Design and Investigation on Portable Thermoelectric Air Chiller

[1]Shaik Ahmad, [2]Parankusum Chandra Sekhar, [3]Ommi Srinivasa Rao, [4]Mulampaka Bhaskar, [5]Sirugudi Kiran Kumar

[1]*Assistant Professor, Mechanical Department, Wellfare Institute of science technology and Management, Visakhapatnam (A.P), India.*

[2,3,4,5]*Student IV/IV B.Tech, Mechanical Department, Wellfare Institute of science technology and Management, Visakhapatnam (A.P), India.*

Abstract

Environment friendly solutions are becoming more prominent as a concern regarding the state of our deteriorating planet. This paper introduces a new method of Refrigeration system which removes heat from the space in order to bring it to a lower temperature than surrounding temperature. This system uses "Thermoelectric cooling module(TEC)"which works on thermoelectric refrigeration, aims to provide cooling by using thermoelectric effect which states that when D.C voltage is applied across two junctions of dissimilar electrical conductors, heat is absorbed from one junction and heat is rejected at another junction which creates a temperature difference. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side. This process does not require any compressor and refrigerants for the refrigeration process,which effectively reduces work input and power consumption.

Keywords - *Peltier Modules, Heat Sinks, Thermoelectric Air Chiller*

I. INTRODUCTION

Refrigeration is the process of removing heat from the space in order to bring it to a lower temperature than surrounding temperature. This Paper deals with the study of **"**Thermoelectric Air Chiller" which works on Thermoelectric refrigeration, aims to provide cooling by using Thermoelectric effects rather than the more prevalent conventional methods like 'vapor compression cycle' or the 'vapor absorption cycle'.

There are three types of thermoelectric effect namely,

- The Seebeck effect,
- The Peltier effect,
- The Thomson effect.

From these three effects, Thermoelectric Air chiller works on the Peltier effect; Thermoelectric cooling technology employs Thermoelectric coolers (TECs), has advantages of high durability, no mechanical moving parts, compact in size, light in weight, and no working fluid.It can be powered by direct current (D.C) electric sources when a potential difference or D.C current is applied across two junctions of dissimilar electrical conductors, a circuit can be created that allows for continuous heat transfer between the conductor's junctions and the heat is absorbed from one junction and heat is rejected at another junction. this is the principle of thermoelectric air chiller originated from the Peltier effect. it is solid state cooling and eco-friendly system. This system can obtain the refrigeration effect up to 16^0C under specified conditions.

Thermoelectric air chiller is basically used as a cooling element in electronic equipment, laser diodes, blood analyzers, portable picnic coolers, Microprocessors, small medical transport containers and recreational vehicle air conditioners.

II. LITERATURE REVIEW

1. Matthieu Cosnier et al[1] conducted an experimental and numerical study on thermoelectric air cooling and air heating system. They achieved cooling power of 50W per one Peltier module with the COP of 1.5 to 2, by maintaining temperature difference on both hot and cold junction as 5ºC.
2. Suwit Jugsujindaet al[2]conducted a study on analyzing thermoelectric refrigerator performance. They fabricated a thermoelectric refrigerator(TER) of [25x25x35 cm^3] by using a Peltier module of [4x4 cm^2]. when a power input of 40W is supplied temperature of TER was reduced from 30ºC to 20ºC in 1 hour, later on temperature reduces gradually in 24 hours. They achieved a maximum COP of TER and TEC as 0.65 and 3.0.
3. Riff and Guoquanet al[3] presented an experimental study on comparative investigation of thermoelectric air conditioners versus vapor compression and vapour absorption air conditioners. Three different domestic air conditioners are compared and fabricated a compact air conditioner using TEC.
4. Riffat and Qiuet al[4]compared performances of thermoelectric and conventional vapour compression air-conditioners. Results show that the actual COPs of vapour compression and thermoelectric air-conditioners are in the range of 2.6-3.0 and 0.38-0.45, respectively. However,

thermoelectric air conditioners have several advantageous features compared to their vapour compression counterparts.

III. THEORY

A. *Objective of the Work*

The main objective of this work is to analyse the working of thermoelectric air chiller. Scope of this work includes:

- Studying the working principles of Thermoelectric cooler(TEC) and its performance parameters.

- Study about new heat sink designs and introduces it in our design to improves the performance of the Peltier Module simultaneously COP of a thermoelectric air chiller.
- Exploring new methods to increase the COP of a Peltier module.

B. *Peltier effect*

French physicist jean Charles athanase Peltier discovered Peltier effect in 1834.this effect states that when a D.C current passes across the junction of two dissimilar metals it creates hot junction on one side and cold junction on another side by the flow of electrons, this electrons transport heat from one junction to another.

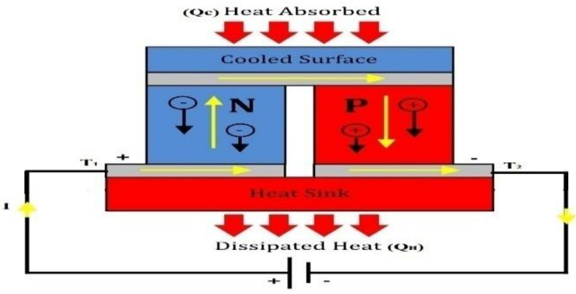

Figure 1: Peltier effect

From the above Figure we can observe that when the D.C current (I) is supplied through the terminals T_1& T_2 the electrons at atomic scale diffuse from valence bond to conduction bond creates a temperature difference between two junctions of dissimilar metal conductors. Here the electrons transport heat from one junction to another and produces cooling effect (Q_C) on one side and dissipated heat (Q_H) on another side. If we reverse the polarity of the applied voltage it can alter the direction of heat flow.

Joule heating effect of whose magnitude is I^2xR (where "R" is electrical resistance), acts opposite to the Peltier effect causes net reduction of the available cooling.

The Peltier cooling or heating effect can be expressed mathematically as

$$Q_C \text{ or } Q_H = \beta \times I = (\alpha T) \times I$$

Where:

- "β" is the differential Peltier coefficient between the two materials A and B in volts.
- "α" is the seebeck coefficient of thermoelectric material.
- "I" is the electric current flow in amperes.
- "Q_C and Q_H" are the rates of cooling and heating, respectively, in watts (W).

IV. DESIGN OF THERMOELECTRIC AIR CHILLER

A. *Design*

"Thermoelectric air chiller"employs latest technology which uses Peltier module(TEC-12706) for the purpose of refrigeration process. It consists of special design heat sinks, Peltier modules, blower fans, operating switch, S.M.P.S (switch mode power supply), and digital temperature indicator. Its design is perforated in such a way that the Peltier modules are placed in between the PVC foam sheet to avoid heat transfer between the hot side and cold side heat sinks. Heat sinks are rigidly fixed to the module with the help of screws to avoid vibrations during the operation. On the hot side we used special purpose heat sinks capable of transmitting huge amount of heat to the surroundings with the help of high throw cooler fans attached to the heat sink. On the other hand,cooling side a cooling chamber is provided consists of three fans to blow the cool air and two fans attached directly to the cool side heat sink for better performance by effective suction of ambient air. Digital thermometer sensor is attached to the cool side heat sinks to note the temperature of the cool air circulating to the space. Power supply 230V A.C is converted to 12V 20A D.C output in the S.M.P.S.

Fig 2.1 Right Side View of Thermoelectric Air chiller

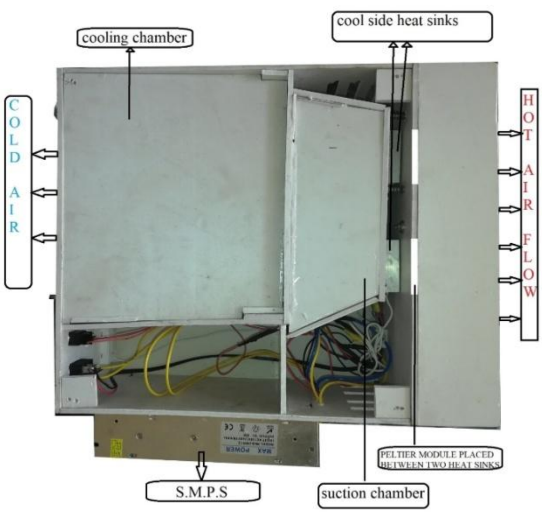

Fig 2.2 Top view of Thermoelectric Air chiller

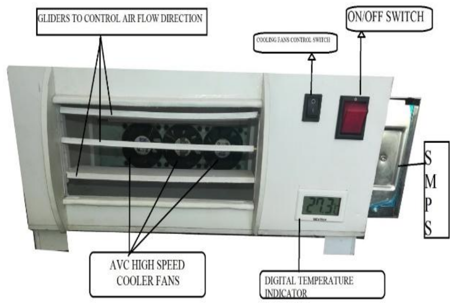

Fig 2.3 Front View of Thermoelectric Air chiller

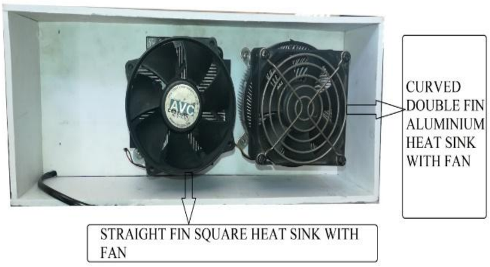

Fig 2.4 Rear View of Thermoelectric Air chiller

Fig 2.53D view of Thermoelectric Air chiller

B. Working of Thermoelectric Air chiller

Thermoelectric air chiller works on the principle of Peltier effect, when Peltier modules are energized current flow takes place between the P&N type semiconductor materials due to this heat is absorbed from one junction and heat is rejected at another junction which creates a temperature difference by the flow of electrons. At the atomic scale, an applied temperature gradient causes charge carriers in the material to diffuse from the hot side to the cold side. Now the heat sinks which are attached to the Peltier module start transferring heat flow and this heat energy is transferred to the surroundings with the help of cooler fans.

It is provided with special design curved and straight shaped double fin heat sink on the hot side of the Peltier module which efficiently remove the high temperature and maintains hot side of the module constantly between 24-30°C from 70°C and provides cooling effect of -10°C on the low temperature side of module surface, this temperature is Increased to 4°c on inner aluminum heat sink by absorbing the heat of the atmospheric air. The cooler fans attached to the low temperature heat sink blows air constantly at 18-20°C.the thermoelectric cooler (TEC) placed between the heat sinks maintain a temperature difference up to 70°C.Figure shows the working of Thermoelectric air chiller.

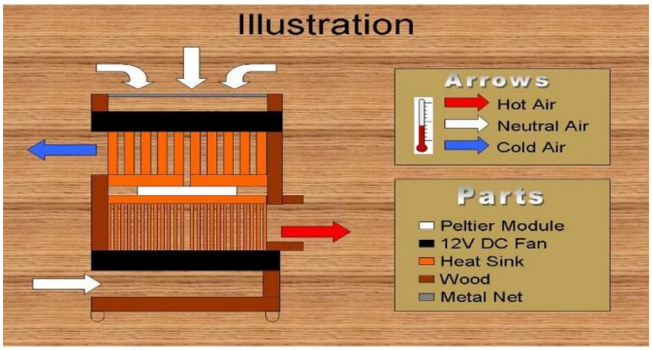

Fig 3: working of thermoelectric air chiller

C. Circuit Diagram of Thermoelectric Air chiller

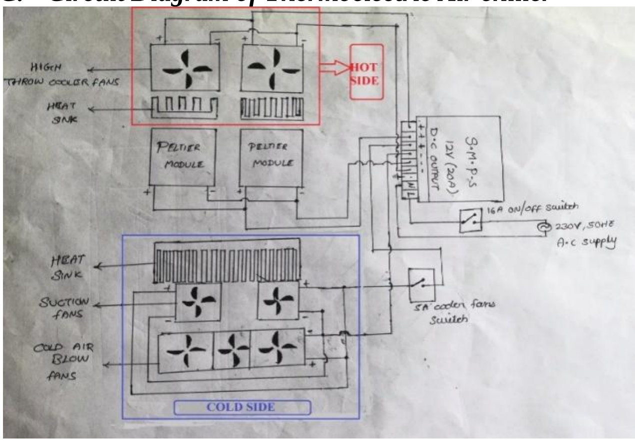

Fig 4: circuit diagram of Thermoelectric Air chiller

V. MATHEMATICAL CALCULATIONS

When D.C current is passed across the junction of two dissimilar materials, heat is absorbed at one junction and dissipated at the another junction. This Phenomenon is known as Peltier Effect. Thermal network model of TEC is shown in the Fig 5. The various parameters and equations used for calculating the performance of thermoelectric air chiller are given below

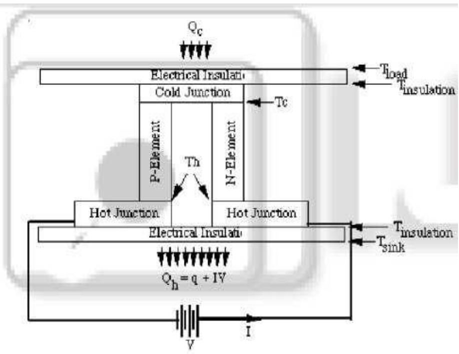

Fig 5: Thermal network model

Assumptions

- There is no heat loss from the system.
- Thermal physical properties such as Resistivity, conductivity etc. does not change with temperature.

- Heat transfer takes place through the P type and N type semiconductor only.

A.Nomenclature

COP-Coefficient of performance
I-Current (A)
K-Thermal conductivity (W/m.k)
U-Overall Thermal conductivity(W/m.k)
Q-Peltier heating or cooling capacity (W)
Q_H-heat dissipated(W)
Q_C-heat absorbed (W)
R-Electrical Resistance (Ω)
T_C-cold junction temperature (k)
T_h-hot junction temperature (k)
ΔT-Temperature Difference between two junctions (k)
TEC-Thermoelectric cooler
P-Power consumed (W)
α-differential seebeck co-efficient (mV/k)

A. *Equations*

➢ **Cooling Capacity (Q_c):**

Peltier effect gives the heating and cooling rate of a thermoelectric cooling. The cooling capacity Q_C obtained from the energy balance at the cold side of the Thermoelectric cooler(TEC).

When current "I" flows from the circuit the Peltier cooling obtained at the source which is equal to (αT_C) x I.

Here the obtained cooling effect is opposed by heat conduction at the rate K (T_h– T_c). and the joule heating effect within the thermal elements. It is clearly shown that Joule heating transfers half to the sink and half to the source, each half being equal to $0.5(I^2R)$. So, the expression for cooling power is,

$$Q_C = (\alpha T_C) \times I = (\alpha T_h) \times I$$

- For the cold junction

$$Q_c + 0.5I^2R + U(T_h\text{-}T_C) = (\alpha T_C) \times I$$

- For the hot junction

$$Q_h\text{-}\ 0.5I^2R + U(T_h\text{-}T_C) = (\alpha T_h) \times I$$

$$Q_h + U\,(T_h\text{-}T_C) = (\alpha T_h\, I) + 0.5I^2 R$$

Thus the thermoelectric cooling is

$$Q_c = (\alpha T_C\, I) - 0.5I^2 R - U(T_h\text{-}T_C)$$

And heating is

$$Q_h = (\alpha T_h\, I) + 0.5I^2 R - U(T_h\text{-}T_C)$$

➢ **Energy supplied (P):**

The power consumed(W) in the thermo element is equal to the joule heating and input power used to create the temperature difference of the Peltier module.

Now energy input to the system as per first law of thermodynamics is given by

$$\oint \partial Q = Q_{net} = –Q_h –Q_c = \alpha I\,(T_h\text{-}T_C) + I^2R$$

Note: Negative sign indicates that energy has to be supplied to the system.

Now $(COP)_C$ = Qc/Energy supplied

$$Q_c = (\alpha T_C I)\text{-}0.5I^2 R\text{-}U(T_h\text{-}T_C)$$

$$P = \alpha I\,(T_h\text{-}T_C) + I^2 R$$

Similarly, $(COP)_h = Q_h$/Energy supplied

$$Q_h = (\alpha T_h\, I) + 0.5I^2R\text{-}U(T_h\text{-}T_C)$$

$$P = \alpha I(T_h\text{-}T_C) + I^2R$$

B. *Experimental Setup*

The construction and design arrangements of thermoelectric air chiller is shown in figure (2.1-2.5)

- **TEC 12706 Specifications:**

In this study we utilized two TEC_1-12706 Peltier modules, whose specification are as follow.

Table : Model Number for TER			
Module: Model TEC1-127-06L			
Q_{max}	60 Watts	Dimensions	
I_{max}	6 Amp	Width	40 mm
V_{max}	15.4 V	Length	40 mm
T_{max}	90 °C	Thickness	3.5 mm
Number of Thermocouple	127		

Table 1: specification of TEC1-12706

The material chosen in TEC is Bismuth telluride. The properties of a 127 thermocouples, 6A Bismuth Telluride module TEC1-127-06L are:

Seebeck coefficient (α) = 53mV/k
Module thermal conductance (K) = 0.1815 W/m.k
Module resistance (R) = 1.96k/W

- **Temperature difference:**

By using"*digital temperature sensor*" final temperature at the surface of module and the heat sink measured on both hot side and cold side are as follow.

Hot side temperature T_h = 40˚C
Cold side temperature T_c = 18˚C
Hence, Temperature difference can be considered as

$$\Delta T = (T_h - T_c) = (40\text{-}18) = 22^\circ C$$

- **COP thermoelectric air chiller:**

coefficient of performance(COP) of a Thermoelectric Air chiller comes from the COP of a thermoelectric module. COP is the ratio of cooling capacity and Energy Supplied to the TEC.

COP = Qc/Energy supplied (W)

a. Heat absorbed $Q_c = (\alpha T_C\, I) – 0.5I^2 R – K\,(T_h\text{-}T_C)$

$$= (0.053 \times 6 \times 291) – (0.5 \times 6^2 \times 1.96) – [0.1815 \times (313\text{-}291)] = 53.265 \text{ W}$$

b. Energy supplied (P) = $\alpha I\,(T_h\text{-}T_C) + I^2 R$

$$= (0.053 \times 6 \times (313\text{-}291)) + (6^2 \times 1.96) = 77.556 \text{ W}$$

c. COP = Qc/Energy supplied

$$= 53.265/77.556 = 0.686.$$

➢ **Cooling capacity in BTU/hr:**

BTU is known as British thermal unit its value is expressed in hours 1W=3.412 BTU/hr.

We obtained cooling capacity of one module is Qc=53.265W

In our design we have used two Peltier modules so the obtained cooling capacity is

Qc=106.53W=363BTU/hr.

Model Graph:

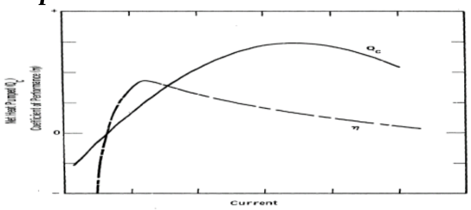

Fig 6: Heat pumping Characteristics of Thermoelectric Air chiller

VI. CONCLUSION

Thermoelectric air chiller employs solid state cooling so its efficient is less than actual refrigeration cycle so its application is limited only for less refrigeration space so it is used for electronics cooling laboratory equipment's etc. But, we have seen that there is a huge scope of research in this field about thermoelectric materials, its fabrication, heat sink design etc. Researchers are working on reducing irreversibility in the systems. so that the performance of Thermoelectric cooler(TEC) increases which adversely increases the COP of thermoelectric air chiller.

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