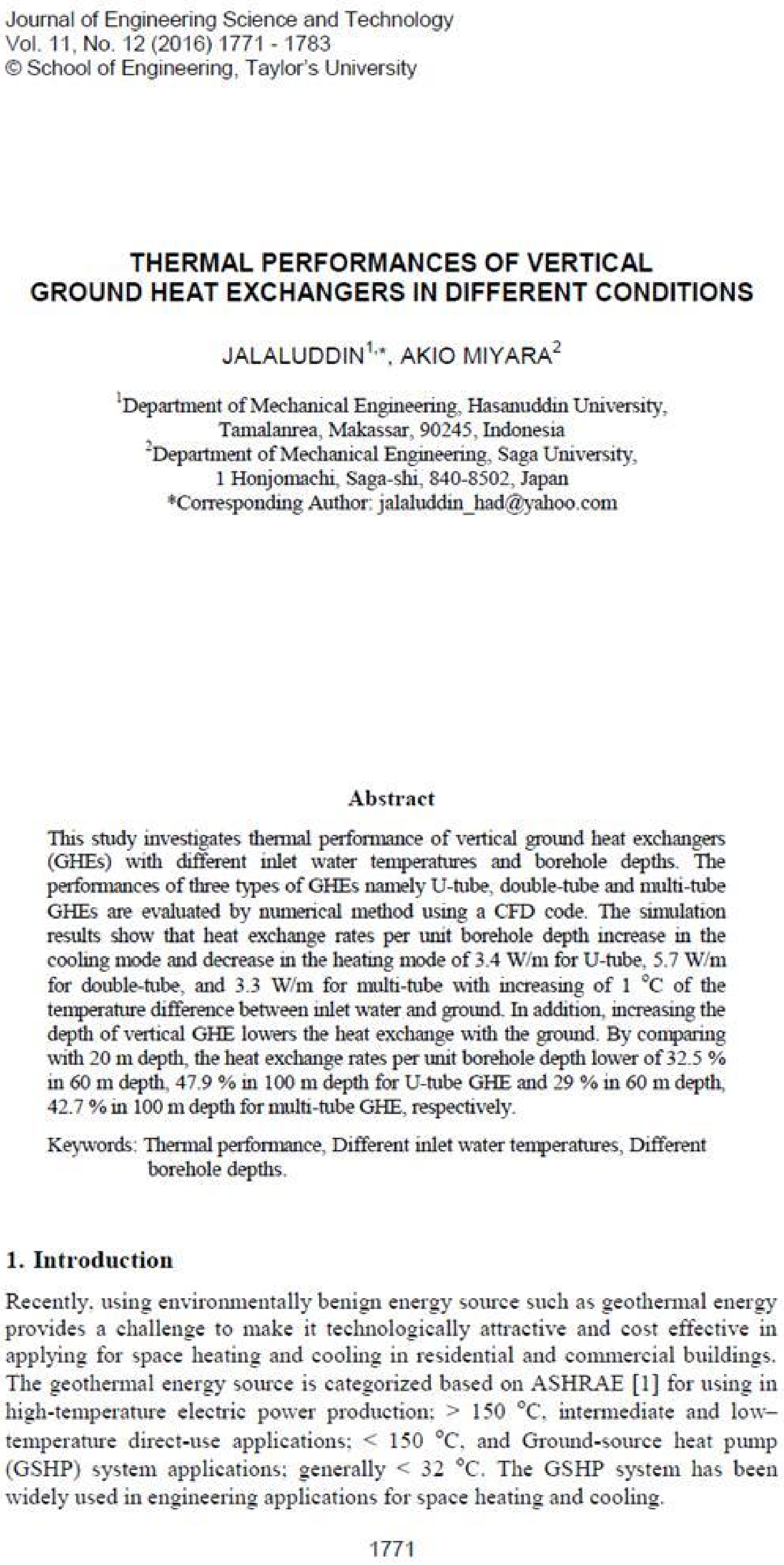
EXPERIMENTAL AND NUMERICAL METHOD

Three kinds of vertical-type ground heat exchangers and two kinds of horizontal-type ground heat exchangers was tested experimentally and numerically.

Figure 1 shows the vertical-type ground heat exchangers. Steel pipes, which are used as foundation pile for houses, were buried in the ground at a depth of 20 m, and used as boreholes for the GHEs. The U-tube and multi-tube GHEs were inserted in the steel pile, and the gaps between the steel pile and tubes were backfilled with silica sand. The U-tube is a polyethylene pipe with an outer diameter of 33 mm. The multi-tube is a polyvinyl chloride pipe with an outer diameter of 20 mm as the central pipe and four polyvinyl chloride pipes with outer diameters of 25 mm placed around the central pipe. The central pipe is the outlet tube and the four pipes around the central pipe are the inlet tubes. The outlet tube is insulated to protect the heat exchange process from the inlet tubes. In the double-tube GHE, a stainless steel pipe with an outer diameter of 139.8 mm is used as the inlet tube of the GHE and a polyvinyl chloride pipe, 48 mm in outer diameter, is installed inside the stainless steel pipe as the outlet tube.

Figure 2 shows the horizontal-type ground heat exchanger. Slinky loops in two orientations: reclined (parallel to ground surface) and standing (perpendicular to ground surface) were installed as ground heat exchanger. Material of the Slinky loop is cupper tube coated with low-density polyethylene (LDPE). The loop

2. **Jurnal Paper submitted to Journal of Engineering Science and Technology (JESTEC) terindeks Scopus**
http://jestec.taylors.edu.my/V11Issue12.htm
http://jestec.taylors.edu.my/Vol%2011%20issue%2012%20December%202016/11_12_10.pdf



Journal of Engineering Science and Technology
Vol. 11, No. 12 (2016) 1771 - 1783
© School of Engineering, Taylor's University

THERMAL PERFORMANCES OF VERTICAL GROUND HEAT EXCHANGERS IN DIFFERENT CONDITIONS

JALALUDDIN[1,*], AKIO MIYARA[2]

[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
*Corresponding Author: jalaluddin_had@yahoo.com

Abstract

This study investigates thermal performance of vertical ground heat exchangers (GHEs) with different inlet water temperatures and borehole depths. The performances of three types of GHEs namely U-tube, double-tube and multi-tube GHEs are evaluated by numerical method using a CFD code. The simulation results show that heat exchange rates per unit borehole depth increase in the cooling mode and decrease in the heating mode of 3.4 W/m for U-tube, 5.7 W/m for double-tube, and 3.3 W/m for multi-tube with increasing of 1 °C of the temperature difference between inlet water and ground. In addition, increasing the depth of vertical GHE lowers the heat exchange with the ground. By comparing with 20 m depth, the heat exchange rates per unit borehole depth lower of 32.5 % in 60 m depth, 47.9 % in 100 m depth for U-tube GHE and 29 % in 60 m depth, 42.7 % in 100 m depth for multi-tube GHE, respectively.

Keywords: Thermal performance, Different inlet water temperatures, Different borehole depths.

1. Introduction

Recently, using environmentally benign energy source such as geothermal energy provides a challenge to make it technologically attractive and cost effective in applying for space heating and cooling in residential and commercial buildings. The geothermal energy source is categorized based on ASHRAE [1] for using in high-temperature electric power production: > 150 °C, intermediate and low–temperature direct-use applications: < 150 °C, and Ground-source heat pump (GSHP) system applications: generally < 32 °C. The GSHP system has been widely used in engineering applications for space heating and cooling.

Nomenclatures

c_p	Specific heat, J/kg K
K	Thermal conductivity, W/m K
L	Borehole depth, m
$\dot{m}$	Mass flow rate, l/min
Q	Heat exchange rate, W
$\overline{Q}$	Heat exchange rate per unit length, W/m
T	Temperature, °C
x	Leg spacing, m
z	Depth, m

Greek Symbols

ΔT	Temperature difference, °C
ρ	Density, kg/m^3

Subscripts

i	inner
O	outer
PE	Polyethylene
PVC	Polyvinyl chloride

Several factors such as local conditions, ground heat exchanger (GHE) parameters, and operation conditions contribute significantly to the thermal performance of the GHE that used in the GSHP system to exchange heat with the ground. Analyzing the GHE performance in those conditions is needed to provide an accurate prediction of the performance in the GSHP system design. A number of studies have investigated the GHE performance in various backfilled materials, concrete pile foundations, and configuration shapes [2-5]. Experimental study of thermal performance of three types of GHEs including U-tube, double-tube, and multi-tube types installed in a steel pile foundation with 20 m of depth had been carried out [6]. This study reported the heat exchange rates of the GHEs in 24 hours of continuous operation with flow rates of 2, 4, and 8 l/min and the effect of increasing the flow rate. The heat exchange rates increased significantly for flow rate increases from 2 to 4 l/min, but only slightly changed from 4 to 8 l/min. The performance of the GHEs has been also investigated in different operation modes [7]. Operating the GHEs with different operation mode shows the different characteristic in their heat exchange rates. The off-time period in the discontinuous operation and extracting heat from the ground in the heating process in the alternative operation mode contributed significantly to the increasing the heat exchange rate.

Esen et al. [8] investigated temperature distributions in the borehole for different boreholes of 30, 60, and 90 m. Furthermore, heat exchange rate of the GHE with considering the effect of running time, shank spacing, depth of borehole, velocity in the pipe, thermal conductivity of grout, inlet temperature and soil type was evaluated by Jun et al. [9]. Variations of inlet water temperature and borehole depth are important factors to the thermal performance of the GHE. Different conditions of ambient climate, space

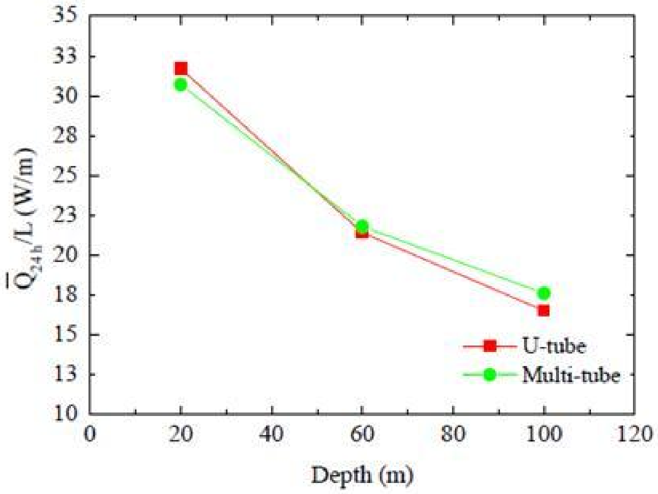


Fig. 7. Average heat exchange rate with various borehole depths.

5. Conclusions

Heat exchange rates of the several types of vertical GHEs were investigated with different inlet water temperatures and various borehole depths. Following conclusions could be drawn from this work:

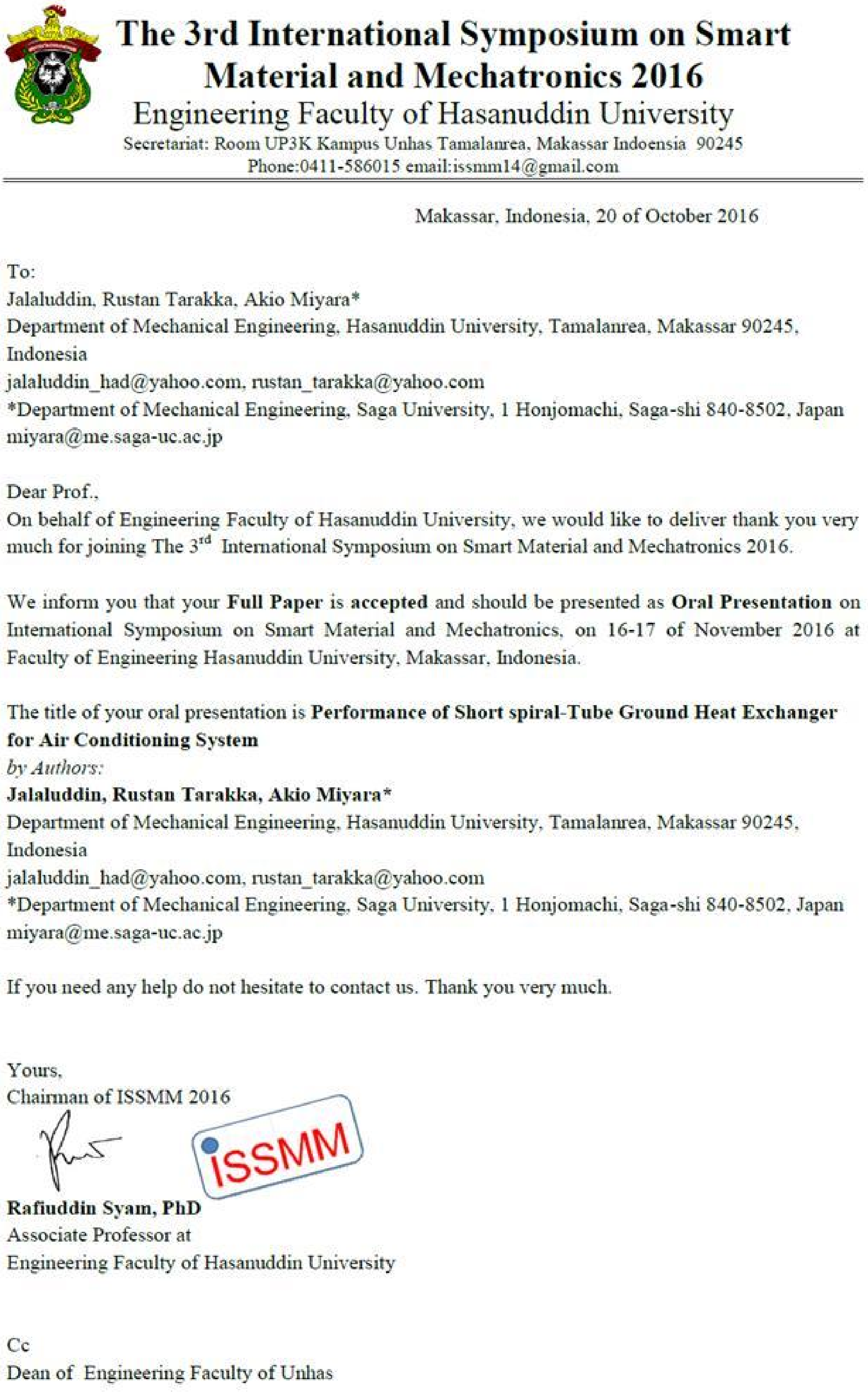
- Temperature difference between the circulated water and the ground surrounding the borehole affects significantly to the heat exchange rate of the GHEs. The heat exchange rates proportionally increase in the cooling mode and decrease in the heating mode with the temperature difference between inlet water and ground. The variation rates per unit temperature difference are 3.4 W/m for U-tube, 5.7 W/m for double tube, and 3.3 W/m for multi-tube.
- The water temperature change between the inlet and outlet does not increase as much as increasing the borehole depth.
- Increasing the depth lowers temperature difference between circulated water and surrounding ground and then lowers the heat exchange rate. By comparing with 20 m depth, the heat exchange rates per unit borehole depth lower of 32.5 % in 60 m depth, 47.9 % in 100 m depth for U-tube GHE and 29 % in 60 m depth, 42.7 % in 100 m depth for multi-tube GHE, respectively.

References

1. ASHRAE (2011). *ASHRAE Handbook: HVAC Applications, SI Edition*. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, N.E., Atlanta, GA 30329.
2. Li, X.; Chen, Y.; Chen, Z.; and Zhao, J. (2006). Thermal performances of different types of underground heat exchangers. *Energy and Buildings*, 38, 543-547.

3. Hamada, Y.; Saitoh, H.; Nakamura, M.; Kubota, H.; and Ochifuji, K. (2007). Field performance of an energy pile system for space heating. *Energy and Buildings*, 39, 517-524.
4. Gao, J.; Zhang, X.; Liu, J.; Li, K.S.; and Yang, J. (2008). Thermal performance and ground temperature of vertical pile-foundation heat exchangers: A case study. *Applied Thermal Engineering*, 28, 2295-2304.
5. Lee, C.; Park, M.; Min, S.; Kang, S.H.; Sohn, B.; and Choi, H. (2011). Comparison of effective thermal conductivity in closed-loop vertical ground heat exchangers. *Applied Thermal Engineering*, 31, 3669-3676.
6. Jalaluddin, Miyara, A.; Tsubaki, K.; Inoue, S.; and Yoshida, K. (2011). Experimental study of several types of ground heat exchanger using a steel pile foundation. *Renewable Energy*, 36, 764-771.
7. Jalaluddin, and Miyara, A.; (2012). Thermal performance investigation of several types of vertical ground heat exchangers with different operation mode. *Applied Thermal Engineering*, 33-34, 167-174.
8. Esen, H.; Inalli, M.; and Esen, Y. (2009). Temperature distributions in boreholes of a vertical ground-coupled heat pump system. *Renewable Energy*, 34, 2672-2679.
9. Jun, L.; Xu, Z.; Jun, G.; and Jie, Y. (2009). Evaluation of heat exchange rate of GHE in geothermal heat pump systems. *Renewable Energy*, 34, 2898-2904.
10. Chen, J.; Xia, L.; Li, B.; and Mmereki, D. (2015). Simulation and experimental analysis of optimal buried depth of the vertical U-tube ground heat exchanger for a ground-coupled heat pump system. *Renewable Energy*, 73, 46-54.

3. ISSMM 2016



The 3rd International Symposium on Smart Material and Mechatronics 2016
Engineering Faculty of Hasanuddin University
Secretariat: Room UP3K Kampus Unhas Tamalanrea, Makassar Indoensia 90245
Phone:0411-586015 email:issmm14@gmail.com

Makassar, Indonesia, 20 of October 2016

To:
Jalaluddin, Rustan Tarakka, Akio Miyara*
Department of Mechanical Engineering, Hasanuddin University, Tamalanrea, Makassar 90245, Indonesia
jalaluddin_had@yahoo.com, rustan_tarakka@yahoo.com
*Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi 840-8502, Japan
miyara@me.saga-uc.ac.jp

Dear Prof.,
On behalf of Engineering Faculty of Hasanuddin University, we would like to deliver thank you very much for joining The 3rd International Symposium on Smart Material and Mechatronics 2016.

We inform you that your **Full Paper** is **accepted** and should be presented as **Oral Presentation** on International Symposium on Smart Material and Mechatronics, on 16-17 of November 2016 at Faculty of Engineering Hasanuddin University, Makassar, Indonesia.

The title of your oral presentation is **Performance of Short spiral-Tube Ground Heat Exchanger for Air Conditioning System**
by Authors:
Jalaluddin, Rustan Tarakka, Akio Miyara*
Department of Mechanical Engineering, Hasanuddin University, Tamalanrea, Makassar 90245, Indonesia
jalaluddin_had@yahoo.com, rustan_tarakka@yahoo.com
*Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi 840-8502, Japan
miyara@me.saga-uc.ac.jp

If you need any help do not hesitate to contact us. Thank you very much.

Yours,
Chairman of ISSMM 2016

ISSMM

Rafiuddin Syam, PhD
Associate Professor at
Engineering Faculty of Hasanuddin University

Cc
Dean of Engineering Faculty of Unhas

ISSMM 2016

Certificate of Appreciation

This Certificate is awarded to

Jalaluddin

as a Invited Speaker on The 3rd International Symposium on

SMART MATERIAL and MECHATRONICS 2016

Organized by Engineering Faculty of Hasanuddin University
Gowa, South of Sulawesi, November 15-17, 2016

Gowa, Indonesia, November 17, 2016

Dean of Engineering Faculty

Dr.-Ing. Ir. Wahyu. H. Piarah, MSME

Chairman,

Rafiuddin Syam, PhD

ISBN: 978-602-60436-0-3

PROCEEDING OF THE 3rd INTERNATIONAL SYMPOSIUM ON SMART MATERIAL AND MECHATRONICS 2016

Makassar-Gowa, 15-17, November, 2016
Campus II , Engineering Faculty of Hasanuddin University
Jl. Poros Malino No 72, Gowa, Sulawesi Selatan, Indonesia

Editor :

- Rafiuddin Syam, PhD – Hasanuddin University—Indonesia
- Prof. Keigo Watanabe-Okayama University-Japan
- Prof. Mitsuhiro Okayasu-Okayama University-Japan
- Prof. Shibata Satoru-Ehime Univesity-Japan

FACULTY OF ENGINEERING
UNIVERSITY OF HASANUDDIN

Editorial Board

Editor In Chief Rafiuddin Syam, PhD

Senior Editors
Prof. Keigo Watanabe-Okayama University-Japan
Prof. Satoru Shibata-Ehime University-Japan
Prof. Satrio Soemantri Brodjonegoro-ITB-Indonesia
Prof. Mitsu Okamura-Ehime University-Japan
Prof. Kiyotaka Izumi—Saga University-Japan
Dr. Ir. Dyah Rini Indriyanti (Associate Editor DOAJ)
Prof. Dadang A Suryamiharja– Hasanuddin University-Indonesia
Prof. Friso de Boer-Charles Darwin University - Australia
Prof. Dr.Adi Maimun bin Abdul Malik-UTM-Malaysia
Prof. Jackrit Suthakorn, PhD- Mahidol University, Thailand
Prof. Sherwin Guirnaldo, PhD – Mindanau State University-Philipine
Prof. Lanka Udawatta,PhD – Moratuwa University - Srilanka
Prof. Samy F. M. Assal,PhD, Alexandria University- Egypt
Prof. Bondan T. Sofyan-UI-Indonesia
Prof. Dr.H.Hammada Abbas – Hasanuddin University-Indonesia
Prof. Effendi Arief– Hasanuddin University-Indonesia
Prof. Zhiqiang Wu-Ehime University-Indonesia
Dr.-Ing Wahyu H Piarah— Hasanuddin University-Indonesia
Dr. Gesang Nugroho, ST, MT-UGM-Yogyakarta-Indonesia
Heru Santoso Budi Raharjo-Ir.M.Eng.Dr-UGM-Yogyakarta-Indonesia
Dr. Indrawanto-ITB-Bandung-Indonesia
Dr. Kusmono–UGM-Yogyakarta-Indonesia
Dr.Ir. Yudi Satria Gondokaryono ITB-Bandung-Indonesia
Dr. Johannes Leonard – Hasanuddin University-Indonesia
Dr. Abdul Kadir Muhammad-PNUP-Makassar-Indonesia
Dr. Ir. Samiadji Herdjunanto, M. Sc – UGM-Yogyakarta -Indonesia.
Ir. Oyas Wahyunggoro, M.T., Ph.D–UGM-Yogyakarta-Indonesia
Hendro Nurhadi, Dipl. Ing., Ph.D–ITS-Surabaya-Indonesia
Dr. Abdul Muis, UI-Jakarta-Indonesia

Editors
Dr. Eng Armin Lawi, MSc--Hasanuddin University-Indonesia
Dr. Jalaluddin, ST,MT--Hasanuddin University-Indonesia
Dr. Irzal Nur, MT--Hasanuddin University-Indonesia
Dr. Ir. Johannes Leaonard--Hasanuddin University-Indonesia
Dr. Eng Wardi, MEng--Hasanuddin University-Indonesia
Dr. Kimiko Motonaka-Okayama University-Japan
Dr. Abdul Kadir Muhammad, ST,MEng
Dr. Haerul Arsyad- Hasanuddin University-Indonesia
Dr. Muh Syahid--Hasanuddin University-Indonesia

November 16, 2016
Room A (Lecture Theatre 1), Session 1

No	Authors	Title	Chairman of Session
1	Faizal Arya Samman, Syafaruddin, Muslimin*	Weeper Control Design based on Microcontroller for Photovoltaic Panel Cleaning System	Rafiuddin Syam, PhD
2	Tomohiko Hasegawa, Keigo Watanabe* and Isaku Nagai	Production of a Tilt Rotor System and a Speed Control of a DC Motor for Quadrotors	
3	Kimiko Motonaka, Keigo Watanabe* and Shoichi Maeyama*	Basic Simulations of Kinodynamic Control Using Local Environmental Information	
4	Maierdan Maimaitimin, Keigo Watanabe, and Shoichi Maeyama	An Emotional Recognition System for Facial Expressions with Surface Common Features	
1	Yu Lang*, Maierdan Maimaitimin and Keigo Watanabe	Design and Implementation of HMM for 3D Emotion Recognition	

November 16, 2016
Room A (Lecture Theatre 1), Session 2

No	Authors	Title	Chairman of Session
1	Daiki Sasakura*, Isaku Nagai, Keigo Wtanabe	Correcting Path of a Shopping Cart Using a Particle Filter and an Environment Map	Dr. Faizal Arya Samman
2	Yin Yin Aye, Keigo Watanabe, Shoichi Maeyama, and Isaku Nagai	An Intelligent Parking System for Vehicles Using an Image-based Fuzzy Controller	
3	Abdul Azis Rahmansyah*, Faizal Arya Samman, Syafaruddin	SPICE Modeling based Maximum Power Point Analysis of 300W Solar Module using Boost Converter	
4	Ryoji Osaki, Shoichi Maeyama, and Keigo Watanabe	Obstacle Avoidance by a Hyperelliptic Potential and a Virtual Spring Method for Omnidirectional Cooperative Transportations	
5	Mulyadi*, A. Erwin E. Putra, Novriany Amaliyah, Muhammad Noor Umar, Azwar Hayat	Bio-ethanol production from Nipa (Nypa fruticans) saps with distillation process utilizing Flat-plate collector.	
6	Jalaluddin, Rustan Tarakka, Akio Miyara*	Performance of Short spiral-Tube Ground Heat Exchanger for Air Conditioning System	

Proceeding of The 3rd International Symposium on Smart Material and Mechatronics 2016
Gowa, Indonesia, 15-18 November 2016 ISBN: 978-602-60436-0-3

Performance of Short spiral-Tube Ground Heat Exchanger for Air Conditioning System

Jalaluddin
Department of Mechanical Engineering, Hasanuddin University, Tamalanrea, Makassar 90245, Indonesia
jalaluddin_had@yahoo.com

Akio Miyara
Department of Mechanical Engineering, Saga University, 1 Honjomachi, Saga-shi 840-8502, Japan
miyara@me.saga-uc.ac.jp

Rustan Tarakka
Department of Mechanical Engineering,
Hasanuddin University, Tamalanrea, Makassar
90245, Indonesia
Rustan_tarakka@yahoo.com

***Abstract*—The use of geothermal energy has been recognized as a possible solution for reducing emissions. This energy source is as 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 short-spiral tube ground heat exchanger (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 47 Watt per meter borehole depth in laminar flow and 65 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. Short spiral-tube borehole depth can be arranged in series and parallel configurations to meet the needs in the application.**

***Key Words*—Ground heat exchanger, short spiral-tube GHE, performance.**

I. 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. 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. Operating the GHEs with different models and various conditions shows the different characteristic in their heat exchange rates [1, 2, 3, 4, 5]. Experimental test of the ground-source cooling system in hot weather condition such Hongkong [6] and Tunisia [7, 8] have been carried-out.

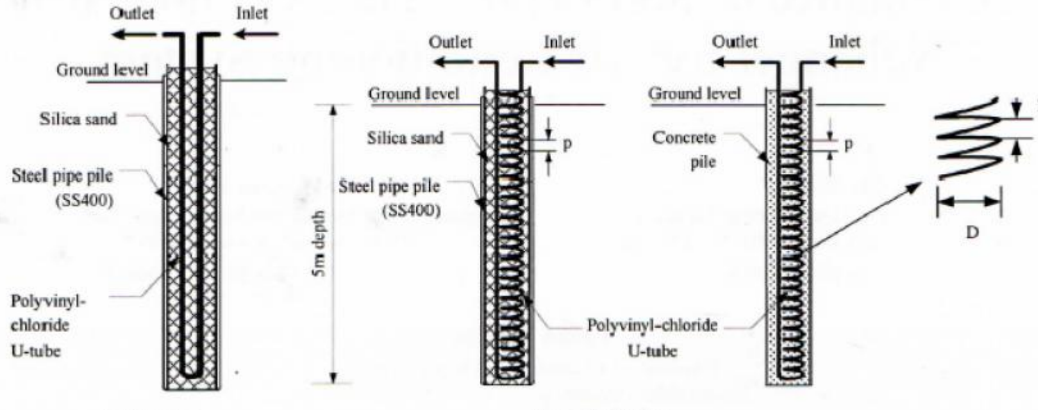
Ground heat exchanger (GHE) is used in the ground-source heat pump to exchange heat with the ground. The spiral-tube GHE is gaining interest in recent years. Analytical solutions of spiral coil ground heat exchangers have developed by Man et al. [9], Cui et al. [10], Man et al, [11] and Li and Lai [12]. 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 with considering the radial dimension and the heat capacity of the borehole or pile [9]. Cui et al. [10] developed the ring-coil source model with 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.

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]. Determining the distance between GHEs (spacing) becomes as an important issue. The effect of distance between vertical helical GHEs on the heat transfer rate (HTR) is studied [18]. An optimum design of horizontal ground heat pump systems is investigated for spiral-coil-loop heat exchangers [19].

The performance of spiral-tube GHE provides a better thermal performance compared with others GHEs. Reducing the borehole depth is attractive economically due to reducing installation cost. Using more than one short spiral-tube GHEs provides the possibility for reducing the borehole depth of the GHE. This work present an investigation of thermal performance of short spiral-tube GHE and comparison with the conventional U-tube GHE.

II. 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 5 m in the



(a) U-tube (b) Spiral tube

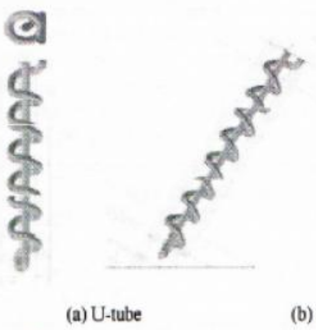
Fig. 1. The schematic diagrams of the conventional U-tube and Spiral- tube GHEs

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 boreholes were backfilled with silica-sand. In addition, the spiral tube was also installed using concrete pile foundation as shown in Figure 1(b).

III. SIMULATION SET-UP

3.1 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 GHE

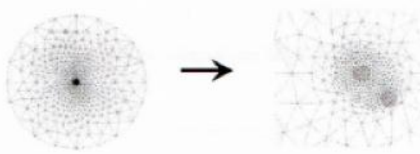
3.2. Grid and Meshing

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).

3.3. Boundary and Initial Conditions

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 of 17.7 °C. The flow rate of circulated water was set to 2 l/min for laminar flow and 8 l/min for turbulent flow.

a) Model b) Mid-view of the Model



c) Top-view of the Model d) Magnified around the borehole

Fig. 3. Grid and meshing of the Spiral-tube GHE model

3.4. Heat Exchange Rate

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.

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

where L is the depth of each GHE.

IV. RESULTS AND DISCUSSIONS

4.1. Temperature Distribution

4.1.1. Borehole temperature distribution

The heat buildup in the ground surrounding the borehole contributes to the thermal performance of GHEs. Figure 4 shows the borehole temperature distribution at 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.

4.1.2. 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 5. Inlet water temperatures for the GHEs were set to be constant of 27 °C (300 K). Water temperatures decrease in the inlet pipes. Decreasing the water temperature in the inlet pipe is higher than that of the outlet pipe which the inlet pipe is spiral pipe. In the laminar flows, water temperature significantly decreases in the inlet pipe.

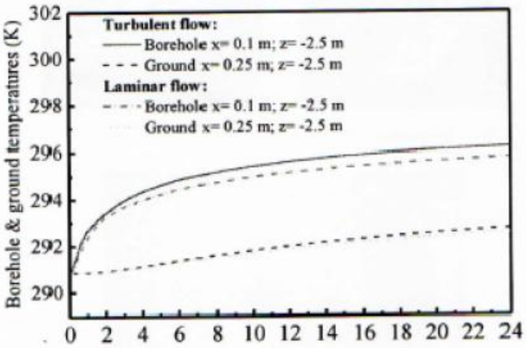


Fig. 4. Borehole and ground temperature distributions

4.2. Heat Exchange Characteristics of Spiral Tube GHEs

Figure 6 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.

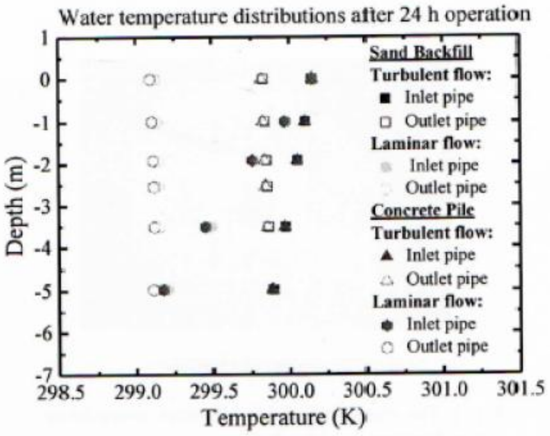


Fig. 5. Water temperature distribution of the GHEs

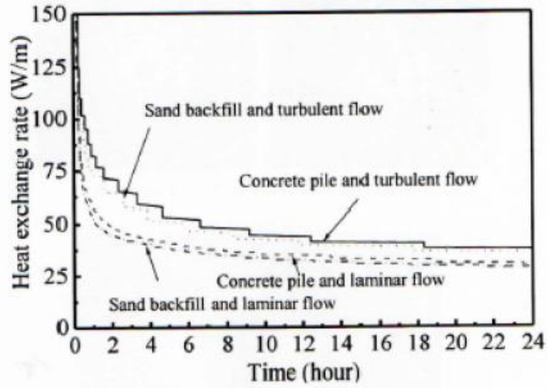
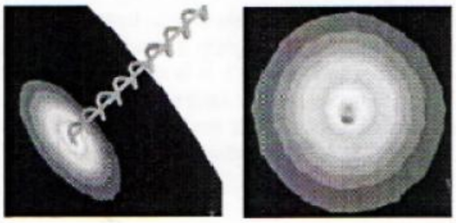
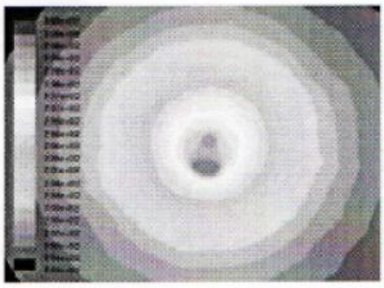


Fig. 6. Heat exchange rate of the GHEs

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 7 and 8. The contours of the GHE installed in concrete pile at 2.5 m depth for laminar and turbulent flows are shown in the Figures 9 and 10. 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.

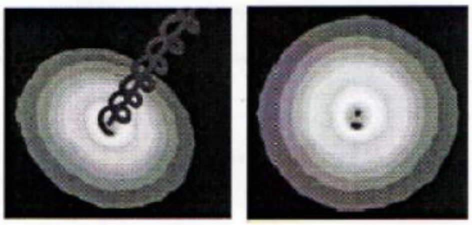


a) Isometric view b) Top-view

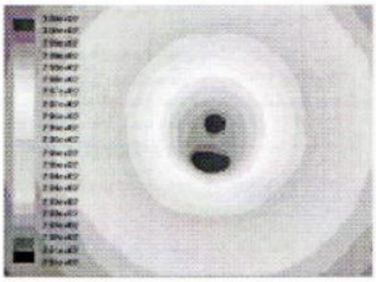


c) Magnified around the borehole

Fig. 7. The cross-sectional temperature contours at 2.5 m depth for laminar flow

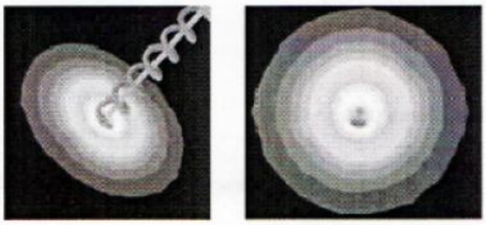


b) Isometric view b) Top-view

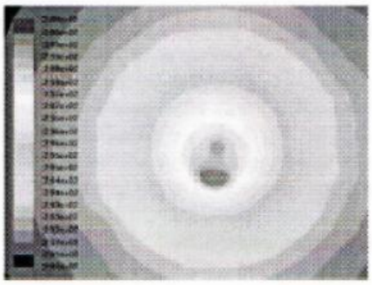


c) Magnified around the borehole

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

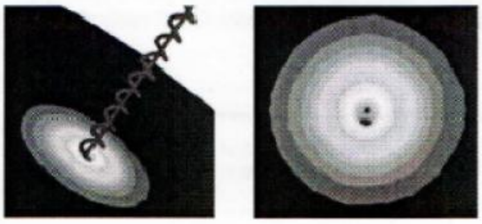


a) Isometric view b) Top-view

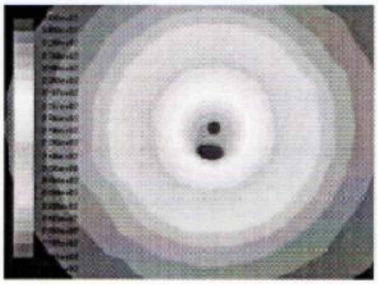


c) Magnified around the borehole

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



b) Isometric view b) Top-view



c) Magnified around the borehole

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

4.3. Comparison with the Conventional U-tube GHE

Heat exchange rate of spiral-tube GHE is of 47 W per meter borehole depth in laminar flow and of 65 W per meter borehole depth in turbulent flow. This GHE is buried in the ground at a depth of 5 m. Heat exchange rate of the conventional U-tube GHE buried in the ground at a depth of 20 m is 24.9 W per meter borehole in laminar flow and 31.5 W per meter borehole in turbulent flows as presented in reference [1]. To study the possibility to reduce the borehole, performances of the conventional U-tube and spiral-tube GHEs are compared. Based on its heat exchange rate, U-tube GHE with 20 m depth will be same with 2 (two) spiral-tube GHEs with 5 m depth. The results show that using the spiral-tube GHE can reduce the borehole about a half compared with using the conventional U-tube GHE.

V. CONCLUSIONS

Performances of the 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 47 and 65 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 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, pp. 764-771, 2011.

[2] 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, pp. 167–174, 2012.

[3] 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), pp. 103-107, 2014.

[4] Jalaluddin and A. Miyara, Thermal Performances Of Vertical Ground Heat Exchangers In Different Conditions, Journal of Engineering Science and Technology, Vol. 11, No. 12, pp. xxx-xxx, 2016.

[5] 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.

[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, pp. 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, pp. 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, pp. 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, pp. 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, pp. 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), pp. 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, pp. 451–458, 2012.

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

[14] [10] Zarrella, A., De Carli, M., Galgaro, A., 2013, Thermal performance of two types of energy foundation pile: Helical pipe and triple U-tube, *Applied Thermal Engineering*, 61, pp. 301-310.

[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, pp. 630-637, 2015.

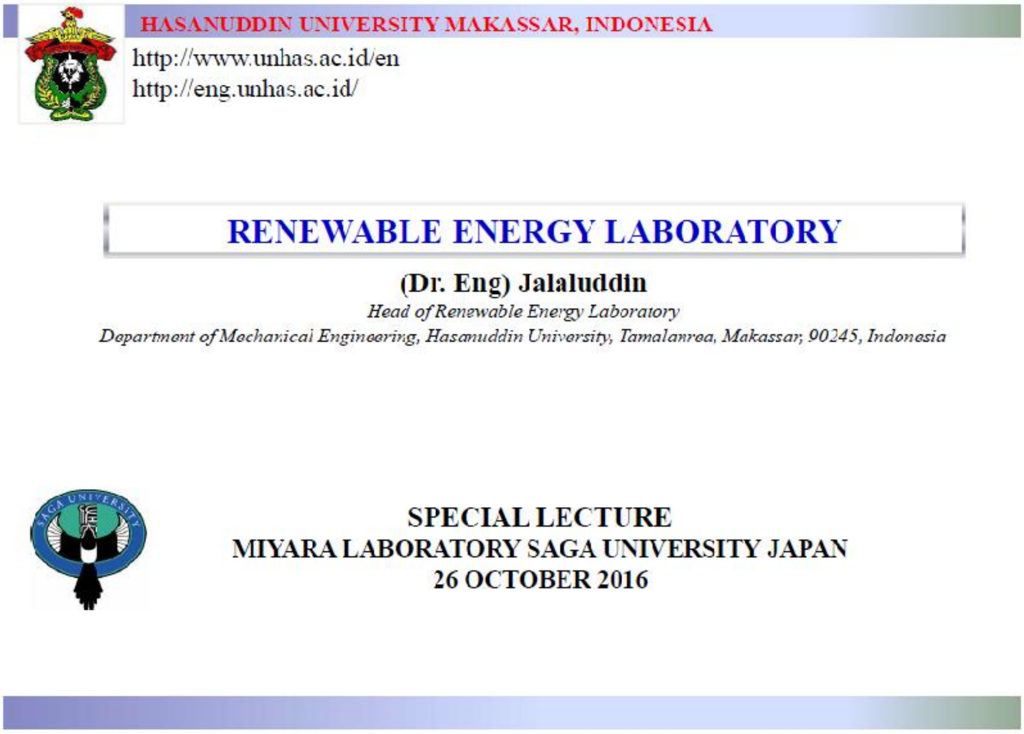
[18] B. Dehghan, A. Sisman and M. Aydin, "Parametric investigation of helical ground heat exchangers for heat pump applications," Energy and Buildings, vo. 127, pp. 999–1007, 2016.

[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, pp. 330–345, 2016.

4. **Hasil-hasil penelitian yang didiskusikan pada ISSMM Conference 2016 akan ditingkatkan untuk disubmit ke Jurnal Internasional Scopus: Journal of Mechanical Engineering © 2016 Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), Malaysia.**

AKTIVITAS PENELITIAN INTERNASIONAL

1. Special Lecture on Miyara Laboratory

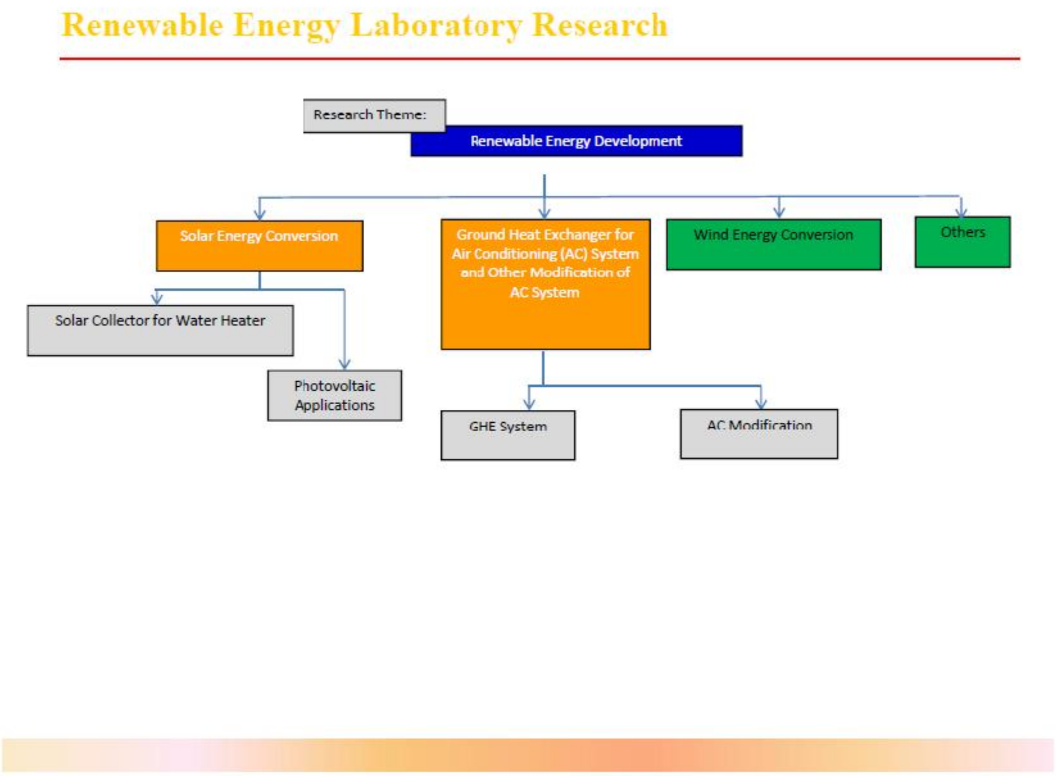


HASANUDDIN UNIVERSITY MAKASSAR, INDONESIA
http://www.unhas.ac.id/en
http://eng.unhas.ac.id/

RENEWABLE ENERGY LABORATORY

(Dr. Eng) Jalaluddin
Head of Renewable Energy Laboratory
Department of Mechanical Engineering, Hasanuddin University, Tamalanrea, Makassar, 90245, Indonesia

SPECIAL LECTURE
MIYARA LABORATORY SAGA UNIVERSITY JAPAN
26 OCTOBER 2016



Renewable Energy Laboratory Research

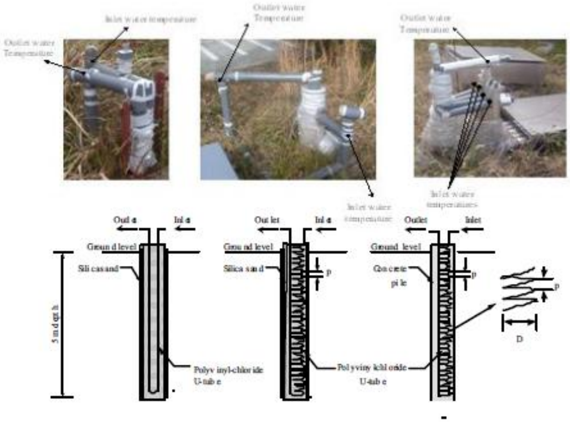
Research Theme:
Renewable Energy Development

- Solar Energy Conversion
  - Solar Collector for Water Heater
  - Photovoltaic Applications
- Ground Heat Exchanger for Air Conditioning (AC) System and Other Modification of AC System
  - GHE System
  - AC Modification
- Wind Energy Conversion
- Others

Renewable Energy Laboratory

Research Topics :

1. Ground Heat Exchangers



Develop a new type……

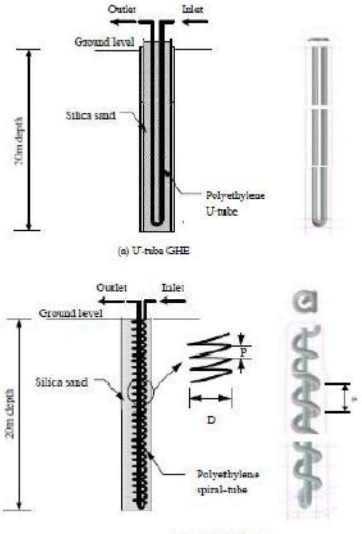


Fig. 1. The schematic diagrams of the U-tube and spiral-tube GHEs.

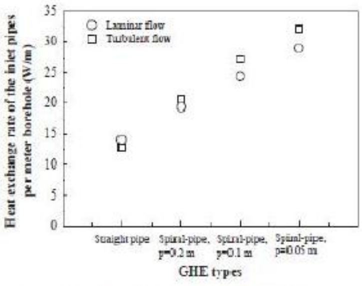


Fig. 6. Heat exchange rate of the inlet pipes per meter borehole.

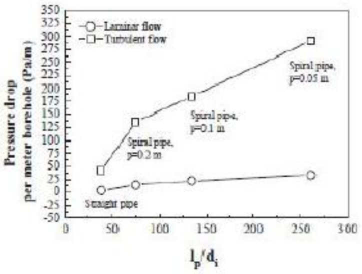


Fig. 11. Pressure drop per meter borehole.

2. Water Solar Heaters System

Figure 5 Solar water heating system with (a) flat-plate absorber plate(b) V-shaped absorber plate.

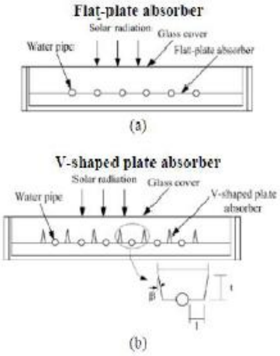


Figure 2 Cross sectional view of solar water heater.

Improvement Performance……

Serpentine Model

Renewable Energy Laboratory (cont.)

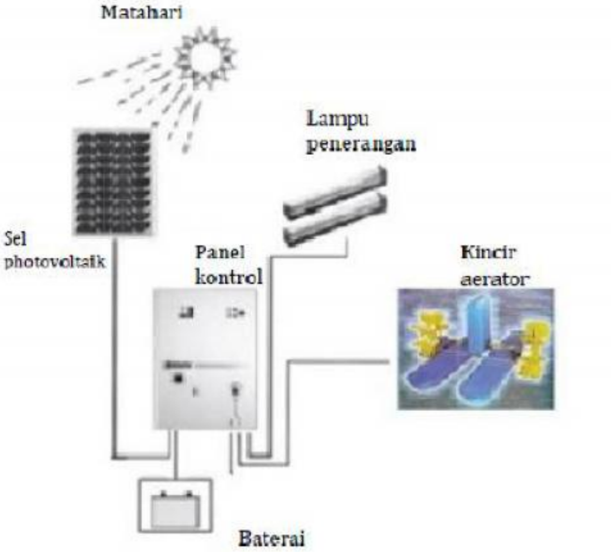
3. Photovoltaic Applications

Energy Building & Agricultural Fields……

Gambar 1. Alat uji modul PV dengan dan tanpa air pendingin a) pipa air pendingin b) permukaan bawah dengan insulasi

Hybrid System PV-T

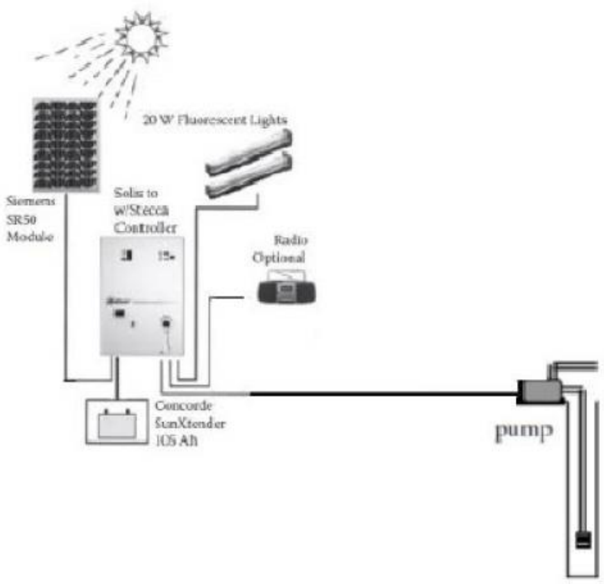
Aerator water mill in the shrimp pond



Gambar 1 Pemanfaatan sumber energi terbarukan dengan teknologi sel photovoltaik untuk kincir aerator dan penerangan.

Water pumping in the shrimp pond

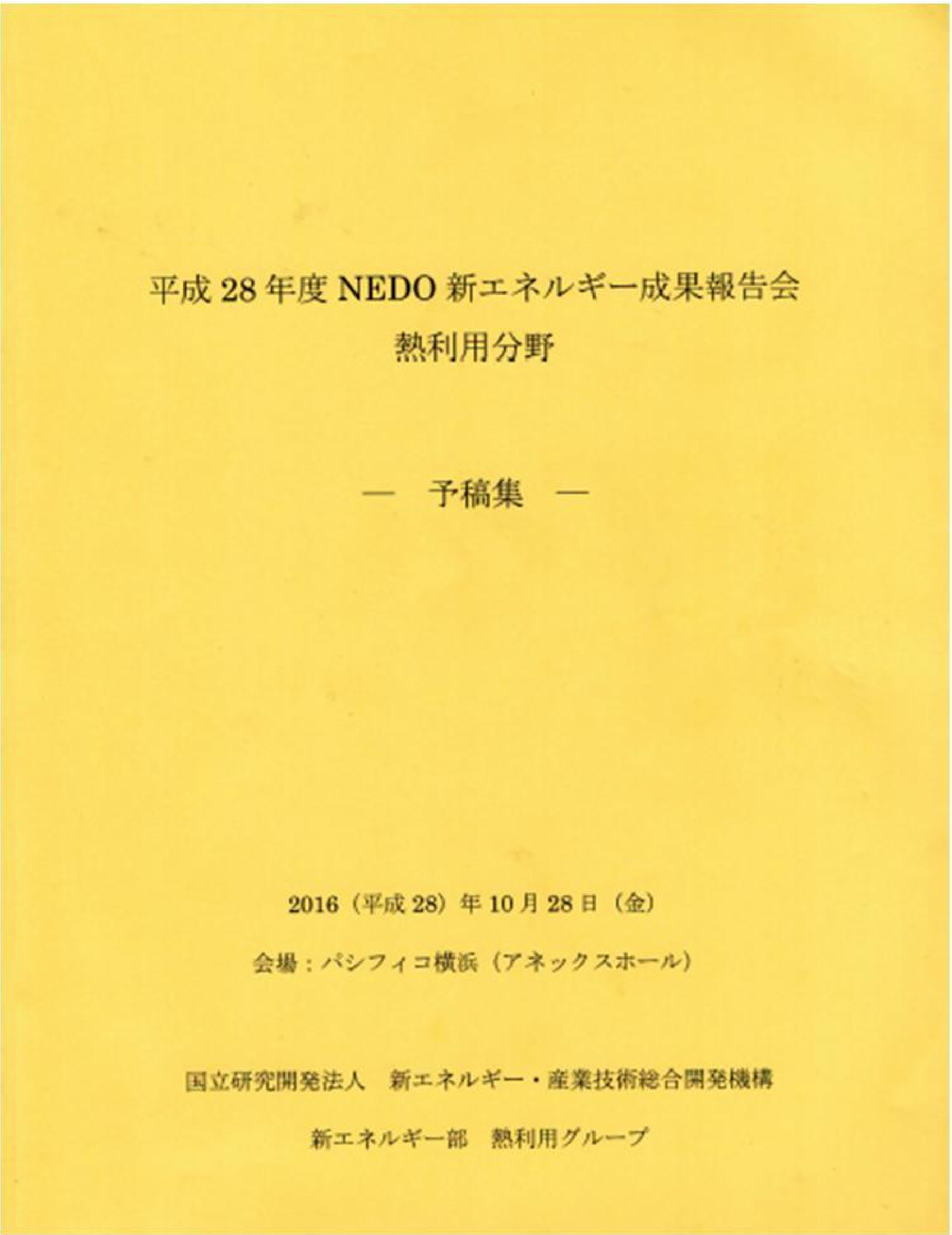
Field Performance Test…



Improve the research scale…..

THANK YOU

2. NEDO Conference, Tokyo Japan, 28 October 2016



平成28年度NEDO新エネルギー成果報告会
熱利用分野

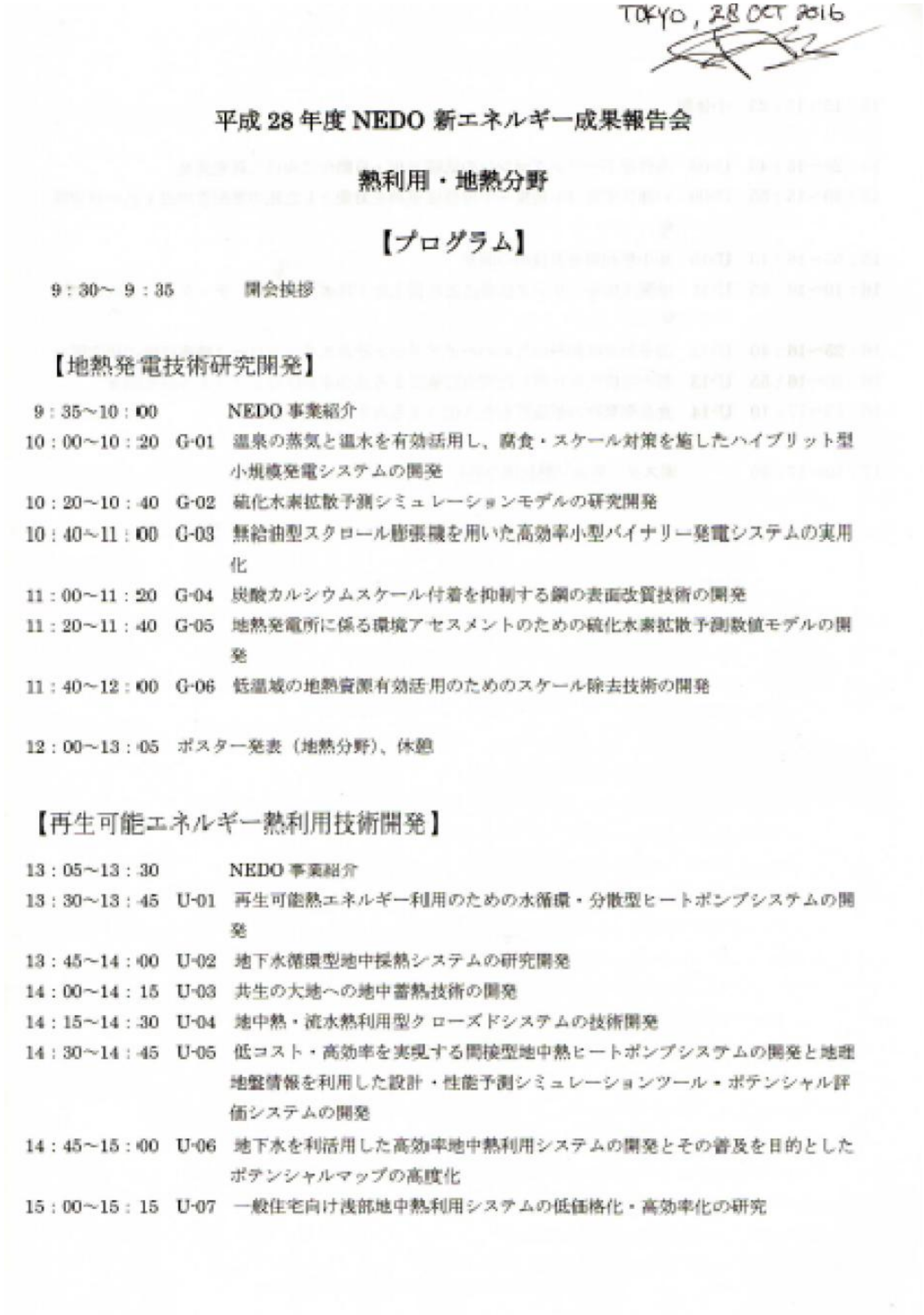
— 予稿集 —

2016（平成28）年10月28日（金）

会場：パシフィコ横浜（アネックスホール）

国立研究開発法人　新エネルギー・産業技術総合開発機構

新エネルギー部　熱利用グループ



TOKYO, 28 OCT 2016

平成28年度NEDO新エネルギー成果報告会

熱利用・地熱分野

【プログラム】

9：30～ 9：35　開会挨拶

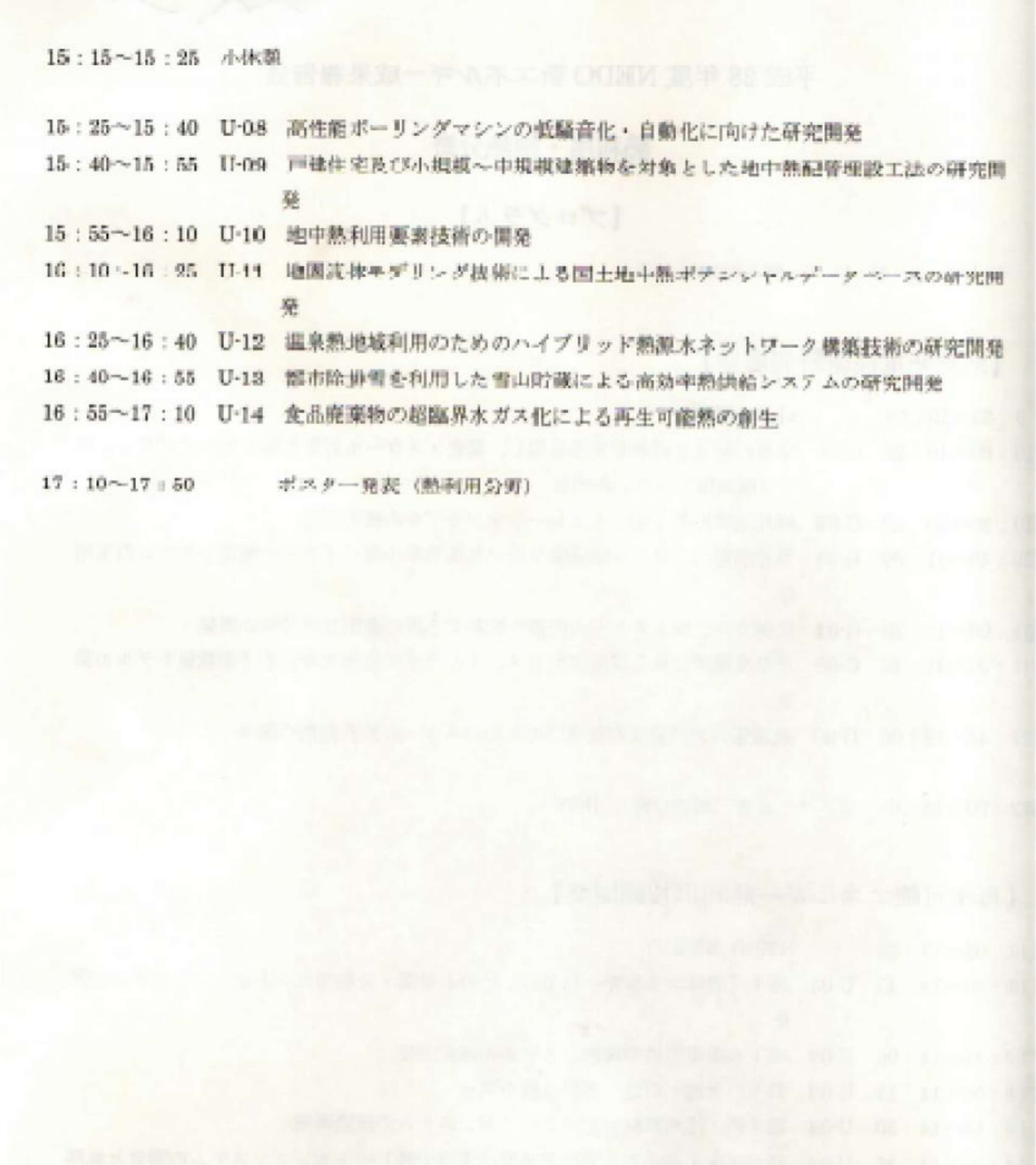
【地熱発電技術研究開発】

9：35～10：00		NEDO事業紹介
10：00～10：20	G-01	温泉の蒸気と温水を有効活用し、腐食・スケール対策を施したハイブリット型小規模発電システムの開発
10：20～10：40	G-02	硫化水素拡散予測シミュレーションモデルの研究開発
10：40～11：00	G-03	無給油型スクロール膨張機を用いた高効率小型バイナリー発電システムの実用化
11：00～11：20	G-04	炭酸カルシウムスケール付着を抑制する鋼の表面改質技術の開発
11：20～11：40	G-05	地熱発電所に係る環境アセスメントのための硫化水素拡散予測数値モデルの開発
11：40～12：00	G-06	低温域の地熱資源有効活用のためのスケール除去技術の開発

12：00～13：05　ポスター発表（地熱分野）、休憩

【再生可能エネルギー熱利用技術開発】

13：05～13：30		NEDO事業紹介
13：30～13：45	U-01	再生可能熱エネルギー利用のための水循環・分散型ヒートポンプシステムの開発
13：45～14：00	U-02	地下水循環型地中採熱システムの研究開発
14：00～14：15	U-03	共生の大地への地中蓄熱技術の開発
14：15～14：30	U-04	地中熱・流水熱利用型クローズドシステムの技術開発
14：30～14：45	U-05	低コスト・高効率を実現する間接型地中熱ヒートポンプシステムの開発と地理地盤情報を利用した設計・性能予測シミュレーションツール・ポテンシャル評価システムの開発
14：45～15：00	U-06	地下水を利活用した高効率地中熱利用システムの開発とその普及を目的としたポテンシャルマップの高度化
15：00～15：15	U-07	一般住宅向け浅部地中熱利用システムの低価格化・高効率化の研究



15：15～15：25　小休憩

15：25～15：40　U-08　高性能ボーリングマシンの低騒音化・自動化に向けた研究開発
15：40～15：55　U-09　戸建住宅及び小規模～中規模建築物を対象とした地中熱配管埋設工法の研究開発
15：55～16：10　U-10　地中熱利用要素技術の開発
16：10～16：25　U-11　地圏流体モデリング技術による国土地中熱ポテンシャルデータベースの研究開発
16：25～16：40　U-12　温泉熱地域利用のためのハイブリッド熱源水ネットワーク構築技術の研究開発
16：40～16：55　U-13　都市除排雪を利用した雪山貯蔵による高効率熱供給システムの研究開発
16：55～17：10　U-14　食品廃棄物の超臨界水ガス化による再生可能熱の創生

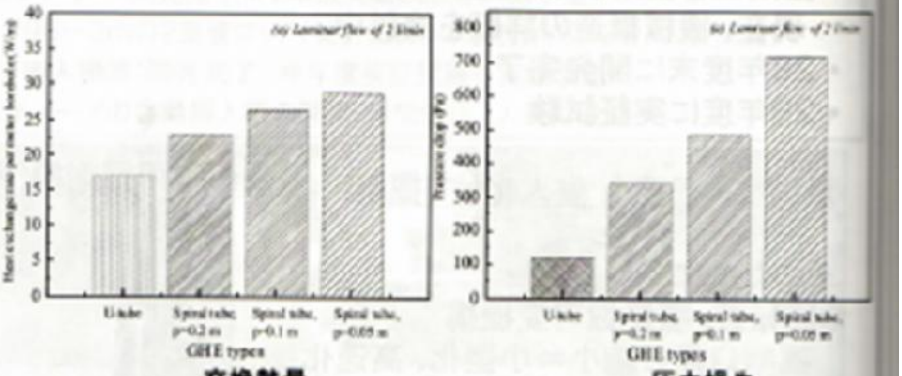
17：10～17：50　ポスター発表（熱利用分野）

③地中熱交換器の研究開発

鉛直スパイラル型地中熱交換器の計算モデル

Jalaluddin and Akio Miyara, Applied Thermal Engineering, 90, 630-637 (2015)

スパイラル管



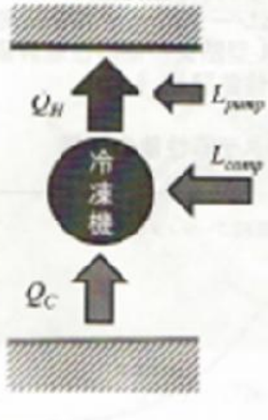
交換熱量　　圧力損失

- ✓ 熱交換量：約2倍，圧力損失：約8倍
- ✓ 熱交換量の増加より，圧力損失の増加が大きい
- ✓ スパイラル型地中熱交換器を使う効果は？
  - ⇒システムCOPの観点から熱交換器を評価

③地中熱交換器の研究開発

地中熱交換器を空調システムに組み込んだ場合のシステムCOP評価

冷房モード
地中へ放熱



冷凍機の成績係数：

$$COP=\frac{Q_C}{L_{comp}}=\frac{Q_H-L_{comp}}{L_{comp}}$$

地中熱交換器のポンプ動力を考慮した冷凍機の成績係数：

$$COP_{sys}=\frac{Q_C}{L_{comp}+L_{pump}}=\frac{Q_H-L_{comp}}{L_{comp}+L_{pump}}$$

地中熱交換器の改良により放熱量とポンプ動力が増加：

$$COP'_{sys}=\frac{Q_H+Q'_H-L_{comp}}{L_{comp}+L_{pump}+L'_{pump}}=\frac{COP_{sys}+Q'_H/\left(L_{comp}+L_{pump}\right)}{1+L'_{pump}/\left(L_{comp}+L_{pump}\right)}$$

成績係数が改善される条件は　$COP_{sys}<COP'_{sys}$

$$COP_{sys}<\frac{COP_{sys}+Q'_H/\left(L_{comp}+L_{pump}\right)}{1+L'_{pump}/\left(L_{comp}+L_{pump}\right)}$$

成績係数が改善される条件は

$$L'_{pump}<Q'_H$$

ポンプ動力は体積流量と圧力損失の積で表されるので

$$L_{pump}=V\Delta p \quad L'_{pump}=V\Delta p'$$

熱交換量増加と圧力損失増加に対する成績係数の改善条件

$$\frac{Q'_H}{Q_H}-\frac{V\Delta p}{Q_H}\frac{\Delta p'}{\Delta p}>0$$

③地中熱交換器の研究開発

COP評価結果

$$\frac{Q'_H}{Q_H} - \frac{V\,\Delta p}{Q_H}\frac{\Delta p'}{\Delta p} > 0$$

$Q_{H\text{-}c}$	$Q_{H\text{-}s} = Q_H$	Q'_H	V	Δp_c	$\Delta p_s = \Delta p$	$\Delta p'$	Criterion
	W/m		m³/s		Pa/m		
Laminar flow (flow rate of 2 liter/min)							
19.4	14.1	5.3	3.333E-05	14.3	3.1	11.2	0.4
24.3	14.1	10.2	3.333E-05	21.6	3.1	18.5	0.7
28.9	14.1	14.8	3.333E-05	33.1	3.1	30	1.1
Turbulent flow (flow rate of 8 liter/min)							
20.6	12.8	7.8	0.0001333	135.7	41.5	94.2	0.6
27.2	12.8	14.4	0.0001333	184.7	41.5	143.2	1.1
32.1	12.8	19.3	0.0001333	291.5	41.5	250	1.5

- 鉛直スパイラル型熱交換器のシステム性能向上効果を確認
- スパイラルピッチが小さいほど，システム性能は増大

---

③地中熱交換器の研究開発

熱交換器フィールド試験

水平スリンキー地中熱交換器（横置）

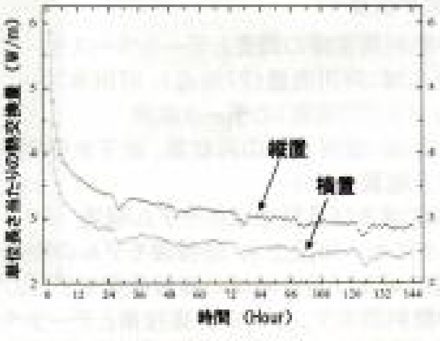
●成果

・水平スリンキー型熱交換器フィールド試験を実施

●今後の課題

・シミュレーション結果と合わせ，性能とコストの両面から総合的評価を実施

水平スリンキー地中熱交換器（縦置）



水平スリンキー型熱交換器フィールド試験結果

Applied Thermal Engineering 90 (2015) 630–637

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research paper

Thermal performance and pressure drop of spiral-tube ground heat exchangers for ground-source heat pump

Jalaluddin [a, *], Akio Miyara [b]

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

HIGHLIGHTS

- Thermal performance and pressure drop of spiral-tube GHE are presented.
- Effects of spiral pitch on thermal performance and pressure drop are analyzed.
- Using a spiral pipe increases heat exchange rate per meter borehole depth of GHE.
- Pressure drop per meter borehole depth also increases in the spiral pipe.

ARTICLE INFO

Article history:
Received 24 March 2015
Accepted 16 July 2015
Available online 26 July 2015

Keywords:
Ground-source heat pump
Ground heat exchanger
Spiral-tube GHE
Heat exchange rate
Pressure drop

ABSTRACT

Thermal performance and pressure drop of the spiral-tube GHE were evaluated in this present work. A numerical simulation tool was used to carry out this research. The heat exchange rates per meter borehole depth of the spiral-tube GHE with various pitches and their pressure drops were compared with that of the U-tube GHE. Furthermore, a comparative analysis between a spiral pipe and straight pipe was performed. In comparison with the straight pipe, using the spiral pipe in the borehole increased the heat exchange rate to the ground per meter borehole depth. However, the pressure drop of water flow also increased due to increasing the length of pipe per meter borehole depth and its spiral geometry. The accuracy of the numerical model was verified for its pressure drop with some pressure drop correlations. The heat exchange rate and pressure drop of the GHEs are presented. As an example, the heat exchange rate per meter borehole depth of spiral pipe with 0.05 m pitch in the turbulent flow increased of 1.5 times. Its pressure drop also increased of 6 times. However, from the view point of energy efficiency, using the spiral pipe in the ground-source heat pump system gives a better performance than using the straight pipe. The heat exchange rate and pressure drop are important parameter in design of the ground-source heat pump (GSHP) system.

1. Introduction

The increase of global warming problem has increased interest in using renewable energy sources. The ground-source heat pump (GSHP) system can be the desirable technologies in renewable energy markets. This system provides efficient space cooling and heating in residential and commercial buildings. The GSHP system is a heat pump coupled with a ground heat exchanger (GHE) that can be oriented vertically or horizontally. The GHE is used in the system to exchange heat with the ground. It is usually buried in 15–150 m depth in vertical type and laid in the bottom of 1–2 m deep horizontal trenches.

The design/simulation methods and programs of models and systems of vertical GSHPs were described in a detailed review [1]. Operating the GHEs with various conditions shows the different characteristic in their heat exchange rates [2,3]. The performances of several types of GHEs applied to the pile foundations in actual buildings were studied by Hamada et al. [4]. Gao et al. [5] also studied several types of vertical pile-foundation heat exchangers.

The spiral tube GHE is gaining interest in recent years. In this type of GHE, a spiral pipe is installed in the borehole or building foundation pile. Modeling of heat transfer of the spiral tube GHE is important research areas. A cylindrical source model considering the radial dimension and the heat capacity of the borehole or pile

---

[*] Corresponding author. Tel./fax: +62 411 588400.
E-mail address: jalaluddin_had@yahoo.com (Jalaluddin).

http://dx.doi.org/10.1016/j.applthermaleng.2015.07.035
1359-4311/

was developed [6]. Cui et al. [7] 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 the spiral coil pipe. A spiral heat source model has been developed for better thermal analysis [8]. A spiral coil source model was developed to consider 3D shape and radial dimension effects [9]. Heat transfer around the helical GHE with varying helical pitch was presented [10]. Comparison study of helical GHE with triple U-tube [11] and double U-tube [12] GHEs were carried out. It is found that the helical GHE provided better thermal performance than others.

The effective borehole thermal resistance of spiral coil energy pile with considering coil pitch, pipe size, pile size and also, groundwater advection effect on the long-term ground temperatures were evaluated [13]. The groundwater flow enhances the heat transfer performance of spiral coil GHE [14]. Another work considering the groundwater advection effect on spiral coil energy piles are reported [15–17].

Various models of spiral-tube GHEs installed in a borehole and concrete pile were simulated [18]. Heat exchange rate and pressure drop are important parameter in design of the GSHP system. The present work investigate the heat exchange rate per meter borehole depth of the spiral tube GHE with various pitches of 0.05; 0.1 and 0.2 m respectively and their pressure drops along the pipe.

2. Ground heat exchangers and its simulation model

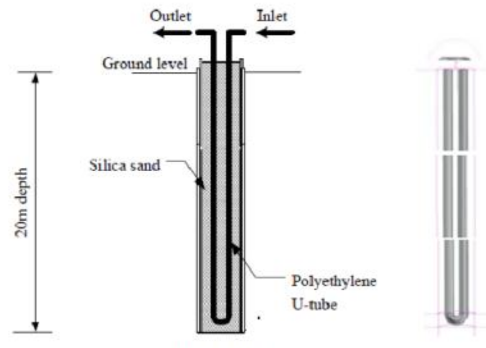
The GHE models such as U-tube and spiral-tube were simulated. A major feature is an analysis of heat exchange rate and pressure drop of water flow in the GHEs. The schematic diagrams of the U-tube and spiral-tube GHEs are shown in Fig. 1. The both GHEs were installed in the borehole of 20 m depth. Inlet and outlet pipes for the both GHEs, U-tube and spiral-tube, are made of Polyethylene pipes. 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. This GHE is performed with three different pitches, $p = 0.05$; 0.1; and 0.2 m. All the related geometric parameters and material thermal properties for the GHEs are listed in Table 1. In the simulation model, ground around the borehole of GHEs is modeled up to 5 m in radius. The ground profiles which is similar with the ground profile of Saga city, Japan [2] consist of Clay and Sandy-clay where from ground level to 15 m in depth is Clay and below 15 m is Sandy-clay. The properties of the ground are presented in Table 2.

Three-dimensional hybrid mesh generation was applied in the GHE models. Numerical mesh of the borehole and ground for the spiral-tube GHE is shown in Fig. 2. The mid-view shown in Fig. 2(b) is in the cross-section of 10 m depth of the borehole and ground. Meshing around the borehole is shown in Fig. 2(d). A numerical simulation tool with computational fluid dynamics software, ANSYS FLUENT 14.5, was used to carry out this research.

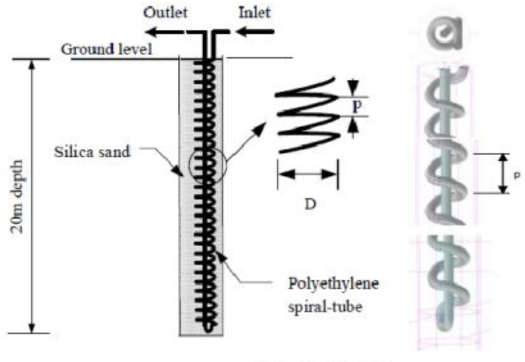
The GHEs models were simulated in cooling mode with constant inlet water temperature of 27 °C (300.15 K). Initial ground temperature is assumed to be constant at 17.7 °C (290.85 K). This temperature was similar with the ground temperature of Saga city, Japan [2] below 5 m in depth. In order to verify the thermal performance in various conditions, the models of GHE operating in laminar and turbulent flows were simulated. The flow rate of circulated water was set to 2 L/min ($Re = 1900$) for laminar flow and 8 L/min ($Re = 7600$) for turbulent flow.

3. Heat exchange rate

Simulation of the U-tube and spiral-tube GHE models was performed. The thermal performances of the GHEs were investigated by calculating their heat exchange rates through the water flow.



(a) U-tube GHE



(b) Spiral-tube GHE

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

Table 1
Geometric parameters and material thermal properties of the GHEs.

Parameters	Value	Unit
Inlet and outlet pipes of the GHEs, U-tube and Spiral-tube (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 of U-tube, x	0.02	m
Pitch for spiral-tube GHEs, p	0.05; 0.1; 0.2	m
Spiral diameter, D	0.1398	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/m^3

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
Sandy-clay (temperature: 293 K; water content: 21.6%)		
Density, ρ	1960	kg/m^3
Specific heat, c_P	1200	J/kg K
Thermal conductivity, $k_{Sandy\text{-}clay}$	2.1	W/m K

f	friction factor (−)
GHE	ground heat exchanger (−)
GSHP	ground-source heat pump (−)
k	thermal conductivity (W/m K)
l	pipe length (m)
L	power input (Watt)
$\dot{m}$	mass flow rate (kg/s)
p	spiral pitch (m)
Δp	pressure drop (Pa)
Q	heat exchange rate (Watt)
Re	Reynolds number (−)
ΔT	temperature difference (K)
V	fluid velocity (m/s)
V	volumetric flow rate (m^3/s)
x	leg spacing of U-tube (m)

Subscripts

o	outer
i	inner
p	pipe
PE	polyethylene
s	straight pipe
c	curved pipe
cri	critis
C	cooling
H	heating
$comp$	compressor
$pump$	pump

References

[1] H. Yang, P. Cui, Z. Fang, Vertical-borehole ground-coupled heat pumps: a review of models and systems, Appl. Energy 87 (2010) 16–27.

[2] Jalaluddin, A. Miyara, K. Tsubaki, S. Inoue, K. Yoshida, Experimental study of several types of ground heat exchanger using a steel pile foundation, Renew. Energy 36 (2011) 764–771.

[3] Jalaluddin, A. Miyara, Thermal performance investigation of several types of vertical ground heat exchangers with different operation mode, Appl. Therm. Eng. 33–34 (2012) 167–174.

[4] Y. Hamada, H. Saitoh, M. Nakamura, H. Kubota, K. Ochifuji, Field performance of a pile GHE system for space heating, Energy Build. 39 (5) (2007) 517–524.

[5] J. Gao, X. Zhang, J. Liu, K.S. Li, J. Yang, Thermal performance and ground temperature of vertical pile-foundation heat exchangers: a case study, Appl. Therm. Eng. 28 (2008) 2295–2304.

[6] Y. Man, H. Yang, N. Diao, J. Liu, Z. Fang, A new model and analytical solutions for borehole and pile ground heat exchangers, Int. J. Heat Mass Transf. 53 (2010) 2593–2601.

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

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

[9] S. Park, S.R. Lee, H. Park, S. Yoon, J. Chung, Characteristics of an analytical solution for a spiral coil type ground heat exchanger, Comput. Geotech. 49 (2013) 18–24.

[10] H. Park, S.R. Lee, S. Yoon, H. Shin, D.S. Lee, Case study of heat transfer behavior of helical ground heat exchanger, Energy Build. 53 (2012) 137–144.

[11] A. Zarrella, M. De Carli, A. Galgaro, Thermal performance of two types of energy foundation pile: helical pipe and triple U-tube, Appl. Therm. Eng. 61 (2013) 301–310.

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

[13] G.H. Go, S.R. Lee, S. Yoon, H.B. Kang, Design of spiral coil PHC energy pile considering effective borehole thermal resistance and groundwater advection effects, Appl. Energy 125 (2014) 165–178.

[14] D. Wang, L. Lu, W. Zhang, P. Cui, Numerical and analytical analysis of groundwater influence on the pile ground heat exchanger with cast-in spiral coils, Energy Procedia 61 (2014) 1784–1788.

[15] W. Zhang, H. Yang, L. Lu, P. Cui, Z. Fang, The research on ring-coil heat transfer models of pile foundation ground heat exchangers in the case of groundwater seepage, Energy Build. 71 (2014) 115–128.

[16] G.H. Go, S.R. Lee, H.B. Kang, S. Yoon, M.J. Kim, A novel hybrid design algorithm for spiral coil energy piles that considers groundwater advection, Appl. Therm. Eng. 78 (2015) 196–208.

[17] W. Zhang, H. Yang, P. Cui, L. Lu, N. Diao, Z. Fang, Study on spiral source models revealing groundwater transfusion effects on pile foundation ground heat exchangers, Int. J. Heat Mass Transf. 84 (2015) 119–129.

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

[19] C.M. White, Streamline flow through curved pipes, in: Proceedings of the Royal Society of London, 1929.

[20] H. Ju, Z. Huang, Y. Xu, B. Duan, Y. Yu, Hydraulic performance of small bending radius helical coil-pipe, J. Nucl. Sci. Technol. 38 (10) (2001) 826–831.

[21] H. Ito, Friction factors for turbulent flow in curved pipes, J. Basic Eng. (1959) 123–134.

[22] S. Ali, Pressure drop correlations for flow through regular helical coil tubes, Fluid Dyn. Res. 28 (2001) 295–310.