Design and Implementation of Low Power Thermoelectric Refrigerator

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Abstract: *The Objective of this study is to design a prototype of thermoelectric Refrigerator using Peltier effect on thermoelectric refrigerate or to achieve and protect a specific temperature, to be maintained a selected temperature at acceptable range. The Interior volume of the thermoelectric refrigerator is 6.8 Liter. The design requirements are to cool the volume (6.8Liter) to a suitable temperature within a short time, low power and low cost.*

The Thermo electrical refrigeration is a new ersatz because it can change waste electricity power to useful cooling, so it's increasing demand desired at the field of food preservation, vaccine storages, cooling of electronic devices and medical services.

The system consists of the thermoelectric chamber, heat sink, thermo couple, fan, insulator material and D.C. Source. The Results of this work show that the reduced energy needed for thermoelectric refrigerator is about 60 Watt, which is less than the power for the traditional refrigerator.

In this study foam insulator is used of thicknesses (20mm, 40mm) and the heat load (Qc) which obtained is (31W, 23W) respectively .

Keywords: Peltier effect, Thermoelectric, Heat sink, Peltier coefficient, foam insulator.

1. Introduction

A thermoelectric phenomenon has two phases in a sense that they don't of themselves allow rise for thermodynamic losses [1]. Also they are always in practice, accompanied for the irreversible effects of the electric resistance and the thermal conduction. It drive out that the performance of any thermocouple as energy convertor that can be represent in terms of differential Seeback coefficient, the electrical and thermal resistances of the two branches. These resistances depend on the electrical and thermal resistive and the ratio of length to cross section area [2].

The electric resistivity "ρ", and the electric conductivity "σ" is define by the relation:[3]

$$I = \frac{\sigma V A}{L} \qquad \text{... (1)}$$

where : I is the electrical current, A cross section area, L length and V a voltage applied.

K: Thermal conductivity is given by the equation:

$$q = -\frac{KA\Delta T}{L} \qquad \text{... (2)}$$

Where: q is the rate for heat flow, ΔT temperature difference between its two ends.

Peltier Effect (P.E.) is the base of the thermoelectric refrigerators. Where one of the three thermo electrical effects is P.E.; while the other two effects are Seeback and Thomson. The effects of the Seeback and Thomson act as a single wire; the P. E. is an ideal juncture phenomenon.

The thermo electrical cooler is a heat pump solid state which is used in applications if the temperature cycling, temperature stabilization, or cooling less than the ambient temperature is required. The products are using thermoelectric coolers including CCD cameras (charge coupled device), microprocessors, laser diodes, portable picnic coolers and blood analyzers [1].

Earlier researcher had studied the causes of thermo electrical refrigerator, were, Onoroh G.I focused on simulation of a thermo electric refrigerator maintained at $4C^{o}$. The performance of the refrigerator was simulated using matlab under varying operation [4]. Sujith G, Antony V. developed a working thermo electric refrigerator to cool and maintain a select temperature at range (5-$25C^{o}$) by using seeback effect.[5].B.J Huang,C.J. chin designed calculation utilizes the performance curve of thermoelectric module that was determined experimentally and an automatic test apparatus was designed and build to illustrate that. [6]

2. Seeback Effect "S.E."

The conductors have two different metals symbols "G" and " H". A juncture temperature at" G" is usually used as an indicator and is stayed on a temperature cool "T_{Cool}".

A juncture temperature at" H" usually used higher temperature than "T_{Cool}". When Appling heat at juncture " H", a voltage "E_{out}" will appear through the thermal terminals "T_1" and "T_2" and the electrical current constantly will flow through the closed circuit. The voltage shown in Fig, (1), is the Seebeck "E.M.F.", which can be write as: [4]

$$E_{out} = \alpha \, (T_{Hot} - T_{Cool})$$ ... (2)

Where:-

$$\alpha : dE \, / \, dT = \alpha_G - \alpha_H$$

α is a differential coefficient of "Seebeck" or coefficient electrical power through two materials, "G" and "H", α is positive when electrical current direction is at the same direction with thermal current, in " volts / K^o".

E_{out}: is the voltage output "volts".

T_{Cool} is the cold temperature thermocouple, in K^o.

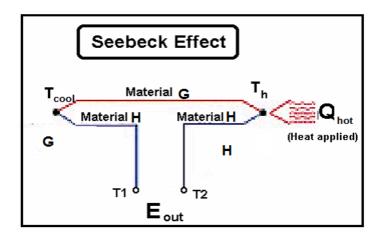T_{Hot} is the hot temperature thermocouple, , in K^o.

Figure (1) Seeback effect

3. Peltier Effect "P.E."

The opposite phenomenon to "S. E." was found by Peltier, the absorber for thermal energy could happen at one of the different metal juncture, while at the other juncture will discharge when closed electrical circuit pass through it.

Figure. (2) Shows the modification of thermocouple circuit. This circuit was modified to find different configuration which explain P.E. The applied voltage (E) terminals "T_1 "and "T_2," causes flow of electrical current (I). Therefore; a slight cooling (Q_{cool}) effect occur at the juncture of thermo couple (G) (while the heat is absorbed)and the effect of heating (Q_{hot})will occur in the juncture (H)(while the heat expelled).P.E. may reversed when changing the flow electrical current direction so will reverse the flow heat direction.

Heating Joule, having a formula of (R x I2) where " R" the electric resistance which result from the flow of current. This effect of heating Joule acts as opposite to the "P.E" and causes lowering for cooling available. The equation of "P.E" can be written as:

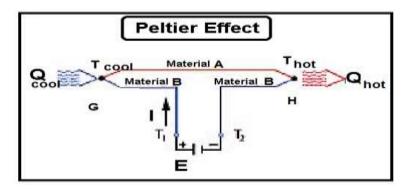$$Q_{cool} = Q_{hot} = I \times ß = I \times (\alpha \times T) \qquad \textbf{...} \quad (4)$$

Where:-

ß: is the differential between the materials "G" and" H" of " Peltier coefficient" (V).

I: is the "electrical current" (A).

Q_{Hot} : is the rate of heating (W)

$Q_{cool:}$ is the rate of cooling (W)

Figure(2) Pelteir Effect .

The important effect for Peltier coefficient " β " at Thermo electrical cooling are as follows:

1) When β less than zero Peltier coefficient (-ve) .
   Electrons with high energy will get to the left from the right. The flow directions of Electric and thermal current are in the opposite.

2) When β more than zero Peltier coefficient (+ve).
   Holes with high energy move from the left to the right, electric current and thermal current flow in the same direction. [7].
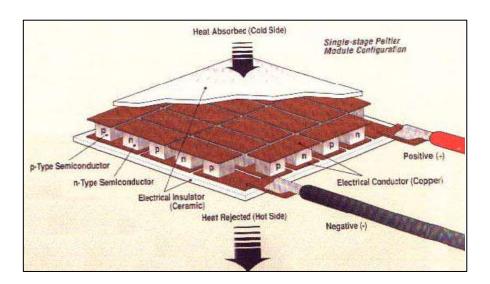
4. Thomson Effect "T.E"

When an electric current is passed through conductor having a temperature gradient over its length, heat will be either expelled from or absorbed by the conductor. Whether the heat is expelled or absorbed depends on the direction of both them (electric current and temperature gradient). This phenomenon, known as "T.E." which is interested in respect of the principles involve, but play's a negligible role at the operation of the practical thermo electrical models.[8].

5. The Principle of Thermoelectric Operation

To two wafers ceramic and group of P-type and N-type are used to manufacture the ideal thermo-electric models by doped semiconductor materials "bismuth-telluride" which placed (sandwiched) between them shown in Fig. (3).

The materials of ceramic for the two sides of the thermoelectric are added to give solidity and is needful for insulation. The material which has an excess electrons is N-type, while; the material which has a deficit of electrons is P -type. To make up a couple it is need one N and one P. Thermoelectric couples are thermally in parallel and electrically in series. A

thermoelectric model can contain" one to several" hundred couples.[4].

Figure(3)Thermoelectric ceramic[9]

When the electrons move from P- type material to N- type material through the electrical connector, the electron jump to higher energy state absorbing thermal energy which is cold side. Continuing through lattice of materiel, the electron flow from N-type material to P- type material through the electrical connector dropping to lower energy and releasing the energy as heat to the heat sink which is hot side. [9].

6. Thermal Calculation:

The convenient thermoelectric for this application, depend on hot temperature surface (T_h), cold temperature surface (T_c) and the heat load (Q_C) which absorbed at a cold surface. When the power D.C.is applied, the thermo electrical hot side released heat.

The hot side is connected with a heat sink When the air cooled the heat sink is used. The temperature of hot side and the transfer of heat is obtain by the Equations 5and 6.

$$T_{hot} = T_{amb} + \theta \, Q_{hot} \qquad \qquad \dots (5)$$

Where:-

T_h : is the temperature of hot side "C^o ".

T_{amb} :is the temperature of ambient "C^o".

θ :is the Thermal resistance for heat exchanger "C^o /W".

$$Q_{hot} = Q_{Cool} + P_{i/p} \qquad \qquad \dots \quad (6)$$

$$COP = Q_{Cool} / P_{i/p} \qquad \qquad \dots \quad (7)$$

Q_{hot}: is the emitted heat to a hot side for the thermo electrical "W".

Q_{Cool}: is the absorbed heat at a cold side which released "W"

COP: is the "performance of coefficient" of the devices which is typically between 0.4 and 0.7.

$P_{i/p}$: is the input electrical power into the thermo electrical "W".[3]

Consider Q_{Cool}, is the load heat (W) which absorbed from at a cold side is complicated, due to all Q_{cool} was taken into account. Through this thermal load were:

1. Active:

- The Q_{cool} for electrical devices " $R*I^2$ ".
- Another load which was generated by the reaction chemical.

2. Passive:

- The Radiation which is represent Q_{cool} loss between two objects close and in different temperatures"
- The Convection which is represents Q_{cool} loss in the air, while the air had different temperature than the object.
- The Insulation losses
- The losses Conduction which is represent Q_{cool} loss through screws, leads, and so on.

- The transient load is the time which required changing the object temperature.

To balance the energy through cold and hot juncture it's produces:-

$$Q_{hot} = (\alpha\ T_{hot}) \times I - C\ (T_{hot} - T_{cool}) + R\ I^2 \qquad \ldots (8)$$

$$Q_{Cool} = (\alpha\ T_{cool}) \times I - C\ (T_{hot} - T_{cool}) - R\ I^2\ /2 \qquad \ldots (9)$$

Where:

$R = R_G + R_H$

$C = (k_G + k_H)\ (A/L)$

At the cold side can obtain the maximum heat absorbed Q_{cool} by differentiating the (Q_{cool}) with respect to (I).

$$d\ Q_{cool}\ /d\ I = 0 \qquad \ldots (10)$$

and

$$I = \alpha\ T_{cool}\ /R \qquad \ldots (11)$$

To get maximum heat absorbed at a cold side, must substitute equation (11) in equation (9) to obtain:

$$Q_{Cool}\ (max) = [(Z\ T_{col}^2)/2 - (T_{hot} - T_{cool})]\ C \qquad \ldots (12)$$

The figure of merit (Z) is from the material G and H

$$Z = \alpha^2\ /\ C\ R \qquad \ldots (13)$$

A thermo electrical get a cold side when the D.C. Power is applied. This side is needed to be coldest than the wanted temperature of the cold object. This case is true when a cold side does not contact with the objects directly, like enclosure cooling. Through the thermo electrical, the different in temperature (ΔT) relate to T_{hot} and T_{cool} due to the formula: (14).[3].

$$\Delta T = T_{hot} - T_{cool} \qquad\qquad \textbf{...} (14)$$

7. Designs

In this study, the main aim is to design and implementation of refrigeration system with a capacity of (6.8 L) of cooling box .This system capable of maintaining the temperature of the materials between (10 C^o – 17 C^o) for a long duration time. The design is introduced through some steps; these steps were for the identification of the problem and analyze it. These design considerations are the heat transfer, methods, materials and geometry. The method which can be used for heat transfer from the surface to the surrounding for thermoelectric refrigerator:-

- Natural convection and forced convection.
- The geometry considered for the system was rectangle. The advantage of rectangle is its simplicity to build and insulate. Shown in table (1).

The material which is selected for the construction of the outer case of the rectangle box is the cork. This material (cork) is desirable because it has low thermal conductivity (σ = 0.0381W/mK), very light available, low price, easy in work (cut and drill), therefore it's easy to make it portable.

The outer surface for the rectangle box is coated by a special paper (paper board) because it has low thermal conductivity (σ = 0.014W/mK) , so it is a good insulation. The internal surface is coated by foam (polyurethane) into two thicknesses (20mm and 40mm) and then coated by sheets of aluminum (AL), the thickness of it about (2mm). From table (1) to table (7) showing the specification of cork box and another materials which are used in this study.

The heat sink made of aluminum, is in contact with the hot side of thermoelectric module when the module leads (positive and negative) are connected to the D.C. power (battery), heat will be dissipated by the hot side of the module (peltier), the heat sink expedites the removal of heat. The heat sinks include free convection and forced convection (by using fans), shown in tables (3) and (4).

To design the thermoelectric components which where needed for the calculation of heat load (Qc) according to the active, passive and air temperature for ambient, the total heat load (Qc) is calculated according to the specification given in tables (1)to (7) and applied it in equations (5) to (14) are Show in figs (4) ,(5),(6), (7).

Table (1): The specification of refrigerator

Diameter	Inner cm	Outer cm
Width	20	24
Height	20	25
Length	35	40
Volume of the box (16.8) liter		

Table (2): The specification of peltier

Model Tec1-12706B			
P_{max}	60w	Dimension mm	
I_{max}	6A	width	35
V_r	12v	Length	40
T_{max}	68 c^o	Thickness	3.5
No. of couples	127		

Table (3): The specification of heat sink

Dimension cm	
Length	14
Width	10
Thickness	2.5
Aluminum metal allow	

Table (4): The specification of fans

	Inner fan mm	Outer fan mm
Diameter	90	60
Rated volt	12v	12v
Rated power	6w	6w

Table (5): The specification of battery

Model 155g51 yasa	
Rated volt	12v
Max. capacity	120 AH (5HR)
Weight	34Kg
Diminution mm	507*222*257

Table (6): The specification of relay

SRD 12	
Rated volt	12v D.C.
Rated current	10 A
Diminution mm	15.3*15.5*19.1

Table (7): Parameters for heat load

| Parameters	Value
Outside tempter T_o (C^o)	45
inside tempter T_i (C^o)	5
Aluminum sheet thickness (mm)	20
Paper cover thickness (mm)	20
Hi ($W/m^2 k$)	10
Ho ($W/m^2 k$)	10
Crock thermal conductivity (W/mK)	0.0381
Paper cover thermal conductivity (W/mK)	0.14
Aluminum sheet thermal conductivity (W/mK)	237
foam thermal conductivity (W/mK)	0.01944
Figure of merit (Z) Bi_2Te_3 (K^{-1})	$1.3*10^{-3}$
Qc at (20mm) foam (W)	31
Qc at (40mm) foam (W)	23
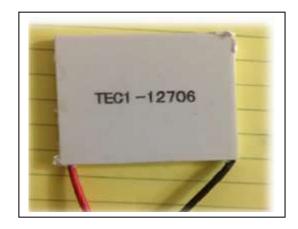
Figure (4): Peltier Device
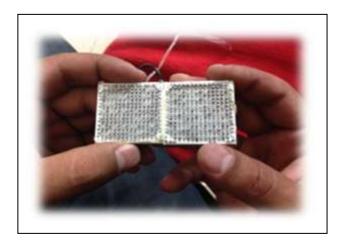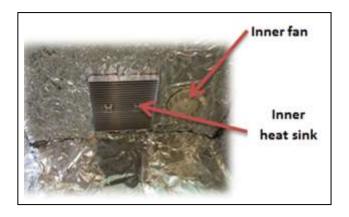
Figure (5): Inside Peltier Device

Figure (6): SRD 12VDC – SL-C Relay

(a) Inner Side Refrigerator

(b) Open Door (front view)   *(c) Closed Door (front view)*

Figure (7): (a),(b),(c) Prototype Of Thermoelectric Refrigerator

Figure (8): UIN-T UT33C multimeter & thermometer

8. Experimentation:

An experimental and performance analysis on thermo electrical refrigerator is conducted. The cold end of the module is used in the design to cool the refrigerator box and the thermometer (UIN-TUT33C^o) shown in fig (8) is used to measure the temperature. The hot end is attached to heat sink for heat rejection. For analyzing the performances of the system the following different ambient temperature are used (35, 25, 20) C^o. which are selected according to the room temperature at different time. The ambient temperature is measured before switching ON the system. The temperature at every 20 minute interval is recorded. The readings are recorded for about 270 minutes. The experiment is repeated for the two thickness of foam (20mm, 40mm).

The conventional system is mainly designed to maintain a fix temperature; the experiments proved that the system designed approximately can maintain fix temperature. The Figures (10, 11, 12) shows the variations of temperature with time. The

lower temperature is attained about 6C^o and at time (150 minutes). It took nearly four and half hours to attained the same from (35,25, 20)C^o ambient temperature for 40mm foam insulator , (3.9 hours for 20mm) foam insulator and(3.5 hours) without insulator. The temperature drop at box is at an average (2, 2.2 And 2.6) C^o per hour for the three cases (without insulter, 20mm foam insulter & 40mm foam insulter) respectively.

9. Results and Discussion

To prove the design system, a prototype thermoelectric refrigerator is built and then the experiment is carried out. The test of thermoelectric refrigerator is done at different temperature ambient (35C^o), (25C^o),(20C^o) as shown in fig. (9),(10),(11) respectively . Different in temperature with thermoelectric cooler about (1 to 2)C^o.

At first the temperature measurement is done without any additional for the system design and with ambient temperature 35C^o, after that adding the foam coat with thickness of (20mm, 40mm) and with Aluminum sheet and compare all the results which are obtained from experiments .Repeated all these procedures steps for the other temperatures (25C^o) ,(20C^o) as shown in fig(9) &(10). The design with the modification by adding the foam coat in to two thickness and aluminum sheet have taken heat load (31W) at (20mm) foam thickness and (23W) at (40mm)foam thickness as shown in fig (12).

10. Conclusions

A thermoelectric cooling system (refrigerator) is designed and developed to achieve a long term cooling in condition of power failure in low power (60W) and low cost. The heat load (Q_c) achieved at the two thicknesses of foam (20mm) is (31W) and at

(40mm) is (23W). The thermo electrical is design to reach the temperature of enclosure at suitable degree. For using the equations in study , detailed information in terms of the parameters pertaining to the thermo electric module under consideration is required, average values of the parameters is used for design and implementation. From the plot of heat load (Q_c) against foam thickness the coefficient of parameters is depended on the temperature difference between the hot side and cold side of the module. The selection of thickness foam is according to standard of foam properties [10].

This study can be used for light heat load to lower the temperature to particular value. This case is one of advantageous project by using low power to drive the refrigerator.
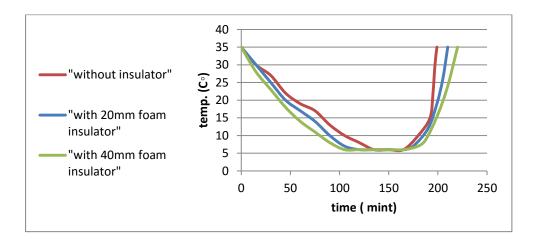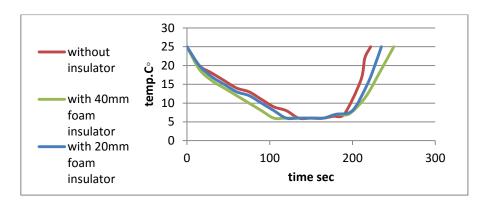

Figure (9:) Time Vs. Temp. at ambient 35 C^o
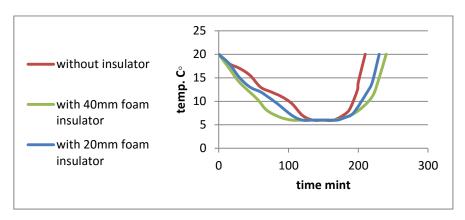
Figure (10): Temp. vs. time at ambient 25 Cᵒ

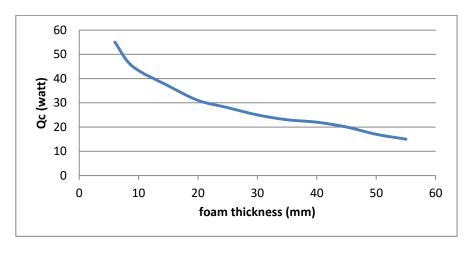**Figure (11): Temp. vs. time at ambient 20 Co**

Figure (12): Heat load (Qc) vs. foam thickness

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Appendix A: Nomenclature

Symbols	Meaning	Unit
I	Electrical current	A
L	Conductor Length	m
A	Cross section area	m^2
V	Voltage applied	V
ρ	Electric resistivity	Ωm
K	Thermal conductivity	W/mk
Q	Heat flow	W
α	Seeback coefficient	V/K
β	Peltier coefficient	
σ	Electric conductivity	A/Vm
T	Temperature	C^o
Cop	Coefficient of performance	
Z	Figure of merit	K^{-1}
R	Electric resistance	Ω
P	Electrical power	W
E out	Voltage output	V
T_c,	Cold temperature thermocouple	C^o
T_h	hot temperature thermocouple	C^o

تصميم وتنفيذ ثلاجه كهروحراريه ذات استهلاك قدره قليلة

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المستخلص: الهدف من هذه الدراسه هو تصميم نموذج اولي لثلاجه كهروحراريه باستخدام تاثير بيلتير للمحافظه على درجات حراريه معينه ضمن نطاق مقبول. الحجم الداخلي للثلاجه الكهروحراريه هو 6,8 لتر. اساسيات التصميم هي لتبريد حجم (6,8 لتر) الى درجات حراره مناسبه بوقت قصير، قدره قليله وكلفه واطئة. الثلاجه الكهروحراريه هي بديل جديد لانه يمكن الاستفاده بها من خسائر الطاقة الكهربائيه الى تبريد مفيد لذا الطلب عليها متزايد في مجال حفظ الاغذيه ،حفظ اللقاحات ،تبريد الاجهزه الالكترونيه والخدمات الطبيه .

المنظومه الكهروحراريه تتالف من:غرفة، مسرب حراري، مزدوج حراري، مروحه، مواد عازله ومصدر تيار مستمر. النتائج المستحصله في هذه الدراسه تبين استخدام طاقه اقل للثلاجه الكهروحراريه وهي تقريبا (60 واط)، وهذه الطاقه اقل من المستخدمه في الثلاجات التقليديه. في هذه الدراسه استخدم الفوم العازل بسمكين (20 ملم، 40 ملم) والحمل الحراري المستحصل هو (31واط ، 23واط) بالتعاقب.

الكلمات الرئيسية: تأثير بيلتير، الكهروحراريات، المسرب الحراري، معامل بيلتير، العازل الرغوي.