TED ANKARA COLLEGE FOUNDATION HIGH SCHOOL

PHYSICS SL

EXTENDED ESSAY

Investigation of Thermoelectric Generator to Be Used As an Energy Source in Daily Life

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Abstract

This essay studies the potential difference production capacity of thermoelectric generators, generators which can convert temperature difference that is applied to the ends of the generator to electrical energy and produce a potential difference, and if they are adequate to be used in our daily lives. A thermoelectric generator (TECI-12706TI25) has been used in this experiment. The system consisted of two containers which contains water of different temperatures. Thermoelectric generator is placed between these containers and by using a digital voltmeter, potential difference between the poles of the generator is measured. Results showed that by applying the maximum temperature difference that can be applied with this apparatus (80 C°), thermoelectric generator can only produce a potential difference approximately about 0.47 volts. However, data showed that temperature difference that is applied and potential difference that is produced is not directly proportional. In fact, graph showed that the general tendency is an exponential one, meaning that by using temperature differences greater than those which are used in this experiment; much more potential difference can be produced. (167 C° should be applied to obtain 1.5 volts and to power an average LED lamp, which works with approximately 1.7 volts, 180 C° of temperature difference should be applied to the ends of the thermoelectric generator.) Results showed that thermoelectric generator can be effective in industrial places where greater temperature differences are available or near ovens. As we do not encounter temperature differences like 180 C° in our daily lives, usage of thermoelectric generators in houses will not be very effective. However, further research and development can make thermoelectric generators more effective to be used against the destructive effects of global warming as they have no harm over the environment.

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1-Introduction

Energy is a vital requirement for today's society. Without energy, people cannot continue to their lives. However, energy sources get fewer and fewer every day. Considering the exponential increase in the number of people on the world, energy sources remain constant. This leads people to search for new ways to obtain energy. Governments rise the funding of the research for discovering new ways of producing energy. Scientists are working harder and harder on this problem, yet it is still not enough against the uncontrollable growth of human population. Countries started to use methods such as nuclear fission to produce more energy. However, its security is debatable and the effects it has on the environment cannot be restored. More environmental friendly ways such as barrages and wind-turbines cause no harm to the environment and yet produce energy without any raw material such as coal. The source of this energy is almost infinite, so it is suitable for being used as an energy source for the future generations, when all mines and petrol have drained. So it is important to find re-usable and recyclable energy sources.

I have been thinking about this problem and started researching for the ways of energy production. I focused on our daily life and tried to find a way to produce energy; energy that is spared and unused. I tried to find a method of producing energy during our daily activities. Eventually, I discovered that it is possible to produce electric energy from the temperature difference of two media. This seemed an excellent method of bringing the lost energy back and use this energy for other purposes. By using devices such as a Peltier device, it is possible to produce energy form the temperature difference of two media.

There is a significant energy loss in our houses, especially during winter. The heat energy that is supposed to keep the house warm, escapes to the outside with many ways. 31% of the energy leaks through floors, ceilings and walls, while 14% of the energy leaks through the fireplace and 10% through the windows. [1] This energy is released without any benefit. However, this temperature difference can be utilized and can be used as a battery. By using this method, electric energy is produced without any effort and it can be used repeatedly.

We can apply this to nearly everywhere. There is a high temperature difference in industrial ovens, or chimneys. It can be used on laptops, windows, water pipes or even on our body. The temperature difference between our body and the environment can be used to produce electricity. The potential difference may be low, but it is still enough for small electrical devices such as LED lamps or a small motor which can be used as a fan in a hot summer day. The applications are

[1] Home Energy Loss 1. *Michigan Environmental Education Curriculum. 3.10.2008. [http://techalive.mtu.edu/meec/module13/HomeEnergyLoss.htm]*

unlimited and the energy is recyclable so it is an adequate method to produce electricity in today's world.

By looking at the working mechanism of a thermoelectric generator, we can say that as the temperature difference between the media increases, the potential difference that is produced by the thermoelectric generator increases. So in industrial areas, which contains industrial ovens which are capable of producing hundreds degrees of temperature difference between the oven and the outer environment, potential difference that is produced by the generator will be higher. However, in residential areas where higher temperatures are rarely encountered, the potential difference produced by the thermoelectric generator will be lesser that industrial areas. So it is more efficient to use the thermoelectric generator in industrial areas or in places where has high temperature differences.

Thermoelectricity is an adequate way of producing energy as it has no harm to the environment and it is totally safe. In brings back the lost heat energy as electrical energy and serves as an environmental friendly method of energy saving. It could help slowing down the global warming and it could inspire people for new ways of producing energy due to temperature difference between walls or ovens for example. It is an alternative way for solar energy as they are both environmental friendly and they have no side effects or waste products. Thermoelectric generators can be used for years and they only need temperature difference to produce energy. Because of that, thermoelectric generators can be used as an energy saving device. They can produce energy for free.

2-Background Information

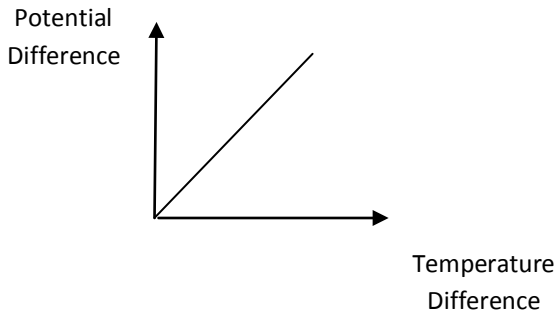
Thermoelectric effect is the conversion of temperature difference of two media into electrical energy. The heat difference between media is converted to potential difference and thus, an electromotive force is produced. The produced potential difference can be used as a simple battery in a direct current circuit. By this method, small electrical devices can be powered only by using the temperature difference.

The thermoelectric effect is reversible. Eventually, if a potential difference is applied to a thermoelectric generator, one side of the generator becomes hot and other side becomes cold, creating a temperature difference between the media. This system is used mainly in water dispensers. When a potential difference is applied to a thermoelectric generator inside a water dispenser, some water gets cold and some becomes hot, allowing the people to obtain hot and cold water. This effect of thermoelectricity is called Peltier effect. While conversion of temperature difference into potential difference is called Seebeck effect.[2] I will be using the Seebeck effect in this experiment.

Thomas Johann Seebeck, discovered the magnetic property of this effect. He set up an experiment consisting of two different metals at different temperatures. When a compass needle is brought nearby, he observed that the needle deflected due to the system. First, he thought that it is only a magnetic effect. However, after the discovery of electromagnetism, researchers found that a current flows through the wire and that current creates the magnetic effect. The thermomagnetic effect then became the thermoelectric effect. Amount of potential difference produced by the thermoelectric generator mainly depends on the temperature values of two media and the thermoelectric coefficients of the materials known as Seebeck coefficients. To put it in a formula;

$$V = (S_{\mathrm{B}} - S_{\mathrm{A}}) \cdot (T_2 - T_1) \quad 1$$

By looking at the formula, we can say that temperature difference is directly proportional with the potential difference. So the expected graph would be like:



[2] Thermoelectric Effect. Wikipedia. 4.10.2008. [http://en.wikipedia.org/wiki/Peltier_effect#Peltier_effect]

The potential difference produced by the generator is due to 2 factors: Charge-carrier diffusion and phonon drag:

a)Charge Carrier Diffusion

In metals, the elements that transfers heat from one end of a metal to the other end is electrons. When we heat a piece of metal, the avarage kinetic energy of the electron particles increase and they start to transfer this energy to nearby metal atoms. This heat transfer is directed towards the relatively cold part of the metal. While transferring this energy, electrons simply diffuse towards the low-energy part of the metal. This movement of electrons creates a current between the surfaces if the circuit is closed. If it is not, it creates a potential difference across the metals. This is called Charge carrier diffusion, in which electrons are used as charge carriers and they diffuse to the medium with lower heat energy.

b)Phonon Drag

The movement of electrons in a metal still continues when the temperature is same everywhere. The movement of electrons to one side of the metal is balanced by the movement of electrons to the opposite side. The net charge would be zero and there would not be a potential difference between the ends of the metal. However, the rate of the electrons may be changed due to impurities in the metal or some structural disorders. Due to these factors, electrons may not move at different rates. Electrons may be denser in one area that another due to electronegativity differences of impurities in a metal. This unbalanced scattering of electrons creates a potential difference across the metal. This is called as electrostatic voltage of a metal.

This two effects form the thermoelectric potential difference: The movement of heat carriers to one end from another and the imbalanced scattering of electrons in a piece of metal. This leads to a current and creates the electromotive force. By this method, we can put this energy into use.

In this experiment, the voltage producing capacity of a thermoelectric generator will be measured and at temperatures which we witness in our daily lives, its efficiency as a power source will be discussed. Mainly, Seebeck effect of thermoelectricity will be used rather than Peltier effect. If it is an adequate source of producing energy, it will provide a totally recyclable and environmental energy and will be efficient in reducing the electricity bills especially in a energy lacking country.

3-Experimentation

a)Research Question

Does a thermoelectric generator (TECI-12706TI25) with different temperature differences applied to it, produce sufficient electrical energy to be used as an energy source in our daily lives?

b)Aim of the Experiment

To investigate the potential difference producing capacity of a thermoelectric generator to use it at an energy source.

c)Key Variables

- Temperature of the containers (dependent variable)
- Potential difference produced by the thermoelectric generator (independent variable)
- Type of the thermoelectric generator (constant)
- Surface area for heat transfer (constant)
- Type of substances used for heat transfer (constant)

d)Materials

- 200 ml of water
- 2 glass containers (100 ml)
- Thermoelectric generator having a surface area of 16 cm^2 (TECI-12706TI25)
- A digital voltmeter (±0.1 V)
- 2 thermometers (± 0.1 °C)
- Bunsen Burner
- 4 ice cubes (2x2 cm^2)

e)Method

Figure 1: The system that is set to record data.

1. Put 100 ml. of water in one of the glass containers and put the other 100 ml of water into the other.
2. Put the thermometers into the containers.
3. Heat the first container until the thermometer shows 85°C by using a Bunsen burner
4. Put 4 ice cubes into the other container and after waiting 2 minutes measure the temperature of the water by using the thermometer.
5. Place the thermoelectric generator vertically on a horizontal surface.
6. Put one container to the one side of the generator and one to the other. Make sure they have the least space between them.
7. Connect one end of the voltmeter to one pole of the generator and other end to the other pole.
8. By observing the thermometers, record the reading of the voltmeter when the temperature difference between the containers is a product of 5.
9. Keep recording until the temperature difference between the containers is zero.
10. Repeat the experiment 14 times and while doing this be careful to place the thermoelectric generator at the exact same place that it is used to be.

4-Data Collection and Processing

ΔT	Trial Numbers and the Potential Difference Produced by the thermoelectric generator (±0.01 V)														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
80.0	0.44	0.43	0.51	0.48	0.46	0.49	0.46	0.47	0.44	0.46	0.50	0.48	0.48	0.45	0.49
75.0	0.39	0.40	0.42	0.42	0.41	0.42	0.40	0.40	0.39	0.40	0.43	0.41	0.42	0.41	0.42
70.0	0.37	0.40	0.36	0.40	0.38	0.40	0.37	0.37	0.36	0.36	0.40	0.39	0.40	0.38	0.39
65.0	0.35	0.36	0.33	0.34	0.34	0.35	0.34	0.34	0.33	0.34	0.35	0.35	0.35	0.34	0.35
60.0	0.32	0.32	0.30	0.30	0.30	0.31	0.30	0.32	0.29	0.30	0.31	0.32	0.32	0.30	0.31
55.0	0.28	0.20	0.26	0.27	0.26	0.27	0.24	0.25	0.24	0.26	0.25	0.27	0.27	0.25	0.26
50.0	0.24	0.18	0.23	0.24	0.23	0.24	0.23	0.23	0.22	0.24	0.21	0.22	0.24	0.23	0.24
45.0	0.22	0.16	0.21	0.21	0.20	0.19	0.21	0.21	0.20	0.21	0.18	0.20	0.21	0.20	0.20
40.0	0.19	0.13	0.18	0.18	0.17	0.18	0.16	0.19	0.18	0.18	0.17	0.18	0.18	0.17	0.18
35.0	0.17	0.11	0.15	0.15	0.14	0.15	0.14	0.16	0.14	0.15	0.15	0.15	0.16	0.15	0.15
30.0	0.15	0.10	0.13	0.12	0.13	0.13	0.12	0.13	0.11	0.12	0.13	0.12	0.12	0.13	0.11
25.0	0.13	0.08	0.10	0.10	0.10	0.11	0.10	0.11	0.10	0.12	0.10	0.11	0.11	0.11	0.10
20.0	0.10	0.07	0.07	0.08	0.07	0.08	0.07	0.08	0.07	0.09	0.07	0.08	0.07	0.07	0.08
15.0	0.08	0.05	0.06	0.06	0.05	0.06	0.07	0.06	0.06	0.08	0.06	0.06	0.05	0.05	0.06
10.0	0.05	0.03	0.04	0.04	0.03	0.05	0.04	0.03	0.04	0.04	0.04	0.05	0.03	0.04	0.05
5.0	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.01	0.02
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ΔT : Temperature difference between the containers (±0.1 °C)

Table 1: Temperature difference between the containers and the potential difference produced by the thermoelectric generator placed between the containers due to temperature difference between the two surfaces of the generator

Temperature difference between the containers (±0.1 °C)	**Mean values of the potential difference produced by the thermoelectric generator (±0.0001 V)**	**Standard deviation of the potential difference data**
80.0	0.4693	0.02344
75.0	0.4093	0.01223
70.0	0.3820	0.01613
65.0	0.3440	0.00828
60.0	0.3080	0.01014
55.0	0.2553	0.01922
50.0	0.2280	0.01613
45.0	0.2007	0.01486
40.0	0.1747	0.01457
35.0	0.1480	0.01320
30.0	0.1233	0.01175
25.0	0.1053	0.01125
20.0	0.0767	0.00899
15.0	0.0607	0.00961
10.0	0.0400	0.00756
5.0	0.0167	0.00488
0.0	0.0000	0.00000

Table 2: Calculating the mean values of the potential difference produced by the thermoelectric generator for each temperature difference that is applied to the generator and finding a standard deviation for the mean values.

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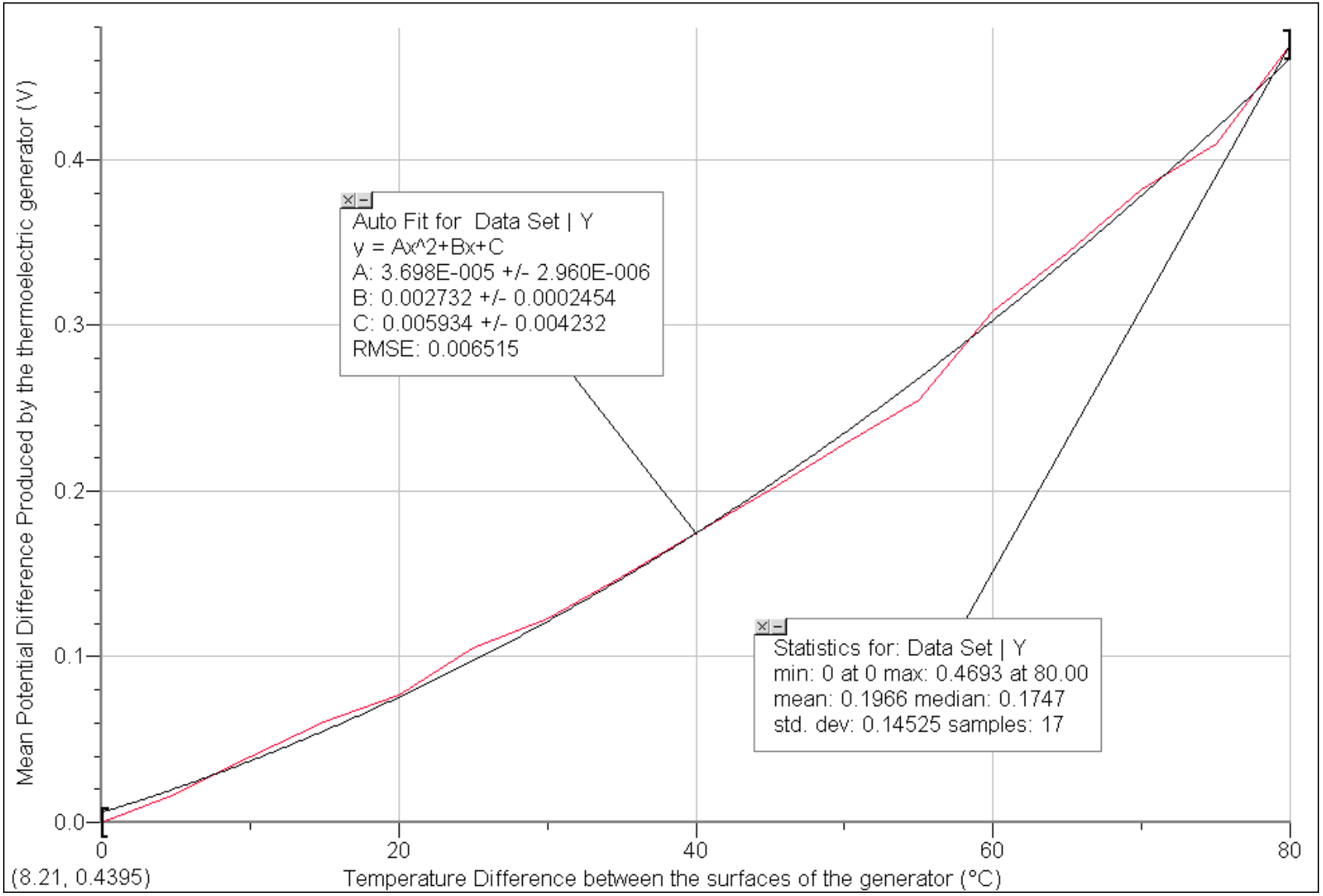
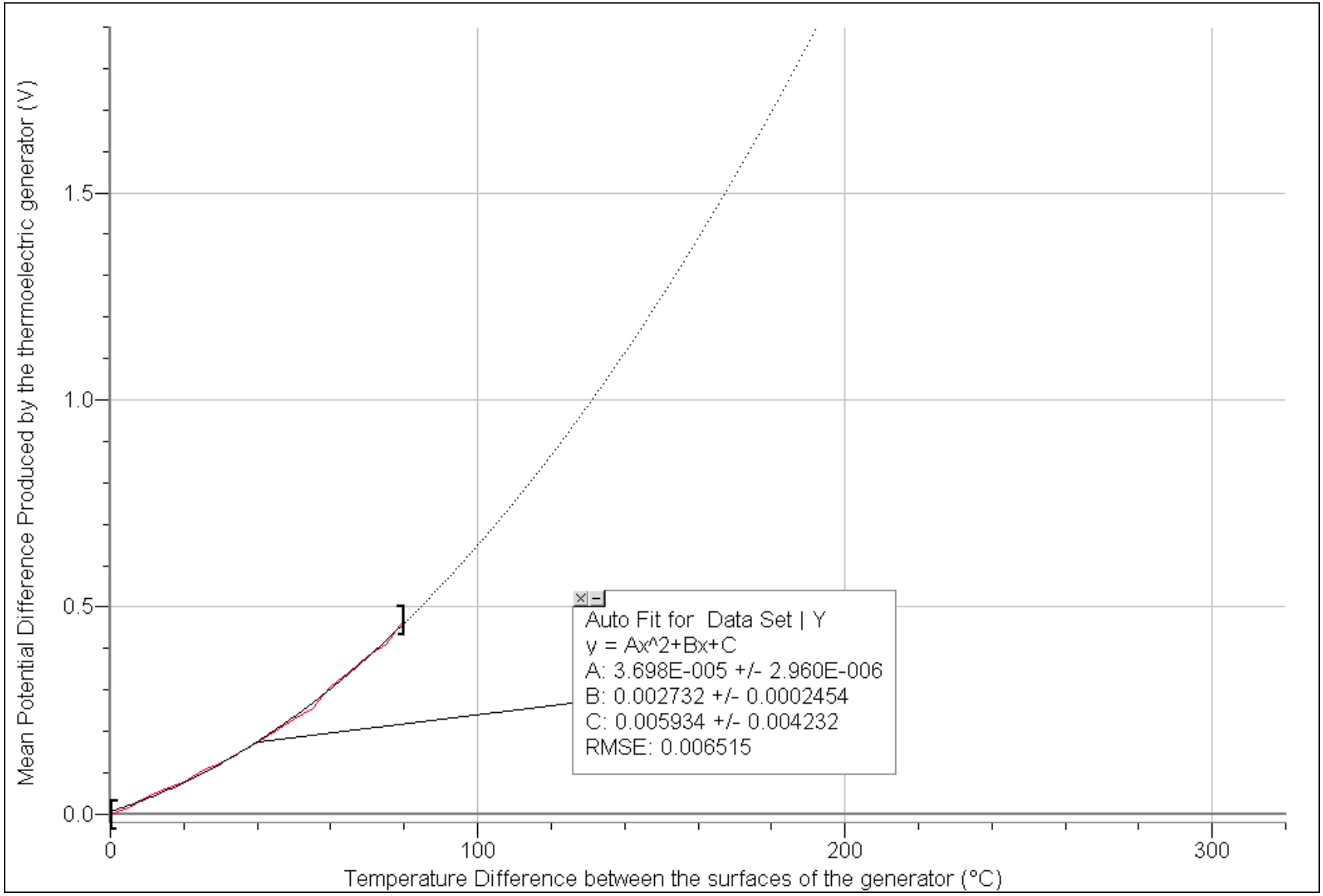


Graph 1: Temperature difference applied to the surfaces of a thermoelectric generator and mean potential difference produced by the thermoelectric generator. The equation of the relation between them and some statistical values were calculated.



Graph 2: Interpolation of the graph according to the equation that is derived between temperature differences and produced potential difference by the thermoelectric generator.

5-Conclusion and Evaluation

In this experiment, the aim is to find if a thermoelectric generator, in the trials a square shaped TECI-12706TI25 is used, produces sufficient energy to be used as an energy source in our daily lives.

To test the potential difference producing capacity of the thermoelectric generator, a simple apparatus is set. The apparatus contains 2 containers having smooth edges and with a volume of 100 ml, a thermoelectric generator (TECI-12706TI25), 200 ml of water, 2 thermometers, Bunsen burner. 4 ice cubes and a digital voltmeter. 100 ml of water is placed in one container. A thermometer is placed inside. By using the Bunsen burner, the container is heated until the thermometer shows 85 °C. In the second container 100 ml of water is placed and 4 ice cubes are added. A thermometer is placed inside the container. Then the terminals of the thermoelectric generator are connected to the digital voltmeter. Two containers are placed side by side and the thermoelectric generator is placed between them with the least space between them. By observing both of the thermometers, data is obtained from the digital voltmeter when the temperature difference between the containers is a product of 5. Many trials were made to get the best results.

As the water boils at 90 °C in the place where the experiment was made, the highest temperature reached in the laboratory is 90°C, so the highest temperature difference that can be achieved in the laboratory by using this apparatus is 80°C. For higher temperature differences, I used the method of interpolating. While interpolating, I derived an equation to define the relation between the temperature difference applied to the generator and potential difference produced by it. The equation is:

$$y = 3.698 \times 10^{-0.05} x^2 + 0.002732x + 0.005934$$

where x is the temperature difference between the surfaces of the thermoelectric generator in Celsius degree and y is the potential difference produced by the thermoelectric generator in volts.

By using the equation or the interpolation on Graph 2, we can calculate some of the potential differences that are needed for some basic devices which are used in our daily lives.

To produce the potential difference that is supplied by a simple AA battery, which produces 1.5 volts of potential difference between its terminals, 167°C of temperature difference must be applied to the surfaces of the thermoelectric generator according to the interpolation. Also to light a red LED (light emitting diode), a temperature difference of 180°C must be applied (red LEDs works approximately with 1.7 Volts).

As a result, to be used as a daily life electrical supply, higher temperature differences must be applied to the surfaces of the thermoelectric generator. This makes thermoelectric generator an impractical source for energy production. It needs temperature differences like 167°C or 180°C, so it is unlikely to have such medium in a house. However it can be used in the ovens or near the heating mechanism of the house where temperature differences may reach the level of 180°C. If used in places like this, thermoelectric generator may recover the energy that is leaked out to the environment. It can help the heating of the house or the lighting of some areas.

Thermoelectric generator may be more efficient if it is used in industrial areas. In the industry, temperature differences may reach greater levels than residential areas. It can produce enough potential difference to power some necessary equipment. It can contribute to the energy saving systems and it can recover the lost heat. By this way thermoelectric generators will help slowing down the global warming. As they are harmless to the environment, they can help saving the environment as well.

Possible sources of error while making this experiment may be the leakage of heat to the environment. As the system is not completely heat proof, some of the heat energy from the containers has leaked to the atmosphere and not to the thermoelectric generator. This may have decreased the efficiency of the thermoelectric generator and may have caused an error in the data. As the standard deviation of higher temperature differences is higher than lower temperature differences, the leakage is an important problem (standard errors of the data may be found at Table 2). As the temperature difference increases, the rate of heat loss increases. That is the main reason for such higher standard deviations at higher temperature differences. Another source of error may be the change of surface area in every trial. The

surface of the thermoelectric generator and the containers are same but in every trial their position may lead to different heating of a point. That causes different potential differences produced in different trials but with the same temperature difference applied to the thermoelectric generator. This may not cause a maximal error as heat loss does but it is still a problem that may have affected the result. Also the position of the thermometers may have caused an error. Thermometers are placed in the container, which means they measure the temperature of the water inside the container. However the temperature difference we are looking for is the temperature difference between the surfaces of the thermoelectric generator. So the thermometers should be placed on the thermoelectric generator not in the containers. However, this may maximize the error. If thermometers are placed on the thermoelectric generator, the distance between the containers and the thermoelectric generator will increase. This will cause a grater increase of heat loss to the environment. To minimize the heat loss to the environment, thermometers should be placed inside the containers. This will create an error but this error is a tiny one compared to the heat loss of the containers to the environment.

To fix these errors, a heat proof environment is needed. The containers should be placed in heat proof medium with only one open space which allows heat transfer. Between the open spaces between heat proof medium, thermoelectric generator must be placed. All of the heat energy that the hot water filled container have, will be transferred to the cold water filled container through the thermoelectric generator. This will minimize the heat loss to the environment and release the maximum potential of the thermoelectric generator. By this method, potential differences greater than the ones that are produced in this experiment will be produced by using the same temperature difference between the surfaces of the thermoelectric generator and the efficiency of the thermoelectric generator will increase. Also a container system should be used that makes the surface of heat transfer for the thermoelectric generator constant. In this experiment I make it as constant as I can however there may be some errors. A stable system should be formed in which the position of the thermoelectric generator does not change at all.

In conclusion thermoelectric generator is not so efficient at lower temperature differences that people usually encounter in their daily lives. Thermoelectric generators can be more efficient at industrial zones like factories. In industrial areas, higher temperature

differences are produced. Higher temperature differences can supply the thermoelectric generator to produce more potential difference. The maximum potential difference that is produced in this experiment is 0.51 Volts with the temperature difference of 80 °C. That is one-thirds of an AA battery so that is not enough for even simple devices. However, by using the high temperature differences that are produced in industrial areas, the potential difference that is produced by the thermoelectric generator will be efficient to power some devices and may help saving the environment. By using the energy that is produced by a thermoelectric generator, we can help slowing down global warming and replace the loss heat from the systems as electrical energy. This may help energy saving and may support people economically. However, to use the thermoelectric generator efficiently, heat loss of the system must be minimized and greater temperature differences must be applied. By making this thermoelectric generator will produce sufficient energy for some devices and this will help energy saving. This experiment shows the efficiency of a thermoelectric generator is greater in higher temperature differences and lesser in lower temperature differences. To use the thermoelectric generator efficiently, high temperature difference should be present.

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