CHARACTERISTICS OF GEOTHERMAL ENERGY OBTAINED FROM A DEEP WELL IN THE COLDEST PROVINCIAL CAPITAL OF CHINA

by

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The abundantly available renewable geothermal energy resources play an important role in people's life in the applications of hot water supply, greenhouse heating, air conditioning, electricity generating, breeding, incubating, drying, irrigating, refrigeration, and so on. This study investigated the characteristics of geothermal energy obtained from a 100 m deep well in Harbin, the coldest provincial capital of China. The effects of air temperature, wind scale, and fluid velocity were also studied. When the air temperature varied in the range of –21.76 ~ –15.27 °C and the wind scale was in the range of 2-5, the tube and soil temperatures varied in the ranges of –1.3 ~ 1.8, 3.9 ~ 4.6, 6.6 ~ 7.7, 7.7-8.7, 8.9 ~ 9.8, 10.4 ~ 11.3, 11.9 ~ 13.1, and 13.4 ~ 14.8 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. Ambient conditions had significant effect on the soil temperature above 1 m whereas nearly no effect on the soil temperature under 5 m. When the fluid velocities were between 0.09 m/s and 0.18 m/s, the tube temperatures reached stable within one hour, and the fluid velocity had slight effect on the tube temperatures. The results obtained from this study offer precious geothermal energy information for the cold regions of China and also the whole world.

Key words: *geothermal energy, characteristics, deep well, cold region, China*

Introduction

According to the global geothermal energy scenario by 2040 [1], the global geothermal energy consumption would be 184.03, 331.60, and 491.32 Mtoe (million tonnes oil equivalent) for the years of 2020, 2030, and 2040, respectively. The average annual increase in these global geothermal energy resources would be 15.32% for the next three decades (based on the global geothermal energy consumption of 86.81 Mtoe in 2010), being much higher than the average annual increase rate of 1.27% in world population (6.52-7.35 billion persons) for the past ten years of 2006-2015 [2].

Geothermal energy is now considered as one of the most promising energy source among the alternative energy sources due to the advantages of reliable, clean, and safe over the fossil fuels [3, 4], these abundantly available renewable geothermal energy resources would

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Figure 1. National territory of China

definitely play more and more important role in people's life in the applications of hot water supply, greenhouse heating, air conditioning, electricity generating, breeding, incubating, drying, irrigating, refrigeration, and so on [5-9].

There are totally four geothermal zones in the world: Circum Pacific Ocean, Mediterranean-Himalaya, Mid-Atlantic Ridge, and Red Sea-Aden-East-African Rift Valley [10]. Among these four geothermal zones, two geothermal zones (Circum Pacific Ocean and Mediterranean-Himalaya) extend across China [5], and China is the top country with the largest utilization of geothermal energy [1]. Figure 1 shows the national territory of China where Harbin locates in the northeast with a longitude between 125° 42′ and 130° 10′ and a latitude between 44 °04′ and 46 °40′, and it has the lowest winter temperature of –38.1 ^{o}C among all the provincial capitals in China [11]. The geothermal energy in Harbin can therefore enrich the geothermal energy information for the cold regions of China and also of the whole world.

The main objective of this study was to investigate the characteristics of geothermal energy obtained from a deep well in Harbin, the coldest provincial capital of China. The three specific objectives were: to present the characteristics of geothermal energy obtained from a deep well in the coldest region of China by demonstrating the tube/soil temperatures at different depths of a 100 m deep well located in Harbin, to determine if the ambient conditions *e. g.* air temperature and wind scale have effects on the characteristics of geothermal energy, and to study the effect of fluid velocity on the tube/soil temperatures.

Experimental

Well drilling

After a careful detection of the soil ground with a 2 m Luoyang spoon to make sure that there were no electric wires or gas pipes, a water well driller machine was then used to drill wells. The water well driller machine is composed of a motor, a controlling switch (push driller or pull driller), a driller, a water pump, and some pipes. When the machine was started and the driller entered the ground, a water stream was connected to the well for: cooling the driller, preventing the soil around the drilled well from collapsing to bury the drilled well, and drawing out the soil in the ground through a discharge pipe thereby improving the drilling. The driller was connected to a steel pipe in 2 m length and the steel pipe was led by the driller to enter the ground soil. When the steel pipe entered, the up side was connected to another steel pipe. Totally, fifty steel pipes were drawn by the driller to reach a depth of 100 m.

Thermocouple placement and tube drop

The U-type tube was used as heat exchanger in this study. The U-type tube is made of polyethylene, and the inner diameter and out diameter are 28 mm and 32 mm, respectively.

Two 100 m deep polyethylene tubes were connected by a U-type polyethylene tube which is usually called U-type head.

Figure 2 shows the schematic diagram of U-type tube and thermocouple placement. Eight thermocouples were located at the points labeled as shown in fig. 2. For each thermocouple, there was an extra five meters for the thermocouple extension cable. For the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, the thermocouple extension cables are 6, 10, 15, 25, 45, 65, 85, and 105 m in length, respectively. The thermocouples and the thermocouple extension cables were tied around one of the U-type tube with scotch tape, this could reduce the frictions and consequently help the tube drop. The U-type tube was filled with water to make the tube heavier. On the other hand, a 2 m silk bag filled with heavy stones was tied along the U-type tube from the U-type head to make sure the U-type tube will be heavy enough to overcome the buoyancy of water in the well. Based on the principle of inertia of energy, the U-type tube with eight thermocouples and one stone bag was then dropped in the well as fast as possible to make sure that the drop was easier.

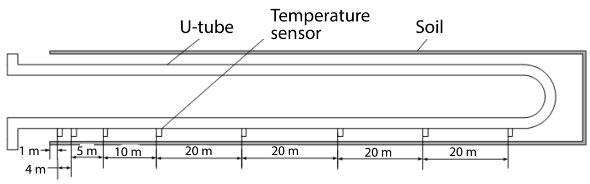

Figure 2. Schematic diagram of U-type tube and thermocouple placement

When the U-type tube was dropped in the 100 m deep well, sand was piled around the U-type tube and water was poured around. A long bamboo was used to stir in the well, making the sand fill the well easily.

Data acquisition

When the tubes over the ground were connected, a water pump (CMF4-40T-A-W-G-BABE, Guangdong Lingxiao Pump Industry Co., Ltd, Yangchun, China) was used to circulate the water in the tube, and a valve was used to control the fluid velocity in the cycle. The eight thermocouple extension cables were connected to a data collecting and recording system located in the room and another thermocouple extension cable was also connected to the system for measuring the ambient temperature. The data collecting and recording system (RS485, Heilongjiang ARCO Technology Co., Ltd, Harbin, China) can record and store the transient temperatures the thermocouples send back. An anemometer (NK-5500, Guangzhou GORDY Electronic Technology Co., Ltd, Guangzhou, China) was used to measure the wind scale. A liquid turbine flowmeter (SDLWGY-40C05SSEN, Beijing Shidatongchuang Test & Control Co., Ltd, Beijing, China) was used to measure the fluid velocity.

Experimental procedure

On the experiment days, the data collecting and recording system was turned on to record the ambient and tube temperatures. The anemometer was turned on to measure the wind scale. When the water pump and liquid turbine flowmeter were turned on, the valve was adjusted to reach the required fluid velocity.

Results and discussion

Ambient conditions

Figure 3 shows the ambient conditions of air temperatures and wind scales of a typical experimental day. The air temperature varied in the range of –21.76 ~ –15.27 ^{o}C with the lowest temperature of –21.76 ^{o}C at 7 a. m. in the early morning and the highest temperature of

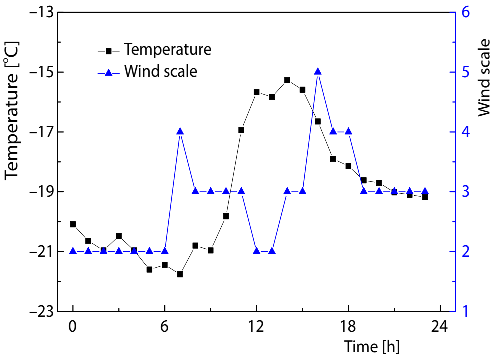

Figure 3. Ambient conditions at different hours for a typical experimental day

–15.27 °C at 2 p. m. in the early afternoon. The wind scale of the typical experimental day was in the range of 2-5. Wind scales of 2, 3, 4, and 5 indicate light breeze, gentle breeze, moderate breeze, and fresh breeze, respectively.

The air temperatures obtained from this study (–21.76 ~ –15.27 °C) are much lower than the values of 5.2-26.9 °C reported by Bakos [12] for those in Greece and the values of 17.0-40.9 °C reported by Ahmad and Rashid [3] for the ones in Pakistan. These may lead to the results that the tube/soil temperatures obtained from this study (–1.3 ~ 14.8 °C, will be detailed in the next section) are lower than the values of 40 ~ 82 °C reported by Bakos [12] for those in Greece and the values of 25.0 ~ 83.0 °C reported by Ahmad and Rashid [3] for the ones in Pakistan.

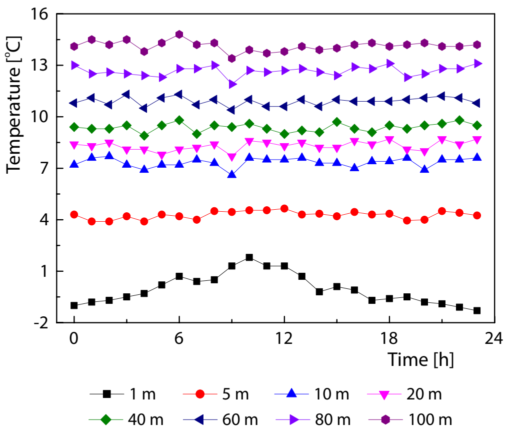

Figure 4. Pipe temperatures at different well depths for a 24 hour day

Tube/soil temperatures at different well depths

Figure 4 shows the tube temperatures at different well depths when the fluid in the tube was stagnant. The tube temperatures varied in the ranges of –1.3 ~ 1.8, 3.9 ~ 4.6, 6.6 ~ 7.7, 7.7-8.7, 8.9 ~ 9.8, 10.4 ~ 11.3, 11.9 ~ 13.1, and 13.4 ~ 14.8 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. The well depth of 100 m had the highest tube temperatures (13.4 ~ 14.8 °C), followed by 80 m (11.9 ~ 13.1 °C), 60 m (10.4 ~ 11.3 °C), 40 m (8.9 ~ 9.8 °C), 20 m (7.7-8.7 °C), 10 m (6.6 ~ 7.7 °C), 5 m (3.9 ~ 4.6 °C), and 1 m (–1.3 ~ 1.8 °C). This was due to the fact that the tube temperature also indicates the soil temperature, and the deeper the location the higher the temperature.

It was also observed that the temperature differences were 3.1, 0.7, 1.1, 1.0, 0.9, 0.9, 1.2, and 1.4 °C for well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. The 1 m well depth had higher temperature difference (3.1 °C) than the other well depths (0.7 ~ 1.4 °C), indicating that the soil temperatures above 1 m was affected significantly by the ambient conditions whereas those at lower depths (under 5 m) would not be significantly affected.

The tube/soil temperatures obtained from this study (–1.3 ~ 14.8 °C) are lower than the value of 501 °C reported by Uchida *et al*. [13] for the soil temperature in Japan, the value of 329.8 °C reported by Huang and Zhi [5] for that in China, the values of 193-240 °C reported by Cerci [14] and Ozturk *et al*. [15] for those in Turkey, the values of 90 ~ 93 °C reported by Ozgener and Kocer [7] for the ones in Turkey, and the values of 40 ~ 82 °C reported by Bakos [12] for those in Greece. These were mainly determined by the well depths. The well depth reported by Uchida *et al*. [13] was 3500 m, the well depth reported by Huang and Zhi [5] was 2006 m, the well depths reported by Cerci [14] and Ozturk *et al*. [15] were 510-2261 m, the well depths reported by Ozgener and Kocer [7] were 153-200 m, and the well depths reported by Bakos [12] were 150-1000 m whereas the well depth of the study was 100 m.

However, the tube/soil temperatures obtained from this study (–1.3 ~ 14.8 °C) are lower than the value of 145 °C (at a well depth of 13 m) reported by Huang and Zhi [5]. This is due to the fact that the well location reported by Huang and Zhi [5] is in the southwest of China whereas the well location of this study is in the northeast of China. This indicates that geothermal energy is significantly dependent on the well location, the results obtained from this study therefore can enrich the geothermal energy information for the cold regions of China and also the whole world.

Effect of fluid velocity

Figure 5 shows the tube temperatures at different well depths when the fluid flowed in the tube. In fig. 5(a), when the fluid velocity was 0.09 m/s, the tube temperatures were in the ranges of 1.3 ~ 3.2, 2.3 ~ 4.5, 2.6 ~ 6.6, 4.4 ~ 7.7, 5.0 ~ 9.4, 4.8 ~ 10.4, 5.1 ~ 11.9, and 5.1 ~ 13.4 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. The tube temperatures varied by 0.3, 1.4, 3.4, 3.0, 4.3, 5.0, 6.2, and 7.6 °C within the first one hour whereas varied by 1.6, 1.5, 2.4, 1.3, 0.8, 1.0, 1.0, and 0.9 °C for the next eight hours for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. It was observed that the tube temperatures varied slightly during the eight hours for all the well depths, and the average tube temperatures were 2.5, 2.8, 3.6, 4.9, 5.3, 5.3, 5.6, and 5.5 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively.

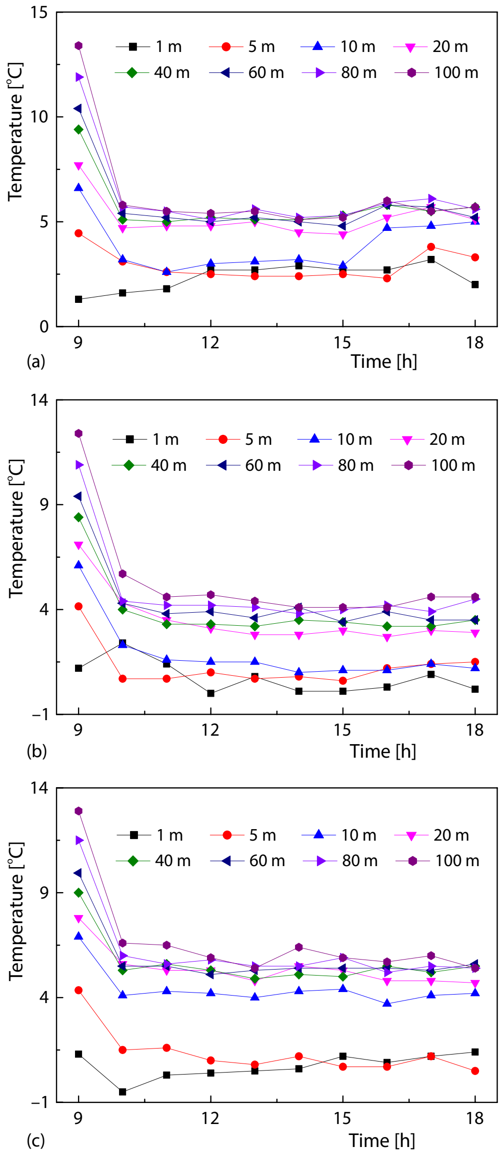

Figure 5. Pipe temperatures at different depths for different fluid velocities; (a) fluid velocity = 0.09 m/s, (b) fluid velocity = 0.135 m/s, (c) fluid velocity = 0.18 m/s

In fig. 5(b), when the fluid velocity was 0.135 m/s, the tube temperatures were in the ranges of 0 ~ 2.4, 0.6 ~ 4.2, 1.0 ~ 6.1, 2.7 ~ 7.1, 3.2 ~ 8.4, 3.4 ~ 9.4, 3.8 ~ 10.9, and 4.1 ~ 12.4 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. It was also observed that the tube temperatures varied significantly within the first one hour whereas varied slightly during the next eight hours for all the well depths, and the average tube temperatures during the eight hours were 0.7, 1.0, 1.4, 3.1, 3.4, 3.8, 4.1, and 4.5 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively.

In fig. 5(c), when the fluid velocity was 0.18 m/s, the tube temperatures were in the ranges of –0.5 ~ 1.4, 0.5 ~ 4.4, 3.7 ~ 6.9, 4.7 ~ 7.8, 4.9 ~ 9.0, 5.1 ~ 9.9, 5.2 ~ 11.5, and 5.4 ~ 12.9 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. It was also observed that the tube temperatures varied significantly within the first one hour whereas varied slightly during the next eight hours for all the well depths, and the average tube temperatures during the eight hours were 0.7, 1.0, 4.1, 5.1, 5.3, 5.4, 5.6, and 6.0 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively.

After one operation hour, the fluid reached heat balance with the soil and the tube temperature nearly reached a constant. When the fluid velocity was 0.09 m/s, the tube temperatures during the last eight hours were in the ranges of 1.6 ~ 3.2, 2.3 ~ 3.8, 2.6 ~ 5.0, 4.4 ~ 5.7, 5.0 ~ 5.8, 4.8 ~ 5.8, 5.1 ~ 6.1, and 5.1 ~ 6.0 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. When the fluid velocity was 0.135 m/s, the tube temperatures during the last eight hours were in the ranges of 1.0 ~ 2.4, 0.6 ~ 1.5, 1.0 ~ 2.3, 2.7 ~ 4.3, 3.2 ~ 4.0, 3.4 ~ 4.3, 3.8 ~ 4.5, and 4.1 ~ 5.7 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. When the fluid velocity was 0.18 m/s, the tube temperatures during the last eight hours were in the ranges of –0.5 ~ 1.4, 0.5 ~ 1.6, 3.7 ~ 4.4, 4.7 ~ 5.6, 4.9 ~ 5.6, 5.1 ~ 5.6, 5.2 ~ 6.0, and 5.4 ~ 6.6 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. It was observed that the fluid velocity didn't have significant effect on the tube temperatures. Similar results were also reported by others [3, 9, 14-17].

Conclusions

The characteristics of geothermal energy obtained from a 100 m deep well in the coldest provincial capital of China was investigated in this study, the following conclusions were obtained.

The air temperature varied in the range of –21.76 ~ –15.27 °C for a typical experimental day, and the wind scale was in the range of 2-5.

When the fluid was stagnant, the tube/soil temperatures varied in the ranges of –1.3 ~ 1.8, 3.9 ~ 4.6, 6.6 ~ 7.7, 7.7-8.7, 8.9 ~ 9.8, 10.4 ~ 11.3, 11.9 ~ 13.1, and 13.4 ~ 14.8 °C for the well depths of 1, 5, 10, 20, 40, 60, 80, and 100 m, respectively. The soil temperature above 1 m was affected significantly by the ambient conditions whereas those under 5 m would not be significantly affected.

The tube temperatures reached constants within one hour, and the fluid velocity had slight effect on the tube/soil temperatures.

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References

[1] Demirbas, A. H., Global Geothermal Energy Scenario by 2040, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *30* (2008), 20, pp. 1890-1895
[2] ***, FAO, 2016, Available at: http://faostat3.fao.org/download/O/OA/E
[3] Ahmad, I., Rashid, A., Study of Geothermal Energy Resources of Pakistan for Electric Power Generation, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *32* (2010), 9, pp. 826-838
[4] Šušteršić, V., *et al*., An Overview of the Regulatory Framework for the Geothermal Energy in Europe and Serbia, *Thermal Science*, *14* (2010), Suppl., pp. S115-S125
[5] Huang, Z., Zhi, W. F., Present Situation and Future of Utilization of Geothermal Energy in China, *Energy Sources*, *20* (1998), 8, pp. 705-708

[6] Urbancl, D., *et al.*, Geothermal Heat Potential – The Source for Heating Greenhouses In Southestern Europe, *Thermal Science*, *20* (2016), 4, pp. 1061-1071
[7] Ozgener, O., Kocer, G., Geothermal Heating Applications, *Energy Sources*, *26* (2004), 4, pp. 353-360
[8] Luo, C., *et al.*, Energy Efficiency Comparison between Geothermal Power Systems, *Thermal Science*, *21* (2017), 6A, pp. 2633-2642
[9] Alsuhaibani, Z., Hepbasli, A., Future Aspects of Geothermal Energy in Saudi Arabia, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *35* (2013), 10, pp. 981-990
[10] Ueckermann, H. I., *Geothermal Energy Research Trends*, Nova Science Pub., N. Y., USA, 2008
[11] Zhang, Y., *et al.*, Application of an Air Source Heat Pump (ASHP) for Heating in Harbin, the Coldest Provincial Capital of China, *Energy and Buildings*, *138* (2017), Mar., pp. 96-103
[12] Bakos, G. C., Low Enthalpy Geothermal Energy for Greenhouse Heating at Nea Kessani Xanthi, Greece, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *29* (2007), 6, pp. 571-579
[13] Uchida, T., *et al.*, Deep Geothermal Resources Survey Project in the Kakkonda Geothermal Field, *Energy Sources*, *20* (1998), 8, pp. 763-776
[14] Cerci, Y., Performance Evaluation of a Single-Flash Geothermal Power Plant in Denizli, Turkey, *Energy*, *28* (2003), 1, pp. 27-35
[15] Ozturk, H. K., *et al.*, Energy and Exergy Analysis of Kizildere Geothermal Power Plant, Turkey, *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, *28* (2006), 15, pp. 1415-1424
[16] Baba, A., *et al.*, Environmental and Exergetic Aspects of Geothermal Energy, Part A: Recovery, Utilization and Environmental Effects, *Energy Sources, 28* (2006), 7, pp. 597-609
[17] Guru, M., Kapulluoglu, A., The Optimization of Electricity Production from Geothermal Sources by a Binary System, Part A: Recovery, Utilization and Environmental Effects, *Energy Sources, 34* (2011), 3, pp. 278-286

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