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Solar Operated Thermoelectric Refrigeration System

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Abstract: The process of lowering the temperature of items below which it would have been normal by storing it in a system that is designed to cool or freeze its contents is defined as refrigeration. A traditional refrigerator utilizes compressor based cooling. This method fails to satisfy with full efficiency when it comes to lower capacities. Considering this into account a concept has been proposed to use thermoelectric refrigeration powered by solar energy.

Keywords: Food storage, Solar energy, Thermoelectric effect, Fins, Refrigeration.

1. Introduction

There is always increase in demand for refrigeration globally in the field of refrigeration, air-conditioning, food storage, vaccine transports, medicinal services. Requirements in industries and domestics utilities need food products, medicinal products to be stored or transported at low temperatures. The quality of the product stored is affected by the temperature fluctuations in the storage. Temperature drops due to the electrical power failure causes deterioration of low sensitive temperature products. The increasing demand for refrigeration in various fields led to production of more electricity and consequently released harmful gas like CO_2which is a contributing factor for global warming. Alternatives to this can be non-refrigerated systems which use insulation where it doesn't extract heat from the load and it only maintains the temperature. This alternate is not suited for a longer period. The concept of thermoelectricity can be classified into 2 parts. Thermoelectric Coolers (TEC) or refrigeration and Thermoelectric Generators (TEG).Thermoelectric refrigeration is a new alternative method. The thermoelectric modules are made of semiconductor materials electrically connected in series configuration and thermally in parallel to create cold and hot surfaces. Although they are less efficient than the vapour compression system in large scale, they are very light, low in cost, silent in operation, and are environmentally friendly. Thermoelectric Devices are solid state devices which directly convert electrical energy to thermal energy and vice versa.

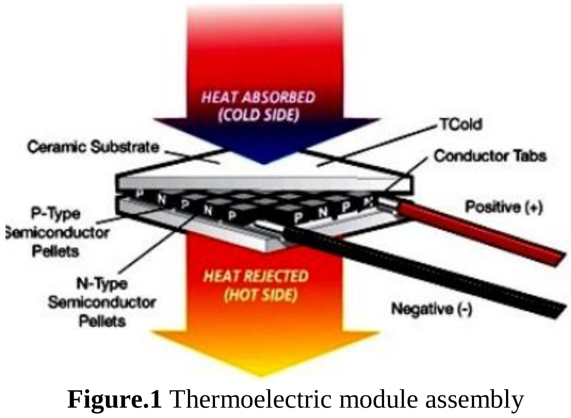

Figure.1 Thermoelectric module assembly

During recent times, a lot of effort has been made to improve the performance and also the power generated by a thermoelectric device, which is thermoelectric power generation. This is done by attaching heat sinks on either sides of the device. Optimizing heat sinks with fins or any other material change could improve the overall efficiency of it but on the other hand the device also has to be optimized. Thomas Seebeck discovered that a continuously flowing current is created when two wires of dissimilar materials are joined together at the ends and heated at one end. This phenomenon is known as the Seebeck Effect. The emf output was found to be: $\Delta E \alpha \Delta T$. Where ΔE and ΔT the emf output and the temperature difference of the junctions.

Later Jean Charles Athanase Peltier a French watchmaker and physicist found that if two dissimilar metals are joined together and an electrical current is supplied it will produce heating and cooling at the ends and that phenomenon is known as Peltier effect.

2. Literature Review

According to Jincan Chena et al.,[1], non-equilibrium thermodynamics ,cycle models of single-stage and two-stage semiconductor thermoelectric refrigeration are experimentally investigated. The coefficient of performance (COP), the rate of refrigeration, and the power input,are the three important parameters which governs the performance of thermoelectric refrigerator. It was concluded that performance of thermoelectric refrigerator depends on temperature ratio of heat sink to cooled space. A simple design was proposed by Beitner,[2] consisting of thermoelectric modules directly powered by an external DC source and an external thermal sink to dissipate heat to ambient by using natural convection cooling. Reed and Hatcher [3] proposed an effective way to increase the heat dissipating capability at the hot end of thermoelectric modules by using the cooling fan. In one of the papers X.C. Xuan et al., [4] Two stage thermoelectric refrigerator was investigated with two design configurations. Two configurations were pyramid style and cuboid style as shown in respective figures. In pyramid style configuration top side is being coldest as current is unidirectional. In cuboid style configuration current can be alternated causing top and bottom side to be switched between heating and cooling mode. To obtain optimization methods other multi stage designs can be used. Jun Luo et al., [5] using finite time Thermodynamics theory performance of a thermoelectric refrigeration system, with multielements was analysed. To improve and maximise the cooling load and coefficient of performance (COP) optimisation of the ratio of the heat transfer surface area of the high temperature side to the total heat transfer surface area of the heat exchangers was done.

3. Working Principle

The p-type and n-type bismuth telluride side of the typical thermoelectric module has ceramic substance of each of their sides as an electrical insulation. These two sides are thermally connected in parallel between the ceramics and are connected in series electrically. Convection, conduction and radiation are the three processes through which radiation occurs in a thermoelectric system. Coefficient of performance is a dimensionless parameter which is used to evaluate and measure the performance of a refrigeration system. The ratio between the amount of cooling produced by the amount of electric energy consumed is defined as the coefficient of performance of a thermoelectric system.

$$COP = \frac{T_{Hot}}{T_{Hot} - T_{Cold}}$$

Where, T_{hot} and T_{cold} are the temperatures of the hot and cold junctions of the thermoelectric refrigerator. The Coefficient of Performance depends on values such as heat load, power applied, difference in temperature required etc. Its value usually lies between 0.3 and 0.7 for single stage devices. However, since the COP is a ratio of output to loss it is possible for it to exceed 1 unlike thermal efficiency which is a ratio of output to input. Higher values of COP are obtained when cooling is being done against a positive temperature gradient, ie the item being cooled is at a temperature above that of the surroundings.

4. Design and layout

Initially the heat load calculations are done for a volume of 27 cubic metres. There are various factors required to be considered while calculating the heat load for an area. The air change load includes both sensible and latent heat calculations. The product and respirational heat load is due to the product which is kept inside the refrigerating space.

Air change load=$\dot{m}$×Cp×ΔT + V× ρ_{air}× Latent heat of vapourisation× change in humidity
Air change load=0.132kW
Product load= m×Cp×ΔT =(2721.55×3.433×(40-5)) / (24×3600)= 3.785 kW
Respirational Heat Q= Mass of Product × respiration heat of product = 0.0528 kW
Total load=0.0528+3.785+0.132=3.9698kW.

The rectangular double walled cabin is made using Mild steel sheets of 1mm thickness. The cabin is coated with black paint so as to prevent most of the heat transfer. Insulation for the cabin is given with 5cm thickness of expanded polystyrofoam. The thermocouple module TEC-12706 is chosen. This thermocouple should provide a cooling load higher than that of the calculated theoretical cooling load. 6 thermoelectric modules are chosen for working with a maximum current of 6 amps and voltage of 12V with the help of solar panel. The minimum power rating for the 6 TEC modules was more than the calculated theoretical cooling load. More number of TEC reduces the amount of cooling time required for the space. Heat sink is designed with aluminium fins with 1 mm thickness and 100mm breadth with a spacing of 3mm.

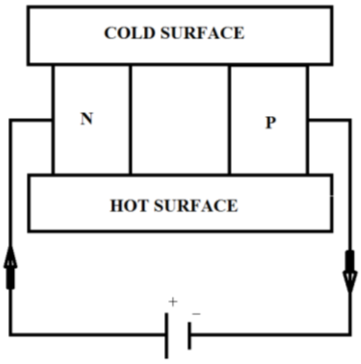

Figure 2: Schematic diagram of working of thermoelectric refrigeration

TEC Module	TEC12706
Operation voltage	12
Voltage max	6
Current max	15
Couple	127

Table 1: Specifications of TEC

5. Result

With the solar power for the thermocouple module, the refrigeration effect is produced in the cold junction to a temperature of 12°C. We have successfully designed a system which satisfies our proposed ideas. This idea is advantageous for low power input for the refrigeration and for a lesser area of refrigeration. Initial heat load calculations helped us design the thermocouple module and the retention time was for 45 minutes. To conclude it can be said that thermoelectric refrigeration is very effective for cooling smaller spaces when compared to the traditional refrigeration systems.

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