A novel merging solar parabolic collector with thermoelectric generator using geothermal energy

A E Atta\textsuperscript{1}, Nabila Shehata\textsuperscript{2*}, Hamdy F M Mohamed\textsuperscript{1,3} and Mohamed R. O. Ali\textsuperscript{4}

\textsuperscript{1}Renewable Energy Science & Engineering Department, Faculty of Postgraduate Studies for Advanced Science (PSAS), Beni-Suef University, P.O. Box 62511 Beni-Suef, Egypt
\textsuperscript{2}Environmental Science and Industrial Development Department, Faculty of Postgraduate Studies for Advanced Science (PSAS), Beni-Suef University, P.O. Box 62511 Beni-Suef, Egypt. E-mail: nabila.shehata@psas.bsu.edu.eg
\textsuperscript{3}Physics Department, Faculty of Science, Minia University, P.O. Box 61519 Minia, Egypt
\textsuperscript{4}Mechanical Power Engineering & Energy Department, Faculty of Engineering, Minia University, Minia, Egypt

*E-mail: Nabila.shehata@psas.bsu.edu.eg

Abstract. Geothermal energy is probably the biggest wellspring of sustainable power sources. Compared with sunlight and wind power the geothermal power has numerous focal points, including being impenetrable to climate changes, having a steady base burden, and high heat productivity (for the high-temperature geothermal assets). In any case, the total capacity of installed geothermal energy plants falls behind sun based and wind. In this work, the geothermal power has been converged with solar energy. A test model concentrator thermoelectric generator utilizing an explanatory dish concentrator was created and tried. A sunlight-based gatherer has been utilized as the hotspot for the hot side of the thermoelectric module and the geothermal power has been applied as the cold wellspring for the cold side for the thermoelectric module. An electric flow as per the Seebeck hypothesis has been produced, as another wellspring of the sustainable power source. The capability of utilizing concentrated sunlight-based power age framework dependent on the thermoelectric module and geothermal power has been examined. The maximum voltage 11.7 V was obtained in the present work, when the maximum temperature for the hot side 93 °C and cold side 21°C.

1. Introduction
The recent energy crisis, the decay of petroleum derivatives the resulting environmental burdens, have gotten progressively critical, with solid consideration being energized the utilization of sustainable energy sources, for example, sunlight based, hydroelectric, wind and geothermal vitality. The International Energy Outlook 2016 (IEO2016) recorded significant development in worldwide energy requests over the 28-year time frame from 2012 to 2040. Worldwide requirement for vitality increments from 549 quadrillion British warm units (Btu) in 2012 to 629 quadrillion Btu in 2020 up to 815 quadrillion Btu in 2040, with 48% development 2040 compared to 2012 [1].

Sustainable energy sources are developing exceptionally quick as a wellspring of vitality for power age, with yearly expanding normal 2.9% from 2012 to 2040 [2]. So as to meet the future quickly developing power request and the natural issues of utilizing fossils fuels, enormous endeavors must be
done in the improvement for sustainability of power supplies including wind, hydropower, sun-oriented and geothermal sources. These inexhaustible sources are foreseen to be the fastest creating to produce electric power. Their contribution to the worldwide mix is estimated to grow from 19% in 2008 to 23% in 2035. Over 82% of increment in hydroelectric and wind power in a similar timeframe. In perspective on the increasingly more stringent need to substitute fossil and nuclear fuels, it is especially critical to advance additionally sustainable power sources like solar, geothermal, thermoelectric module and wind energy [3].

Geothermal energy is probably the biggest wellspring of sustainable power source as per the World Energy Assessment [4]. Compared with solar and wind systems geothermal power has numerous points of interest, including being not to rely upon the climate, having a stable baseload, and high heat productivity if the geothermal asset has high-temperature. However, the maximum limit of installed geothermal power comes behind solar power and wind. In 2011, the introduced intensity of photovoltaic (PV) and wind were 70 and 240 GW, respectively. According to the Geothermal Energy Association (GEA), the all-out geothermal power introduced on the planet was about 11.2 GW as of May 2012. The normal yearly development pace of geothermal power is about 2%, while that of PV is about 58% during a similar time of 2006-2011 [5].

The geothermal energy has been utilized in bygone eras for washing, bathing, and for space heating. These days, it is generally utilized industrially for both creating power and direct uses. Worldwide, geothermal power plants generated about 10 GW of electricity in 2007, and in practice supply 0.3% of global electricity need. An extra 28 GW of direct geothermal power limit is utilized, hot spas, space warming, industrial processes, agricultural, and desalination applications [6]. The innovation utilized for producing power by utilizing the direct use of geothermal energy called the Organic Rankine Cycle (ORC). A remarkable example is the 250 kW ORC plant in Chena Hot Springs, Alaska, which produces electricity from very low temperature (74 °C) geothermal resource [7].

Sunlight based collector is one of the heat exchangers types that change sun-based radiation energy to inside heat control by using a medium. The most noteworthy portion of solar system is the sun-based collector. It is the part which absorbs incoming solar beam, converts it into heat, and moves this heat to a medium (usually water, air, or oil) flowing through the collector. The solar collectors are normally sorted into two classes as per focus proportions; non-focusing - and focusing - collectors [8]. Concentrating solar power (CSP) is a power age innovation that utilizes mirrors, lenses or focal points to focus the sun's beams and, in the vast majority of the present concentrating solar power systems, which it heats a liquid and produces steam. The steam drives a turbine and creates control similarly to ordinary power plants. Various thoughts are being examined and not all future CSP plants will in a general sense use a steam cycle [9]. A non-concentrating solar collector has the equivalent catching territory as its retaining zone while concentrated solar collector depends on the sun's tracking. It usually has inward reflecting surfaces to capture and center the sun-oriented light to a lot littler getting zone, resulting in an increased heat flux with the goal that the thermodynamic cycle can accomplish higher effectiveness when working under higher temperatures [8].

Most current thermal power generation technologies rely on the conversion of thermal energy into mechanical work before electricity is produced. A thermoelectric power module has no moving parts and is conservative, quiet, trustworthy, and clean. Thermoelectric generators (TEGs) productivity can be improved by expanding the temperature gap between cold and hot sides. The thermoelectric power cycle, with charge transporters (electrons) go about as the working medium, follows the fundamental laws of thermodynamics and firmly like the power cycle of a traditional heat engine [10]. Thermoelectric generators (TEGs) are semiconductor gadgets [11]. The benefits of TEGs are various like direct power transformation, not at all like many heat motors that first convert heat power into mechanical power and afterward convert this mechanical power into power utilizing an alternator. There is neither moving parts nor working liquids inside the TEG, consequently no maintenance and no additional costs. The TEG has a long-life expectancy, particularly when working with consistent heat sources. The TEG can be utilized for small scale age in exceptionally restricted spaces or to deliver kilowatts (no scale impact). Close to quiet activities, it appreciates any working position [12].
The low development pace of geothermal power was researched for the principle factors include high initial investment, high exploration risk, long payback, and construction time, trouble to evaluate asset, and trouble to modularize [13]. The main advantage of utilizing geothermal energy for direct use in the low temperature extends to moderate is more common and exist at economic drilling depths [14]. Also, portions of a geothermal could be utilized for instance as an underground heat power stockpiling system [15]. Despite TEGs efficiency is about 5–10%, taking into consideration the reuse of waste energy gain, their efficiency cannot be ignored [16].

2. State of art
Since Seebeck’s discovery, various materials have been considered worthy of generating thermoelectricity. The first TEGs were built on electrical conductors and semiconductors, such as iron, bismuth, lead, antimony, zinc, copper and different alloys. Later, in the 20th century, numerous other thermoelectric materials (TMs) were created: composites, ceramics, etc. Though, the updated semiconductors still the basic TMs for the production of thermoelectric effects [17]. The effectiveness of a thermoelectric module relying on the temperature gaping between both gadget sides [18]. In present-day TEGs, at least two kinds of materials are typically utilized in one leg, to increase the proficiency of the TEG [19]. In solar thermoelectric generator (STEG), the hot side for TEG is the sun absorbs and the cold side is the warmth sink. The devices that utilized in sun-powered thermoelectric power age comprise of two sections. The first is the collector, which ingests sunlight-based radiation as thermal power. The second is a thermoelectric generator that utilizes the consumed thermal power to create flow current [20]. Geothermal resources are classified dependent on their lake temperatures alone [21]. The classic classification of the geothermal energy store temperature is low-enthalpy resource matches repository temperature under 150 °C and high-enthalpy resources are available if the temperature outperforms 150 °C [22].

Thermoelectric power generators have been considered as a good alternative clean technology because of their special advantages. Thermoelectric power gives a decent application in the immediate change of waste heat energy into electric power where it isn't essential to take the heat energy input cost into consider. The use of this innovation in changing over waste heat energy legitimately into electric power can likewise expand the general efficiencies of power transformation systems [10]. A small power generation system comprised of a sunlight-based concentrator (parabolic dish) and thermoelectric module. The sun-powered heat is gathered by the parabolic dish and concentrated on one side of the thermoelectric module to become (hot side). While the opposite side's temperature is kept lower as (cool side). The temperature gap is created between the hot side and the cool side produces electrical energy by the thermoelectric generator. This power will be put away into the battery. In this system, the most extreme temperature contrast came to around 202 °C and the maximum open voltage was about 3.8 V [23]. The productivity of a small power generation system comprising of thermoelectric module and sun oriented parabolic dish gatherer together to create the power was improved utilizing. The TEG performance was enhanced by the perfectly insulated heat sink and acrylic cover that encloses the receiver plate. There is a 2.11% expansion in all-out effectiveness for TEG with spread. The greatest voltage of the thermoelectric module was 4 V, which is 10.75% more than TEG without cover for the same sunlight radiation [24].

A small scale solar parabolic dish thermoelectric generator was investigated. Solar parabolic dish collector is made of satellite dish antenna fitted with a polished aluminum sheet as concentrator surface. It is made of satellite dish reception apparatus fitted with a cleaned aluminum sheet as concentrator surface. The thermoelectric generator is put on the focal plane with manual tracking for the parabolic dish. The concentrated sunlight-based radiation and the water that cooled heat sink was the driving potential to produce power. The operating factors such as receiver plate temperature, power output, and conversion efficiency are studied with respect to solar radiation. They inferred that beneficiary plate temperature, power output, and change proficiency are shifting legitimately with the sun-powered radiation [25]. A power generator manufactured which was provided by the thermostatic water circulator, imitation the geothermal. The cooling cycle was made out of a water pump and water holder.
Thermal couples for temperature measurements were installed at the input and output pipes. The values of voltage, current, and power were measured by electrical multimeter. The TEG system could produce more than 1 KW at a temperatures gap of around 120 °C. The prompt effectiveness of the TEG system arrived at 4.5% at an input temperature of around 95 °C on the hot side and a temperature of 30 °C on the cold side. This proficiency increment exponentially increases the input temperature [26]. Afterward, this module was improved by investigating the TEG temperature and mechanical structure. The output power was improved by 34.6% and the efficiency raised from 4.5 to 6.5% [27].

Fan et al. [28] created a model of concentrator TEG utilizing sun parabolic dish 180 cm diameter. The massed system as the CTEG was able to produce electric of up to 5.9 W when the temperature distinction was 35 °C. A high open voltage was acquired from the thermoelectric generator utilizing sunlight power (57 V DC) when the temperature gapping was 67 °C. The system comprised of 8 emptied tube sun-oriented gatherers (4-series and 2 parallel) and 24 TEG associated arrangement. The absolute yield voltage is a total of TEG singular voltage [29]. Electric power was created from sunlight-based lake utilizing a blend of thermoelectric modules and thermosyphon. The short current and the open-circuit voltage esteem were 0.4 A and 26 V, respectively when the temperature gapping of 75 °C was kept up maintained across 16 (3D) thermoelectric cells. The TEG comprised of 3 layers (2 cool sides and one hot side). This type of TEG was more effective [30].

A small power generation system has been built manufactured utilizing joined the system, thermoelectric modules, and thermosyphon for producing power from low heat sources like a solar lake. The temperature gapping between the upper convective zone and the lower convective zone of sun-oriented lake is 20 °C produces 4.6 V and 0.12 A [31]. Various methods for utilizing thermoelectric power systems were checked on. The most effective path for improving thermoelectric power system execution is to use it with hybrid systems. The thermoelectric module can be utilized with, parabolic collectors and flat plate collectors or evacuated tube collectors to generate heat and electricity. Such a hybrid system increases the overall performance and efficiency of the thermoelectric power generation system which can be economic device [32]. The aim of this study is to develop and test a hybrid system based on geothermal energy for the purpose of increasing its efficiency. Three different models will be used by changing the hot and cool sides to improve the effectiveness of each side.

Electricity from solar energy was produced using a thermoelectric generator (TEG) system. Two-phase closed thermosiphon type (TPCT) was powered by the solar system. Heat a pipe is used to heat the hot surface of the TEG, and a 1200 cc capacity passive water-cooled system was implemented to cool the cold side using five TEGs. The system was operated by solar power under three different conditions: non-reflector, semi-reflector and full-reflector. Electrical and thermal data was recorded in a computer from 08:00 to 15:00. The highest difference in temperature between the hot- and cold-side was 88.9 °C. The highest open circuit voltage values in total were 4.38V, 7.53V and 8.20V [33]. Mismatch of thermoelectric materials is considered a reason for the low efficiency of conversion. Subsequently, choosing the material and optimizing the models is a significant step before implementation of large scale production. Comsol-Multiphysics (5.3) software was applied for this purpose. The results showed that the maximum simulated conversion efficiency was 9.2% at temperature gradient 500 K [34].

An analysis of a point-of-use thermoelectric generator was presented. The design, implementation and performance of the generator for powering electronic monitoring devices and charging batteries was discussed. using six Laird thermoelectric modules (Laird PB23 Series, HT8, 12). It was revealed that placing a hot side for TEG on a 160°C steam pipe with a 30°C ambient environment for a cold side for TEG (A T of 130°C), TEG produced 31.2 volts (V) open circuit and 0.89 amperes (A) short circuit [35]. Optimization model has been developed to simulate TEG based power generation system. TEG module has been chosen from the commercially available modules with efficiency of 1.91% for the targeted low-grade waste heat temperature of Th=90 °C and Tc=14 °C. Predicted maximum net power was 99 W from 50 TEG modules [36].

Zhang et al [37] found the peak output voltage and power values of the device in single-output mode range from 183.1 to 370.7 mV and 33.5 to 137.2 mW, respectively.
In this work, we aim to test a combination between a thermoelectric module with geothermal energy (low Temperature) as a cold side (GTEM), and connected it to a solar collector (parabolic dish) as a hot side (STEM). And to optimize this system.

3. Experimental set up

The geothermal system pilot-scale consists of the following components: The solar parabolic dish collector: A concentrate solar thermal energy on a focal line made of copper pipe filled with hot fluid (Therminol oil PV-1 or water) and connected with the hot side insulated storage tank as shown in figure 1(a). Two major internal tanks as shown in figure 1(b), the first tank contains the hot source and the other one contains the cooled water and geothermal system. Thermoelectric modules consist of 12 TEG, (Bi2Te3) connected in series and located in the middle of the two separated insulated tanks TEGs connected with AVO-Meter to measure the output open voltage as shown in figure 1(c).

A geothermal system, using the ground as a source heat exchanger designed to cool the cooling medium (water) circulated in 2 parallel pipes made of PVC, buried in 1 m depth under sand soil and connected to the cold insulated tank as shown in figure 2. Ten calibrated Thermo-Couples are used to measure temperatures in the main points along the experiment starting with inputs of hot fluid that passing through the copper pipe in solar parabolic dish ending with cooling water passing through the soil temperatures. The temperature of these thermo-couples was measured by a digital data logger. Both solar radiation intensity and wind speed were also measured by (Digital LCD Wind Speed Meter Pyranomete). The experimental part of this work was carried in the Heat Engines Laboratory of Mechanical Power Engineering and Energy of premises of the Faculty of Engineering, Minia University, Egypt.

Figure 1. The main movable components of the system; (a) parabolic trough, (b) tanks assembly, and (c) TEG fixed on the bottom of the tank.

Figure 2. Photos of the geothermal system pilot scale.
The merged SPD/TEG/GHP system is built, flushed and cleaned as shown in figure 3. The ambient temperature is measured by a calibrated digital thermometer. The terminal oil is pumped into SPD for heating. The solar oil streams into the protected cylinder in the solar parabolic dish to fall into a tank to represent to the hot side of the TEG. On the other side, the tap is opened to the flow of water into the geothermal system to be cooled and then the water enters the insulated tube into the reservoir which represents the cold side for TEG. The measurement was recorded for a sunshine period 6 h from 9 a.m. till 3 p.m. Ten calibrated thermocouples are used to measure temperatures in the main points (input oil for SPD, output oil from SPD, Tank for hot side, Tank for cold side, input water for geothermal system, soil temperature for geothermal system and output water). These measurements are done by data Logger GL 240 every 30 min.

Figure 3. Diagrammatic sketch for the test rig.

The experiments were done in three models to gauge the effectiveness of the system in each model. In the model (1), water is used in the solar collector to be used as a hot Side for TEG. In the model (2), water is replaced with solar oil to measure its impact on the efficiency of the system. In the model (3), the soil is dampened instead of dried to improve the effectiveness of the cooling system on the cold side for TEG in the geothermal system.

4. Results and Discussion
Figure 4 shows the solar beam radiation intensity as a function of the time during the days in the model (1). It is clear that the solar intensity increases with time up to 12 o'clock and then it decreases with time. The maximum solar intensity is at 12 o'clock because the sun is perpendicular to the earth around this time. The temperature of both hot and cold sides as a function of the time in the model (1) using the water for three different runs at 15, 17 and 20 August is shown in figure 5. The behaviors of the three runs are almost the same indicating that there are no many differences during one week in August. It is clear that the cold side temperature did not change with the time indicating the temperature stability in the geothermal system. On the other hand, the hot side temperature of the TEG increases over time until it reaches its maximum value at 12 o'clock and then it decreases. This conduct is nearly equivalent to the power of solar radiation conduct (figure 4) which states that high sun-based radiation power prompts increment the temperature of the hot side.
Using solar collector to heat the water which used for the hot side and the geothermal system was used as the cold side for TEG. The open voltage as a function of time for these three days is shown in figure 6. It is clear from the figure that, the open voltage increases by increasing the time until it reaches its maximum value at 12 o'clock and then it decreases. This increases on the open voltage connected to increase the temperature difference between the hot and cold side $[\Delta T = T_{hot} - T_{cold}]$ of the TEG at 12 o'clock. The maximum open voltage is about 5.9 V when the solar radiation intensity is maximum at noon where $\Delta T$ is 35 °C and the solar radiation is 1062 W/m².

The solar beam radiation intensity as a function of the time during the days in the model (2) is shown in figure 7. It is clear that the solar intensity increases with time up to 11:30 am and then it decreases with time. The maximum solar intensity is at 11:30 am because the sun is perpendicular to the earth around this time. Figure 8 shows the temperature of both hot and cold sides as a function of the time in the model (2) using the therminol vp–1 oil for three different runs at 23, 24 and 25 August. The behaviors of the three runs are almost the same indicating the stability of the system. Clearly that the temperature of the hot side of the TEM in the second model higher than that of the hot side in the first model. The maximum value of the temperature of the hot side in the second model 96 °C while in the first model
65 °C. On the other hand, the cold side temperature did not change with the time indicating the temperature stability in the geothermal system.

The open voltage readings as a function of time for three days (Three runs) is shown in figure 9. The open voltage increments by expanding the temperature gap between the hot and cold side \( \Delta T = T_{\text{hot}} - T_{\text{cold}} \) of the TEG. The maximum open voltage in model (2) is 10.2 V when the solar radiation intensity is maximum at noon where \( \Delta T \) is 59 °C and the solar radiation is 1051 W/m².

According to Özbas (2019), 8.2 volt was produced using 5TEG when the temperature difference on both sides of the TEG was 89 °C. In this work, 10.2 volt were obtained using 12 TEG when the temperature difference was 59 °C. we can conclude that our system is effective although it applies higher number of TEG where the difference in temperature between the two models is 30 °C [33].
earth around this time. Figure 11 shows the temperature of both hot and cold sides as a function of the time in the model (3) using the therminal vp–l oil for one run on 27 August. In this run, water was added to the soil to become moist soil. This was a major cause of hypothermia on the cold side of the TEG. On the other hand, the hot side temperatures didn’t change from the previous model. On other hand, figure 12 shows the open voltage as a function of time for the model (3). It was discovered that diminishing the cold side temperatures increment the gapping in temperature between the hot side and the cold side, which prompts increment of the open voltage outside from the TEG. In this case, the maximum open voltage value is 11.7 V when ΔT is 72 °C and the solar radiation is 1056 W/m².

Our results are lower than that achieved in other studies. This difference arises from the TEG number or efficiency. For example, 57 V (DC) was generated using 24 TEG at Δt = 67 °C [29] while in this work, we use only 12 TEG. Our results also less than Ref. [30]. due to the difference in efficiencies of the TEG.

Figure 12. Output voltage vs. time for model (3).

5. Conclusions
The most proficient route for improving the thermoelectric generator is to utilize it in hybrid systems. In this system, the thermoelectric module was combined with geothermal energy (low Temperature) as a cold side (GTEM), and connected to a solar collector (parabolic dish) as a hot side (STEM). In addition, any increase in the temperature difference will increase system efficiency. Nowadays, this innovation is presently being developed stage, and need improvement to build its effectiveness by the research of new thermoelectric semiconductor materials.

References
[1] Doman L E 2016 International Energy Outlook 2016 With Projections to 2040 (Washington: https://www.eia.gov/outlooks/ieo/)
[2] Doman L E 2013 International Energy Outlook 2013 with Projections to 2040 (Washington: https://www.eia.gov/outlooks/ieo/)
[3] Teske S, Crespo L and Richter C 2016 Solar Thermal Electricity: Global outlook 2016 (Netherlands: Otto Heldringstraat ) (Belgium : Rue de l’Industrie 10, B-1000 Brussels) (Spain: Apartado 39E-04200 Tabern ) P12
[4] Brown M M, Desai N and Doucet G 2000 *Energy and the Challenge of Sustainability*. **UNDP** (New York : NY 10017) P165

[5] Kalogirou S A 2004 *Prog. Energy Combust. Sci.* **30** 231

[6] Panzera F, Sicali S, Lombardo G, Imposa S, Gresta S and Amico S D 2016 *Environ. Earth. Sci.* **75** 1140

[7] Erkan K, Holdman G, Blackwell D, and Benoit W 2007 *Thirty-Second Workshop on Geothermal Reservoir Engineering* Stanford University, Stanford, California, January 22-24, 2007 SGP-TR-183.

[8] Tian Y, Zhao C Y 2013 *Appl. Energy* **104** 538

[9] Gielen D 2012 *Renewable Energy Technology Cost Analysis Series* (Germany: IRENA) 2

[10] Ismail B I, Ahmed W H 2009 *Recent Pat. Eng.* **2** 27

[11] Doms I, Merken P and Van Hoof C 2007 *IEEE* **44** 17530

[12] Champier D 2017 *Energy Convers. Manag.* **140** 167

[13] Kewen L, Changwei L and Pingyun C 2013 *Thirty-Eighth Workshop on Geothermal Reservoir Engineering* (Stanford, California)

[14] Lund W J, Boyd L T 2016 *Geothermics* **60** 66

[15] Andersson O 2007 *Aquifer Thermal Energy Storage (ATES)* (Paksoy: Springer ) 155

[16] Mamur H and Ahiska R 2014 *Int. J. Renew. Energy Environ. Eng.* **4** 128

[17] Polozine A, Sirotinskaya S, and Schaeffer L 2014 *JMR* **17** 1260

[18] Aydogan H, Ozelik E A, Acaroglu M and ISIK H 2014 *Appl. Mech. Mater.* **446** 858

[19] Karpe S 2016 *Int. J. Curr. Eng. Technol.* **4** 144

[20] Fan H, Singh and Akbarzadeh A 2011 *J. Electron. Mater.* **40** 1311

[21] Muffler P and Cataldi R 1978 *Geothermics* **7** 53

[22] Chandrasekharam D and Bundschuh J 2008 *Low-Enthalpy Geothermal Resources for Power Generation* (London : Taylor & Francis Group) 149

[23] Zhu N, Matsuura T, Suzuki R and Tsuchiya T 2014 *Energy Procedia* **52** 651

[24] Muthu G, Shanmugam S and Veerappan R A 2014 *Energy Procedia* **54** 2

[25] Eswaramoorthy M, Shanmugam S and Veerappan R A 2013 *Int. J. Energy. Eng.* **3** 62

[26] Liu C, Chen P, and Li K 2014 Thirty-Ninth Workshop on Geothermal Reservoir Engineering Stanford, California, P 24-26

[27] Chen J, Li K, Liu C, Li M, Jia L and Jiang S 2017 *Energies* **10** 1329

[28] Lertsatitthanakorn C, Jamradoedluk J and Rungsiyopas M 2014 *Energy Procedia* **52** 150

[29] Faraji A Y, Date A, Singh R and Akbarzadeh A 2014 *Energy Procedia* **57** 2112

[30] Singh M, Nirapure S and Mishra A 2015 *IOSR J. Mech. Civ. Eng.* **12** 40

[31] Tundeea S, Srijajonga N and Charmmongkolpradita S 2014 *Energy Procedia* **48** 453

[32] Sathawane N S and Walke P V 2014 *Int. J. Adv. Res. Sci. Eng.* **3** 36

[33] Özbaş E 2019 *Experimental Investigation of Passive Water Cooling in Solar Heating Thermoelectric Generator* (Turkey: Gazi University)

[34] Yusuf A and Ballikaya S 2020 *Appl. Sci.* **10** 1

[35] Dell R, Petralia M T, Pokharel A and Unnthorsson R 2019 *Thermoelectric Generator Using Passive Cooling* (London : intechopen)

[36] Rana S, Date A, Iqbal A and Akbarzadeh A 2019 *Energy Procedia* **160** 723

[37] Zhang Z, Wu Y, Li W and Xu D 2020 *Energies* **13** 947
