ASEAN Engineering Journal

Full Paper

AN ELECTRIC CONVERSION SET OF GEOTHERMAL ENERGY USING A THERMOELECTRIC DEVICE: CASE AT A HOT SPRING

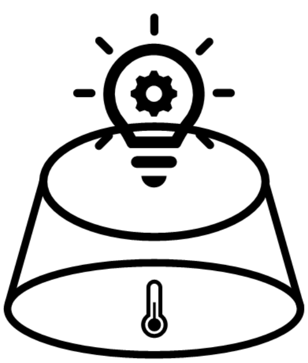
Trinet Yingsamphancharoen [a,d,e], Wichok Promdaung[b,d,e] , Sompong Bangyeekhan[c,d*]

[a]Department of Welding Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok, 10800, Bangkok, Thailand
[b]Department of Electrical Engineering Technology, College of Industrial Technology, King Mongkut's University of Technology North Bangkok, 10800, Bangkok, Thailand
[c]Department of Teacher Training in Mechanical Engineering, Faculty of Technical Education, King Mongkut's University of Technology North Bangkok, 10800, Bangkok, Thailand
Center of Welding Engineering and Metallurgical Inspection, Science and Technology Research Institute, King Mongkut's University of Technology North Bangkok, 10800, Bangkok, Thailand
[e]Operations Center of Integrated Innovation Research and Development under Industrial Standards and Technopark, King Mongkut's University of Technology North Bangkok, Bangkok, 10800, Thailand.

Article history
Received
12 December 2023
Received in revised form
23 June 2024
Accepted
12 September 2024
Published online
28 February 2025

*Corresponding author
sompong.b@fte.kmutnb.ac.th

Graphical abstract



Hot Spring to produce Electricity

Abstract

This research aims to study the effects of hot- and cold-water flowrates on electrical production of a thermoelectric device to design and build a heat-to-electricity conversion kit block. A test stand was used to simulate the Raksawarin Hot Springs, Ranong Province in Thailand. This hot spring has a temperature of 65 °C and cold water from a nearby canal at 27 °C. We use 20 sheets of a thermoelectric material (TE) model TEC1-12706, size 40x40 mm^2, designed as hot and cold-water blocks with dimensions of 200 x 50 x 660 mm^3. The natural temperature of this hot spring, 65±2 °C, and cold-water stream at 27±2 °C, were simulated. An experimental test stand that provides hot water was controlled by a thermostat. The cold-water flow is controlled using a water pump and flow meter. Experimental results showed that at equal hot- and cold-water flowrates of 2.0 liters per minute, the average maximum voltage was 0.12 V for each TE generator. In the case of 20 TE pads (10 pcs. in series and two sets in parallel) under a constant hot water flowrate of 2.5-5 liters per minute, the TE plates generated maximal power, about 2.0 V, 170 mA, and 0.3-0.4 Watts.

Keywords: Hot Spring Energy; Thermoelectric; Electrical Generator; Hot and Cold-water Flowrates; Geothermal

1.0 INTRODUCTION

Almost every country in ASEAN has a lot of hot springs except Brunei Darussalam. Such as table 1,

Table 1 Low temperature hot spring in the Asean country

	Hot Spring's Name	Temperature (°C)	Ref.	Country
1	Kenh Ga	53	[1];	Vietnam
2	Dam Rong	45	[1];	
3	Binh Chau	82	[2];	
4	Blue Spring &	56		Lao DPR

	Pathong Cave			
5	Maung La Lodge	50		
6	Kasi	40	[3];	
7	Te Teuk Pus	70	[4];	Cambodia
8	Healthy Hot Spring of Lashio	45	[5];	Myanmar
9	Aung Thapyay	55	[6];	
10	Pinlong	90	[7];	
11	La	49	[8];	Malaysia
12	Sg. Lalang	52	[9];	
13	Selayang	46	[10];	
14	Sembawang	70	[11];	Singapore
15	Baslay	60	[12];	
16	Ardent Hibok-Hibok	40	[13];	Philippine
17	Mambukal	43	[14];	
18	Toya Devasya	39	[15];	Indonesia
19	Pangururan	40	[16];	
20	Angseri	36	[17];	
21	Marobo	49	[18];	Timor Leste

The same thing, the water temperature of almost all hot springs in Thailand does not exceed 100 °C. This is because Thailand's location is not at the junction of tectonic plates and major fault lines such as the Ring of Fire in East Asia. However, Thailand has some minor faults from which geothermal energy can be harvested. Examples of this are the Mae Tha fault in Lampang Province of the North and along the Ranong fault in southern Thailand, respectively. These minor faults create hot springs that have moderately high temperatures.

Most of them are low-heat hot springs. The water temperature is about 40-100°C. Except in the Indonesia and the Philippines where there are active volcanoes, very high-temperature hot springs are found [19,20]. However, there are still more low-temperature hot springs than high-temperature hot springs. These low temperature hot springs are used for therapeutic, relaxation, and tourism purposes only [1,2,3,4,5,6, 7,8,9,10,11,12,13,14,15,16,17,18]. Although some high thermal hot spring has been developed to produce electrical energy, it is a small amount, such as the Fang hot spring in Chiang Mai province in Thailand using steam turbine technology to produce electricity [21,22]. It has a capacity of 300 kilowatts. This is operated by the Electricity Generating Authority of Thailand (EGAT). Its temperature is 130°C. However, this technology only applies to hot spring sources with high water temperatures exceeding 100 $^{\circ}$C. and high hot water pressure [23,24,25,26]. Such technology cannot be used in low-temperature hot springs [23,24,25,26]. But with low-heating ponds, there are a lot of them in many countries as shown in paragraph 1. There has been a lot of research into the use of thermoelectric (TE) to produce electricity in this case. An example of this is a system where the waste heat from internal combustion engines can be used to produce electricity using TEs [27, 32], as well as from other types of waste heat [33,34,35,36, 37,38,39] and from hot springs [40,41]. In another application, human body heat is converted into electrical energy to serve in wireless body application [42, 43]. Heat always flows from a warmer to a cooler area when no external energy is applied. Maintaining a constant temperature difference between the hot and cold sides of a TE is critical to effectively generate electricity. The results of this study on the suitability of TE power generation were compared with simulation results to evaluate the TE series by Suter *et al*., 2012 [44].

It is easy to install TE on heat exchanger plates with heating and cooling sides from the source. Heat is converted to electricity by P-N semiconductors from TE [38,43]. However, TE technology using transform heat-cooling energy to electrical energy also finds disadvantages in the TE sheet, the heat transfer for electricity production of TE is heat conduction. Heat will spread from the TE hot side to different sides of TE. This phenomenon will reduce different temperatures, and there will be reduced electricity production too [45,46,47]. The hot water obtained from such low-temperature hot springs has a low over flowrate from the hot springs. This low flowrate creates a barrier that causes heat to build up in the water block. This causes the heat from the hot side to rush to the cold side faster, causing electricity production to decrease. Finding the appropriate natural flowrate for both hot and cold-water heat exchange water blocks to optimize the design of the source. It allows designing a suitable water block without the need for a pump. Similarly, research has shown that the hot fluid flowrate affects the retention of the temperature differential. In turn, this affects power generation from TEs. [48, 49, 50]

Geothermal power generation utilizing TE technology has received increasing attention in recent years. Catalan *et al*. (2019) [51]; proposed a TEG system prototype composed of a two-phase closed thermosyphon (TPCT) as a hot-side heat exchanger and two thermoelectric modules, and it considers different cold-side heat exchangers. The hot-side thermosyphon was installed underground to extract geothermal energy from a shallow hot dry rock (HDR) reservoir, and the cold-side thermosyphon dissipated heat into the environment through convective heat transfer with the surrounding air. With geothermal energy in the Timanfaya National Park (Canary Islands, Spain), one of the greatest shallow HDR fields in the world with 5000 m^2 of characterized geothermal anomalies presenting temperatures up to 500 °C at only 2 m deep., there is potential for generating electricity at 681.53 MWh by Catalan *et al*. 2020 [52]. Due to the limitations of the national park, building a power plant using other methods such as buildings is therefore impossible. So, they applied TE 8 modules of 4.5W each (36W per module), generating up to 286.94 kWh of electricity per year from the HDR source by Suter *et al*. 2012 [44]. They make a heat transfer compare with CFD. The heat transfer model is then applied to optimize a 1 kWe stack with the hot water inlet and outlet temperatures of 413 K and 393 K, respectively. For cold water inlet and outlet temperatures of 293 K and 298 K, respectively, for either a maximum heat-to-electricity efficiency of 4.2% or a minimum volume of 0.0021 m3. In 2021, Heping *et al*. 2021 [53]. They experiment with a heat exchange stacking module system designed and developed with a uniform flowrate at a temperature difference of 96.4 °C. It was found that the TE module was effective 1.64 % at a flowrate of 0.026-0.06 kg/s. Later in 2023, Heping *et al*. (2023). [54]; they also designed and developed a 5-story stacked module set, 3 cold water floors and 2 hot water floors, consisting of 32 modules, 24 TEG per floor, capable of producing a maximum power of 1.044 kW at a different temperature is 91 °C, with cold water having a value of 15 °C, hot water having a value of 106 degrees. In February 2014, Changwei *et al*. (2014) [55]; they designed a generator using modules by studying a temperature difference of 120 °C to produce 1 kW of electrical energy. In July of the same year, this group of researchers also presented a research report on a 500W thermal generator using 96 pieces of TEG to produce electricity with a temperature difference between hot and cold water of 200°C. It was concluded that the difference in hot and cold temperatures would be important in thermoelectric power generation. Additionally, in July 2020, Changwei *et al*. [56]; their study was conducted using a TEG instrument built to measure productivity and efficiency at water flowrates at different, and different temperatures, and differences between the hot and cold sides. The effect of these parameters on the voltage output power and performance is monitored and analyzed. The five-layer TEG device can produce approximately 45.7 W of electricity with a temperature difference of 72.2°C between the cold and hot sides. The power of each module is approximately 0.51 W at this temperature difference by Kewin *et al*., 2020 [57]. In the same year November (2020), researchers designed a six-layer TE suit for field testing with the Bottle Rock heat source in Geysers, California, USA. The entire six-layer TEG device produces approximately 500 W of electricity with a temperature difference of approximately 152 ◦C between the hot and cold fluid manifolds. Each TEG chip can generate approximately 3.9 W. The steam pressure at the inlet of the TEG device is approximately 122 psi, close to a wellhead pressure of 125. Psi. After optimizing the field infrastructure, the TEG device produces electricity without leakage at wellhead pressures of 125 psi and temperatures above 176 ◦C (349 ◦F). Field testing of the six-layer TEG device. At the Bottle Rock geothermal power plant, it is considered a success by Kewin *et al*., 2021 [41].

Although there are many studies on harvesting geothermal energy. It has been found that the heat sources in the previous research all have temperatures over 100 ◦C, and the cold water is temperate from warm and cold countries. That is, the temperature is about 15-20 ◦C. And the difference in temperature from past research is the lowest at 72.2 ◦C by Kewin *et al*., 2020 [57]. This is compared to the cold-water temperature in tropical countries, which is approximately 27-30 ◦C, with the hot springs having a low temperature. Approximate hot spring temperatures in ASEAN countries are much lower than in previous research (less than nearly 2 times). Therefore, there is no prior research, that has a very low-temperature difference of 40 ◦C maximum and its minimum low pressure is 40 psi (pump pressure), while the pressure of hot water from a hot spring previous research =125 psi (wellhead pressure) by Kewin *et al*., 2021 [41].

The objectives of this research are to design and build a heat exchange device, a TE unit for producing electricity from a natural low-temperature hot spring source. Include finding the flowrate of cool and hot water that affect to produce electricity.

2.0 METHODOLOGY

2.1 Physical Characteristics Of The Raksa Warin Hot Springs

Raksa Warin Park is located in Ranong Province in southern Thailand. This park has hot mineral water pools at a constant 65 °C temperature. It has three main ponds, the Father, Mother and Daughter ponds. The Father Pond is the largest, shown in Figure 1. It is a circular pond, 2.80 m in diameter. Our study simulated the hot water from this pond and that of Ranong canal which is a rather small canal near the hot springs. Its water temperature is 25-27°C all times.

Figure 1 Raksa Warin hot springs in Ranong Province of Thailand with a water temperature of 65 °C [58]

The hot springs are in a park that is used daily. Therefore, we simulated the flow and temperature control in the laboratory for convenience and safety by designing the experiments as follows.

2.2 Physical Model of Hot Springs for Testing And The Data Recording Process

The experiment set is made model from physical data natural hot spring water temperature and water temperature from the Ranong canal. We set the hot water temperature to 65±2°C and the cold-water temperature to 27±2°C (this water temperature from the nearly the Had Som Pan cannel). Both water flows passed through a 100 x 50 x 100 mm³ water block (Heat exchanger) for only one TE plate before upgrading to a 200 x 50 x 660 mm³ water block for 20 TE plates attached, as shown in (Figure 4) for producing power. This TE is a 12 V-6A (No. 1), this equipment specification shown in Table 2, with a 40 x 40 mm² cross-section (No. 2). The hot and cold water are flowed by pumps (No. 4) from water tanks (No. 5). The flowrates are measured using flow meters (No. 3). The hot water is heated (No. 7), and its temperature controlled by a thermostat (No. 6). The voltage is recorded to verify the effect of increased flowrates. The tests were repeated seven times.

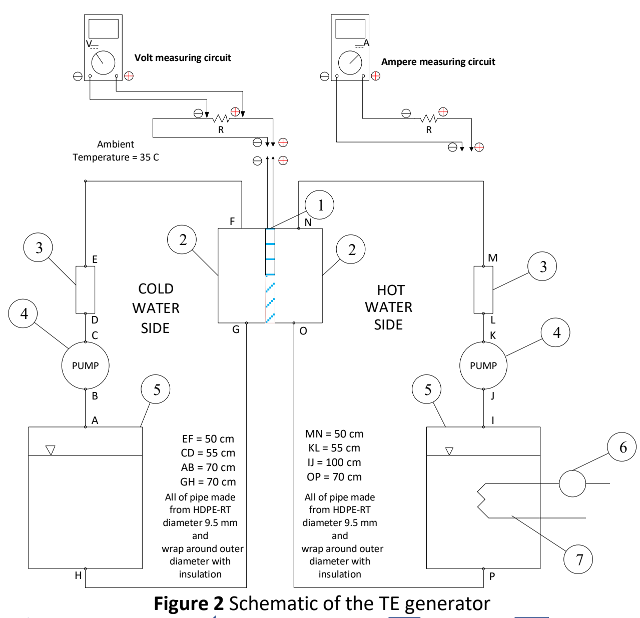


Figure 2 Schematic of the TE generator
cold-water flow hot water flow insulator TE

The hot and cold side water temperatures were measured using bimetallic strip thermometers mounted at the middle of the hotpot and in the cold-water tank. We did not measure the temperature of the TE directly. The water flow temperature was also measured using a bimetallic strip thermometer. Two multimeters (Fluke 175) were used to measure the electricity produced by the equipment with an accuracy of 0.15% of voltage and 1.0% of current that shown at Table 3. All the temperature values were visually acquired and manually written on a data sheet. We measure the voltage with an open circuit and evaluate the current with a closed circuit by connecting the measuring circuit with a resistance of 165 ohms as shown in Figure 2.

Table 2 TE 12706 Commercial module specification and testing conditions [59]

12706 TE Specifications	
Model	TEC1-12706
Voltage	12 V
V_{max}	15.4 V
I_{max}	6A
Q_{max}	92 W
DT_{max}	75 °C
Internal	1.98 Ohm+/- 10%
Type	Cooling cells
Testing conditions	
Flowrate (hot side)	1-5 L/min
Temperature	65±2 °C
Flowrate (Cool side)	1-5 L/min
Temperature	25±2 °C

Table 3 Maximum uncertainty of the instruments or parameters.

Device Name	Device type	Accuracy or Uncertainty	Resolution
Thermometer	DT1312	0.1%	0.1°C
Water flow meter (Hot/Cool)	Rotameter	±5%	0.5L/min
Maximum uncertainty of parameters			
Energy parameter		6.7% [60]	

2.3 Installing The TE In The Water Block And Experimentation.

2.3.1 Only One TE Plate In The Experimental Case

Only one TE plate was installed into a water block assembly, shown in Figure 3. It was tested by circulating cold and hot water through the block. This was done to assess the effect of these water flowrates on electricity production by measuring output voltages with a multimeter. Allowing the hot water to flow freely and controlling the cold-water flowrate from 0.8-2.0 L/min was done to determine the influence of the flowrate on power generation by the TE plates.

2.3.2 The Experimental Case TE 20 plates

The water block set consists of a hot and cold water block made of steel but connected to a 2 mm thick flat copper plate along the top attached to TE. The water block size is 100x50x660 mm³ as shown in Figure 4(a). The two surfaces of TE (hot and cold) are attached with smooth silicone as shown in Figure 4(b). Connect TE to the series hot side with the hot water block side as shown in Figure 4(c). Installed in the second series and connected to the first series circuit in parallel as shown in Figure 4(d). The circuit is obtained by installing two series and paralleling them. Adjust the alignment of the entire set of plates to the horizontal level as shown in Figure 4(f). Install the insulator attaches between the hot and cold water block and tighten the metal belt as shown in Figure 4(g). The cold water was turned on and its flowrate varied while maintaining one of four fixed hot-water flowrates from 2.5-5.0 L/min. The hot-water flowrates were selected to match the average water flowrate from the natural hot springs.

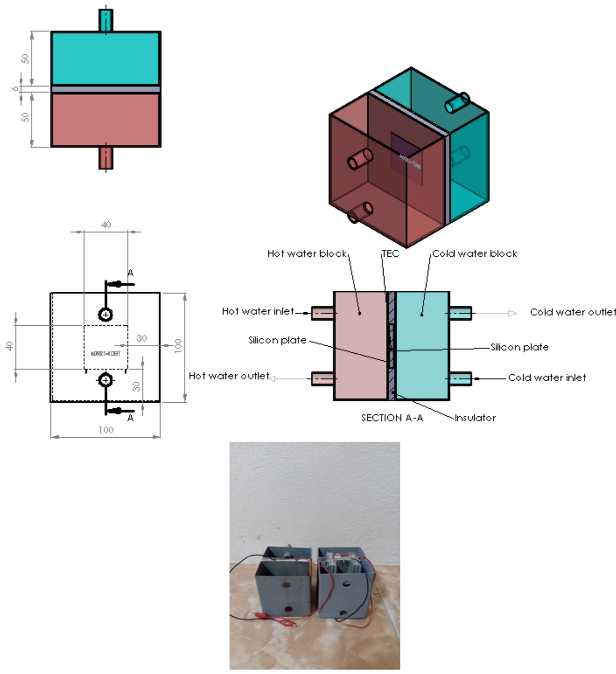


Figure 3 Water block set, size 100 x 50 x 100 mm³, is made using 1 TE cooling pad

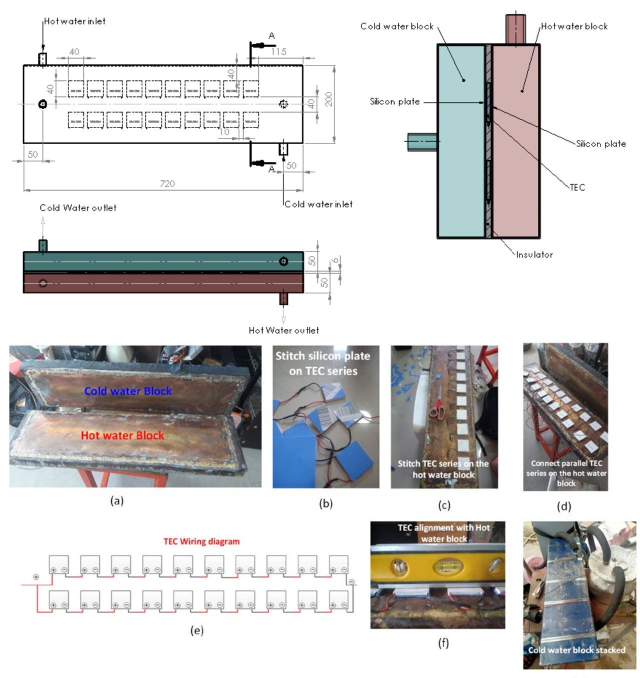


Figure 4 (a) A 200 x 50 x 660 mm³ flat copper plate, (b) TEC1-12706 stitched together with heating silicone, (c) the water block attached

with 10 TE cooling pads series, (d) parallel two series TE set, (e) wiring diagram of the 20 TE pieces, Alignment surface TE before cold water block stacked, and (g) Stackable cold water block on TEC

2.3.3 Use Testing Experience from Only One TE Plate to Test 20 TE Plate

In the first part of the test, the flowrates that affect electricity production were adjusted on both the hot- and cold-water sides. This affects the electricity production of the TE plate. Measure the generated voltage with a multimeter. Four experimental cold-water fixed flowrates were used, 0.8, 1.0, 1.5, and 2.0 L/min, while allowing hot water to flow freely. In the last case, the cold- and hot-water flowrates were equal. In the second part of the experiment, the optimal flowrate from the first part was applied to test the power generation with 20 TE panels attached to a 200 x 50 x 660 mm^3 water block. The power output and corresponding conversion efficiencies of the TEGs are calculated as follows:

$$Q_H = U_H I_H \tag{1}$$

$$P_{out} = U_{out} I_{out} \tag{2}$$

$$\eta Q_H = P_{out} \tag{3}$$

Where Q_H, U_H and I_H are the power of the heater, the voltage and the current of the heater, respectively. P_{out}, U_{out} and I_{out} are the output power, the output voltage and the electrical current, respectively. Then, the TE conversion efficiency is given by Eq. (3). Suter *et al*. (2012) [44]; present the power of the heater can be found from

$$Q_H = \dot{m}_H c_p \left(T_{H,in} - T_{H,out}\right) \tag{4}$$

The thermal conductivity coefficient k of a TE is defined in Eq. (5) to include the heat conduction of two ceramic layers.

$$k = \frac{q\delta}{\Delta T} = \frac{Q_H \delta}{A\left(T_h - T_c\right)} \tag{5}$$

where k and δ are the thermal conductivity coefficient and the thickness of the thermoelectric module, respectively. A and q are the surface of the heater and the heat flux across the TE modules, which are defined as $q = Q_H / A$, where T_h, T_c and ΔT are the hot side temperature, cold side temperature, and the corresponding temperature difference, respectively [45,46, 47,48,49,50], [61,62]. The ΔT term is a primary consideration in this paper because the other parameters for calculation the power use values from commercial TE properties. Furthermore, the flowrates in the current research are rather low. Thus, the results are shown in terms of flowrate affecting ΔT and ΔT affecting electricity generation in terms of the Q_H.

3.0 RESULTS AND DISCUSSION

3.1 Effect of The Flowrate to Produce Electricity.

In Case (a), we controlled the cold-water flowrate at 0.8 L/min and the hot-water flowrate was varied. The maximum voltage produced was only 0.09 V, as shown in Figure 5(a). For Case (b), the cold-water flowrate was controlled at 1.0 L/min and the hot-water flowrate was varied. The maximum voltage produced was 0.10 V, as shown in Figure 5(b). Then in Case (c), we controlled the cold-water flowrate at 1.5 L/min, and the hot-water flowrate variation. The maximum voltage was 0.09 V, as shown in Figure 5(c). Finally, in Case (d), the cold-water flowrate was controlled at 2.0 L/min and the hot-water flowrate was varied. The maximum voltage was only 0.10 V, as shown in Figure 5(d)

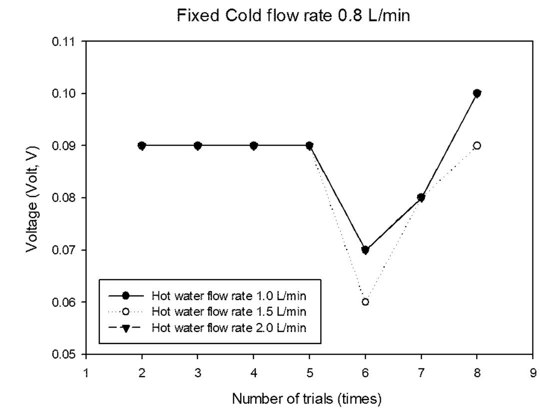


Figure 5 (a) Voltages with a fixed cold-water flowrate of 0.8 L/min varying hot water flowrate.

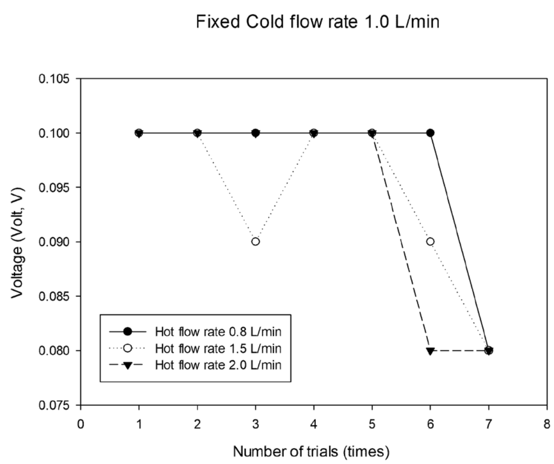


Figure 5 (b) Voltages with a fixed cold-water flowrate of 1.0 L/min varying hot water flowrate.

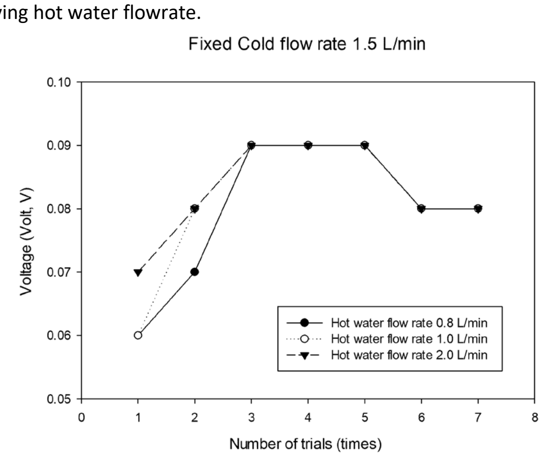


Figure 5 (c) Voltages with a fixed cold-water flowrate of 1.5 L/min varying hot water flowrate.

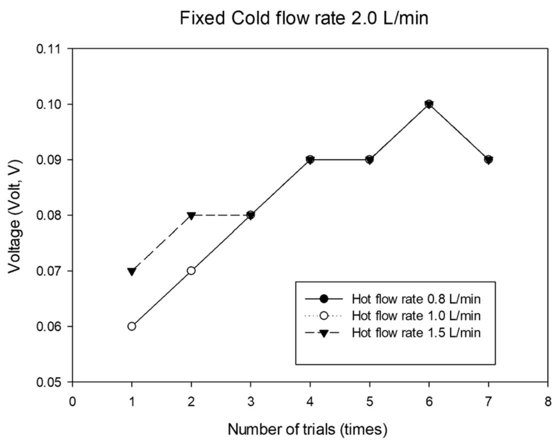


Figure 5 (d) Voltages with a fixed cold-water flowrate of 2.0 L/min varying hot water flowrate.

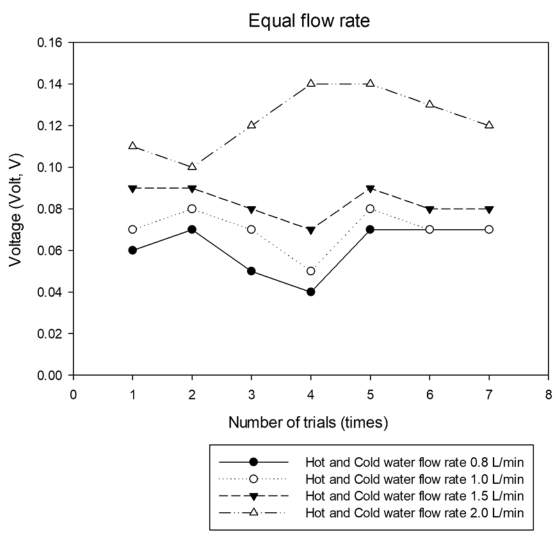


Figure 6 Voltages with the same hot and cold-water flowrates

The electrical measurement of 7 experiments in 1 hour of the generator set with only 1 TEC plate. It was found that in the first period of the test at a low flowrate the thermal steady state quickly. However, the electrical voltage produced in the low flowrate test is small, approximately 0.09-0.1 V, as shown in Figures 5(a) - 5(d). Controlling is the slow or fast flowrate of hot and cold water. It was found that when the flowrate of hot and cold water was equally controlled, it produced the best electricity. Controlling the flowrate of hot and cold water at 2.0 liters per minute resulted in a high voltage of 0.12-0.14 volts, as shown in Figure 6.

3.2 Use 20 TE pieces to produce electricity.

Since the TEC 1-plate heat exchanger system doesn't have a lid, it is impossible to increase the flowrate further. (This causes water to overflow the water block set). Therefore, we designed a closed system but still adjusted the flowrate on the hot water side to be close to the natural overflowing flow of the hot spring. By increasing the number of TECs in series to 10 and parallel to 2 sets, for a total of 20 TECs and adjusting the flowrate for hot water to be constant from 2.5-5.0 liters/minute and adjusting the flowrate for cold water from 1 liter per minute up to 7 liters per minute.

We adjusted the hot water flow in the system until the thermal was in a steady state. Then measure the open circuit voltage and get the voltage as shown in Figure 7. The voltage is 1.8-2.0 V and it has been found that increasing the flowrate of cold water more than hot water will help produce slightly more voltage. In closed circuit current measurement, the current measured is 160-170 mA as shown in Figure 8. Increasing the cold-water flowrate more than the hot water flowrate will help produce slightly more electricity. In this case, the power that can be obtained by calculating multiply between voltage and current, there is experimental result as shown in Figure 9.

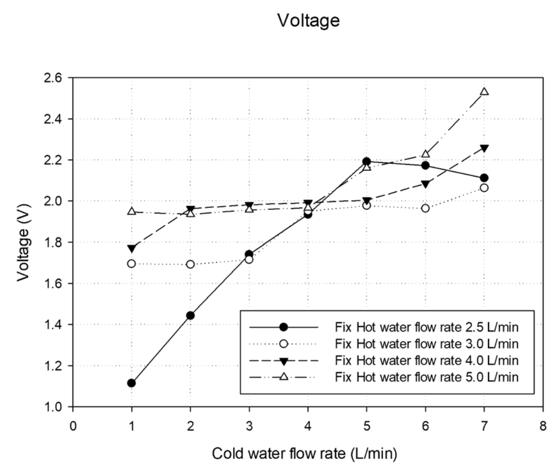


Figure 7 Voltages that can be produced from 20 TE plates at various cold- and hot-water flowrates**.**

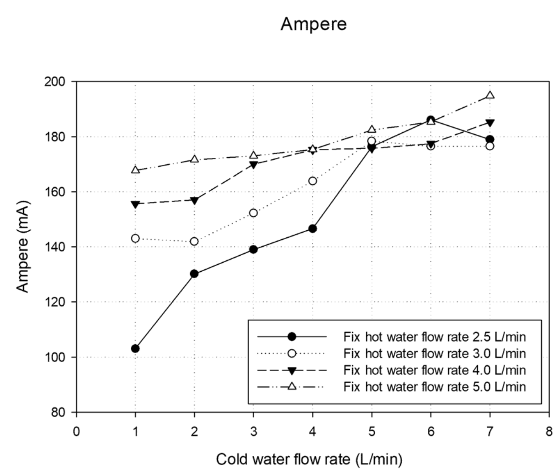


Figure 8 Electrical currents that can be produced from 20 TE plates at various flowrates.

We controlled the flowrate of hot water at 2.5, 3, 4, and 5 L/min and varied the flowrate of cold water from 1, 2, 3, 4, 5, 6, and 7 L/min. The ampere of the electricity was measured using a multimeter in the same manner as the voltage measurements. The ampere was characterized as increasing with the flowrates of both the hot and cold water, as shown in Figure 8.

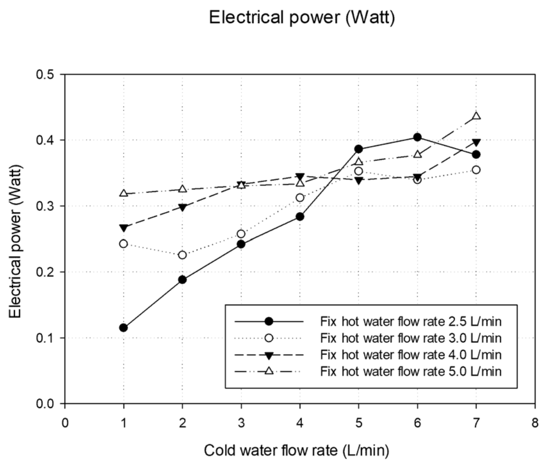


Figure 9 Electrical power that can be produced from 20 TE plates at various flowrates.

Electrical power can be calculated by multiplying voltage and ampere. It increased with the flowrates of both hot and cold water, as shown in Figure 9. In a test of the 20 TE water block, it was found that increased flowrates will also improve power generation. From the tests, hot water flow was controlled from 2.5-5.0 L/min since these flowrates reflect seasonal variability at Raksa Warin hot springs. It was found from the tests that both the voltage and power varied in the same way. The voltage was 1.8-2.0 V, as shown in Figure 7, with a current 160-170 mA, shown in Figure 8. This yields a power of about 0.3-0.4 W, as depicted in Figure 9.

The efficiency of this power generation set can be found in Equation 3, where the heat entering the heat exchanger has a temperature of $T_{H,in}$ 65 $^{\circ}$C and when the temperature is in a steady state. The hot water outlet temperature is $T_{H,out}$ 55 $^{\circ}$C, while the maximum flowrate is the same at 5 liters/minute or equal to 0.834 kg/s. The efficiency of the system is calculated from

$$\eta = \frac{P_{out}}{\dot{m}_H \, c_p (T_{H,in} - T_{H,out})}$$

It was found the efficiency of the system is 28%. The geothermal electric power generation system created by the researchers is similar to the work of Changwei *et al*,. 2014 [55]. However, that is not similar because this heat exchanger is not stackable. We want to design to be able to easily modify and maintain the heat exchanger because we consider that calcium carbonate that comes with hot spring water will cause deposits inside the heat exchanger. Although the capacity to produce electricity per area of this research is low, less than 10 kW/m^3 compared to Panasonic's research, (2011) [40]; and 200 kW/m^3 in Kewin *et al*,. (2021) [41]; this may be Because the main factor is that the temperature difference of this research is less than that of research [40]; and the hot water pressure at the hot water inlet pipe in this research has less hot water inlet pressure than that of research [41]; However, the electricity production of the water block set (Heat exchanger) is characterized by high flowrates on both the hot and cold water sides. This improves electricity production according to Seebeck's theory, similar to previous research [45,46] which found that if the temperature difference between the hot and cold sides is larger, the result in electricity production will be higher [48,49,50], [52,59,60].

4.0 CONCLUSION

The water flowrates and the temperature difference between hot- and cold water affect electricity production. This research's energy source is a natural hot spring with low temperatures and flowrates. There are many hot springs of this type in Thailand, and almost all are not used for energy. The development of equipment to convert heat energy to electricity from this hot spring source has obstacles. However, it can help in remote areas with such energy sources to have locally produced energy. The determination of power generation in this research considers the temperature difference mainly caused by low flowrates. Other TE properties were used according to the factory specifications. From Eq. 5, a large ΔT result is high Q_H and high electrical power production.

Acknowledgement

The research was supported by the College of Industrial Technology of King Mongkut's University of Technology North Bangkok, Funding Code Res-CIT0285/2021. We also thank the Center of Welding Engineering and Metallurgical Inspection (Science and Technology Research Institute) and students for helping measure the flowrates of cold and hot water.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

References

[1] Traveldudes. 2023. Top 5 Hot Springs in Vietnam. [Online]. Available: https://www.traveldudes.com/best-hot-springs-in-Vietnam [Accessed: November 2023]

[2] I Tour Vietnam. 2024. Top 5 Hot Springs in Vietnam Worth a Visit. [Online]. Available: https://www.itourvn.com/blog/top-hot-springs-in-Vietnam/ [Accessed: November 2023]

[3] Rebecca, H. 2023. Hot Springs in Laos. [Online]. Available: https://www.hotsprings.co/laos-hot-springs/ [Accessed: November 2023]

[4] Green Era Travel. 2017. TeTeukPus Hot Spring Kampong Speu. [Online]. Available: https://www.greeneratravel.com/Te-Teuk-Pus-Hot-spring-kampong-speu.html [Accessed: November 2023]

[5] Ramu, N. 2016. Lashio Hot Springs. [Online]. Available: https://www.tripadvisor.com/Attraction_Review-g739113-d5993511-Reviews-Lashio_Hot_Springs-Lashio_Shan_State.html [Accessed: November 2023]

[6] MyLocalPassion 2022. Natural Hot Springs in Tanintharyi. [Online]. Available: https://www.mylocalpassion.com/posts/natural-hot-springs-in-tanintharyi [Accessed: November 2023]

[7] Aung. 2023 Pinlong Hot Spring. [Online]. Available: https://mm.asiafirms.com/shan-state/pinlong-hot-spring-646354.html [Accessed: November 2023]

[8] Besut District Council. 2023. La Hot Spring. [Online]. Available: https://mdb.terengganu.gov.my/index.php/en/visitors/places-of-interest/la-hot-spring [Accessed: November 2023]

[9] Sglalanghotspringventures, 2023. Sg Lalang Hotspring. [Online]. Available: https://www.facebook.com/Sg-Lalang-Hotspring-Sememyih-100069896830388/ [Accessed: November 2023]

[10] Selangor.travel. 2023. Selayang Hot Spring. [Online]. Available: https://selangor.travel/listing/selayang-hot-spring/ [Accessed: November 2023]

[11] Wikipedia.2016. Sembawang Hot Spring Park. [Online]. Available: https://en.wikipedia.org/wiki/Sembawang_Hot_Spring_Park [Accessed: November 2023]

[12] Erik, 2018. M. Baslay Hot Spring. [Online]. Available: https://www.tripadvisor.com/Attraction_Review-g659926-d13170174-Reviews-Baslay_Hot_Spring-Dauin_Negros_Oriental_Negros_Island_Visayas.html [Accessed: November 2023]

[13] Ella, L. 2017. 16 Best Philippines Natural Hot Spring Resorts for a Relaxing Vacation. [Online]. Available: https://guidetothephilippines.ph/articles/adventure-and-outdoors/best-philippines-hot-spring-resorts [Accessed: November 2023]

[14] Corky, N.2017. Mambukal Hot Spring Resort. [Online]. Available: https://www.tripadvisor.com/Hotel_Review-g298464-d1028092-Reviews-or20-Mambukal_Hot_Spring_Resort-Bacolod_Negros_Occidental_Negros_Island_Visayas.html [Accessed: November 2023]

[15] Travelingyuk. 2017. 12 Best Indonesia Natural Hot Springs. [Online]. Available: https://authentic-indonesia.com/blog/12-best-indonesia-natural-hot-springs/ [Accessed: November 2023]

[16] Indonesia-tourism, 2017. [Online]. Available: https://www.laketoba.com/pangururan-thermal-bath/ [Accessed: November 2023]

[17] Leah. 2017. G. Angseri Hot Spring. [Online]. Available: https://www.tripadvisor.com/Attraction_Review-g608496-d3356825-Reviews-or10-Angseri_Hot_Spring-Tabanan_Bali.html [Accessed: November 2023]

[18] Max, C. 2017. Marobo Hot Springs. [Online]. Available:https://www.atlasobscura.com/places/marobo-hot-springs [Accessed: November 2023]

[19] Lau, H. C. 2023. Decarbonization of ASEAN's power sector: A holistic approach. *Energy Reports*. 9: 676–702. DOI: https://doi.org/10.1016/j.egyr.2022.11.209

[20] [Leynes, R. D., Pioquinto, W. P. C., and Caranto, J. A. 2005. Landslide hazard assessment and mitigation measures in Philippine geothermal fields. *Geothermics.* 34(2): 205–217. DOI: https://doi.org/10.1016/j.geothermics.2004.08.002

[21] Chaiyat, N., Chaychana, C., and Singharajwarapan, F. S. 2017. Geothermal Energy Potentials and Technologies in Thailand. *Journal of Fundamentals of Renewable Energy and Applications.* 04(02): 1000139. DOI: https://doi.org/10.4172/2090-4541.1000139

[22] Ramingwong, T., Suthep L., Pongpor A., and Surachai P. 2000. Update on Thailand geothermal energy research and development. P*roceedings World Geothermal Congress 2000. Kyushu* – Tohoku. Japan. 28 May – 10 June. 377-386.

[23] Lund, W. J. and Andrew, C. 2007. Examples of combined heat and power plants using geothermal energy. *Proceedings European Geothermal Congress 2007.* Unterhaching. Germany. 30 May-1 June. 1-8.

[24] Bayu, R., Mochammad, S. B., Widjonarko, Cries A., Dianta, M. K., Miftah, H. 2023. A Genetic Algorithm approach for optimization of geothermal power plant production: Case studies of direct steam cycle in Kamojang. *South African Journal of Chemical Engineering.* 45: 1-9.

[25] Rudiyanto, B., Bahthiyar, M. A., Pambudi, N. A., Widjonarko, and Hijriawan, M. 2021. An update of second law analysis and optimization of a single-flash geothermal power plant in Dieng, Indonesia. *Geothermics.* 96: 102212. DOI: https://doi.org/10.1016/j.geothermics.2021.102212

[26] Vaccari, M., Pannocchia, G., Tognotti, L., and Paci, M. 2023. Rigorous simulation of geothermal power plants to evaluate environmental performance of alternative configurations. *Renewable Energy.* 207: 471–483. DOI: https://doi.org/10.1016/j.renene.2023.03.038

[27] Nuwayhid, R. Y., Shihadeh, A., and Ghaddar, N. 2005. Development and testing of a domestic woodstove thermoelectric generator with natural convection cooling. E*nergy Conversion and Management.* 46(9–10): 1631–1643. DOI: https://doi.org/10.1016/j.enconman.2004.07.006

[28] Zhao, Y., Li, W., Zhao, X., Wang, Y., Luo, D., Li, Y., and Ge, M. 2023. Energy and exergy analysis of a thermoelectric generator system for automotive exhaust waste heat recovery. *Applied Thermal Engineering*. 122180. DOI: https://doi.org/10.1016/j.applthermaleng.2023.122180

[29] Feng, M., Lv, S., Deng, J., Guo, Y., Wu, Y., Shi, G., and Zhang, M. 2023. An overview of environmental energy harvesting by thermoelectric generators. R*enewable and Sustainable Energy Reviews.* 187: 113723. DOI: https://doi.org/10.1016/j.rser.2023.113723

[30] Lan, S., Li, Q., Guo, X., Wang, S., and Chen, R. 2023. Fuel saving potential analysis of bifunctional vehicular waste heat recovery system using thermoelectric generator and organic Rankine cycle. *Energy.* 263. 125717. DOI: https://doi.org/10.1016/j.energy.2022.125717

[31] Gürbüz, H., and Akçay, H. 2023. Development of an integrated waste heat recovery system consisting of a thermoelectric generator and thermal energy storage for a propane fueled SI engine. Energy. 282: 128865. DOI: https://doi.org/10.1016/j.energy.2023.128865

[32] Raut, P., and Vohra, M. 2022. Experimental investigation and comparative analysis of selected thermoelectric generators operating with automotive waste heat recovery module. *Materials Today: Proceedings*. 50: 994–998. DOI: https://doi.org/10.1016/j.matpr.2021.07.227

[33] Maneewan, S., and Chindaruksa, S. 2009. Thermoelectric Power Generation System Using Waste Heat from Biomass Drying. *Journal of Electronic Materials*. 38(7): 974–980. DOI: https://doi.org/10.1007/s11664-009-0820-5

[34] Niu, X., Yu, J., and Wang, S. 2009. Experimental study on low-temperature waste heat thermoelectric generator. 188(2): 621–626. DOI: https://doi.org/10.1016/j.jpowsour.2008.12.067

[35] He, J., Li, K., Jia, L., Zhu, Y., Zhang, H., and Linghu, J. 2024. Advances in the applications of thermoelectric generators. *Applied Thermal Engineering.* 236: 121813. DOI: https://doi.org/10.1016/j.applthermaleng.2023.121813

[36] Xu, Y., Xue, Y., Cai, W., Qi, H., and Li, Q. 2023. Experimental study on performances of flat-plate pulsating heat pipes without and with thermoelectric generators for low-grade waste heat recovery. *Applied Thermal Engineering*. 225: 120156. DOI: https://doi.org/10.1016/j.applthermaleng.2023.120156

[37] Miao, Z., Meng, X., and Liu, L. 2023. Improving the ability of thermoelectric generators to absorb industrial waste heat through three-dimensional structure optimization. *Applied Thermal Engineering*. 228: 120480. DOI: https://doi.org/10.1016/j.applthermaleng.2023.120480

[38] Olabi, A. G., Al-Murisi, M., Maghrabie, H. M., Yousef, B. A., Sayed, E. T., Alami, A. H., and Abdelkareem, M. A. 2022. Potential applications of thermoelectric generators (TEGs) in various waste heat recovery systems. *International Journal of Thermofluids. 1*6: 100249. DOI: https://doi.org/10.1016/j.ijft.2022.100249

[39] Özcan, Y., and Deniz, E. 2023. Solar thermal waste heat energy recovery in solar distillation systems by using thermoelectric generators. *Engineering Science and Technology, an International Journal*. 40: 101362. DOI: https://doi.org/10.1016/j.jestch.2023.101362

[40] Panasonic Develops Thermoelectric tubes for Compact Geothermal Electricity Generation and Waste Heat. 2011. [Online]. Available: https://news.panasonic.com/global/press/data/en110630-4/en110630-4.pdf [Accessed: November 2023]

[41] Li, K., Garrison, G., Zhu, Y., Moore, M., Liu, C., Hepper, J., Bandt, L., Horne, R., and Petty, S. 2021. Thermoelectric power generator: Field test at Bottle Rock geothermal power plant. *Journal of Power Sources.* 485: 229266. DOI: https://doi.org/10.1016/j.jpowsour.2020.229266

[42] Nozariasbmarz, A., Collins, H., Dsouza, K., Polash, M. H., Hosseini, M., Hyland, M., Liu, J., Malhotra, A., Ortiz, F. M., Mohaddes, F., Ramesh, V. P., Sargolzaeiaval, Y., Snouwaert, N., Özturk, M. C., and Vashaee, D. 2020. Review of wearable thermoelectric energy harvesting: From body temperature to electronic systems. *Applied Energy.* 258: 114069. DOI: https://doi.org/10.1016/j.apenergy.2019.114069

[43] Wang, Z., Leonov, V., Fiorini, P., and Van Hoof, C. 2009. Realization of a wearable miniaturized thermoelectric generator for human body applications. *Sensors and Actuators A: Physical.* 156(1): 95–102. DOI: https://doi.org/10.1016/j.sna.2009.02.028

[44] Suter, C., Jovanovic, Z. R., and Steinfeld, A. 2012. A 1kWe thermoelectric stack for geothermal power generation – Modeling and geometrical optimization. *Applied Energy.* 99: 379–385. DOI: https://doi.org/10.1016/j.apenergy.2012.05.033

[45] Kewen, L., Changwei, L., and Pingyun, C. 2013. Direct power generation from heat Without mechanical work. *38th Workshop on Geothermal Reservoir Engineering Proceedings. California. 11-13 February. 1-6.*

[46] Changwei L., Pingyun C., and Kewen L. 2014. A 1 KW Thermoelectric Generator for Low-temperature Geothermal Resources. *39th Workshop on Geothermal Reservoir Engineering Proceedings. Californi*a. 24-26 February. 1-12.

[47] Gu, C., Dong, C., Zhang, B., Du, H., Ye, C., Bu, Z., Gu, H., Ye, Y., Zhong, Y., and Du, Y. 2023. Experimental research on thermoelectric characteristics of a thermoelectric generator with external influencing factors optimization. *Case Studies in Thermal Engineerin*g. 103863. DOI: https://doi.org/10.1016/j.csite.2023.103863

[48] Rogl, G., Grytsiv, A., Yubuta, K., Puchegger, S., Bauer, E., Raju, C., Mallik, R. C., and Rogl, P. 2015. In-doped multifilled n-type skutterudites with ZT= 1.8. *Acta Materialia*. 95: 201–211. DOI: https://doi.org/10.1016/j.actamat.2015.05.024

[49] Mona, Y., Do, T. A., Sekine, C., Suttakul, P., and Chaichana, C. 2022. Geothermal electricity generator using thermoelectric module for IoT monitoring. *Energy Reports.* 8: 347–352. DOI: https://doi.org/10.1016/j.egyr.2022.02.114

[50] Ge, M., Li, Z., Zhao, Y., Xuan, Z., Li, Y., and Zhao, Y. 2022. Experimental study of thermoelectric generator with different numbers of modules for waste heat recovery. *Applied Energy.* 322: 119523. DOI: https://doi.org/10.1016/j.apenergy.2022.119523

[51] Catalan L., Aranguren P., Araiz M., Perez G., and Astrain D. 2019. New opportunities for electricity generation in shallow hot dry rock fields: A study of thermoelectric generators with different heat exchangers. *Energy Conversion and Management.* 200: 112061. DOI: https://doi.org/10.1016/j.enconman.2019.112061

[52] Catalan L., Aranguren P., Araiz M., Perez G., and Astrain D. 2020. Computational study of geothermal thermoelectric generators with phase change heat exchangers. *Energy Conversion and Management.* 221: 113120. DOI: https://doi.org/10.1016/j.enconman.2020.113120

[53] Yang W., Xie H., Sun L., Ju Ch., Li B., Li C., Zhang H., and Liu H. 2021. An experimental investigation on the performance of TEGs with a compact

[54] heat exchanger design towards low-grade thermal energy recovery. *Applied Thermal Engineering.* 194: 117119. DOI: https://doi.org/10.1016/j.applthermaleng.2021.117119

[55] Xie, H., Gao, T., Long, X., Sun, L., Wang, J., Xia, E., Li, S., Li, B., Li, C., Gao, M., and Mo, Z. 2023. Design and performance of a modular 1 kilowatt-level thermoelectric generator for geothermal application at medium-low temperature. Energy Conversion and Management. 298: 117782. DOI: https://doi.org/10.1016/j.enconman.2023.117782

[56] Liu Ch., Chen P., and Li K. 2014. A 1 KW Thermoelectric Generator for Low-temperature Geothermal Resources. *Proceedings, Thirty-Ninth Workshop On Geothermal Res*ervoir Engineering. Stanford University, Stanford, California, February 24-26. [Online]. Available: https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2014/Li.pdf. [Accessed: June 2024]

[57] Liu Ch., Chen P., and Li K. 2014. A 500 W low-temperature thermoelectric generator: Design and experimental study. International Journal of hydrogen energy. XXX: 1-9. DOI: http://dx.doi.org/10.1016/j.ijhydene.2014.07.163

[58] Li K., Garrison G., Moore M., Zhu Y., Liu Ch., Horne R., and Petty S. 2020. An expandable thermoelectric power generator and experimental studies on power output. *International Journal of Heat and Mass Transfer*. 160: 120205. DOI: https://doi.org/10.1016/j.ijheatmasstransfer.2020.120205

[59] DarkInSeiOnG. 2017. The Raksavarin National Park (Hot Spring). [Online]. Available: https://commons.wikimedia.org/wiki/File:Geyser_Hot_springs_Landmark_At_Raksawarin_Public_Park_in_Ranong,_Southern_Thailand_,_Hot_spring_for_relaxation_01.jpg [Accessed: November 2023]

[60] Mirmanto, M., Syahrul, S., and Wirdan, Y. 2019. Experimental performances of a thermoelectric cooler box with thermoelectric position variations. *Engineering Science and Technology, an International Journal*. 22(1): 177–184. DOI: https://doi.org/10.1016/j.jestch.2018.09.006

[61] Tian, M.-W., Aldawi, F., Anqi, A. E., Moria, H., Dizaji, H. S., and Wae-hayee, M. 2021. Cost-effective and performance analysis of thermoelectricity as a building cooling system; experimental case study based on a single TEC-12706 commercial module. *Case Studies in Thermal Engineering.* 27: 101366. DOI: https://doi.org/10.1016/j.csite.2021.101366

[62] Gao, H. B., Zong, S. C., Zhang, C. W., Li, H. J., and Huang, G. H. 2021. Experimental investigation of the performance of a thermoelectric generator at various operating conditions. *IOP Conference Series: Earth and Environmental Science.* 702(1): 012001. DOI: https://doi.org/10.1088/1755-1315/702/1/012001

[63] Min, G. 2013. Thermoelectric Module Design Under a Given Thermal Input: Theory and Example. J*ournal of Electronic Materials.* 42(7): 2239–2242. DOI: https://doi.org/10.1007/s11664-013-2591-2