A review analysis of three different cases of air cooled thermoelectric refrigeration system, 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=0.5Imax.

INTRODUCTION

On applying a direct current of suitable magnitude within a thermoelectric circuit temperature difference is noticed at each of the junctions.One end absorbs heat and becomes cold while the other end rejects heat and becomes hot.For system to work as refrigeration system cold end is kept inside the volume which is to be cooled.For system to work as heat pump, the hot end is kept inside the volume which is needed to be kept warm

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.Mostly we use refrigeration system based on vapor compression system.

Thermoelectric refrigeration works on the principle of peltier effect.Now the question arises what is peltier effect actually 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 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 or 09 is the current in ampere.

For the design of a typical thermoelectric module one needs to have the knowledge of size of TEM, no of couples within a TEM, contact resistance between thermoelectric elements and copper plates.Increase in thermal resistance due to junction should also be taken care of.Moisture is very harmful for a TEM, therefore a good quality moisture resisting element is used for protecting TEM from moisture.

LITERATURE REVIE

Reviews on Different research Works

A detailed literature survey was done for understanding the topic more effectively and precisely

V V kulkarni et al[1] studied three different cases with the module TEC-12715 to create a refrigeration effect within the cabinet.These cases are as follows:

1st case:Two thermoelectric modules were connected in parallel for a volume of cabinet which was 66500 cm^3. Force convection heat sink was used to remove the heat from hot side of thermoelectric modules. Force convection was done by a fan blowing air towards heat sink to remove excess heat from hot side of thermoelectric module.A temperature difference of 9.8°C (from 27.5°C to 18.2°C) was obtained in 25 minutes for an input of 184.68W to thermoelectric cooler assembly when both modules were in operation.

2nd case:Only module was operation for same volume of box.A temperature drop of 4.4°C was obtained in 16 minutes for an input of 100.8 W to thermoelectric cooler assembly.

3rd case:Both the thermoelectric modules were in operation simultaneously for a reduced volume of box (V=32190 cm^3).A temperature difference of 10°C between ambient temperature and temperature inside the box for an input of 195.6W to thermoelectric cooler assembly

Manoj kumar Rawat et al[2] designed and developed an experimental thermoelectric refrigerator having a capacity of 1 Litre.Outer casing was made up of MS sheet.For thermal insulation polyurethane foam sheet has been provided inside the box to prevent reversal of heat flow.A thin copper sheet (0.4 mm) was fixed inside the box for uniform distribution of temperature.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.Cold side of TEM mounted on refrigeration cabinet and hot side of module was fixed on heat sink.A black anodized heat sink fan assembly with a thermal resistance of 0.5°C/W. has been used for each module to enhance heat removal rate.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 et al[3] designed a TSF device based on thermosyphon with phase change which distributes the heat from the hot side of peltier pellet to the whole surface of finned heat sink.Here heat dissipation from hot side of thermoelectric module was optimized resulting in increase of COP of thermoelectric refrigeration system.The thermosyphon system consisted of prismatically closed chamber with a fluid inside it. In the bottom part of the back face ,hot side of the peltier pellet is placed in touch with a chamber surface.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.

TSF spreads the heat from little hot surface (peltier pellet) over a big surface.Using TSF reduces the thermal resistance between hot side of Peltier pellet and chamber containing fluid.Outer part of TSF containing vertical fins was optimized used CFD software FLUENT.Two models in 3D were implemented, one for natural convection through fins, other through the forced convection through the fins.For the model of natural convection spacing between fins was varied, length of fins and width of fins was also simultaneously varied .Four different heat flows were taken.For model of forced convection through the vertical fins mass flow rate of air was varied.Temperature of air was kept constant at 293 K same as the ambient one.Spacing between the fins and height of fins was also varied.Here aim was to minimize the thermal resistance $R_{disp.}$

$$R_{disip} = \frac{T_{w2i} - T_a}{Q_H} \qquad (2.1)$$

R_{disip} was obtained with the help of FLUENT simulations

Application of TSF was observed in thermoelectric domestic refrigerator
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.Comparison was

made between the COP of heat sink with TSF incorporated it and traditional finned heat sink and it was found that COP of heat sink with TSF was greater than COP of traditional heat sink

K V Mali et al[4] designed a thermoelectric refrigerator with an interior volume of 5 liters' to maintain a temperature in the range of 5°C to 25°C and retention for next half an hour.High impact polystyrene was used to build the outer casing as it has low thermal conductivity which decreases the heat transfer through the cabinet.The components of air cooler were as follows an internal heat sink, a thermoelectric module and an external heat sink.The amount of heat transferred to internal heat sink was found out to be 33 W.The test was conducted at different ambient temperatures 21°C, 15°C, 32°C and 43°C.The temperature varied from 5°C to 15°C with temperature within TEC as less than 1°C.The retention time for low temperature was calculated as per test procedure.6 A of current was needed for thermoelectric module.Battery providing this amount of current is very huge and bulky, much the bigger than air cooling cabinet.

EXPERIMENTAL SETUP AND METHODOLOGY

Description of the experimental system

We have studied 3 different cases namely single stage air cooled thermoelectric refrigeration system,2 stage air cooled thermoelectric refrigeration system & single stage water cooled thermoelectric refrigeration system.

Single stage air cooled system consists single thermoelectric module TEC-12715,an aluminium plate of 2 mm thickness having a size of 17cmx17cm,an intel air cooled air cooled heat sink with TDP of 130W,a temperature sensor with an accuracy of ±0.3°C,two switch mode power supply,nitrile insulation tape,polystyrene sheet with a thickness of 1.8cm.A CAD model of single stage thermoelectric refrigeration system was drawn in autodesk inventor.Fig 3.1 shows the CAD model of single stage thermoelectric refrigeration system.

Experimental setup of single stage air cooled thermoelectric refrigeration system consists of all the components mentioned in above fig.Refrigeration cabinet is made of polystyrene material.Inner dimensions of polystyrene cabinet is 15cmx15cmx15cm with a thickness of 1.8cm.Polystyrene has a low thermal conductivity,thus it decreases the transfer of heat from surrounding to the enclosed space within the cold cabinet.Above the cabinet an aluminum plate is mounted with the help of nitrile tape.Thermoelectric module is sandwiched between the heat sink and aluminum plate.It is fastened to the aluminium plate and the heat sink with the help of screws and nuts.Thermal grease is applied on both sides of thermoelectric module to decrease the contact resistance.Fig.3.2 shows the experimental setup of single stage air cooled thermoelectric refrigeration system.

2 stage thermoelectric refrigeration system consists of 2 thermoelectric modules,aluminium plate of 2mm thickness having a size of 17 cmx17cm,a polystyrene cabinet with a thickness of 1.8cm with inner dimensions of 15cmx15cmx15cm,a temperature sensor with accuracy of ±0.3°C,switch mode power supply,nitrile tape for insulation purpose,an intel heat sink with TDP of 130W and an AC outlet.Fig 3.3 shows the arrangement of various parts used in 2 stage thermoelectric refrigeration system with the help of a CAD model.

Experimental setup of 2 stage air cooled thermoelectric refrigeration system is depicted in fig 3.4.It consists of polystyrene cabinet with it's top portion open.Aluminium plate is attached to the top portion of cabinet with the help of nitrile tape.Thermocouple lead of temperature sensor is placed inside cabinet to measure the temperature of cabinet.Both the thermoelectric modules are placed above the aluminium plate.Thermal grease is applied at each of the junctions to lower thermal contact resistance.Air cooled heat sink of intel make with TDP of 130W is placed at the top of both the thermoelectric modules.Assembly is tightened with the help of screws and nuts.

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.

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.

Experimental Procedure

We have studied three different cases namely:

I^{st} Case: single stage air cooled thermoelectric refrigeration system

2^{nd} Case:2 stage air cooled thermoelectric refrigeration system

3^{rd} Case:single stage water cooled thermoelectric refrigeration system

RESULTS AND DISCUSSION

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

depicts variation of temperature inside the polystyrene cabinet with respect to time for currents namely at 5A,8A and 11A.When current was fixed at 5A a drop of 6.8°C was observed in 10.9 minutes.When current was changed to 8A a drop of

8.6 °C is seen in 10.3 minutes.On changing the current to 11A a drop of 6.8°C is seen in 10.166 minutes.So we can conclude that maximum temperature drop in minimum amount of time was observed when supply current was taken at 8A.The maximum current capacity of this thermoelectric module is 15A and 8A near about half of the maximum current.So,we can say that maximum efficiency of single stage thermoelectric refrigeration system was observed at $I=0.5I_{max}$.

depicts showing the variation of temperature of polystyrene cabinet with respect to time for a single stage air cooled thermoelectric refrigeration system at 5A,8A and 11A.From this graph we can observe that least temperature of 17.2°C was achieved when current was taken at 8A.We know that cooling capacity of thermoelectric module is as follows:

$$Q_c = \alpha ITc - \frac{1}{2} I^2 R_m - K_m (T_h - T_c) \qquad (4.1)$$

Q_c must be high enough to bring the down the temperature of polystyrene cabinet within a minimum time.At the lowest current of 5A Q_c is very low,at 11A I^2R_m is very high,therfore the optimum current is 8A.

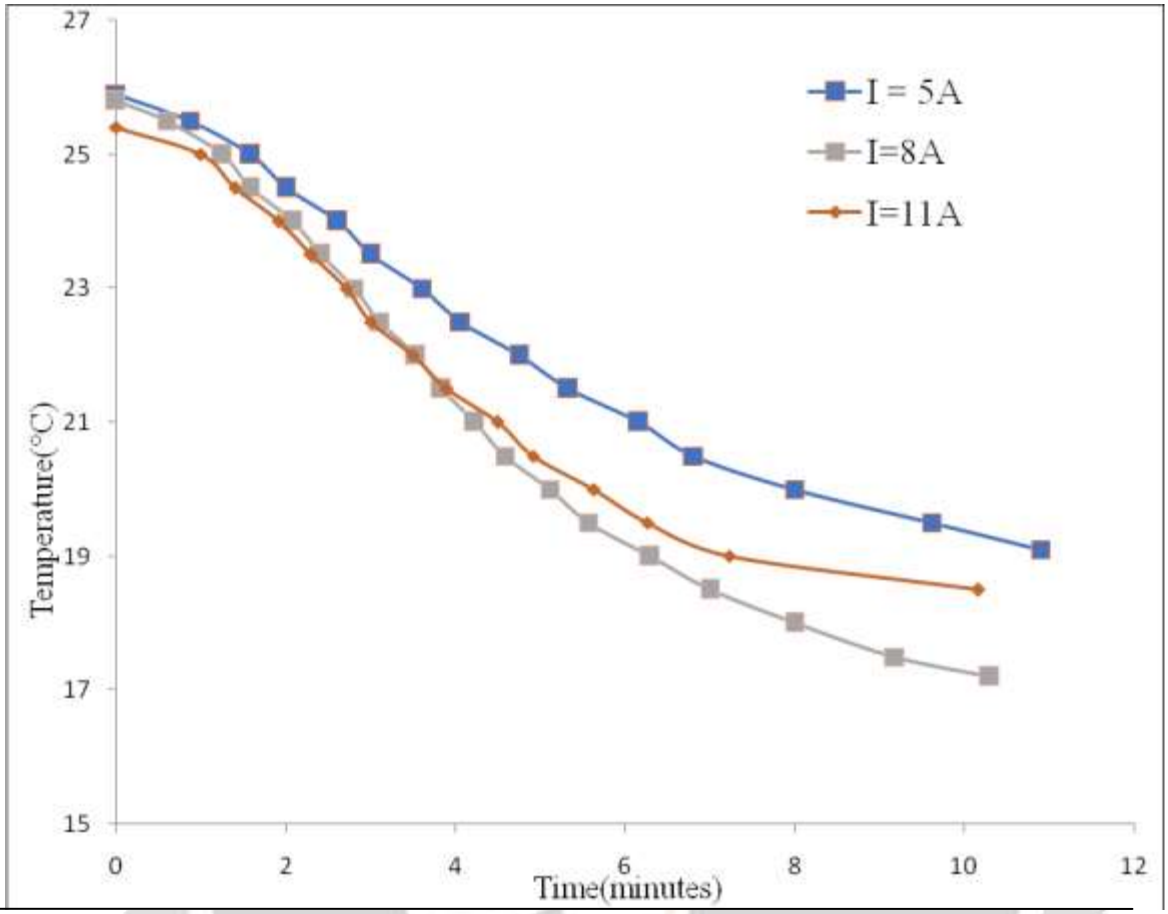

Fig.4.1 Temperature Variation with time for a single stage thermoelectric assembly at different currents

4.2. The effect of current on temperature inside a polystyrene cabinet for a two stage air cooled thermoelectric refrigeration system

Here we have taken two thermoelectric modules instead of single thermoelectric module.Both the thermoelectric modules were placed one above the other.This arrangement is also known as cascaded thermoelectric assembly.Both the modules were connected in a parallel configuration so that when current was supplied through the SMPS it was distributed equally among thermoelectric modules having a constant voltage of 12V across each of them.Table 4.4,4.5 and 4.6 depicts the variation of temperature with respect to time inside the polystyrene cabinet when current supplied were 5A,8A and 11A respectively.

A drop of 4.3°C was seen in 13.2 minutes when applied current was 5 A.On applying a current of 8A temperature dropped to 18.9°C in 12 minutes.So we noticed a drop of 5.8°C in 12 minutes when input current was 8A.On increasing the supply current to 11A temperature decreased to 19.1°C within 14.75 minutes.So we can say that a drop of 5.8°C was observed when input current was fixed at 11A.Fig 4.2 depicts the variation of temperature of polystyrene cabinet with respect to time for a 2 stage air cooled thermoelectric refrigeration system at 5A,8A and 11A.So on comparing the three different cases we can say a maximum drop of 5.8°C was achieved in a minimum time of 12 minutes when input current was fixed to 8A.

On comparing the single stage air cooled thermoelectric system with 2 stage thermoelectric system we find that the single stage thermoelectric system has performed better at 8A compared to 2 stage thermoelectric system.In case of single stage thermoelectric refrigeration system a drop of 8.6°C was observed in 10.33 minutes where as in 2 stage thermoelectric refrigeration system a drop of 5.8°C was observed in 12 minutes when current was fixed at 8A.The reason behind this is probably that current distributes equally among both the thermoelectric modules in 2 stage thermoelectric configuration(parallel connection) resulting in decreased cooling capacity of each individual module.Thus we can say that single stage thermoelectric system performs better than 2 stage thermoelectric system when the electrical supply in 2 stage thermoelectric system is parallel in nature.

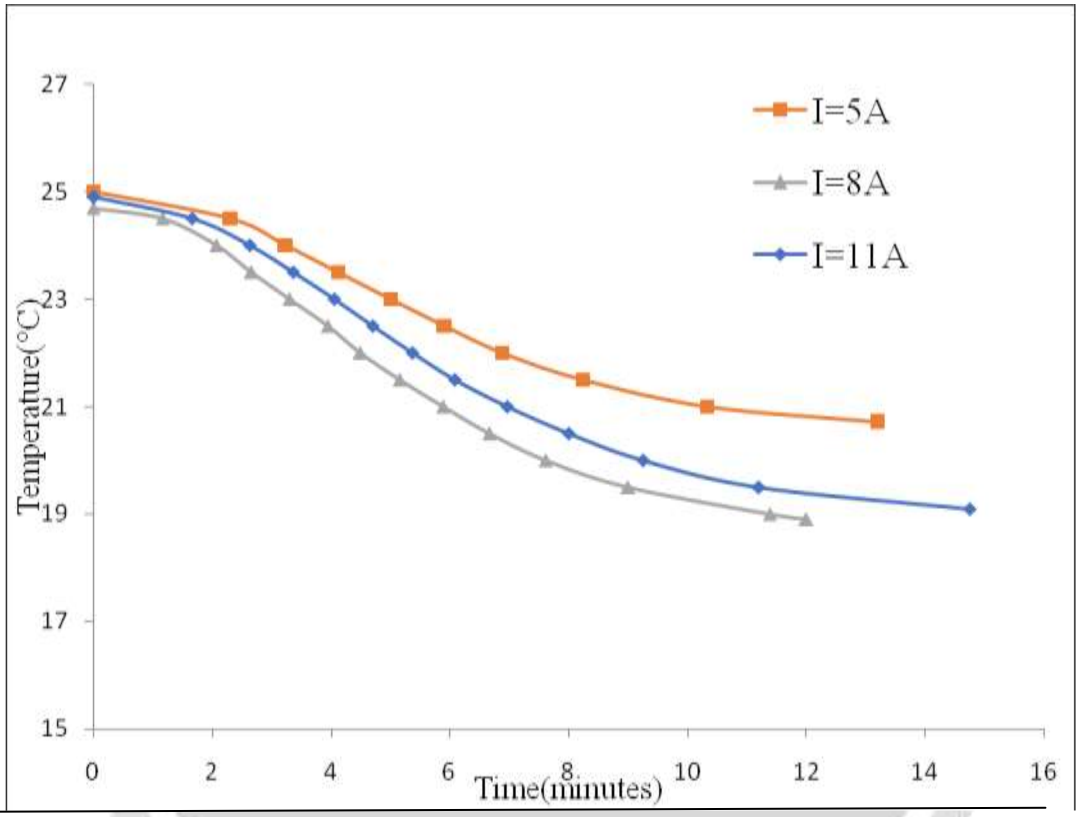

Fig.4.2 A plot of Temperature variation Vs time at different currents for 2 stage TEM

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

Here we have taken a water cooled heat sink instead of air cooled heat sink.Water is better when compared to air for removing the joule heat from thermoelectric module.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 4.7.Current was now changed to 8A and variation of temperature with respect to time was noted in Table 4.8.Table 4.9 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.

Fig 4.3 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.

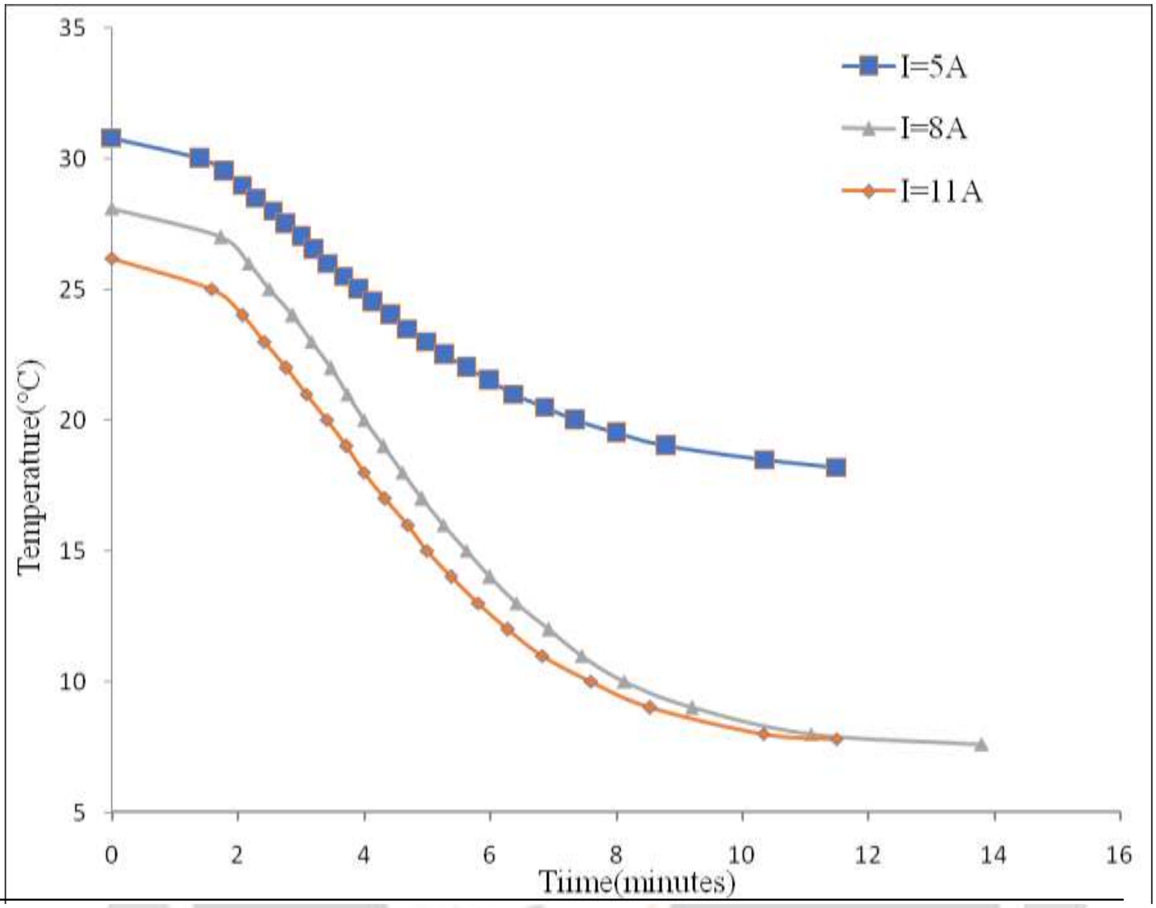

Fig.4.3 Temperature variation with time at different supply current for single stage water cooled

CONCLUSION AND FUTURE SCOPE

Thermoelectric refrigeration system is a good alternative to conventional vapor compression refrigeration systems because here no refrigerant is used.So, there is hardly any chance of leakage of refrigerant into environment.Thermoelectric system is a solid state device since it does not consists of any movable parts such as compressor etc.Therefore we can say that thermoelectric system is a reliable system with very less chances of permanent failure

The only drawback of using thermoelectric refrigeration system is its low coefficient of performance. More work has to be done and comparatively less cooling capacity can be derived from it.Currently COP of thermoelectric system lies in the range of 0.5 to 0.8. Research is being done to improve COP of thermoelectric systems.

Currently thermoelectric refrigeration system is being used in medical industry, electronic industry, aerospace etc.

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.

In the single stage water cooled refrigeration system we can also replace reservoir by a suitable sized radiator if we need to build a compact sized refrigerator system working on thermoelectric system for our domestic use.Thermostat can also be incorporated in our design to cut off power from thermoelectric module as soon as desired temperature is reached in refrigeration cabinet.

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