THERMOELECTRIC COOLING AND HEATING BY PELTIER EFFECT

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Abstract : Conventional refrigeration has its own drawbacks, the major one being global warming due to Chlorofluorocarbon (CFC) refrigerants. Thermoelectric refrigeration (TER) is an alternative solution for food preservation, medical services, vaccine storages, and military fields .TER uses thermoelectric effect known as Peltier effect wherein heat is given out or absorbed when electric current passes across a junction between two dissimilar materials This heat, which is absorbed or given out can be used to refrigerate or heat an enclosed volume. The current study deals with how effectively this heat transfer can be made use of. Three cases are considered, first case is for cooling, the second case is for refrigeration as well as for heating purpose and the third case is only for heating purpose. The design requirements chosen are to use the heat in such a way that steady temperatures are reached within a short time and to provide retention time of at least half an hour.

A working prototype of TER was fabricated, integrated and tested. The response parameters like time taken for attaining equilibrium, minimum and maximum temperatures obtained were studied. It was found that the case where both heating and cooling were used simultaneously had the best value of COP. Finally, it was concluded that a better heat transfer can give the best out of Thermo Electric Refrigeration system. Although having lesser effectiveness compared to conventional refrigeration, TER can deliver the best wherever conventional refrigeration is impossible & works as long as current is being made available.

IndexTerms – Peltier effect, thermoelectric refrigeration, heating, cooling.

I. INTRODUCTION

Thermoelectric effects have a wide range of applications starting from working of a thermocouple to electricity generation. Refrigeration is one such application wherein Peltier effect is made use of. The Thermoelectric effect is direct conversion of temperature difference to electric voltage and vice versa. A thermoelectric device creates voltage when there is a difference in temperature on each side. Conversely, when a voltage is applied to it, it creates a temperature difference. The first case is from which we can generate electricity, and the second case results in heat absorption as well as dissipation which was effectively utilized in the present study.

As an alternative for Conventional refrigeration, thermoelectric refrigeration slowly gained importance and now being used in many fields. The basic advantage is that it uses a thermoelectric module whose ends develop heat and cold simultaneously whenever current is passed through the junction. In the present study, apart from the cooling effect produced by peltier module, the heat generated was also utilized, which otherwise goes as waste in refrigeration system. The design consists of a chamber for the hot side too, which served as a cabin for the materials to be heated. Because of this, the work output can be increased and thereby increasing the COP of the entire system. The case of refrigeration only, can also be considered and the COP can be found out. In this way thermoelectric effect usage can be optimized thereby increasing the efficiency.

The Peltier effect is a temperature difference created by applying a voltage between two electrodes connected to a sample of semiconductor material. This phenomenon can be useful when it is necessary to transfer heat from one medium to another on a small scale. It is basically the converse of Seebeck effect.

2. MATERIALS AND METHODOLOGY

A standard Thermo electric module (TEC) consists of any number of thermocouples connected in series and sandwiched between two ceramic plates. By applying a current to the module one ceramic plate is heated while the other is cooled. Cooling capacity varies from fraction of Watts to many hundreds. Different types of modules are single stage, two stage, three stage, four stage, center hole modules etc. Figures 1(a) and 1(b) shows the typical TEC used for study.

Fig1(a) Single stage TEC

Fig. 1(b) cut away View of TEC

Fig.2. Heat sink with blower fan

The specifications of Heat Sink employed are 85.4x85.4x41.5mm, Fan Size: 70 x70mm, Bearing Type: Rifle bearing, Rated Voltage: DC 12V, Speed: 3300 RPM±10%, and Power Connector: 3-pin type. The photographic view of heat sink employed was shown in figure 2.

Fig.3. 12V 5A Adaptor

Fig. 4. Cabins

fig 5. TEC1-12706

This heat sink is fitted with a blower fan to blow away the heat energy or cold energy received from the module. The entire heat sink sits inside the cabin on both sides of thermo electric module. There is also an aluminium block (40x40x50mm) used to connect the heat side of TEC to the heat sink because the Peltier module is totally inside the cooling side cabin. Aluminium is used, as the thermal conductivity is about 200 W/mK and also weighs very much lesser compared to other elements. Required insulation is provided on the block in order to reduce the heat lost due to convection.

The main heat sink parameter for the selection process is its thermal resistance. Heat sink resistance can be termed as the measure of the capability of the sink to dissipate the applied heat. The equation is $R=(T_h-T_\infty)/Q_h$, where R is the thermal resistance (in K/W) and T_h, the hot side temperature and T_∞, ambient temperature respectively. Q_h is the heat load into the heat sink which is the sum of TEC power P_e and heat absorbed. $Q_h=Q_c+ P_e$ .Power supply is an important part for a TEC assembly which is a direct current device. The quality of the DC current is important. Current and voltage of a TEC can be determined by the charts provided by the manufacturer. TEC's power is the product of required voltage and current. (P = IV). Figure 3 shows the power supply adaptor used for the study.

It is important to know the maximum power that can be supplied by the adaptor, and 12V 5A power supply adapter was used for study as the working range of Peltier module is 50-72W. The thermocol cabin with a volume space of 0.0102734 m^3 was used in the study(after subtracting the volume occupied by the heat sink). Figure 4 shows the cabins used for the experimentation. The TEC was selected considering few factors such as dimensions, cooling load, heating load, and power supply etc. The model of TECs employed for the study was manufactured in China by Hebei I.T (Shangai) Co. Ltd. The model no. of the module was TEC1-12706. The idea was to select a TEC which has a cooling power greater than the calculated TEC. TEC1-12706 operates with an optimum voltage of 12V. It has maximum voltage of 12V. Maximum input current is 5A. Maximum power output is 60W. Figure 5 depicts the Peltier module used for the present study.

3. EXPERIMENTATION AND CALCULATIONS

The experimental setup consists of two cabins, one for cooling and the other for heating. Peltier module is fitted inside the cooling cabin and the cold end is directly attached to the heat sink provided and a blower is attached to sink to circulate the cooling effect to the entire cabin.

The other side of Peltier module is connected to an aluminum block whose other end is connected to the heat sink fitted inside the heating cabin. Thermocouple probes are inserted into the cabins. Figure 6 shows the set-up used for experimentation. When the power supply is switched ON, the Peltier module generates cooling and heating on two sides respectively. The experimental investigations were carried out for three different categories as mentioned here. (a)The use of cooling cabin only which was referred as Case 1 hereafter. (b)The use of both cooling and heating cabins simultaneously was considered as Case 2 hereafter. (c)The use of heating cabin only was referred as Case 3, hereafter in this study.

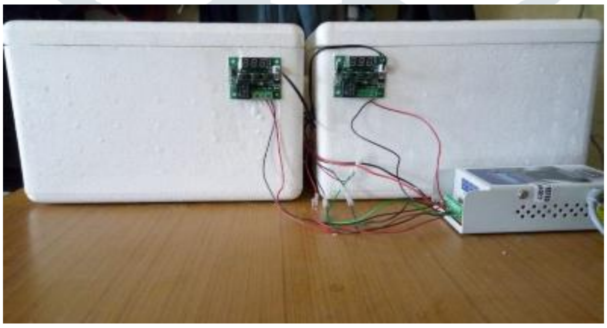

Fig. 6. Experimental Set-up

3.1 Parameters considered:

Ambient temperature (T_a) = 32℃ =305 K
• Volume of cabin = l*b*h Where l = length of cabin = 26.3 cm
b = breadth of cabin = 26.3 cm h = height of cabin = 15.3 cm
Hence Volume = 26.3*26.3*15.3 = 10582.857 cm^3 = 0.010582 m^3
Equivalent cabin space = Volume of cabin – volume of heat sink
= 10582.857 – (6.8*6.5*7.0) = 10582.857 – 309.40 = 10273.45 cm^3 = 0.01027345 m^3
(Since dimensions of heat sink are 6.8 cm, 6.5 cm, 7.0 cm.)
• Density of air (ρ_a) = 1.2 Kg/m^3
• Hence the mass of air contained in each cabin = (1.2)*(0.01027345) = 0.01232814 Kg
• The specific heat at constant pressure (C_p) = 1007 J/KgK
• Specifications of Peltier module:

Maximum input current (I_{max}) = 5A
Maximum DC voltage (V_{max}) = 12V
Capacity of Peltier module (Q_{max}) = 60W
Maximum temperature difference (ΔT_{max}) = 66 ℃

3.2 Case 1:When only cooling cabin is used:

Theoretical COP:

Cold side temperature of Peliter module (T_c) = 12℃ = 285K
Hot side temperature of Peltier module (T_h) = 34℃ = 307K
Seebeck co-efficient (α_m) = V_{max}/T_h = 12307= 0.0390 V/K
Rm= Electrical Resistance of Peltier Module = $[(T_h - \Delta T_{ma})/T_h]*(V_{ma}/I_{max})$= 1.88 Ω
Km= Thermal conductance of Peltier module = $[(T_h - \Delta T_{max})/2\Delta T_{max}]*[(V_{max} * I_{max})/T_h]$ = 0.3568/K
Net Refrigerating Effect (NRE):
$Q_c = (\alpha_m * T_c * I) - (1/2 * I^2 * R_m) - K_m * (T_h - T_c)$
= (0.0390*285*5)–(0.5*5^2*1.884) – 0.3568*(307 – 285)= 24.176 W.
Work Input:
W = $\alpha_m * I * (T_h - T_c) + I^2 R_m$
= (0.039*5*22) +(5^2*1.884)
= 57.39 W
Theoretical COP = (Qc/W)=(24.176/51.39) = **0.470**

Actual COP:

Cold side temperature of Peliter module (T_c) = 18℃ = 291K
Hot side temperature of Peltier module (T_h) = 34℃ = 307K
Mass of air cooled (m) = 0.012328 Kg
Work input = Input of Peltier module + Input of blower fan
W = (12*5) + (12*1) = 72 W
Cooling load (Q_c) = (mCpΔT/t) =(0.012328∗1007∗(305−291)/80) = 2.17 W
(since $\Delta T = (Ta - Tc)$)
Actual COP (C_1) = (Q_c /W) = (2.17/72) = **0.0313**
Similarly the calculations for other two cases can be carried out

3.3 Case 2 : when both heating and cooling cabins are used:

Cold side temperature of Peliter module (T_c) = 23℃ = 296K
Hot side temperature of Peltier module (T_h) = 45℃ = 318K
Theoretical COP = **0.467** and Actual COP (C_2) = **0.0441**

3.4 Case 3: when only heating cabin was employed

Cold side temperature of Peliter module (T_c) = 30 ^{0} c = 303K
Hot side temperature of Peltier module (T_h) = 52 ^{0} c = 325K
Theoretical COP = **0.4633** Actual COP (C_3) = **0.0265.**

4. RESULTS AND DISCUSSIONS:

The results obtained for all the three different cases considered were discussed and Performance was analyzed using graphs

4.1 CASE-1 :Cooling cabin is only used: The figure 7 shows the photographic view of refrigeration set-up wherein it is employed only for cooling purpose.

Fig.7. Photographic view of case-1

The temperature inside the cooling cabin after attaining steady state (Tc) = 18℃ = 291K
• The temperature inside the heating cabin is found to be (Th) = 34℃ = 307K
• The theoretical COP is found to be **0.470** but the actual COP is found to be **0.0313.**
• The reason behind drop in actual COP is because of the volume considered, as Darshan Suryawanshi [4] considered a volume of 1m3 (COP = 0.1939) whereas the study was done considering a volume of 0.0102734 m3.
• Hence, an improvement in COP can be seen if the volume considered is higher and also when an efficient heat sink is designed.
• Figure 8 shows the variation of temperature in cooling cabin (case 1).

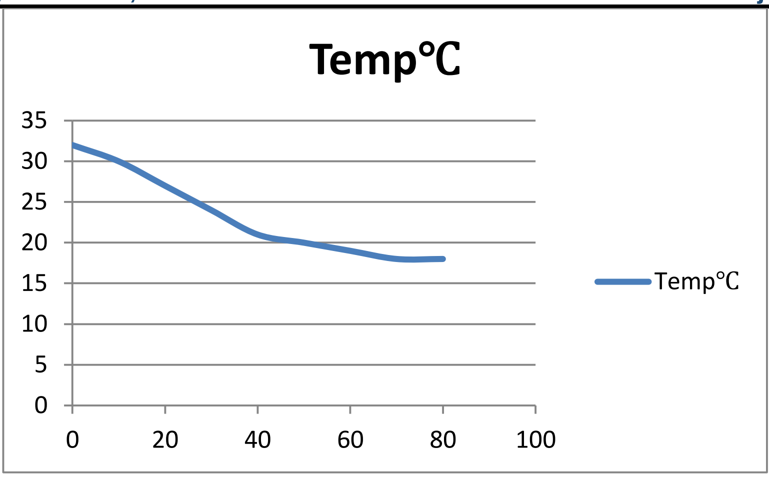

Fig.8 Variation of temperature with respect to time in cooling cabin

It was observed that the variation for the initial stage was rapid and then there was only a little change in the drop of temperature.

• The temperature remained constant at 18°C after 80 seconds

4.2 CASE -2) Heating and cooling cabins are used simultaneously

The figure 9 shows the photographic view of refrigeration set-up wherein it is employed for cooling and heating purpose simultaneously.

Table.1. Experimental Values

Case 1(only Cooling)		Case 2(Cooling and Heating)				Case 3(only Heating)	
Temperature (°C)	Time (Sec)	Temperature (°C)	Time (Sec)	Temperature (°C)	Time (Sec)	Temperature (°C)	Time (Sec)
32	0	32	0	32	0	34	20
30	10	31	10	33	10	37	40
27	20	29	20	35	20	41	60
24	30	28	30	37	30	44	80
21	40	27	40	40	40	48	100
20	50	26	50	43	50	52	120
19	60	25	60	45	60	52	140
18	70	24	70	45	70		
18	80	23	80				
		23	90				

- The temperature inside the cooling cabin after attaining steady state (Tc) = 23°C = 296K

• The temperature inside the heating cabin after attaining steady state (Th) = 45°C = 318K

• The theoretical COP is found to be **0.467** but the actual COP is found to be **0.0441.**

• The minimum temperature attained in cooling cabin is increased due to usage of heating cabin.

• The COP of the system is increased compared to Case 1 as we increased the output, keeping the input constant.

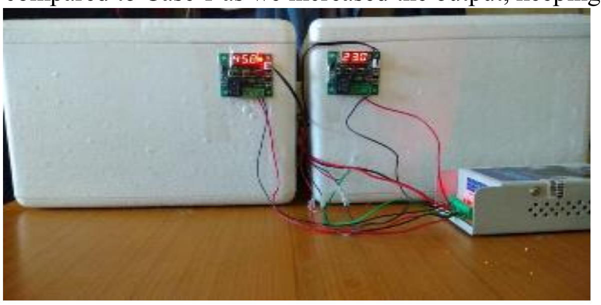

Fig.9 . Photographic view of case-2

The figure 10, below depicts the variation of temperature in cooling cabin

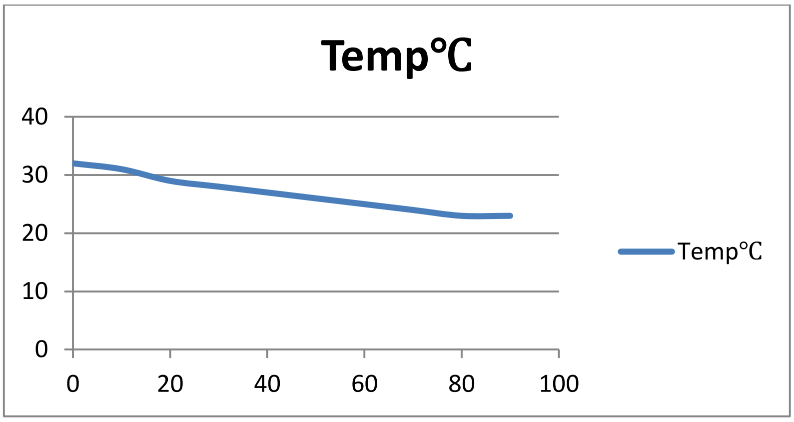

Fig 10.Variation of temperature with respect to time in cooling cabin

The graph depicts the variation of temperature wherein temperature was seen linearly decreasing at all points with time.

• The final temperature is saturated at 23℃ inside the cooling cabin.

• The figure 11. below depicts the variation of temperature inside the heating cabin.

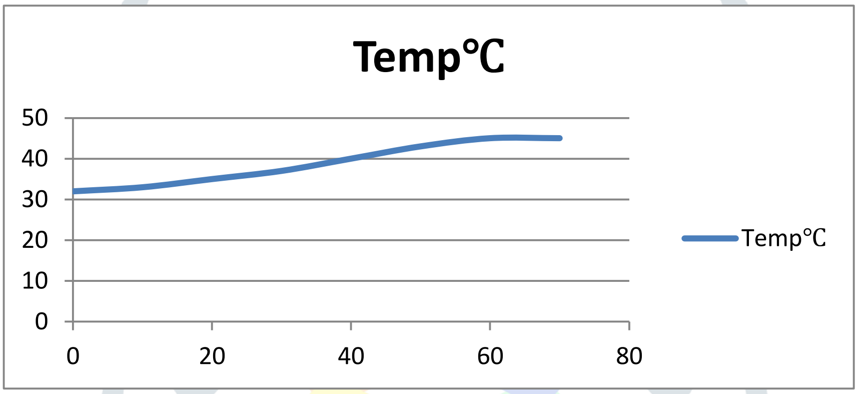

Fig.11 Variation of temperature with respect to time in heating cabin

- The variation of temperature is rapid compared to cooling cabin and the cabin attained equilibrium at a temperature of 45℃.

4.3 CASE -3) When heating cabin is only used

The figure 12 shows the photographic view of refrigeration set-up wherein it is employed only for heating purpose.

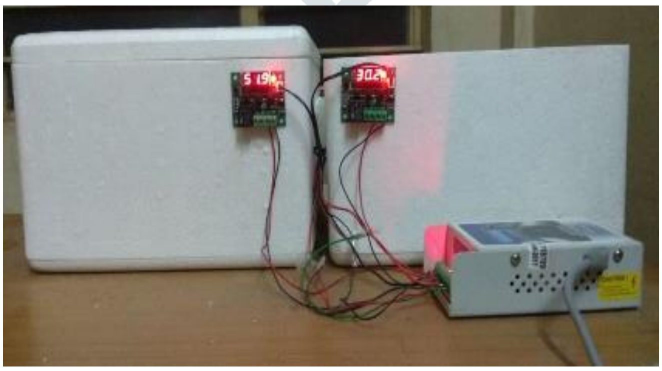

Fig. 12. Photographic view of case-3

The temperature inside the cooling cabin is found to be (Tc) = 30℃ = 303K

• The temperature inside the heating cabin after attaining steady state (Th) = 52℃ = 325K

• The theoretical COP is found to be **0.4633** but the actual COP is found to be **0.0265.**

• The COP can be improved by providing a better heat sink based on the research work of Mayank Awasthi [3] wherein the design of heat sink is discussed.

• The reduction in COP is also seen compared to the above two cases.

• The figure 13 below shows the variation of temperature in heating cabin

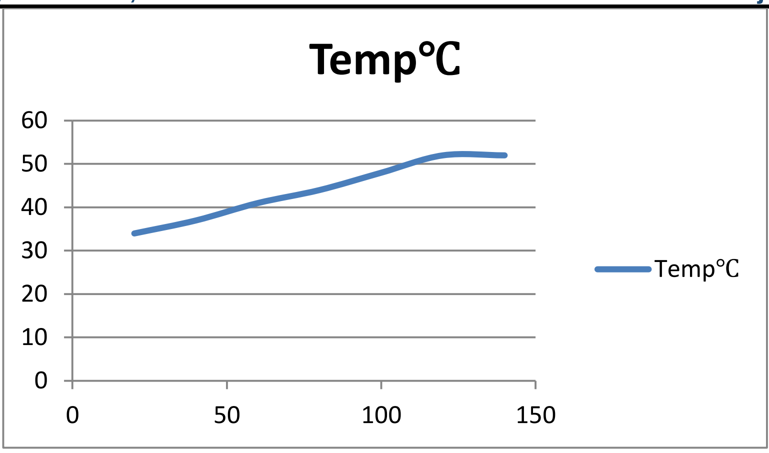

Fig.13 Variation of temperature with respect to time in heating cabin

It can be observed that the pattern followed is much linear in comparison with the other two cases.
• A high value of 52℃ is attained at which the saturation occurred.

Comparison with conventional refrigeration:

• The main advantage that thermoelectric refrigeration has over conventional refrigeration is the emission of harmful CFCs which may lead to ozone depletion, found in conventional refrigeration.
• As there is no usage of any refrigerant in TECs, there is no emission of any kind of harmful gases.
• The COP of thermoelectric refrigeration is far too lesser than the conventional refrigeration.
• It still finds application in portable refrigeration, medical and military fields wherein conventional refrigeration cannot be used.

5.CONCLUSIONS

- Actual COP values are for Case 1) COP= 0.0313; Case 2) COP= 0.0441; Case 3) COP= 0.0265.
- COP of case 2 is found to be higher among all the 3 cases investigated because of the fact that both cooling and heating sides were utilized.
- Among COPs of case 1 and case 3, case 1 has a better value as the refrigerating effect was utilized to full extent and Peltier module was inside the cooling cabin.
- COP of case 3 can be improved if an effective heat sink is used for heat transfer. The intermediate aluminum block is also one of the reason for such a low value.
- It can be concluded that TER system is much effective if it can be used for heating and cooling simultaneously.
- Although the obtained COP values are nowhere near the conventional refrigeration, TER can be effective when conventional refrigeration is not feasible.
- An effective Peltier module was observed to reach -40℃ [12], which can be utilized to the full extent if efficient heat transfer is achieved.

6.FUTURE SCOPE of WORK

The study was carried out with working of modules using an arbitrary heat sink. The heat transfer from module to heat sink can be improved by providing a better heat conducting sink. The volume of refrigerated space can also be improved/altered to achieve a better value of COP. There can be improvement if the aluminum block used in between was replaced with another material. Further study can be done on how to utilize the entire cooling and heating sides of Peltier module. Thermoelectric effect can be observed as long as electricity is supplied to the assembly. Hence, by using a micro controller, one can regulate the amount of cooling required for a particular application. Further improvements like usage of multiple Peltier modules and using better insulated chambers can also be thought of.

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