An Experimental Investigation to Predict the Influence of Number of Peltier Modules and Input Voltage during Non-Conventional Cooling

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***Abstract*—Requirement of low temperature (air conditioning and refrigeration) has many applications in the industry. However, excessive use of refrigerants for this purpose leads to ozone depletion and increase in global warming. Development of an alternative eco-friendly refrigeration system is in great demand. Non-conventional cooling using Seebeck and Peltier effect is gaining importance as an alternative. The data pertaining to the number of modules and input voltage required to obtain a specific temperature drop is not available in the literature. Hence, in the present work an equipment is developed and experimental investigation is carried out to find the effect of number of modules and the input voltage to obtain a temperature drop of water by 10 ^{O}C. The time taken for lower input voltages (2 V to 6 V) is 50 to 30 minutes. For input voltage of 10 V the time taken to reduce the temperature of water is only 10 min. The data obtained from the experimental investigation predicts the number of modules required to cool the water to 0 ^{o}C and also the heat transfer rate for every 1 ^{o}C change in temperature. The results will help to design thermo-electric coolers of different capacities with temperature control.**

***Index Terms*—Peltier Effect, Refrigeration, Non-conventional cooling**

I. INTRODUCTION

Global warming and Energy crisis have become the major concern for developing as well as developed countries. Conventional refrigeration systems, besides having many industrial /domestic / commercial applications significantly contribute to ozone layer depletion and energy consumption. Hence, the need for non-conventional and systems with energy conservation are gaining more and more importance. Thermo-electric refrigeration is one of the solutions and the present research work focuses on the non-conventional cooling using Peltier effect. The advantage of this technique is that there are no moving parts, lightweight, free of maintenance, silent during work, less electrical consumption, heating and cooling can be done with the same module, wide operating temperature range, highly precise temperature control (to within 0.1°C) and environment friendly.

S.B. Riffat et al.[1] applied thermo-electric system for refrigeration. Cold side was replaced with a heat pipe and phase change material. Without the use of heat sink fan, the temperature of the cold junction was reduced few degrees and then increased. However, by using a fan the cold junction temperature continued to decrease. Anutosh Chakraborty and Kim Choon Ng [2] formulated for the entropy flux and plotted T-S diagram for thermo-electric cooler. Current density, temperature gradient, Seebeck coefficient and local temperatures were considered as the parameters which effects the cooling. Chien-Yi Du and Chang-Da Wen [3], experimentally and numerically analyzed a one-stage thermo electric cooler. The thermo electric cooler was made of Thomson effect. An increase in temperature difference between hot and cold side was observed for higher current input. It was emphasized that a specific current is to be selected during the design of a thermo-electric cooler. Satheeshkumar Palaniappana and Balachander Palanisamy [4] analyzed and compared Pb-Te and Bi-Te combination for thermo-electric modules. At ambient temperature, Pb-Te module showed lower performance than Bi-Te module. Gang Tan and Dongliang Zhao [5] introduced a design procedure to integrate thermo-electric cooling with a phase change material. Wei et al.[6] reviewed the development of the thermoelectric cooler and generator. They suggested for a research of materials with high "figure of merit" and generator to be used for the electricity production in place of PV technology. ZhongBing Liu et al.[7] reviewed various thermoelectric cooling techniques used for zero energy buildings. Yazeed Alomair et al.[8] constructed a chiller using thermo-electric cooling. With increase in water bulk mean temperature, the heat removal rate was observed to increase. The capacity of the evaporator significantly affected heat removal rate.

Earlier researchers have used thermoelectric modules for cooling and heating but the data related to the number of modules required to obtain a heating/cooling rate is not available. Hence, an experimental setup is designed and developed to obtain time-temperature data with respect to the variation in input voltage and number of modules. The data will be used to propose the input voltage and number of modules required to obtain the temperature difference of 10 ^{o}C and the results can be extrapolated to obtain higher cooling rates.

A. Principle of Peltier Effect

If current is passed through a pair of dissimilar metals, there occurs heating at one junction and cooling at the other junction. The schematic of Peltier circuit is shown in Fig. 1. Two junctions are made with two dissimilar metals A and B. When voltage is applied, one junction shows low temperatures and the other junction shows high temperatures.

The amount of temperature difference depends upon the material combinations. Peltier varied the current and observed the heating and cooling rate for different sets of elements. He found that:

$$q \alpha I \qquad (1)$$

where q is the cooling or heating rate and I is the current. The proportionality constant is called as Peltier coefficient, π i.e.,

$$q= \pi * I \qquad (2)$$

where π is the coefficient for two different metals.

Hence Peltier effect can be used to replace the conventional refrigeration system. In the present work the Peltier Module made of Bismuth and Telluride is employed.

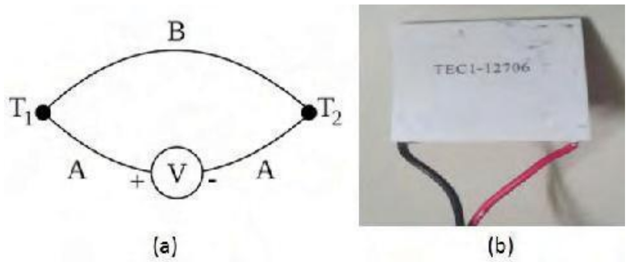

Figure 1. (a) Schematic of Peltier Circuit (b) Module

II. EXPERIMENTATION

Aim of the present work is to reduce the temperature of 500 ml of water by 10 °C and suggest input voltage, time taken and number of modules required to meet this objective. An equipment is designed and constructed to perform experimental investigation. The components required by the equipment are a) Thermo-electric module b) Tapping transformer c) Heat sinks d) Fans e) MCB unit f) Digital temperature indicator g) Thermo couple h) Energy meter i) Thermo coal container with copper plates attached to modules j) Five copper plates of 0.5 mm thick and 20 sq.cm area h) Thermal paste. The technical specifications of the thermo-electric module (Fig. 1(b)) used in the equipment are as given in table I below.

TABLE I
TECHNICAL SPECIFICATIONS OF THE PELTIER MODULE

1	Operational voltage	12 V DC
2	Current Max.	6 Amp
3	Power Nominal	60 Watts
4	Power Max.	92.4 Watts
5	Operating temperature	-30 °C to 70 °C
6	Couples	127

Figure 2. Transformer with five ouput voltages (2V, 4V, 6V, 8V, 10V)

Figure 3. Experimental Setup

A circuit consisting of transformers, five in number, is designed to convert the available AC power input to DC (Fig. 2). There are five output terminals each having a maximum capacity of 10 amps at 12-Volt DC current. In the experimentation, it is required to vary the input voltage to the module. As the maximum voltage input to the modules is 12 V, tapping transformer is specially designed to vary the voltage from 2 V to 10 V individually for each thermo electric module. For this purpose knobs are attached to each of the terminals to vary the voltage from 2 to 10 in steps of 2 Volts.

Fig. 3 shows the complete equipment designed for the experimentation. Cold side of five thermo-electric modules (Peltier modules) are attached to the copper plates, placed at the bottom of the container holding 500 ml water at atmospheric temperature. Each module is connected to the tapping transformer. The transformer 5 outputs are

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connected to the main circuit and each output is controlled by a switch. The switches are used to on/off the supply of voltage to each module. Each module (hot side) is mounted on an aluminum heat sink and each heat sink is connected to a 12 V, DC cooling fan. Each cooling fan is connected to the main power supply using an on/off switch. As the input supply to the fans is to be DC, a converter for each fan is employed. A digital temperature indicator is connected to a thermo couple probe to measure the temperature of ambient air and water.

500 ml of water is taken in a container made of thermo coal. Thermo coal is selected as a container to prevent the heat loss from the walls to the atmosphere. Copper plates are placed in the grooves provided at the bottom of the container and the gap is sealed with water resistant gum. Water is in contact with the copper plates fixed on the cold side of the Peltier modules. Heat sink is attached directly on the hot side of each module. A small out let pipe is grooved at the bottom of the container to remove and replace the water for every experiment. The pipe is closed during the experiment with a clip. Initial and final temperature of water is recorded for every experiment.

In the first set of experiments, temperature of water is recorded (Table II) by changing the input voltage to 2 V, 4 V, 6 V, 8 V and 10 V. As the rated voltage is 12V, the maximum operating limit is taken as 10 Volts. Water is removed and replaced for every experiment. Atmospheric temperature is recorded as 35 ^{o}C.

TABLE II.
RECORD OF TEMPERATURE OF WATER VARYING VOLTAGE

Expt. No.	No. of Modules	Voltage of each module (V)	Initial temperature of water (°C)	Final temperature of water (°C)	Heat transfer rate Q (W)
1	4	2	33	32	2090
2	4	4	33	30	6270
3	4	6	33	28	10450
4	4	8	33	25	16720
5	4	10	33	22	22990

In the next set of experiments the temperature of water is recorded (Table III), keeping the input voltage as maximum i.e 10 V, varying number of modules as 1, 2, 3 and 4. The time given for each experiment is 10 minutes. As mentioned earlier water is removed and replaced for every experiment.

TABLE III.
RECORD OF TEMPERATURE OF WATER VARYING NUMBER OF MODULES.

Expt. No.	No. of Modules	Voltage of each module (V)	Initial temperature of water (°C)	Final temperature of water (°C)	Heat transfer rate Q (W)
6	1	10	33	32	2090
7	2	10	33	30	6270
8	3	10	33	27	12540
9	4	10	33	22	22990

Final experiment is performed with 5 modules, input voltage at 10 V, initial temperature of water and atmosphere at 33 (^{o}C) and 34 (^{o}C) respectively. Four modules are placed one at each corner and the fifth module is placed at the center of the container. The Time-Temperature history of water is recorded (Table IV) and tabulated.

TABLE IV.
TIME-TEMPERATURE HISTORY OF WATER

S.No	Temp. of Water (°C)	Time (minutes)	Total heat transfer rate at a given instant of time Q(W)	Heat transfer rate for every 1 °C change in temperature Q (W)
1	33(Initial)	0	0	0
2	32	0.3	2090	2090
3	31	0.7	4180	2090
4	30	1.1	6270	2090
5	29	1.6	8360	2090
6	28	2.3	10450	2090
7	27	3.1	12540	2090
8	26	3.9	14630	2090
9	25	4.8	16720	2090
10	24	5.7	18810	2090
11	23	6.7	20900	2090
12	22	7.6	22990	2090
13	21	8.9	25080	2090
14	20	11.2	27170	2090

III RESULTS AND DISCUSSION

A. Effect of Input Voltage

Water at an initial temperature of 33 ^{o}C is cooled using 4 Peltier modules placed one at each corner of the container varying the input voltage 2 V, 4V, 6V, 8 V and 10 V. The temperature of water is reduced with increase in input voltage (Table II). The time taken for lower input voltages (2 V to 6 V) is about 50 to 30 minutes. The final temperature is recorded once the drop in temperature is steady. However for input voltage of 10 V the time taken to reduce the temperature of water is only 10 min. and the drop is unchanged later with time.

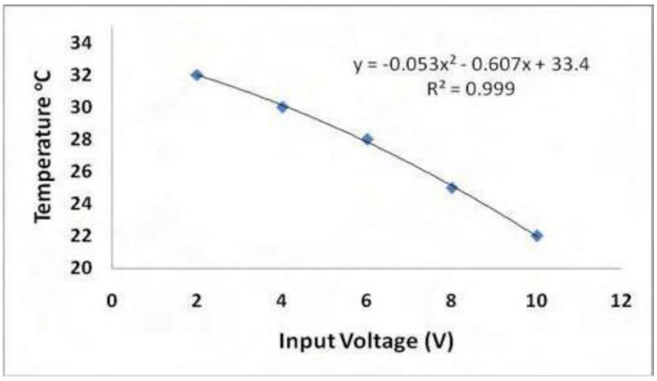

Figure 4 Variation of temperature with increase in input voltage

It can be inferred from this result that the cooling rate can be increased or decreased by increasing or decreasing the voltage input (Fig. 4). However, as the rated voltage of the module is 12 V, the maximum input voltage is fixed to 10 V. It is interesting to observe that for a specific input voltage the temperature of water reaches a steady state. The investigation is continued to find the effect of number of modules on cooling rate.

B. Effect of number of Modules

Keeping initial temperature of water at 33 °C and input voltage at 10 V, experiments are performed by varying the number of modules. Input voltage is supplied for each module through each output of the transformer.

Table II gives the record of temperature of water for increase in number of modules. Fig. 5 gives the variation of temperature of water with increase in number of modules. Equations shown in the graphs are obtained by curve fitting the experimental data points. These equations can be used to interpolate or extrapolate to predict the values beyond the range of observed data.

With increase in number of modules the rate of cooling is increased. For an input voltage of 10 V using one module give a temperature drop of only 1 °C in 10 min. However using 4 modules the drop in temperature is increased to 11 °C. The result can be inferred that with increase in number of modules the drop in temperature or cooling rate can be increased. In the present experimentation, a temperature drop of 10 °C is achieved using 4 modules at 10 V, within 10 Minutes.

The last experiment is repeated to record the temperature-time history while cooling of 500 ml of water initially at 33 °C with 5 modules at 10 V (Table III). Fig. 6 gives the drop in temperature of water with time. It clearly shows that with increase in time the drop in temperature is increased. It has been observed with 4 modules that a temperature drop of 10 °C is achieved in 10 minutes and there is no further drop with time until an addition of one more module.

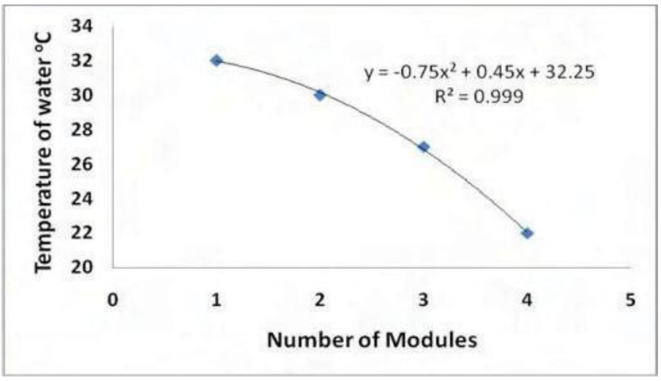

Figure 5. Variation of temperature with increase in number of modules

Fig. 7 shows the graph obtained from the extrapolated experimental data to predict the number of modules required to further reduce the temperature of water. It is interesting to observe that if the number of modules is increased to 7, the temperature of water can be reduced to 'zero' degree Celsius for the present quantity of water taken. The work can be extended further by varying the quantity of water and time required to cool to the required temperature.

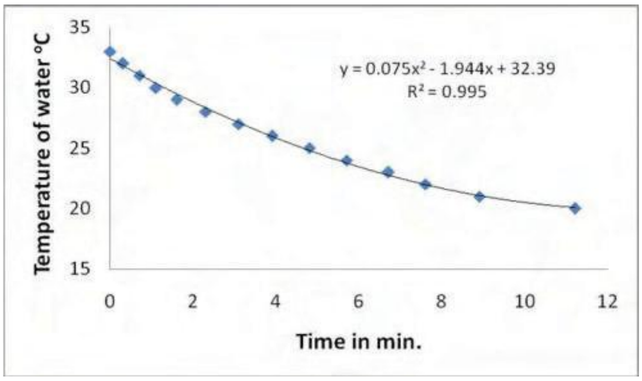

Figure 6. Fall in Temperature of water with time with 5 modules

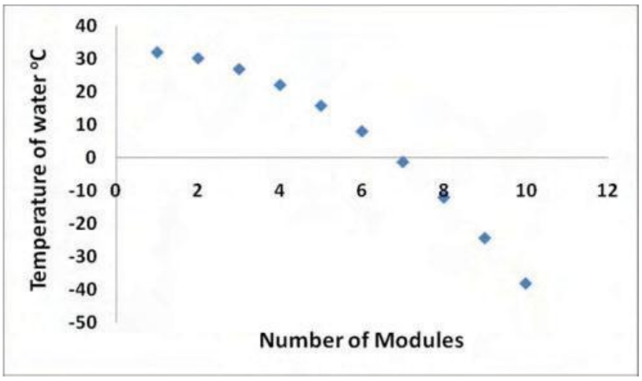

Figure 7. Extrapolated data for increase in number of modules

C. Heat Transfer rate

Heat transfer rate depends on the convective heat transfer coefficient 'h' between the copper plates and water. However, the value of 'h' for the present system is unavailable in the literature. Hence, the heat transfer rate is estimated using the heat lost by the water varying the input voltage and number of modules. The following heat energy equation is used for this purpose.

$$Q = m\, C_p\, \Delta T_w \quad (3)$$

where m=mass of water

C_p = specific heat of water

ΔT_w= difference in initial and final temperature of water

Fig. 8 shows the change in heat transfer rate with increase in input voltage. Table II shows the heat transfer rate estimated for each experiment. The value of 'Q' is increased with increase in input voltage. This is because of the increase in heat absorption by the copper plates with voltage. As all the final temperature values are recorded after the steady state condition, the heat transfer shows direct proportionality with voltage.

$$Q \propto V \quad (4)$$

Table III shows the change in the value of 'Q' with increase in number of modules. The value increased with increase in number of modules as the convective area increases. It is interesting to observe that the 'Q' value achieved in 10 min. at higher voltage (10 V) is same when 4 modules are used at lower voltages. i.e when 4 modules at 2 V and 4 V obtained a heat transfer rate of 2090 W and 6270 W respectively (Table II, Expt. No. 1 &2). Whereas, at 10 V (i.e highest voltage) the heat transfer rate is same when there are 1 module and 2 modules respectively (Table III, Expt. No 6 &7). For the first case the time taken is more (nearly

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50 min). But the experimental results given in table III are taken at 10 min. for each experiment. Fig. 8 shows the change in heat transfer rate with change in input voltage.

Table IV shows the value of heat transfer rate for every 1 ^{o}C change in temperature. It is interesting to observe that the value of Q is 2090 W even with 5 modules operating at 10 V each which is same as Expt. No. 1 and 6. This is because of continuous cooling the difference in temperature of water is less. But, during the experiments 1 to 9 the ΔT of water is high. Total heat transfer rate with five modules is 27170 W. Table III and IV clearly show that, to obtain a required temperature drop, the time required with more number of modules is less.

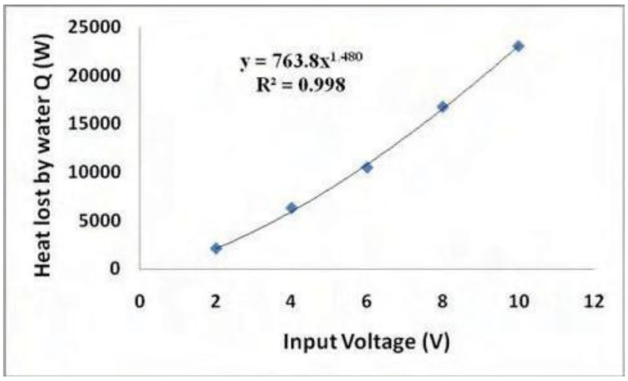

Figure 8. Heat lost by water with increase in input voltage

IV. CONCLUSIONS

An experimental investigation is carried out to obtain low temperatures using Peltier Modules and find the effect of increase in input voltage and number of modules on drop in temperature of 500 ml of water.

- Drop in temperature of water is increased with increase in input voltage. The difference of temperature increases between the hot and cold surfaces of the modules with increase in voltage input.
- Cooling rate increases with increase in number of Peltier modules as cooling area is increased.
- Increase in input voltage increases cooling rate. Time taken for cooling is lowest at the rated voltage.
- Extrapolated data shows sub-zero temperatures can also be attained with increase in number of modules.
- The data recorded can be used to design controlled cooling units using Peltier modules.

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