A Review Paper On Thermoelectric Refrigerator

Ankoo Ghosh[1], Dipali More[2], Muniza Fondoo[3], Urmila Bodke[4]
[1, 2, 3, 4]Dept of Electronics & Telecommunication
[1, 2, 3, 4] Finolex Academy of Management & Technology, Ratnagiri,
Maharashtra, India

Abstract- *This paper discusses about various parameters required for manufacturing of thermoelectric refrigerator. Stating with the environmental effects of conventional refrigerants used in day to day life along with their high power consumption, this paper reviews an alternative ecofriendly equipment-Thermocouple. Analyzing the property of conductivity in various metals along with in detail study of various thermocouple devices, heat sinks, power supplies, insulators, sensors & controller and selecting the most efficient one is the soul motto of this literature review. Study of various thermoelectric properties like Seebeck effect and Peltier effect has also been included in this review paper.*

Keywords- Thermocouple, heat sink, insulator, Seebeck effect, Peltier effect.

I. INTRODUCTION

A conventional cooling system contains three fundamental parts - the evaporator, compressor and condenser. The evaporator or cold section is the part where the pressurized refrigerant is allowed to expand, boil and evaporate. During this change of state from liquid to gas, energy (heat) is absorbed. The compressor acts as the refrigerant pump and recompresses the gas to a liquid. The condenser expels the heat absorbed in the evaporator plus the heat produced during compression, into the environment or ambient. A thermoelectric has analogous parts. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element (p-type).

The first important discovery relating to thermoelectricity occurred in 1823 when a German scientist, Thomas Seebeck, found that an electric current would flow continuously in a closed circuit made up of two dissimilar metals provided that the junctions of the metals were maintained at two different temperatures. Some 12 years later French watchmaker, Jean Charles Athanase Peltier, discovered thermoelectric cooling effect, also known as Peltier cooling effect, Peltier discovered that the passage of a current through a junction formed by two dissimilar conductors caused a temperature change. The true nature of Peltier effect was made clear by Emil Lenz in 1838; Lenz demonstrated that water could be frozen when placed on a bismuth-antimony junction by passage of an electric current through the junction.

II. LITERATURE REVIEW

The Seebeck Effect- When there is a temperature difference in a thermoelectric material, an electric current is created due to movement of holes and electrons in the semiconductor materials. The effect that causes this behavior is called the Seebeck Effect [1].

The Peltier Effect- Heat must be continuously added to or rejected from the body in order to keep the junction temperatures constant when there is a current passing through it. The total amount of heat added or rejected is proportional to the amount of current supplied this phenomenon is called the Peltier Effect [1].

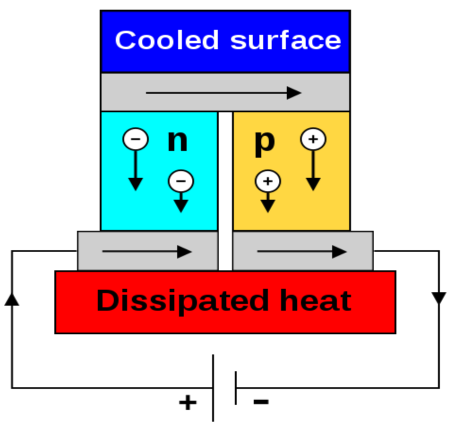

Fig. 1- Peltier Effect

Fig.1 Illustrates the Peltier Effect in a simple block diagram format.

Generally cooling system used in refrigerator utilizes working fluid and a compressor for the heat transfer. Thermal energy is absorbed and released as the working fluid undergoes expansion and compression and it changes phases from liquid to vapor and then back respectively. Peltier coolers offer temperature control. However conventional refrigerators have more efficiency than peltier coolers but even though these peltier coolers are used where small size is needed and cooling demands are not too great, e.g. for cooling electronic components[2].

Most of the research done so far deals with an objective of low energy consumption and refrigeration effect enhancement because refrigerator and air conditioners are the most energy consuming home appliances. Thermoelectric Refrigeration provides cooling effect by using thermoelectric effect, whereas conventional cooling system such as those used in refrigerators utilize a compressor and working fluid to transfer heat and here thermal energy is absorbed and released as the working fluid undergoes expansion and compression and changes phases from liquid to vapor and back, respectively[3].

Thermoelectric cooling system has advantages such as lightweight, reliable, noiseless and portable. It also uses electrons rather than refrigerant as a heat carrier and also it is feasible for outdoor applications in cooperation with solar PV cells. As thermoelectric coolers will either heat or cool depending on the polarity of applied DC power, this feature eliminates the necessity of providing separate heating and cooling functions .Thermoelectric refrigeration emerges as ALTERNATIVE GREEN REFRIGERATION technology due to their distinct advantages mentioned above making them complete environment friendly[4].

As said by M. Zebarjadi, K. Esfarjani, M. S. Dresselhaus, Z. F. Ren and G. Chen- in Large area devices provide sufficient power to illuminate light-emitting-diodes, this Organic thermoelectric modules screen-printed on paper by using conducting polymer poly (ethylenedioxythiophene):poly(styrenesulfonate) and silver paste is been studied. Without any encapsulation the stability of this proof-of-concept module was tested at 100degree Celsius for over 100h. Here one thing is cleared that decrease in performance of device was not caused by the deterioration of the materials but by degradation of the interface between the conducting polymers and silver paste. With this result organic thermoelectric modules could be used to harvest heat energy at low temperature and the interface stability must be improved [5].

Thermoelectricity is the direct conversion of temperature gradient to electrical voltage, and vice versa. This paper on ‘Thermo-electric devices’ seeks to give an overview of the thermoelectric phenomenon, the bulk semiconductor thermoelectric devices, and the new ways to increase performance of thermoelectric devices by going to low dimensional materials and new material structures. For more heat flow more thermoelectric elements are required .different approaches were implemented using single type arrangements. A configuration of multiple single type thermo-elements connected in parallel thermally and in series electrically but this configuration requires low voltage with high current, which was impractical commercially. Another configuration was a set of single type thermo-elements connected parallel thermally and in series electrically but this would allow for larger heat transfer, but interconnects shorting the conductor surface limited the process of heat transfer. The solution for this problem is using both n type and p type thermo-elements to form a couple and this is the peltier thermocouple [6].

Three different materials were explored for the construction of the outer casing and frame of the device. These were aluminum, stainless steel and Hips. High impact polystyrene is desirable as it has a low thermal conductivity. It makes the device very light and portable while maintaining rigidity. It is readily available and reasonably priced. It is easy to work with it as it is easy to cut and drill Hips sheets. The outer casing and container would be made by first making a mold and applying a cloth coated with resin [7].

Thermal properties represent the response of a material to the application of heat. As a solid absorbs energy in the form of heat, its temperature rises and its dimensions increase. Many applications of metals, ceramics, polymers, and composites are based upon their unique thermal properties. Thermal conductivity is the property that characterizes the ability of a material to transfer heat, and it is defined as the rate of heat transfer per unit area. From the studies done in the paper it is clear that aluminum is 99.9999% pure and well annealed which is same as that of Gold. It’s accuracy near room temperature is 2-3% and that at other temperatures is 3-5%. These values are very close to Gold. The Average of the absolute relative errors (AARE) of aluminum is 0.7753% which is higher than Gold (AARE for Gold is 0.6415%).Tin is 99.9999% pure and well annealed. It’s accuracy near room temperature is up to 3% and that at other temperatures is 3-15%. The Average of the absolute relative errors (AARE) of tin is 0.6689% [8].

With reference to the material studied from the article aluminum is the lightest metal, although not very strong as stainless steel, it is one third of its weight. Tensile strength of aluminum increases with decrease in temperature, while maintaining toughness making it suitable for cold environment. Steel becomes brittle at low temperature. Aluminum has excellent resistance to corrosion. The thermal conductivity of aluminum is better than steel. It is good for both heating and cooling applications. Since aluminum is non-toxic, it is suitable for edible products. Aluminum has an electrical conductivity high enough for use as an electrical conductor. Aluminum is an excellent reflector of radiant energy. It makes aluminum ideal as an insulator to protect against the sun’s rays in summer and heat loss in winter [9].

A heat sink is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature at optimal levels.

Electronic components invariably generate unwanted heat during operation. As electronic systems have become more powerful and at the same time more compact, problem of efficient and reliable heat removal, which is needed for safe operation of the component, has become difficult. Electronic components and assemblies tend to be of a small scale and they are typically cooled by air flowing at moderate velocities. The combination of small dimensions, the use of air as the cooling fluid and low velocities normally results in laminar convection and hence correspondingly low values for heat transfer coefficients.

In general, when gas cooling needs to be enhanced, it is achieved by the use of cooling fins, which increase the surface area available for heat transfer. Extended heat transfer surfaces are often used with electronic systems with fins providing a heat sink for the thermal loading. Heat generated by the electronic component is conducted to a base plate of length L, to which cooling fins of height H and width t are attached. Both sides of each fin participate in the cooling process, with convection taking place in the channels of width b formed by adjacent fins. Although various flow configurations and fin geometries are possible for the cooling process, rectangular fins are considered the most till date. Heat transfer coefficient is a quantitative characteristic of convective heat transfer between a fluid medium (a fluid) and the surface (wall) flowed over by the fluid. The heat transfer coefficient and fin efficiency will vary along the flow path because of entry effects for the thermal and momentum boundary layers in the inlet region; in the entrance region heat transfer coefficients derived for fully-developed flow are not applicable. In addition the flow will be ill-defined at the entry because of disturbances caused by the bluff nature of the leading edges of the fins. Finally it was found that the mean velocity in the flow passages between fins was 87.7% higher because of a reduced flow area through the heat sinks [10].

Insulation Type and Material-

The type indicates composition (i.e. glass, plastic) and internal structure (i.e. cellular, fibrous). The form implies overall shape or application (i.e. board, blanket, pipe covering).

1) Fibrous Insulation- They are composed of small diameter fibers which finely divide the air space. The fibers may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together. Silica, rock wool, slag wool and alumina silica fibers are used. The most widely used insulations of this type are glass fiber and mineral wool. Glass fiber and mineral wool products usually have their fibers bonded together with organic binders that supply the limited structural integrity of the products.
2) Cellular Insulation- Composed of small individual cells separated from each other. The cellular material may be glass or foamed plastic such as polystyrene (closed cell), and elastomeric.
3) Granular Insulation- Composed of small nodules which may contain voids or hollow spaces. It is not considered a true cellular material since gas can be transferred between the individual spaces. This type may be produced as a loose or pourable material, or combined with a binder and fibers or undergo a chemical reaction to make a rigid insulation. Examples of these insulations are calcium silicate, expanded vermiculite, perlite, cellulose, diatomaceous earth and expanded polystyrene [11].

Thermal conductivity coefficients of **granular coniferous greenery** insulation materials and the factors influencing this indicator were studied by implementing an experimental plan. The experiment showed that the thermal conductivity of freely poured heat insulation materials depends on the size of granules and whether or not the raw material is washed and re-dried (therefore reducing its density). The thermal conductivity coefficient of the material made from fine (< 8 mm) washed spruce greenery granules is equivalent to existing and already widely used natural heat insulation materials. If solutions are found to prevent the disintegration of the granules and to reduce their combustibility while maintaining environmental safety throughout the life cycle in future studies, the physical properties of the material would be more advantageous in comparison to the heat insulation materials already on the market [12].

There are two basic types of temperature sensors- Contact sensors and non-contact sensors.

Contact sensors include- Thermocouples, Resistance Temperature Detectors (RTDs), Thermistors, IC Temperature Sensors (LM35), Bimetallic.

Non-contact sensors include- Optical Pyrometer.

1) Thermistor- It is another type of temperature sensor, whose name is a combination of the words THERM-ally sensitive res-ISTOR. A thermistor is a special type of resistor which changes its physical resistance when exposed to changes in temperature. It has Negative Temperature Coefficient of resistance.
2) Resistance Temperature Detectors (RTDs) are temperature sensors that contain a resistor that changes resistance value as its temperature changes. They have been used for many years to measure temperature in laboratory and industrial processes. RTDs are used to measure temperatures from -196° to 482° C (-320° to 900° F).
3) A pyrometer is used to measure the temperature of an object from a distance, without making contact. The method used for making these non-contacting temperature measurements is known as radiation pyrometer. Non-contact temperature sensors use the concept of infrared radiant energy to measure the temperature of objects from a distance. After determining the wavelength of the energy being emitted by an object, the sensor can use integrated equations that take into account the body's material and surface qualities to determine its temperature [13].

DS18B20 temperature sensor is applied to the dynamic capacity increase of high voltage transmission lines to measure the conductor temperature and ambient temperature. The paper is focused on the experiment of DS18B20 both in the laboratory and outside. From the result of the lab temperature measurement data analysis, using 4 DS18B20's is the most suitable plan, considering both accuracy and economical efficiency. In the experiment outside, four groups of conductor (uncharged) temperature and four groups of ambient temperature. The data proved that DS18B20 has good stability, and small measurement error. It is suitable for measuring the temperature of conductor and ambient in dynamic capacity increase, and helpful to improve the accuracy of the calculation of capacity increasing.

DS18B20 temperature sensor: Measuring range -55℃ to 125℃, accuracy±0.5℃ [14].

As described by Onoroh Francis and group, a new dimension has been added to the cooling challenge by reduction of temperatures using thermoelectric module. With the continued demand for improved cooling technology to enhance performance, reliability and reduction in operating cost, a thermoelectric cooling may be considered a potential candidate. The thermoelectric refrigerator designed by them maintains the temperature of enclosure at 4℃ with very less power requirement [15].

III. METHODOLOGY

Thorough study of the whole Literature Review leaves us on a platform to build a very own Thermoelectric Refrigerator. The best thermocouple module will be semiconductor based 'Peltier Thermocouple' for its excellent heat transfer characteristics and low power consumption (40W-60W). The metal to be selected for the container happens to be Aluminum (99% purity) for its good heat conducting behavior. Also, Aluminum Sheets are easily available in hardware stores and very cheap comparing to Tin and Gold. Rectangular Fin Heat Sinks will be used on the hot region of thermocouple module for dissipating maximum amount of heat into the environment from the refrigerator chamber. A 12V 6A DC power supply providing a total Power of 72W will be sufficient to power up the whole refrigerator. For insulation, Fibrous Insulation of Glass Fiber or Mineral Wool will be the most appropriate one. Glass Fiber has a tendency of bonding together with organic binders that supplies the limited structural integrity of the product. After analyzing various temperature sensors, the DS18B20 temperature sensor will be the best match for our Model due to its wide measuring range from -55℃ to 125℃ with accuracy of ±0.5℃. Arduino UNO, being an open source 8-bit microcontroller board with 14 Digital pins and 6 Analog pins suits right for the Model. All the operations like setting temperature value of the refrigerator, turning ON and OFF the power supply, displaying the temperature inside the refrigerator, can be easily programmed on IDE platform of the Arduino.

IV. CONCLUSION

Reviewing all the concerned Research Papers and Articles it can be thus concluded that by selecting the appropriate modules, sensor, controller and components one can precede to actual fabricate an eco-friendly less power consuming Thermo electric Refrigerator.

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