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DESIGN AND DEVELOPMENT OF COOLING UNIT FOR IMPACT TESTING MACHINE

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ABSTRACT

Since everyone is concerned about the environment, we decided to make a small contribution to help solve this issue. Everyone is worried about Ozone layer depletion and melting of glaciers, so it has become part of our concern to contribute to overcome this issue. Most refrigeration systems use refrigerant which is harmful to the environment. So, we thought of making a refrigeration system which is less harmful to the environment than the current preferred systems like Vapour Absorption System. This led us to develop thermoelectric refrigeration system using the concept of Peltier effect.

1. INTRODUCTION

1.1 Need of project

This project is focused on the design and fabrication of an efficient refrigeration system for the purpose of performing impact testing experiments on the specimens of various materials under variable temperature conditions. These tests will be conducted using an impact testing machine. A specimen's capacity to withstand high rate loading is tested using an impact testing machine. The service life of a material is also determined by using this machine. The cooling system will be placed in close proximity to the machine. This is so that the specimen can be cooled to the desired temperature by using the cooling system and then it can be immediately tested on the impact testing machine. Our hope is that this project will enable the students to learn more about the properties of various materials at different temperatures.

1.2 Background

In order to achieve efficient cooling of the test specimens we researched various methods of refrigeration such as Vapour Absorption System. However, due to size and shape constraints we had to drop this idea. Other refrigeration systems we researched include Vapour Compression System. However, this system is commonly used for refrigeration and we wanted to find a cheaper alternative due to which we chose to reject this idea. We also researched Vortex Tube refrigeration system but we had to reject this idea too because of this system being highly expensive. Most refrigeration systems use refrigerant which is harmful to the environment. Hence, we thought of making a refrigeration system which is environment friendly due to which we found both Vapour Compression System and Vapour Absorption System undesirable for the refrigeration of the test specimens since they both use refrigerant. This led us to develop a thermoelectric refrigeration system using the concept of Peltier effect. This type of refrigeration system does not use refrigerants or greenhouse gases. Hence, it is environment friendly. Moreover, it does not occupy too much space and is compact in size. Due to the reasons stated above we have come to the conclusion that thermoelectric cooling is the most optimum way to cool the test specimens. In thermoelectric cooling exchange of heat is done by using Peltier effect.

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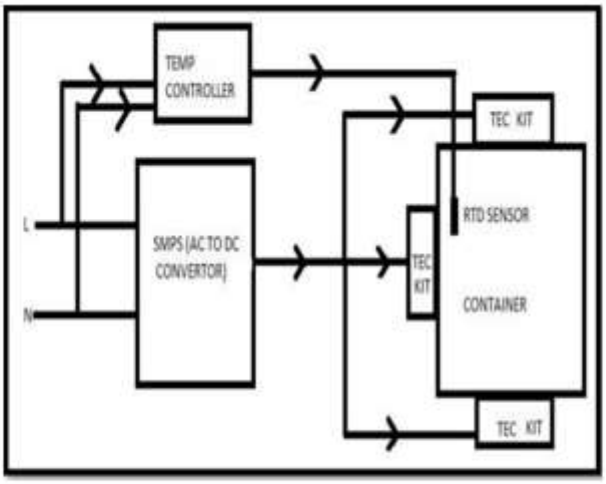

Figure: Circuit diagram of project

2. PROBLEM DEFINITION

Impact testing is used to know the toughness of materials by calculating the amount of energy absorbed during fracture. Impact testing has to be performed at various temperatures to uncover any effect on impact energy. According to literature survey we are not able to perform impact testing under different temperatures in our regular educational field. Generally, specimens are tested at room temperature on the impact testing machine. Due to this we can only study the properties of the material at room temperature. It is important to study the change of material's behavior and its properties under different temperatures because when the temperature we can only study the properties of the material at room temperature. It is important to study the change of material's behavior and its properties under different temperatures because when the temperature of the material changes to critical ductile temperature there is a drastic change in the material property. For example, mild steel becomes brittle at sub-zero temperatures.

3. OBJECTIVES

This project aims to help students learn about the properties of various materials and how they change with respect to temperature. The main objective of this project is to be able to test specimens of various materials using the impact testing machine at desired temperatures and to design and fabricate an environment friendly refrigeration system to fulfil this.

4. LITERATURE REVIEW

After conducting an extensive literature review we deduced the following information which is useful and relevant to our project-

- During the refrigeration process as the temperature of the refrigerating system continues to decrease the coefficient of performance of the refrigerator also decreases and takes much more time for cooling.
- Thermoelectric modules can only be used for light heat loads.
- A radiator fan can be used to circulate the cool air on the cool side of the TEC module whereas a cooling fan can be used to dissipate the hot air on the hot side of the TEC module.
- The thermoelectric refrigerator has advantages such as it being self-contained, solid-state construction which eliminates the need for refrigerants or connection to chilled water supplies and having superior flexibility.
- Another advantage of thermoelectric refrigeration system is that it is small and compact in size which makes it suitable for our project since it requires the refrigerator to be in close proximity to the impact testing machine.
- Thermoelectric refrigeration systems have reduced maintenance costs.
- Thermoelectric refrigeration systems are not as expensive as other refrigeration systems such as Vapor Compression refrigeration system and Vortex Tube refrigeration system making them a lot more affordable.

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- Thermoelectric refrigeration systems do not use refrigerants or greenhouse gases due to which they are environment friendly.

5. TECHNICAL SPECIFICATION

- **Peltier Module –** We have opted for an unpopular Peltier module i.e. TEC1-12715 instead of a more popular one (TEC1-12706), as it is neglected due to a higher price but we think that it has better efficiency than the regular one. This module has a lower resistance of 0.8 Ω and hence can help in reducing the electric power usage, maximum energy consumption of 150W. It can work under a wide temperature range of -25℃ to 50℃.
- **Temperature Controller –** We have installed a temperature controller with an in-built PID controller, which can help us to control and maintain the temperature of the cabin and the specimens with an accuracy of 0.1℃. It can be operated on an AC supply, with 10A current. It can detect temperature change in range of -25℃ to 100℃.
- **Power Source –** Except for the Temperature controller, rest of the apparatus works on DC power supply and hence a DC source or an AC to DC converter is required. The converter is an SMPS with an efficiency of 80% and can provide with a DC output of 12V.
- **Heat Sink –** A set of heat sinks is attached to both the sides of the Peltier module, as it helps to regulate the heat on the outside and spread the coolness on the colder side of the pettier plate. The hotter side requires a bigger heat sink to increase the rate of dissipation of the heat produced. We have opted for Aluminium heat sinks, copper can also be good choice.
- **Radiator Fans –** A radiator fan is used for force convection, which is required to regulate the heat away from the heat sink, in order to make it available for further heat dissipation from the hot side of the Peltier plate. It rotates at high speeds of 3300 rpm.
- **Cooling Fans –** Cooling fans are required on the inside of the cabin, as it helps to regulate the cool air, created near the inner heat sink, throughout the cabin. It rotates at slightly lower speeds of 1800 rpm.
- **Cabin –** For economic purposes we have used a thermocol cabin, as it is cheap and light in weight. It also helped in successfully keeping the specimens isolated from the surrounding temperature.

6. BASIC WORKING

The Peltier effect, Thomson effect and the Seebeck effect are all included under the term "Thermoelectric effect". The direct conversion of temperature differences to electric voltage and vice versa through a thermocouple is what is known as the thermoelectric effect.

When there is a different temperature on each side of thermoelectric devices they create a voltage. The converse of this is also true, when a voltage is applied to thermoelectric devices heat is transferred from one side of the device to the other. This results in the creation of a temperature difference. There are multiple applications for which this effect can be used which include generation of electricity, measuring temperature or to change the temperature of objects.

When a voltage difference is produced between two dissimilar electrical conductors or semiconductors due to a temperature difference between the two substances this phenomenon is known as Seebeck effect. The reverse phenomenon of the Seebeck effect is known as the Peltier effect. Heat is evolved at one junction and absorbed at the other junction when an electric current is passed through the circuit of a thermocouple. This phenomenon is known as the Peltier effect.

In our project we created a thermoelectric refrigeration system by using a thermoelectric module in a cooling box. We attached a heat sink on both the hot side and the cool side of the thermoelectric module in addition to this we attached a radiator fan on the hot side of the module and a cooling fan on the cool side. The radiator fan on the hot side was used to dissipate the hot air to the surroundings whereas the cooling fan on the cool side of the module circulated the cool air inside the cooling box.

We used Thermocol as the insulating material. We have installed a temperature controller in order to check the temperature, inside the cooling box containing the specimen, during the refrigeration process. A temperature

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controller can also be used to modulate the temperature inside the cooling box according to the desired temperature. In order to supply electricity to the refrigeration system for the cooling process to take place we made use of an AC to DC convertor since Peltier cooler works on direct current power supply.

7. HEAT LOAD CALCULATION

Dimension of cabin:

• Cabin
 Length= Width = depth = 8 inch = 0.2032 m
 Volume = $(0.2032)^3$ =8.39 x 10-3 m^3 = 8.39 liters
• Door
 Length = 5 inch = 0.127 m^3
 Width = 4 inch = 0.1016 m^3
• Thickness of insulator = 1.5 inch = 0.038 m
• Thickness of outer material (A1) = 0.001 m

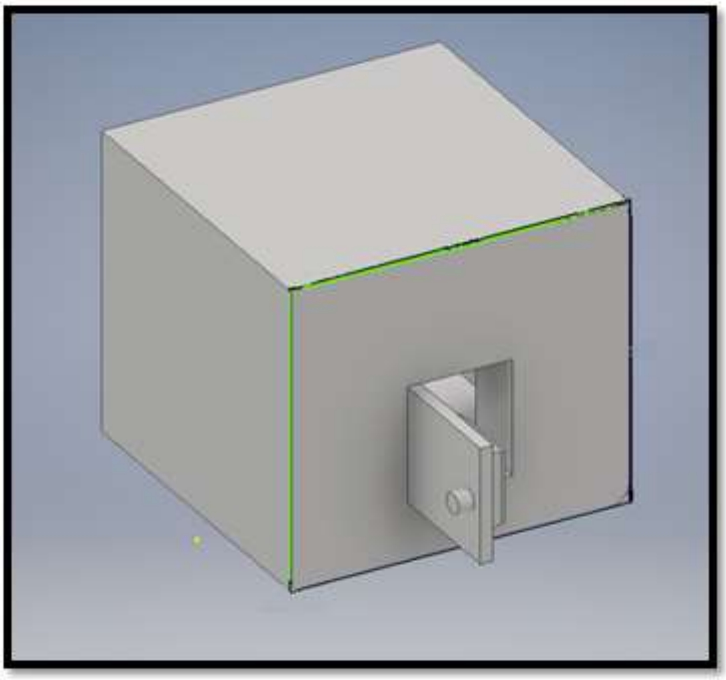

Figure: Cabin

Calculation of heat load:

• Total heat load = sensible heat gains through structure of cabin +
heat gain due to infiltration+
heat gain from products +
heat gain from power equipment +
heat gain from solar radiation +
heat gain through glass area +
heat gain due to ventilation +
heat gain from occupants +
heat gain through lighting equipment.

1) Sensible heat gains through structure of cabin by conduction:

Heat transfer under steady state condition is

$Q = UA (t_o - t_i)$

Where, U= overall heat transfer coefficient

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$= 1 / \frac{1}{ho} + \frac{x1}{k1} + \frac{x2}{k2} + \frac{1}{hi}$

ho = outer heat transfer coefficient (force convection) = (6 to 30 w/mk) = 15 w/mk
velocity = (πDN / 60) =15.08 m/s
where D = 120 mm; speed = 2400 rpm

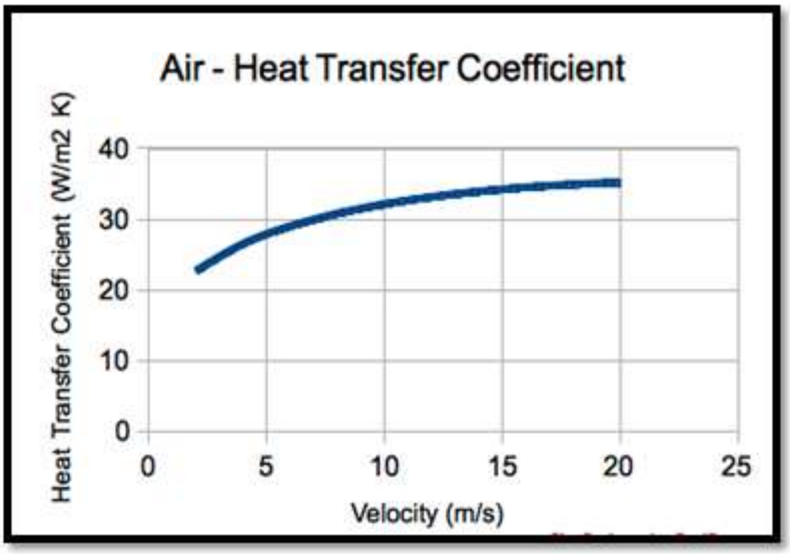

Figure :Graph of Air heat transfer coefficient

According to the graph,
h_o = 34.8; h_i = inside heat transfer coefficient (forced convection) = (10 - 200)
Velocity = (πDN / 60) = 10.053 m/s
where D= 80mm; speed = 2400 rpm
According to the graph,
h_i = 33 W/mK
A = $(0.2032 \times 0.2032)^{6} =$ 0.2477 m^2
K_1 = 205 W/m
K_2 = 0.03 W/mK
U = 0.7543 W/mK
Q = 0.7543 x 0.2477 x (28-(-10)) = 7.099 W

Heat gain through infiltration:

Through wall (due to leakage) = $\frac{L \times W \times H \times Ac}{60}$

$= \frac{(0.2032)^3 \times 1}{60}$

=1.39 x 10^{-4} m^3 / min
Air infiltration is ½ of above calculation = 7 x 10^{-5}
Air infiltration due to opening and closing of cabin door
Mass of air = 1.225 kg/ m
Volume of cabin = 8.39 liter
Total mass of air = (1.225 x 8.39)/1000 = 0.01027 kg
Assuming that ⅓ of air is exchanged when door is open or closed = 3.429 x 10^{-3} kg
Energy lost = m x C_P x $\frac{dt}{time} = \frac{(3.42 \times 1.005 \times (28+10)}{60}$ = 2.178 W
Total infiltration = 2.738 + 7 x 10^{-5} = 2.73807 W

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1) Heat gain from product:

Cooling load below freezer = Q_c = m x C_p m x (DT)

Assume standard specimen is of mild steel

Volume = (55 x 10 x 10) x 10^{-9}=5.5 x 10^{-6} m^3

Density of MS = 8000 kg/m^3

Mass of specimen = Density x Volume = 8000 x 5.5 x 10^{-6} = 0.044 kg

Specific heat of MS (1% C) = 475 J/kgC

Q_c = 0.044 x 475 x (28-(-10)) = 794 J …. from 1 specimen

Total heat gains from 3 specimen = 3 x 794 = 2382.2 J

Assume 3 hours for reaching that temperature

$$Q_c = \frac{2382.2}{3 X 3600} = 0.2206W$$

2) Heat gain from power equipment:

Q = number of equipment x wattage

= 1 x 1.8 = 1.8 W

TOTAL HEAT LOAD = 7.099 + 2.738 + 0.2206 + 1.8 = 11.857 W

To determine cooling the hot side with air or liquid coolant:

Conduction:

Area = 50 x 50 = 2500 mm^2 = 2.5 x 10^{-3} m^3

K = 205 W/mK

dT= (60-28) Q = 385*0.24*(60-28)/0.04=73.92 kw = 474 W

Convection:

Assume finite fin with heat lost at tip

L = 0.097 m w = 0.094 m t = 0.04 m h = 34.8 W/m^2K

Area, A_c = 0.097 x 0.094 = 9.409 x 10^{-3} m^2

Perimeter, P = 2 x (0.097+0.094) = 0.38 m

K = 205W/mK

$$m = \sqrt{\frac{hP}{KAc}} = 2.614$$

$$Q = \sqrt{h \times P \times K \times Ac} \text{ x Dt x } \frac{\sinh(ml) + \left(\frac{h}{mk}\right)\cosh(ml)}{\cosh(ml) + \left(\frac{h}{mk}\right)\sinh(ml)} = 49.26 \text{ W}$$

8. COST ESTIMATION

Table : Cost Estimation

Sr. No	Component	Rate	Quantity	Amount
1	Peltier Plate (TEC1-12715)	500	2	1000
2	Temperature Controller	1100	1	1100
3	SMPS	900	2	1800

4	Inner heat sink	200	2	400
5	Outer heat sink	200	2	400
6	Radiator fan	500	2	1000
7	Cooling fan	300	2	600
8	Cooling Cabin	100	1	100
9	Miscellaneous	1000	-	1000
10	Total Cost			7,400 /-

9. PROTOTYPE OF PROJECT

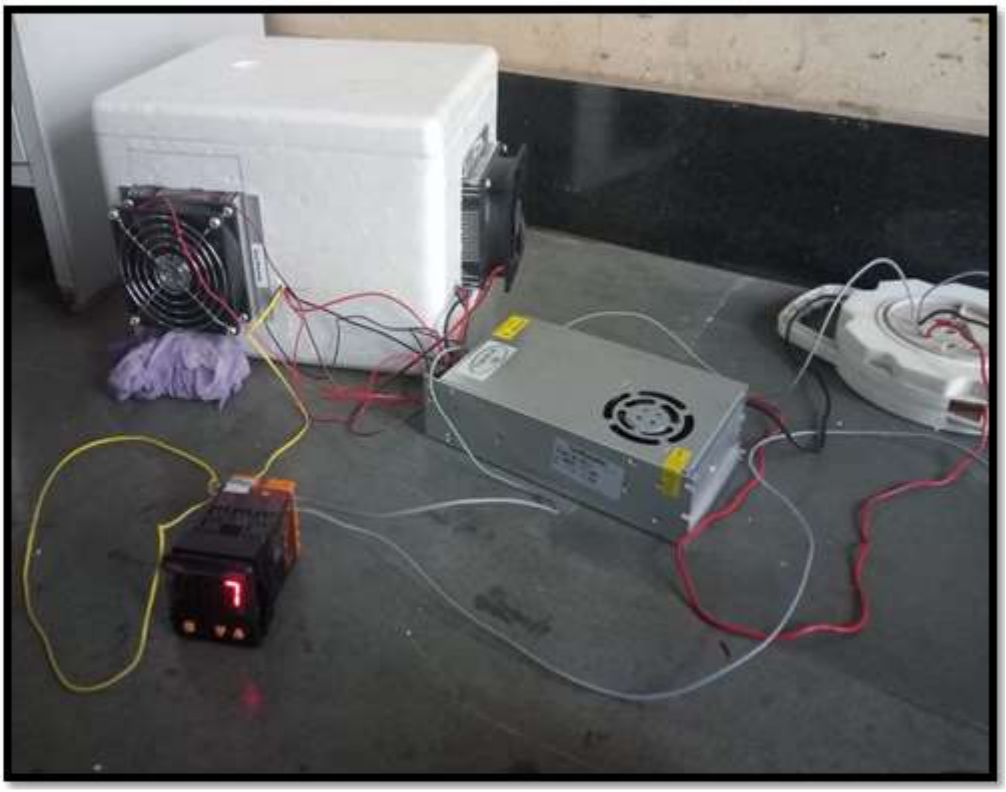

Figure: Photo of project

10. TESTING AND OBSERVATION

We have done a couple of iterations regarding our project and have obtained a number of possible advancements that can be done, which acted as stepping stones for us to reach the next iteration. We have successfully achieved a spike drop in the temperature graph after a lot of trying and use of certain qualities of the components of our apparatus that we found out during the experimentation.

Iteration 1:

Initially we started with only a single set of Peltier plate for the cooling of the cabin. As per the requirements, the other components of the project are selected and connected, like the Peltier plate works on DC power and hence the normal power outlets available cannot be used and hence, SMPS are connected to convert this AC power supply to DC power supply for the apparatus. The SMPS is connected to the power supply to convert the AC power to DC power which is then supplied to all the components that are connected to the SMPS. For 1st iteration we only had 1 set of all the components which are connected to SMPS, i.e. radiator fan, cooling fan and the Peltier plate. The rest of the components do not require power supply and hence does not need to be connected to the SMPS. The Peltier plates are sandwiched between the two heat sinks, cooling side of Peltier is attached to the smaller heat sink and heating side to the larger heat sink. This kit is then connected to SMPS and fitted in the wall of the cabin with minimum openings possible to reduce losses.

- The temperature inside the cabin is first indicated on the temperature controller.
- The whole apparatus is supplied with electric supply.
- With the time, there is a temperature difference created between the two sides of the Peltier plate.
- The heat from the heating side of Peltier plate is dissipated by the heatsink and radiator fan which results in further cooling of cooling side.
- The inner heat sink and the cooling fan cool the air around it and regulate the cool air around the cabin.
- Due to losses we could not reach the desired values.
- We conducted the experiment for just above an hour to reduce the temperature by about 10 °C.

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- During the first iteration, we could only achieve to reduce the temperature from room temperature to 16 °C.
- This made us realize that we need more than 1 Peltier plate to obtain the desired temperature.
- Further, we also found out that providing external cooling to the outer heat sink, it increases the rate of heat dissipation through the outer heat sink, which results in more efficient cooling.

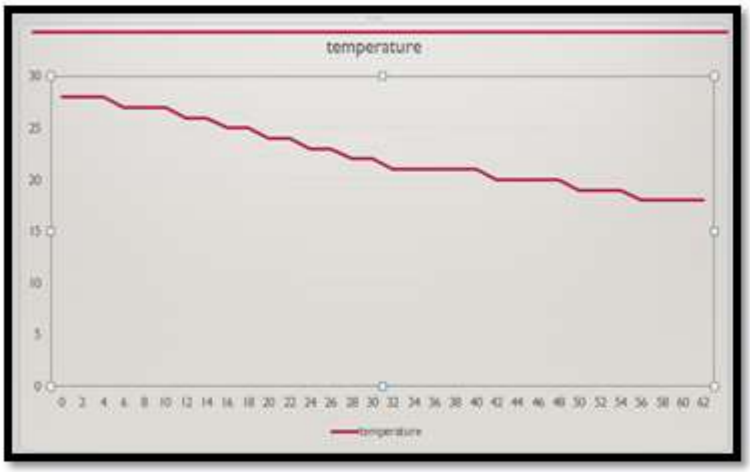

Figure: Temperature fall near cooling sink

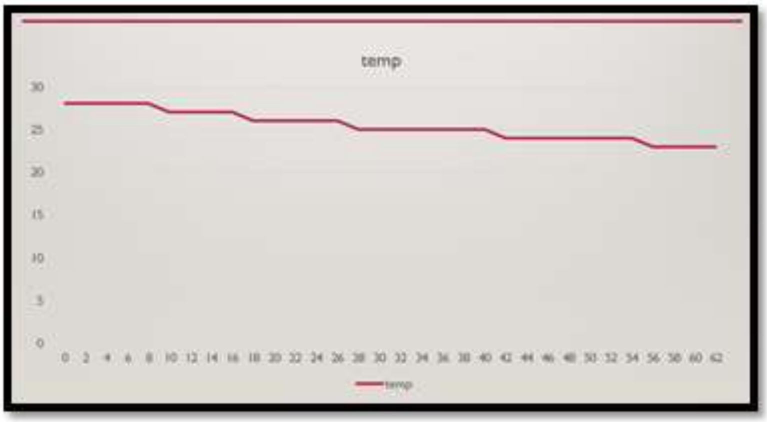

Figure: Temperature fall at the corner of the cabin

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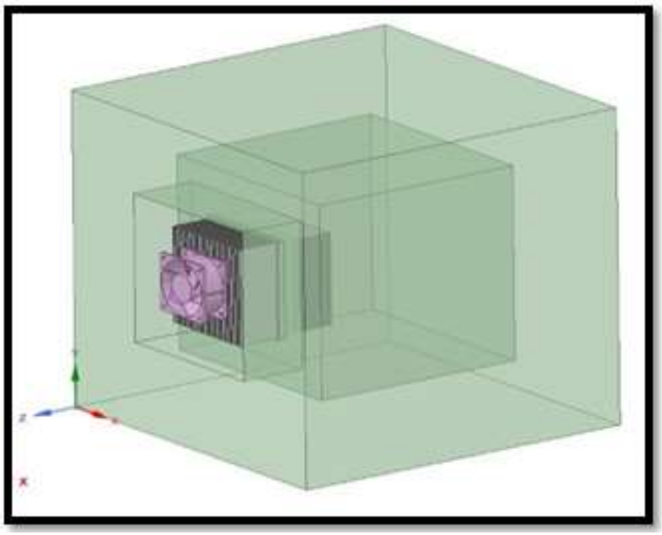

Figure: Model of cooling unit

Iteration 2:

After the conclusions from the first iteration, we made some advancement in our apparatus which would further lead us to reach the desired temperature. We equipped the apparatus with one additional Peltier kit and the other components that are to be attached to it.

We tried to find out a way to reduce the power consumption by the whole apparatus and hence we connected all the components to the SMPS in parallel connections, which reduced the resistance opposing the current, at same amount of voltage supplied. This resulted in the reduction of power consumption.

We had to cut through another wall of the cabin to accommodate the second set of equipment. This led to more number of small openings which leads to loss of cooled air and hence to avoid it we sealed patches with the help of thermal grease, which possess insulation properties.

For obtaining better efficiency we opted external cooling for the outer heat sink. At first we would manually put water on the outer heat sink, but then we used a more efficient way of watering the heat sink with the help of acrylic pipes and pump. The pump would take the water from a basin or a sump and then deliver it to the heat sink drop by drop. Some of this water would evaporate from the heat dissipated by heat sink and the remaining water is again collected in the sump for reuse. We have attached the second kit on the adjacent wall, to that of the first kit, so as to provide a flow frame for both the cooling fans to evenly cool and regulate the air evenly throughout the cabin. This pattern of airflow covers more areas of the cabin as it is not a turbulent flow of air, rather it is a well operated flow of cool air. After all the components are connected, they are provided with the power supply and the observations and conclusions are noted.

- In this iteration we have reduced the amount of losses.
- Without the external cooling efforts with the help of water pumped to the heat sink, we could only reach temperature of 10℃.
- We also tried to use water cooling alone instead of radiator fan, by submersing the heat sink into container filler with water, but it seemed to have a lot of difficulties for installation and maintenance.
- Thus, we finally opted for pump and acrylic pipes to water the heat sink for external cooling.

We have successfully been able to reduce the temperature by a considerable range. We were able to reduce the temperature from room temperature to 7℃.

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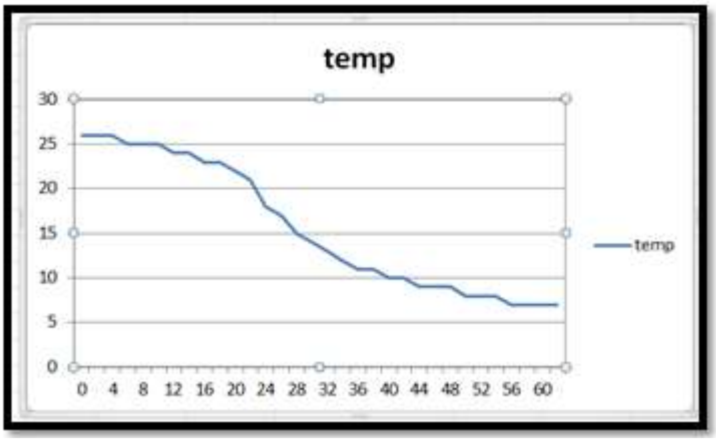

Figure: Observation of iteration 2

11. CONCLUSION

We have successfully completed the prototyping of a cooling system based on Peltier effect for the refrigeration of impact testing machine specimens. We have achieved the targeted cooling performance and in order to further enhance the cooling performance of the refrigeration system future improvements can be carried out. From our experiments thermoelectric refrigeration seems to be the optimum cooling system for the refrigeration of impact testing machine specimens due to it being small and compact in size, it being affordable and having low maintenance cost as well as it being environment friendly as it does not use refrigerants or greenhouse gases.

12. FUTURE SCOPE AND APPLICATION

Although we have successfully achieved the temperature for a refrigerator, but the temperatures for a freezer can also be achieved if these iterations are continued a step ahead and also various other accolades can be achieved with certain changes in the system.

- **Additional Module -** The temperature can be dropped to 0°C or less by installing an additional set of Peltier Module, which increases the overall rate of cooling.
- **Water Cooling -** Due to decrease in the efficiency of the module near the threshold of 0°C, external cooling system including water and pipes can be used to increase the efficiency of the Peltier Module and further decrease the temperature of the freezer at a faster rate. Installation of water cooling for the heat sinks can help in reduction of cost by removing the radiator fans.
- **Heater-** The system can also be used as a heater until a certain range, depending on the specifications of the Peltier module, by reversing the direction of the Peltier Modules.
- **Cost -** The cost can be further reduced by mounting the Peltier modules on the same heat exchanger made of copper and only 1 fan for that heat exchanger, this will also reduce the electric consumption.
- **Time -** The rate of cooling can be increased by the means of arranging the Peltier Modules in stacks.
- **Eco-Friendly –** The system although eco-friendy as it does not use any kind of refrigerants or pollutants that may harm the environment, but we have used thermocol for the cabin construction, which can be replaced by stainless steel for fully eco-friendly system but this may spike the expenses by a bit.
- **Electricity Consumption –** Electricity consumption of the system can be reduced by parallel connection of the Peltier modules to the power source, as it reduces the current without affecting the voltage. Also, stacking of Peltier modules may help. For further energy conservation, the system can be equipped and fully operated by solar power with a battery backup.
- **Commercial use –** The compactness of the system makes it suitable for schools, colleges and industries as a freezer for Impact Testing specimens, which can help observing the behaviour of the material under influence of various temperature ranges.
- **Domestic use –** It can also be used as a normal refrigerator or a freezer in households.

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