Fabrication and Performance Study of Thermoelectric Refrigerator

Mr. Raju Goodelly[1], Dr. SCV Ramana Murty Naidu[2], Mr. D. Venkat[3], Mr. D.Jemin Chakravarthy[4], Mr. K. Kalyan Reddy[5], Mr. B. Sathish[6]

[1]Associate Professor, [2]Professor, [3-6]Students
Department of Mechanical Engineering, Kallam Haranadhareddy Institute of Technology, Guntur, A.P., India

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Abstract: *Refrigerator and air conditioners are the most energy consuming home appliances and for this reason many researchers had performed work to enhance performance of the refrigeration systems. Most of the research work done so far deals with an objective of low energy consumption and refrigeration effect enhancement. Thermoelectric refrigeration is one of the techniques used for producing refrigeration effect. Thermoelectric devices are developed based on Peltier and Seebeck effect which has experienced a major advances and developments in recent years. The coefficient of performance of the thermo electric refrigeration is less when it is used alone; hence thermoelectric refrigeration is often used with other methods of refrigeration. Some of the research and development work carried out by different researchers on TER system.*

In the present work, the thermoelectric refrigerator was fabricated using 4 thermoelectric modules and applied electric power of 50 W. The thermoelectric refrigerator is provided with the fans on both cold and hot ends to insist the forced convection. The temperature of cold water placed inside the refrigerator was measured on time basis for every 10 minutes interval. The temperature of water inside the refrigerator was decreasing continuously from 30^0C to 18.5^0 in 1 hour. In this work it is analyzed that the maximum COP of TER was 0.558 and maximum refrigeration effect was 27.90W

Keywords: Refrigerator, Peltier Effect, Seebeck Effect, TER System, Thermoelectric Module, Cold and Hot Ends, Temperature, Refrigeration Effect, C.O.P. etc.

1. INTRODUCTION

Refrigeration means removal of heat from a substance or space in order to bring it to a temperature lower than those of the natural surroundings. Thermoelectric cooling is a way to remove thermal energy from a medium, device or component by applying a voltage of constant polarity to a junction between dissimilar electrical conductors or semiconductors. Thermoelectric Refrigeration provides cooling effect by using thermoelectric effect i.e. Peltier effect rather than the more prevalent conventional methods like those using the vapor compression cycle'' or the 'gas compression cycle . Thermoelectric Refrigeration finds applications in electronic systems and computers to cool sensitive components such as power amplifiers and microprocessors. TER can also be used in a satellite or space application to control the extreme temperatures that occur in components on the sunlit side and to warm the components on the dark side. In scientific applications like digital cameras and charge-coupled devices (CCDs) TER is used to minimize thermal noise, thereby optimizing the sensitivity and image contrast.

The coefficient of performance (COP) of compression refrigerators decreases with the decrease in its capacity. Therefore, when it is necessary to design a low capacity refrigerator, TER is always preferable. Also, better control over the space temperature is the major advantage of the TER. Hence, TER is good option for food preservation applications & cooling of pharmaceutical products.

In the present work, the thermoelectric refrigerator was fabricated using 4 thermoelectric modules. The thermoelectric refrigerator is provided the fans on both cold and hot ends to insist the forced convection. Along with the fabrication work it is analyzed the performance of TER system and plotted the results obtained from the system.

2. NOMENCLATURE

C.O.P	--	Coefficient of Performance
TER	--	Thermoelectric Refrigerator
T	--	Water Temperature (^0C)
t	--	Time (min.)
m_w	--	Mass of Water (^0C)
ΔT	--	Decrease in Temperature of Water (^0C)
C_p	--	Specific heat of Water (J/Kg-K)
RE	--	Refrigeration Effect (W)
P	--	Power Input (W)
Ti	--	Initial Temperature of Water (^0C)

3. HISTORY OF REFRIGERATION

Refrigeration may be defined as the process of achieving and maintaining a temperature below that of the surroundings, the aim being to cool some product or space to the required temperature. One of the most important applications of refrigeration has been the preservation of perishable food products by storing them at low temperatures. Refrigeration systems are also used extensively for providing thermal comfort to human beings by means of air conditioning.

3.1 Natural Refrigeration:

In olden days refrigeration was achieved by natural means such as the use of ice or evaporative cooling. In earlier times, ice was either:

- Transported from colder regions,
- Harvested in winter and stored in ice houses for summer use or,
- Made during night by cooling of water by radiation to stratosphere.

In Europe, America and Iran a number of icehouses were built to store ice. Materials like sawdust or wood shavings were used as insulating materials in these icehouses. Later on, cork was used as insulating material. Literature reveals that ice has always been available to aristocracy who could afford it. In India, the Mogul emperors were very fond of ice during the harsh summer in Delhi and Agra, and it appears that the ice used to be made by nocturnal cooling.

3.2 Artificial Refrigeration:

Refrigeration as it is known these days is produced by artificial means. Though it is very difficult to make a clear demarcation between natural and artificial refrigeration, it is generally agreed that the history of artificial refrigeration began in the year 1755, when the Scottish professor William Cullen made the first refrigerating machine, which could produce a small quantity of ice in the laboratory. Based on the working principle, refrigeration systems can be classified as vapour compression systems, vapour absorption systems, gas cycle systems etc.

The Various artificial refrigeration methods are:

- Vapour compression refrigeration systems, including
- Vapour absorption refrigeration systems
- Solar energy based refrigeration systems
- Air cycle refrigeration systems
- Steam and vapor jet refrigeration systems
- Thermoelectric refrigeration systems
- Vortex tube refrigeration systems

3.3 Thermoelectric Effects:

The thermoelectric effect is the direct conversion of temperature differences to electric voltage and vice versa. A thermoelectric device creates a voltage when there is a different temperature on each side. Conversely when a voltage is applied to it, it creates a temperature difference (known as the Peltier effect). At atomic scale (specifically, charge carriers), an applied temperature gradient causes charged carriers in the material, whether they are electrons or electron holes, to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated; hence, the thermally induced current.

This effect can be used to generate electricity, to measure temperature, to cool objects, or to heat them or cook them. Because the direction of heating and cooling is determined by the polarity of the applied voltage, thermoelectric devices make very convenient temperature controllers. Traditionally, the term thermoelectric effect or thermoelectricity encompasses three separately identified effects. They are: (i) Seebeck effect (ii) Peltier effect (iii) Thomson effect.

3.3.1 Seebeck Effect:

The Seebeck effect is the conversion of temperature differences directly into electricity. Seebeck discovered that a compass needle would be deflected when a closed loop was formed of two metals joined in two places with a temperature difference between the junctions. This is because the metals respond differently to the temperature difference, which creates a current loop, which produces a magnetic field. Seebeck, however, at this time did not recognize there was an electric current involved, so he called the phenomenon the thermo magnetic effect, thinking that the two metals became magnetically polarized by the temperature gradient. The Danish physicist Hans Christian Orste played a vital role in explaining and conceiving the term "thermoelectricity". According to Seebeck the EMF generation in the circuit is proportional to the temperature difference between the hot and cold ends.

The voltage developed can be derived from:

$$V = \int_{T1}^{T2} \left(S_B(T) - S_A(T)\right) dt$$

3.3.2 Peltier Effect:

The Peltier effect bears the name of Jean-Charles Peltier, a French physicist who is discovered in 1834 the calorific effect of an electric current at the junction of two different metals. When a current is made to flow through the circuit, heat is evolved at the upper junction (at T2), and absorbed at the lower junction (at T1). The Peltier heat absorbed by the lower junction per unit time, Q can be termed as:

$$Q = \pi_{AB} * I = (\pi_B - \pi_A) * I$$

An interesting consequence of this effect is that the direction of heat transfer is controlled by the polarity of the current; reversing the polarity will change the direction of transfer and thus the sign of the heat absorbed/evolved. A Peltier cooler/heater or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other. Peltier cooling is also called thermoelectric cooling (TEC).

3.3.3 Thomson Effect:

The Thomson effect was predicted and subsequently experimentally observed by William Thomson (Lord Kelvin) in 1851. It describes the heating or cooling of a current-carrying conductor with a temperature gradient.

Any current-carrying conductor (except for a superconductor), with a temperature difference between two points, will either absorb or emit heat, depending on the material. If a current density J is passed through a homogeneous conductor, heat production per unit volume is:

$$q = \left[\rho * J^2 - \mu * J * \frac{dT}{dx}\right]$$

4. MECHANISM OF TER SYSTEM

4.1 Basic Principles:

A semiconductor (called a pellet) is used because they can be optimized for pumping heat and the type of charge carriers within them can be chosen. In the N type semiconductor (doped with electrons) the electrons move towards the positive end of the battery. The semiconductor is soldered on two ends with conductive material, like copper. By applying the voltage, the heat is transported in the direction of current flow.

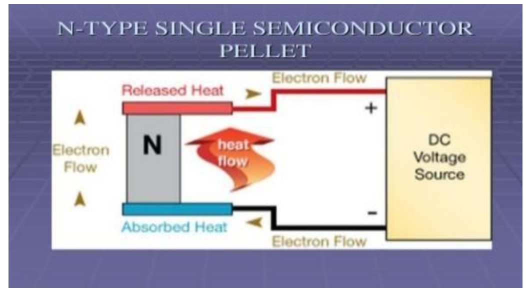

Fig-1: Electron Flow in TER System

When a p-type semiconductor (doped with holes) is used instead, the holes and heat are moves in the direction opposite to the current flow. Essentially, the charge carriers dictate the direction of heat flow.

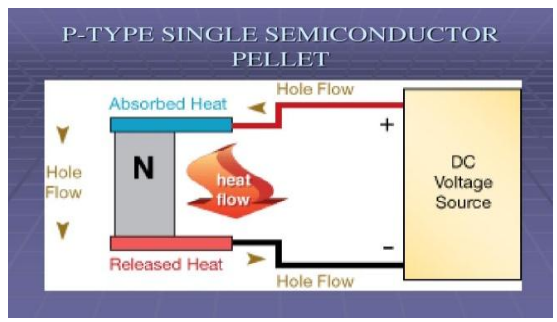

Fig-2: Holes Flow in TER System

4.2 Method of Heat Transport:

Electrons can travel freely in the copper conductors but not so freely in the semiconductor. As the electrons leave the copper and enter the hot-side of the p-type, they must fill a "hole" in order to move through the p-type. When the electrons fill a hole, they drop down to a lower energy level and release heat in the process Then, as the electrons move from the p-type into the copper conductor on the cold side, the electrons are bumped back to a higher energy level and absorb heat in the process. Next, the electrons move freely through the copper until they reach the cold side of the n-type semiconductor. When the electrons move into the n-type, they must bump up an energy level in order to move through the semiconductor. Heat is absorbed when this occurs.

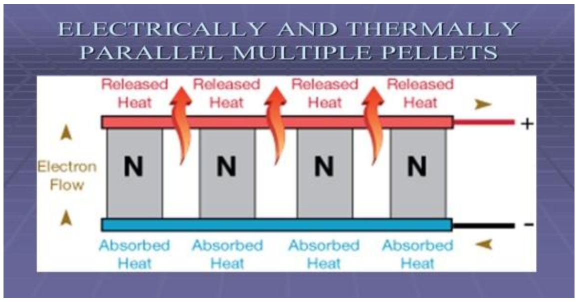

Fig-3: Electrically & Thermally Parallel Multiple Pellets

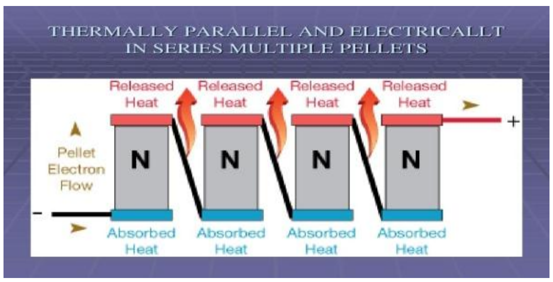

Fig-4: Electrically Series & Thermally Parallel Multiple Pellets

4.2.1 N and P-Type Pellets:

The most efficient configuration is where a p and n TE component is put electrically in series but thermally in parallel. The device to the right is called a couple. One side is attached to a heat source and the other a heat sink that dissipate the heat away. The side facing the heat source is considered the cold side and the side facing the heat sink the hot side. Between the heat generating device and the conductor must be an electrical insulator to prevent an electrical short circuit between the module and the heat source. The electrical insulator must also have a high thermal conductivity so that the temperature gradient between the source and the conductor is small. Ceramics like alumina are generally used for this purpose.

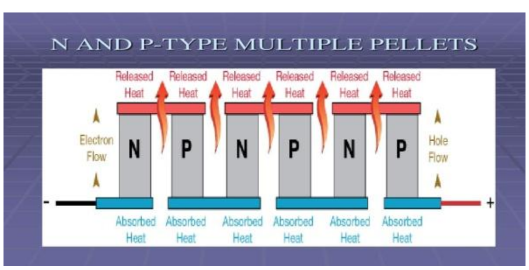

Fig-5: N and P-Type Pellets

4.2.2 Semiconductor Doping:

N doped semiconductors have an abundant number of extra electrons to use as charge carriers. Normally, a group IV material (like Si) with 4 covalent bonds (4 valence electrons) is bonded with 4 other Si. To produce an N type semiconductor, Si material is doped with a Group V metal (P or As) having 5 valence electrons, so that an additional electron on the Group V metal is free to move and are the charge carriers

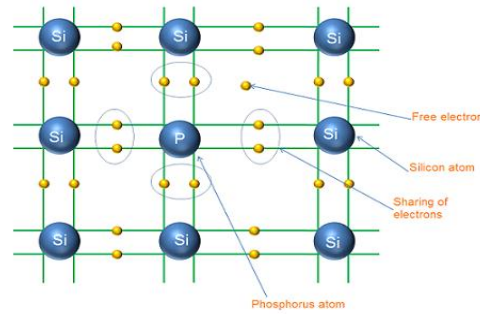

Fig-6: N-Doped Semiconductors

For P type semiconductors, the dopants are Group III materials (In B) which has 3 valence electrons; these materials need an extra electron for bonding which creates "holes". P doped semiconductors are positive charge carriers. There's an appearance that a hole is moving when there is a current applied because an electron moves to fill a hole, creating a new hole where the electron was originally. Holes and electrons move in opposite directions.

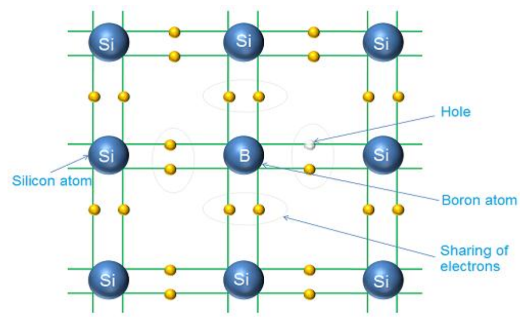

Fig-7: P-Doped Semiconductors

5. EXPERIMENTAL SETUP:

The present study is carried out to analyze the performance of a thermoelectric refrigerator, which is made of an insulated wooden box of size 35cm x 35cm x 30cm and 4 thermoelectric modules with heat sinks and axial flow fans to insist the forced convection.

Fig-8: TER Cabin

Fig-9: Axial Flow Fan

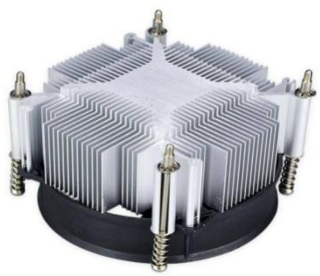

Fig-10: Heat Sink

5.1 Working Principle:

In the present work, the TER System works based on the peltier effect. By supplying the power to the solid state thermoelectric modules, the outer surface acts as hot surface and inner surface acts as cold surface. The heat is extracts from the inner space of the cabin to be cooled and rejects heat to the atmosphere. During this process the refrigeration effect will be produced.

5.2 Advantages of TER System:

- Small size and light weight.
- Compact and reliable.
- Steady-state operation.
- No moving parts and fluids.
- Durable and maintenance-free.
- Very long operation life.
- Effective in spot cooling.
- Environmentally friendly.
- No chlorofluorocarbons.
- Ability to heat and cool.
- Work in any orientation.
- Generate no electrical noise.
- Can power directly by PV cells.

5.3 Applications of TER System:

- Thermoelectric cooling is used in medical and pharmaceutical equipment, spectroscopy systems, various types of detectors, electronic equipment, portable refrigerators, chilled food and beverage dispensers, and drinking water coolers.
- Requiring cooling devices with high reliability that fit into small spaces, powerful integrated circuits in today's personal computers also employ thermoelectric coolers.
- Using solid state heat pumps that utilize the Peltier effect, thermoelectric cooling devices are also under scrutiny for larger spaces such as passenger compartments of idling aircraft parked at the gate.
- Inertial Guidance Systems, Night Vision Equipment, Electronic Equipment Cooling, Cooled Personal Garments, Portable Refrigerators.
- Computer Microprocessors, Microprocessors and PC's in Numerical Control and Robotics, Medical Instruments, Hypothermia Blankets, Pharmaceutical Refrigerators - Portable and Stationary, Blood Analyzers, Tissue Preparation and Storage, Restaurant Equipment, Cream and Butter Dispensers.

5.4 Experimental Readings:

Initial Temperature of Water (T_i) = 30^0C
Electrical Power Input (P) = 50 W
Mass of Water Cooled (m_w) = 1 Kg

Table-1: Temperature Readings

S. No.	Time (t) (Minutes)	Water Temperature (T) (^{0}C)
1.	10	26
2.	20	23
3.	30	21.5
4.	40	20
5.	50	19
6.	60	18.5

5.4.1 Sample Calculation:

$$\text{Refrigeration Effect (RE)} = \frac{m_w * C_p * \Delta T}{t * 60}$$

Where

m_w	=	Mass of water cooled(Kg)
t	=	Time (Min.)
ΔT	=	Decrease in Temperature (^{0}C)
C_p	=	Specific heat of water (J/Kg-K)
C_p	=	4186 J/Kg-K

$$\text{Refrigeration Effect (RE)} = \frac{1 * 4186 * (30 - 26)}{10 * 60}$$

$$\text{Refrigeration Effect (RE)} = \mathbf{27.90\ W}$$

Therefore, $$\text{C.O.P.} = \frac{RE}{P} = \frac{27.9}{50} = \mathbf{0.558}$$

RESULTS & DISCUSSION:

6.1 Results:

The aim of this experimental work is to fabricate and analyze the performance of thermoelectric refrigerator. Finally, the obtained results were plotted.

Table-2: C.O.P. of TER System:

S. No.	Time (Min)	Water Temperature (^{0}C)	R. E. (W)	C.O.P.
1.	10	26	27.90	0.558
2.	20	23	24.41	0.488
3.	30	21.5	19.76	0.3952
4.	40	20	17.44	0.348
5.	50	19	15.34	0.306
6.	60	18.5	13.37	0.2674

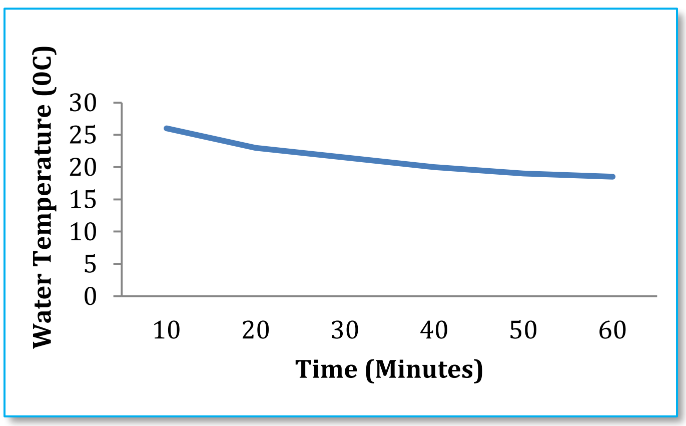

Chart-1: Time Vs Water Temperature

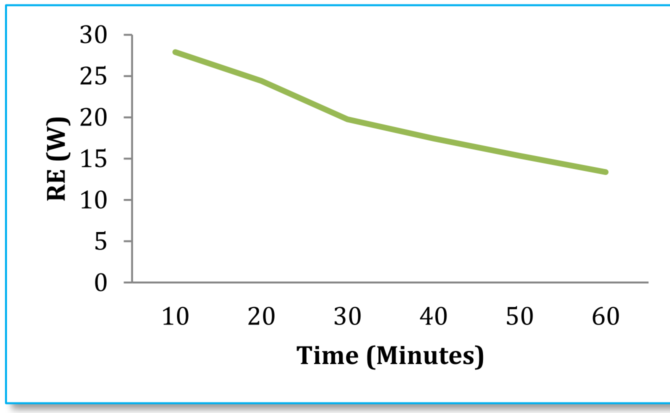

Chart-2: Time Vs Refrigeration Effect

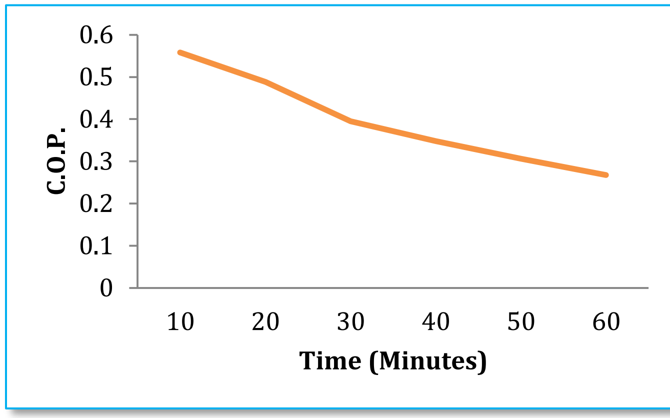

Chart-3: Time Vs C.O.P.

6.2 Discussion:

From the Charts 1 to 3 plotted above, it is clear that the Water temperature, refrigeration effect and C.O.P. of the system are decreasing with time. But the performance of the system is stabilized after 1 hr. and the C.O.P. is constant after that. In the initial stage the maximum refrigeration effect and C.O.P. are recorded as 27.90 W and 0.558 respectively.

7. CONCLUSIONS

We have been successful fabricated a system that fulfils the proposed goals. In the present project, the maximum refrigeration effect of the fabricated system at 50W power input is observed as 27.90W and the maximum C.O.P. at the same power as 0.558. . However we do realize the limitations of this system. The present model can be used only for light heat load to lower its temperature to a particular temperature. The system is unable to handle fluctuations in load. Extensive modifications need to be incorporated before it can be released for efficient field use. This is one of the advantageous project which uses low power to drive refrigerator. This project work has provided us an excellent opportunity and experience, to use our limited knowledge.

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