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Utilization of Waste Combustion Heat as an Alternative Renewable Electric Energy Source Based on Thermoelectric Generator

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Abstract

Thermoelectric generator is one alternative energy source that is using a temperature difference system to produce electrical energy. This research study aims to utilize combustion heat waste using a thermoelectric generator as a source of renewable electricity. This research method uses the experimental method. The thermoelectric system was made using seven thermoelectric modules TEC1 - 12706 arranged in series by varying the combustion media in the form of Rice husk, Sengon sawdust (*Albizia chinensis*) and Teak sawdust (*Tectona grandis)*. The test is done by measuring the output voltage, the temperature of the cold side and the hot side which are then analyzed to get the output power and generator efficiency. From the trial results it was found that the greater of the temperature difference, then the output voltage, output power and generator efficiency increase. Output voltage, output power and maximum efficiency of testing prototype thermoelectric generator that generated were 4.64 V, W 20.38 and 16.46 % with fuel Teak sawdust in the tenth minute when the temperature difference of 76.17 ^{0}C.

Said Key: *thermoelectric generator, alternative energy, electrical energy*

1. Introduction

Energy becomes a necessity that cannot be separated from daily life. One of the energy needed for human life is electrical energy. In developing countries like Indonesia, electricity is obtained by processing various kinds of fossil resources. Exploration of fossil fuels was carried out on a large scale to meet electricity consumption needs. This condition causes a decrease in the amount of fuel reserves, especially oil and gas that triggers an increase in prices and the occurrence of an energy crisis.

Therefore, there is a need for technological innovation by utilizing alternative renewable energy sources that are inexpensive, easily manufactured and have high caloric value. One of the devices included in the free energy power plant is a thermoelectric generator by utilizing waste heat burning Rice husks and sawdust.

This research proposes the use of thermoelectric generators that can convert heat directly into electricity without a driving machine. So that the heat generated from burning Rice husk and wood sawdust can be directly converted into electrical energy. Some of the things that make thermoelectric generators attractive are the characteristics of generators with long service periods, low maintenance costs, long usage time, no noise, and no moving parts or complex mechanical parts. In addition, thermoelectric generators have a wide range of power production, ranging from *microWatts* to hundreds of Watts. So that electricity production can be adjusted to the availability of fuel. However, thermoelectric generators also have weaknesses, including the low conversion efficiency value, which ranges from 5-10% (Nuwayhid, 2005). However, material technology that continues to develop promises thermoelectric materials with better efficiency.

Characteristics of Thermoelectric Modules

Thermoelectric modules are composed of two p-type and n-type semiconductor materials that are connected in series. The semiconductor is inserted between the ceramic plates. The module scheme thermoelectric can be seen in Figure 1.

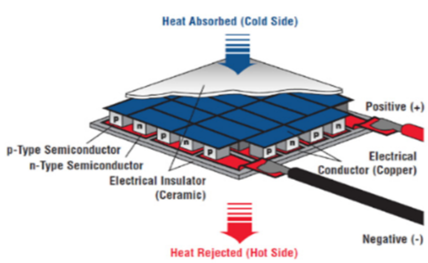

Figure 1. Thermoelectric Scheme Modules

The characteristics of a thermoelectric module depend on the Seebeck effect, the Peltier effect, and the Thompson effect. Potential differences arise in the circuit of two different conveying materials when there is a temperature difference at the connection or junction (Laird, 2013: 1). This generation system is called the Seebeck effect.

$$S = \frac{dV}{dT} \qquad (1)$$

Equation (1) shows the Seebeck coefficient (S) is the gradient of the change in voltage to temperature in a particular material. Seebeck coefficient is a nonlinear quantity as a function of temperature and depends on the material and molecular structure of the material.

Two p-type and n-type semiconductor materials are arranged in such a way, then the heat enters on one side and is disposed from another side. Movement of this heat will force the current carrier the majority of p-types and n-types for circulates as in Figure 2. This movement will produce a voltage difference between the tip of the p-type and n-type semiconductor material.

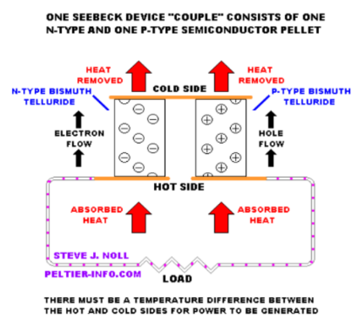

Figure 2. The working principle of the thermoelectric generator

This thermoelectric module will be placed in a series that connects heat and cold sources. In this research, heat is produced from the burning of Rice husk and wood sawdust waste. Research conducted by Maneewan (2009) by utilizing waste heat in a biomass-fueled dryer at a drying room temperature between 64 ^{0}C - 81 ^{0}C, using 12 types of thermoelectric generator modules capable of converting 4.08% of heat energy into electrical energy. With the amount of electrical energy generated 24.4 W. Whereas Nuwayhid conducts research by cooling the thermoelectric module using natural convection cooling. Applied to household wood stoves using a single module. The result is 4.2 W of electric power can be generated in this system.

Thermoelectric Permformance Analysis

Thermoelectric generator performance is determined by the parameters of the Seebeck coefficient (S_M), electrical resistance (R_M) and thermal conductivity (K_M). These parameters can be calculated by the equation (applies to temperature ranges –100 ^{0}C to +150 ^{0}C).
Seebeck coefficient (Buist 1983: 4)

$$S_{M_{TH}} = S_{M_{TC}} = s_1 T + \frac{s_2 T^2}{2} + \frac{s_3 T^3}{3} + \frac{s_4 T^4}{4}$$

$$S_M = (S_{M_{TH}} - S_{M_{TC}}) / \Delta T \qquad (2)$$

S_{MTH} is the hot side Seebeck coefficient and S_{MTC} is the cold side Seebeck coefficient. For modules with 71 semiconductor pairs with a current of 6 A, the value of $s_1 = 1.3345 \times 10^{-2}$, $s_2 = -5.37574 \times 10^{-5}$, $s_3 = 7.42731 \times 10^{-7}$, $s_4 = -1\,,27141 \times 10^{-9}$. Whereas electrical resistance (Buist 1983: 5)

$$R_{M_{TH}} = R_{M_{TC}} = r_1 T + \frac{r_2 T^2}{2} + \frac{r_3 T^3}{3} + \frac{r_4 T^4}{4}$$

$$R_M = (R_{M_{TH}} - R_{M_{TC}}) / \Delta T \qquad (3)$$

R_{MTH}, R_{MTC} and R_M are respectively hot, cold side and module electrical resistance. The coefficient for modules with 71 semiconductor pairs and 6 A currents is $r_1 = 2{,}08317$, $r_2 = -1{,}98763 \times 10^{-2}$, $r_3 = 8.53832 \times 10^{-5}$, $r_4 = -9{,}03143 \times 10^{-5}$. For thermal conductivity modules (Buist 1983: 5)

$$K_{M_{TH}} = K_{M_{TC}} = k_1 T + \frac{k_2 T^2}{2} + \frac{k_3 T^3}{3} + \frac{k_4 T^4}{4}$$

$$K_M = (K_{M_{TH}} - K_{M_{TC}}) / \Delta T \qquad (4)$$

where K_{MTH} is thermal side thermal conductivity, K_{MTC} is cold side thermal conductivity and K_M is module thermal conductivity. For modules with 71 semiconductor pairs and 6 A current has a coefficient of $k_1 = 4.7621 \times 10^{-1}$, $k_2 = -3.89821 \times 10^{-6}$, $k_3 = -8.64864 \times 10^{-6}$, $k_4 = 2{,}20869 \times 10^{-8}$. In this study the TEC 1- 12706 thermoelectric module with 127 semiconductor pairs and 6 A currents, then the S_M, R_M and K_M prices must be converted using the following equation (Buist 1983: 6)

$$S_{new} = S_M \times \frac{N_{new}}{71} \qquad (5)$$

$$R_{new} = R_M \times \frac{6}{I_{new}} \times \frac{N_{new}}{71} \qquad (6)$$

$$K_{new} = K_M \times \frac{I_{new}}{6} \times \frac{N_{new}}{71} \qquad (7)$$

with the S_{new} Seebeck coefficient of the new module, the R_{new} the electrical resistance of the new module and the K_{new} thermal conductivity module.

In this study because it is not efficiency measurements were taken part, then efficiency is defined as ratio Among the output power (P_{out}) generated by the thermoelectric generator with the input power from (Q_H) like equation 8.

$$\eta_G = \frac{P_{out}}{Q_H} \times 100\% \qquad (8)$$

With P_{out} is the generator output power whose value can be calculated by equation 9 (Duffie 1991: 37):

$$P_{out} = V_{out} \,.\, I = \frac{N \times S_N \times \Delta T}{4 \times R_N} \qquad (9)$$

V_{out} is the load voltage generated by TEG, I is the current generated by TEG. While Q_H is the energy value can be calculated with equation 10 (Duffie 1991: 24).

$$Q_H = (S_N \times T_H \times I) - (0{,}5 \times I^2 \times R_N) + (K_N \times \Delta T) \qquad (10)$$

2. Experiments Procedure

This research uses the experimental method. The research procedure was carried out in several stages including the study of literature, making software and hardware, designing, assembling and testing of the performance of the prototype thermoelectric generator.

Tools and materials used

1. 24 cm iron furnace × 8 cm × 9 cm with a base thickness of 5 mm
2. plates Stainless steel 30 cm × 9 cm × 1 mm
3. 7 pieces termoelectric generator TEC1-12706
4. Digital Multimeter *Heles UX 879 TR.*

5. LED lights 4 W
6. Arduino Uno, Arduino IDE and Comm Operator PAL
7. LCD 16 × 2 cm
8. Temperature sensor LM 75
9. Digital scales
10. Rice husks and sawdust

Design of thermoelectrick generator

Overall design of the thermoelectric generator in this research is shown in Figure 3.

Figure 3. Design of thermoelectrick

Design of thermoelectric generator in this research is consists of hot plate and cool plate from *stainless steel* material measuring 30 cm × 10 cm × 0.1 cm. Between the two plates are placed 7 module elements (in this study TEC1 - 12706) arranged in series, so that the generator can produce a greater voltage. TEC is glued together by thermal paste which is useful for perfect heat transfer process as shown in figure 4.

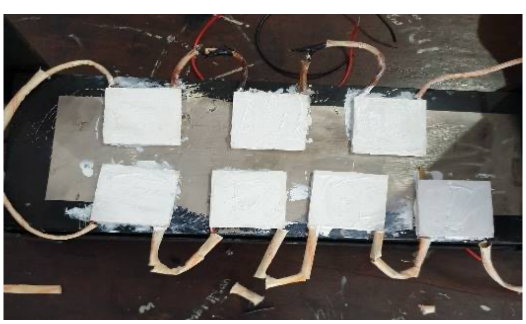

Figure 4. TEC Installation

TEC function is as a tool to convert heat energy into electrical energy. Rice husks and sawdust stoves are made of iron with a size of 24 cm x 8 cm x 9 cm with a thickness of 0.5 cm. This is intended so that the base of the furnace is flat and not curved, so that the hot side of the thermoelectric generator can adhere perfectly. The hot side of the thermoelectric generator is supplied from the heat from the combustion of Rice husk and sawdust, while the cold side uses cold water media which is inserted in the reservoir and at the bottom of the cold side is equipped with a water circulation system through two hoses to drain water from the reservoir with a capacity 1.5 liters go to the cold side and to dispose of the remaining water. The water functions as a cooler for thermoelectric elements.

Thermoelectric Testing

Testing Installation *Generator thermoelectric* can be seen in Figure 5.

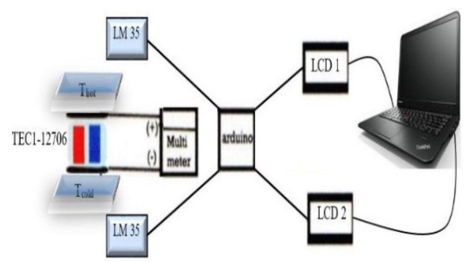

Figure 5. Thermoelectric generator test installation

Installation component consists of two LM 35 temperature sensors that are two thermocouples which are installed on the hot side and the cold side to detect heat (Thot) and cold temperature (Tcool). The real time and temperature read by the sensor are then processed by the Arduino Uno microcontroller and Arduino IDE software and the results are displayed on the LCD screen 1 and LCD 2. The data that appears on the LCD screen is integrated and can be stored in a laptop using the Comm Operator Pal every 2 minutes measurement for 10 minutes, while measuring the output voltage using a digital multimeter. The complete thermoelectric generator test equipment is shown in Figure 6.

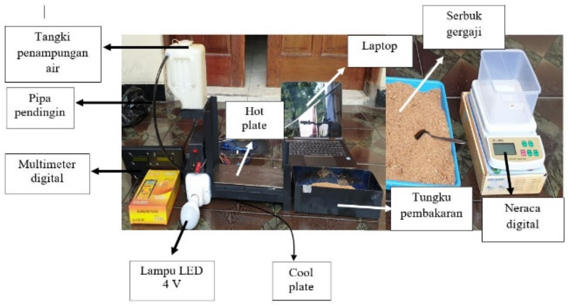

Figure 6. Thermoelectric generator test equipment

There are three variables used in this research. They are control variable, independent variable, and dependent variable. Control variables are quantities that do not change or are deliberately controlled so that they are of fixed value. In this research is the heating time and fuel mass. The independent variable is the amount whose value changes so that it can affect the results, in this research is the type of fuel (Rice husk, Sengon sawdust waste and Teak sawdust waste). The dependent variable is the variable that binds the research data, in this Research is the temperature T_{hot}, T_{cool}, output voltage and LED lights

Measurement of Generator Output Voltage

Measurement of output voltage is carried out with varying fuel on burning stoves (Rice husks, Sengon saws and Teak sawdust) to find out the best capabilities of thermoelectric generators. The increase in temperature and output voltage is measured with each increase of time for the first two minutes to the tenth minute. As an electrical load 4W LED lights are used as shown in Figure 7.

Figure 7. Measurement of the thermoelectric generator output voltage

3. Results and Discussion

This test is carried out to determine the output voltage generated, thermoelectric modules which are arranged in series when the module is loaded.

Testing the difference in temperature and time of the thermoelectric generator

Table 1. Results of testing the difference in temperature and time using three fuels

Real time (menit)	Sekam Padi			Serbuk Gergaji Kayu Sengon			Serbuk Gergaji Kayu Jati		
	T_{hot} (^0C)	T_{cool} (^0C)	ΔT (^0C)	T_{hot} (^0C)	T_{cool} (^0C)	ΔT (^0C)	T_{hot} (^0C)	T_{cool} (^0C)	ΔT (^0C)
0	25,39	21,48	3,91	29,30	25,88	3,42	25,39	21,48	3,91
2	36,13	22,46	13,67	45,41	28,32	17,09	52,73	25,39	27,34
4	52,73	25,39	27,34	58,11	29,79	28,32	79,68	29,30	50,38
6	65,92	28,81	37,11	74,71	30,76	43,95	90,82	27,83	62,99
8	79,68	29,30	50,38	80,02	29,79	50,23	92,29	27,79	64,50
10	90,35	29,79	60,56	92,29	29,79	62,50	104,00	27,83	76,17

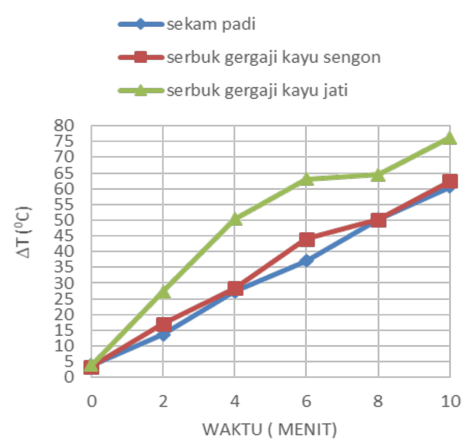

Figure 8. Graph of the difference between hot and cold temperatures and combustion time using three fuels

In Figure 8. it can be seen that the effect of burning time of Rice husk and sawdust waste on temperature difference between the hot and cold sides is directly proportional where the longer the combustion time it causes the greater the difference in temperature of the thermoelectric generator. The graph shows the temperature difference between the two sides of the thermoelectric module (ΔT) which changes every two minutes of heating time.

This is due to the unstable heating every minute and the ability of the cold side of the thermoelectric module to release heat.

The temperature on the cold side will increase due to the heat conduction from the hot side and the temperature on the hot side will change according to the heat received from the combustion, so that the heat will be channeled to the cold side of the generator design. When two or more objects occur in thermal contact, there will be a flow of heat from objects that have high temperatures to low temperature objects in accordance with the theory of heat transfer (Giancolli, 2011).

The graph in Figure 8 shows that the greatest ΔT reaches 76.17 ^{0}C which is in the tenth minute of fuel use Teak sawdust, it is because the heating value of Teak sawdust (5786 cal/g) is greater than the heating value of Sengon sawdust (3,500 cal/g) and Rice husk (3,300 cal/g). On the graph can also be seen that in the eighth minute for thermoelectric generators with Rice husk fuels and Sengon sawdust shows ΔT at 50 ^{0}C the difference is not so significant, this is because the values have almost the same heat rate

Testing the difference in temperature and thermoelectric output voltage

Tabel 2. Data from the test results of the difference in temperature and output voltage using three fuels

Real time (menit)	Sekam Padi			Serbuk Gergaji Kayu Sengon			Serbuk Gergaji Kayu Jati		
	ΔT (^{0}C)	V (volt)	Lampu LED	ΔT (^{0}C)	V (volt)	Lampu LED	ΔT (^{0}C)	V (volt)	Lampu LED
0	3,91	2,74	Redup	3,42	3,07	Terang	3,91	3,14	Terang
2	13,67	3,02	Terang	17,09	3,15	Terang	27,34	3,45	Terang
4	27,34	3,34	Terang	28,32	3,40	Terang	50,38	3,68	Terang
6	37,11	3,40	Terang	43,95	3,62	Terang	62,99	3,86	Terang
8	50,38	3,62	Terang	50,23	3,86	Terang	64,50	4,32	Terang
10	60,56	4,01	Terang	62,50	4,24	Terang	76,17	4,64	Terang

Figure 9 shows a graph of the relationship between ΔT and the thermoelectric generator output voltage. It can be seen that the output voltage will increase with increasing of ΔT. At the beginning of the combustion the output voltage produced from the combustion of Rice husk has a value below 3 volts, while for the combustion results of the Sengon sawdust and Teak sawdust the output voltage produced is more than 3 volts. The LED lights with Rice husk fuel starts bright when the multimeter shows a voltage of 3.02 volts with a temperature difference of 13.67 ^{0}C. The maximum output voltage of Rice husk is 4.01 volts with a temperature difference of 60.56 ^{0}C, Sengon sawdust by 4.24 volts with a temperature difference of 62.50 ^{0}C and Teak sawdust fuel of 4.64 volts with a temperature difference of 76.17 ^{0}C.

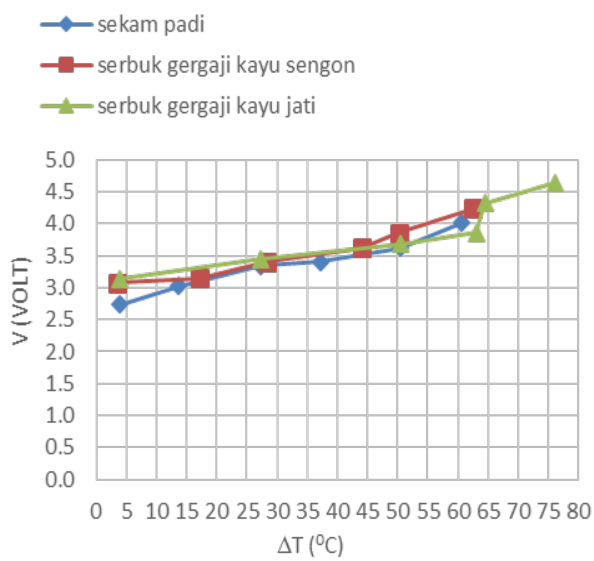

Figure 9. Graph of hot and cold temperature difference and generator output voltage

Thermoelectric output voltage generated by testing using Teak sawdust fuel is more optimal than the voltage generated by the fuel of Rice husk and Sengon sawdust, this is because the amount of heat absorbed and ΔT given by thermoelectric is more optimal using Teak sawdust. The measurement results above are in accordance with the Seebeck effect theory that the voltage produced is proportional to the temperature gradient, the higher the temperature difference (ΔT) obtained, the higher the voltage produced. The dimensions of the thermoelectric module used in this study are 40 mm × 40 mm × 3.8 mm with the number of semiconductors 127 and a current of 6 amperes, so the Seebeck coefficient value for the number of modules used (S_{new}) using equation (5) is 0.054 V /K.

Testing the difference in temperature and thermoelectric output power

Table 3. Data on the results of the difference in temperature and output power using three fuels

Real time (menit)	Sekam Padi			Serbuk Gergaji Kayu Sengon			Serbuk Gergaji Kayu Jati		
	ΔT (^{0}C)	V (volt)	P (watt)	ΔT (^{0}C)	V (volt)	P (watt)	ΔT (^{0}C)	V (volt)	P (watt)
0	3,91	2,74	0,05	3,42	3,07	0,04	3,91	3,14	0,05
2	13,67	3,02	0,62	17,09	3,15	0,99	27,34	3,45	2,55
4	27,34	3,34	2,55	28,32	3,40	2,77	50,38	3,68	8,89
6	37,11	3,40	4,78	43,95	3,62	6,76	62,99	3,86	13,93
8	50,38	3,62	8,89	50,23	3,86	8,84	64,50	4,32	14,61
10	60,56	4,01	12,90	62,50	4,24	13,74	76,17	4,64	20,38

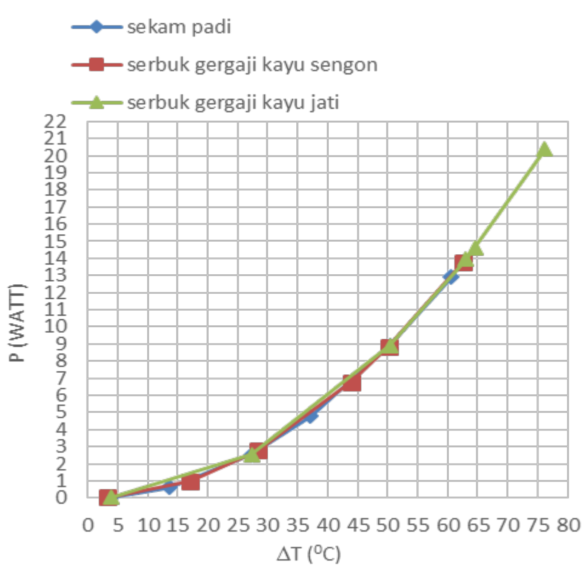

Figure 10. Graph of the difference between hot and cold temperatures and output power

Power is the ability of the work tool to produce electricity. Mathematically power is the multiplication of voltage and current. Output power is calculated using equation (9). From this equation can be simulated the effect of the number of thermoelectric series arrangement on the current generated. Figure 10 shows that the output power is directly proportional to the temperature difference between the hot side and the cold side. The maximum output power produced by a thermoelectric generator is 20.38 Watts when the temperature difference is 76.17 ^{0}C for Teak sawdust waste fuel.

Testing the difference in temperature and efficiency of the thermoelectric generator

Table 4. The temperature difference between the test data and using three fuel efficiency

Real time (menit)	Sekam Padi				Serbuk Gergaji Kayu Sengon				Serbuk Gergaji Kayu Jati			
	ΔT (^{0}C)	P (watt)	QH (watt)	η %	ΔT (^{0}C)	P (watt)	QH (watt)	η %	ΔT (^{0}C)	P (watt)	QH (watt)	η %
0	3,91	0,05	2,32	2,15	3,42	0,04	2,00	1,94	58,11	0,05	2,28	2,19
2	13,67	0,62	10,58	5,87	17,09	0,99	4,65	6,81	62,01	2,55	27,51	9,27
4	27,34	2,55	27,92	9,14	28,32	2,77	29,88	9,26	62,50	8,89	71,69	12,40
6	37,11	4,78	45,42	10,52	43,95	6,76	58,32	11,59	62,99	13,93	100,00	13,93
8	50,38	8,89	72,31	12,30	50,23	8,84	69,74	12,68	64,50	14,61	98,00	14,91
10	60,56	12,90	92,78	13,90	62,50	13,74	94,88	14,49	76,17	20,38	123,82	16,46
Rata - Rata	32,16	4,97	41,89	8,98	34,25	5,52	43,24	9,46	64,38	10,07	70,55	11,53

Figure 11. Graph difference in hot and cold temperatures and the efficiency of thermoelectric generator

Figure 11 illustrates the relationship of temperature difference between both sides of thermoelectric modules (ΔT) and the efficiency of thermoelectric generators (η_G). To determine the magnitude of the efficiency of the thermoelectric generator equation (8) is used. The efficiency is greatly influenced by the heat energy produced by the thermoelectric module and the output power, so the efficiency does not have a direct relationship with the temperature difference between the two sides of the thermoelectric module (ΔT). Figure 11 explains that the design of a generator system that uses

Teak sawdust fuel has the greatest efficiency of 16.46 % with a temperature difference of 76.17 ^{0}C compared to using Rice husk which only has an efficiency of 13.90 % or Sengon sawdust has an efficiency of 14.49 %

4. Conclusion

Based on the results of measurements, calculations and data analysis that has been done on the utilization of heat from the combustion of three types of waste (Rice husk, wood sawdust and wood sawdust teak) thermoelectric generator-based generators arranged in series produce conduction heat which can be utilized to convert heat energy into electrical energy.

Thermoelectric generator systems are capable of producing electrical energy by utilizing temperature differences. The use of different waste fuels (Rice husk, Sengon sawdust and Teak sawdust) affects the temperature difference in thermoelectric so that it also influences the source of output voltage provided by thermoelectric. The average temperature difference between the hot and cold sides of the results obtained from overall testing 32,16 ^{0}C for 34,25 ^{0}C Rice husk for Sengon sawdust and 64,38 ^{0}C for Teak sawdust, while the average output voltage was 3, respectively, 36 V, 3.56 V and 3.85 V.

The heat potential produced by burning Teak sawdust waste is the most optimal with the conduction heat transfer value of 123.82 Watts. The maximum electric power produced by thermoelectric is 20.38 Watts with a temperature difference obtained by thermoelectric at 76.17 ^{0}C using Teak sawdust waste fuel with the average efficiency of generator η = 16,46 %.

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References

[1] Burke, E., Buist. R., "Thermoelectric Coolers as Power Generators", 18th Intersociety Energy Conversion Engineering Conference, Orlando, Florida, 1983.

[2] Duffie, JA; Beckman, WA, 1991, "Solar Engineering of Thermal Processes", New York: John Wiley.

[3] Manewan, S., Chindaruksa, S., "Thermoelectric Power Generation System Using Waste Heat from Biomass Drying", J. Electronic Materials, 2009, Vol 38, no. 7

[4] Minister of Energy and Mineral Resources 2003, "Renewable Energy and Energy Conservation (Green Energy) Development Policy", Ministry of Energy and Mineral Resources, Jakarta.

[5] Nuwayhid, RY, Rowe, DM, and Min, G., "Low Cost Stove - Top Thermoelectric Generator for Region with Unreliable Electricity Supply", J. Renewable Energy, 2003, 29 pp. 205 - 222.

[6] Nuwayhid, RY, Hamade, R., "Design and Testing of a Locally Made Loop Type Thermosyphonic Heat Sink for Stove Top Thermoelectric Generators", J. Renewable Energy 2005, 30, pp. 11011116.

[7] Nurhadi Budi Santosa, 2015, "Get to know Thermoelectric (Peltier)", PPPPTK BOE Malang.

[8] Sumarjo Jojo, Santosa, Permana Imron, "Utilization of the heat source of the stove using 10 thermoelectric generators arranged in series for lighting applications", J. Machine Technology (SINTEK Journal), 2017, Volume 11, no 2.

[9] Harli Priscilla. S., Aji Nur. W., Setiawan. A. Prototype Testing of Used Cooking Oil Thermoelectric Generators, J. J. Electricity and Renewable energy, 2013, volume 12, no 2.

[10] Muamar K., Mahdi. S., Mansur. G., "Utilization of Heat Energy as a Small-Scale Alternative Electric Power Plant Using Thermoelectrics", J. Online Electrical Engineering, 2016, vol 1 no 3.

[11] Thermoelectric / peltier cooling, www. Thermo.Com (accessed June 21, 2019).

[12] Peltier Device Information Directory, www.PELTIER-INFO. Com (accessed June 21, 2019).

[13] Priadi, Yudhi. "Thermoelectric Turns Thermal Energy into Electricity", www.yudhipri.wordpress.com/2010/07/05 (accessed June 22, 2019).