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Experimental Test of the Thermoelectric Performance on the Dispenser Cooler

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Abstract— **This study aims to find out of the cooling performance of thermoelectric coolers with single, double series, and double parallel circuit. The experiment was conducted in the Cooling and Heating laboratory of Mechanical Engineering Department, Hasanuddin University, Makassar. The data taken were hot side temperature, cold side temperature, water temperature, and ambient temperature. Data analysis was carried out on water temperature, temperature difference, absorbed heat, and COP with some variations of thermoelectric circuit and DC electric voltage in 360-minute period. The result reveal that the best module was the double thermoelectric arranged with a series circuit in the voltage of 10 V. This could be seen after 360 minutes with cold water temperature of 12°C, temperature difference of 28°C, absorbed heat of 19.52810 and COP of 1.25268.**

Keywords: ***thermoelectric cooler , water temperature, DC electric voltage.***

I. INTRODUCTION

The national need for energy is increasing along with the growth of national economy that needs the efforts to ensure the continuous availability of energy in sufficient quantity and quality at a reasonable price level. With the decreasing amount of energy derived from fossil, humans are trying to find new sources of alternative energy. One of the solutions that can be used to generate energy and is environmentally friendly is by using thermoelectric.

The selection of the thermoelectric module specification is based on the heat load, the temperature difference and the electrical parameters used. Thermoelectric cooler has several advantages including no noise, easy maintenance, environmentally friendly and does not require a lot of additional components. In addition, another benefit of thermoelectric cooler as the engine is able to reduce air pollution and Ozone Depleting Substances (ODSs) because it no longer uses Hydrochlorofluorocarbons (HCFCs) and Chlorofluorocarbons (CFCs) known as Ozone Depleting Substances (ODSs) [1].

Thermoelectric first discovered in 1821 by the German scientist Thomas Johann Seebeck. He connected copper and iron in a circuit. Between the two metals are then placed compass needle. When the metal is heated, it turns the compass needle move. Later known, it happens because electricity that occurs in metals cause the magnetic field. This magnetic field that moves a compass needle. This phenomenon known as the Seebeck effect [2].

Seebeck's discovery inspires Jean Charles Athanase Peltier to examine the opposite of the phenomenon. He flows the electric discharge on two metal pieces glued together in a series. When electrical power is applied, the heat absorption occurs at the junction of the two metals and heat release in another connection. This heat release and absorption revert each other when the current is reverted . The discovery which occurred in 1934 then known as the Peltier effect [3]. Seebeck and Peltier effect is then the basic for the development of thermoelectric technology.

Simple mode of cooling is by using a thermoelectric device. However, due to the limits of thermoelectric materials performance, one degree of the thermoelectric cooler machine can only be operated with a small temperature range. If the temperature ratio between the heatsink and cooling is large, then the coolant engine with one degree of thermoelectric will lose its effectiveness. Thus, the application of thermoelectric with two or more levels are combined in the coolant engine is an important method to improve the performance of thermoelectric [4].

II. THEORETICAL FOUNDATION

A thermoelectric device works by converting heat energy directly into electricity (thermoelectric generators), or otherwise, the electricity generating cold (thermoelectric coolers). Thermoelectric module composed by semiconductor material arrangement (usually Bismuth Telluride) which uses three principles of thermodynamics, known as Seebeck effect, Peltier and Thomson. Its construction consists of a pair of P-type semiconductor material and N-type which forms thermocouple like a sandwich between two thin ceramic wafers [5].

Thermoelectric cooler (TEC), which is a semiconductor circuit by utilizing the Peltier effect has been used as a cooling device on some mini cooling system. In which cooling has become a necessity in modern society that has been proven to improve the quality in terms of taste and hygiene of food and beverages [6].

Generally, thermoelectric module, has a measurement of 40mmx40mm or smaller and has less than 4 mm thick. Age of a thermoelectric module in accordance with the industry standard is about 100,000-200,000 hours and more than 20 years when used as a coolant, and by the number and voltage which is appropriate with the characteristics of each module [5].

Test using thermoelectric cooler module is the application of the Peltier effect to move heat. Thermoelectric cooler which is used consists of a number of pairs of P-type and N-type semiconductor connected in series and parallel thermal electricity. Heat which is pumped directly can be changed by changing the pole which is flowed by DC electricity. The thermoelectric semiconductor material composed of N-type made from a mixture of bismuth-telluride-selenium (BiTeSe) and P type made from a mixture of bismuth-antimony-telluride (BiTeSb). The use of bismuth telluride on thermoelectric cooler based on some studies that suggest that bismuth telluride is a material that has the best performance even though it has limitations on the heat temperature [7].

In this study we want to know the performance of cooler using single, double series, and double parallel assembled thermoelectric cooler.

In analyzing the performance of thermoelectric modules can be observed in Figure 1, the heat transfer occurs from the heat load to the cold side of the thermoelectric module can be determined from the amount of heat that is pumped by the Peltier effect, heat moves from the hot side to the cold side because the thermal conductivity of thermoelectric materials, and partly of the total Joule heating effect generated by the electric current to thermal resistance [8].

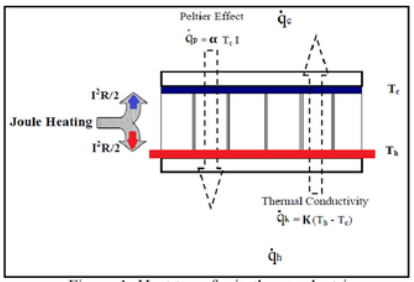

Figure 1. Heat transfer in thermoelectric

Heat pumped by the Peltier effect

Heat which is pumped by the Peltier effect (q_p) is the electrical energy which is supplied and can be known by determining the value of the Seebeck coefficient (α), the cold side temperature (Tc), and the electric current supplied to the thermoelectric (I).

$$\dot{q}_p = \alpha \cdot T_c \cdot I \quad (1)$$

Heat transfer because of thermal conductivity

The amount of heat move due to thermal conductivity (q_k) is influenced by the magnitude of the thermal conductivity (K) and the value of the temperature difference (ΔT).

$$\dot{q}_k = K . \Delta T \quad (2)$$

Joule heating effect generated by the electric current

Joule heating effect (q_J) is the heat loss that occurs as a result of electrical current which can be determined from the value of the square of the electric current (I) and electrical resistance (R) and assumed to be divided toward the cold side and hot side.

$$\dot{q}_J = \frac{I^2 \cdot R}{2} \quad (3)$$

Heat absorbed at the cold side of the thermoelectric module

$$\dot{q}_c = \alpha \cdot T_c \cdot I - K . \Delta T - \frac{I^2 \cdot R}{2} \quad (4)$$

Heat released at the hot side of the thermoelectric module

$$\dot{q}_h = \alpha \cdot T_c \cdot I - K . \Delta T + \frac{I^2 \cdot R}{2} \quad (5)$$

As described above, to determine the absorbed calorific value (q_c) and the released heat (q_h) on thermoelectric can be written in equation (4) and (5), where the first term is given electrical energy, the second term is the heat energy transmitted by conduction, and the third term is the loss of heat due to electrical current.

Based on the type of thermoelectric modules used, TEC1-12706, number of connection elements (N) is 127 so that the thermoelectric module is twice of the number of connection elements (2N).

Seebeck coefficient value element (α_m), thermal conductivity element (Km), and the thermal resistance elements (ρ) usually can be seen from the data vendors or from the corresponding equations form a thermoelectric material, in this case the material used is Bismuth Telluride.

Seebeck coefficient

Value of the Seebeck coefficient (α) is determined by the value of the Seebeck coefficient element (α_m) and the number of elements on the thermoelectric modules.

$$\alpha = 2 . \alpha_m . N \quad (6)$$

Seebeck coefficient of the element

$$\alpha_m = \alpha_0 + \alpha_1 T_{ave} + \alpha_2 T_{ave}^{\ 2} \quad (7)$$

α_0 = 2.2224 x 10-5; α_1 = 9306 x 10-7; α_2 = -9905 x 10-10

Thermal conductivity

The amount of the thermal conductivity (K) is determined by the thermal conductivity of the element (Km), the geometry factor (G), and the number of elements on the thermoelectric modules.

$$K = 2 . K_m . N . G \quad (8)$$

Thermal conductivity of the element

$$K_m = K_0 + K_1 T_{ave} + K_2 T_{ave}^{\ 2} \quad (9)$$

K_0 = 6.2605 x 10-2; K_1 = -2777 x 10-4; K_2 = 4,131 x 10-7

Electrical resistivity

The amount of electrical resistance (R) is determined by electrical resistance elements (ρ), the geometry factor (G), and the number of elements on the thermoelectric modules.

$$R = \frac{2.\rho.N}{G} \quad (10)$$

Electrical resistivity of the element

$$\rho = \rho_0 + \rho_1 T_{ave} + \rho_2 {T_{ave}}^2 \quad (11)$$

$\rho_0 = 5.112 \times 10^{-5}$; $\rho_1 = 1.634 \times 10^{-6}$; $\rho_2 = 6.279 \times 10^{-9}$

By substituting equation number (6), (8), (10) into equation number (4) can be obtained calorific value which is absorbed at the cold side of the thermoelectric module:

$$\dot{q}_c = 2N\left[\alpha_m . I . T_c - K_m . \Delta T . G - \left(\frac{I^2\rho}{2G}\right)\right] \quad (12)$$

By substituting equation number (6), (8), (10) to equation number (4) can be obtained calorific value which is released on the hot side of the thermoelectric module:

$$\dot{q}_h = 2N\left[\alpha_m . I . T_c - K_m . \Delta T . G + \left(\frac{I^2\rho}{2G}\right)\right] \quad (13)$$

The electric power supplied to the thermoelectric module

The amount of electrical power supplied to the thermoelectric module influenced the size of the electric current (I) and the amount of the electrical resistance (R).

$$P_{in} = I^2.R \quad (14)$$

Energy equilibrium

According to the working principle of thermoelectric based on Peltier effect, heat is absorbed from the cold side by q_c and the heat released to the environment by qh. The difference between the two is the amount of electrical power required or $P_{in} = q_h - q_c$ [9] so that the thermoelectric energy equilibrium can be written in the following equation:

$$\dot{q}_h = \dot{q}_c + P_{in} \quad (15)$$

Figure of merit

Figure of merit (Z) is the default for determining the efficiency of thermoelectric materials. If the value of Z increases the capability of thermoelectric materials also increased. Figure of merit value varies depending on the needs of the thermoelectric material temperature [7].

$$Z = \frac{{\alpha_m}^2}{\rho . K_m} \quad (16)$$

Coefficient of Performance (COP)

COP is a measure of the efficiency of a thermoelectric cooler that can be seen from the comparison of the amount of heat absorbed at the cold side (q_c) to the amount of incoming power (P_{in}) [5].

$$COP = \frac{q_c}{P_{in}} \quad (17)$$

Average heat absorbed at the cold side of the thermoelectric module up to 360 minutes

Average heat can be determined by determining the total heat absorbed at the cold side (Σq_c) the amount of heat absorption occurs (Σn).

$$\bar{q}_c = \frac{\Sigma \dot{q}_c}{\Sigma n} \quad (18)$$

Heat absorbed from the water

Heat absorbed from the water can be determined by determining the value of the mass of water (m), specific heat of water (Cp), and the difference between water temperature (ΔTw) and time difference (Δt).

$$\dot{q}_w = \frac{m \cdot C_p \cdot \Delta T_w}{\Delta t} \quad (19)$$

Average heat absorbed from the water up to 360 minutes

Average heat can be determined by determining the total heat absorbed from water (Σq_w) against the amount of absorption of heat occurs (Σn).

$$\bar{q}_w = \frac{\Sigma \dot{q}_w}{\Sigma n} \quad (20)$$

III. Research Methodology

The research method used is the experimental method. Thermoelectric performance testing carried out by variation of the DC power supply given, which is 8 V, 10 V, 12 V and variation of module by using single module, multiple series module, and multiple parallel module with a 360-minute long test as shown in Figure 1 and Figure 2 .

Data collection was performed by measuring the cold side, hot side , water temperature, and ambient temperature using a thermocouple and a temperature controller. Determination of the value of the element geometry factor (G) is using the AZTEC software; version 3.1 [10]. Data processing done by calculating the calorific value absorbed, heat removed, the electrical power used, figures of merit, and COP.

Single Thermoelectric Testing Installation

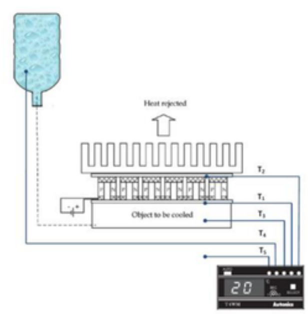

Figure2. Single Thermoelectric Testing Installation

Double Thermoelectric Testing Installation

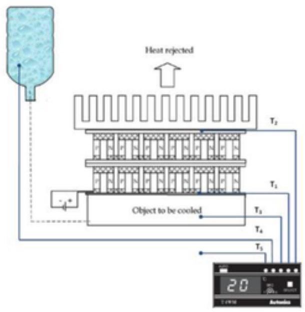

Figure 3. Double Thermoelectric Testing Installation

IV. Model Analysis and Discussion

From the results of data collection and the calculation in the research, the thermoelectric performances are:

The temperature of the hot side of the thermoelectric module

In the initial conditions before supplying the voltage, the hot side temperature is at room temperature and after the supplying the voltage, the hot side temperature will increase until it reaches a certain temperature. It shows that in thermoelectric, hot side temperature will increase by the addition of voltage.

The temperature of the cold side of the thermoelectric module

At first, the cold side temperature is at room temperature and then decreases until it reaches a certain temperature. Cold side temperatures will continue to drop to constant conditions. In single thermoelectric, giving 8 V and 10 V of voltage can reach temperatures lower than 12 V. At double thermoelectric with series circuit, the voltage of 10 V can reach the lowest cold side temperatures among the three variations of voltage. In double thermoelectric arranged in parallel, the voltage of 8 V can reach the lowest cold side temperatures among the three variations of voltage.

Different temperature of thermoelectric module

In the initial condition, the temperature difference value is zero because the temperature of the hot side and the cold side is at the same temperature. In a single thermoelectric, the greater the applied voltage, the value of the temperature difference will be even greater. Likewise on double thermoelectric series, the greater the applied voltage, the value of the temperature difference will increase. But for parallel thermoelectric double, on the voltage of 12 V the value of the temperature difference is low because the value of Th and Tc tend to be constant and not increased since the beginning of cooling.

The temperature of the cooled water

At the beginning of cooling, water temperature is around 29°C and then will continue to decrease until a certain temperature. In single thermoelectric, giving the voltage of 8 V and 10 V can reach lower water temperature is than giving the voltage of 12 V. The addition of voltage to the double thermoelectric which is assembled series can accelerate the decrease in water temperature. In parallel double circuit with the voltage of 12 V can be seen that very little heat is absorbed from the water. This is because the temperature reaches 56°C heat and heat can not be released properly into the air so that the side of the thermoelectric cooler can only reach temperatures of 29°C and the water temperature can reach 28°C only.

Heat absorbed at the cold side of the thermoelectric module

The calculation of the absorbed heat associated with the amount of the electric current generated from a given DC voltage. The amount of electric current is influenced from the resistance or thermoelectric module. The greater the voltage, the electric current generated is also getting bigger and the greater the electrical resistance, the current generated will be smaller. Determination of the electrical resistance depends on the number of constituent elements of the thermoelectric module [4]. For double thermoelectric, the number of elements of the module is two times of the number of elements of single module. However, the resistance is also affected from the series type. For double thermoelectric series, the resistance and the variables that influenced the electric current is twice bigger than of that of a single thermoelectric. While for the double parallel thermoelectric, the amount of resistance and the variables associated with the electric current is half of a single thermoelectric. This can be proved by calculating the energy balance which can be seen in appendix of calculation table, where the amount of heat released (q_h) is the amount of electric power required (Pin) and the amount of heat absorbed at the cold side (q_c) [10].

In Figure 3 it can be seen the increase in the value of the absorbed heat affected from the increase in the electrical voltage to each circuit. For voltage of 8V, the highest qc value is indicated by a series of parallel double that is equal to 17.44189 W. For voltage of 10V, the highest qc value indicated by a single sequence that is equal to 20.61895 W. For a voltage of 12 V, the highest qc values indicated by a single sequence that is equal to 24.71738 W. I suggests that the increase in the value of the absorbed heat is proportion to the increase of the applied voltage but depends on the variation of the thermoelectric circuit.

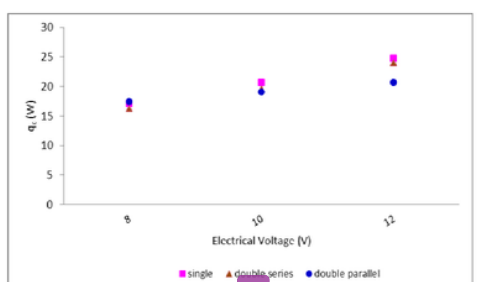

Figure 4. Graph of electrical voltage to the heat absorbed at the cold side on 360 minutes

The electric power supplied to the thermoelectric module

Figure 4 is a graph of relation between voltage electricity to the electrical power supplied and variations of sequence at 360 minutes. From the graph it can be seen that the greater the voltage applied to each circuit, electrical power used is also greater. When compared to the third variation of the thermoelectric circuit, double circuit series shows the value of the lowest power. This shows a double thermoelectric series is a series that consumes the least power among the three variations of the circuit.

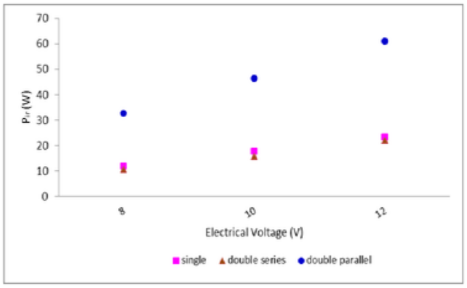

Figure 5. Graph of electricity voltage to the electrical power supplied with the circuit variation on 360 minutes.

Coefisien of Performance (COP)

COP value is a measure of the efficiency of a thermoelectric cooler that can be seen from the comparison of the amount of heat absorbed at the cold side (qc) to the amount of incoming power (Pin). Now, thermoelectric cooling still has low COP value that it can not compete with vapor compression cooling system [9].

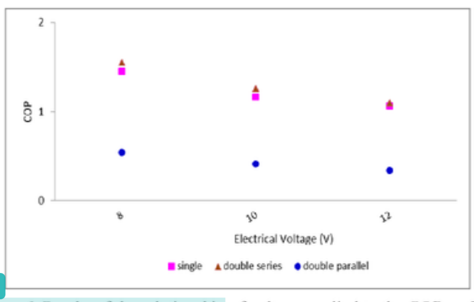

Figure 6.Graphs of the relationship of voltage applied to the COP on 360 minutes

Figure 5 is a graph of the relationship between the COP to the applied voltage and variation of circuit on 360 minutes. The amount of COP influenced by heat absorbed at the cold side and the amount of electrical power used. For voltage of 8V, the highest COP values shown in multiple series, by 1.55046. For voltage of 10V, the highest COP values shown in multiple series circuit is equal to 1.25268. For voltage of 12V, the highest COP value is shown in a series of multiple series that is equal to 1.09192. It shows that voltage variation given, double series circuit showed the highest COP value compared to other circuit variations.

From the three variations of the thermoelectric circuit, best known performance is a thermoelectric module which is arranged in double circuit with the voltage of 10 V as it can achieve the lowest water temperature, the lowest power consumption, and best cooling speed.

V. CONCLUSION

From the calculation results and discussion can be concluded as follows:

1. After analyzing the performance of single thermoelectric, best known performance generated by giving voltage of 8 V.
2. After analyzing the performance of double thermoelectric with series assembled, the best performance is produced by giving voltage of 10 V.
3. After analyzing the performance of double thermoelectric with paraller circuit, best performance generated by giving voltage of 8 V.
4. Of the three variations of the circuit, the best performance is the double thermoelectric modules with series assembled on voltage of 10 V.

Symbol

C_p = Specific heat of water [J/kgK]
G = The geometry factor [cm]
I = Electric current [A]
K = Thermal conductivity [W/K]
K_m = Thermal conductivity of elements [W/cmK]
m = Mass of water [kg]
N = Number of elements on the thermoelectric
P_{in} = Electric power [W]
$\dot{q}_c$ = Heat absorbed at the cold side of the thermoelectric [W]
$\dot{q}_h$ = Heat released at the hot side of the thermoelectric [W]
$\dot{q}_w$ = Heat absorbed from the water [W]
R = Electrical resistance [Ω]
T_c = Cold side temperature [K]
V = Electrical voltage [V]
Z = Figure of merit [K^{-1}]
α = Seebeck coefficient [V/K]
α_m = Seebeck coefficient of the element [V/K]
ρ = Resistance of electric element [Ωcm]
ΔT = Temperature difference [K]
ΔT_w = Temperature difference of water [K]
Δt = Time difference [s]

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