Performance Analysis of Water Cooled Thermoelectric Module TEC- 12715

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Abstract- **Thermoelectric refrigeration system uses peltier effect to produce hot and cold ends at each of its junctions. Cold end is kept inside the cabinet to produce cooling effect inside that cabinet. Thermoelectric device can work either as a refrigeration system or as heat pump. This work presents an analysis of variation of temperature with respect to time for water cooled thermoelectric assembly. Here TEC-12715 thermoelectric module was used for cooling the refrigeration cabinet. The current was varied from 5A to 11A and time was noted for temperature to drop from ambient temperature to 10-15°C.Results showed that maximum decrease in temperature of polystyrene cabinet was observed when I=0.5I_{max}.**

Keywords: Thermoelectric module; TEC-12715; Peltier effect; Thermo electric refrigeration system; TEM

I INTRODUCTION

We generally use thermoelectric refrigeration system when cooling load on the system is less.For example, in designing a refrigeration system having capacity less than 1 TR (tones of refrigeration) thermoelectric refrigeration can be used.Thermoelectric refrigeration works on the principle of peltier effect.When two junctions are created by joining two different metals and a battery is connected to the circuit, one end is observed to be hot and other end is observed to be cold.This effect is known as peltier effect.A single-stage thermoelectric module can achieve a temperature difference up to 70°C.Thermoelectric modules comes in following categories such as TEC-12706,TEC-12709,TEC12712,TEC-12715 and so on.Appropriate TEM is selected according to the application we have.Here TEC denotes thermoelectric 127 denotes no of P-N couples, 06 ,09,12 or 15 is the current in ampere.

II LITERATURE REVIEW

Sujith et al [1] carried out experimentation on 40 litre cooling chamber.Cooling chamber was to be maintained at 10°C to 15°C for a long duration.Thermoelectric device TEC-12706 was decided based upon the heat load calculated.Thermosiphon system was used for carrying away heat from hot side of the thermoelectric module.The lowest temperature achieved was 13°C at the time of 7.5 hours.Coefficient of performance (COP) came out to be 0.124 which is well below the COP of conventional refrigeration system.

Manoj Kumar Rawat, Himadri Chattopadhyay & Subhasis Neogi [2] designed and developed an experimental thermoelectric refrigerator having a capacity of 1 Litre.Four numbers of super cool make thermoelectric cooling modules (I_{max}=4 A, V_{max}=7.8 A & Q_{max}=19 W) were selected on the basis of active and passive heat removal from thermoelectric refrigeration cabinet.The performance of single TEM was evaluated at 0.5I_{max}, 0.25I_{max} and 0.75I_{max}.Optimum performance was obtained at I=0.5I_{max}. That means temperature reduction at cold side of module was maximum when I =0.5I_{max} (i.e. I= 2 A).So at this optimized current of 2A four cases were studied.In first case performance of thermoelectric refrigeration was evaluated without any heat load inside the refrigeration cabinet.In 2nd case 50 ml of water was taken inside the cabinet. In 3rd case 75 ml of water was taken inside the cabinet.In 4th case 100 ml of water was taken inside the cabinet.A temperature reduction of 11°C was observed without any heat load and 9°C with 100 ml of water inside the cabinet when the ambient temperature was 23°C in first 30 minutes.COP was found out to be 0.1 for 100 ml heat load condition.

D. Astrain, J.G. Vian & M. Dominguez [3] developed a thermoelectric domestic refrigerator.

Here heat dissipation from hot side of thermoelectric module was optimized resulting in increase of COP of thermoelectric refrigeration system.The heating effect produced by hot side of peltier plate is utilized to vaporize the liquid contained in the close chamber.Vapor on reaching the top side of container condenses on coming in contact of vertical fins and it again comes down in the container.This way self feed cycle continues.Using TSF reduces the thermal resistance between hot side of peltier pellet and chamber containing fluid.Here aim was to minimize the thermal resistance R_{disp}Two prototypes were built, one with traditional finned heat sink and other with phase change TSF device.An increase in COP was clearly observed when TSF was used in place of traditional finned heat sink

III EXPERIMENTAL SET UP

A Single Stage Water Cooled Thermoelectric Refrigeration System.

Fig 1 depicts the CAD model of single stage water cooled thermoelectric refrigeration system.This CAD model was made in autodesk inventor.The single stage water cooled thermoelectric refrigeration system consists of a thermoelectric module TEC-12715,nitrile tape for insulation purposes,polystyrene sheet with 1.8cm thickness,a temperature sensor with thermocouple,a hollow water jek with one inlet and one outlet for chilled water flow,a reservoir,a chilled solution of ethylene glycol with water,an aluminium plate of 2mm thickness and size of

15cmx15cm,a water pump with reservoir,a bakelite plate of dimensions same as that of aluminium plate and switch mode power supply for powering TEM and water pump.

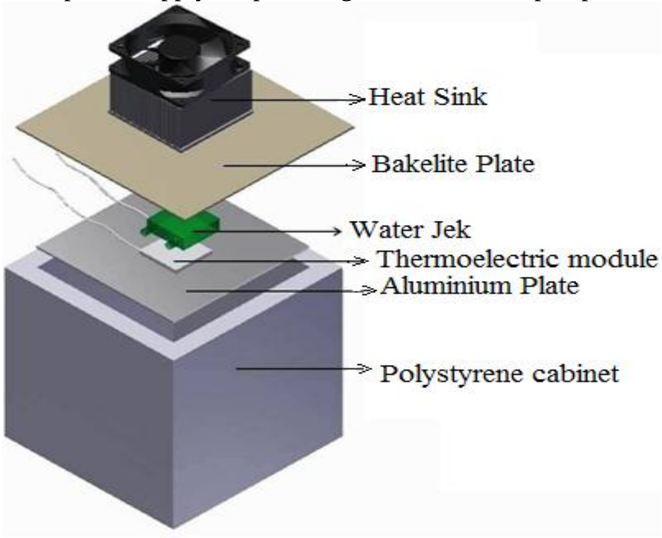

Fig 1 : CAD model of single stage water cooled thermoelectric refrigeration system

Fig. 2 depicts the experimental arrangement of single stage water cooled thermoelectric refrigeration system.It's CAD model depicts the way in which different parts of this system are assembled together.First of all a polystyrene cabinet of inner dimensions 15cmx15cmx15cm was built.Thickness of this polystyrene cabinet was 1.8 cm.Top portion was left open for keeping the aluminium plate on it.Thermocouple leads were placed inside the polystyrene cabinet for measuring temperature of polystyrene cabinet.Dimensions of the aluminum plate were 17cmx17cm.Aluminium plate was fixed to the polystyrene cabinet with the help of nitrile tape.Thermoelectric module was kept on aluminium plate with thermal grease on its both sides.Cooling water jek with one water inlet and water outlet was fixed on top of thermoelectric module.A bakelite plate of dimensions same as that of aluminium plate was fixed on the top of water cooling jek.Above the bakelite plate a heat sink coupled with CPU fan was placed on it.Whole assembly from aluminium plate to the heat sink was fastened with the help of screws and nuts.Water pump used in domestic desert coolers was used to force chilled water through the water jek.This chilled water flowing through the water jek takes away the heat generated at the hot side of TEM.

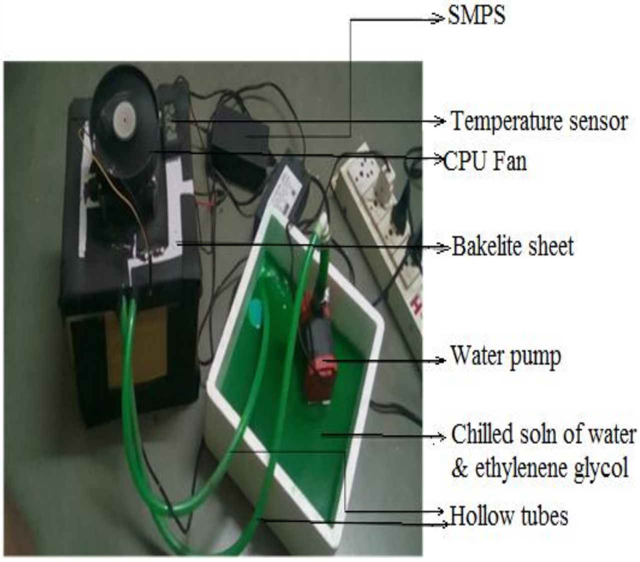

Fig 2 Experimental arrangement of single stage water cooled thermoelectric module

IV METHODOLOGY

A Project objective

In this proposed work a refrigeration system whose capacity was 3.375 Litres was developed.Inside temperature of this refrigeration cabinet was to be maintained at 20°C.Temperature of surrounding environment was assumed to be at 28°C.Heat load was determined corresponding to inside temperature of cabinet.Peltier module was decided based on heat load calculated.Heat sink with a maximum thermal design power was used for carrying away heat from hot side of thermoelectric module.

B Geometry

A rectangular box with the shape of a cuboid having an internal dimension of 15cmx15cmx15cm was built having a thickness of 1.8cm.The top most portion of this box was left open.An aluminum plate of thickness 0.02cm and size of 18.6cm x18.6cm was kept on the topmost portion of the box.Cold side of thermoelectric module was kept in contact with this aluminium plate and hot side of this module was kept in contact with the water jek.Chilled water is allowed to flow through this water jek with the help of water pump to take away the excess heat from the hot side of module.Above the water jek a bakelite plate is placed.An air cooled heat sink is supported on this bakelite plate.Nitrile tape is used to insulate the cabinet from surrounding environment.

C Materials

The refrigeration cabinet was made up of polystyrene sheet having a density of 0.33kg/m^3,thickness of 1.8cm and thermal conductivity of 0.33W/mk.Aluminium plate having a thickness of 0.02cm,thermal conductivity of 138W/mk and density of 2680kg/m^3 was placed on the top of refrigeration cabinet to provide a uniform cooling inside the refrigeration cabinet.

D Specifications of TEC

Items	Parameter
Max. Operating Tem	<90°C
Max. Cooling Power	136 W
Tem. Difference Max	65
Input Voltage Max	15.4 v
Max. Current	15 A

Table 1: Datasheet of thermoelectric module TEC-12715[4]

E Selection of thermoelectric module

For the temperature of refrigeration cabinet to drop,the amount of heat that is to be removed by thermoelectric module must be greater than the amount of heat that infiltrates the cabinet.We have used TEC-12715 in our project because the cooling power of TEC-12715 is greater that heat load of refrigeration cabinet.

F Heat sink selection

For selecting a heat sink for a particular application like for thermoelectric systems we need to know the junction temperature between heat sink and hot side of TEM ,surrounding temperature ,electrical power (V×I) across a thermoelectric element,dissipating heat load Q.So the formula we used here is as follows:

$T_H = T_A + (V\times I + Q) \times R_Q$

$75 = 30 + (12\times 5 + 63.2) \times R_Q$ [5]

$R_Q = 0.36°C/W$

Where,

T_H = temperature of hot side of TEM

T_A = surrounding temp of air

Q = heat load in watts

V×I = power rating of TEM

R_Q = thermal resistance of heat sink

Smaller the thermal resistance bigger the heat sink.However it is best to use heat sink with a high thermal design power.We have used intel make air cooled heat sink with a thermal design power of 130W.

G Heat load calculation.

The elements in the heat load consists of active heat load and passive heat load Active heat load:Active load arises due to dissipation of some power in resistive element of circuit.Suppose current flowing through an element is I and resistance of element is R_m then power dissipated here will be equal to I^2R_m.This power dissipation is converted to heat in watts.So active heat load will come out to be= I^2R=60W

Passive heat load:Passive heat load is the heat transfer that is occurring via conduction and convection from ambient temperature to inside of the system.Calculating heat leakage load from room air to inside the box which would be maintained at 20°C for

a) 4 outer surfaces are made of polystyrene foam and

b) 1 outer surface is made of aluminium plate

Calculating passive heat load for 4 surfaces

a) Q = U×A×ΔT for 4 outer surfaces

Where,

U= overall heat transfer coefficient

$$U = \frac{1}{\frac{1}{\alpha_1} + \frac{\delta_w}{\lambda_w} + \frac{1}{\alpha_2}},$$

α_1 and α_2 are heat transfer coefficients outside in and inside the box

δ_w=Thickness of box =1.8 cm or 0.018 m

λ_w=thermal conductivity of Thermocol or polystyrene foam =0.03 w/mk

α_1 =10 w/m^{2}k = α_2 assumed

A = outside area of box=4x [0.186mx0.168m] =0.124992 m^2

One surface will be kept on ground so it is assumed that no heat transfer will take place from ground to inside the box

ΔT=Difference in temperature between room air and temperature maintained inside the box ΔT=10 (30-20)

In this case,

$$U = \frac{1}{\frac{1}{10} + \frac{0.018}{0.033} + \frac{1}{10}}$$

U=1.341 w/m^{2}k

So, Q =1.341x0.124992x10

=1.676 W

b) Calculating heat leakage from room air to inside the box which would be maintained at 20°C for 1 outer surface is made of aluminium plate of thickness 0.002m

$$U = \frac{1}{1/10 + 0.002/205 + 1/10}$$

U=5 w/m^{2}k

A=0.034596 m^2

ΔT=10 (30-20)

Q=UxAxΔT

Q=5x0.034596x10

Q=1.7298 W

Total heat load: =60+1.676+1.7298 =63.40 W

H Experimental procedure

Here a chilled water is used for removing heat from hot side of TEM,that is why we called this case as single stage water cooled thermoelectric refrigeration system.Mass flow rate from the water pump is kept constant,current is taken at 5A. Readings were noted in a table and a graph was plotted depicting the variation of temperature with respect to time for a fixed current of 5A.Now the current is changed to 8A.Again readings are noted in a table and a graph is plotted showing the variation of temperature of polystyrene cabinet with respect to time. In the final case current was incremented to 11A ,readings were noted in a table and a graph was plotted showing how the temperature varies with the respect to time for an input current of 11A.A comparison was done amongst the three different cases for different values of currents.

V RESULTS AND DISCUSSION

A The effect of current on temperature inside a polystyrene cabinet for a single stage water cooled thermoelectric refrigeration system

Chilled water at 10°C was supplied through the water jek for removing heat from hot side of thermoelectric module.Here a single thermoelectric module was taken.Current was supplied at 5A and variation of temperature with respect to time was noted in Table 2.Current was now changed to 8A and variation of temperature with respect to time was noted in Table 3.Table 4 depicted variation of temperature with respect to time for a current supply of 11A.In the whole process mass flow rate of water through the water cooled heat sink was kept constant.

Temp (°C)	Time(minutes)
30.8	0
30	1.4
29	2.066
28	2.55
27	3
26	3.4333
25	3.91666
24	4.4333
23	5
22	5.61666
21	6.38
20	7.36
19	8.8
18.2	11.5

Table 2 Variation of Temperature with time for single stage water cooled TEM at 8A

p (°C)	Time(minutes)
28.1	0
26	2.1666
24	2.8666
22	3.466
20	4
18	4.6
16	5.25
14	6
12	6.9166
10	8.133
7.6	13.8

Table 3 Variation of Temperature with time for single stage water cooled TEM at 8A

Temp (°C)	Time(minutes)
26.2	0
24	2.06
22	2.766
20	3.4166
18	4
16	4.7
14	5.38
12	6.2833
10	7.6
7.8	11.5

Table 4 Variation of temperature with time for single stage water cooled TEM at 11A

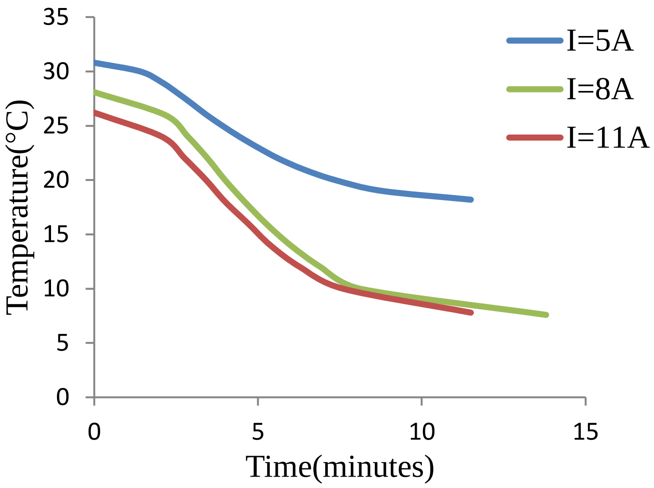

Fig 3 Temperature variation with time at different supply currents.

Fig 3 shows a comparison of variation of temperature with respect to time within the enclosed space of polystyrene cabinet at different currents.A drop of 12.6°C is observed in 11.5 minutes when supply current is fixed at 5A.When supply current was changed to 8A a temperature drop of 20.5°C was observed in 13.8 minutes.On changing the supply current to 11A a temperature drop of 18.4°C was observed in 11.5 minutes.Comparing all the three cases at different currents we can conclude that the optimum current was 8A at which lowest temperature was achieved in minimum amount of time

VI CONCLUSION

From our experiment we observed that a large decrease in temperature for a least amount of time was obtained for the case when we used a chilled solution of water to extract heat from hot side of single stage thermoelectric refrigeration system. Optimum performance in this case was obtained keeping current = 0.5 times maximum current.Maximum temperature drop occurred in a miminium amount of time when I=8A which is approximately half of the maximum current.

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