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DESIGN AND CFD ANALYSIS OF THERMOELECTRIC COOLING SYSTEM

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ABSTRACT

Greenhouse effect is caused mainly due to the emission of greenhouse gases. In vapour compression refrigeration system emission of greenhouse gas is a major issue. In order to tackle this, world should adopt thermoelectric refrigeration system which is completely a CFC free technology. Thermoelectric refrigeration system is working on the principle of peltier effect. In this paper working of peltier effect, storage container design, heat sink selection, thermoelectric cooling module selection are discussed. A prototype of 1.5 liter container fabricated which could be operated between 8°C to 35°C. CFD validation also approached in the enhancement of performance improvement of the system. The design requirements, available options for optimization of system are also presented.

Key words: Peltier effect, CFC free technology, thermoelectric cooling.

INTRODUCTION

A French physicist Jean Charles Peltier in 1934 found the thermoelectric effect which is commonly known as peltier effect. It is the reverse effect of Seebeck effect. When a direct current is passed around a circuit of different materials one junction gets heated while the other junction is cooled. This is known as peltier effect. This effect is attained in thermoelectric modules which are solid state heat pumps.

Refrigeration is a process of removing the heat from a substance or space in order to bring it to a temperature lower than those of the natural surroundings. In this context, this project aims to provide cooling effect by using Peltier Effect rather than the conventional methods like those using the 'vapour compression cycle' or the 'gas compression cycle'.

The coefficient of performance of compression refrigerators decrease with the decrease of it's capacity. Therefore, when it is necessary to design a refrigerator for cooling a chamber of only a few litres capacity, thermoelectric cooling is always preferable. Also for controlling the temperature of small units, thermoelectric cooling has no competition from existing refrigerators of the conventional types.

Most of the semiconducting materials are used as thermoelectric materials. In TE module at the cold side of junction heat is absorbed by the electrons as they pass from lower energy level in p type semiconductor element to a high energy level in the n type semiconductor element. The DC power supply gives the required amount of energy to move the electrons through the system.

The objective of this paper is to utilize peltier effect to cool and maintain 8°C to 35°C for an interior volume of 1.5 liter. Also an attempt made to optimize the system for enhancement of overall performance.

A computational technology that enables one to study the dynamics of things that flow. CFD is concerned with numerical solution of differential equations governing transport of mass, momentum and energy in moving fluid. Using CFD, one can build a computational model on which physics can be applied for getting the results. The CFD software gives one the power to model things, mesh them, give proper boundary conditions and simulate them with real world condition to obtain results. Using CFD a model can be developed which can breed to give results such that the model could be developed into an object which could be of some use in our life.

Working schematic of thermoelectric cooling :

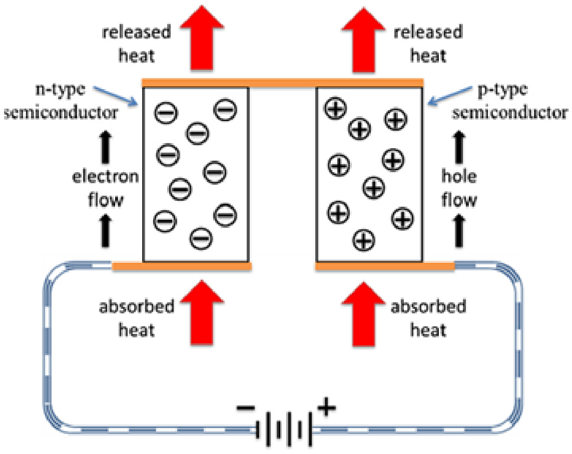

Fig.1 TEC system

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DESIGN PARAMETERS

Heat load estimation, heat sink design, TE module selection, selection of materials are all the various design considerations in a TE refrigeration system.

HEAT LOAD ESTIMATION

The heat load may consist of two types: active or passive, or a combination of the two. An active load is the power which is dissipated by the device being cooled. It is generally equal to the input power to the device. Passive heat loads are parasitic in nature and may consist of radiation, convection or conduction. [3]

ACTIVE HEAT LOAD

- $Q_{active} = v^2/R = vI = I^2R$ (1)
- Q_{active} = active heat load (W)
- v = voltage applied to the device being cooled (volts)
- R = device resistance (ohms)
- I = current through the device (amps)
- RADIATION
- $Q_{rad} = F\ e\ s\ A\ (T_{amb}^4 - T_c^4)$ (2)
- Q_{rad} = radiation heat load (W)
- F = shape factor (worst case value = 1)
- s = Stefan-Boltzman constant (5.667×10^{-8} W/m^{2}K^4)
- A = area of cooled surface (m^2)
- T_{amb} = Ambient temperature (^{O}K), T_c = TEC cold ceramic temperature (^{O}K)
- CONVECTION
- $Q_{conv} = h\ A\ (T_{air} - T_c)$ (3)
- Q_{conv} = convective heat load (W)
- h = convective heat transfer coefficient (W/m^{2}C)
- A = exposed surface area (m^2)
- T_{air} = temperature of surrounding air(C)
- T_c = temperature of cold surface (C)

Table 1: Typical Values of Convection Heat Transfer Coefficient

Process	h (W/m^2 ^{O}C)
Free Convection – Air	2-25
Forced Convection – Air	25-250

CONDUCTION

- $Q_{cond} = (k\ A)(\Delta T)/(L)$ (4)
- Q_{cond} = conductive heat load (W)
- k = thermal conductivity of the material (W/m C)
- A = cross-sectional area of the material (m^2)
- L = length of the heat path (m)
- ΔT = temperature difference across the heat path(C)

TRANSIENT

Some designs require a set amount of time to reach the desired temperature. The following equation may be used to estimate the time required:

- $t = [(\rho)\ (V)\ (C_p)\ (T_1 - T_2)]/Q$ (5)
- ρ = Density (g/cm^3)
- V = Volume (cm^3)
- C_p = Specific heat (J/g C)
- T_1-T_2 = Temperature change (C)
- $Q = (Qt_o + Qt_t) / 2$ (W)

Qt_o is the initial heat pumping capacity when the temperature difference across the cooler is zero. Qt_t is the heat pumping capacity when the desired temperature difference is reached and heat pumping capacity is decreased.

Using above stated standard calculations it is arrived that maximum heat to be extracted from the hot side of the peltier element is,

Q_{max} = 47.8W

Assuming a factor of safety 1.5, the heat sink is designed for a maximum heat load of 72 W

For this maximum heat the suitable commercially available TE module is selected . Its specification is as follows:

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Table 2: Dimensions and properties involved in heat load estimation

Sl no	Parameter	Symbol	Dimension
1	Specific gravity of vaccine	S	1.004
2	Volume of insulin (10 ml Bottles – 10 Nos)	V_b	$10x10^{-5}m^3$
3	Mass of insulin	m	0.1004 kg
4	Specific heat capacity of Insulin	C_p	4.187kJ/kg K
5	Température Différence(45-5)	ΔT	40º C
6	Density of glass	ρ	2500kg/m3
7	Volume of each bottle $\pi/4$ x $(2.5^2 – 2.1^2)$ x 4	V_b	5.78cm3
8	Specific heat capacity of bottle	C_p	0.84 kJ/kg K
9	Dimension of inner chamber	L× b× h	15cmx10cmx8cm
10	Density of air @ 20º C	ρ_a	1.205 kg/m3
11	Mass of air	m_a	8.676x10-4 kg

Model: TEC-12706
- Operational Voltage : 12 VDC
- Current Max : 6 Amp
- Voltage Max : 15.2 VDC
- Power Max : 92.4 Watts
- Power Nominal : 60 Watts
- Couples : 127
- Dimension : 40 x 40 x 3.5mm

Table 3: Heat sink specification:

Sl no	Parameter	Symbol	Dimension
1	Thickness of Stainless steel pane	L_1	2mm
2	Thickness of insulation	L_2	10mm
3	Thermal conductivity of Stainless steel	K_1	16W/mK
4	Thermal conductivity of Polystyrene	K_2	0.026W/mK
5	Area of side (.08 x .075 x 2)	A_1	0.012 m^2
6	Area of side (.08 x .15 0 x 2)	A_2	0.024 m^2
7	Area of side (.075 x .150 x 1)	A_3	0.01125 m^2

Fig.2 Experimental set up with data logger system

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Table.4 Experimental readings of thermoelectric cooling system

Current (A)	Voltage (V)	Power (W)	Peltier Cold side Temperature (°C)	Time (mins)
0.5	1.5	0.75	25	0
0.8	2.9	2.32	23.5	0.5
1	3.3	3.3	21	1
1.2	4.5	5.4	15	5
1.4	5	7	12	8
1.5	7	10.5	10.2	10
1.61	7.4	11.914	8	15
1.62	8	12.96	6.1	20
1.63	11.9	19.397	5.3	25

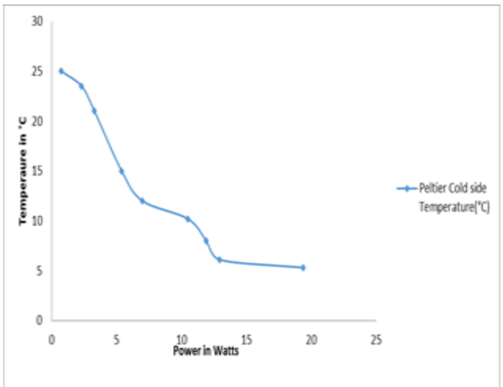

Fig 3. Temperature Vs Power plot

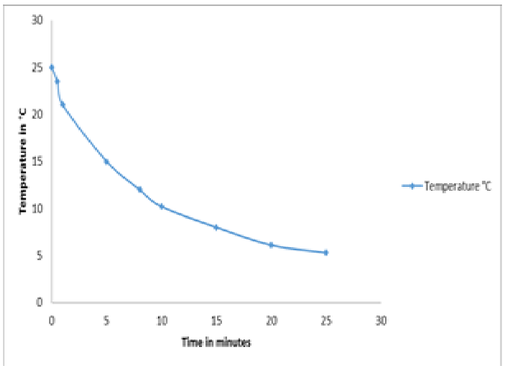

Fig.4 Temperature Vs time plot

CFD ANALYSIS:

Analysis for the various conditions was first given using CFD software.The results obtained were then imported to ANSYS Workbench FEA software.The following results were obtained

FIN IN COLD JUNCTION WITH FAN

This condition assumes the fin and fan in cold junction.

TEMPERATURE DISTRIBUTION

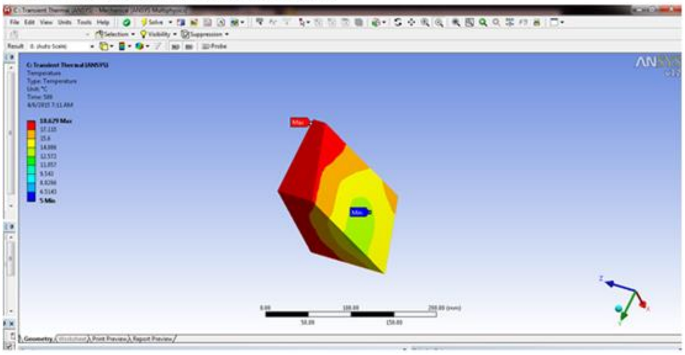

Fig 5. Temperature distribution for fin and fan at cold side

TEMPERATURE - TIME PLOT

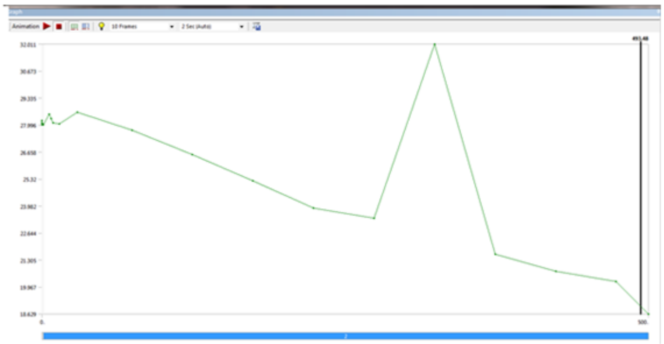

Fig 6. Temperature time plot for fin and fan in cold side

FIN PLACED ON HOT JUNCTION

TEMPERATURE DISTRIBUTION

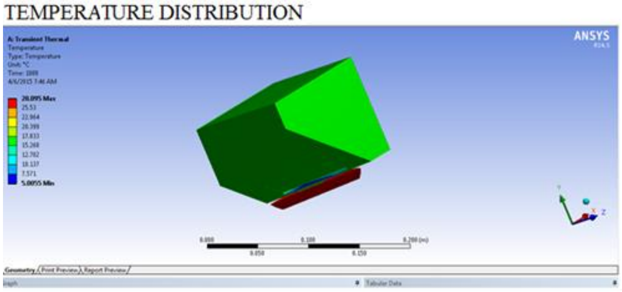

Fig 7. Temperature distribution for fin paced in hot side

TEMPERATURE - TIME PLOT

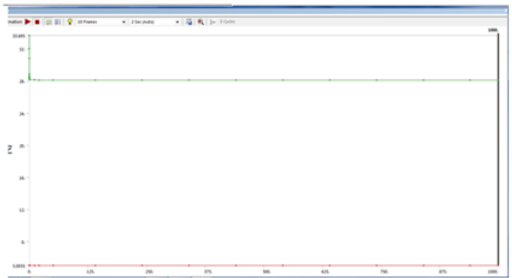

Fig 8. Temperature time plot for fin at hot sid

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RESULT

MAXIMUM TEMPERATURE: 28 C
MINIMUM TEMPERATURE: 5.1 C
TIME STEP : 1500 s
MAXIMUM TEMPERTURE: Air
MINIMUM TEMPERATURE : Solid

FIN IN THE HOT JUNCTION WITH FAN

This condition assumes the fin and fan kept in hot junction.

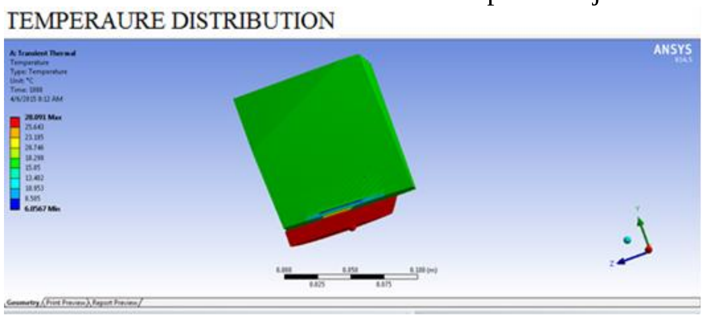

Fig 9. Temperature distribution for fin and fan at hot side

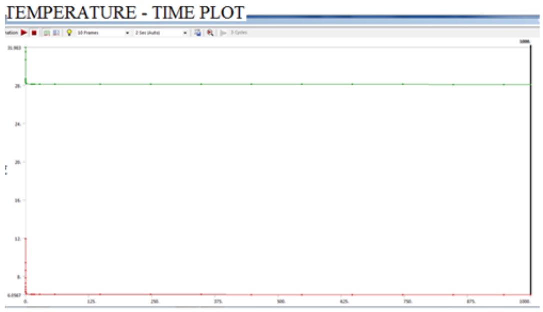

Fig 10. Temperature time plot for fin and fan at hot side

RESULT

MAXIMUM TEMPERATURE: 28 C
MINIMUM TEMPERATURE: 6.1 C
TIME STEP : 1500 s
MAXIMUM TEMPERTURE: Air
MINIMUM TEMPERATURE : Solid

CONCLUSION

This paper evaluates the design parameters involved with thermoelectric cooling system. An experimental work is carried out to obtain a temperature up to 5 degree Celsius. An attempt made in validating the experimental work with the CFD analysis by giving sufficient boundary conditions. Further this work could be enhanced with different thermoelectric materials to attain high performance.

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