International Journal of Research in Advent Technology, Vol.6, No.6, June 2018
E-ISSN: 2321-9637
Available online at www.ijrat.org

Modeling and Numerical Analysis of Compressor less Solar Refrigerator

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Abstract- In this paper, a distinct type of solar refrigeration system is described by employing Peltier module. Thermoelectric modules form basic building stone in this refrigerator for producing the thermoelectric cooling. The thermoelectric effect can be a source of refrigeration. In such a device, one side of a surface gets cooled while other side becomes hot. The heat so produced on the outer side is rejected with the help of heat sink fans. So, cooling effect is achieved without involvement of greenhouse gaseous. Thermoelectric modules are optimized by semiconductors. They can be utilized for regulating temperature by working as a heat pump to help computing devices and integrated circuits in favorable temperatures to enhance processing efficiency. Global warming can be reduced which occurs due to conventional refrigeration systems. Both AC and DC supply can be used in this apparatus. Finally, the lowest temperature achieved by the model is 15.8 ^{o}C and 18.3 ^{o}C in 25 min with only one Peltier module in operation at different times in a week.

Index Terms-Thermoelectric Effect, Peltier Module, Charge Controller, See beck Effect**.**

1. INTRODUCTION

Refrigeration can be accomplished by the direct conversion of electrical to thermal energy. Thermoelectric refrigeration technology has been used commercially to cool electronic equipment and for small portable refrigerators used for recreational activities. Thermoelectric devices use two dissimilar semi-conducting materials, one P-type and one N-type. Since these materials are generally poor conductors of heat, they are often joined by a conducting material such as copper to form the junction between the two. The conventional sources of energy is fast depleting and hence renewable energy resources are to be extracted in order to make sure the energy availability to our upcoming future generations. The overuse of conventional resources causes climate change. Physical evidences of climate change are melting glaciers, Vegetation quality and quantity reduction, Habitat loss, Loss of species, Sea level rise and increasing demand of fossil fuels and subsequent pollution through their use. Solar energy has high potential in Indian subcontinent along with most of the areas on earth apart from Polar Regions. The introduction and usage of such portable, mobile, pollution less and compact refrigerator would be a considerable replacement of the conventional type of refrigerators and their associated environmental concerns. Further developments in this field can bring more efficient refrigerators having greater C.O.P. and enhanced reliability. [1].

2. LITERATURE REVIEW

A study was done to collect data in relation with thermoelectric energy conversion ways and the subsequent outcomes of such an experiment and the relations that define such conversions.

Loffe and Angrist performed a study of the thermodynamics of direct conversion of thermal to electrical energy. Loffe also conducted a analysis of the thermodynamics of thermoelectric refrigeration [2].

2.1. Peltier Structure

Peltier Module is the component which works on Peltier effect. An electrified junction of two different types of materials which act as pure conductor, which experience heating and cooling effects, is called Peltier Effect. If we are considering two different conductors A & B, when current is to flow through the junction of these conductors, a few amount of heat may be generated at the point of junction. This generated heat is called Peltier Heat**.** The cabinet is such designed so that cooler side is inside and the hotter side is outside which would create the refrigerator like ambience inside without the use og compressors. The basic difference is the absence of refrigerant or working fluid in this model which forms the basis for any environmental pollution. A typical Peltier structure is shown in Figure 1 [3].

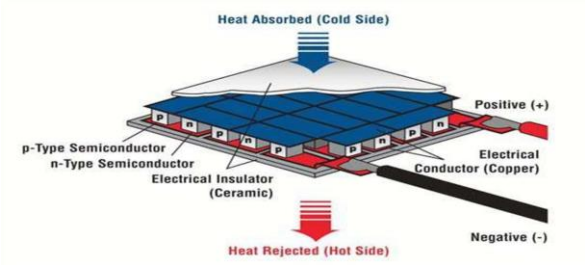

Fig.1: Peltier Structure

The Peltier effect occurs at the junction of the two different substances because energy is always conserved.

3. THERMOELECTRIC REFRIGERATION

Figure 2 depicts a TEC attached with a thermal source and sink. Heat is received from the source at T_L and rejected to the sink at T_H. An external direct current source has been provided to the TEC. Also, these conductors are assumed to have negligible thermal and electrical resistances when compared to the P- and N-type semiconductors used therein. The semiconductors are assumed to inherit uniform rectangular cross-section; thermal conductivity, electrical resistivity and See beck coefficient for each material are taken to be constant. Power given to the system is P.

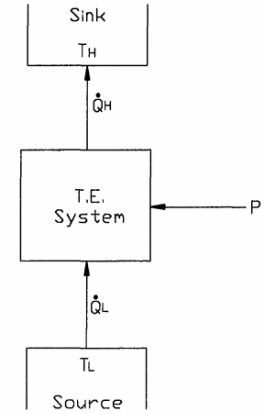

Fig.2: Schematics of Thermal System

Figure 3 shows a schematic diagram of the thermoelectric refrigerator circuit. Heat is conducted through both legs of the refrigerator in parallel whereas the current flows in series. It is assumed that conductors C_1, C_2 and C_3 are isothermal at temperatures T_H and T_L respectively.

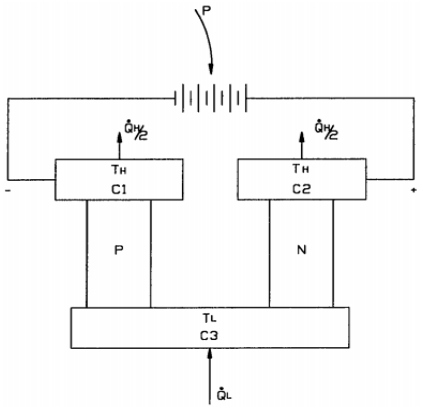

Fig.3: Schematic of a typical circuit

COP for a thermoelectric refrigerator is given by the following equation,[4]

$$COP = \frac{Q_C}{P} \quad \ldots\ldots (1)$$

The thermoelectric refrigeration system presented here is of compact and simple design, highly reliable, and the usage of CFC- free working elements. A comparison of thermoelectric refrigerator has been shown in Table 1 over conventional refrigerator.

Table 1: Comparison table

S. No.	Criteria	Thermo electric refrigerator	Normal refrigerator
1	Cooling method	Non Cyclic refrigeration	Vapour compression cycle
2	Components	Thermo electric module	Condenser, Compressor, Evaporators
3	Main advantage	Portable, Durable, No refrigerant required	High COP
4	Power Consumption	12-56 volts	220 volts
5	COP	Comparatively less	High COP
6	Uses	Insulin preservation Cars, travelling uses, etc	Ice Cold water etc.

4. MODELING OF PROJECT

The Peltier module used in this Model is TEC 12710. This unit works on 5 volts DC and a maximum current of 5.5 amps at full load. The power rating of this unit is 18 watts [5].

To avoid the fluctuation of sunrays on solar panel, we used charge controller in solar refrigeration system. Also, charge controller prevents battery overcharge and electrical overload.

Cooling fan of our refrigerator is mounted on the heat sink. The main purpose of the cooling fan is to dissipate heat from the heat sink by taking in fresh air. Heat sink is a passive heat exchanger that cools a device by dissipating heat into the surrounding medium. The heat sink is generally made up of aluminum. The heat sink used in this model is of dimension 7.5cm X 8cm X 4.5 cm (L x B x H). Heat sinks function by efficiently transferring thermal energy ("heat") from an object at high temperature to a second object at a lower temperature with a much greater heat capacity. This rapid transfer of thermal energy quickly brings the first object into thermal equilibrium with the second, lowering the temperature of the first object, fulfilling the heat sink's role as a cooling device. Efficient function of a heat sink relies on rapid transfer of thermal energy from the first object to the heat sink, and the heat sink to the second object. Thermocol has been used as insulator in making the body of refrigerator. The battery used here has following specifications:

Voltage: 12 V
Current: 7Ah

The model is within wooden casing or plywood case in order to save refrigeration cabinet from outer convection, radiation and conduction from the surroundings.

The final assembled model is shown below in Figure 3.

Fig.3: Final Model

5. SPECIFICATIONS, WORKING AND ANALYSIS

Dimensions: Outer (wooden):- 10x11x13.8 (inches)
Inner (cabinet):- 10x7x8.5 (inches)
Partitioned cabinet: - 8x5.3x5 (inches)
Voltage: DC 12V; AC 100-240V (along with rectifier)

Figure 4 shows a block diagram of the model so made.

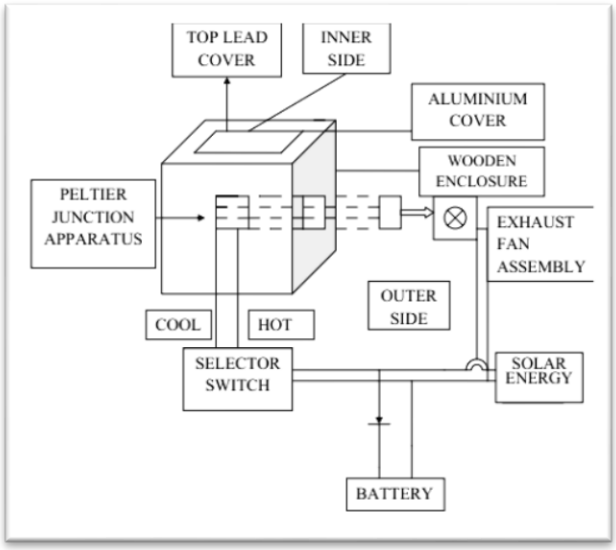

Fig.4: Block Diagram

The refrigerator is fed with power supply from a battery of 12 volt DC 7.5 Ah. When the switch is turned on, a LED indicating that the fridge is now online, starts glowing. Then Peltier device which is insulated from the cooling side and configured in the fridge produces cooling effect on inner side and heat is rejected on outer side. At the hotter side of the Peltier module, a heat sink with a fan attached to it works to reject the heat from the Peltier unit in ambient atmosphere. The thermoelectric Device is so configured in a casing with insulation methods and heat sink so that appreciable refrigeration takes place every time the fridge operates. To turn the fridge off, switch is operated. Glowing LED will also stop glowing. The battery used in the fridge is charged from the solar panels using a charge controller rated 12volts, 10 amps.

6. TESTING AND PERFORMANCE

An evaluative testing of the model was done and temperature was recorded as per time. The input parameters, ambient conditions were noted as:

Input to the fan =12V
Ambient temperature =30.8^{o}C
Voltage to the cooler =6.5V
Current to the cooler =3.30A
Power input to the cooler =21.45W
Thermal insulation: Thermocol insulated aluminium foil

The temperature was recorded using digital thermometer with respected to time is given in Table 2.

Table 2: Temp of box v/s Time

Temp inside box (^{o}C)	Time (min)
30.8	0
17.3	5
16.9	10
16.5	15
15.9	20
15.8	25

When a power input of 21.45 W was given to the thermoelectric cooler, it gave a temperature difference of 15^{O}C in 20minutes.
Infiltration of heat due to Door Opening was recorded as 3^{o}C per minute.
When the temperature is measured at *x = 0* (near the module and perpendicular direction to the module surface), it was lowest of 15.8^{o}C;
When the temperature is measured at *x=8.1 inches* (extremity of the box), it was 20.8^{o}C.

The intrinsic properties of the thermoelectric model so selected are given here as:

The thermoelectric cooler module material chosen is Bismuth telluride. The properties of a 31 couple, 9A Bismuth Telluride module [6] are:
See beck coefficient = 0.01229 V/k
Module thermal conductance = 0.1815 W/k
Module resistance = 0.344Ω

6.1. COP of Model

The coefficient of performance of the thermoelectric cooler is obtained from equation 1,
Q_C is cooling capacity per module and P is electrical power input.

$$Q_C = \alpha T_C I - \frac{1}{2} I^2 R - K(T_H - T_C)$$

And

$$P = \alpha I (T_H - T_C) + I^2 R$$

Where, α is See beck coefficient, I is current, R is module resistance and K is module thermal conductance and T_H, T_C are temperature of hot side and cold side of module respectively. [7]

Following observations were obtained in 25 min of operation in day time. The T_H and, T_C were recorded with digital thermometer and stop watch as shown in Table 3. The T_H and T_C during 25 min of operation recorded as 59.1^{o}C and 18.3^{o}C respectively. The COP was calculated at current 3.3 Amps as 1.433.

Table 3: T_H and T_C with time

Temp inside the box T_C(^{o}C)	Hot side temperature T_H(^{o}C)	Time (min)
33.5	33.5	0
29.6	44.1	2
23.0	52.8	5
21.8	54.1	7
19.8	57.1	10
19.1	59.2	12
18.9	59.3	15
18.5	59.3	18
18.4	59.3	20
18.3	59.1	22
18.3	59.1	25

The temperature drop with time is shown in the graph depicted in the figure 5. We see, that after a specific time a stable temperature difference is created between the outside hot temperature T_H and the inside cold temperature T_C irrespective of the ambient temperature and input conditions. So, this can be inferred that the TEC model so innovated can work even better in cars having a cool ambient inner temperature and thus help in assuring better performance of the portable refrigerator.

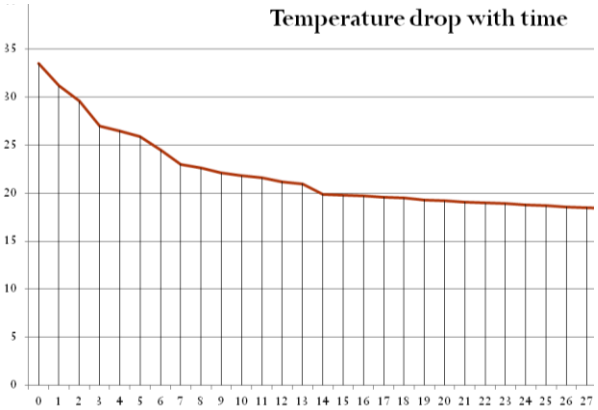

Fig.5: Temperature (Y-axis) Time (X-axis) Plot

It can be seen from Figure 6 that the C. O. P increases with an increase in input current, gets to a peak value and then begins to decreases at various temperature differences. The unique feature of the graph is with the DT (Difference in Temperature) = 20, the smallest temperature difference, it shows that the C. O. P. is maximum with a smaller temperature difference between the source and the sink. Therefore, for optimum performance of the thermoelectric cooler, the temperature difference between the source and sink should be kept as low as possible.

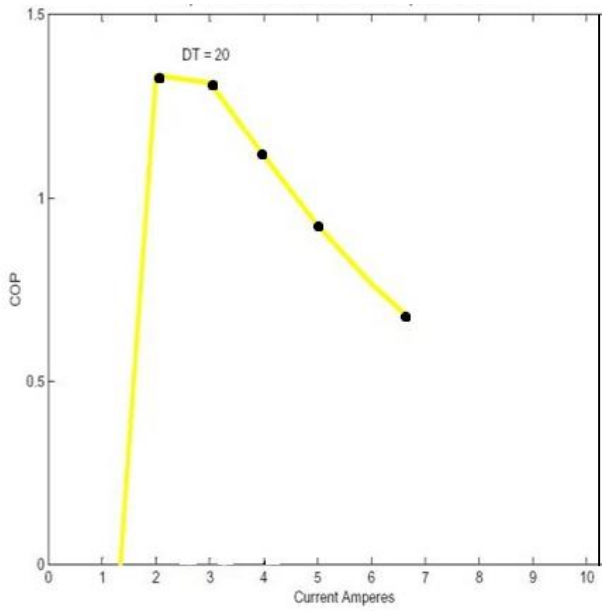

Fig. 6 Graph of COP Vs current at various temperature differences

7. CONCLUSIONS

On the basis of the above data, it can be proclaimed that the above device or TEC can be comfortably utilised for acute chilling requirements where cooling is needed in lesser time. To increase the volume of the fridge maintaining the same temperature inside the fridge, number of peltier units and heat sink has to be increased. PID controllers can be used for making it a temperature controlled fridge. This fridge can also be equipped with a LCD display and digital temperature sensor. This system is provided with a solar panel charge controller which can be easily used to charge the battery from the solar panels. In addition to the battery, normal 220 volt AC supply can be used to charge the batteries as well. The minimum temperature obtained in such aforesaid conditions mentioned was 18.3^{o}C at a good COP 1.433. The following uses are prevalent:

- For preservation of insulin and other medicinal drugs.
- For preservation of food stuffs (fresh potatoes, pumpkins, honey dew, egg plant, cucumbers, sweet potatoes, winter squash, etc. and curd formation retaining the curd fat and WHEY fats.
- For preserving frequently undisturbed stuffs, such as electronic equipments, specialised coating paints and semi-solid compounds in industrial applications.
- For cold water while outside applications such as sporting activities or military expeditions.
- For beverages and canned foods (tomato puree, fruit extracts, etc.)

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