Design and Analysis of Solar Powered Thermoelectric Refrigerator

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Abstract- The objective is to develop a solar powered refrigerator using peltier effect and some refrigerating materials. Thermoelectric cooling technologies are becoming popular as these are eco-friendly and can be used in remote areas. This project emphasizes on the use of refrigerating materials like Vanadium oxide, plastic film etc. for designing the refrigerating cabinet/box and analyzing its effect on COP by making various prototypes. This project also deals with design and analysis of solar thermoelectric refrigerator for maintaining the temperature range up to 10°C. Thermoelectric refrigerator has a lot of scope in refrigeration, air-conditioning, food preservation, medical services etc.

Indexed Terms- Peltier effect, Solar panel, Heat sink, and TEC module.

I. INTRODUCTION

Refrigeration is the process of removing heat and lowering the temperature of an enclosed space. Conventional refrigeration system are using CFC's and HFC's as a refrigerant. Hence, it is a great concern for environment as it causes depletion of ozone layer. Therefore, the need is to look up to some renewable resources. So, the best suitable option is the solar thermoelectric refrigerator. It can be used in remote areas where grid power is unavailable. These are solid state devices which means they does not have any moving parts. Thermoelectric refrigerator uses the peltier effect for cooling appliances by creating heat flux between the junctions of two different types of materials. Though, the COP of the system is lower than conventional ones but research is going on for developing better, efficient and economical system. Hence, external research is going on for developing better refrigerating material to increase the COP. The working principle of TER is based on peltier effect. It states that when a current is supplied to two dissimilar materials connected in a closed circuit then heat is either rejected or absorbed at the junction.

II. EXPERIMENTAL SETUP

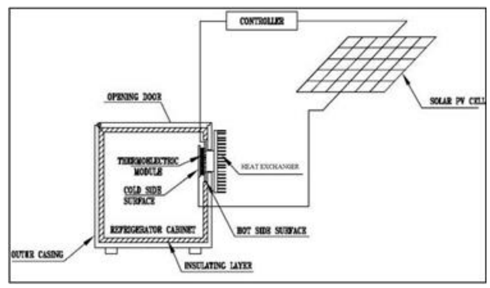

Fig.1 Experimental Setup Diagram

The project is mainly consists of following components:-

1. Solar Panel-

Solar panel are used for conversion of solar energy into DC voltage. Specifications-

- Maximum power (P_{max})-20W
- Voltage at P_{max}(V_{mp})-16.8V
- Current at P_{max}(I_{mp})-1.19A

2. Solar Charge Controller-

It is used to protect the battery bank from overcharging and under discharging.

3. Thermoelectric Module-

It is composed of two ceramic substrates that act as a foundation and electrical insulation for P-Type and N-Type Bismuth Telluride dice which is connected electrically in series and thermally in parallel between ceramics. Specifications-

- Model:TEC1-12706
- Size: 40mm x 40mm x4mm
- Operates from 0~15.2V DC &0~6A
- Operates Temperature: -30^{0}C to70^{0}C

- Maximum power consumption- 91.2 Watts

4. Refrigerator Cabinet /Box-

Fig 2. Refrigerator Cabinet /Box

The refrigerator cabinet is the most crucial component in which the process of isolating the most crucial & vulnerable products are preserved. The cabinet dimension are $250\times 250 \times 265$ mm. Conventionally, it is made up of Aluminium, but we are trying different combination of various materials which are insulating, conducting or sandwich material etc. which can have great effect on COP, as COP is a function of material dimension property of a thermocouple, the temperature of hot and cold side.

Based on desired properties, cost, availability we have shortlisted the following materials

Sr No.	Material	Temperature
1.	Sandwich Film of Silicon Dioxide & Hafnium Dioxide	Allows it to cool up to 5℃.
2.	Vanadium Dioxide	When heated up to 68℃ it starts cooling
3.	PDMS Films (Polydimethyl siloxane)	Can cool up to 9℃ .

Table No.1. Material details

Practical COP of commercially available thermo electric refrigerator is much less. Hence, by adopting different material combination for cabinet can cause significant temperature drop inside the cabinet than the ambient temperature, this leads to the reduction in temperature difference of hot and cold side. Therefore, heat load is reduced and COP also increases. This will save electricity.

Hence, different prototypes has to build for detailed study. However, this are yet to be realised in practice.

5. Temperature Controller-

It is used to control the temperature. Its function is to take input from a temperature sensor and output is given to fan.

6. Heat sink and Fan assembly-

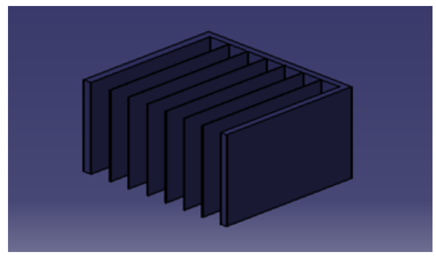

Fig.3 Heat Sink

Heat sink and fan assembly provides peltier cooling benefits. The fan is placed opposite to heat sink which increases the air flow improving the thermal efficiency. Specifications-

- Model:TEC1-12706
- Size: 40mm x 40mm x4mm
- Operates from 0~15.2V DC and0~6A
- Operates Temperature: -30℃ to70℃
- Max power consumption: 91.2Watts

7. Battery Bank-

Batteries are a common feature in most types of PV systems that are not connected to the utility grid. In addition to providing storage, they can be used for start-up current, power conditioning etc.

III. EXPERIMENTAL WORKING

The process of solar powered thermoelectric refrigerator is simple that is when sunlight falls on the PV cells of solar panel it causes electron hole pair generation which in turn generates current. This current is transferred to battery bank. From battery it is supplied to thermoelectric cooler (TEC) module. This module is composed of P-Type and N-Type semi-conductor. The current flows heating P-Type as a hot junction needed to be cooled and N-Type as cold junction needed to be heated. As a result, the hot side becomes hotter and cold side becomes cooler (Peltier effect). The excess heat is given to heat sink and fan assembly. At last the refrigeration effect is produced in cabinet.

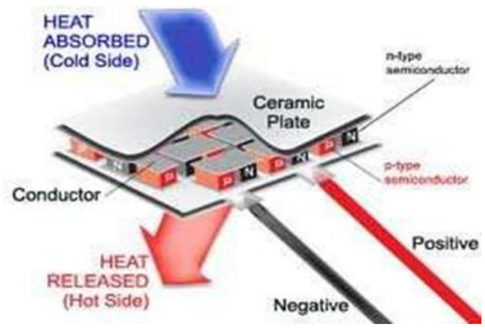

Fig. 4 Peltier Effect

IV. DESIGN

The performances of a thermoelectric cooler are expressed as follows-

QC = $(\alpha m \times I \times Tc) - \frac{1}{2}(\frac{I^2}{2} \times Rm) - (Km \times (Th-Tc))$

W = $\alpha m \times I \times (Th-Tc) + (I^2 \times Rm)$

COP = $\frac{Q_c}{W}$ $\alpha m = 2\alpha N$

Rm = $\frac{2\rho t n N}{G}$

Km=2NKG

In the above equations the αm, Km, Rm are the device Seeback voltage, device thermal conductance and device electrical resistance under the assumption of all identical couple and the unidirectional heat flow.

Rm = $\frac{Th-\Delta Th}{Th} \times \frac{V_{max}}{I_{max}}$

Km = $\frac{Th-\Delta T_{max}}{2\Delta T_{max}} \times \frac{V_{max} \times I_{max}}{Th}$

Z = $\frac{2 \times \Delta T_{max}}{(Th-\Delta T_{max})^2}$

Where Imax is the maximum input current at Qc=0, Vmax is maximum DC voltage at Qc=0 and ΔTmax is the maximum temperature difference at Imax, Vmax and Qc=0.

For module, TEC1-12706

T_h=25, T_c=10, Q_{max}=50W, ΔT_{max}=66K, I_{max}=6.4A, V_{max}=14.4V

$\alpha_m = \frac{V_{max}}{Th} = = \frac{14.4}{298} = 0.04832$ V/°K

$R_m = \frac{Th-\Delta Th}{Th} \times \frac{V_{max}}{I_{max}} = \frac{(298-66)}{298} \times \frac{14.4}{6.4}$ =1.75 Ω

Km = $\frac{Th-\Delta T_{max}}{2\Delta T_{max}} \times \frac{V_{max} \times I_{max}}{Th} = \frac{298-66}{2\times 66} \times \frac{14.4\times 6.4}{298}$

= $\frac{2\times 66}{(298-66)^2}$ = 0.5435 /°K

Z = $\frac{2 \times \Delta T_{max}}{(Th-\Delta T_{max})^2} = \frac{2\times 66}{(298-66)^2}$ =0.00245 /°K

QC = $(\alpha m \times I \times Tc) - \frac{1}{2}(\frac{I^2}{2} \times Rm) - (Km \times (Th-Tc)$

= $(0.04832\times 286\times 6.4) - \frac{1}{2}(6.4^2 \times 1.75) - (0.4535\times (25-10)$

= 45.79 Watts

W = $\alpha m \times I \times (Th-Tc) + (I^2 \times Rm)$

= $(0.04832\times 6.4\times (25-10) + (6.4^2 \times 1.75)$

=76.3187 Watts

COP = $\frac{Q_c}{W} = \frac{45.79}{76.3187}$ = 0.599

COP = 0.599 ≈ 0.6

V. SIMULATION & ANALYSIS

A numerical simulation was done with ANSYS software, which uses the finite element approach to simulate the physical model. The thermoelectric system consists of one pair of P and N semiconductor materials sandwiched between the electrodes of 0.1mm thick. To create the physical environment for an analysis, ANSYS AIM is used to establish a simulation model of the physical problem. The simulation of Heat sink is also done by using Ansys Workbench 17.1 to get the temperature distribution.

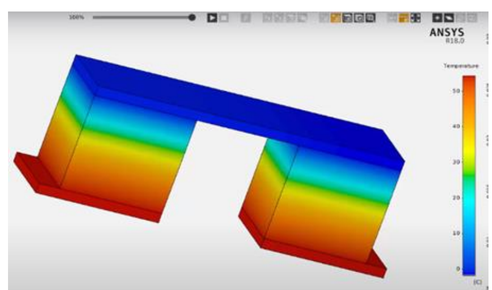

Fig.5 Temperature distribution of P-N Junction Module on ANSYS AIM software

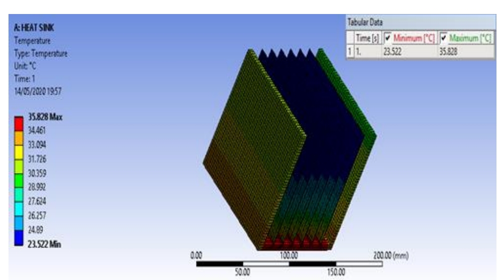

Fig 19 Temperature distribution of Heat Sink [Fins]

RESULTS

With the help of this TE refrigeration system we can get the refrigerating effect without help of compressor. The theoretical results are calculated and the following result are obtained:

1) W = 76.3187Watt
2) Qc = 45.79 Watt
3) COP = 0.6

By comparing with conventional vapor compression cycle, for the same output the TE refrigerator requires less input.

The temperature was varied from [-1.7917 to 54.315], between the cold and hot side of the model. The temperature distribution of fin is been observed in which the temperature is decreased from 35.828 ºC to 22.522ºC

CONCLUSION

1) Solar thermoelectric refrigerator is the need to protect the environment as it uses both solar and electrical energy.
2) It is the boon for the people residing in high temperature zones.
3) Though it has low COP and high cost but the solution to this problem is the advancement of new techniques, materials, better design, better heat transfer rate which will greatly improve the COP.
4) The analytical calculation shows that the system has huge potential for the generation of electricity.
5) Finally there is lot of scope of research for the better development of solar powered thermoelectric refrigerator.

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