Konya Mühendislik Bilimleri Dergisi., c. 8, Özel Sayı, ss. 76-91, 2020
Konya Journal of Engineering Sciences v. 8, Special Issue, pp. 76-91, 2020
ISSN: 2667-8055 (Elektronik)
DOI: 10.36306/konjes.822181

ANALYSIS OF ELECTRICAL ENERGY IN THERMOELECTRIC GENERATOR IN SANDWICH DESIGN

[1]Hakan TERZİOĞLU, [2]Abdullah Cem AĞAÇAYAK

[1]Konya Technical University, Faculty of Engineering and Natural Sciences, Department of Electrical-Electronics Engineering, Konya, TURKEY
[2] Konya Technical University, Vocational School of Technical Science, Department of Electrical, Konya, TURKEY
[1]hterzioglu@ktun.edu.tr, [2]acagacayak@ktun.edu.tr

(Geliş/Received: 05.11.2020; Kabul/Accepted in Revised Form: 23.12.2020)

ABSTRACT: Researchers and industry are seeking to manage energy better by increasing the efficiency of the energy system because of the increasing importance of energy in recent years. For this reason, a shift towards alternative energy sources to provide electricity has begun. As for alternative energy sources, interest in renewable energy sources is increasing day by day. Solar, wind and thermal sources are the most prominent renewable energy sources. Today we use of thermal sources in greenhouse, fish breeding, thermal facilities, city heating and electricity production. Nowadays, it is known that when we move thermal water from the source to the place to be used, it can be converted into electrical energy by utilizing the heat it emits around it. In this study, the effects of the type of the material and the placement of the thermoelectric generator (TEG) on the efficiency of two Thermoelectric Modules (TEM) were investigated by using thermal sources from renewable energy sources. Hot and cold water was passed through the sandwich blocks which were made from Copper, Aluminum and Brass materials, and the power produced in TEG was analyzed. As TEG, TEC1-12706 and TEC1-12710 materials were used. As a result of experimental studies, it is observed that the type of the material that conveys thermal water and the order of transmission of hot/cold water through sandwich blocks have an effect on the power produced by both TEC1-12706 and TEC1-12710

Key Words: *Thermoelectric generators, output power and efficiency, renewable energy source.*

Sandviç Tasarımı İçerisindeki Termoelektrik Jeneratörde Elektrik Enerjisinin Analizi

ÖZ: Son zamanlarda enerjinin gittikçe artan öneminden dolayı, araştırmacılar ve sanayi, enerji sisteminin verimliliğini artırarak enerjiyi daha iyi yönetmek istemektedirler. Bu nedenle elektrik enerjisini sağlamak için alternatif enerji kaynaklarına yönelim başlamıştır. Alternatif enerji kaynaklarından ise yenilenebilir enerji kaynaklarına olan ilgi her geçen gün artmaktadır. Güneş, Rüzgâr ve Termal kaynaklar yenilenebilir enerji kaynaklarının öne çıkanlarıdır. Günümüzde termal kaynaklardan seracılık, balık yetiştirme, termal tesisler, şehir ısıtması ve elektrik üretimi gibi birçok alanda faydalanmaktayız. Günümüzde termal suyu kaynağından faydalandığımız yere taşırken, etrafına yaydığı ısıyı elektrik enerjisine dönüştürebileceğimiz bilinmektedir. Bu çalışmada yenilenebilir enerji kaynaklarından termal kaynaklar kullanılarak, elektrik üretiminde termal suyun taşındığı malzemenin türünün ve Termoelektrik Jeneratörün (TEG) yerleşim şeklinin farklı iki Termoelektrik Modülün (TEM) verimi üzerindeki etkisi incelenmiştir. Sıcak ve soğuk su Bakır, Alüminyum ve Pirinç malzemelerinden oluşturduğumuz sandviç bloklardan geçirilerek TEG'de üretilen güç üzerindeki analizi gerçekleştirilmiştir. TEG olarak da TEC1-12706 ve TEC1-12710 malzemeleri kullanılmıştır. Yapılan deneysel çalışmalar sonucunda termal suyun geçtiği malzemenin türünün ve

sıcak/soğuk suyun sandviç plakalardan geçme sırasının hem TEC1-12706'nın hem de TEC1-12710'nun ürettiği güç üzerinde etkili olduğu görülmüştür.

Anahtar Kelimeler: *Termoelektrik jeneratörler, çıkış gücü ve verim, yenilenebilir enerji kaynağı.*

1. INTRODUCTION

Rapid population growth and industrialization in developing countries today cause a surge in demand for energy. Energy production is one of the main factors that reflect the economic and social development potential of a country. Therefore, energy and energy conversion systems that countries have in the world are considered as a measure of development. In order to meet the increasing energy demand with developing technology all over the world, studies are carried out to obtain efficient, cheap and clean energy from alternative energy sources. For this purpose, interest in alternative energy sources, renewable energy sources in particular, is increasing day by day.

In terms of usage, energy sources are divided into renewable and non-renewable energy sources. Non-renewable energy sources are fossil sources, such as coal, oil, natural gas, LPG and wood, which are expected to be consumed in the near future.

Nuclear energy which is again a non-renewable energy source is a type of energy that requires great attention in terms of production and recycling. Renewable energy sources are the resources that can be renewed in the future such as biogas, hydraulic, wind, sun, tidal wave energy, thermal (thermal), geothermal. Although other renewable energy sources are less than geothermal energy, they have negative effects on the environment. In addition, due to reasons such as the efficient use of these resources at specific time intervals, the inadequacy of their technologies and the high cost of their costs, scientists attach more importance to alternative energy sources such as geothermal energy (Champier, 2017;Terzioğlu *et al.*, 2018).

Geothermal energy does not have the potential to compete with non-renewable sources of energy. It is a type of energy that stands out with its pollutant-free, renewable, sustainable, domestic and environmentally friendly features when appropriate technologies are used. In this study, using thermal sources amongst renewable energy sources, the effect of the material conveying thermal water during electricity generation and the placement of Thermoelectric Generator (TEG) on the efficiency of two different TEGs were investigated (He *et al.*, 2017; Ağaçayak *et al.*, 2019; Çimen *et al.*, 2017). Apart from this, many studies have been carried out regarding the use of TEMs as TEGs. Some of these studies are related to obtaining electric energy with TEG at the same time from the heat obtained using solar energy. There are studies conducted about the waste heat is being used again to convert it to electricity while turning solar energy into another energy source. Some of these studies have investigated the design and test results of a combined system of thermosyphon and thermoelectric modules (TTM) to generate electricity from low-grade thermal sources such as a salt-layer solar pool. Thus, it is stated that it is possible to produce a completely passive and simple power supply system for field applications away from power lines using the temperature differences in the solar pool (Singh *et al.*, 2011; La Rocca *et al.*, 2017). In another study using solar energy, a simple arrangement of plane reflectors designed to receive maximum solar energy at noon was used to heat the TEG. Thus, it is determined how many TECs can be used with the energy produced by the models same as TEGs (Khattab and El Shenawy, 2006; Serbülent and Kemal, 2009; Tugay, 2010; Maneewan *et al.*, 2005). In some studies related to solar energy, energy recycle is examined by generating electricity with TEG from the waste heat generated during the production of electricity by PV panels (Champier, 2017; Omer *et al.*, 2017). Some of the solar-powered thermoelectric generator investigations have focused on mathematical modeling and experimental device development (Champier, 2017; Sun *et al.*, 2017). Studies have been carried out on the conversion of exhaust heat energy of vehicles' exhaust gas to electric energy using TEGs (Akçay, 2015; Kushch *et al.*, 2001). In some of these studies, it has been concluded that the output power of the TEG depends on the speed of rotation of the motor (Demir and Dincer, 2017; Kaya, 2010). It is stated that the energies obtained with TEGs can be used in battery charging systems of vehicles (Tie and Tan, 2013; (Kim *et al.*, 2017; Meng *et al.*, 2017). It is suggested

to use the finite time thermodynamics in the technical solution of recovery of waste heat from thermoelectric power generated by exhaust gas. There are also studies that analyze the effect of some key parameters such as exhaust gas inlet temperature, exhaust gas and heat transfer coefficient of the cooling water on the optimal length of the thermoelectric elements (Meng *et al.*, 2017). A TEG system focuses on the structure of the exhaust gas outlet duct in the application of automotive exhaust heat recycle and it has been evaluated the maximum net power output of an object that best suits its size with a sandwich-plate band exhaust exchanger taking into account the effect of exhaust temperature changes on the exhaust heat exchanger (He *et al*, 2017; Kim *et al.*, 2017; Meng *et al.*, 2017). TEGs are used in different systems and will continue to grow.

In the experiments we have done, a design that can be used in the production of electricity by TEM has been created. In the production of electrical energy from TEM, it was seen that the design of the plates in which the thermal water was applied was effective on the electrical energy produced. In the experiment that is carried out, the electric energy is produced by TEMs placed in hot-cold-hot plates and cold-hot-cold plates. Analyzes have been carried out on the power produced in the TEG with the mentioned connection types. At the same time, the effect of thermal water at different pressures on the power produced by TEC was also analyzed. As TEG, TEC1-12706 and TEC1-12710 materials were used. In the article, TEC1-12706 and TEC1-12710 are expressed as TEG-12706 and TEG-12710, respectively. As a result of the experimental studies made, it is seen that the hot-cold-hot connection type is more efficient.

2. THERMOELECTRIC MODULE

A thermoelectric module consists of a ceramic plate on two sides to provide heat conduction and electrical insulation as shown in Figure 1. Between these ceramic plates are P and N type semiconductors which are electrically connected to each other in series and thermally in parallel with copper conductors. While the heat is carried by electrons from the cold environment to the hot environment with the voltage from the direct current source, the transfer of heat from one end of the module to the other end shows the use of the thermoelectric modules as a thermoelectric cooler (TEC) (Terzioğlu and Ağaçayak, 2018; Ağaçayak *et al.*, 2017; Ağaçayak *et al.*, 2018;Terzioğlu, 2020).

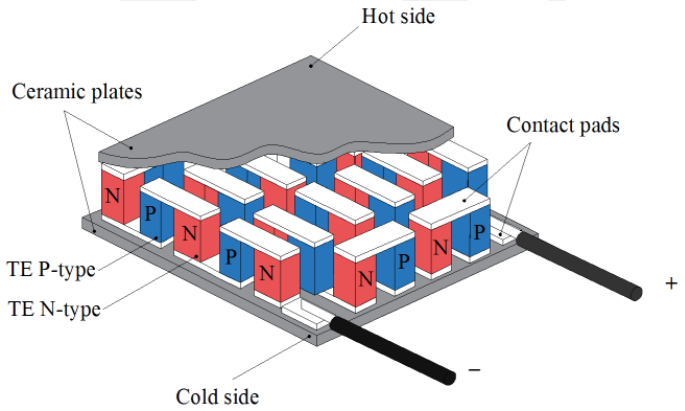

Figure. 1. Structure of a TEM.

3. THERMOELECTRIC GENERATOR (TEG)

If one of the ceramic surfaces of TEM which is used as TEC by applying DC voltage to its ends is applied cold and the other one is applied hot, the temperature difference between the two surfaces is generated to produce a modular DC current as shown in Figure 2 and thus a thermoelectric power generator is obtained. DC current is generated by thermoelectrically generated electricity, and electrons

move through P and N type semiconductors as a result of heat flow (Demir and Dincer, 2017; Montecucco *et al.*, 2017; Hossam *et al.*, 2017).

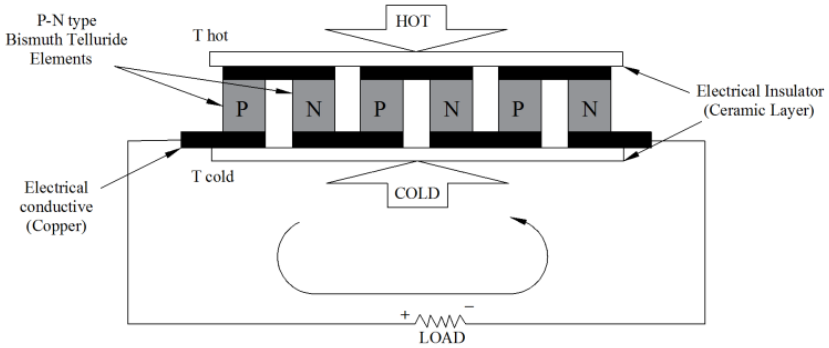

Figure. 2. Thermoelectric generator (TEG)

4. MATERIAL AND METHOD

In this study, a closed hot-cold water circulation system was designed and the TEMs were operated as TEG in the laboratory environment and electrical energy was produced. In the experimental system designed as a closed system, hot-cold water was passed from modules made of copper-aluminum and brass materials. Plates made of copper, aluminum and brass materials have formed sandwich blocks with 3in each. TEMs were placed between the plates in these blocks. Thus, the effect of the material in which the thermal water is conveyed on the power produced by the TEMs is determined. In addition, the effect on different TECs was examined using two different thermoelectric modules, TEG-12706 and TEG-12710, during the experiment.

In this study, thermal water was passed through it using a plate with sizes of 100x100x20 mm. In the designed plates, the distribution of the temperature on the plates was equal and the design characteristics were verified in another study (Yalçin *et al.*, 2016). These plates are made of 3 materials, copper, aluminum and brass. TEG-12706 and TEG-12710 were placed between the formed plates. In addition, as shown in Figure 3, a thermocouple temperature sensor was installed between the TECs placed on the surface of each plate to measure the plate temperature.

In Figure 3 there can be seen the 8 TECs placed between the plates and the shapes of copper sandwich blocks. Four of the 8 TECs used were connected in series to each layer in series. TEC electrical circuit connections were made in 2 groups connected in series by parallel connection. This design has been applied to each material type and TEC type in the whole system.

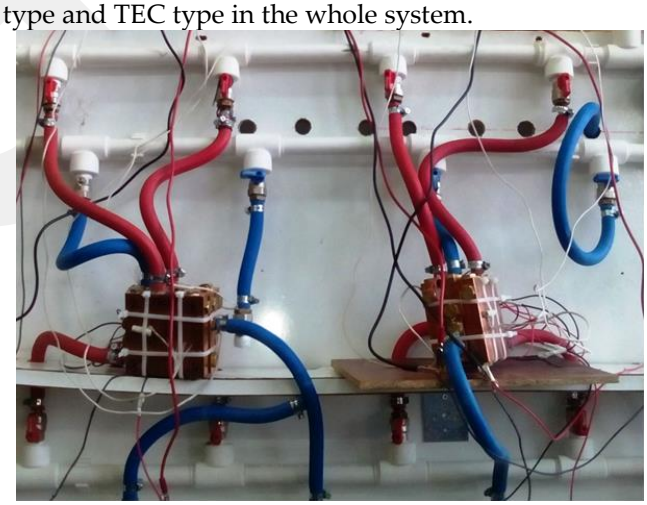

Figure 3. Image of sandwich blocks formed by TEG-12706 and TEG-12710, TEGs placed between copper

5. THE EXPERIMENTAL SETUP

The experimental setup used for the passage of the thermal water from the prepared blocks shown in Figure 4. In the experimental setup shown in Figure 4, two independent closed systems are designed for hot and cold water circulation. The red arrows show a closed system of hot water and the flow direction of the water, and the blue arrows show the closed system of cold water and the flow direction of the water. Hot and cold water circulation is provided by two separate WILO RSL 15 / 5-3 ku model 84W combi engines. In these closed systems, the hot and cold sides are supplied with water from outside and the pressure of the system is set as 1-2,5 and 3,5 bar. Thus, experiments were carried out at different pressure values. In the designed system, the hot and cold water entering the plates and the hot and cold water coming from the plates can be continuously measured with sensors.

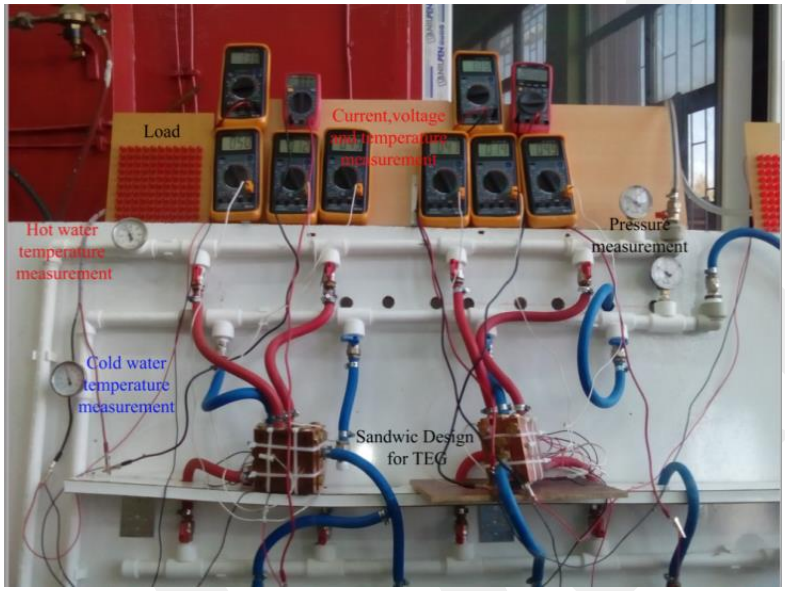

Figure 4. View of the connection of the system designed.

In order to obtain hot water in the designed system, two heat sources were used which are formed by connecting two heat exchangers in series. This allows the hot water in the system to reach the desired value faster. Since the water introduced to the system is influenced by both the plates where hot water is transmitted due to the fineness of the thermoelectric modules as well as from the plates where cold water is conveyed using a propeller heat exchanger to cool the cold water, it is ensured that it is held in a certain cold temperature by air. In the system, two expansion tanks are used separately for cold and hot closed water systems. Thus, the small water escaping from the system is replaced by the additional water from the water tanks and to keep the pressure at the same value for a long time. In the experiments, the temperature values on the plates and the voltage and current values produced by the thermoelectric modules were measured using measuring instruments. The charge obtained by connecting 121 red LEDs of 10mm in parallel to each other is connected to the output of the TECs to see if the system is operating under charge.

6. RUNNING THE EXPERIMENTATION

Experiments were carried out by connecting sandwich copper, brass and aluminum blocks to the system at 3 different motor speeds at 3 different pressures. In each experiment, 2 pieces of sandwich blocks from the same material and TEG-12706 to TEG-12710 were placed between these blocks and the power they produced at the same temperature and pressure were compared. Each sandwich block contains 8 pieces of TEC. Under these conditions, 18 experiments were conducted and the energy and power produced by the TECs were observed. In this study, when the pressures for each material type and TEC

ranges are 1-2,5 and 3,5 bar and the revolving speed motors are in the 1-2-3 level, 20 experiments were carried out on the sandwich blocks, each consisting of 3 plates, passing hot-cold-hot and cold-hot-cold water. Figure 5 shows hot-cold-hot and cold-hot-cold connected blocks. Experiments have been carried out to determine the effect of the type of material conveying thermal water on the power obtained from TEGs.

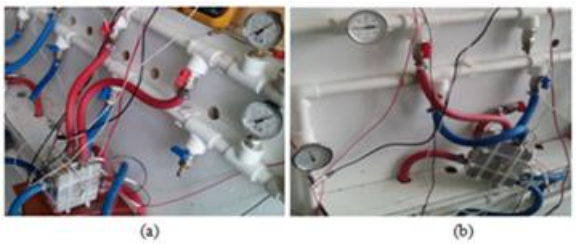

Figure 5. The image of sandwich blocks in the system with (a) hot-cold-hot (b) cold-hot-cold connection.

Starting from the initiation of the system in the experiments, the voltage (V), current (A) values and time obtained from the (TH) 81odüle hot surface, (TC) 81odüle cold surface and geothermal energy are measured until the hot water reach to 100 ^{0}C. In the experiments performed, the duration of completion of an experiment varies between 30 and 70 min. In experiments, considering that about %88 of geothermal energy in Turkey is low and medium temperature (30-100 ^{0}C), threshold is determined to be 100 ^{0}C.

7. EVALUATION OF EXPERIMENTAL RESULTS

Experiments at various speeds and pressures were carried out on the sandwich blocks formed with 3 plates consisting of 3 different materials in the experiment setup with the hot-cold-hot and cold-hot-cold connection. In the experiments performed, 20 tests were performed for each TEC module. The results of the experiments with the TEG-12706 module are given in Table 1. As shown in Table 1, while the temperature difference (T) between the surfaces is 65 ^{0}C, the passage of thermal water from different materials affects the power change. Table 1 shows that the rate of thermal water movement and the pressure are also effective on the power generated from the sandwich block of TEG-12706 with the hot-cold-hot connection type. As seen in Table 1, the best power in copper was recorded as 0,835 W when the motor speed was at the 3rd level and the pressure was 3,5 bar. It is seen that the best power in aluminum material is produced as 2,485 W when the speed of the motor is in 3rd level and the pressure is 3,5 bar. In case of brass material, it is seen that the best power is produced at 1,755 W when the speed of the motor is at 3rd level and the pressure is 3,5 bar. When Table 1 is examined, the water pressure and speed were influential depending on the material in which the thermal water was conveyed. Under these conditions, the highest power of 3 different materials was obtained with Aluminum at 3,5 bar as 2,485 W.

Table 1. TEG-12706 power(W) values at ΔT = 85 ^{0}C for hot-cold-hot connection.

Motor Speed	Copper Plate		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	0,495 W	0,599W	0,621W
II	0,465W	0,535W	0,6463 W
III	0,516 W	0,504 W	0,835 W
Motor Speed	**Aluminum Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	2,054 W	2,216 W	2,211W
II	2,171 W	2,189 W	2,128 W
III	2,148 W	2,191 W	2,485 W
Motor Speed	**Brass Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	1,278 W	1,431 W	1,369 W
II	1,335 W	1,53 W	1,57 W
III	1,472 W	1,53 W	1,755 W

The current-voltage and power graphs of the experiments in which the highest power among the three different materials are obtained in the tests performed in the sandwich block of TEG-12706 with hot-cold-hot connection type are given in Figure 6-8.

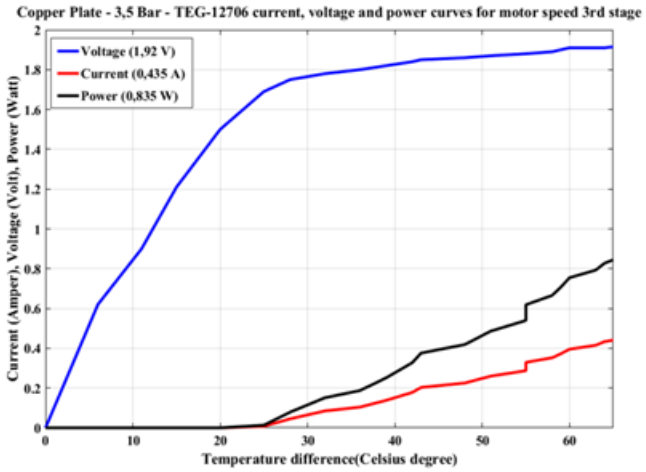

Figure 6. TEG-12706 current, voltage, power curves of Copper Material in Hot-Cold-Hot Sandwich Block Connection Type - 3,5 Bar pressure - Motor Speed at 3rd level.

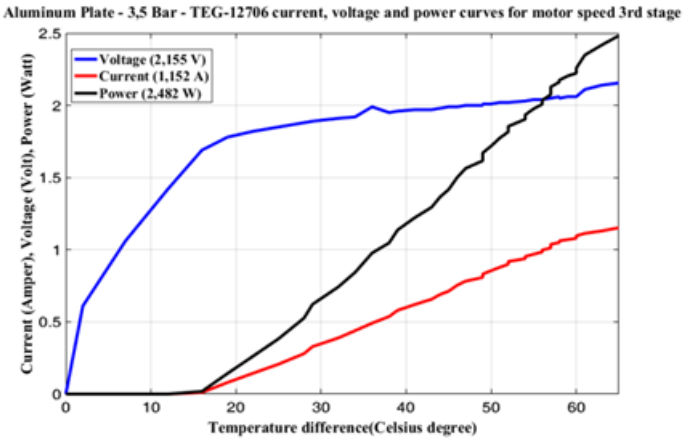

Figure 7. TEG-12706 current, voltage, power curves of Aluminum Material in Hot-Cold-Hot Sandwich Block Connection Type - 3,5 Bar pressure- Motor Speed at 3rd level.

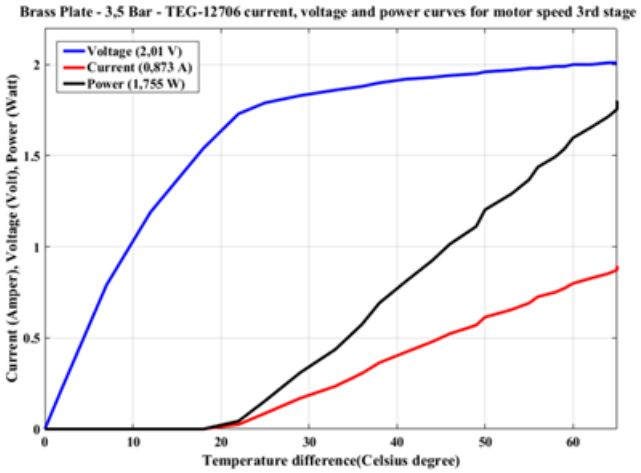

Figure 8. TEG-12706 current, voltage, power curves of Hot-Cold-Hot Sandwich Block Connection Type Brass Material - 3,5 Bar pressure- Motor Speed at 3rd level.

In Figure 9, the highest power values of the tests performed in the type of hot-cold-hot connection of sandwich block TEG-12706 appear as a single graph. As can be seen in Figure 9, the highest power is achieved when thermal water is passed through the Aluminum material. Also, the earliest power value was obtained from the experiment with aluminum when the temperature reached 15 ^{0}C.

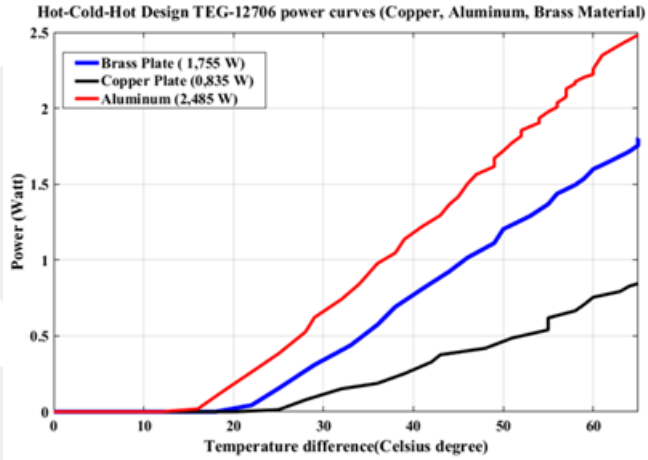

Figure 9. Power curves for TEG-12706 in Hot-Cold-Hot Sandwich Block Connection Type with Copper-Aluminum-Brass Material.

The results of the sandwich block TEG-12706 sandwich block cold-hot-cold connection tests are given in Table 2. In Table 2, it is seen that the best power in copper material is produced as 0,914 W when the speed of the motor is at 1st level and the pressure is 3,5 bar. It is seen that the best power in aluminum material is produced as 2,416 W when the speed of the motor is at 2nd level and pressure is 1 bar. In brass, it is seen that the best power is produced as 2,538 W when the speed of the motor is at 3rd level and the pressure is 1 bar. As seen in Table 2, the highest power was obtained as 2,538 W when the thermal water was passed through Brass, the pressure is 1 bar and motor power is at 3rd level. When these values are compared with the hot-cold-hot connection type given in Table 2, it is seen that the change of the connection type of the sandwich blocks is also influential on the power produced by TEG-12706.

Table 2. TEG-12706 power(W) values at ΔT = 65 ^{0}C for cold-hot-cold connection.

Motor Speed	Copper Plate		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	0,914 W	0,514 W	0,532 W
II	0,603 W	0,501 W	0,495 W
III	0,594 W	0,51 W	0,556 W
Motor Speed	**Aluminum Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	1,725 W	1,593 W	1,488 W
II	2,416 W	1,654 W	1,532 W
III	1,738 W	1,601 W	1,59 W
Motor Speed	**Brass Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	1,65 W	1,599 W	1,502 W
II	1,622 W	1,702 W	1,602 W
III	2,538 W	1,734 W	1,527 W

The current-voltage and power graphs of the experiments in which the highest power is obtained from 3 different materials within the sandwich block of TEG-12706 are shown in Figure 10-12.

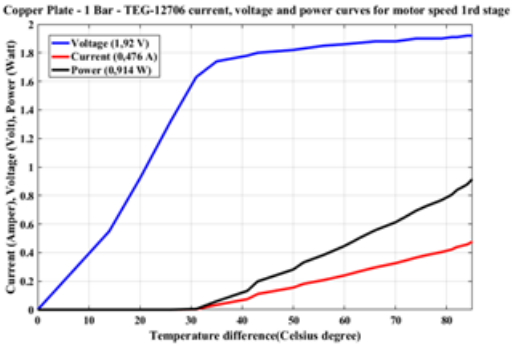

Figure 10. TEG-12706 current, voltage, power curves for Copper Material in Cold-Hot-Cold Sandwich Block Connection Type - 1 Bar pressure- Motor Speed at 1st level

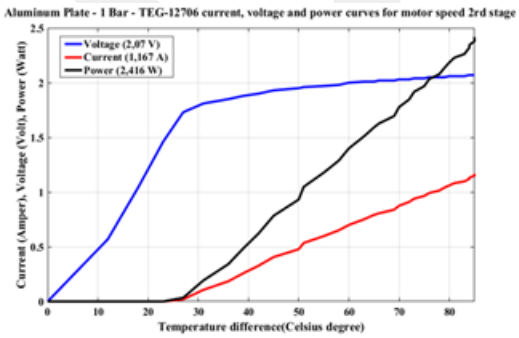

Figure 11. TEG-12706 current, voltage, power curves for Aluminum Material in Cold-Hot-Cold Sandwich Block Connection Type - 1 Bar pressure - Motor Speed at 2nd level

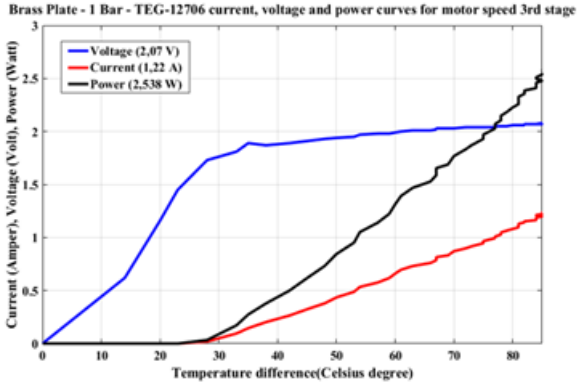

Figure 12. TEG-12706 current, voltage, power curves for Cold-Hot-Cold Sandwich Block Connection Type with Brass Material - 1 Bar pressure - Motor Speed at 3rd level.

In Figure 13, the highest power values of the experiments carried out when the sandwich block consisting of TEG-12706 was cold-hot-cold connection type are seen as a single graph. As seen in Figure 13, the highest power is obtained when the thermal water is passed through the Aluminum material. Also, the earliest power value was obtained from the experiment with rice when the temperature reached at 19 ^{0}C.

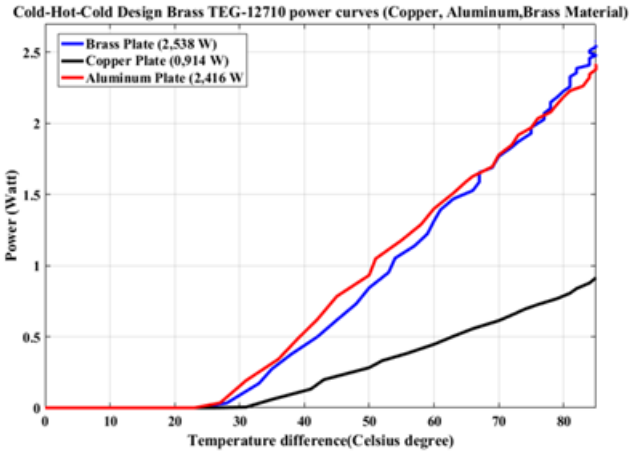

Figure 13. Copper-Aluminum-Brass Material power curves for TEG-12706 with Cold-Hot-Cold Sandwich Block Connection Type.

The results of the experiments made on the sandwich block with hot-cold-hot connection type TEG-12710 are given in Table 3. As shown in Table 3, the best power of 3 material types was obtained when the motor speed was at 3rd level and the pressure was 3,5 bar. It is observed that the maximum power produced were 1,66 W with copper structure, 3,524 W with aluminum structure, and 3,2494 W with the brass structure under these conditions. As shown in Table 3, the highest power was obtained as 3,524 W, at the pressure of 3,5 bar when the thermal water was passed through the Aluminum, and the motor speed was at 3rd level. As shown in Table 3, the highest power rating was obtained at 3,524 W, when the thermal water was passed through Aluminum, the pressure was 2,5 bar and motor speed at 3rd level.

Table 3. TEG-12706 power(W) values at $\Delta T = 85\ ^0C$ for hot-cold-hot connection.

Motor Speed	Copper Plate		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	0,539 W	0,598 W	0,998 W
II	0,558 W	0,676 W	1,036 W
III	0,539 W	0,558 W	1,666 W
Motor Speed	**Aluminum Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	3,213 W	3,045 W	3,544 W
II	3,315 W	3,03 W	3,2395 W
III	3,161 W	3,524 W	3,45 W
Motor Speed	**Brass Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	1,369 W	1,721 W	1,412 W
II	1,5461 W	1,8 W	1,1376 W
III	1,566 W	1,898 W	2,567 W

The current-voltage and power graphs of the experiments in which the highest power is obtained from three different materials from sandwich blocks made of TEG-12710 in hot-cold-hot connection type are given in Figure 14-16.

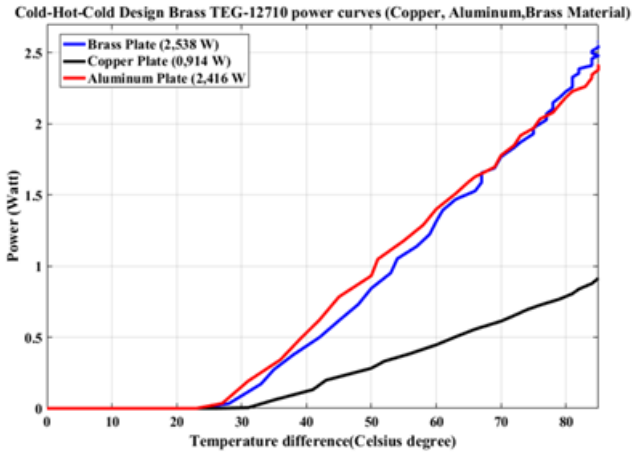

Figure 14. TEG-12710 current, voltage, power curves for Copper Material in Hot-Cold-Hot Sandwich Block Connection Type - 3,5 Bar pressure - Motor Speed at 3rd level.

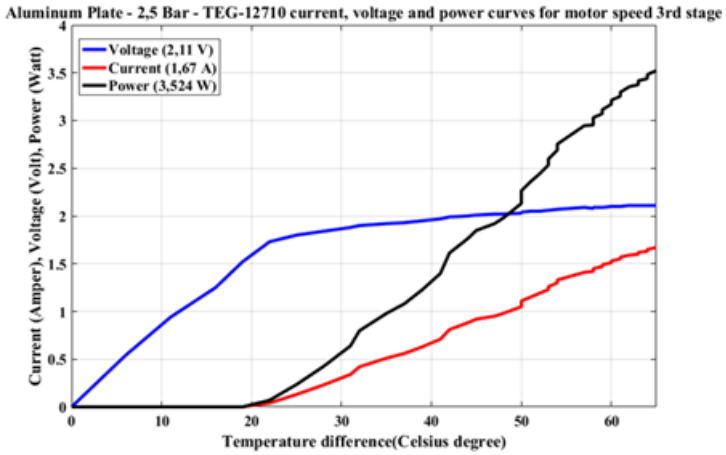

Figure 15. TEG-12710 current, voltage, power curves for Aluminum material in Hot-Cold-Hot Sandwich Block Connection Type - 2,5 Bar pressure - Motor Speed at 3rd level.

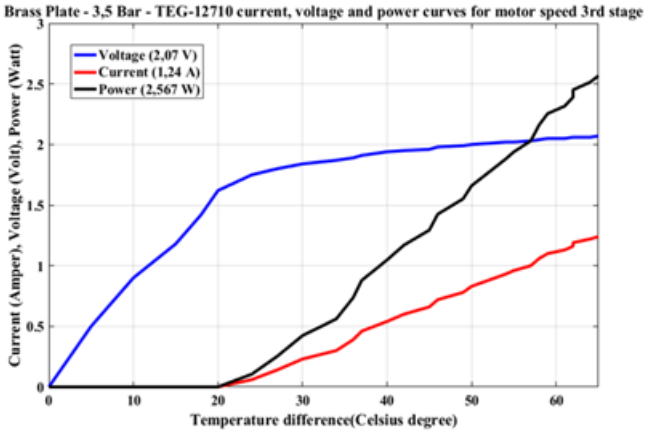

Figure 16. TEG-12710 current, voltage, power curves for Brass Material in Hot-Cold-Hot Sandwich Block Connection Type - 3,5 Bar pressure - Motor Speed at 3rd level.

In Figure 17, the highest power values of experiments performed using TEG-12710 appear as a single graph. As can be seen in Figure 17, the highest power is obtained when the thermal water is passed through the Aluminum material. Aluminum and brass are very close to each other in power generation, but the performance of copper is low compared to them. In addition, the earliest power value was obtained when the temperature reached 21 ^{0}C in the experiments with Aluminum and Brass

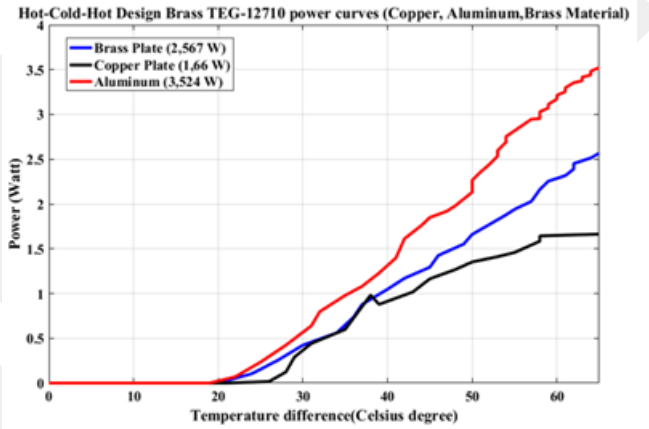

Figure 17. Power curves for TEG-12710 with Copper-Aluminum-Brass Material of Hot-Cold-Hot Sandwich Block Connection Type.

The results of the tests carried out when the sandwich block made with TEG-12710 is of cold-hot-hot connection type are given in Table 4. In Table 4, the best power for copper was produced as 1,78 W when the motor speed was at 3rd level and the pressure was 3,5 bar. The best power in aluminum material was 5,326 W when the engine speed was at 2nd level and the pressure was 3,5 bar. In case of brass material, the best power was produced as 2,863 W while the motor speed was at the 2nd stage and the pressure was 3,5 bar. As seen in Table 4, with TEG-12710, the highest power value was obtained as 5,326 W when the thermal water was passed through Aluminum, the motor speed was at the 2nd level and the pressure was 3,5 bar.

Table 4. TEG-12710 POWER (w) values at $\Delta T = 65\ ^0C$ with cold-hot-cold connection.

Motor Speed	Copper Plate		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	0,4836 W	1,119 W	0,798 W
II	0,3843 W	0,9359 W	0,722 W
III	0,4026 W	0,4048 W	1,78 W
Motor Speed	**Aluminum Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	3,5474 W	3,3072 W	3,483 W
II	3,5145 W	3,7878 W	5,326 W
III	3,7062 W	3,4132 W	3,749 W
Motor Speed	**Brass Plate**		
	1 Bar	**2,5 Bar**	**3,5 Bar**
I	0,9168 W	0,9741 W	1,86 W
II	0,955 W	0,9359 W	2,863 W
III	0,9359 W	0,974 W	0,9359 W

The current-voltage and power graphs of the experiments in which the highest power is obtained with 3 different materials in the sandwich block with TEG-12710 and cold-hot-cold connection type are given in Figure 18-20.

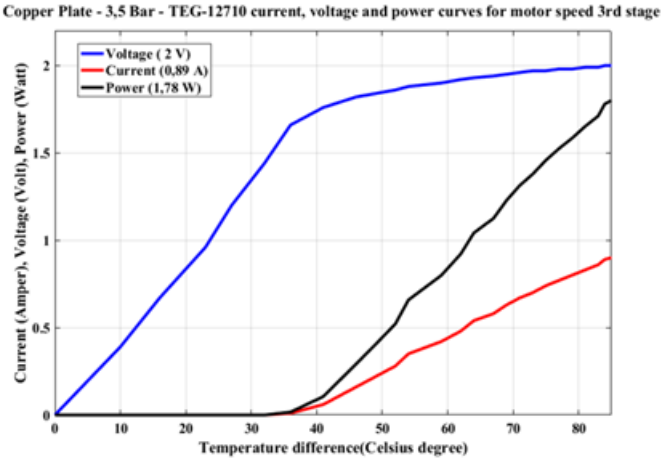

Figure 18. TEG-12710 current, voltage, power curves for Copper Material with Cold-Hot-Cold Sandwich Block Connection Type - 3,5 Bar pressure - Motor Speed 3rd level.

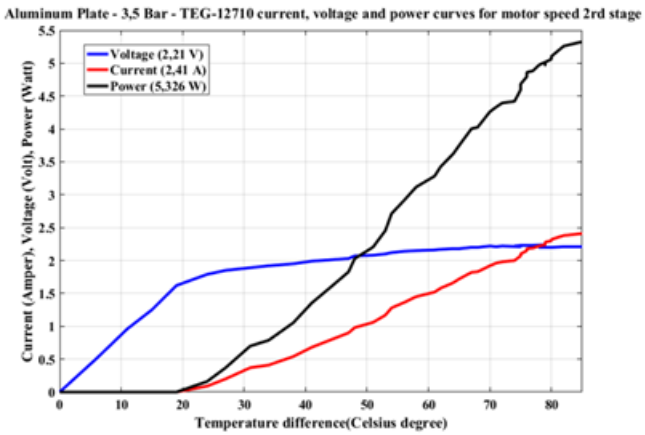

Figure 19. TEG-12710 current, voltage, power curves for Aluminum Material with Cold-Hot-Cold Sandwich Block Connection Type - 3,5 Bar pressure- Motor Speed at 2nd level.

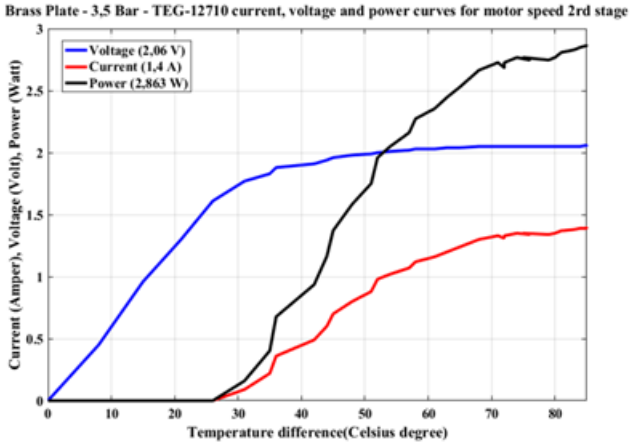

Figure 20. TEG-12710 current, voltage, power curves for Brass Material with a Cold-Hot-Cold Sandwich Block Connection Type - 3,5 Bar pressure - Motor Speed at 2nd level.

In Figure 21, the highest power values of experiments performed using TEG-12710 appear as a single graph. As can be seen in Figure 21, the highest power is obtained when the thermal water is passed through the aluminum material. In addition, the earliest power value was obtained when the temperature reached 20 ^{0}C in the experiment with Aluminum.

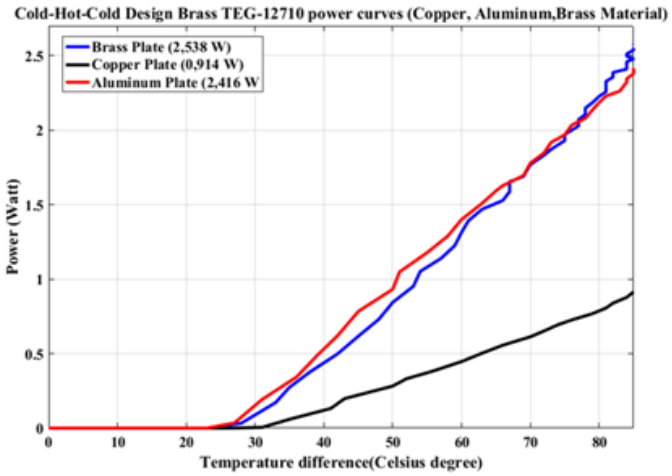

Figure 21. Power Curves for Copper-Aluminum-Brass Material with TEG-12710 and Cold-Hot-Cold Sandwich Block Connection Type.

8. RESULTS AND DISCUSSIONS

In this study, it was determined that the energy obtained by using TEC was affected by the type of material circulated in the thermal water and the speed and pressure of the water. As a result of the experiments carried out, it has been seen that the material through which the thermal water is conveyed, the water pressure and the connection of sandwich blocks to the system have an effect on the energy produced by the TEC.

In this study, TEGs were placed between hot-cold-hot and cold-hot-cold plates. As a result of this work It was observed that the design of the plates carrying thermal water was effective in the amount of electricity generated in TEG.

The temperature difference between the plates in hot-cold-hot operation was 65 ^{0}C, while in cold-hot-cold operation a temperature difference of 85 ^{0}C was formed. This shows that the plates affect each other as temperature.

Highest power value for TEG-12706 in hot-cold-hot sandwich structure. The highest power value for the TEG-12710 in the same sandwich structure was obtained from aluminum plates at 3,524 W at 2,5 bar pressure at level 3.

Highest power value for TEG-12706 in cold-hot-cold sandwich structure. The highest power value for the TEG-12710 in the same sandwich structure was obtained from the aluminum plates at the engine level at a pressure of 3,5 bars at 5,326 W.

The amount of electrical energy produced from TEG placed in cold-hot-cold sandwich design is higher than the hot-cold-hot design.

As a result of the experiments, the best power value from copper, aluminum and brass was obtained from aluminum, while the lowest power value was obtained from copper material.

When the best results of the experiments were evaluated, 5 of the 12 best values were realized with the engine 3. Level water pressure was 3.5 bar. However, if the highest power value is 5,326 W, the engine is at the 2nd level water pressure at 3,5 bar .

REFERENCES

Ağaçayak, A. C., Neşeli, S., & YalçınG, T. H. (2017). The Impact of Different Electric Connection Types in Thermoelectric Generator Modules on Power. *International Journal of Engineering Research & Science (IJOER), 3*, 2395-6992.

Ağaçayak, A. C., Terzioğlu, H., Neşeli, S., & Yalçin, G. (2019). Mathematical Modeling Of Thermoelectric Generator By Regression Analysis. *Selçuk-Teknik Dergisi*, 132-143.

Ağaçayak, A.C., Terzioğlu, Çimen, Neşeli, Yalçın, (2018). "The Effects of Speed and Flow Rate on Power in Thermoelectric Generators", *International Journal of Intelligent Systems and Applications in Engineering*, Vol.6, pp.65-71.

Akçay H. (2015). The conversion of heat lost in the exhaust and cooling system of a spark ignition engine fuelled with LPG to a usable energy via a TEJ module. *M.Sc. Süleyman Demirel University*, Isparta, Turkey.

Champier, D. (2017). Thermoelectric generators: A review of applications. *Energy Conversion and Management, 140*, 167-181.

Çimen, H., Ağaçayak, A. C., Neşeli, S., & Yalçin, G. (2017). *Comparison of Two Different Peltiers Running as Thermoelectric Generator at Different Temperatures.* Paper presented at the 2017 International Renewable and Sustainable Energy Conference (IRSEC).

Demir, M. E., & Dincer, I. (2017). Performance assessment of a thermoelectric generator applied to exhaust waste heat recovery. *Applied Thermal Engineering, 120*, 694-707.

He, W., Wang, S., & Yue, L. (2017). High net power output analysis with changes in exhaust temperature in a thermoelectric generator system. *Applied Energy, 196*, 259-267.

Hossam A.G, C.A.Barry S, Derek S, Cole S, Thomas S, David N, Dominique P, Emmanuel B, (2017). *Evaluation and optimization of thermoelectric generator network for waste heat utilization in nuclear power plants and non-nuclear energy applications*. Annals of Nuclear Energy; 101: 454-464.

Kaya, A. Y. (2010). Experimental research of thermoelectric system that worked by the heat on exhaust gas. *M.Sc. Süleyman Demirel University*, Isparta, Turkey.

Khattab, N., & El Shenawy, E. (2006). Optimal operation of thermoelectric cooler driven by solar thermoelectric generator. *Energy Conversion and Management, 47*(4), 407-426.

Kim, T. Y., Negash, A., & Cho, G. (2017). Direct contact thermoelectric generator (DCTEG): A concept for removing the contact resistance between thermoelectric modules and heat source. *Energy Conversion and Management, 142*, 20-27.

Kushch, A. S., Bass, J. C., Ghamaty, S., & Eisner, N. (2001). *Thermoelectric development at Hi-Z technology.* Paper presented at the Proceedings ICT2001. 20 International Conference on Thermoelectrics (Cat. No. 01TH8589).

La Rocca, V., Morale, M., Peri, G., & Scaccianoce, G. (2017). A solar pond for feeding a thermoelectric generator or an organic Rankine cycle system. *International Journal of Heat and Technology, 35*(1), S435-S441.

Maneewan, S., Hirunlabh, J., Khedari, J., Zeghmati, B., & Teekasap, S. (2005). Heat gain reduction by means of thermoelectric roof solar collector. *Solar Energy, 78*(4), 495-503.

Meng, F., Chen, L., Feng, Y., & Xiong, B. (2017). Thermoelectric generator for industrial gas phase waste heat recovery. *energy, 135*, 83-90.

Montecucco, A., Siviter, J., & Knox, A. (2017). Combined heat and power system for stoves with thermoelectric generators. *Applied Energy, 185*, 1336-1342.

Omer, G., Yavuz, A. H., & Ahiska, R. (2017). Heat pipes thermoelectric solar collectors for energy applications. *International Journal of Hydrogen Energy, 42*(12), 8310-8313.

Serbülent G, Kemal A, (2009). Power generation using concentration solar collectors and thermoelectric generators. *5th International Advanced Technologies Symposium (IATS'09); 13-15 May 2009*; Karabük, Turkey

Singh, R., Tundee, S., & Akbarzadeh, A. (2011). Electric power generation from solar pond using combined thermosyphon and thermoelectric modules. *Solar Energy, 85*(2), 371-378.

Sun, D., Shen, L., Yao, Y., Chen, H., Jin, S., & He, H. (2017). The real-time study of solar thermoelectric generator. *Applied Thermal Engineering, 119*, 347-359.

Terzioğlu, Neşeli &Yalçın, (2018). Termoelektrik Jeneratörler ve Kullanım Alanlarına Genel Bir Bakış. *Mühendislik Alanında Akademik Çalışmalar*, Editör: Prof. Dr. HATİPOĞLU Murat, Dr. Öğr. Üyesi Gündoğan Kadir, Basım sayısı:1, Sayfa Sayısı 160, ISBN:978-605-288-624-3

Terzioğlu, & Ağaçayak, (2018). Analysis of Thermoelectric Cooler Used to Produce Electrical Energy in Terms of Efficiency. *Academic Studies In Engineering*, Editör:Prof. Dr. Hatipoğlu Murat, Dr. Öğr. Üyesi Gündoğan Kadir, Basım sayısı:1, Sayfa Sayısı 134, ISBN:978-605-288-611-3

Terzioğlu H., (2020). Analysis of effect factors on thermoelectric generator using Taguchi method. *Measurement,* 149,1-10

Tie, S. F., & Tan, C. W. (2013). A review of energy sources and energy management system in electric vehicles. *Renewable and sustainable energy reviews, 20*, 82-102.

Tugay M. (2019). Getting optimum level in the generation of electrical energy by means of thermoelectric convertors using parabolic reflector having dinamics structure. *M.Sc. Kırıkkale University*, Kırıkkale, Turkey.

Yalçın, Selek, & Terzioğlu, (2016). "Termoelektrık Jeneratör ile Maksimum Enerji Elde Edilmesi için Levha Tasarımı" *In UMYOS 5th Internatıonal Vocational School Symposium*, Vol.1, pp.909-16. Prizren.