Development of Portable Air Conditioning System Using Peltier and Seebeck Effect

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***Abstract*—The society bustle factor in this day and age, most people want to find equipment that is often used in everyday life in a small and light weight design. The purpose of this project is to develop portable air conditioning system without using any gas. The system used thermoelectric heat pump as main device for producing cool air known as Peltier Effect. The generating system theoretically can recycle the heat loss to produce additional electricity for other usage. The efficacy of this system tested using two types of experimental using Peltier and Seebeck Effect. Both experimental are conducted using 3 specific volumes; 1) 1000cm3; 2) 4000cm3; and 3) 9000cm3. As a result, temperature for heating and cooling systems achieve around 16 – 40 degree Celcius (oC) while the voltage generated around 12V in 30 minutes.**

***Index Terms*—Thermoelectric Heat Pump; Peltier Effect; Seebeck Effect.**

I. INTRODUCTION

Thermoelectric cooling system is achieved when a direct current is passed through one or more pairs of n- and p-type of semiconductor materials. Figure 1 is a diagram of a single pair consisting of n- and p-type semiconductor materials. In the cooling mode, direct current is allowed to passes through n and p junction of a semiconductor material. The temperature, denoted as TC (Cold Temperature) of the interconnecting conductor is decreased while heat is absorbed from the environment. This heat absorption from the environment (cooling) occurs when electrons pass from a low energy level in the p-type material through the interconnecting conductor to a higher energy level in the n-type material. The absorbed heat is transferred through the semiconductor materials through electrons to the other end of the junction, denoted as TH (Hot Temperature) where the electron are liberated once it return to a lower energy level in the p-type material. This phenomenon is called the Peltier effect [1-2].

A second phenomenon is also important in thermoelectric cooling system known as Seebeck Effect. When a temperature differential is established between the hot and cold ends of the semiconductor material, a voltage is generated. This voltage is called the Seebeck voltage, and it is directly proportional to the temperature differential. The constant of proportionality is referred to as the Seebeck coefficient [3-5].

The Peltier effect is controlled by the Peltier coefficient, defined as the product of Seebeck coefficient of the semiconductor material and the absolute temperature. The Peltier coefficient relates to a cooling effect as current passes through the semiconductor junction n to p, and a heating effect when current passes through p to n junction, as shown in Figure 1. Reversing the direction of the current reverses the temperature of the hot and cold ends [2].

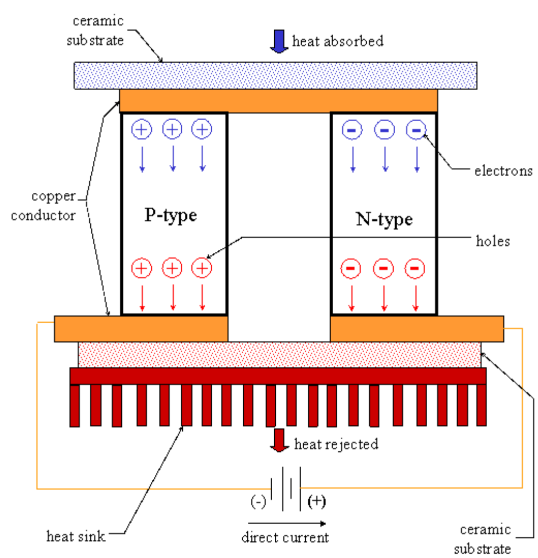

Figure 1: Schematic of thermoelectric module operation for cooling and heating

II. RESEARCH BACKGROUND

This research is based on the application of conventional air-conditioning system that used coolant as a medium for cooling system. Hence, the initiative of this system is focused on replacing coolant with Peltier module which able to generate hot and cold system in one device. This unique device is not using any gas that might harmful to the users. There are some products developed based on Peltier module that focused more on cooling system such as cabinet cooling system [6], Peltier cooling system utilizing liquid heat exchanger combined with pump [7] and Peltier Effect Based Solar Powered Air Conditioning System [8]. Most of the new products focus on Peltier itself in order to replace the conventional system.

Not only that, the Peltier cells inside Portable Air-Conditioning System is cold so small heat sink unit is mounted at the cold side of the Peltier cells to increase the rate of releasing heat outside of unit. Heat sink is simulated using Comsole Multiphysics to study the fin arrangement in order to optimize heat transfer area [9]. This is because the fin arrangement of the heat sink affected the heat transfer of the system. The more heat released makes this system more efficient regarding the temperature difference between cooling and heating system. The blower fan attach to the heat sink has the role to distribute the cold air equally at maximum rate in the container

III. RESEARCH METHODOLOGY

A. Experiment of Peltier Effect

In these experiments, it was observed that in conductors the flow of heat and electricity were fundamentally related and reversibly intertwined. The earlier experiments consisted of assembling a closed loop consisting of two conductors, and demonstrating that a temperature difference across the ends creates a voltage between these, and leads to a flow of current and generation of electricity. In later experiments it was shown the effect is reversible, in that applying a voltage across the ends leads to current flow through the conductors, and produces a temperature difference across the ends. The first property is a means by which deep space missions are powered (where the heat is generated by a radioactive source), and is also being considered for wider scale applications such as power generation from waste heat that is produced from both natural and human-created sources. The latter property allows for refrigeration through a purely electronic means, with the advantage of no mechanical or moving components.

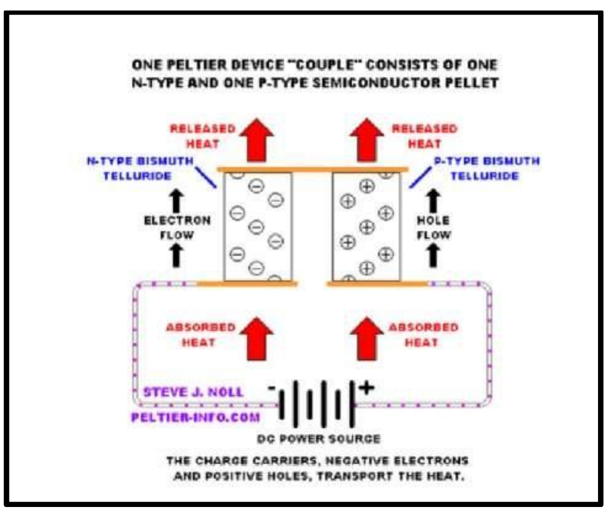

Figure 2: Peltier Effect Concept

The present fundamental understanding of the thermoelectric effect is based on modern condensed matter physics. At a simple level, the effect may be intuitively understood by analogy, where the carriers of electricity in the conductor (the charge) are regarded as gas molecules in a container. Here, a temperature difference across the ends of the container would lead to corresponding differences both in the gas density and energy of the molecules. A temperature difference also causes this imbalance to occur with charge carriers in a conductor, and leads to a voltage between the ends thus flow of electricity. The reverse process occurs when the charge carriers are made to move by a voltage supplied through an external power source. Here, theses carriers transport heat from one side to the other as they move through the conductor.

B. Experiment of Seebeck Effect

Thermoelectric power generator based on the principle of Seebeck Effect that when the junctions of two different metals are maintained at different temperature, the emf is produced in the circuit. Thermoelectric power generation (TEG) devices typically use special semiconductor materials, which are optimized for the Seebeck Effect. The simplest thermoelectric power generator consists of a thermocouple, comprising a p-type and n-type material connected electrically in series and thermally in parallel. Heat is applied into one side of the couple and rejected from the opposite side. An electrical current is produced, proportional to the temperature gradient between the hot and cold junctions. As the heat moves from hot to cold side, the charge carrier moves in the semiconductor materials and hence the potential deference is created. The electrons are the charge carriers in the case of N- type semiconductor and Hole are in P-type semiconductors. In a stack, number of P-type and N-type semiconductors is connected. A single PN connection can produce a Seebeck voltage of 40 mV. The heat sources such as natural gas or propane are used for remote power generation.

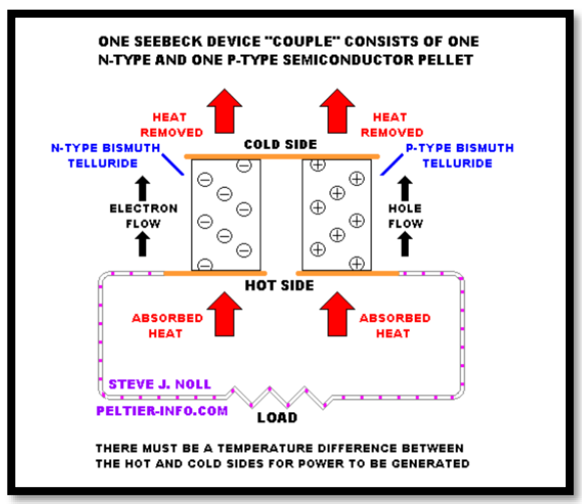

Figure 3: Seebeck Effect Concept

At the heart of the thermoelectric effect is the fact that a temperature gradient in a conducting material results in heat flow; this results in the diffusion of charge carriers. The flow of charge carriers between the hot and cold regions in turn creates a voltage difference.

Thermoelectric materials are determined by their figure of merit to represents their standard of performance, or efficiency defined by:

$$Z = \frac{\alpha}{kR} \quad (1)$$

where: α = Seebeck coefficient
k = Thermal conductivity constant
R = Electrical resistivity

The efficiency of a Peltier material can be measured by calculating the Seebeck coefficient. Seebeck coefficient is directly proportional to the voltage generated by the Peltier. In order to achieve high figure of merit, the material of Peltier must have low electrical resistivity and thermal conductivity.

The figure of merit can be calculated based to the electrical conductivity as shown below:

$$\boldsymbol{Z\overline{T}} = \frac{\alpha^2\overline{\boldsymbol{T}}}{kR} \quad (2)$$

$$\overline{\boldsymbol{T}} = \frac{\boldsymbol{T_H + T_L}}{\boldsymbol{2}} \quad (3)$$

where: T_H = Temperature high
T_L = Temperature low

The maximum efficiency, η of a Peltier device can be defined using the figure of merit, temperatures of the hot side and cold side.

$$\text{N} = n_{carnot}\left[\frac{\sqrt{1+Z\overline{T}}-1}{\sqrt{1+Z\overline{T}}+\frac{T_L}{T_H}}\right] \quad (4)$$

The value of carnot efficiency can be calculated by:

$$n_{carnot} = 1 - \frac{Temperature\ low}{Temperature\ high} \quad (5)$$

By referring to Peltier electric generating calculation, the potential electricity generated by the Peltier device can be calculated by:

$$V = \alpha(T_h - T_c) \quad (6)$$

where: V = Thermoelectric material figure of merit
α = Seebeck coefficient
T_k = Temperature at hot side
T_c = Temperature at cold side

The Seebeck coefficient can be calculated by:

$$\alpha = \frac{\overline{x}V}{\overline{x}T} \quad (7)$$

where: $\overline{\boldsymbol{x}}V$ = average voltage generated
$\overline{\boldsymbol{x}}T$ = average temperature difference

The magnitudes of voltage generated are affected by the temperature difference 1 ºC across the Peltier device, as stated the Seebeck effect. Material with high Seebeck effect is the main factor to increase the efficiency of the Peltier device

IV. Results and Discussion

As the result from this experiment, the Peltier effect are being measured using several volume of container as shown in Figure 5 which is 1000 cm^3, 4000 cm^3 and 9000 cm^3

Figure 4: Tested Container

The result recorded in Table 1 shows that the time taken for testing this experiment is from one minutes to ten minutes. Generally from the result obtained shows that at seventh minutes the temperature start being constant. The smallest container shows the coldest temperature recorded in ten minutes compared to the larger container.

Table 1
Data taken in 10 minutes for heating and cooling system

Time (min)	1000cm^3 (°c) Cold	1000cm^3 (°c) Hot	4000cm^3 (°c) Cold	4000cm^3 (°c) Hot	9000cm^3 (°c) Cold	9000cm^3 (°c) Hot
1	24	26	26	26	28	26
2	24	26	26	26	28	27
3	23	27	25	27	26	28
4	21	30	24	28	26	30
5	18	32	22	29	25	32
6	17	32	22	33	23	36
7	16	34	19	35	20	36
8	16	36	18	37	20	38
9	16	38	18	39	19	38
10	16	40	18	39	19	38

Generally from the result obtained shows that the system can achieve about 16°C for cold system and about 40°C for hot system which enables it for operating in both conditions. From the result, it shows that the Peltier devices itself is dominant to hot temperature, apart from this to spreading the hot temperature within the container is more faster compare to cold temperature.

For the Seebeck operation, the data used using the temperature difference from small container generate the Seebeck coefficient, α=161.28 mV/ ºC. Table 2 shows the relationship between temperature differences with Seebeck coefficient.

As the result obtained in Table 2 from Seebeck Effect, time taken to record the voltage produced by the peltier is for 30 minutes. The temperature different is obtained from the value of hot and cold temperature comes out direct from the peltier. The voltages are measured by using PWM voltage controller which is attached directly to peltier polarity port. From the calculation and measurement has been done, the data collected from both activities was recorded. The Seebeck coefficient was calculated by using average of voltage and average of temperature different.

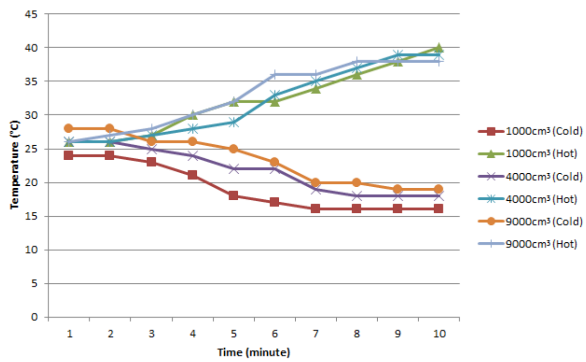

Figure 5: Data experiment for heating and cooling process

Table 2
Result from Seebeck Effect experimental

Time (min)	α(mV / ºC)	Temperature Different (°C)	Voltage calculated (V)	Voltage Measured (V)
5	161.28	22	3.55	3.12
10	161.28	32	5.16	5.16
15	161.28	48	7.74	7.82
20	161.28	62	9.99	9.63
25	161.28	69	11.12	11.85
30	161.28	74	11.93	12.10

Lastly, the result obtained from this experiment shows that this system can be operated in both hot and cold system in one container. Not only has that, in about 30 minute this system able to generate voltage around 12 V that capable in recharging back the battery. The generated voltage depends on the temperature difference between hot and cold system. The higher temperature difference generated, the less time consume for the system generate 12 V.

V. CONCLUSION

In conclusion, this Portable Air Conditioning System can be used in dual mode operation, heating and cooling also able to generate electricity using heat transfer occur in the system. This system achieves minimum temperature 16ºC and maximum around 40ºC and maximum voltage occur in about 30 minutes. For future development, this system can be used as a replacement for conventional air-conditioning system that using coolant that can be harmless for human in long term.

ACKNOWLEDGMENT

The authors appreciate the support granted (PJP/2014/FTK(1B)/S01297) by Universiti Teknikal Malaysia Melaka (UTeM) in pursuing this research.

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