Utilization of condenser waste heat of cold storage as energy conversion system based on thermoelectric generators

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Abstract. The energy conversion system based on thermoelectric generator (TEG) is a system that functions to convert heat energy from temperature differences into electrical energy. One of the heat sources that can be used is condenser waste heat. The condenser heat has a temperature of around 60-70 °C which could potentially be used as an energy source based on thermoelectric generators. This study aims to design an energy conversion system from condenser waste heat in a cold storage. The system design will be tested for variations in the series, parallel, and series-parallel TEG configurations. The second test used a temperature variation of 40 - 110 °C with an increase of 10 °C. The results showed that variations in the TEG configuration and temperature used in the thermoelectric generator had a major influence on the power produced. The series configuration is the best configuration that can produce the greatest power. The temperature that can produce the greatest power in this study is 110 °C where the higher the temperature, the higher the power produced. However, the test carried out on the condenser waste heat in cold storage produces quite a small amount of power because the temperature difference between the cold side and the hot side is relatively low so that the power produced is small. Then the test with a stabilizer also produces small power and an unstable current so that it cannot be used as an energy source in a power bank. However, this shows that condenser waste heat has good potential and prospects as an alternative energy source based on thermoelectric generators.

1. Introduction
Along with the increase in the world’s population, energy needs are increasing day by day. The rapid industrialization accompanied by demographic changes has depleted the natural resources and energy that exist on this earth. Economic and population growth continues to drive the need for energy, so that energy problems are increasingly complex and entrenched in Indonesia. According to the Agency for the Assessment and Application of Technology (2018) the population growth rate of 0.71% per year and an average GDP of 6.04% per year resulted in an increase in final energy demand by 5.3% per year during 2016-2050. In 2016, energy demand will increase from 795 million BOE to 4,569 million BOE in 2050. The share of energy demand in the industrial sector increases from 35.5% in 2016 to 46.8% in 2050. Electricity demand is projected to increase more than 7 times to 1,611 TWh in 2050. Meanwhile, electricity production will grow by an average of 6% per year from 250 TWh to 1,767 TWh [1].

According to Nurdin et al, (2013) thermoelectric is a tool for converting temperature differences into a potential difference and vice versa [2]. Thermoelectricity is influenced by three effects, the Seebeck, Thompson and Peltier effects. The Seebeck effect illustrates that if two metal materials
(semiconductors) are connected in an environment with two different temperatures, then the material will flow electric current or electromotive force [3]. Thermoelectric generators are small plate-shaped devices that operate as heating machines by converting heat directly into electricity [4]. According to Salim et al. (2018) on the characteristics of the thermoelectric generator and thermoelectric cooler with variations in resistor loading and setting the temperature difference between the two sides of the element at 70 °C, the value of the electric voltage is generated using a 1.48 V thermoelectric generator and a 1.02 V thermoelectric cooler [5]. Based on Reyanuargo et al. (2013) thermoelectricity of hot steam AC condenser can produce a voltage of 3.14 volts and 0.16 watts of power at an average temperature difference of 34 °C [6]. Cold storage is a cooling machine that accommodates objects that will undergo a cooling process. Cold storage units are commonly used in everyday life to cool or preserve foods such as meat, vegetables and fruits as well as drinks [7], [8]. Cold storage is a cooling machine that has low efficiency, so that a lot of energy is wasted, 30% of the waste heat of the cooling system has a potential power of 0.66 k [9]. The waste heat with a high enough temperature and a long operating time of 24 hours can be used as a thermoelectric heat source for the generator.

The voltage generated by the thermoelectric is influenced by differences in temperature. According to Mustakim (2018) in testing the cooling performance of the best cooling variation is water with the highest temperature difference of 48.3 °C, while the air conditioner with the highest temperature difference is 21.9 °C [10]–[12]. So that by using water or cooling liquid, the optimal thermoelectric voltage will be obtained.

Based on the above factors, it is necessary to have new and renewable innovations, namely using a thermoelectric generator with a cold storage condenser waste heat source. The thermoelectric generator uses the condenser waste heat as the hot side and uses water as the cold side. The aim of this study is to design an energy conversion system from condenser waste heat in a cold storage.

2. Methodology

2.1. Design of Energy Conversion System based on Thermoelectric Generator (TEG)

The design of energy conversion system based on Thermoelectric Generator (TEG) by using Autocad 2007 can be shown in Figure 1 and 2. Figure 3 and 4 are the specification every part of energy conversion system based on Thermoelectric Generator (TEG) design.

![Figure 1](image1.png)

**Figure 1.** Part of the energy conversion system based on Thermoelectric Generator
Figure 2. Design of Energy Conversion System based on Thermoelectric Generator

Figure 3. Design of Conductor (in mm), Front View (a), Top View (b) and Side View (c)
2.2. Manufacture of an Energy Conversion System based Thermoelectric Generator (TEG)

The manufacture of an energy conversion system based thermoelectric generator consists of 5 main components including a condenser waste heat pipe, conductor, cooling system, voltage stabilizer and battery.

![Block Diagram of the Energy Conversion System](image)

**Figure 5.** Block Diagram of the Energy Conversion System
A conductor is an object that can conduct heat. The conductor in this study serves to transfer heat from the condenser waste heat to the thermoelectric module and serves to expand the heat-received surface of the thermoelectric module. The material used as a conductor in this study is aluminium. In the conductor, there is the addition of a clamp which is used to attach the conductor to the condenser pipe so that it can be attached to the condenser pipe.

The type of thermoelectric used is TEG SP1848. The existing thermoelectric modules are arranged in series and parallel to determine the effect of the thermoelectric configuration on the output voltage and current. The cooling system functions as a thermoelectric cooler so that the temperature difference between the hot side and the cold side is higher. The cooling system used in this study is a water cooling system. The cooling system consists of a water pump, water block, radiator, fan and water. The water in this generating system functions as a coolant in the thermoelectric to increase the temperature difference on the cold and hot thermoelectric sides. The water pump is used as a water line to the thermoelectric with a voltage source from the power supply. The radiator is used as a container for water as well as cools the water. Water block is used as a conductor between water and thermoelectric.

The voltage source generated by the thermoelectric is then flowed to the charger module so that the current and voltage released are in accordance with the input or specifications of the battery used. Battery specifications used are 3.7 V and 1 A.

To determine the potential of electrical energy generated by the exhaust heat of cold storage condenser, a test was carried out without stabilizers and with stabilizers. The test was carried out with three repetitions and the data obtained were the voltage on the thermoelectric generator, external resistance, current in the thermoelectric, heat source temperature, cold side temperature, hot side temperature, voltage on the voltage stabilizer, current on the voltage stabilizer and time.

2.3. Performance Test of an Energy Conversion System based Thermoelectric Generator (TEG)
The test is carried out by applying a thermoelectric generator system that has been made on the hot pipe of the cold storage condenser in order to utilize the power source generated. Data collection was carried out in two stages. First, this data collection is done by varying the thermoelectric configurations in series, parallel and series parallel with a fixed resistor load. The best configuration will be used for the next test. The best configuration indicator is to produce the greatest power and is suitable for use as a charge. The data obtained at this stage include the voltage on the thermoelectric, current, cold side temperature, hot side temperature, and the thermoelectric resistance of the generator. Second, the test is done by varying temperature of TEG hot side. The temperature variations used are 40 °C, 50 °C, 60 °C, 70 °C, 90 °C, 100 °C, and 110 °C.

The analysis of data is using equations below [13]. The power calculated by using equation (1)

\[ P = V \times I \]  

The efficiency of the thermoelectric generator system can be calculated by equation (2).

\[ \eta = \frac{P}{Q_h} \times 100\% \]  

Equation (3) is to calculation of heat absorbed.

\[ Q_h = n (\alpha T_h I - 0.5 I^2 R + K \Delta T) \]  

Seebeck coefficient is calculated by using equation (4).

\[ \alpha = \frac{V}{\Delta T \times n} \]  

Thermal conductance is calculated by using equation (5).

\[ K = k \frac{A}{L} \]  

Then the resistance is calculated by using equation (6).
\[ \Sigma \varepsilon + \Sigma (R_2 + R_{Int}) = 0 \]  \hspace{1cm} (6)

Nomenclature:
P = Power (Watt)
V = Voltage (Volt)
I = Current (Ampere)
\( \eta \) = Efficiency of the thermoelectric generator (%)
P = Power produced by the thermoelectric generator (W)
Q_h = Heat absorbed by the thermal side of the thermoelectric (W)
k = Thermal conductivity (W/mK)
K = Thermal conductance (W/K)
A = Cross-sectional area (m^2)
L = Thickness (m)
\( T_o \) = Temperature at condenser heat pipe (K)
\( T_h \) = Thermoelectric hot side temperature (K)
\( T_c \) = Thermoelectric cold side temperature (K)
\( \Delta T \) = Temperature difference between the hot and cold sides (K)
\( \alpha \) = Seebeck coefficient (V/K)
x = Number of thermoelectric modules
n= Number of thermoelectric thermocouples
\( R_L \) = External resistance (Ω)
\( R \) = Internal resistance (Ω)

3. Results and Discussion
In this study, data has been obtained including time, condenser pipe temperature (\( T_1 \)), conductor temperature (\( T_h \)), coolant temperature (\( T_c \)), TEG output current (\( I_1 \)), TEG output voltage (\( V_1 \)), voltage stabilizer output current (\( V_2 \)), and the output current of the voltage stabilizer (\( I_2 \)). Based on observations, the condenser does not work for 24 hours but works when the temperature in the cold storage rises. When the desired cold storage temperature has been reached, the condenser will shut off. In the first test the condenser turns off when the cold storage temperature reaches -24 °C and turns on again at -19 °C. Then the test is carried out again when the cold storage is empty and the condenser turns off at -25 °C then turns on again at 10 °C.

3.1. Design of Energy Conversion System based Thermoelectric Generator (TEG)
Energy conversion system based thermoelectric generator is a thermoelectric generator system by utilizing condenser waste heat as a source of heat energy and using circulated water as the cooling system. The number of thermoelectric used is 5 types of TEG SP 1848. The stages of the process of manufacture a generator system based on a thermoelectric generator starts from the design process, the process of manufacture a conductor, and the manufacture of the cooling system. The results of the process of making an energy conversion system based thermoelectric generator will be described in detail as follows:

a. Conductor Manufacturing
The conductor is a component that functions as a medium for transferring heat from one point to another. In this study, the condenser pipe used as a test is a pipe with a diameter of 4.2 cm. Meanwhile, the 4 x 4 cm thermoelectric surface will not completely stick to the cylindrical condenser waste heat pipe. This will reduce the energy received by the thermoelectric plate generator. Therefore a conductor of a suitable size is given as a medium to expand the thermoelectric surface which is exposed to heat so that the heat energy received is greater. As with the conduction transfer theory which states that the amount of energy from conduction heat transfer is proportional to the value of thermal conductivity, cross-sectional area, and is proportional to the thickness. The greater the value of thermal conductivity and cross-sectional area, the greater the energy received. Meanwhile, the
greater the thickness of the conductor, the smaller the energy received. Thus, the conductor in this study uses aluminium with a high thermal conductivity of 205 W/m °C and a total thickness of 1.8 cm. The conductor is also given a clamp which functions to attach the conductor to the condenser and coolant pipes. The manufacturing result of the conductor can be shown in Figure 6.

![Image of aluminium conductor and clamp]

**Figure 6. Aluminium Conductor and Clamp**

b. **TEG Cooling System Manufacturing**

The cooling system functions to cool the cold side of the thermoelectric generator so that the temperature difference between the cold side and the hot side increases. The cooling system used is a water cooling system. This cooling system consists of water fluid, water block, pump, mini radiator and fan. The manufacturing results of the cooling system are shown in Figure 7.

![Image of cooling system]

**Figure 7. Cooling System**

The working system in this cooler is to utilize the heat transfer system in the fluid, when the water block is attached to the cold side of the thermoelectric, the water block will receive heat and the fluid temperature increases. Then the fluid in the water block will be sucked in by the water pump which will flow to the radiator. On the radiator itself, there are fins which function to expand the surface and accelerate the transfer of hot water fluid to the environment. On the radiator there is also a fan which functions to accelerate heat transfer from the fins to the environment so that the fluid temperature in the radiator decreases. The low temperature fluid is pumped into the water block and the heat transfer of the water block with the thermoelectric cold side occurs. The system works continuously.
c. **TEG System Manufacturing**

The TEG system used in this study consists of a thermoelectric configuration, voltage stabilizer, and battery. There are 5 thermoelectric used in series, parallel and series parallel. The other component used is a voltage stabilizer with an input specification of 3-5 volts and an output of 5 volts and a DC input of 0.9-5 Volt 5V USB. The stabilizer serves to increase and stabilize the voltage so that it can be used as a charge. Then the power bank used has an input specification of 5V and 1 A. The TEG system can be shown in Figure 8.

![Figure 8. TEG System (a) series, (b) series-parallel, (c) parallel](image)

### 3.2. Performance Test Results

Preliminary testing is carried out to determine the initial performance of the energy conversion system based TEG. In the first preliminary test, it is known that the system is working properly which can produce a current of 105 mA at a fixed 10 Ohm resistor load and produce a current of 24.8 mA at the LED load. This first preliminary test system shows that the cooling system and conversion system are working well and can be tested further. The second preliminary test on the cold storage condenser shows that the system works well, the conductor can stick well to the condenser pipe without any shift. The cooling system functions normally by keeping the side temperature stable and the conversion system can produce output power.

a. **The Characteristics of TEG SP1848**

Thermoelectric generator is a module that functions to convert heat into electricity. TEG SP 1848 is a type of thermoelectric that is easily found in Indonesia. TEG SP 1848 can accept a maximum temperature of 125 °C. If the received temperature exceeds the maximum temperature then the TEG is damaged. TEG SP1848 can be used for 24 hours without causing damage, but the power output is not optimal. The dimensions of the SP1848 TEG module are 4 x 4 x 0.3 cm. TEG SP1848 has a conductance of 0.0025 W/K.

b. **Effect of Temperature and TEG Configurations on Power**

Based on testing temperature variations and circuits, the relationship between temperature and power is obtained as in Figure 9.
Figure 9 shows the relationship between TEG hot side temperature and TEG configurations on power. The resistance used for this test is 10 Ω. Based on Figure 9, the power value is linear with the TEG hot side temperature. The greater the temperature value of the TEG hot side, the output power also increases. At conditions of 40 °C, the series, parallel and series parallel configurations power are obtained respectively 0.035 W, 0.004 W and 0.01 W. Meanwhile, at the TEG hot side temperature of 110 °C, the power is 1.52 W, 0.34 W, and 0.864 W in series, parallel, and series parallel configurations, respectively. The results of these two conditions indicate that an increase in temperature from 40 °C to 110 °C also increases the power. These results are linear with research conducted by Djafar et al. (2014), the design that can produce the highest power is the thermoelectric in a series configuration, which can produce a power of 19.9 W, while the thermoelectric connected in parallel can produce 2.78 W in temperature difference of 12°C [14]. As well as the results of research conducted by Putra (2009), that there is an increase in maximum power up to 8 Watts at a temperature difference of 40 °C and produces 3 Watts of power at a temperature difference of 15 °C [3]. The increase in power in each variation is caused by the TEG configurations, the current and voltage generated by the series configuration is greater than that of the parallel and series parallel configurations, so the power generated is also large. The results of this test can be said that the series configuration is the best series that can produce the highest power. So to make a good energy conversion system it is necessary to use a series configuration.

c. Effect of Changes in Thermoelectric Hot Side Temperature on Current and Voltage

In testing the thermoelectric generator system with variations in temperature and circuit, a graph of the relationship between temperature and voltage and current is obtained as shown in Figure 10.
Figure 10. Graph of the Effect of Changes in Temperature on Current (a) and Voltage (b)

Figure 10 shows that increasing in the temperature of the TEG hot side, the currents and voltages in all circuits will also increase. The voltage obtained at the TEG hot side temperature conditions of 40 °C in a series of 0.5 V, in parallel of 0.1 V and in series parallel of 0.2 V. While the current value was obtained in series is 0.07 A, 0.04 A in parallel and 0.05 A in series parallel. At the TEG hot side temperature conditions of 110 °C, the series voltage is 3.8 V, the parallel voltage is 1.7 V and the series parallel voltage is 2.7 V. While the current value obtained in the same conditions in the series circuit is 0.4 A, in the parallel circuit is 0.2 A and series parallel circuit is 0.32 A. So that in this case the temperature increase on the hot side of the TEG is linear with current and voltage values.

To produce high currents and voltages, it is necessary to have a high TEG hot side temperature. The results also showed that the higher the heat received by the thermoelectric generator, the higher the resulting voltage and current. As in research by Djafar (2008), the test for hot fluid temperatures from 35 °C to 50 °C obtained a temperature difference from 4.25 °C to 15.8 °C and produced a voltage of 139.3 mV to 581.5 mV [14].

d. Effect on of temperature difference (ΔT) on power (P) and efficiency (η)

Based on Figure 11, it can be seen that there is no significant change in power and efficiency to changes in temperature differences because in testing the temperature increase is not significant. However, the effect of temperature differences on power can be attributed to previous tests where the hot side temperature was proportional to the power produced. Thus, the temperature difference can be said to be linear with power and efficiency. The greater the temperature difference, the greater the power to be generated and the system the more efficient. The test results show that power and efficiency are directly proportional. The greater the power produced, the efficiency will also increase. In this test, an efficiency of 2.3% is obtained when the power is 0.133 W and an efficiency of 2% is obtained at the resulting power condition of 0.114 W. As in the theory that efficiency is the ratio between the heat absorbed by the thermoelectric (Qh) and the power (P) generated by the thermoelectric. So that to increase the thermoelectric efficiency is necessary to increase the power of the thermoelectric. Meanwhile, to increase the thermoelectric efficiency, it is necessary to increase the value of the temperature difference between the cold side and the hot side.

The test results of using condenser exhaust heat as an energy conversion system based on thermoelectric generator obtained an average power and efficiency of 0.129 W and 2%. The average voltage generated in the test is 1.578 V. If it is assumed that the voltage for each TEG is the same, then each TEG produces a voltage of 0.3 V. This voltage is higher than previous research, 0.174 V conducted by[15]. While the power and efficiency produced are relatively the same when compared to the research of Kumar et al., namely 2.21%. The value of this efficiency value is influenced by several factors, especially at a high enough ambient temperature, which causes the cold side temperature to not be maximized and affects the value of the difference in temperature and power generated [16].
However, the test results show that the condenser exhaust heat has the potential to be a thermoelectric generator based power plant if it is designed on a large scale and has good prospects as an alternative energy that utilizes exhaust heat and is environmentally friendly.

![Graph showing the relationship between temperature difference (ΔT) to power (P) and efficiency (η).](image)

**Figure 11.** The relationship between temperature difference (ΔT) to power (P) and efficiency (η)

### 4. Conclusion

The energy conversion system based on a thermoelectric generator consists of thermoelectric generator configurations, conductor, clamp, voltage stabilizer, battery and cooling system. The performance testing has been done by varying the TEG configurations, the temperature of TEG hot side of 40 °C -110 °C and using fix resistance of 10 Ω. The increase in power in each variation is caused by the TEG configurations, the current and voltage generated by the series configuration is greater than the parallel and series parallel configurations. The series configuration of TEG is the best configuration that can produce the highest power than other configurations. The relationship between TEG hot side temperature and power, current and voltage are the greater the temperature the greater the power, voltage and current values. The test results of using condenser waste heat as an energy conversion system based on thermoelectric generator obtained an average power and efficiency of 0.129 W and 2%, respectively.

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