Design and Fabrication of Thermoelectric Refrigerator for Liquid Cooling by Automatic Temperature Micro-Controller

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Abstract

Refrigeration is defined as science of reducing temperature of object and maintains the temperature below the atmosphere. In 1834, Jean Peltier while investigating Seebeck effect, found that direct current can produce refrigeration effect when it is passed through pair of two dissimilar metals was further known as Peltier effect and then thermoelectric refrigeration started evolving and till now it has covered wide range of a applications. Thermoelectric refrigeration systems are compact, reliable, noiseless, flexible and environment friendly. Due low COP and requirement of DC supply it is restricted to small capacity system. Thermoelectric refrigeration setup is fabricated and tested for load and no load condition. For no load condition this system took 4 minute to reduce the temperature by 110C. For load condition it took 21 minutes to reduce the temperature by 80C. These results are produced on fabricated thermoelectric refrigeration system with 4 Peltier modules. Theoretical COP of the thermoelectric refrigeration system was found to be 0.548 while actual COP was 0.1939 for no load conditions and 0.03002 for load conditions.
Keywords: Thermoelectric refrigeration, Seebeck effect, Peltier effect, COP, Peltier module, Experimental Setup

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I. INTRODUCTION

Refrigeration has been defined as the science of providing and maintaining temperature below that of surrounding atmosphere [1]. Refrigeration provides temperature differential for processes like food preservation, food processing, storage applications etc. Another requirement of refrigeration is in developing scientific equipment and their operation under controlled environment to get reliable result. [2]. This can be achieved by using conventional refrigeration systems which uses Chloro-Fluoro-Carbons (CFCs) and Hydro Chloro-Fluoro-Carbons (HCFCs) as refrigerants. These CFCs and HCFCs are mainly responsible for environmental degradation such as Ozon layer depletion, global warming. As a result, there is need to develop clean refrigeration technology and hence extensive research is happening in field of thermoelectric refrigeration.[3]

Thermoelectric refrigeration works on principle of peltier effect. Jean peltier, a french physicist found the peltier effect in 1934. It is reverse of Seebeck effect. When a direct current is passed around a circuit of different materials, one junction gets cooled and another junction gets heated. This is known as peltier effect. This effect is attained in thermoelectric modules. These thermoelectric modules consist of P-N type semiconducting materials. N-type material is doped such that it has excess number of electrons (which are required to complete perfect molecular lattice structure). P-type material has deficiency of electrons resulting into holes. Excess electron in N-type material and holes in P-type materials are the carrier of heat energy in thermoelectric module.[4]

A. *Thermoelectric Refrigeration Works on the Thermoelectric Effects Such as:*

1) *Seebeck Effect:*

In pair of dissimilar metals, when two junctions are kept at different temperatures, emf(electromotive force) generates. This is known as Seebeck effect. After conducting tests on various combinations of a set of materials and by varying the temperatures of junctions, seebeck found that emf output is directly proportional to temperature difference, i.e $\Delta E \alpha \Delta T$, where ΔE & ΔT the emf output and temperature of junctions.[5]

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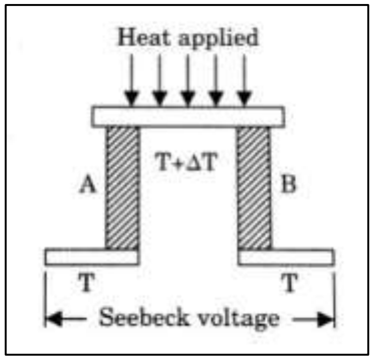

Fig. 1: Seebeck effect[1]

2) Peltier Effect:

In a pair of dissimilar metals, when direct current is passed through it, there is heating at one junction and cooling at other junction. By varying the current, peltier observed the heating and cooling rate for different sets of elements. He found that q α I, where q is cooling or heating rate.[4]

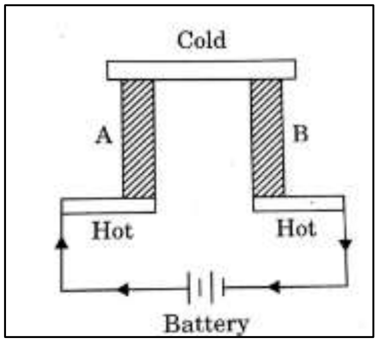

Fig. 2: Peltier effect[2]

Jaspalsinh dabhi et al. [5] have done the analysis of thermoelectric refrigeration system and found effect of different input parameters on coefficient of performance of thermoelectric refrigeration system. In their study they observed that COP of TE system increases with increasing current upto certain value then it further decreases, COP decreases with increase in input power and temperature difference.

Dongliang Zhao et al. presented advancement in thermoelectric materials and showed that recent research provides possible way that may lead to significance progress in thermoelectric cooling. In addition to this, they also presented potential applications of thermoelectric refrigeration in five different categories such as Civil, Medical, Automobile, Electronics, laboratory and equipment etc. All these study of different researchers provides avenue to identify future of thermoelectric refrigeration.[6]

II. DESIGN METHODOLOGY

Design methodology discusses the different parameters used to design thermoelectric refrigeration system and necessary calculations required to select number of Peltier modules.

A. Cooling load calculations :

$$\text{Cooling load} = \text{Refrigeration Effect} = \frac{m*Cp*\Delta T}{t}, \textit{ where m= mass flow in Kg}$$

Cp= specific heat of fluid KJ/KgK
ΔT= temperature difference in K
t = time required in sec

This formula gives cooling load and then it is possible to select number of Peltier modules.

B. Selection of number of Peltier modules:

Fixed Parameters:
1) Mass of water = 1kg
2) Cp for Water = 4.18 KJ/KgK
3) Temperature Difference = 10 ^{o}C
4) Time = 5 min

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$$\text{Refrigeration effect} = \frac{m*Cp*\Delta T}{t} = \frac{1*4.187*10}{5*60} = 0.13956 \text{ KW}$$

$$\text{Number of Modules} = \frac{\text{Refrigeration Effect (W)}}{\text{Capacity of one Peltier module (W)}}$$, where Minimum capacity of on peltier module =60W

$$\text{Number of Modules} = \frac{139.56}{60} = 2.32 \approx 3 \text{ modules.}$$

Efficiency of thermoelectric refrigeration is around 0.2 to 0.4 and due to surrounding losses, selecting four peltier modules for design of thermoelectric refrigeration system for safer side.

1) Design Parameters:

Heat Sink with fan = 4
Aluminium Bar (400*40*20) = 1
Atmospheric Temp = 32˚C

III. FABRICATION AND ASSEMBLY

Assembly of Thermoelectric cooling system consists of following major parts.
1) Power supply – 12V DC, necessary for working of Peltier modules and fans
2) Micro-Controller unit – To control and operate relay unit according to temperature
3) Relay unit – Act as switch to ON & OFF Peltier modules and heat sink fan
4) Temperature sensors – To sense temperatures at inlet and outlet of pipe
5) Cooling system with Peltier modules – To get Refrigeration effect
6) Heat sink with fan – Dissipate the heat to the surrounding
7) LCD Display- To indicate temperatures and settings of temperature.

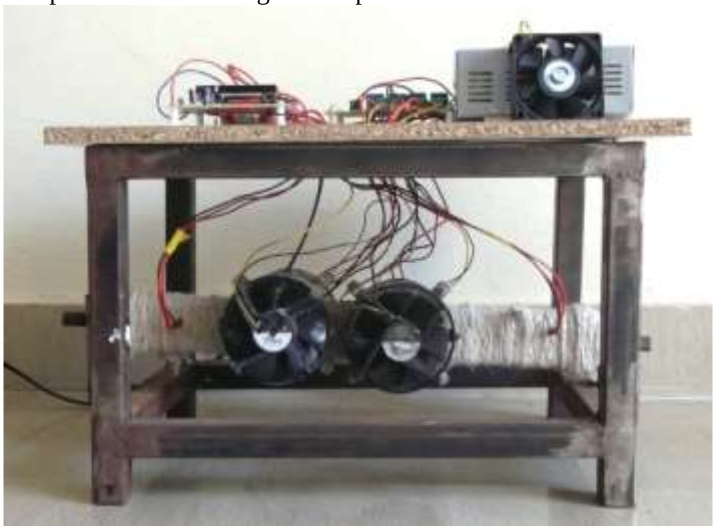

Fig. 2: Front view of experimental set up of thermoelectric refrigeration system

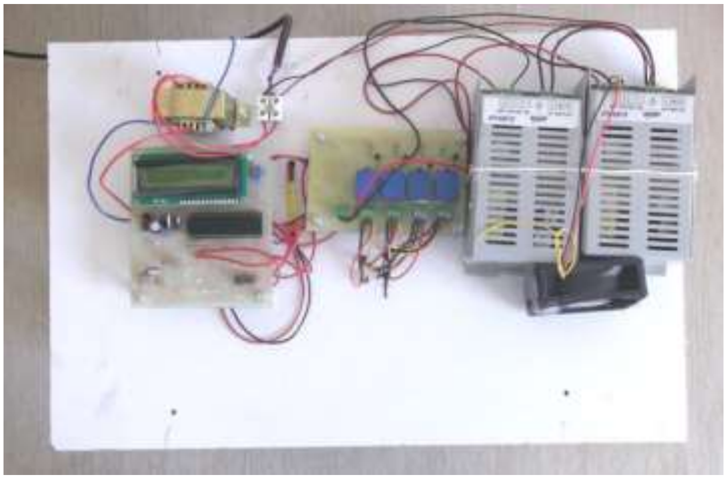

Fig. 3: Top View of experimental set up of thermoelectric refrigeration system

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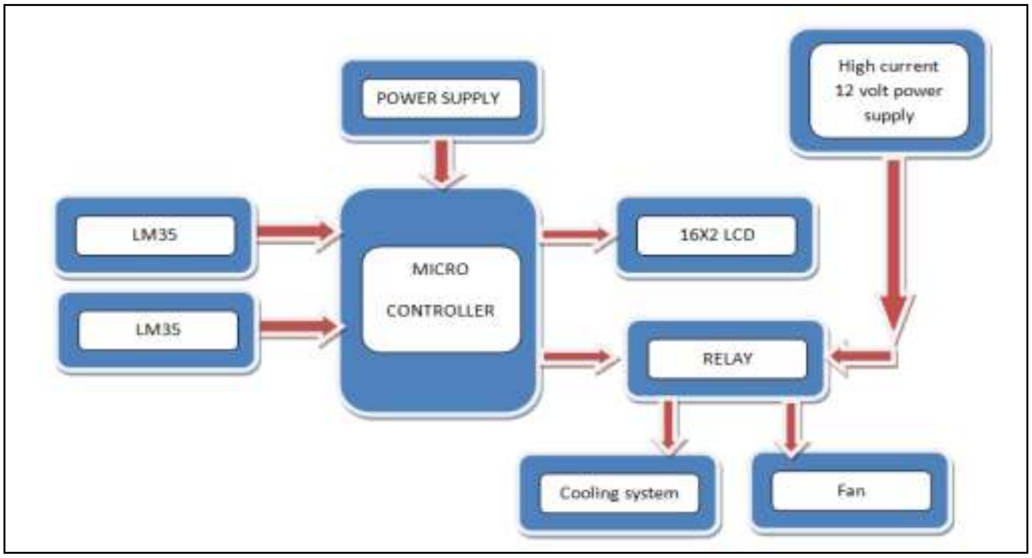

Fig. 4: Block diagram of thermoelectric refrigeration system

IV. EXPERIMENTAL ANALYSIS

A. *Experimentation*

Experimental setup is made which is discussed in previous chapter. Testing is decided to perform without load condition. Test was carried out in a room having 32° C atmospheric temperature.

Instruments involved in testing are

- Experimental setup
- Thermometer
- Stopwatch
- Following steps are involved in experimentation:
- All the connections are checked.
- Atmospheric temperature is recorded by using thermometer.
- Power supply is provided to experimental setup with the help of power cord.
- Required output temperature is set by using push buttons.
- Initial temperature values from LCD display was recorded.
- Peltier modules with heat sink & fan are ON by relays and cooling started.
- Time is recorded for decrease in temperature from 31° C to 20° C by using stopwatch.
- Table of time & temperature is prepared and further analysis is made.

B. *Precautions:*

1) Do not operate Peltier module without heat sink and fan.
2) Check all the electrical connections properly.
3) Avoid overheating of transformer and SMPS.

C. *Observation*

1) For No load condition:

Test was carried out in a room having 32° C atmospheric temperature and the air was moving through the pipe as a load.

Table - 4.1
Variation of temperature with time (No load)

Temperature (°C)	*Time (Sec)*
31	0
30	6
29	8
28	11
27	14
26	27
25	45
24	64

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23	*91*
22	*144*
21	*180*
20	*238*

From the above graph it can be inferred that
1) For decrease in temperature from 31º C to 27º C, cooling rate is fast it is near about linear.
2) From 27º C to 22º C, time required for cooling is increased and thus cooling rate is moderate.
3) Beyond 22º C, Cooling rate becomes low and take much more time for cooling.

2) For load condition:

For the load condition 0.2736 liter of water is filled inside the Aluminum bar. Test was carried out in a room having 34º C atmospheric temperature.

Table - 4.2
Variation of temperature with time (Load)

Temperature (ºC)	*Time (Sec)*
31	*0*
30	*27*
29	*131*
28	*243*
27	*365*
26	*501*
25	*676*
24	*920*
23	*1272*

V. CALCULATIONS

A. Theoretical COP of the system:

For Module TEC1-12706
T_h = Temperature of hot side of Peltier module 25^0C =298K
T_c= Temperature of cold side of Peltier module 10^0C =283K
I_{max} = Maximum input current = 5A
V_{max}= Maximum DC Voltage = 12V
Q_{max}= Capacity of Peltier Module = 60W
ΔT_{max}= Maximum Temperature Difference = 66K

$$\alpha_m = \text{Seebeck Voltage} = \frac{\text{Vmax}}{\text{Th}} = \frac{12}{298} = 0.0402\ \text{V}/^0\text{K}$$

$$R_m = \text{Electrical Resistance of Peltier Module} = \frac{(\text{Th}-\Delta\text{Tmax})}{\text{Th}} * \frac{\text{Vmax}}{\text{Imax}} = \frac{298-66}{66} * \frac{12}{5} = 1.868\Omega$$

$$K_m = \text{Thermal Conductance of Peltier Module} = \frac{(\text{Th}-\Delta\text{Tmax})}{2\Delta\text{Tmax}} * \frac{\text{Vmax}*\text{Imax}}{\text{Th}} = \frac{298-66}{2*66} * \frac{12*6}{298} = 0.4246\ /^0\text{K}$$

Refrigerating Effect is given by
$Q_c = (\alpha_m * Tc * I) - \frac{1}{2}(I^2 R_m) - K_m * (T_h - T_c)$
$Q_c = (0.04026*283*5) - \frac{1}{2}(5^2*1.868) - 0.4246 * (298 - 283)$
Q_c = 27.248 W
Input Power is given by
$W = \alpha_m * I * (T_h - T_c) + I^2 R_m$
$W = 0.04026 * 5 * (298 - 283) + (5^2 * 1.868)$
W = 49.71 W
Theoretical COP of the system:
$COP_{th} = \frac{Q_c}{W} = \frac{27.248}{49.71} = 0.548$

B. Actual COP of the system:

1) For no load condition

Let, m = mass of air = 1kg
C_p = Specific heat of air = 1.007 KJ/KgK
ΔT = Temperature Difference = 11K
t = Time in sec = 238 seconds
Refrigeration Effect is given by
$Q_c = \frac{m*C_p*\Delta T}{t} = \frac{1*1.007*11}{238} = 0.04654\ \text{KW} = 46.542\ \text{W}$

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Input Power is given by
W =Power Consumption of Peltier Module $*$ Number of Peltier Modules
W = 60 * 4 = 240 W
Actual COP
$COP_{act} = \frac{46.5420}{240} = 0.1939$
2) For load condition
Let, m = mass of water filled inside the pipe = 0.2736 Kg
C_p = Specific heat of water = 4.187 KJ/KgK
ΔT = Temperature difference = 8K
t = Time in sec = 1272 seconds
Refrigerating Effect is given by
$Q_c = \frac{0.2736*4.187*8}{1272} = 7.204$ W
Input Power is given by
W= Power Consumption of Peltier Module $*$ Number of Peltier Modules
W = 60 * 4 = 240 W
Actual COP
$COP_{act} = \frac{Q_c}{W} = \frac{7.204}{240} = 0.03002$

VI. Result and Discussion

Experimental observations are recorded and graph of temperature versus time is plotted. After starting of Peltier module and heat sink with fan, cooling is started.

A. No Load Condition:

Temperature is decreased to 20° C from 31° C in 238 seconds which is nearly 4 minutes. The graph of temperature versus time is as follows.

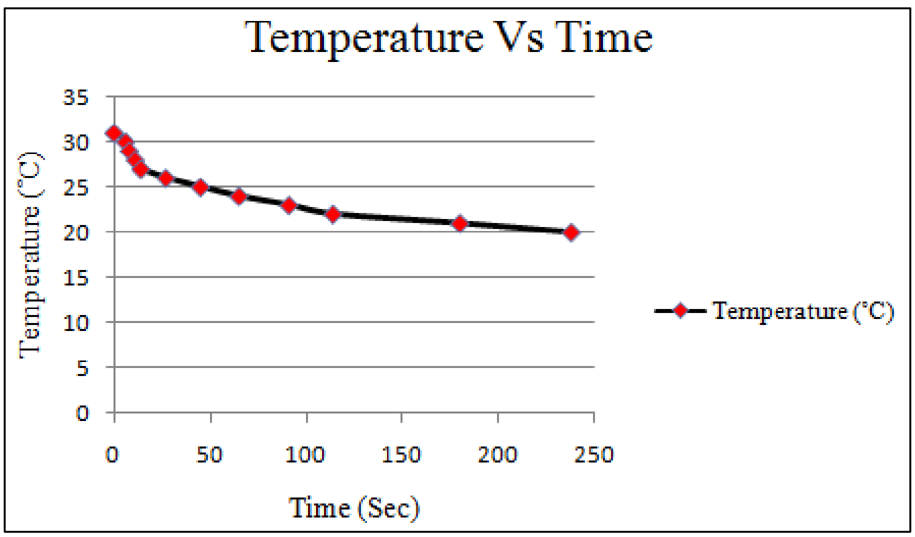

Fig. 4.1: Variation of temperature with time for no load condition

From the above graph it can be inferred that
1) For decrease in temperature from 31° C to 27° C, cooling rate is fast it is near about linear.
2) From 27° C to 22° C, time required for cooling is increased and thus cooling rate is moderate.
3) Beyond 22° C, Cooling rate becomes low and take much more time for cooling.

B. Load Condition:

Temperature is decreased to 23° C from 31° C in 1272 seconds which is nearly 21 minutes and 12 seconds. The graph of temperature versus time is as follows.

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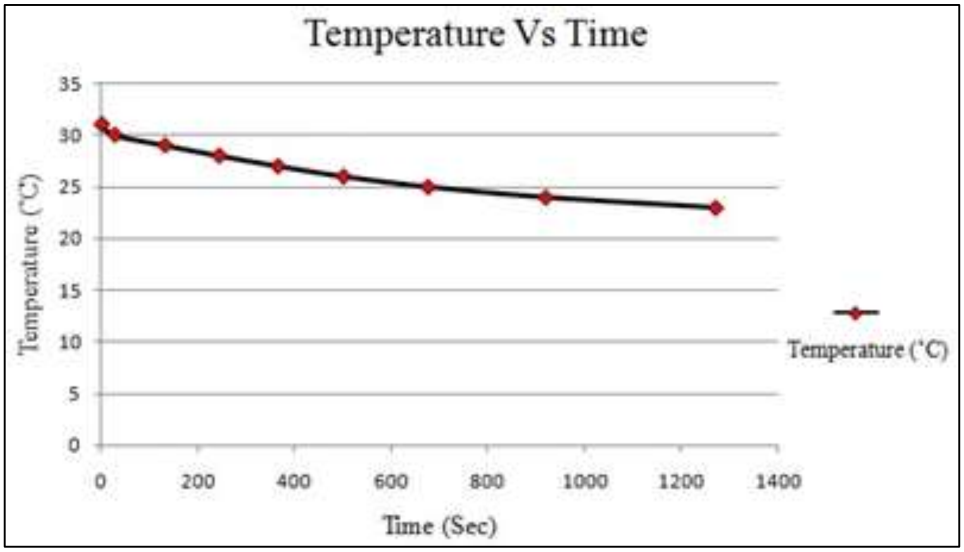

Fig. 4.2: Graph of Temperature with Time for load condition

From the above graph it can be inferred that
1) For decrease in temperature from 31^o C to 28^o C, cooling rate is fast.
2) From 28^o C to 25^o C, time required for cooling is increased and thus cooling rate is moderate.
3) Beyond 25^o C, Cooling rate becomes low and take much more time for cooling.

Factors responsible for reduction in cooling rate are as follows:
1) Heat loss at the ends of clips to the surrounding.
2) Temperature difference between hot side and cold side is increased and this reduces the cooling effect.
3) Heat loss to the air which is flowing through the pipe.
4) Heat loss at non-insulated portion.

VII. CONCLUSIONS

The test was carried out for two conditions, one at no load and second at load condition. During no load condition reduction in temperature up to 20ºC was recorded from initial temperature of 31ºC within 4 minutes and the atmospheric temperature was recorded as 32ºC. The Theoretical COP of the system was calculated as 0.5481. The actual COP of system was 0.1939. For the load condition, 0.2736 liter of water was filled in pipe and setup was run. The reduction in temperature of water up to 23ºC was recorded from initial temperature 31ºC within 21 minutes. The atmospheric temperature was 34ºC. The actual COP of the system was 0.03002.

1) For no load condition, initially the temperature reduces at the faster rate from 31ºC to 25ºC. Beyond that time required for cooling increases. Similarly for load condition initially the temperature reduces at a faster rate from 31ºC to 28ºC also time required for further reduction much increase.
2) The reason behind to reduce cooling rate as follows
   - The temperature difference between hot and cold side of Peltier module increasing with time.
   - Losses in insulation.
   - Losses at end of the pipe.

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