Design and Fabrication of Thermoelectric Solar Refrigerator

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Abstract - The global increasing demand for refrigeration, led to production of more electricity and consequently more use of chlorofluorocarbons (CFCs) which acts as a contributing factor in the depletion of ozone layer. Thermoelectric refrigeration is new alternative because it can convert waste electricity into useful cooling. Therefore, thermoelectric refrigeration is greatly needed, particularly for developing countries where long life and low maintenance are needed. The objective of this study is to design and develop a working thermoelectric refrigerator that utilizes the Peltier effect to refrigerate and maintain a selected temperature. The requirements are to cool this volume to temperature within a time period of 2 hours and provide retention of at least next half an hour. Our project also utilizes the solar energy to run a thermoelectric system. In this project we have fabricated a thermoelectric system using both solar power and electrical power supply. The project has various applications like, food preservation, military or aerospace, medical and pharmaceutical equipment.

KEY WORD: Thermoelectric module, CFC, Peltier effect, Refrigeration, Transformer, solar power, TER.

1. INRODUCTION

Refrigeration is a process of removing heat from a low-temperature reservoir and transferring it to a high-temperature reservoir. The work of heat transfer is traditionally driven by mechanical means, but can also be driven by heat, magnetism, electricity, laser, or other means. Refrigeration has many applications, including, but not limited to: household refrigerators, industrial freezers, cryogenics, and air conditioning. Heat pumps may use the heat output of the refrigeration process, and also may be designed to be reversible, but are otherwise similar to air conditioning units.

Refrigeration has had a large impact on industry, lifestyle, agriculture, and settlement patterns. The idea of preserving food dates back to at least the ancient Roman and Chinese empires. However, mechanical refrigeration technology has rapidly evolved in the last century, from ice harvesting to temperature-controlled rail cars.

The introduction of refrigerated rail cars contributed to the westward expansion of the United States, allowing settlement in areas that were not on main transport channels such as rivers, harbors, or valley trails. Settlements were also developing in infertile parts of the country, filled with newly discovered natural resources. These new settlement patterns sparked the building of large cities which are able to thrive in areas that were otherwise thought to be inhospitable, such as Houston, Texas, and Las Vegas, Nevada.

In most developed countries, cities are heavily dependent upon refrigeration in supermarkets, in order to obtain their food for daily consumption. The increase in food sources has led to a larger concentration of agricultural sales coming from a smaller percentage of existing farms. Farms today have a much larger output per person in comparison to the late 1800s. This has resulted in new food sources available to entire populations, which has had a large impact on the nutrition of society.

2. LITERATURE REVIEW

Journal papers and patents explored here are related directly or indirectly to the proposed area of work that is design and development of a Thermoelectric Solar refrigerator. These papers are to support and enlighten the whole process of design in the specific area.

"Performance Evaluation of a Thermoelectric Refrigerator", Onoroh Francis, Chukuneke Jeremiah Lekwuwa, Itoje Harrison John International Journal of Engineering and Innovative Technology (IJEIT) Volume 2. From above research paper we have studied about the Seebeck effect, thermoelectric refrigerator, hybrid refrigerator and thermoelectric materials. Thermoelectric cooling provides a promising alternative R&AC technology due to their distinct advantages. Use of Thermoelectric effect to increase the COP of existing cooling system. "Design and Development of Thermoelectric Refrigerator ", Mayank Awasthi International journal of mechanical engineering and robotics. From above research paper we have studied about thermoelectric component like heat sink. The design requirements are to cool this volume to temperature within a less time period and provide retention of at least next half an hour. The design requirement, options available.

"A Review on use of Peltier Effects ",AjitkumarNikamDr.Jitendra hole Mechanical Engineering Department, Rajashri Shahu college of engineering , Pune. From above research paper we have studied about use of peltier plate in refrigerator. Coefficient of performance (C.O.P) which is a criterion of performance of such device is a function of the temperature between the source and sink. For maximum efficiency the temperature difference is to be kept to the barest minimum.

Solar Energy for Cooling and Refrigeration Dr. R.E. Critoph and Mr. K. Thompson Engineering Department, University of Warwick, Coventry CV4 7AL, UK. From this research paper, the need to replace the peak load demand for electricity for air conditioning applications coupled with the desire of gas utilities to balance their heating loads with a summer alternative has lead to the development of heat powered refrigeration cycles. The result has been research into improved desiccant materials and cycles to both improve performance and reduce costs.

WHO report EPI/ CCIS/85.4, 'Solar powered refrigerator for vaccine storage and icepack freezing, Status summary June 1986', 1986. This paper describes how to calculate vaccine volumes at each level of the cold chain. It is an important document for anyone involved in planning and buying equipment for storing and transporting vaccines.

3. PELTIER EFFECT

It states that "when an electric current flows across two dissimilar conductors, the junction of the conductors will either absorb or emit heat depending on the flow of the electric current". The heat absorbed or released at the junction is proportional to the input electric current. The constant of proportionality is called the Peltier coefficient.

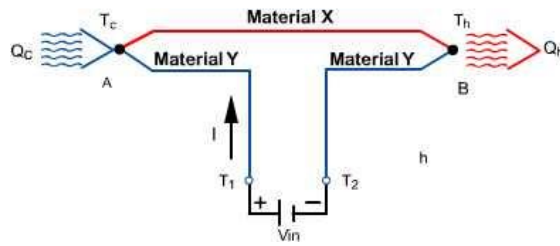


FIG 1 PELTIER EFFECT

4. COMPONENTS

- Solar cell
- Battery
- Thermoelectric module
- Heat sink
- Cooling fans
- Aluminium box
- Polystyrene foams sheet
- Wires
- Temperature sensor
- Diode
- Transformer
- Resistor
- Capacitor

SPECIFICATIONS OF SOLAR PANEL

(STC Standard Testing Condition: 1000W/M2 AM1.5, 25℃.)

S.NO	DESCRIPTION OF GOODS	TECHNICAL SPEC.
1	Open Circuit Voltage (Voc)	21.2V
2	Maximum Power Voltage (Vmp)	17.8V
3	Maximum Power Current (Imp)	2.5A
4	Maximum Power (Ppm)	15Wpm
5	Tolerance	±5%

TABLE 1 TECHNICAL CHARACTERISTICS OFSOLAR PANEL

Specifications of battery

S.NO	DESCRIPTIONS OF GOODS	TECHNICAL SPECIFICATION
1	VOLTAGE	12V
2	CURRENT	7A

TABLE 2 SPECIFICATIONS OF BATTERY

Specifications of TEC1-12706 Thermoelectric module

TYPE	COUPLES	Imax (A)	Umax (V)	Qcmax(w) ΔT =0	ΔTmax(°C) Qc=0	DIMENSIONS (mm)			R
				Th=27°C		L	M	H	(Ω)
TEC1-12703	127	3	15.4	26.7	70	40	40	4.9	3.42
TEC1-12704		4		36.8	70	40	40	4.5	3.02
TEC1-12705		5		46.5	70	40	40	4.2	2.51
TEC1-12706		6		53.3	70	40	40	3.8	1.98
TEC1-12707		7		62.2	70	40	40	3.6	1.71
TEC1-12708		8		71.1	70	40	40	3.4	1.51
TEC1-12709		9		80.1	69	40	40	3.4	1.36
TEC1-12710		10		88.9	69	40	40	3.3	1.08
TEC1-127085	127	8	15.4	71.1	70	50	50	5.1	1.51
TEC1-127105		10		88.9	70	50	50	4.5	1.12
TEC1-12712		12		106.7	70	50	50	4.2	0.91
TEC1-12714		14		124.4	70	50	50	4.3	0.81
TEC1-127155		15		133.3	70	50	50	3.6	0.75
TEC1-12718		18		160.1	70	50	50	3.6	0.68
TEC1-12720		20		177.8	69	50	50	3.4	0.59
TEC1-12722		22		195.6	69	50	50	3.4	0.55
TEC1-12726		26		232.5	68	50	50	3.3	0.48
TEC1-127305		30		266.7	68	50	50	3.1	0.43
TEC1-127106	127	10	15.4	88.9	70	62	62	6.1	1.05
TEC1-12712		12		106.7	70	62	62	5.9	0.91
TEC1-12714		14		124.4	70	62	62	5.9	0.81
TEC1-12715		15		133.3	70	62	62	5.8	0.75
TEC1-12718		18		160.1	70	62	62	5.6	0.68
TEC1-127206		20		177.8	70	62	62	5.6	0.59
TEC1-12722		22		195.6	70	62	62	5.3	0.55
TEC1-12726		26		232.5	69	62	62	4.3	0.48
TEC1-12730		30		266.7	69	62	62	3.9	0.43
TEC1-12740		40		335.6	68	62	62	3.6	0.27

TABLE 3 SPECIFICATIONS OF TEC1-12706 THERMOELECTRIC MODULE

5 LAYOUT OF THERMOELECTRIC SOLAR REFRIGERATOR

5.1 3D Layout of Thermoelectric Solar Refrigerator

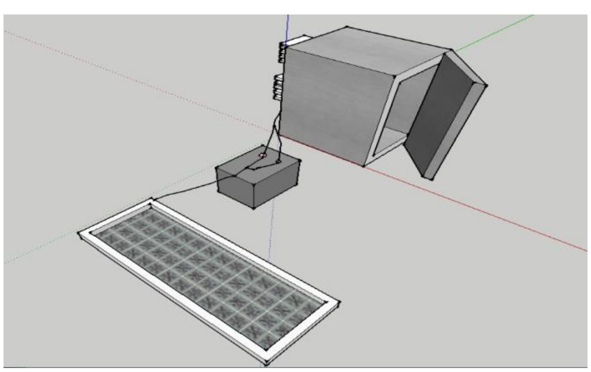


FIG 2 LAYOUT OF SOLAR TTHERMOELECTRIC REFRIGERATOR

5.2 2d Layout of Thermoelectric Solar Refrigerator

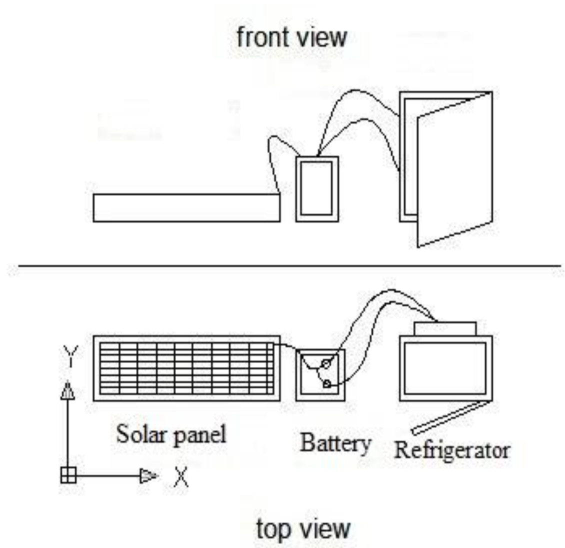


FIG 3 2D LAYOUT OF THERMOELECTRIC SOLAR REFRIGERATOR

5.3 Schematic diagram of Thermoelectric solar refrigerator

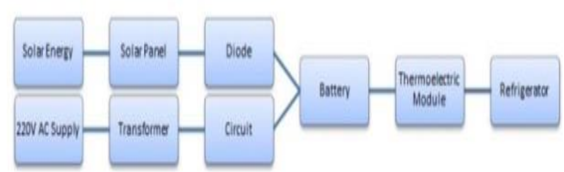


FIG 4 SCHEMATIC DIAGRAM OF THERMOELECTRIC SOLAR REFRIGERATOR

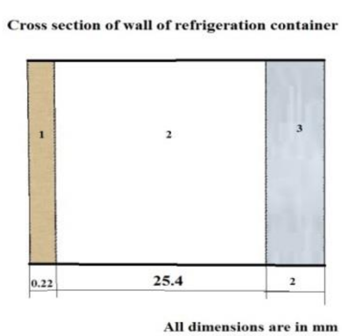
6. WORKING PRINCIPLE

In the battery (12V, 7.5Ah) circuit, the solar panels absorb the sunlight and convert into electricity. The output voltage of the solar panel is 12V (depending on the direction of sunlight). This electricity is utilized for charging the 12V battery which is connected after the solar panel. From the battery, current flows directly into A.C/battery conversion switch and then into the Peltier module. In the AC mains circuit, a two pin plug is inserted into socket mains and is connected to the SMPS circuit. We get 240V AC current from the mains, but the peltier assembly (peltier module and cooling fan) requires only 12V and should be DC current. Hence the SMPS circuit is used here. The conversion of AC current into DC current is done by the Diode and Capacitor. By using a step down transformer, the voltage is brought down to 12V DC current. After the conversion, it goes into the AC/Battery conversion switch and then into the Peltier assembly. Refrigerated container has inner dimensions of (20cm × 20cm × 30cm). It is made of aluminium sheet of thickness 2mm. Then the edges were welded to form a box. For insulation purposes, 25.4mm thick polystyrene foam (thermocol) is attached to the outer surface of the aluminium box. To keep the thermocol attached to the box, duct tape is wrapped around the thermocol, to ensure that it is packed tightly. The door is also made of thermocol sheet and is wrapped using duct tape. The peltier assembly (includes peltier module, heat sink and cooling fan) is attached to the back side of the refrigeration container using four screws. These screws also act as a junction between container and the module. Finally, the components of the prototype are fixed to the wooden base using glue. It ensures that the components do not move from their respective positions. Figure 5 shows final developed solar powered thermoelectric refrigerator.

7. EXPERIMENTAL SETUP

FIG 5 EXPERIMENTAL SETUP

8.THERMAL RESISTANCE OF REFRIGERATOR CONTAINER



(1) Insulation tape of Thickness t_1=0.22mm, Thermal conductivity k_{tape}=1.2$^{W}/_{mk}$ (2) Thermocol of Thickness t_2=25.4mm, Thermal conductivity $k_{thermocol}$=0.033$^{W}/_{mk}$ (3) Aluminium of Thickness t_3=3mm Thermal conductivity k_{Al}=205$^{W}/_{mk}$ (4) Air of Heat transfer coefficient h_{air}=15 $^{W}/_{m^2k}$

Thermal resistance

(R) $=\frac{1}{h_{air}}+\frac{t_1}{k_{tape}}+\frac{t_2}{k_{thermocol}}+\frac{t_3}{k_{tape}}+\frac{1}{h_{air}}$

(R) =770.0234$m^2\ k/$w

Mass of air

Volume of air V =L*B*T =0.3*0.2*0.2

V =0.012 m^3

Density of air ρ =1.225kg/ m^3

Mass of air m_{air} =V*ρ =0.0147kg

m_{air} =14.4x 10^{-3}kg

Heat removing capacity of Peltier module

Specifications of Tec1-12706 peltier module

I_{max} = 6A

V_{max} =15.4V

$Q_{c_{max}}$ =53.3W

ΔT_{max} =70℃

R =1.98Ω

T_h =27℃

T_c =15℃

Heat rejection capacity of peltier module

Q_c = $(\propto_m{*}T_c{*}I)-(\frac{1}{2}{*}I^2{*}R_m)-(K_m{*}(T_h-T_c))$

Where

$\propto_m = \frac{V_{max}}{I_{max}} = \frac{15.4}{300}$

$\propto_m = 0.05133 ^{V}/_{K}$

$R_m = \frac{T_h - \Delta T_{max}}{T_h} * \frac{V_{max}}{I_{max}}$

$R_m = 0.367\Omega$

$K_m = \frac{T_h - \Delta T_{max}}{2\Delta T_{max}} * \frac{V_{max} * I_{max}}{T_h}$

$K_m = 0.0193 ^{W}/_{K}$

$Q_c = (\propto_m * T_c * I) - (\frac{1}{2} * I^2 * R_m) - (K_m * (T_h - T_c))$

$Q_c = 94.25J$

Specifications of Fins

Length l = 0.02m, Face width b = 0.05m, Thickness t=0.002m, Base temperature T_0=80℃, Surrounding temperature T_a=30℃, Heat transfer coefficient h =$50 ^{W}/_{m^2k}$, Thermal conductivity k_{Al} =$205 ^{W}/_{mk}$

Amount of heat transferred through the fin

$Q_{fin} = \sqrt{PhkA_{fin}}(T_0 - T_a)\tanh(ml)$

Where

A_{fin} =b x y

A_{fin} =0.0001m^2

P =2(b+y)

P =0.104m

$m = \sqrt{\frac{hp}{kA_{fin}}} = \sqrt{\frac{5.2}{0.0205}}$ =15.92kg

tanh(ml) =0.30805

$Q_{fin} = \sqrt{0.1066} * 50 * 0.3080$

$Q_{fin} = 5.02 ^{KJ}/_{hr}$

Heat transfer For Number of Fins

$Q_{total} = n\,[kA_{cs}m\,(T_0 - T_a)\tanh(ml)]$

$Q_{total} = 30.17 ^{KJ}/_{hr}$

Efficiency of Fin

$\eta_{fin} = \frac{\tanh(ml)}{ml} = \frac{0.2923}{0.3184}$

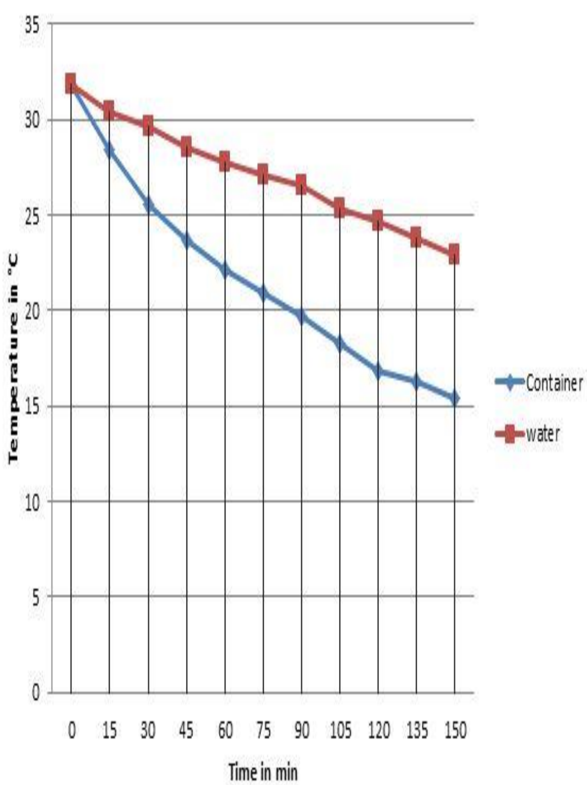
η_{fin} =88.2%

Effectiveness of Fin

$\varepsilon_{fin} = \sqrt{\frac{Pk}{hA_c}}$

ε_{fin} =65.29

9. GRAPH FOR TIME VS TEMPERATURE



10. ADVANTAGES

- It saves electrical power supply.
- It is the portable system.
- Energy efficient system.

- Eco-friendly system.
- It has given an option to the use of refrigerant by the TEC module.
- Ultimately it reduces the harmful effects which are occurred by the refrigerant.
- It is the clean source of energy.
- excess power produced by the refrigerator can be used for the other domestic purpose.
- solar refrigerator can be very useful in far off remote places where there is no continuous supply of electricity.

11 APPLICATIONS

- Outdoor cooling, carrying the portable refrigerator along for food preservation, drinks preservation, medicines etc.
- Cooling in cars
- Cooling of electronic equipment
- Cooling of an experimental set-up, in a laboratory
- In rural India, in summers when there is no electricity, solar powered thermoelectric cooler comes as a relief
- Can be carried along when travelling outdoors.

12 LIMITATIONS

- Refrigeration rate is quite slow.
- Time consuming system.
- Costly system.

13 CONCLUSION

A portable thermoelectric refrigeration system was fabricated and tested for the cooling purpose. The refrigerator was designed based on the principle of a thermoelectric module to create a hot side and cold side. The cold side of the thermoelectric module was utilized for refrigeration purposes whereas the heat from the hot side of the module was eliminated using heat sinks to absorb the heat and fans to reject it. In order to utilize renewable energy, solar energy was integrated to power the thermoelectric module in order to drive the refrigerator. Furthermore, the solar thermoelectric refrigerator avoids any unnecessary electrical hazards and provides an environmentally friendly product. In this regard, the solar thermoelectric refrigerator does not produce CFCs and HCFCs which is believed to cause depletion of the atmospheric ozone layer. In addition, there will be no vibration or noise because of the difference in the mechanics of the system. In addition the rejected heat from the solar thermoelectric refrigerator is negligible when compared to the rejected heat from conventional refrigerators. Hence, the solar thermoelectric refrigerator would be less harmful to the environment. The experimental results of developed prototype of TER system shows a 10$_o$C temperature reduction at 250ml water inside refrigeration space of developed TER has been experimentally found with respect to 31$_o$C ambient temperature in 120 minutes. The refrigeration cabinet itself has been experimentally shown to have a 16$_o$C reduction in temperature with respect to 31$_o$C ambient temperature in 120 minutes. Also it has been experimentally found that the developed TER system can continuously work for 3 hours when the battery is fully charged with solar panel. The energy efficiency of solar thermoelectric refrigerators, based on currently available materials and technology, was still lower than its compressor counterparts. Nevertheless, a marketable solar thermoelectric refrigerator would be made with an acceptable performance through some improvements. For example, further improvement of COP can be achieved with use of increased figure in merit peltier modules. The efficiency of the system may also be further improved by through improving module contact resistance, thermal interfaces and heat sinks. This can be achieved by installing more modules in order to cover a greater surface area of the system.

REFERENCES

[1] "Performance Evaluation of a Thermoelectric Refrigerator", byOnoroh Francis, Chukuneke Jeremiah Lekwuwa, Itoje Harrison John.

[2] "Solar Air-Conditioning: Design for a Compressor-LessSystem using Peltier Effect", by Ashok KumarYadav, ShatrughanSingh ,Gaurav Gupta.

[3] "Review of solar refrigeration and cooling systems, Energy and Buildings", by IoanSarbu, CalinSebarchievici.

[4] "Performance analysis of a thermoelectric air conditioning", by Edson Nogueir, José Rui Camargo.

[5] "Design and experimental investigationof portable solar thermoelectric refrigerator", by Sabah Abdul-wahab, A. Elkamel, Ali Al-Damkhi, Hilal S. Al Rubai'ey.

[6] "Thermoelectric Solar Refrigerator", by Sandip Kumar Singh, Arvind Kumar.

[7] "Photovoltaic Driven DualPurpose Thermoelectric Refrigerator for Rural India", by SurithNivas M, Vishnu Vardhan D, Raamkumar PH, Sai Prasad S , Ramya.K.

[8] "Review on Magnetic Refrigeration in cooling usingMagnetocalorific Effect ", by ShlokChoudhary, SuprabhatA.Mohod, ManojB.Dhawade

[9] "Techno-economic performance analysis of solar coolingsystems", by A. M. R. Al-Marafie, R. K. Suri, G. P. Maheshwari.

[10] "Review on application of thermoelectric peltier module in cooling and power generating technology", by Swapnil S. Khode, Pratik Kale,

[11] "Development and experimental study of solar powered thermoelectric system", by Manoj Kumar Rawat, Prasanta Kumar Sen, HimadriChattopadhyay, SubhasisNeogi

[12] "Design and experimental investigation of portable solar thermoelectric refrigerator", by . Sabah A. Abdul-Wahab, Ali Elkamel, Ali M. Al-Damkhi, Is'haq A. Al-Habsi, Hilal S. Al-Rubai'ey', Abdulaziz K. Al-Battashi, Ali R. Al-Tamimi, Khamis H. Al-Mamari, Muhammad U. Chutani

[13] “Photovoltaic Driven Dual Purpose Thermoelectric Refrigerator for Rural India”, by SurithNivas M, Vishnu Vardhan D, Raamkumar PH, Sai Prasad S, Ramya.K,.
[14] “Thermoelectric cooling and power generation”, by Francis J. DiSalvo.
[15] “Review on portable solar thermoelectric refrigerator cum air cooler”, by Manoj B. Dhawade, EktaMourya, AnuragYadav, David Samuel, Suprabhat A. Mohod, Vaibhav N Deshpande,
[16] “Thermoelectric Refrigeration by Using Solar Energy for Domestic Appliance”, by Umesh V. Sangale, Prof. PriyankaJhavar, Dr.G.R.Seloskar.S,
[17] http://home.iae.nl/users/pouweha/lcd/lcd.shtml
[18] http://www.doc.ic.ac.uk/~ih/doc/lcd/
[19] "Solar Refrigerator For Vaccines In Rural Areas”, by Dr. V.Karthikeyan, L.Kalaivani, L.Naveena, B.Nivetha .