Design of Compact Air Cooling System using Thermoelectric Module (Peltier Element)

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Abstract - *This paper focuses on designing a compact thermoelectric cooling system using a liquid cooling method to dissipate heat. Two experiments were performed using a TEC 12715 Peltier element, a water block, and a radiator using an ethylene glycol-based coolant. The first experiment used a cardboard duct to guide the air whereas the second one used a 3D printed casing made from PLA material which reduced the losses caused in the first experiment and made the system design more compact. The temperature difference between the cool air obtained and the ambient was 8 degrees celsius in the first case and 10.2 degrees celsius in the second case which was better than the traditional heat sink and axial fan-based system by 4 to 5 degrees. The system was made more compact using two small pumps instead of one big pump and also reducing the size of the reservoir.*

Key Words: Peltier, thermoelectric cooling, radiator, water block

1. INTRODUCTION

Many attempts have been made till date to use the thermoelectric effect for cooling air. The use of thermoelectric modules such as Peltier elements requires a strong system to dissipate the heat generated so as to give sufficient cooling effect. A lot of heat is generated by the Peltier and thus the dissipation of heat in small amount of space becomes a challenge. For this purpose, heatsink and fans were usually used which gave air five to six degrees cooler than the atmosphere.

A paper published on the helmet cooling system by students of University of Mumbai, in January 2019 aimed to cool the inside compartment of the helmet using the Peltier module. They used a big heat sink and a fan to dissipate heat from the Peltier element and were able to reduce the temperature of air by 6.4 degrees in 7.5 minutes. [1]

Another paper published by M. Hariri, A.F. Abdullah, and M.I. Ahmed in 2013 experimented thermoelectric cooling inside the helmet. The system had a Peltier module and a heat sink which could produce air 6.2 degrees cooler than the ambient temperature in 6 minutes. [2]

The current paper focuses on increasing the degree of cooling and giving better results using the peltier module. Experiments were performed using coolant as a medium to dissipate heat and produce the required cooling. The observations were recorded and results were plotted down.

2. COMPONENTS

2.1 Peltier element

2.1.1 Working details of Peltier element

A Peltier element is a thermoelectric module that consists of two different materials joined together to form a junction. It uses electrical energy to pump heat energy from one side of the junction to the other side. Heat energy is transferred across the junction when DC electric current is supplied across the junction. Thus, a Peltier element consists of two sides viz. hot side and the cold side. The cold side is attached to the heat sink to get the cooling effect whereas the heat is continuously removed from the hot side to maintain the cooling effect on the cold side. Thus, the Peltier element is used as a heat pump in the air cooling system.[3]

2.1.2 Specifications

1. Model: TEC1-12715
2. Operating Voltage (V_{DC}):12
3. V_{MAX} :15V
4. I_{MAX} : 15 A
5. Q_{MAX} : 55w
6. ΔT_{MAX}: 74 degree celsius
7. Dimensions: 40*40*3.6
8. Weight :30g

2.1.3 Specification details

1. Q_C (Cold junction heat rejected): This is the amount of heat extracted from the cold junction. This head should not exceed Q_{MAX} – the maximum amount that can flow out from the cold junction for a particular thermoelectric module.
2. Q_H (Hot junction heat flow): Amount of heat that flows into the hot junction. It is the sum of heat rejected in cold junction and the electric power input ($V_P I_P$).
3. T_2: Hot Junction Temperature (Should not exceed the maximum working temperature of the Peltier element)
4. T_1: Cold Junction Temperature

5. ΔT_{MAX}: Maximum allowed temperature difference between the cold junction and hot junction for the given Peltier element.
6. V_P: Voltage input to the Peltier element the thermoelectric module. Its value should not exceed V_{MAX}
7. I_P: Current input to the Peltier element or the thermoelectric module. Its value should not exceed I_{MAX} [4]

2.2 Axial fan

1. Dimensions: 80*80*2.5mm
2. Current rating: 0.25 Amp
3. Voltage: 12V
4. Airflow: (MAX) 11.32 ~ 32.40CFM

2.3 Radial blower fan

1. Voltage rating: 5v DC
2. Current rating: 0.38A
3. Brushless blower
4. Dimensions: 70*75*13mm

2.4 Heat sink on the cooling side

1. Aluminium Heatsink;
2. Tooth number: 13
3. Tooth thickness:1.1mm
4. Baseplate thickness:2.2mm
5. Size:40mm*40mm*10mm
6. Weight: 19g

2.5 Water block

1. Material: Aluminium
2. Weight: 127g
3. Dimensions: 40*40*12mm

2.6 Radiator

1. Dimensions: 105*81*25mm
2. Type: Crossflow
3. Material: Aluminium

2.7 Power source

1. Input 240V 50hz
2. Output 12V15amps

2.8 Pumps

Pump1
1. Power: 40W
2. Voltage : 220-240V
3. Weight:0.4 kg

Pump 2
1. Operating Voltage DC :3V to 6V Submersible + Non-Submersible Pump (BOTH)
2. Flow Rate: 80 ~ 120 L/H,
3. Maximum Lift: 40 ~ 110 mm

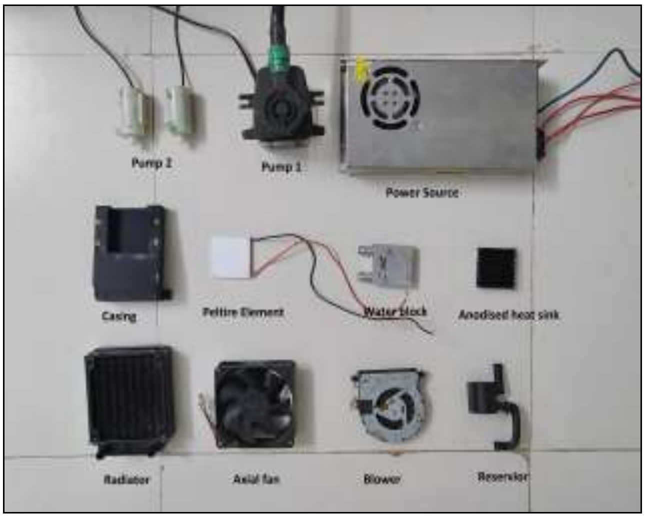

Fig -1: Components of cooling system

3. EXPERIMENTATION

3.1 Experiment 1

In order to get more cooling effect, we have selected the TEC 12715 Peltier module. This module takes a stand over TEC 12706 module as it produces more temperature difference between the cooling and heating side of it. It is obvious that to get more cooling effect, more heat needs to be removed from the hot side of peltier element.

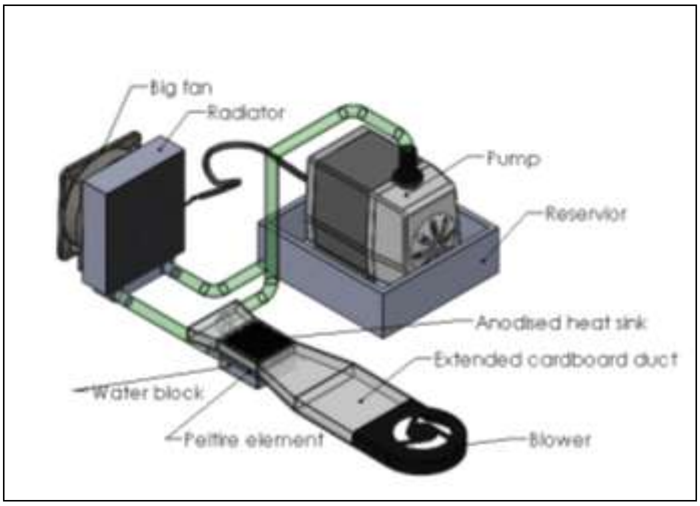

Fig -2: CAD model of experiment 1

Components: Peltier (TEC-12715), aluminum water block, small radiator, anodized aluminum heat sink on the cooling side, blower with a cardboard duct, coolant, power source.

Description: As electric supply with the required specifications is given to the Peltier, the Peltier acts as a heat pump and starts pumping heat from the cold side to the hot side. The heat generated at the heating side is conducted to the water block through a thermal paste in between the surfaces to ensure proper conduction. The heat is now absorbed by the coolant that is being circulated inside the water block. This hot coolant is then transferred to the radiator where heat removal takes place. A fan at the back of the radiator ensures forced convection which results in faster heat removal from the coolant. This comparatively cooler coolant is again transferred to the water block with the help of a pump and the cycle of heat removal from the heating side continues.

The cooling effect developed by the Peltier at its cold side is transferred to the cooling heat sink. The heat sink now looses heat and becomes cooler. The atmospheric air is blown on the heatsink through a cardboard duct with the help of blower on its surface which results in cold air output. The experiment was conducted and the following observations were noted down.

Initial coolant temperature=27.1 degree celsius
Current Ip=15 A
Voltage Vp = 12 V
Ambient Temperature = 27.3 degree celsius.

Table -1: Experiment 1 Readings

T1	t1	T2	t2
27.3	0	27.1	0
26	22	28	31
25	35	29	55
24	42	30	72
23	52	31	156
22	60	32	178
21	78	33	191
20	126	34	211
19.3	213	34	226

T1: Cool air temperature (Degree celsius)
t1: Time (Seconds)
T2: Coolant Temperature (Degree celsius)
t2: Time (Seconds)

After around 4 minutes stable condition of the Peltier was achieved giving the following results.

Stable condition:

Time: 226 secs(3:46min)
Cool air temperature(T1): 19.3 degree celsius
Coolant temperature (T2): 34 degree celsius

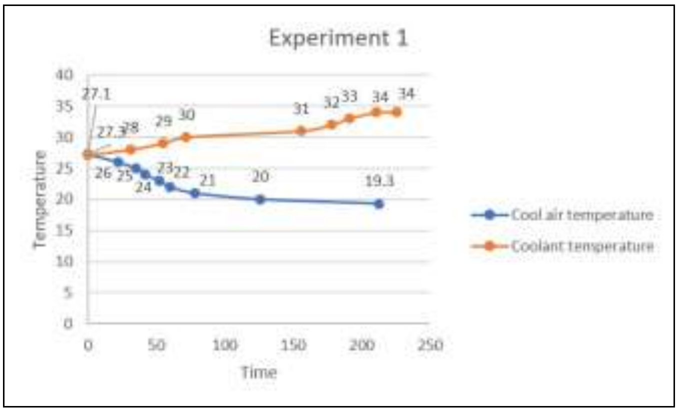

Chart -1: Temperature vs Time for Experiment 1

The graph of temperature vs time is a plot for cool air temperature and coolant temperature. It can be seen that the temperature of the cool air at the output of the cardboard duct is 19.3 degrees celsius. It's 8 degrees lesser than ambient temperature.

3.2 Experiment 2

The previous experiment showed that the cooling can be achieved up to 8 degrees lesser than ambient temperature. The components in the previous experiment were quite large in size. So, there's a need to develop a compact model for the reservoir and pump. Also, the duct which was used to blow cool air was made of cardboard. Being made by hand, there was leakage of cold air and relative movements between the Peltier, water block, and anodized heat sink. There were chances of getting relatively good output if a rigid casing is designed to hold the parts and allow the flow of air at the same time. Therefore, a compact design is made for the cooling system. The working is same as experiment 1.

Components: Peltier (TEC-12715), aluminum water block, small radiator, anodized aluminum heat sink on the cooling side, blower, small reservoir, 2 small pumps, 3D Printed PLA casing, coolant, power source.

Description: The casing is manufactured using additive manufacturing (3D printing). PLA is chosen as the material because of the less cost associated with it less and it's easy availability. The strength of PLA is lower than any other 3D printable materials available in the market. As there is no structural load on the casing, relatively low-cost PLA was chosen as casing material. It confines the water block, Peltier element, and anodized heat sink rigidly and avoids relative motion between them. It also minimizes the losses.

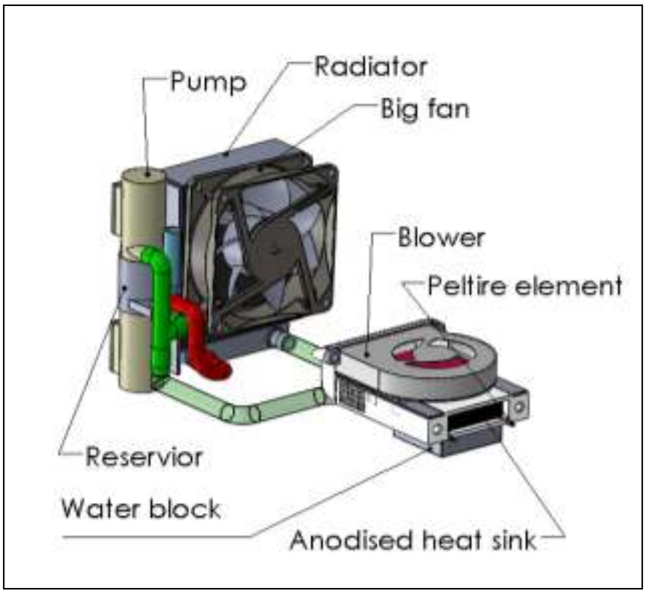

Fig -3: CAD model of experiment 2

Two Small pumps are integrated into the reservoir. This ensures low space consumption. The reservoir is 3D printed in PLA. This new compact design was tested and the following were the observations.

Initial coolant temperature= 29.7 degree celsius
Current Ip=15A
Voltage Vp = 12V
Ambient Temperature = 30.4 degree celsius.

Table -2: Experiment 2 Readings

T1	t1	T2	t2
30.4	0	29.7	0
28.42	13	31	30
26.5	23	32	45
24.8	39	33	69
23.6	44	34	90
22.9	90	35	126
21.8	116	35	156
20.6	140	34	175
20.2	175	35	180

T1: Cool air temperature (Degree celsius)
t1: Time (Seconds)
T2: Coolant Temperature (Degree celsius)
t2: Time (Seconds)

After around 3 minutes stable condition of the Peltier was achieved giving the following results.

Stable condition:

Time = 180 secs(3min)
Cool air temperature(T1) = 20.2degree celsius
Coolant temperature (T2) = 35 degree celsius

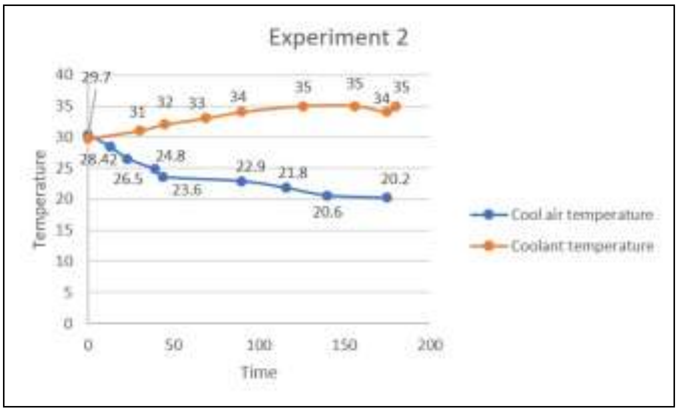

Chart -2: Temperature vs Time for Experiment 2

The graph of temperature vs time is a plot for cool air temperature and coolant temperature. It can be seen that the temperature of the cool air at the output of the casing is 20.2 degrees celsius. It's 10.2 degrees lesser than ambient temperature and 2.2 degrees lesser than the previous setup. This is achieved because the leakages and relative motion between the parts were avoided. This lead to lower losses and increased temperature difference.

Fig -4: Assembly of components

4. RESULTS

Table -3: Result table

Expt. No.	Temperature (Degree Celsius)				Time (Sec)
	Ambient	Coolant	Cool air	Difference Ambient & cool air	
1	27.3	34	19.3	8	213
2	30.4	35	20.2	10.2	180

5. CONCLUSION

From the result table, we can conclude that the liquid cooling method to remove heat from the Peltier gave better results as compared to the traditional heat sink and fan method. Also, the temperature that achieved is 20.2 degrees when the atmospheric temperature was 30.4 degrees. The setup is compact and able to provide 10.2 degrees cooler air than the atmosphere in 3 minutes. Hence this system can be used in small scale air cooling applications.

6. FUTURE SCOPE

The more the heat removed from the heating side of the Peltier more is the cooling effect achieved. To achieve more cooling we have used liquid cooling. More cooling can be achieved when slight modifications are made. The size of the overall setup can be smaller.

[1] The use of a copper radiator to remove heat from the liquid will enhance the achieved cooling effect. As the thermal conductivity of copper is higher than aluminum the heat transfer rate will be more. But, the mass will increase as the density of copper is higher than aluminum. So, there is a need for material that has a relatively lower density and higher thermal conductivity.

[2] Replacing aluminum water block with copper water block will increase the cooling output.

[3] Reducing the thickness of the radiator fan to make it more compact and increasing the rpm to compensate for the discharge.

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