Design, Development and Analysis of Thermoelectric Refrigerator for Increased Efficiency

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Abstract- *R. E. Smalley, 1996 recipient of the Nobel Prize in chemistry, stated that energy is the number one problem facing humanity for the next 50 years. If this projection comes to fruition, as it most probably will, proper implementation of technologies that generate and convert energy will be of immense importance. A large market is currently in place for which thermoelectric (TE) technology can provide diverse energy solutions. In recent years, with the increase awareness towards environmental degradation due to the production, use and disposal of Chloro-Fluoro Carbons (CFCs) and Hydro Chlorofluorocarbons (HCFCs) as heat carrier fluids in conventional refrigeration and air conditioning systems has become a subject of great concern and resulted in extensive research into development of novel refrigeration and space conditioning technologies. Thermoelectric cooling provides a promising alternative R&AC technology due to their distinct advantages. A brief introduction of thermoelectricity, principal of thermoelectric cooling and thermoelectric materials has been presented in this paper. The cost-effectiveness of this technology has been also discussed in this paper.*

The calculated COP of developed experimental thermoelectric refrigeration cabinet was 0.12.The temperature difference between the heat source & the heat sink was found to be 20.8°C when the system was run for 6000 seconds. The COP of the model can be increased by introducing the Cascading System & by using multiple fans of better efficiency. Also, the bulk production would enhance the cost effectiveness of the system.

Keywords:- Thermoelectric, Refrigeration, Seebeck, Peltier

I. INTRODUCTION

Charles Athanase reversed the flow of electrons in Seebeck's circuit to create refrigeration. This effect is known as the Peltier Effect. This idea forms the basis for the Thermo-electric refrigerator.

The Peltier effect is a temperature difference created by applying a voltage between two electrodes connected to a sample of semiconductor material. The Peltier effect is one of three types of thermoelectric effect; the other two are the Seebeck effect and the Thomson effect. In a Peltier-effect device, the electrodes are typically made of a metal with excellent electrical conductivity. The semiconductor material between the electrodes creates two junctions between dissimilar materials, which, in turn, creates a pair of thermocouple voltage is applied to the electrodes to force electrical current through the semiconductor, thermal energy flows in the direction of the charge carriers.

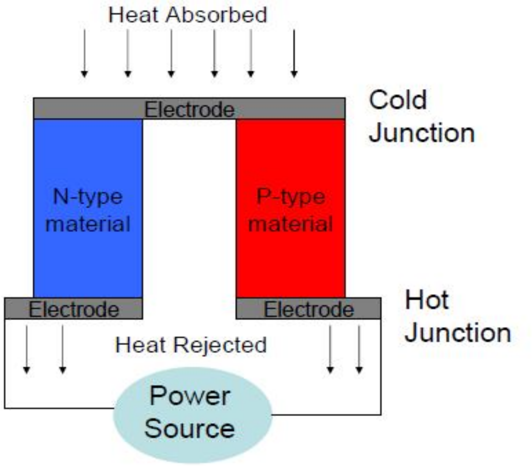

Fig.1 Peltier Effect

When a temperature gradient is introduced along the length of a metal wire, electrons start to diffuse from one end to the other end of the wire (Chambers, 1977). The direction of electron diffusion depends on the electrical properties of the metal wire. By convention, if electrons diffuse from the hot end towards the cool end of the wire, a negative thermoelectric emf is generated in the wire with respect to the hot end. Similarly, if electrons diffuse from the cool end towards the hot end of the wire, a positive thermoelectric emf is generated in the wire with respect to the hot end. This phenomenon in metals, known as the Seebeck effect, was first observed by physicist Thomas Johann Seebeck (1770-1831). Seebeck observed that when two dissimilar metal wires are formed into a closed loop and its two junctions are held at different temperatures, it has the ability to deflect a galvanometer needle. The phenomenon was later attributed to electrical current through the wires. Metals have different thermoelectric sensitivities, or Seebeck coefficients. For example, iron has a Seebeck coefficient of 19 µV/°C at 0°C, which means that for every 1°C difference in temperature, a positive thermoelectric emf (or Seebeck voltage) of 19 µV is induced in iron at temperatures around 0°C. As mentioned in the previous paragraph, a negative thermoelectric emf can also be induced in a metal, so Seebeck coefficients can also have negative values. For example, constantan (a copper-nickel alloy) has a Seebeck coefficient of -35 µV/°C at 0°C. It should be noted that the relationship between Seebeck voltage and temperature is linear only for small changes in temperature. For larger temperature ranges, the relationship becomes non-linear. It is therefore important to state the temperature at which the Seebeck coefficient is being specified. A thermocouple is made from two dissimilar metals that are co-joined at one end (Figure 1) and can be used as a temperature sensor. As shown in Figure 1, a thermocouple consisting of metal A with Seebeck coefficient αA and metal B with Seebeck coefficient αB produces a thermoelectric emf (E) which is a function of the temperature of its tip (T1), the temperature of the measuring point (T2), and the thermocouple's Seebeck coefficient (α = αA - αB). The relationship is mathematically expressed in Equation 1. ( ) E = α T1 − T2 (1) The operation of a thermocouple is based on the different Seebeck coefficients of the dissimilar metals. If the two metals of the thermocouple were alike, or had the same Seebeck coefficient, the net emf produced at its measuring point would be zero. To measure the Seebeck voltage generated by a thermocouple, one can either use commercially available thermocouple readers or establish one's own thermocouple circuit. The reader may find it useful to review existing literature and become familiar with the different types of thermocouple circuits (Omega, n.d.). Since Science Education Review, 9(3), 2010 104 thermocouples are relative temperature sensors, a thermocouple circuit requires a known reference temperature, such as an ice bath, for proper operation.

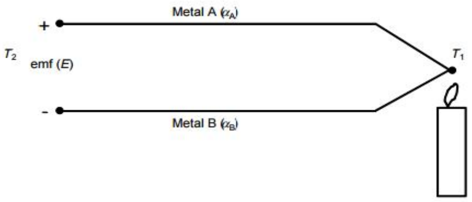

Fig.2 Seebeck Effect

The figure of merit represents the quality of performance of a thermoelectric material, sometimes it is multiplied by temperature. It is defined as:

$$Z = \frac{\alpha}{\rho k}$$

Where ρ is the electrical resistivity, k is the thermal conductivity, and α is the Seebeck Coefficient.

Note: low electrical resistivity and thermal conductivity are required for high figure of merit. These values are temperature dependent. Therefore, the figure of merit is temperature dependent. P and N type material have different figures of merit and are averaged to determine the material's overall quality.

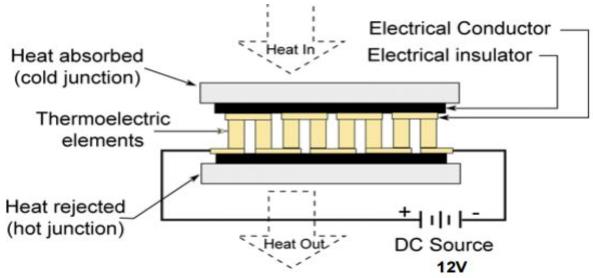

Fig. 3: Thermoelectric Refrigeration System

II. DESIGN AND MANUFACTURING

2.1 Design requirements for the thermoelectric cooler

- Utilize Peltier effect to refrigerate and maintain a specified temperature
- Perform temperature control in the range 20-25 degrees Celsius.
- Maintain temperature accuracy within ± 0.2 C°
- Interior cooled volume of (21cm x 21cm x 21cm)
- Low Noise and Vibration Levels
- Weight Less than 30 kg.

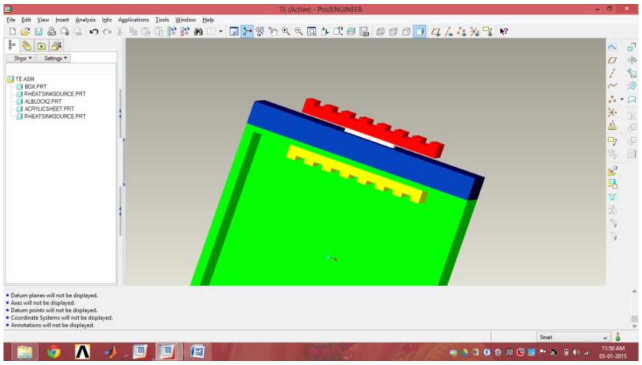

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Fig. 4: Design of components in PRO-E

2.2 Cooling Cabin

Material used: Galvanized Iron sheet (GI)
Galvanized iron & steel: Characteristics, Uses & Problems:

Galvanizing is a process of coating iron with zinc in order to provide greater protection against corrosion for the iron base. The process of galvanizing sheet iron was developed simultaneously in France and England in 1837. Both of these methods employed a "hot dipping" process to coat sheet iron with zinc. Like tinplate, early galvanized metals were hand dipped. Today almost all galvanized iron and steel is electroplated.

2.3 Specification of GI Sheet (Galvanized Iron Sheet):

1. Grade: SGCC
2. Standard: JIS G3302 1998
3. Zinc coating weight: 60g/m2
4. Tensile strength: 275.5 N/mm2
5. Edge: cut edge

Cabin size:
i) 12x12x12 cubic inch
ii) 8 x 8 x 10 cubic inch (Refrigeration area).

2.4 Insulation:

- The cabin is insulated using thermocol2 inch thick jacket (except the top surface) Sandwiched between the GI sheets.
- Plywood (12.5x12.5x0.6 cubic inch) is provided to insulate the roof of the cabin.
- Rubber insulation is provided to seal the door and plywood at the roof.
- Door dimensions: 9.5 x 9.5 x 1.5 cubic inch.

2.5 Heat Source & Heat Sink:

- Metals are used to sandwich the semiconductor. Because the TE performance is also dependent on these materials, an optimal material must be chosen, usually cast Aluminium. Size: 7.5 X 7.5 square inch

2.6 Aluminium Block Conductor:

- In order to reject the heat efficiently and maintain a significant temperature difference between heat sink & source we need a conductor block to be mounted just over the heat sink.

Dimensions: 4X4X4 cubic cm

Material: Aluminium

We have found out that in the absence of cold plate, the convective heat transfer is very low even if we installed a fan, Only a temperature difference of 1 degree Celsius is obtained at middle portion of chamber and a difference of about 10 degree celsius is obtained near the surface of the module, regardless of the time. Even we installed fans with a thought to increase the temperature difference but it also not helped for the same. In order to get an appreciable temperature difference in the middle portion also, the heat transfer from the surface of module should be done through conduction first, then through convection in the air. To overcome the earlier mentioned problem instead of direct convection through the surface we have to first install a cold plate (heat sink) on the surface of module for getting conduction and then convection in the air.

2.7 Thermoelectric Module:

Specifications: 1 No., 12V, 1.5A Consists of 24 arrays
Size: 4X4X0.05 cubic cm
Material: Bi_2Te_3

2.8 Fan & Fan Box:

Size: 12X12X5 cubic inch
Material: Galvanized sheet
Fan specification: 12V DC, 7.6 Watt Power
Fan diameter: 4 inches

2.9 AC to DC Converter:

Specifications: 12 Volts ,5.2 Ampere

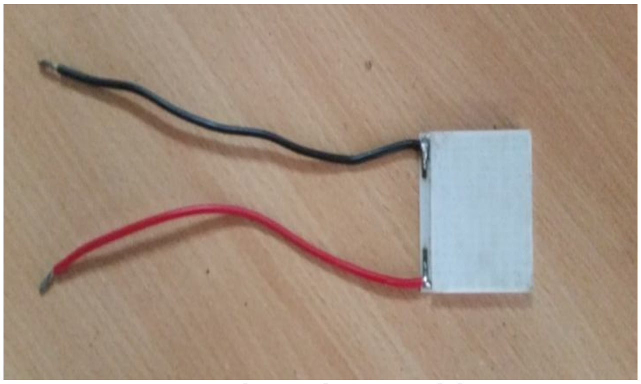
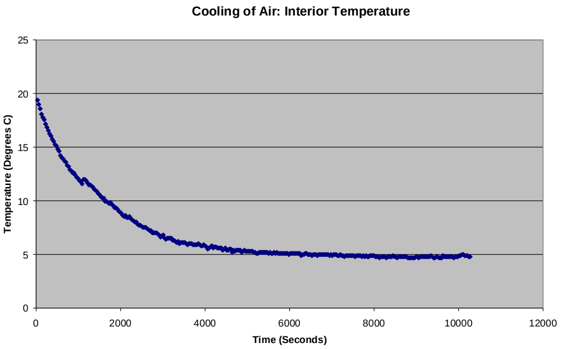


Fig.5: Thermoelectric module

Fig.6: Final Assembly

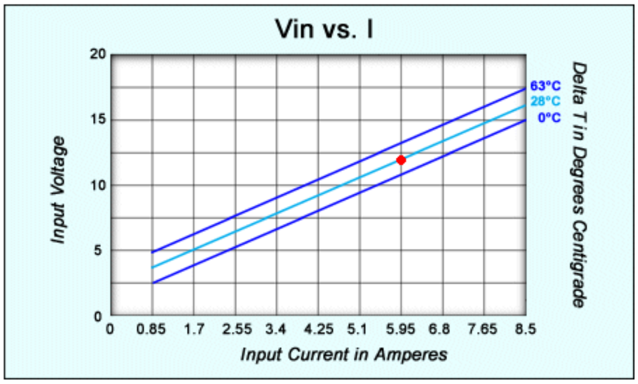
III. ANALYSIS OF THERMOELECTRIC REFRIGERATOR

m1 = V1 x ρ1 = (0.00926 x 1.2) = 0.0111132 Kg
m2 = V2 x ρ2 = (0.000907 x 2700) = 2.4489 Kg
Power delivered = V x I = (12 x 5.2) = 62.4 W
Energy i/p=Q1= Pxt = (62.4 x 6000) = 374400 J
Heat removed = Q2 = [(m1 x Cp1 x ΔT) + (m2 x Cp2 x ΔT)] = [(0.0111132 x 1000 x 20.8) + (2.4489 x 900 x 20.8)] = 46074.56256 J
COP = Q2 / Q1 = 46074.56256 / 374400 = 0.12

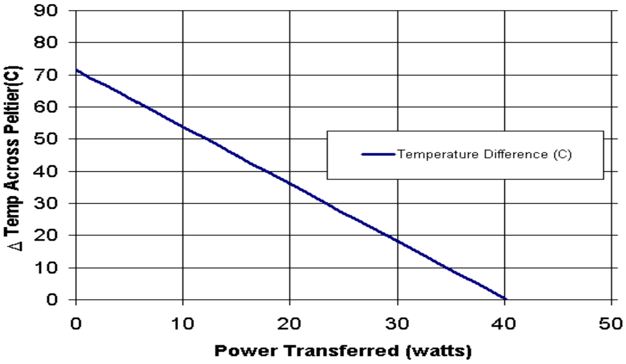


Graph.1: Temperature vs time

The Peltier module is running at 12V and 5.2 amps of current. The following Vin vs. I graph shows a normal operating range of the TEM.

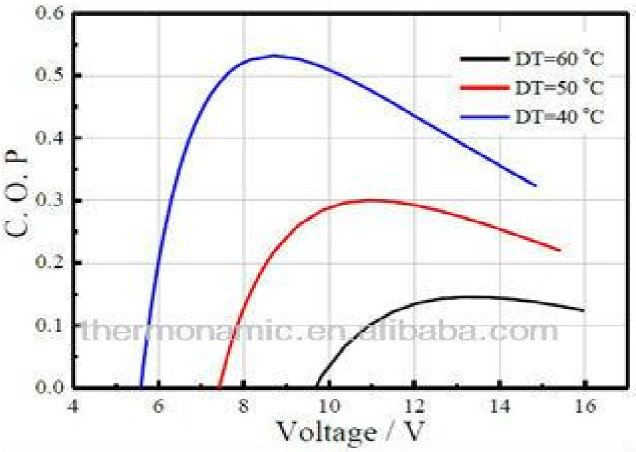


Graph.2: V_{in} vs I



Graph.3: ΔT across Peltier vs Power Transferred

The above graph shows the power to be transferred to get certain drop in temperature across the module.



Graph.4: COP vs Voltage

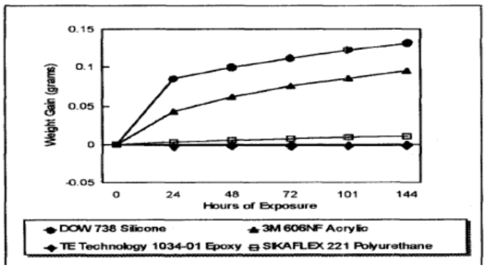
IV. ADVANTAGES OF THERMOELECTRIC COOLING

- No Moving Parts
- Small Size and Weight
- Ability to Cool below Ambient
- Ability to Heat and Cool with the same module
- Precise Temperature Control
- High Reliability
- Electrically "Quiet" Operation
- Operation in any Orientation
- Convenient Power Supply
- Spot Cooling
- Ability to Generate Electrical Power
- Environmentally Friendly
- Thermoelectric devices have been successfully subjected to shock and vibration requirements for aircraft, ordinance, space vehicles, shipboard use and most other such systems.
- More precise in the control of temperatures
- A thermoelectric refrigerator with an inner volume of 55 X 103 m^3 has been designed and built. It needs a continuous electric current (maximum 12 V) what makes it suitable for automobile industry applications

V. DISADVANTAGES

- The main disadvantage is linked to the electricity consumption. The electric energy consumed by a thermoelectric refrigerator is higher in comparison with current compression refrigerators (approximately the same as a vapour compression one with an inner volume of 100 X 103 m3).

- Moisture Effect: Moisture must not penetrate into the thermoelectric module area.
- Shock and Vibration:. While a thermoelectric device is quite strong in both tension and compression, it tends to be relatively weak in shear. When in a sever shock or vibration environment, care should be taken in the design of the assembly to insure "compressive loading" of thermoelectric devices.
- Condensation: A common problem with TE cooling is that condensation may occur causing corrosion and eroding the TE's inherent reliability. Condensation occurs when the dew point is reached.



Graph.5: Weight gain vs Hours of exposure

VI. CONCLUSION

There are several different types of cooling devices available to remove the heat from industrial enclosures, but as the technology advances, thermoelectric cooling is emerging as a truly viable method that can be advantageous in the handling of certain small-to-medium applications. As the efficiency and effectiveness of thermoelectric cooling steadily increases, the benefits that it provides including self-contained, solid-state construction that eliminates the need for refrigerants or connections to chilled water supplies, superior flexibility and reduced maintenance costs through higher reliability will increase as well.

The calculated COP of developed experimental thermoelectric refrigeration cabinet was 0.12.The temperature difference between the heat source & the heat sink was found to be 20.8°C when the system was run for 6000 seconds. The COP of the model can be increased by introducing the Cascading System & by using multiple fans of better efficiency. Also, the bulk production would enhance the cost effectiveness of the system.

The available literature shows that thermoelectric cooling systems are generally only around 5–15% as efficient compared to 40–60% achieved by conventional compression cooling system. This is basically limited by figure of merit of thermoelectric material and efficiency of heat exchange system. Continuous efforts are given by researchers for development of higher figure of merit thermoelectric materials may provide a potential commercial use of thermoelectric refrigeration and space conditioning system. Also compatibility of thermoelectric cooling systems with solar energy made them more useful and appropriate for environment protection.

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