MODELLING OF PORTABLE TEMPERATURE CONDITIONER BASED ON PELTIER MODULE

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ABSTRACT

The proposed paper consists of modelling of a portable temperature conditioner made of thermoelectric module (TEM) or Peltier module (TEC) which can be used for both cooling and heating purpose. The Peltier module is a device in which heat flux is created at the junction of two dissimilar conductor or semi-conductors when a voltage is applied across it. The reverse process will take place when the polarity of the current given to the module is reversed. The modelling consists 1) Heat load calculation, which is the measure of heat taken by the load. 2) Design of thickness of insulated container for holding the load (here water). 3) Design of optimum heat sink for adequate heat dissipation to the atmosphere. The simulation is carried out using ANSYS steady state thermal 4) Design for finding out the convection constant for selecting the fan for forced convection with desired cubic feet per minute (cfm).

Keywords: - *Peltier module, heating, cooling, simulation, convection*

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1. INTRODUCTION

Peltier Cooling Modules (TEC or a TEM) generally, they are used for cooling purposes, however they can be also used for heating (reversing the electric current flow) and can be even used on generation of electrical power and are available in different sizes in market. The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice-versa [1]. A TEC module produces temperature difference when a voltage is applied across it and can also produce voltage if temperature difference is applied across its two sides. . At the molecular scale, a change in applied temperature causes the charge carriers in the material to get diffused from the hot side region to the cold side region. This is how the effect of electricity generation is carried out in TEC module [9]. The direction of heating and cooling is determined by the polarity of the applied voltage, so it can be used as temperature controllers. The term "thermoelectric effect" can be defined by explaining three effects: The Seebeck effect, Peltier effect, and Thomson effect [2]. The Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. Thomson effect phenomenon which explains that whenever there is an electric current passing through a single material that has a temperature difference across its length, a heat evolution or heat absorption would take place. This transfer of heat is superimposed on the common production of heat associated with the electrical resistance to currents in conductors. A physicist named William Thomas invented this effect in the year 1854.

Thermoelectric modules have (Peltier modules) have a lot of applications in such as cooling applications of small-volume devices, typical of which are to stabilize the temperature of Peltier modules can be used in portable cooling boxes for medicine transport and can also be used for picnic items storage. Moreover, it can be used for thermoelectric heating when the current polarity is reversed. But thermoelectric refrigeration seems to have made a little impact on the domestic refrigeration market. The main factors that determine the marketability of a thermoelectric refrigerator are price and running cost, together with reliability, quietness, flexibility and temperature stability as important considerations. Price reflects the manufacturing cost, while the running cost is mainly determined by the coefficient-of-performance (COP) of the cooling unit [3].

The TEC module is a unique cooling device which has a lot of advantages, in which the electron gas serves as the working fluid. It is inherently noiseless, reliable and environmentally friendly. It is now possible to develop an economically-viable thermoelectric refrigerator which has improved performances and the inherent advantages of environmentally-friendly silent operation, high reliability, and ability to operate in any orientation. In this paper, prototype of thermoelectric temperature conditioner is described with mechanical optimization in order to increase the rate of heat dissipation [8].

2. SYSTEM CONSTRUCTION

In order to successfully design and build a portable temperature conditioner, the system must,

1.Make use of thermoelectric cooling module (TEC) to cool the refrigeration compartment.
2.Make use of the appropriate isolation to ensure that the temperature in the refrigeration compartment stays constant.
3. Make use of a properly designed heat sink for effective dissipation of heat

In Figure. 1 all sections of the system are shown. The important components of the project are the insulated compartment (made of polystyrene covered with ceramic fiber wool), holder, current control circuit, battery pack, temperature sensor, heat sink, LCD module and the thermoelectric cooling module.

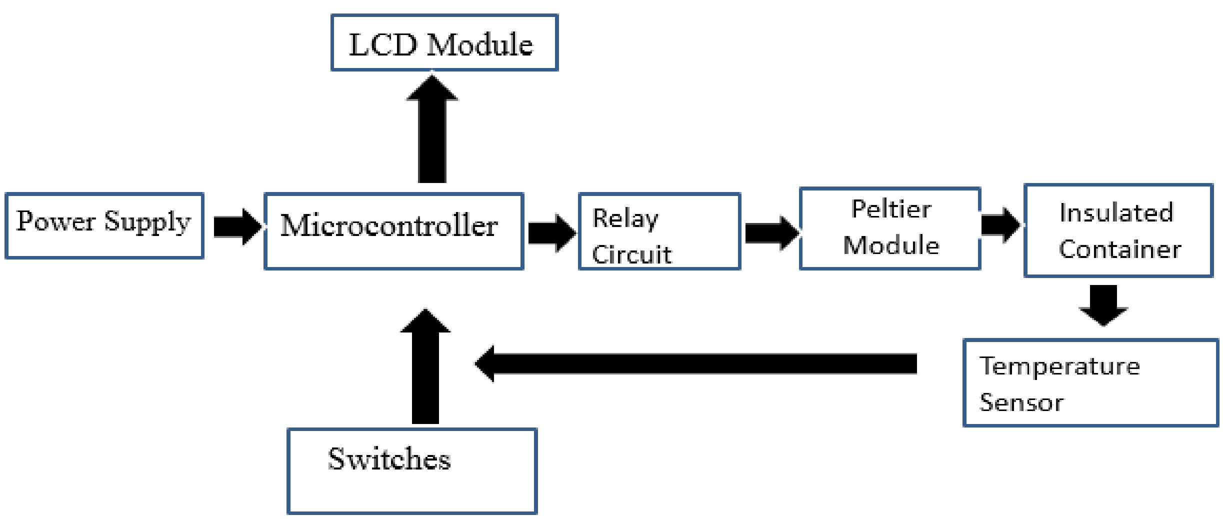

Figure-1: Functional architecture for the preliminary design of the project

The functional architecture consists many components in which power supply is from a 12 V dc source. An Arduino/Genuino Uno microcontroller board based on ATmega328P is used on to which the LCD is interfaced. Peltier module is connected to the Arduino board using relay circuit. A thermally insulated container holds the whole set up along with a steel container which contains water to be cooled or heated. Heat produced on the hot side is rejected by attaching a fan-cooled heat sink so as to increase forced convection heat transfer. An LM35 temperature sensor is used to sense the temperature and displays the same using an LCD Module. The current polarity can be reversed by using switching circuits.

3. DESIGN CONSIDERATIONS

Design procedure starts with the heat load calculation which is actually the amount of heat taken by the load (here water). Heat load is calculated to find out the specification for the TEC module. Heat load calculation gives us an idea about the amount of heat required to raise the temperature of the load (water). Heat load depends on, change in temperature, mass of the load, and an intrinsic characteristic of the material forming the body called specific heat (Cp). The thickness of the insulated compartment for holding the specified quantity of water is then calculated [7]. The design procedure continues with the design of an optimum heat sink. After the design of the heat sink, the convection constant for forced convection is calculated so as to select the cooling fan of desired cubic feet per minute (cfm).

3.1 Heat load calculation

The amount of heat energy (q) is lost or gained by a material is equal to the weight of material (m) multiplied by its specific heat-capacity (Cp) multiplied by the change in temperature (ΔT) (final temperature – initial temperature) [5].

$$Q = Cp \times m \times \Delta T \quad (1)$$

The value of Cp depends upon the material. The paper is dealing with the heat load calculation of a container having 500 ml of water, which is placed in contact with a thin aluminum sheet attached with a Peltier module. Here heating and cooling takes place through conduction. Substituting the values in equation (1) and taking the assumption that the water will cool up to 5^0C in 20 minutes (1200 seconds). Then for container and water the amount of heat was calculated and was found to be 59.4 KJ. The total wattage corresponding to this amount of heat can be calculated from the equation (2):

$$\text{Wattage} = \text{Total heat (KJ)}/\text{Time (s)} \quad (2)$$

And the total wattage was found to be 49.97 watts. Assuming that the water will heat up to 70°C for 25 minutes (1500 seconds). Then for the container and water the amount of heat was calculated and was found to be 78.946 KJ. And the total wattage was found to be 52.63watts. So, a TEC module with a specification of 72 watts is selected to cool 500 ml of water for 20 minutes and to heat the same for 25 minutes with a factor of safety1.5.

3.2 Design of thickness of insulated container

A thermally insulated container made by polystyrene, covered in series with ceramic fiber wool is selected as the material for the insulation of the cooling holder, because of its good insulating properties. The wall thickness of the insulated container is calculated by taking the fact the insulated container is designed in a way such that the time taken for the water in the container to attain its normal ambient temperature from 5^0C is 9 hours (32400 seconds).

Heat gained or lost through walls can be calculated by the equation (3)[5]:

$$Q=(A*\Delta T*k)/\Delta X \quad (3)$$

A = surface area of the container (m^2)

ΔT = temperature difference (^{0}C)

k = thermal conductivity (W/mK)

ΔX = thickness of insulating chamber (m)

From this equation, the thickness of the insulating chamber was found to be 0.047 m which is approximated as 0.05 m for the ease in availability of the material.

3.3 Heat sink design

A heat sink is a passive heat exchanging material having high thermal conductivity which is used for transferring the heat generated by an electronic or a mechanical device to a medium, where it is dissipated away from the device, thereby regulating the device's temperature at desired optimal levels. Heat sink can also be incorporated with a fan so that forced convection can be used for effective cooling. A heat sink is designed in such a way, to maximize the surface area which is in contact with the cooling medium surrounding it, such as the air. Velocity of the air, choice of heat sink material, protruded design of the fins and surface treatment are the main factors that can affect the performance of a heat sink.

There are two heat sink types: active and passive.

Active heats are the heat sinks where, the utilization of the power supply will take place, usually with a fan type or some other Peltier cooling. Passive heat sinks are 100% reliable, as they are no mechanical components present in them. Passive heat sinks are made of an aluminum-finned radiator that dissipates heat through convection. There is need of a steady airflow across the fins or passive heat sinks to work to their full capacity. In this paper, a number of random heat sink simulations are done on ANSYS software and the best suited heat sink having better heat dissipation capability is selected [4]. The ANSYS simulation results of two random heatsinks are shown in fig: from which the second heat sink is selected because of better performance in heat dissipation. From the knowledge of the simulation results so far done, forced convection is found to be the suitable heat transfer mode for the specified requirement.

The first heat sink design has a total of 100 fins having same size and shape. Each fin has a dimension of 2x2x50mm.It has a base plate dimension of 40x40mm and a thickness of 20mm.

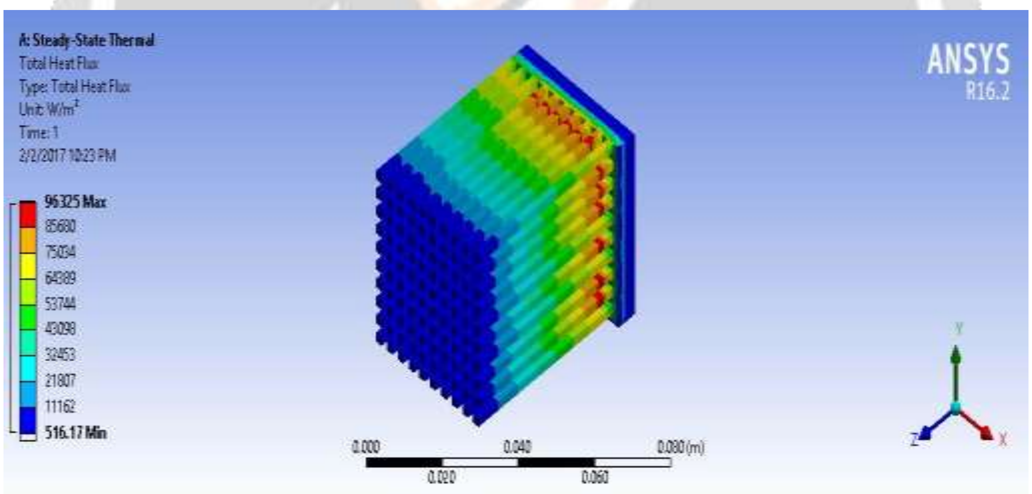

Figure-2: Heat sink design 1

From first heat sink design Figure (2). Red color indicates the maximum heat flux transfer which is found to be 96325 w/m^2 and the blue color indicates minimum heat flux transfer and is found to be 516.17W/m.^{2} The intermediate colors indicate the intermediate heat flux transfer. The average heat flux is found to be 43098 W/m^2. The average wattage from this heat flux can be calculated from the equation [6]:

$$W_{(avg)} = \text{Heat flux } (W/m^2) * \text{area } (m^2) \quad (4)$$

The average wattage is found to be 1793 w. However, this heat sink design is not opted, because the heat flux is not evenly distributed, the theoretical calculation for the convection constant (discussed later) does not meet the required specification and also because of the unavailability of this designed heat sink.

Because of the unavailability of the custom-made heat sink a standard sized heat sink having total of 117 fins with two types of fin distributed over the base plate is opted for simulation [Figure (4)]. The fins distributed on the two edges of the heat sink have more length compared to the fins on the other two edges. Main dimension of the heat sink is 40x40x11mm. Tooth thickness of 1.1mm and a base plate thickness of 2.2 mm.

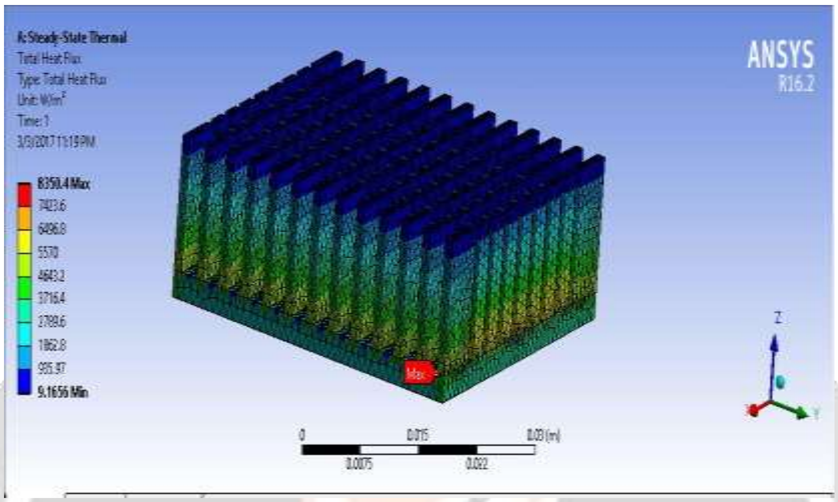

Figure-3: Heat sink design 2

Figure-4: Standard sized heat sink

From Figure (3): The maximum heat flux transfer is found to be 8350.4 W/m^2 and the minimum heat flux transfer is found to be 9.1656W/m.^{2} The average heat flux transfer is found to be 4643.2 W/m^2. The average wattage can be calculated from equation (4) and is found to be 61W. Here, the heat flux distribution is more evenly distributed and the theoretically calculated value for the convection constant (discussed later) meet the required specification

3.4 Design of convection constant for forced convection

Heat energy transferred between a surface and a moving fluid at different temperatures is known as convection. In reality this is a combination of diffusion and bulk motion of molecules. Near the surface the fluid velocity is low, and diffusion dominates. Away from the surface, bulk motion increases the influence and dominates. Convective heat transfer can take two forms [7].

1. Natural or Free Convection

Natural convection is caused by buoyancy forces due to density differences caused by temperature variations in the fluid. At heating the density change in the boundary layer will cause the fluid to rise and be replaced by cooler fluid that also will heat and rise. This continuous phenomenon is called free or natural convection.

2. Forced or Assisted Convection

Forced convection occurs when a fluid flow is induced by an external force, such as a pump, fan or a mixer.

Here we use forced convection to dissipate the amount of heat generated in the TEC module. The value of convection constant (h & hl) for meeting the required heat dissipation is calculated with the help of the selected simulation result from which Qfin is also found out [10]. The value of h (convection constant for the lateral surface of the fin) and hl (convection constant for the top surface of the fin) is calculated from the equation (5):

$$Qfin = (Tb - T\infty) * \frac{\left(\tanh(mL)\right) + \left(\frac{hl}{mk}\right)}{((1 + (\frac{hl}{mk}) * \tanh(mL))} * (hPkA)\text{^}0.5 \tag{5}$$

Where, $m = \sqrt{(\frac{hP}{kA})}$ (6)

Q fin = heat through each fin

A = cross sectional area of fin (m^2)

h = convection constant at lateral surface of fin

hl = convection constant at the tip of fin

k = thermal conductivity

P = perimeter (m)

T∞ = Ambient temperature (^{0}C)

Tb = base plate temperature (^{0}C)

After calculating the value for the convection constant, the value of air flow is also calculated and is found to be 22 cfm. A 12V brushless DC cooling fan corresponding to the calculated cfm is selected.

4. CONCLUSION

TEC module has a lot of advantages which include small size and weight, low power consumption, absence of moving parts, ability to heat and cool with the same module, ability to cool beyond ambient temperature, precise temperature control etc. By considering these advantages, TEC module can be used for many applications including portable cool boxes for medicine transport, simple food and beverage coolers. In this paper, mechanical simulation using ANSYS software was done for the heat sink design for the purpose of heat dissipation.

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6. REFERENCES

[1] R. M. Farias,L. A. O. Rocha,E. D. Dos Santos,Numerical Study of Reservoir Cooling by Means of Peltier Effect2009 3rd Southern Conference on Computational Modeling

[2] Rohit Sharma; Vivek Kumar Sehgal; Nitin; Abhinav Thakur;Adnan Munir Khan; Ashish Sharma; Pankaj Sharma,Peltier Effect Based Solar Powered Air Conditioning System,2009 International Conference on Computational Intelligence, Modelling and Simulation.

[3] Yahya A. Alhammad; W. F. Al-Azzawi; Tarek A. Tutunji,Current control to improve COP of thermoelectric generator and cooler for PV panel cooling,2016 13th International Multi-Conference on Systems, Signals & Devices (SSD).

[4] Piaopiao He; Zhangfu Chen; Lianqiao Yang; Jianhua Zhang; Luqiao Yin; Tingting Nan,Performance enhancement of merge pin schottky diode with graphene films as heat sink by ANSYS simulation,2016 13th China International Forum on Solid State Lighting (SSLChina)

[5] Heat and mass transfer R.KRajput

[6] Heat and mass transfer Data book, C.P Kothandaraman.

[7] K.Pramanick,P.K.Das,Constructural design of thermoelectric device

[8] Gao Min [*], D.M. Rowe, Experimental evaluation of prototype thermoelectric domestic-refrigerators

[9] Saket Kumar[1], Ashutosh Gupta[2], Gaurav Yadav[3], HemendHU Pal SingK[4],Peltier Module for Refrigeration and Heating using Embedded System

[10] N. Zabihi and R. Gouws,Verifying the Cooling Capacity and Power Consumption of Thermoelectric Cooling Holders for Vaccine Storage.