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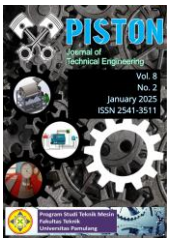

Design and Construction of a Satay Grill Based on Thermoelectric Generator as a Source of Electrical Energy

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Abstract: Thermoelectric Generator is a technology used to generate electrical energy by utilizing the Seebeck effect, which occurs due to the temperature difference between the hot and cold sides. This study aims to determine the voltage generated by the thermoelectric generator from the process of burning satay using coconut shell charcoal. In this experiment, 6 pieces of thermoelectric generator type TEG1-241-1. 4-1. 2 were used which were connected in series. The pieces were mounted on aluminum material measuring 165 x 110 x 15 mm, and equipped with a heatsink at the bottom of the satay grill body for cooling. The heatsink used is an extrude model. Testing began when the charcoal had reached a red color. The maximum voltage generated reached 2,25 V in seven minutes, with a temperature difference reaching 5,9 °C. The temperature on the hot side was recorded at 102,2 °C, while on the cold side it was 96,3 °C.

Keywords: Satay Grill, Thermoelectric Generator, Aluminum, Charcoal, Heatsink

Abstrak: *Termoelektrik generator merupakan teknologi yang digunakan untuk menghasilkan energi listrik dengan memanfaatkan efek Seebeck, yang terjadi akibat perbedaan suhu antara sisi panas dan dingin. Penelitian ini bertujuan untuk mengetahui tegangan yang dihasilkan oleh termoelektrik generator dari proses pembakaran sate menggunakan arang tempurung kelapa. Dalam eksperimen ini, digunakan 6 keping termoelektrik generator tipe TEG1-241-1. 4-1. 2 yang disambungkan secara seri. Keping-keping tersebut dipasang pada material aluminium dengan ukuran 165 x 110 x 15 mm, serta dilengkapi heatsink di bagian bawah body pemanggang sate untuk pendinginan. Heatsink yang digunakan adalah model extrude. Pengujian dimulai ketika arang sudah mencapai warna merah. Tegangan maksimum yang dihasilkan mencapai 2,25 V dalam waktu tujuh menit, dengan perbedaan suhu mencapai 5,9 °C. Temperatur pada sisi panas tercatat 102,2 °C, sedangkan pada sisi dingin sebesar 96,3 °C.*

Kata kunci: *Pemanggang Sate, Termoelektrik Generator, Aluminium, Arang, Heatsink.*

INTRODUCTION

Indonesian specialty food made from meat with a skewered and grilled process, one of which is satay, where satay is processed by grilling using charcoal from wood or coconut shells, besides that it can also use a grill with gas fuel [1]. The process of grilling satay using charcoal requires air flow from a fan or a hand fan made of woven bamboo. This air flow keeps the embers burning, so that it can be used to grill meat that has been prepared in advance [2]. In addition, the heat generated during the satay grilling process can be used as a source of electrical energy through thermoelectric generator (TEG) technology.

Thermoelectric generator is a power generation technology that has a small size and is lightweight. As one of the alternative energy sources, this generator offers efficiency ranging from 2.5 to 6.5 percent [3]. The working principle of this generator relies on the Seebeck effect, which utilizes the temperature difference between

the cold side and the hot side [2], [4], [5]. Thermoelectric generator is a device consisting of p-type and n-type semiconductor materials connected in series, shown in Figure 1. When heat is applied to the hot side of the thermoelectric generator, the electrons contained in the p-type and n-type semiconductors will be moved away from the heat source, thus creating an electric current [2], [5], [6]. Conversely, if the thermoelectric is supplied with DC electric current, it will create a temperature difference between the cold and hot sides, known as thermoelectric cooling. One application of this technology is as a room cooler that can produce temperatures up to 20°C [7]–[9].

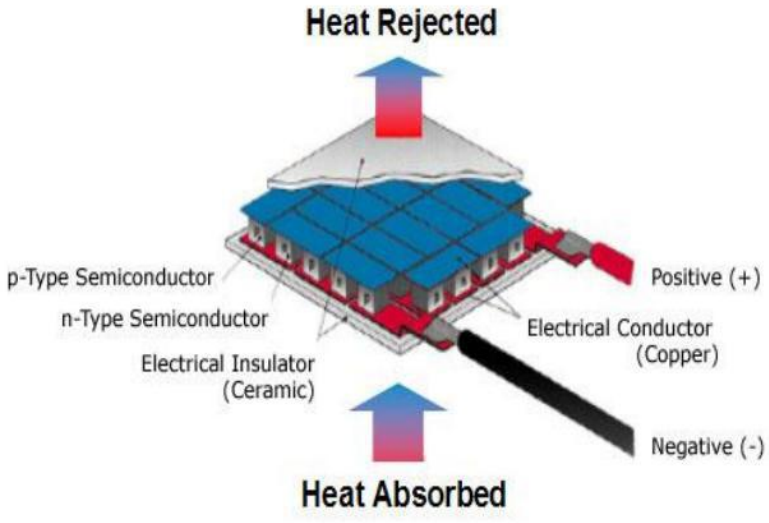

Figure 1. Thermoelectric Generator [2], [5], [6].

Research on thermoelectric generators as power plants has been conducted by several researchers. Among them, the utilization of heat generated from a heater with a voltage of 60 V produces the highest power of 0.055 W and a maximum current of 0.279 A, with an average temperature difference of 14.87 °C [10]. In addition, the use of exhaust heat from motorcycle exhausts can produce a voltage of 14.44 V at a temperature of 90 °C [11]. Other studies also show that waste heat energy generated from condensers in air conditioning (AC) systems can produce a voltage of 3.14 V and a power of 0.16 W [12]. On the other hand, the heat generated from LPG gas stoves can also be utilized as a source of electrical energy, using 10 TEGs with series connections can produce a voltage of 1.62 V at a hot and cold temperature difference of 39 °C [13]. In another study, the difference in hot and cold temperatures reached 200 °C using water as a cooling medium, which was able to produce a voltage of up to 500 W. Conversely, without using water as a cooling medium with a temperature difference of 80 °C, a voltage of 160 W was obtained using 100 thermoelectric generators [14].

The use of water as a heating medium was also analyzed by Lukman and colleagues. By using one thermoelectric chip, they produced a voltage and power of 1.797 mV and 125.79 mW respectively with a temperature difference of 19.8 °C [15]. Meanwhile, Jizhe Wang and his team compared the experimental results with a simulation of the use of a thermoelectric generator that utilizes hot water flowing through a pipe. The temperature difference created was 10.5 K producing a voltage and power of 3.4 mV and 126 nW [16]. The thermoelectric generator as a source of electrical energy by utilizing the heat of charcoal on the satay grill attached to the side of the satay grill using 7 TEG SP 1848 type thermoelectric generators connected in series produced the highest voltage of up to 25.4 Volts at a hot side temperature of 189 ^{o}C and a cold side temperature of 144 ^{o}C [2].

This study aims to determine the maximum voltage produced by utilizing the heat of the charcoal grill using TEG1-241-1.4-1.2. This study aims to determine the maximum voltage generated by utilizing the heat of charcoal on the bottom of the satay grill using TEG1-241-1.4-1.2, it is expected that by taking heat from the bottom it can produce maximum voltage because the heat is evenly distributed, where previously it was done on the side of the grill body where the charcoal heat was not all to the side of the satay grill body.

METHODS

This research begins with the design of a satay grill design that can be seen in Figure 2. This satay grill is made with a predetermined size with the addition of several specific components. such as battery charger, inverter, TEG, heatsink, and fan.

Figure 2. Satay Grill Design: a). Top view, and b). Bottom view

After the design is made, the satay grill body is made by cutting the plate followed by the process of combining each plate that has been cut with the SMAW welding process, where the welding process is the formation of metallurgical bonds at the joints of metal or alloy metals which are carried out in a melted or liquid state using energy [17], [18]. The material used is 30 mm thick iron plate, the grill body is made with a size of 600 x 150 x 50 mm, and the height of the legs that function as satay grill supports is 800 mm using 20 x 20 mm hollow iron material, this material is not only more economical, but also has a fairly high conductivity value and is easy to shape. Meanwhile, in the middle of the satay stand (meat that has been skewered), solid iron with a diameter of 6 mm and a length of 150 mm is used as seen in Figure 3.

Figure 3. The satay grill that has been made

The power generator used is a thermoelectric generator type TEG1-241-1.4-1.2 [19]–[22]. Where as many as 6 TEG pieces are connected in series, on the hot side of the TEG attached to a solid aluminum material measuring 165 x 110 x 15 mm by applying paste, where this paste functions as an adhesive and heat conductor, after that the other side of the solid aluminum material is attached to the bottom of the satay grill, while the cold side of the TEG is attached to the heatshink that has previously been applied with paste, the position of the heatshink is located on the outermost part so that it can be passed by free air as seen in figure 4. The heatsink as a cooler uses aluminum material with an extrude model because it has better performance than the slot heatsink model [23], [24].

Figure 4. Satay grill with TEG installed

The charcoal used in the satay grilling process, as well as for testing purposes, comes from coconut shells. This is because coconut shells have excellent thermal diffusion properties, which are caused by the high cellulose and lignin content. The chemical composition of coconut shells consists of approximately 26.6% cellulose, 27.7% pentosan, and 29.4% lignin [25]. In addition, coconut shells are a type of hardwood, with a water content of approximately 9% - 10% calculated based on dry weight [26]. The heat from the coconut shell charcoal produced can be absorbed by the hot side of the TEG through the aluminum material attached to the bottom of the satay grill body.

Testing is done as seen in the Figure 5, where by measuring several temperature points passed by heat from the hot charcoal to the hot side of the TEG and the cold side of the TEG as well as the voltage and power generated by the thermoelectric generator by keeping the charcoal embers burning and red. Testing was carried out from the beginning until the next 30 minutes, where the hot temperature was obtained from the aluminum material attached to the hot side of the thermoelectric generator, while the cold temperature on the cold side of the thermoelectric generator was obtained by blowing air from the surrounding environment.

Figure 5. Testing the satay grill with a data acquisition set

Testing begins when the charcoal starts to turn red (hot), where the hot temperature is obtained from the charcoal attached to the lower body of the satay grill to the aluminum material attached to the hot side of the thermoelectric generator at points 1and 2, while for the cold temperature on the cold side of the thermoelectric generator attached to the heatshink at point 3 and the heatshink fins exposed to the surrounding air at point 4 are seen in Figure 6.

Figure 6. Temperature sensor mounting point on the satay grill

RESULT AND DISCUSSION

The test was carried out for 30 minutes by measuring the temperature at point 1, point 2, point 3, point 4, voltage and power on the satay grill. In addition, voltage measurements were also carried out on the satay grill with a constant resistance of 500 Ω. Table 1 shows the results of temperature measurements at each point, as well

as the voltage and power produced by the thermoelectric generator (TEG). From the observations, it can be seen that the highest voltage occurs on the hot side of the TEG with a temperature reaching 102,2 ° C, while the cold side of the TEG shows a temperature of 96,3 ° C after 30 minutes the charcoal starts to glow. After this period, the voltage fluctuates due to the temperature difference between the hot and cold sides, although both experience an insignificant increase.

The maximum voltage reaches 2,25 V due to the increasingly even distribution of charcoal heat, which makes the heat absorbed by the aluminum more even. This contributes to the maximum heat absorption on the hot side of the thermoelectric generator. In addition, there is also a convection heat transfer from the grill wall to the heatsink which is increasingly balanced. Overall, the greater the temperature difference that occurs, the higher the voltage produced by the thermoelectric generator. The voltage produced is 2.25 V with a temperature difference of 5.9 ºC, while with TEG SP 1848 the voltage produced is 25.4 V with a significant temperature difference of 45 ºC [2]. Utilization of heat in pipes using stainless steel material produces 3.4 mV [16]. Utilization of condenser heat using a thermoelectric generator where the temperature difference achieved is 34 ºC produces a voltage of 3.14 V [12]. In addition to the number of thermoelectric generators, there is also a factor of heat conductors used on the hot side of the thermoelectric generator.

Table 1. Test Results of Satay Grill Based on Thermoelectric Generator

Time (minute)	Temperature (ºC)				Voltage (Volt)
	1	2	3	4	
0	27,5	27,3	26,7	27,3	0
3	30,6	30	34,5	30	0,009
6	46,4	37	36,2	37	1,15
9	54,7	53,3	53,5	42,4	1,23
12	65,6	55,6	57,1	48,3	1,69
15	70,3	62,5	62,5	50,2	1,94
18	84,9	71,1	62,4	52,4	1,97
21	90,2	87,3	74,5	62,2	2,01
24	93,1	91,7	81	72,1	2,06
27	112,2	101,6	86,1	80,1	2,12
30	122,1	102,2	96,3	91,3	2,25

CONCLUSIONS

Based on the test results conducted for 30 minutes, the maximum voltage generated by six thermoelectric generators connected in series reached 2,25 V. The peak voltage occurred at the 30th minute, when the hot side reached a temperature of 102,2 °C, while the cold side was at a temperature of 96,3 °C. The temperature difference between the hot and cold sides plays an important role in influencing the voltage generated by the thermoelectric generator; the greater the temperature difference, the higher the voltage generated. Even heat distribution occurs thanks to convection from the satay grill body to the heatsink.

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