Palestine Polytechnic University

College of Engineering

Building an Experimental System for Waste Heat Transfer at Constant Temperature to TEG Using Water Phase Change

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Building an Experimental System for Waste Heat Transfer at Constant Temperature to TEG using Water Phase Change

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1/8/2017

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الملخص

يهدف المشروع بشكل أساسي الى الاستفادة من الطاقة الحرارية الضائعة من غازات العادم، وذلك من خلال استغلال هذه الطاقة في توليد طاقة كهربائية، يمكن استخدامها بشكل مباشر لتشغيل ادوات كهربائية أو تخزينها في بطارية من خلال استخدام أنظمة التحويل الكهروحرارية (Thermoelectric Generator). وحيث أن هذه الأنظمة لا تتحمل درجات حرارة مرتفعة، لذا فإنه يجب ضبط درجة حرارة التشغيل عند حدود التحمل لهذه الانظمة حتى لا تتعرض للتلف.

وفي هذا المشروع تم استخدام هذه الانظمة لبناء جهاز تجارب للاستفادة من الطاقة الحرارية الضائعة، حيث يستخدم فكرة تثبيت درجة الحرارة حوالي 100 درجة مئوية من خلال تغيّر الحالة الفيزيائية للماء من سائل الى بخار ومن البخار الى ماء على شكل دورة مغلقة.

Abstract

The project mainly aims to take advantage of the thermal energy lost from the exhaust gases, through the utilization of this energy to generate electrical energy, these can be directly used to run electric tools or stored in the battery by using thermoelectric generator systems (TEG). As these systems don't bear the high temperatures, so it must be set when the operating temperature limits under the endurance of these systems to protect it from damaging.

In this project, we used these systems to build the experiences device to benefit from the thermal energy lost, where the idea is set the temperature about 100 ° C by changing the physical state of water from liquid to steam and the steam to water in closed cycle.

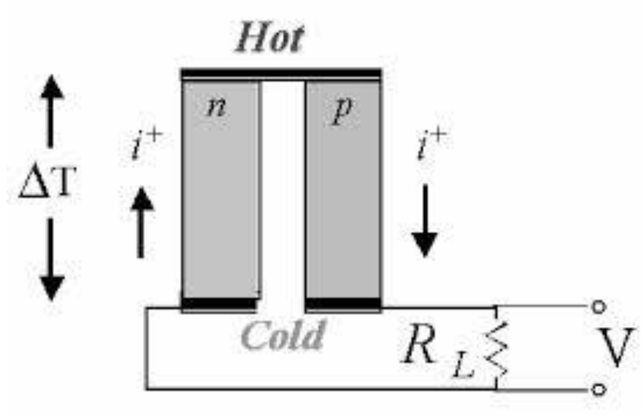
CHAPTER 1

1.1 Introduction

Energy harvesting is a subject of great scientific interest. Energy harvesting devices generate electrical power from energy sources that are often overlooked and untapped.

Some examples of energy recovery techniques are water heat recycling, heat recovery ventilation, heat recovery steam generators, and so on. Waste heat recovery by using ThermoElectric Generators (TEGs) is another attractive method. TEGs can directly convert thermal energy to electrical energy and have the advantages of compact device, light weight, no noise, and no mechanical vibration. TEGs have found its potential in many applications, such as space applications, thermal energy sensors. Waste heat from automotive vehicles is considerable as well. For a typical gasoline-fueled-internal-combustion-engine vehicle, about 40% of the fuel energy is discharged from the exhaust pipe and about 30% is lost into the coolant. Making good use of these waste heats improves the energy efficiency and saves money and if a small percentage of this waste energy could be regenerated into electric power and used to charge the battery pack of a Hybrid or Extended Range Electric Vehicle, or prevent the actuation of a conventional vehicle's alternator. Major Original Equipment Manufacturers (OEMs) like BMW and Honda testing this technology. Rotten Gruber said in initial research work involves a high-temperature circuit "A heat exchanger recovers heat from the engine exhaust; the heat is used to warm a fluid under high pressure. The heated fluid then turns into steam to power an expansion turbine that generates electric energy from the recovered heat. The reclaimed heat can provide up to 10% improvement in fuel consumption for long-distance journeys in a vehicle powered by a turbocharged four-cylinder engine [1].

This work focuses on exploring ways to obtain additional energy from the waste heat of source using the basic thermoelectric generator, which consists of thermocouples, and have both p-type and n-type elements and are connected electrically in series to obtain the desired output voltage and thermally in parallel. Heat flows into the hot side of the thermocouple and is rejected from the cold side, which produces an electric potential. The electric potential is proportional to the temperature difference between the hot and the cold junctions [2]. The basic thermoelectric generator is shown in the next page in **Figure 1.1.**



Figur1.1: Basic Conventional Thermoelectric Generator [2].

In a conventional thermoelectric generator, the hot ends of both p-type and n-type materials are connected electrically, and a load is connected across the cold junction to produce a voltage (Seebeck effect). In a thermoelectric generator, the load is connected the electrical load, thereby providing electrical power. TEG devices are generally at the hot end for ease of connection. The voltage produced causes current flow through temperature limit devices. There has a source temperature must be controlled, and in most of waste heat case the temperature is variable, and can easily reach high level above those that the TEG can resist. Thus, controlling the source temperature to stay under the temperature limit of TEG is an essential element in waste heat recovery in this project, the water phase change will be used for this purpose. This helps to control temperature and increase heat flow at the same time due to heat of evaporation (Control in the latent heat of water).

1.2 Purpose of the Project

The objective of this project is an improvement of previous project, which it was Building an Experimental System for Waste Heat Transfer at Constant Temperature to TEG Using Water Phase Change to meet:

1) Converts waste heat directly into electrical energy at constant temperature.
2) Determine the effect of using water phase change on power output.
3) Determine the effect of quantity of water that using in phase change.
4) Determine the percentage of the project's success (Efficiency).

1.3 Problem Statement and Statement of Need

The system built using water phase change in heat transfer from the heater to evaporate water to generate steam. In this project, we endeavor to stabilize the temperature under than the temperature limit for TEG, to protect and avoid damage TEGs. The need for additional efficiency is dictated by the subsequent need to utilize energy from that source. This project focuses on investigating the possibility of increasing the efficiency of the current process in which energy is extracted from water vapor. By adding fines on cold side of thermoelectric generator (TEG) and on upper plate of inside the case, it might be possible to convert some of the enthalpy of vaporization to electrical work.

1.4 Scope of the Project

The scope of this project is to determine the effectiveness of temperature control and energy transfer through capturing some of the entropy of vaporization of water.

1.5 Importance of the Project

The experimental system that is going to be built could be used in labs, and using a TEG and water phase change will achieve better results for her transfer in terms of constant temperature. Vehicles containing this device can charge battery for electric services, and minimize the need for auxiliary batteries. The project investigates one promising method for raising the efficiency of thermoelectric generator systems for use in electric services vehicles with the hope of increasing their acceptance for use in general transportation. Possible benefit of using this technology in vehicles helps to reduce of emission of Green House Gases from transportation sources, and reduce fuel consumption. The project could help to create a cleaner environment.

1.6 Methodology

The Thermoelectric Generator (TEG) project lead by BMW is focused on generating electric current from waste heat to improve overall engine efficiency. There is great potential for considerable fuel savings if the electrical energy required by all of the systems in an automobile can be produced using waste heat rather than relying solely on the vehicle's generator. In the beginning, TEG was installed as a separate module in the exhaust system underneath the vehicle, engineers of BMW decided to integrate the TEG in the radiator of the exhaust gas recirculation system. In this configuration, customer testing has shown that 250 Watts can be generated while CO_2 emissions and fuel consumption are reduced by 2% at the same time. Researchers forecast that TEGs will lead to fuel consumption savings of up to 5% under real everyday driving conditions in the future [3].

Figure 1.2 shows the design that works to reduce environmental pollution and increase fuel economy.

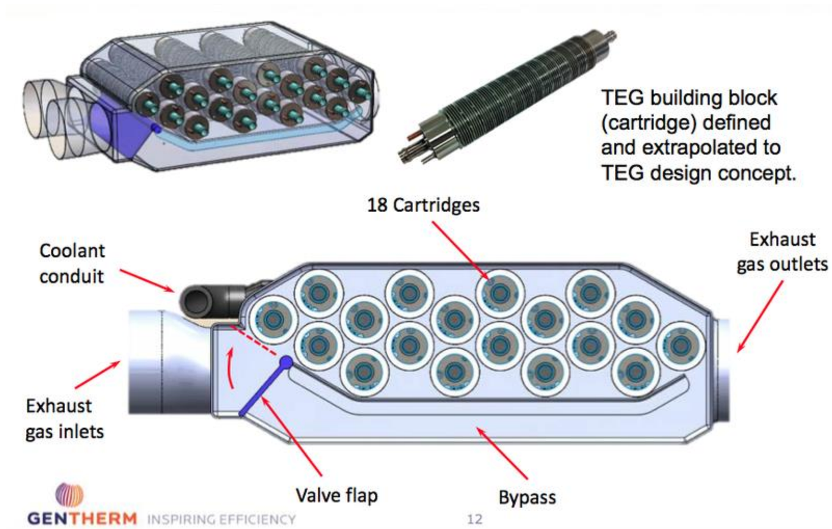


Figure 1.2: Design to reduce environmental pollution and increase fuel economy. [3]

The methodology used during this project will encompass the following:

1- Select suitable thermoelectric materials (TEG) that can be used at specific temperatures.
2- Collect material properties from reference software, research papers on thermoelectric materials, handbook of heat transfer and thermodynamic.
3- Calculate thermal resistances per square meter across the thermoelectric generator.
4- Calculate temperature difference across the thermoelectric material.
5- Calculate the overall efficiency of the generator.
6- Calculate the energy output of the generator.
7- Calculate the total energy outputs.

8- Calculate the percentage increase in overall efficiency.

The collected data includes temperatures and material properties at specific temperatures.

1.7 Project System

The project system has several components, **1-Gas Cylinder** to supply heat energy to heat the water inside the system by **2-Heater Core** to convert it into a vapor phase that travels through the **3-Steam Pipe** to the **4- Condensation Box** where it insulated thermally from all surfaces without the upper surface, were the heat energy transfer from this surface, and under this surface (inside) we set two fins to increase the area of heat transfer, and upper it (hot side) we set the **5-TEG** which it's number 6 are connected in series and above TEGs existing **6- Fins and Fans** to cooling upper side of TEGs, and then the steam cools (loss energy) and condenses to return in liquid phase, and returns through **7-Liquid Pipe** to Heater Core flow through **8-Pressure Gauge**, **9-Thermistor** and **10-Flow Meter** to read its value. The **Figure 1.3** shows the form of the experimental system.

Figure 1.3: Form of the project system

1.8 Assumptions

1- Isolated system.
2- Device dimensions are standard.
3- Closed volume analysis system.
4- The tank is stationary and thus the kinetic and potential energy changes are zero.

5- The energy stored in the resistance wires and heat transferred to heat exchanger, pipes and upper box is neglected.
6- The tank size = 3L.
7- Pure water weight = 400 gram.

1.9 .1 Schedule time _First semester

Table 1.1: Schedule Time of First Semester

Task\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Selecting Project Title																
Data Collection																
Identify Function and Task																
Design and Analysis																
Documentation																

1.9.2 Schedule Time _Second Semester

Table 1.2: Schedule Time of Second Semester.

Task\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Modify the design of project																
Data collection																
Analysis the system																
Documentation																

1.10 Budget and Cost Table

Table 1.3: Explanation of Coast (NIS)

Component	Number #	Coast of one unit (NIS)
Stand	1	300
Gas Cylinder	1	130
Heater Core	1	50
Condensation Box	1	250
Insulation	1	15
Pressure Gauge	1	25
Thermistor	2	35
TEG	6	100
Fins and Fans	5	20
Pipes	4	20
T Joint	3	12
Clamp Multimeter	1	300
Total Cost	———	1956

1.11 Project Organization

The present project has been prepared in five chapters:

- In Chapter 1, The document is introduction and objectives and problem state are focused.
- In Chapter 2, It will be exposed background (TEG).
- In Chapter 3, Proposed System Design.
- In Chapter 4, Building an Electrical Circuit System.
- In Chapter 5, Experimental Results and Conclusion.

CHAPTER 2

Thermoelectric Generator

2.1 Introduction

A thermoelectric generator or TEG (also called a Seebeck generator) is a solid state device that converts heat (Temperature Differences) directly into electrical energy through a phenomenon called the Seebeck effect (a form of thermoelectric effect). Thermoelectric generators function like heat engines, but are less bulky and have no moving parts. However, TEGs are typically more expensive and less efficient. The following **Figure 2.1** shows the Thermoelectric generator.

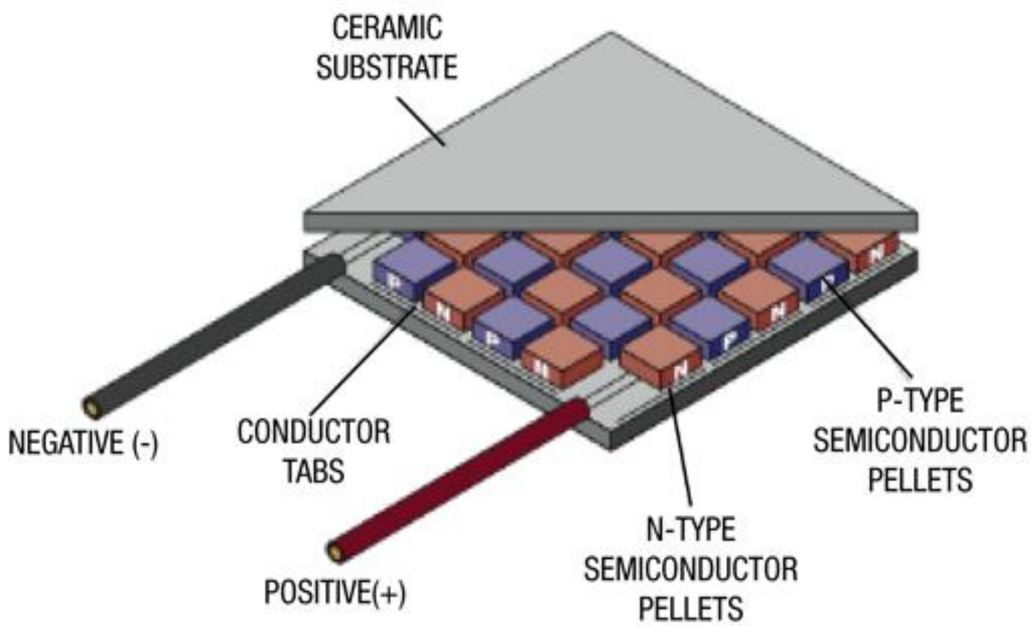


Figure 2.1: Thermoelectric generator [2].

Thermal gradient formed between two dissimilar conductors can produce electricity, at the heart of the thermoelectric effect is the fact that a temperature gradient in a conducting material results in heat flow, this results in the diffusion of charge carriers. The flow of charge carriers between the hot and cold regions in turn creates a voltage difference.

2.2 Seebeck Effect

The Seebeck effect is the development of a voltage difference that is proportional to the temperature difference between two different materials. Seebeck discovered that when a closed loop is formed using two different metals at two junctions, with a temperature difference between the junctions, a compass needle placed near the loop is deflected. This deflection indicates that two metals at different temperatures produce a voltage that induces a current when the circuit is completed and the current produces a magnetic field. The Seebeck effect is the voltage created in the presence of a temperature difference between junctions of two different metals. Thus, when the metals form a closed loop, the voltage causes continuous current to flow in the conductors. The voltage developed will be reflect a temperature difference of the order of several micro volts per degree temperature difference [4]. The following **Figure 2.2** shows the principle Thermoelectric generator (Seebeck Effect).

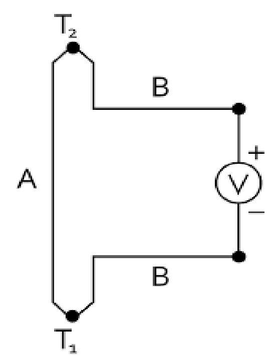


Figure 2.2: Seebeck Effect [4].

2.3 Construction

Thermoelectric power generators consist of three major components: thermoelectric materials, thermoelectric modules and thermoelectric systems that interface with the heat source.

a) Thermoelectric materials

Thermoelectric materials generate power directly from heat by converting temperature differences into electric voltage. These materials must have both high electrical conductivity (**σ**) and low thermal conductivity (**κ**) to be good thermoelectric materials. Having low thermal conductivity ensures that when one side is made hot, the other side stays cold, which helps to generate a large voltage while in a temperature gradient. The measure of the magnitude of electrons flow in response to a temperature difference across that material is given by the Seebeck coefficient (**IS**).

The main three semiconductors known to have both low thermal conductivity and high power factor were bismuth telluride (Bi_2Te_3), lead telluride (PbTe), and silicon germanium (SiGe). The **Figure 2.3** shows the performance of these materials at different temperatures.

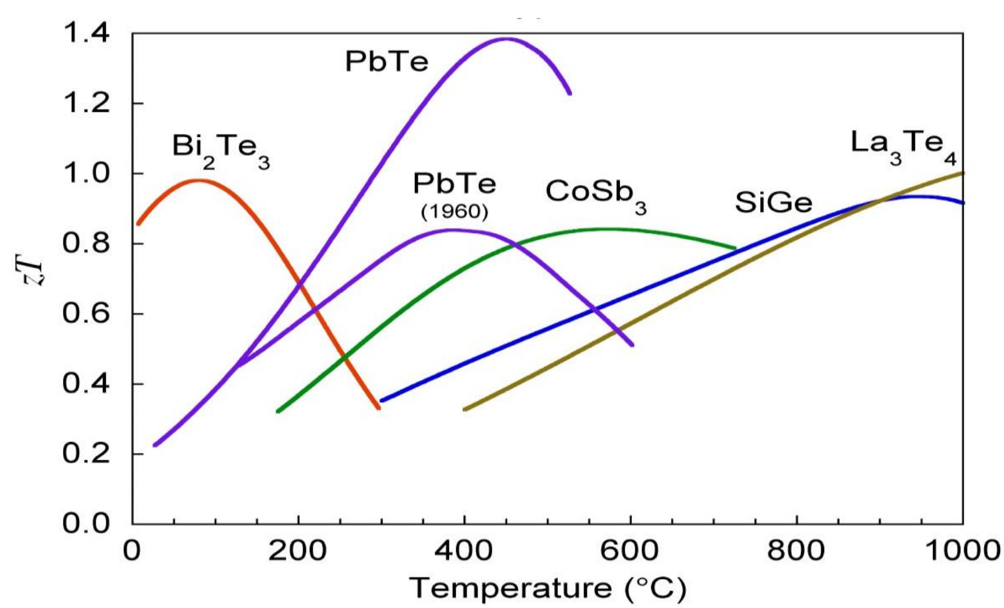


Figure 2.3: See beck Effect [5].

These materials have very rare elements which make them very expensive compounds.

What is ZT?

Expresses the efficiency thermoelectric depends on three main parameters: seebeck coefficient (α), electrical resistivity (ρ) and thermal conductivity (λ) at given temperature.

$$ZT = \frac{\alpha^2 T}{\rho\lambda} \tag{2.1}$$

b) Thermoelectric module

A thermoelectric module is a circuit containing thermoelectric materials that generate electricity from heat directly. A thermoelectric module consists of two dissimilar thermoelectric materials joining in their ends: an n-type (negatively charged); and a p-type (positively charged) semiconductors. A direct electric current will flow in the circuit when there is a temperature difference between the two materials. Generally, the magnitude has a proportional relationship with the temperature difference. (i.e., the more the temperature difference, the higher the current.)

In application, thermoelectric modules in power generation work in very tough mechanical and thermal conditions. Because they operate in very high temperature gradient, the modules are subject to large thermally induced stresses and strains for long periods of time. The following **Figure 2.4** shows the principle Thermoelectric generator.

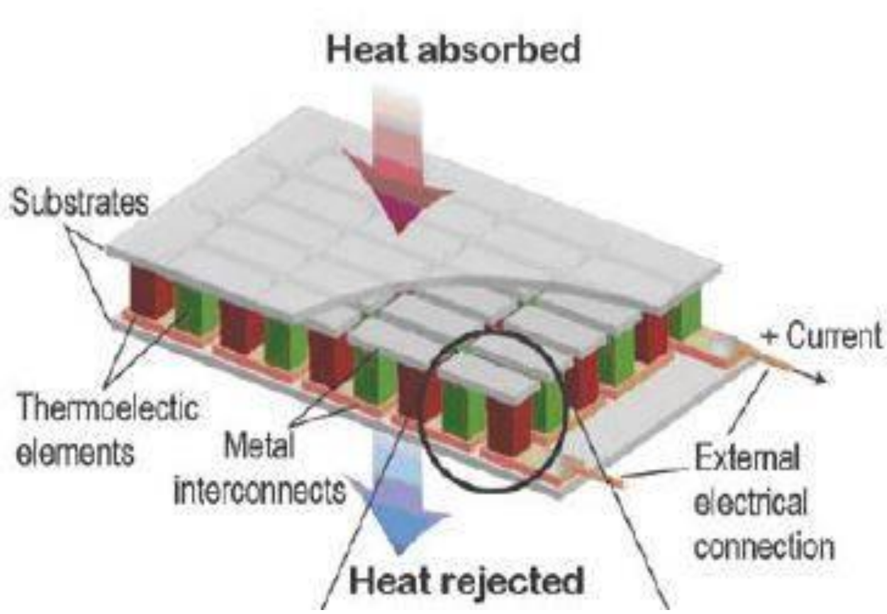


Figure 2.4: Thermoelectric module [2].

c) Thermoelectric system

Using thermoelectric modules, a thermoelectric system generates power by taking in heat from a source such as hot exhaust flue. In order to do that, the system needs a large temperature gradient, which is not easy in real-world applications. The cold side must be cooled by air or water. Heat exchangers are used on both sides of the modules to supply this heating and cooling.

There are many challenges in designing a reliable (TEG) system that operates at high temperatures. Achieving high efficiency in the system requires extensive engineering design in order to balance between the heat flow through the modules and maximizing the temperature gradient across them.

To do this, designing heat exchanger technologies in the system is one of the most important aspects of (TEG) engineering. In addition, the system requires to minimize the thermal losses due to the interfaces between materials at several places.

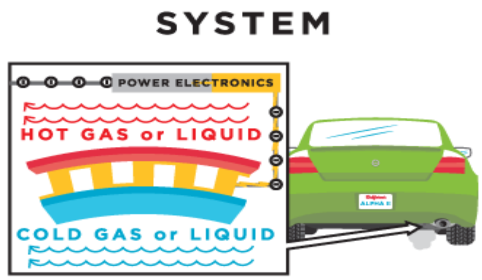


Figure 2.5: Thermoelectric system [2].

2.4 Materials for TEG

Only a few known materials to date are identified as thermoelectric materials. Most thermoelectric materials today have a ZT value of around unity, such as in Bismuth Telluride (Bi_2Te_3) at room temperature and lead telluride (PbTe) at 500-700K. However, in order to be competitive with other power generation systems, TEG materials should have ZT of 2-3 range. The **Figure 2.6** shows the Thermoelectric efficiency with temperature.

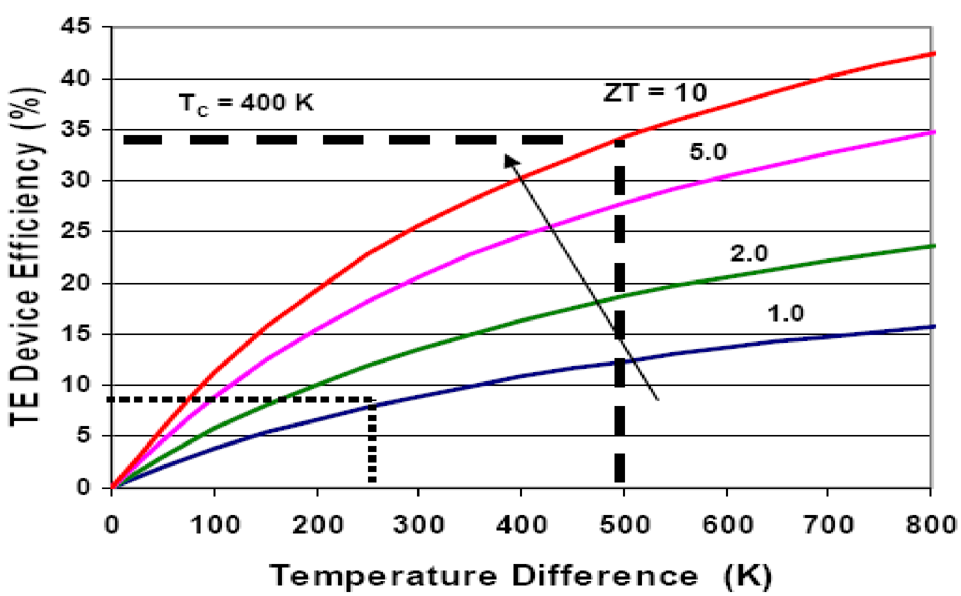


Figure 2.6: Thermoelectric efficiency with temperature [5].

Most research in thermoelectric materials has focused on increasing the Seebeck coefficient (IS) and reducing the thermal conductivity, especially by manipulating the nanostructure of the thermoelectric materials. Because the thermal and electrical conductivity correlate with the charge carriers, new means must be introduced in order to conciliate the contradiction between high electrical conductivity and low thermal conductivity as indicated.

When selecting materials for thermoelectric generation, a number of other factors need to be considered. During operation, ideally the thermoelectric generator has a large temperature gradient across it. Thermal expansion will then introduce stress in the device which may cause fracture of the thermoelectric legs, or separation from the coupling material. The mechanical properties of the materials must be considered and the coefficient of thermal expansion of the n and p-type material must be matched reasonably well.

2.5 Applications of TEG

Thermoelectric generators can be applied in a variety of applications. Frequently, thermoelectric generators are used for low power remote applications or where bulkier but more efficient heat engines such as Sterling engines would not be possible. Unlike heat engines, the solid state electrical components typically used to perform thermal to electric energy conversion have no moving parts. The thermal to electric energy conversion can be performed using components that require no maintenance, have inherently high reliability, and can be used to construct generators with long service free lifetimes.

With modern society to protect the environment, energy conservation is increasing, more people are considering how to effectively solar heat, ocean thermal, geothermal, industrial waste heat, heat of combustion waste heat, etc. Produced by various heat sources on earth into electricity. So thermoelectric power generation technology will be more widely used.

2.6 Efficiency

The efficiency of a thermoelectric converter depends heavily on the temperature difference ΔT=$(T_h - T_c)$ across the device. This is because the thermoelectric generator, like all heat engines, cannot have efficiency greater than that of a Carnot cycle ($^{\Delta T}/_{Th}$). The efficiency of a thermoelectric generator is typically defined as

$$\mathrm{h} = \frac{\Delta \mathrm{T}}{\mathrm{Th}} \frac{\sqrt{1+\mathrm{ZT}}-1}{\sqrt{1+\mathrm{ZT}}+{}^{\mathrm{Tc}}/_{\mathrm{Th}}} \tag{2.2}$$

Where the first term is the Carnot efficiency and *ZT* is the figure of merit for the device. While the calculation of thermoelectric generator efficiency can be complex, 4 use of the average material figure of merit, *ZT*, can provide an approximation for *ZT*.

$$\mathrm{ZT} = \frac{\alpha^2 \mathrm{T}}{\rho \mathrm{K}} \tag{2.3}$$

Here, Seebeck coefficient (α), electrical resistivity (ρ), and thermal conductivity (κ) are temperature (T) dependent materials properties.

Recently, the field of thermoelectric materials is rapidly growing with the discovery of complex, high-efficiency materials. A diverse array of new approaches, from complexity within the unit cell to nanostructure bulk, nanowire and thin film materials, has all lead to high efficiency materials.

CHAPTER 3

Proposed System Design

3.1 Proposed System Description and Specification

We will apply waste energy recovery system in build device experimental. Device consists of a water gas to generate steam, the fins heat exchanger to transfer thermal energy to TEG, and from the opposite surface contains fins heat exchanger with a fan to increase the temperature difference.

3.2 Thermoelectric Generator Module Specifications

We selected the TEGs type (TEP 1-126T200) in accordance with the operation temperatures in our system taking into account the material cost of each piece. In the following is a some of specifications we take it from its data sheet. The **Figure 3.1** shows the Thermoelectric generator module used in this project.

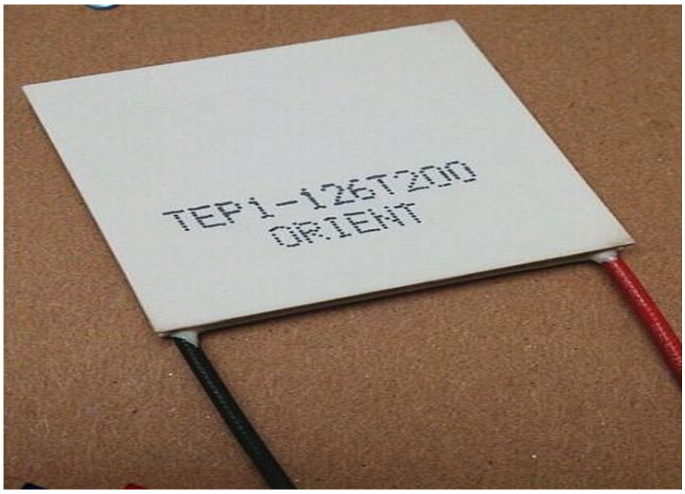


Figure 3.1: Thermoelectric generator module [2].

- Side posts with the word close to the cooling surface (cold)
- No word into the side of the posts in the heat absorbing surface (hot side)
- Red wire to positive, black wire to the negative, when the temperature difference between both power generation
- Use temperature between -40 degrees to 200 degrees:
- Short-term temperature 240 degrees
- Long-term temperature resistant to 200 degrees

Installation Notes: Power chip must be installed on a flat surface (especially cold). Mounting surface height error should not exceed 20 m Heating surface temperature shall not exceed 200 Degree.

This module has a weight of 25 grams, dimensions as shown in **Figure 3.2** and **Table 3.1**, output voltage, current and power as shown in **Figures 3.3**, **3.4** and **3.5**, respectively [5].

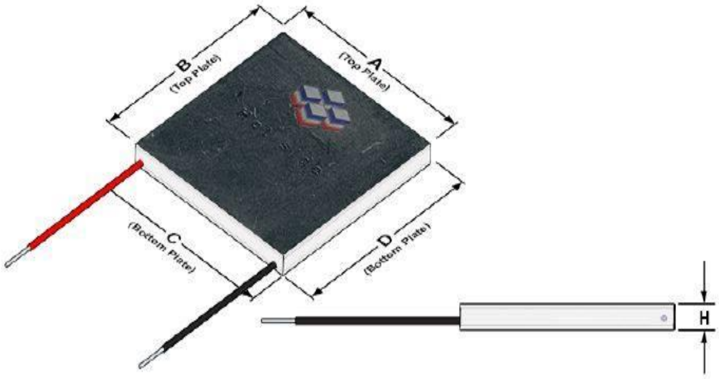


Figure 3.2: Thermoelectric module dimensions [5].

Table 3.1: Thermoelectric module dimensions. (All dimensions in mm)

Top plate		Bottom plate		Height
A	B	C	D	H
40	40	40	40	3.3

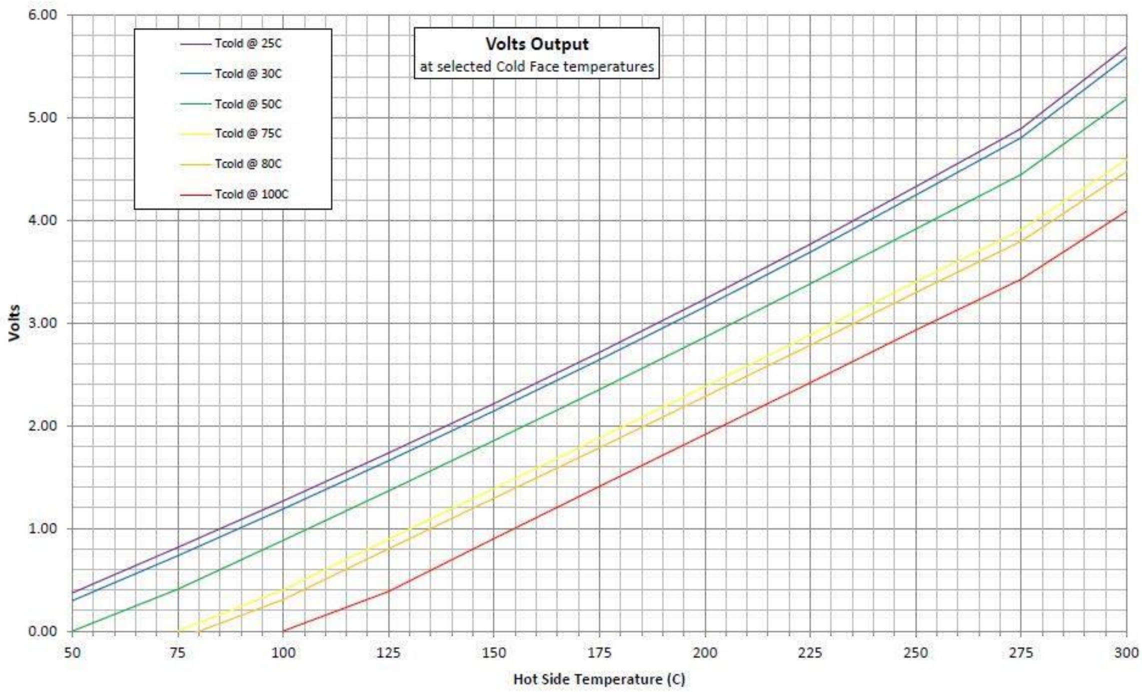


Figure 3.3: TEG output voltage [5].

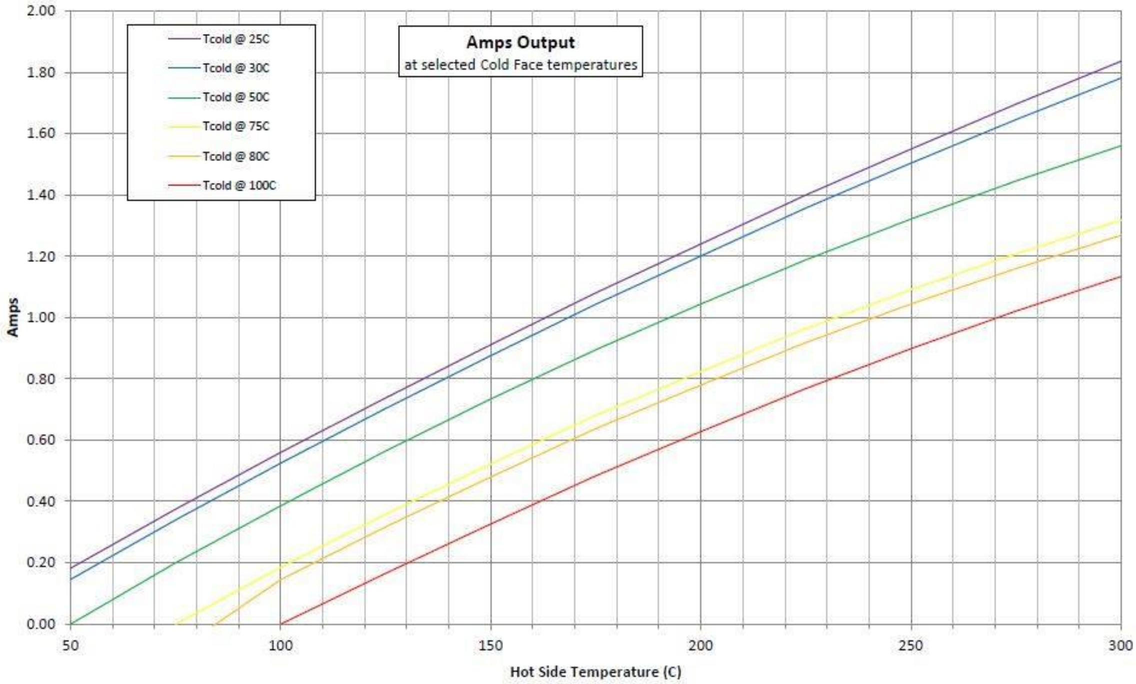


Figure 3.4: TEG output current [5].

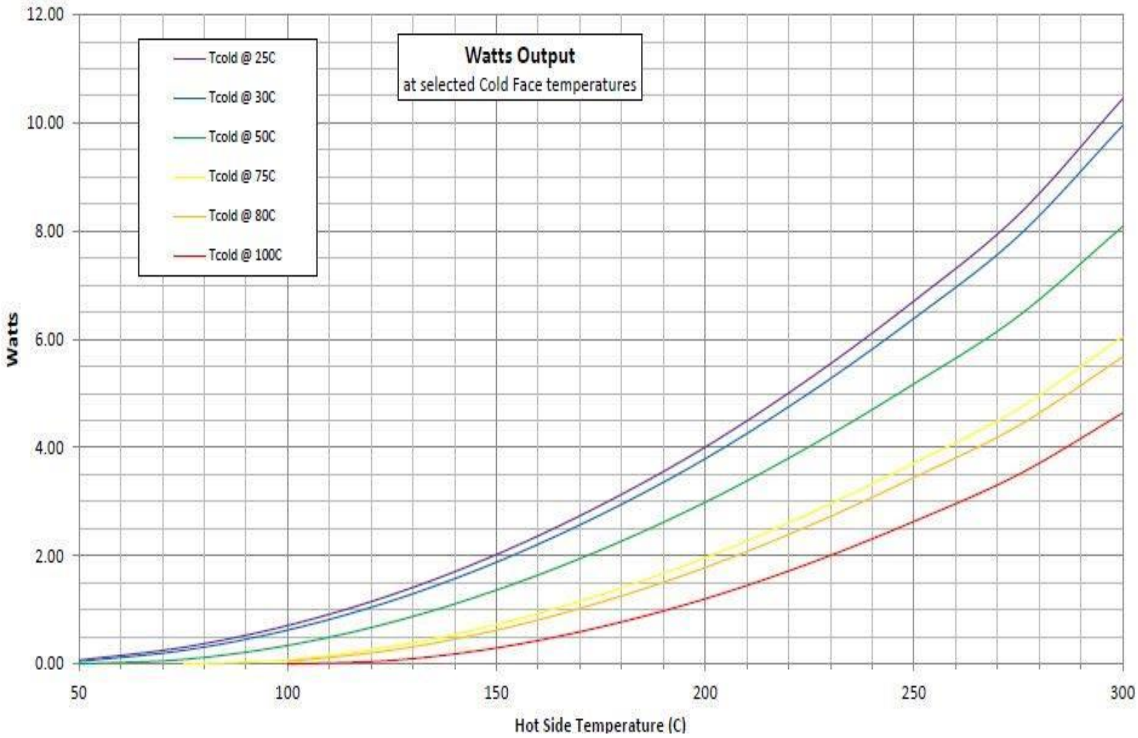


Figure 3.5: TEG output power [5].

3.3 System Operating Principle

When operation device the water is heated and converted from a liquid to a vapor and produces energy transmitted to the (TEG) through the heat exchanger fins while maintaining the required degree of the scope of the operating temperature, and the (TEG) converts it into electricity are shipped in battery.

3.4 System Design Components

3.4.1 Energy Balance:

The conservation of energy principle can be expressed as follows: The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process. That is,

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the system}\end{pmatrix} = \begin{pmatrix}\text{Change in the total}\\ \text{energy of the system}\end{pmatrix}$$

$$E_{in} - E_{out} = \Delta E_{A=system} \tag{3.1}$$

This relation is often referred to as the **Energy Balance** and is applicable to any kind of system undergoing any kind of process. The successful use of this relation to solve engineering problems depends on understanding the various forms of energy and recognizing the forms of energy transfer [6].

The change in the total energy of a system during a process is the sum of the changes in its internal, kinetic, and potential energies and can be expressed as

$$\Delta E = \Delta U + \Delta KE + \Delta PE \tag{3.2}$$

Where,

$$\begin{aligned} \Delta U &= m\left(u_2 - u_1\right) \\ \Delta KE &= \frac{1}{2} m\left(V_2^{\,2} - V_1^{\,2}\right) \\ \Delta PE &= mg\left(z_2 - z_1\right) \end{aligned} \tag{3.3}$$

When the initial and final states are specified, the values of the specific internal energies u_1 and u_2 can be determined directly from the property tables or thermodynamic property relations. Most systems encountered in practice are stationary, that is, they do not involve any changes in their velocity or elevation during a process **Fig.3.5**. Thus, for stationary systems, the changes in kinetic and potential energies are zero (that is, KE=PE=0), and the total energy change relation in Eq. 3.1 reduces to ΔU=E-U for such systems. Also, the energy of a system during a process will change even if only one form of its energy changes while the other forms of energy remain unchanged [6].

Stationary Systems

$$z_1 = z_2 \rightarrow \Delta PE = 0$$
$$V_1 = V_2 \rightarrow \Delta KE = 0$$
$$\Delta E = \Delta U$$

Figure 3.5: For stationary systems ΔKE = ΔPE=0; thus ΔE= ΔU [6].

In the next **Figure 3.6**, shows how to get the temperature nearly constant from temperature 100(C) to 120(C).

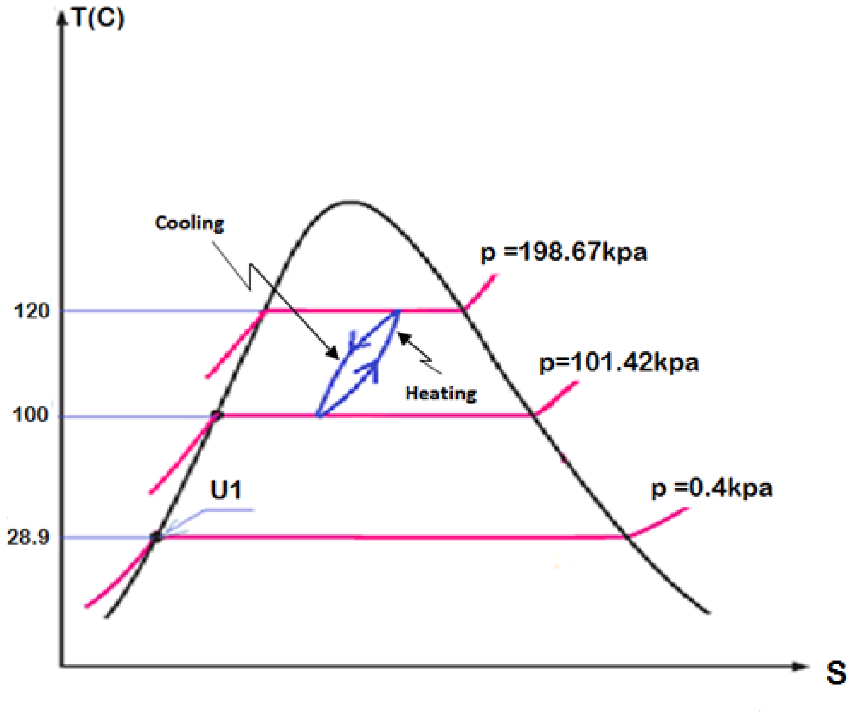


Figure 3.6: T-S diagram.

There are three graphs in the previous chart. The first graph shows boiling water at a temperature of 28.96 C, pressure 0.4 kPa and then the energy system needs to be calculated by the Eq.3.3. The second graph shows the beginning of the installed temperature at a temperature of 100 C and pressure 2 kPa. The third graph shows the introduction of energy into the system stops at a temperature of 120 C and pressure 198.67 kPa. The cooling and heating graph shows install temperature during system work.

In the next **Figure 3.7,** shows how the water behaves on a constant volume system with different temperatures.

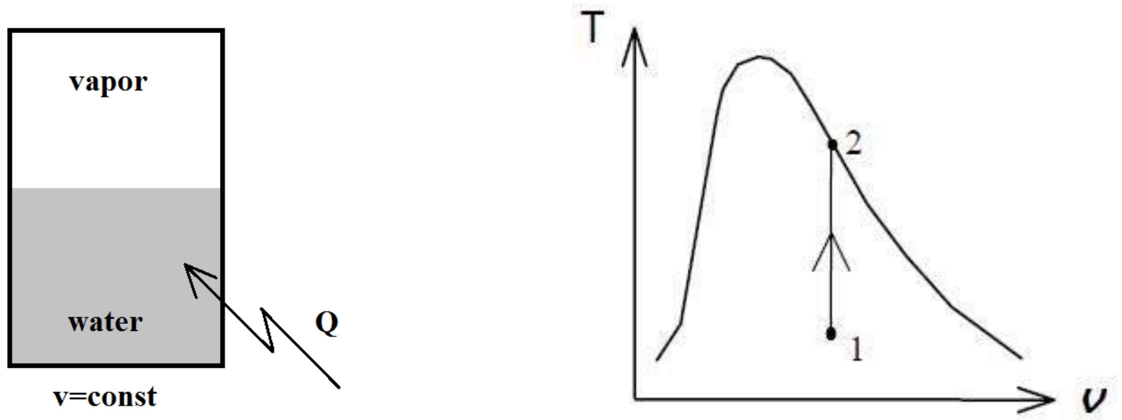


Figure 3.7: T-V diagram [6].

3.4.2 Insulation:

Thermal insulation is the reduction of heat transfer (the transfer of thermal energy between objects of differing temperature) between objects in thermal contact or in range of radiative influence. Thermal insulation can be achieved with specially engineered methods or processes, as well as with suitable object shapes and materials. Heat flow is an inevitable consequence of contact between objects of differing temperature. Thermal insulation provides a region of insulation in which thermal conduction is reduced or thermal radiation is reflected rather than absorbed by the lower-temperature body.

The insulating capability of a material is measured with thermal conductivity (k). Low thermal conductivity is equivalent to high insulating capability (R-value). In thermal engineering, other important properties of insulating materials are product density (ρ) and specific heat capacity (c). In the following **Table 3.2** shows the types and characteristics of insulators [7].

Table 3.2: Shows the Types and Characteristics of Insulators [7].

	Type	Temperature range, °C	Thermal conductivity, mW/m · °C	Density, kg/m^3	Application
1	Linde evacuated superinsulation	−240–1100	0.0015–0.72	Variable	Many
2	Urethane foam	−180–150	16–20	25–48	Hot and cold pipes
3	Urethane foam	−170–110	16–20	32	Tanks
4	Cellular glass blocks	−200–200	29–108	110–150	Tanks and pipes
5	Fiberglass blanket for wrapping	−80–290	22–78	10–50	Pipe and pipe fittings
6	Fiberglass blankets	−170–230	25–86	10–50	Tanks and equipment
7	Fiberglass preformed shapes	−50–230	32–55	10–50	Piping
8	Elastomeric sheets	−40–100	36–39	70–100	Tanks
9	Fiberglass mats	60–370	30–55	10–50	Pipe and pipe fittings
10	Elastomeric preformed shapes	−40–100	36–39	70–100	Pipe and fittings
11	Fiberglass with vapor barrier blanket	−5–70	29–45	10–32	Refrigeration lines
12	Fiberglass without vapor barrier jacket	to 250	29–45	24–48	Hot piping
13	Fiberglass boards	20–450	33–52	25–100	Boilers, tanks, heat exchangers
14	Cellular glass blocks and boards	20–500	29–108	110–150	Hot piping
15	Urethane foam blocks and boards	100–150	16–20	25–65	Piping
16	Mineral fiber preformed shapes	to 650	35–91	125–160	Hot piping
17	Mineral fiber blankets	to 750	37–81	125	Hot piping
18	Mineral wool blocks	450–1000	52–130	175–290	Hot piping
19	Calcium silicate blocks, boards	230–1000	32–85	100–160	Hot piping, boilers, chimney linings
20	Mineral fiber blocks	to 1100	52–130	210	Boilers and tanks

Insulation Calculations:

Q: Heat Transfer Through Aluminum [W].

K: Thermal Conductivity [W/m°C].

K_f: Fiber Glass Thermal Conductivity [W/m°C].

R_{th}: Thermal Resistance of The Various Materials [m^2°C$/W$].

h_i: Convective Heat Transfer Coefficient from The Hot Water [W/m^2°C].

h_o: Convective Heat Transfer Coefficient from Air [W/m^2°C].

U: Overall Heat Transfer Coefficient [W/m^2°C].

ΔT: Difference Temperature Between In and Out the System [°C].

A: Outside Area for System [m^2].

ΔX: Insulation Thickness [m].

l: Length of Box [m].

w: Width of Box [m].

t: Thickness of Box [m].

<u>Givens:</u>

K_{AL}= 205 [W/m℃]

K_f = 0.086 [W/m℃]

h_i=6000 [W/m^2℃]

h_o=22.7 [W/m^2℃]

T_{out}= 30 (℃) =303 [K]

T_{in}= 120 (℃) = 393 [K]

l= 260 [mm]

w= 100 [mm]

t = 3 [mm]

<u>Solution:</u>

$$A = l \times w$$

$$= 0.26m \times 0.10m$$

$$= 0.026\ [m^2]$$

Without Insulation:

$$R_{th,\text{without insulation}} = \frac{1}{\text{hi}} + \frac{1}{\text{ho}} + \frac{\Delta\text{X}}{\text{Kf}} \tag{3.4}$$

$$R_{th} = \frac{1}{6000} + \frac{1}{22.7} + \frac{0.003}{205}$$

$R_{th,\text{without insulation}}$ = 0.044 [℃/W]

$$U = \frac{1}{Rth} \tag{3.5}$$

U=22.7 [W/m^2℃]

$Q_{\text{without insulation}} = U \times A \times \Delta T$ (3.6)

$Q_{\text{without insulation}} = 22.7 \times .026 \times (393 - 303)$

$Q_{\text{without insulation}} = 53.118$ [W]

With Insulation:

Assume we would reduce the heat loss through the wall by 80 percent.

$$\frac{\text{Rth without insulation}}{\text{Rth with insulation}} = 0.2$$

$$\frac{\text{Rth without insulation}}{\text{Rth with insulation}} = \frac{0.044}{\text{Rth with insulation}} = 0.2$$

$R_{\text{th,with insulation}} = \frac{0.044}{0.2} = 0.22$

$R_{\text{th,with insulation}} = R_{\text{th,,without insulation}} + R_f$

$0.22 = 0.044 + R_f$

$R_f = 0.22 - 0.044$

$= 0.176$ [$°C/W$]

We know that:

$$R_f = \frac{1}{hi} + \frac{1}{ho} + \frac{\Delta x}{kal} + \frac{\Delta x}{kf}$$

$$0.176 = \frac{1}{6000} + \frac{1}{22.7} + \frac{0.003}{205} + \frac{\Delta x}{0.086}$$

X = 0.0113 = 11.3 [mm]

$$U = \frac{1}{Rf}$$

U = 5.68 [W/m^2°C]

$Q = U \times A \times \Delta T$

$Q = 1.196 \times 0.026 \times (393 - 303)$

Q = 13.92 [W]

3.5 Sketch for components system

3.5.1 Gas Cylinder:

A gas cylinder or tank is a pressure vessel used to store gases at above atmospheric pressure. High-pressure gas cylinders are also called bottles. And it contains Liquefied petroleum gas or liquid petroleum gas (LPG or LP gas), also referred to as simply propane or butane, are flammable mixtures of hydrocarbon gases used as fuel in heating appliances, cooking equipment, and vehicles. The following **Figure 3.8**, shows The Gas Cylinder.

Figure 3.8: Shows the Gas Cylinder [8].

3.5.2 Heater Core:

A heater core is a mini radiator part of the heating systems that is snuggled deep inside the center of your dash, it is used in heating the cabin of a vehicle. When the heat is on, hot coolant from the vehicle's engine block is passed through a bypass hose to a winding tube in the heater core where heat is transferred from the coolant to air that flows into the passenger compartment. Fins attached to the core tubes increase surface for heat to transfer to air that is forced past them, forced by a fan. We will use it in reverse, which will be used to heat the water passing through it and turn it from liquid to gas. Where it will get the thermal energy from burning the gas in the gas cylinder. The following **Figure 3.10,** shows the Heater Core.

Figure 3.9: shows Heater Core. [9]

3.5.3 Condensation Box:

The Condensation Box is called, because the condensation process is done in its interior. It is designed from aluminum because its conductivity is high and is equal to 205 W / m. It has two fins that Installed on the upper side of box to increase the area of heat exchange. The box has an entrance for steam and an outlet for condenser water. The dimensions of the box were chosen based on the area of the electronic pieces used and it thickness is proportional to the pressure and heat in this system. The following **Figure 3.10,** Shows Condensation Box.

Figure 3.10: The Condensation Box.

3.5.4 Pressure Gauge:

Many techniques have been developed for the measurement of pressure. Instruments used to measure and display pressure in an integral unit are called pressure gauges. The widely used to know pressure is Bourdon gauge, they are classified as mechanical pressure measuring instruments, and thus operate without any electrical power. Which it does both measures and indicates to the value of pressure. Bourdon pressure gauges are used for the measurement of relative pressures from (0.6-7000) bar. Also, these Bourdon pressure gauges are suitable for liquid or gaseous media, which are not highly viscous or crystallising, so long as they do not attack copper alloy parts. The following **Figure 3.11,** shows the Bourdon Pressure Gauge.

Figure 3.11 Bourdon Pressure Gauge [10].

3.5.5 Thermistor:

In the vehicle, the Thermistor is a device with a variable electrical resistance, determined by the ambient temperature: when cold, its resistance is high; when hot, its resistance is low. The vehicle's battery provides power to operate the gauge, when the ignition is switched on. The indicating meter is of either the common moving-coil or the bimetal-strip type. One of the earliest types of water temperature gauge was a thermometer mounted in perhaps the easiest and most visible position at that time - on the radiator cap. A later type suitable for both oil and water temperature measurement employed a bimetal-strip device, enclosed within a heating coil, for both the transmitter and the dashboard indicator. When the engine is first switched on, the battery alone heats the coil; the mean battery current is therefore maximum and the indicator metal strip warms up, moving the pointer, to which it is attached, to the cold position. As the engine temperature increases, the water (or oil) has its own heating effect on the transmitter bimetal strip, so that less and less current is drawn from the battery. Thus, there is less heating of the indicator bimetal strip, which cools, moving the pointer towards the hot position. The following **Figure 3.12,** shows The Thermistor.

Figure 3.12: Shows the Thermistor [11].

3.5.6 Flow Meter:

We designed a device that measures the flow of water passing through the system (condensed water). It is a Scaling glass tube that bears high temperature and pressure, and a manual seal to close the tube from the bottom. Where we close seal, and turn on the stopwatch and calculate the amount of water inside the pipe with time to know the amount of flow then. The following **Figure 3.13,** shows Flow Meter.

Figure 3.13: shows Flow Meter

3.5.7 Air Cooling System:

The environmental air can be used to cool the other side of the TEG’s, but it’s necessary to increase the surface area of TEG’s cold side in order to increase cooling efficiency. That can be achieved using a heat exchanger which may be aluminum fins settled on the TEG’s cold side, the next **Figure 3.14,** Show Fins Heat Exchanger.

Figure 3.14: Fins heat exchanger [12].

3.5.8 Clamp Multimeter:

The Type of   Clamp Multimeter is UNI-T UT 202. Were its use for monitoring the system and measurement the temperature under electronic pieces and temperature of pipes and connections. We will display their characteristics and functions. The following **Figure 3.15,** shows Clamp Multimeter.

Figure 3.15, shows Clamp Multimeter.

Specification:

- DC Voltage: 200mV / 2V / 20V / 200V / 600V
  - best accuracy: +/- (0.8% + 1)
- AC Voltage: 2V / 20V / 200V / 600V
  - best accuracy: +/- (1.2% + 5)
- AC Current: 2A / 20A / 200A / 400A
  - best accuracy: +/- (1.5% + 5)
- Resistance: 200 Ohm / 2 k Ohm / 20 k Ohm / 200 k Ohm / 2 M Ohm / 20 M Ohm
  - best accuracy: +/- (1% + 2)
- Temperature: from -40 to + 1000 ° C, from -40 to + 1832 ° F
  - best accuracy: +/- 1% + 3 (° C), +/- 1% + 6 (° F)

Special Functions:

- Auto ranging
- Diode
- Continuity buzzer
- Max Hold
- Data Hold
- Full icon display
- Sleep mode
- Low battery display
- Input impedance for Voltage measurement: 10 M Ohm
- Max. Display 1999 (35.6 x 18mm)

CHAPTER 4

Building an Electrical Circuit System

To build this system we need the electrical system consists of two circuits. The first, providing electric power to the thermistor, as in **Figure 5.1** and fans to operate and reduce the heat of the fins, were it was 3 fans and all was connected parallel with 12 volts, as in **Figure 5.2**. The second one takes the energy generated from the system, where we used 6 TEG's was connected series to generate output voltage up to 12 volts with load, capable of charging the car battery, the following **as in Figure 5.3**.

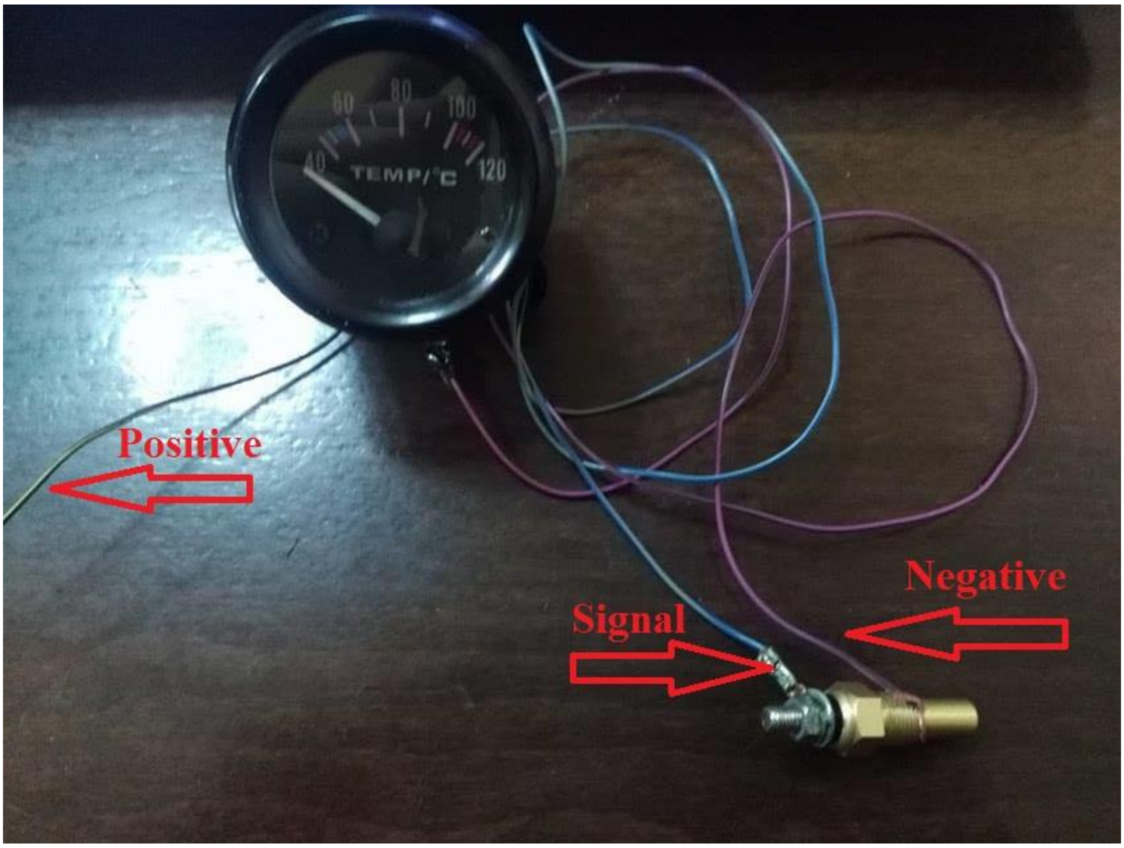


Figure 5.1: connect electric power to the thermistor

Figure 5.2: fans in parallel connected.

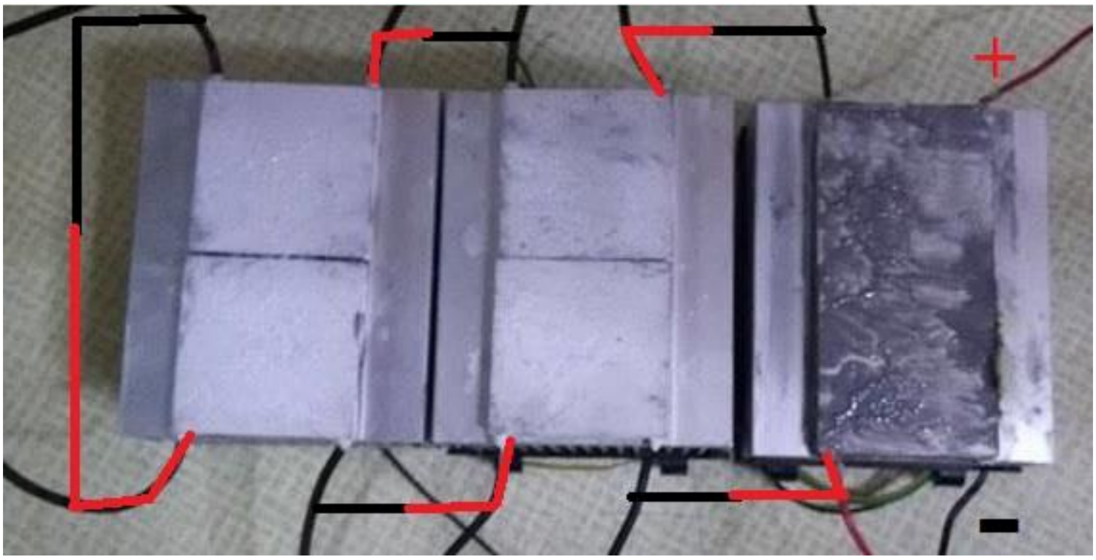


Figure 5.3: 6 TEG's connect in series.

CHAPTER 5

Experimental Results and Conclusion

5.1The experiment was carried out in environmental conditions:

1. The experiment was conducted in a closed room

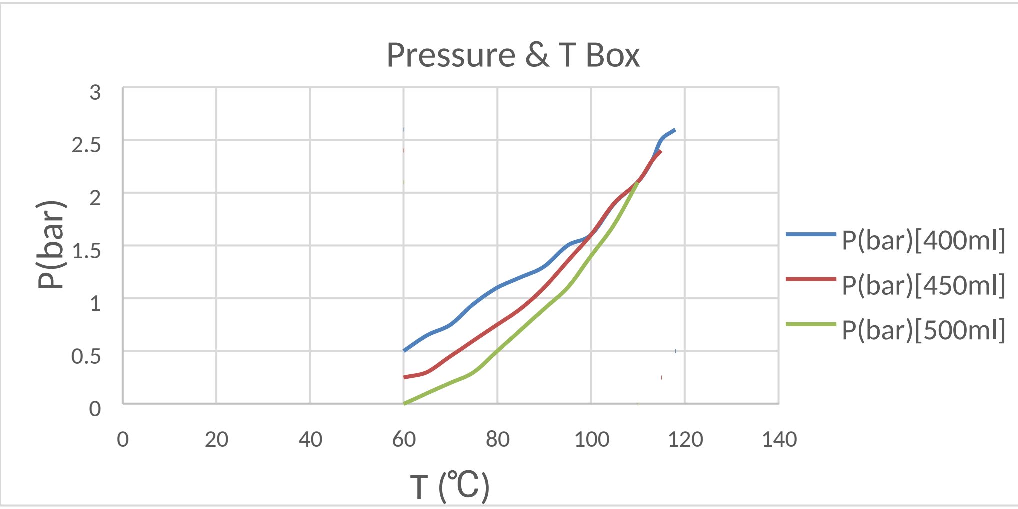
2. The experiment was conducted at 25C

3. The experiment was conducted at a pressure of 93 K psi

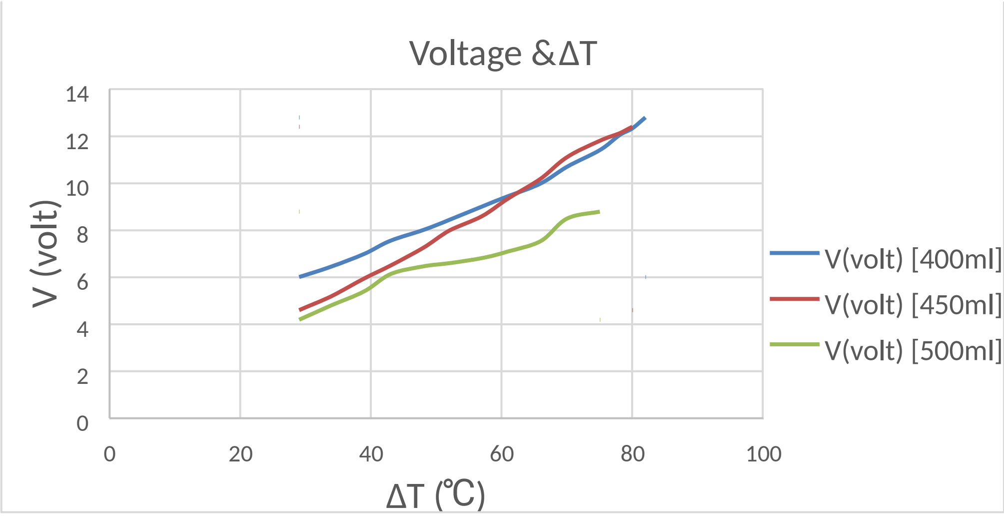
The result of the experiments divided to two sections. The first, at open loop circuit (without load), and the second, at closed loop circuit (with load). The load is 30 LEDs, it was connected each 3 LEDs in series as a group and all groups was connected in parallel.

5.2 Results at Open Loop Circuit

The next curve is show the relation between The Pressure (bar) and the Temperature (C) of the box for different volumes.

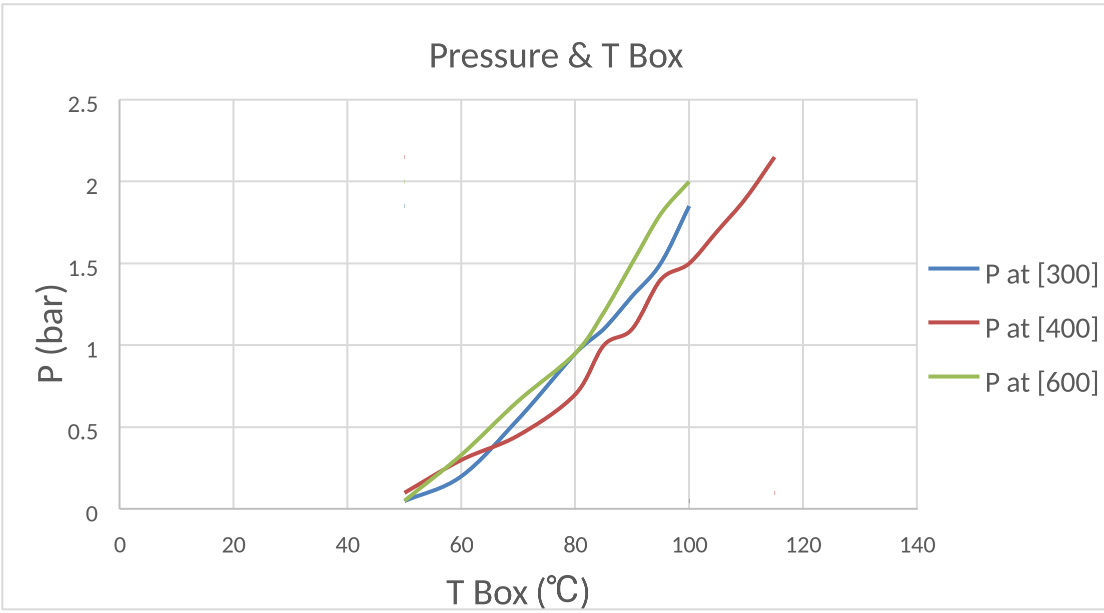


The next curve is show the relation between The Voltage (V) and the Delta temperature (C) of the box and fins for different volumes, at open loop circuit (without load).

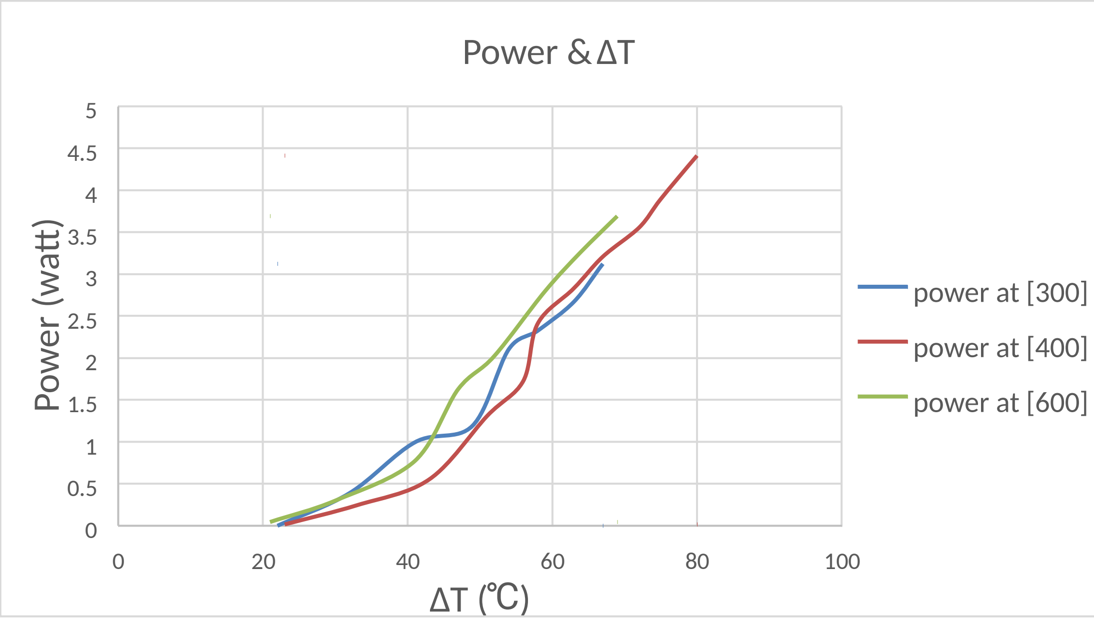


5.3 Results at Closed Loop Circuit

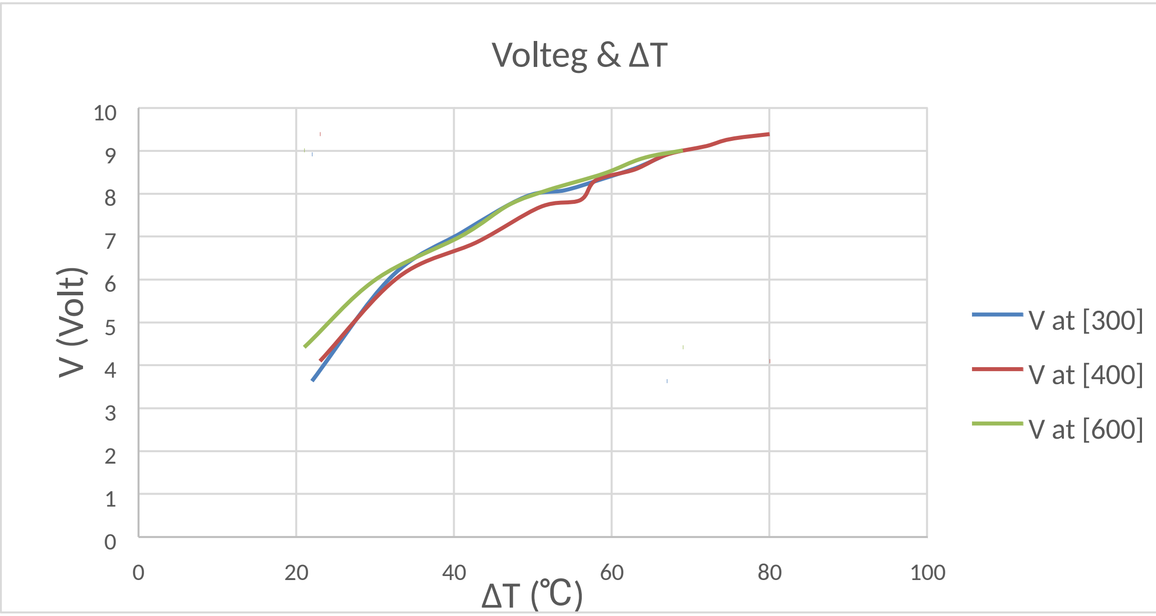
The next curve is show the relation between The Pressure (bar) and the Temperature (C) of the box for different volumes.



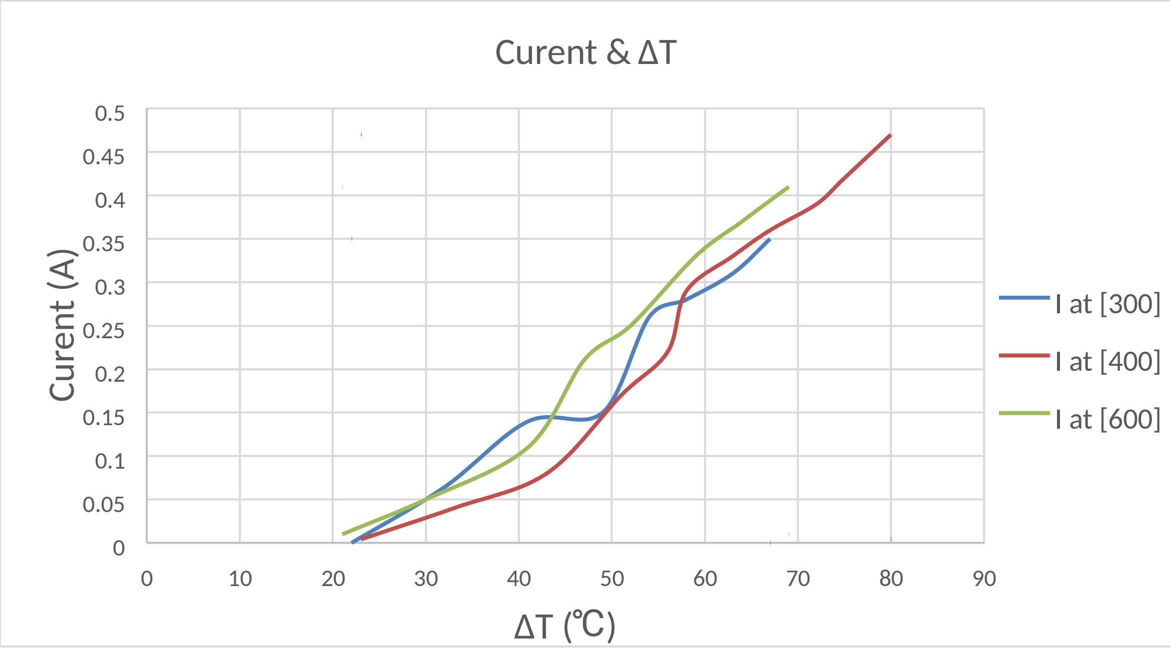
The next curve is show the relation between The Power (watt) and the Delta Temperature (T) of the box and fins for different volumes.



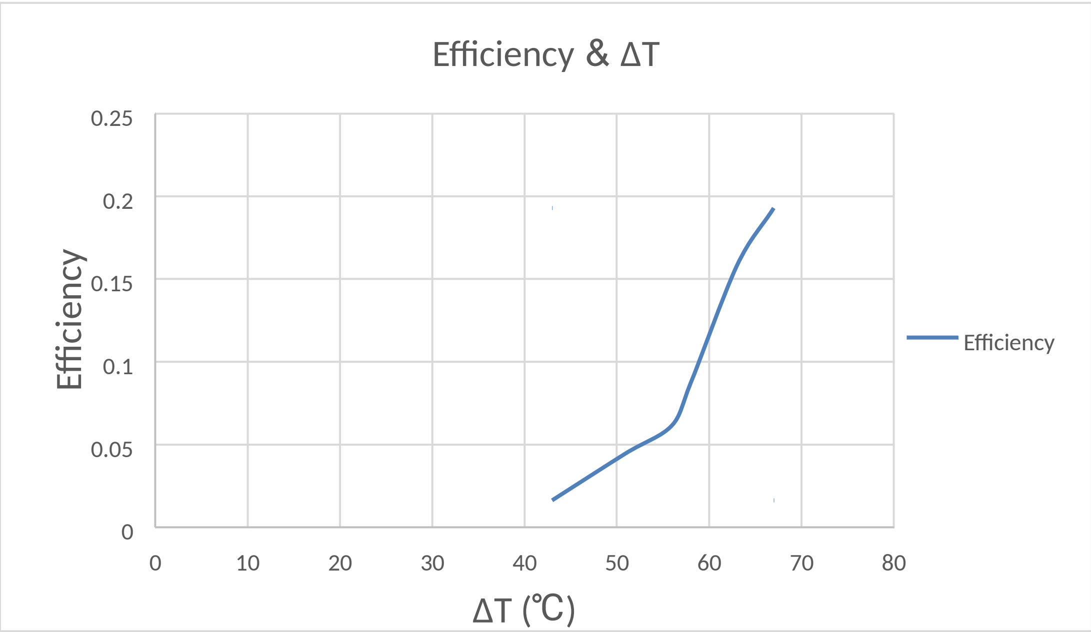
The next curve is show the relation between The Voltage (V) and the Delta temperature (C) of the box and fins for different volumes.



The next curve is show the relation between The Current (A) and The Delta Temperature (C) of the box for different volumes.



The next curve is show the relation between The Efficiency of the system and The Delta Temperature (C) of the box.



5.4 Conclusion:

The results at open loop circuit larger than closed loop circuit in voltage, because it hasn't load. But in the pressure, it was close to each other.

The results at close loop circuit was clear. The curves Indicate to more water in the system can increased pressure and output power, but here we are governed by the size of the all system. Were If the amount of water is small, the whole water will evaporate, thus decreasing in the condensation ratio. As the amount of water increases, the evaporation and condensation (phase change) will be rapid and the results will be very good, but it will be difficult to take the flow value of condensation water. Therefore, the appropriate value is a medium between that, so we selected the 400 ml.

The process of the phase change of water improved the results value, in terms of the output power and stability of the value of the output power at constant incoming heat. But the efficiency of the system was very low, because more than one reason. Firstly, the efficiency of TEGs was very bad as the largest energy it can generate about 8 watts in where the system gives heat in kilowatts and this heat is not exploited well. Also, the number of TEGs used is 6 pieces, this is a little and to improve results we should use 32 pieces instead of 6 pieces.

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