DEVELOPMENT OF THERMOELECTRIC REFRIGERATOR

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JANUARY, 2011

CERTIFICATION

This work has not been presented elsewhere for the award of a degree or any other purpose.

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I certify that this work has been carried out by Mr. Ibikunle 'Rotimi Adedayo, in the Department of Mechanical Engineering of the Federal University of Technology, Akure.

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Thank you all, God bless.

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January, 2011

DEDICATION

This project work is dedicated to the Almighty God: who through his infinite mercy and compassion, favours me and gives me the grace to successfully complete the academic and the research works of this programme. He is my God forever.

ABSTRACT

This research was aimed at developing a thermoelectric refrigerator. This thermoelectric refrigeration is with the aim of encouraging a local and indigenous thermoelectric industry and to ameliorate the harmful effect of Chloroflurocarbons (CFCs) refrigerants on the ozone layer. Thermoelectric refrigerator is a device that is able to remove heat, from the food items charged into a refrigerating chamber; through the electrical energy supplied to its module. The heat removed is deposited at the hot heat exchanger outside the refrigerating chamber. The capacity of the prototype designed is 30 W, using electrical energy of 12 V and current of 2.5 A. The module used to produce this capacity is (type *inbc* 1 – 127. 05) a single stage of size 40 mm by 40 mm by 4.0 mm with a transformer of 300 turns in primary winding and 15 turns in secondary winding, using a primary resistor of 1846 Ω and 4.8 Ω as its secondary resistor. The heat exchangers adopted are: finned rectangular Aluminum Alloy hot heat exchanger (135 mm long, 102 mm wide and 15 mm high) and a square block Aluminum Alloy Cold heat exchanger (43 mm long, 43 mm wide and 25 mm high), instead of condenser and evaporator used in vapour compression system. The experimental results showed that with the aid of the module and the heat exchangers adopted in the system developed it would cool food items such as Tomato (153g) and Banana (100g), from 29°C to 4°C within four hours of cooling using fruits samples such as Banana, Tomato and Lemon. Moreover, there was no further heat removal observed after the fruits were cooled for four hours. The optimum coefficient of performance (COP) was 0.76 at 2.5A electric current supplied to the thermoelectric module.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 REFRIGERATION

In general, refrigeration can be defined as any process of heat removal, from a region of low temperature and deposit at a region of high temperature. More specially (Dossat, 1979) defined refrigeration as the branch of science that deals with the process of reducing and maintaining the temperature of a space or material below the temperature of the surroundings. This is accomplished by removing heat from body being refrigerated and transferred it to another body whose temperature is higher than that of the refrigerated body or space. Since the heat removed from the refrigerated body is transferred to another body, it is evident that refrigerating and heating are actually opposite ends of the same process often only the desired result distinguishes one from the other.

1.2 DEVELOPMENT OF REFRIGERATION

Modern refrigeration has many applications. The first, and probably still the most important, is the preservation of food. Most foods kept at room temperature spoil rapidly. This is due to the rapid growth of bacteria. At usual refrigeration temperatures of about 4.4°C (40°F), bacteria grow quite slowly. Food at this temperature will keep much longer. Refrigeration preserves food by keeping it cold. Other important uses of refrigeration include air conditioning, beverage cooling and humidity control. Many manufacturing processes also use refrigeration.

Andrew *et al.*, 1975 explained that the refrigeration industry became important commercially during 18^{th} century. Early refrigeration was obtained by the use of ice. Ice from lakes and ponds were cut and stored in the winter in insulated store rooms for summer use. The use of natural ice required the building of insulated containers or ice boxes for stores and homes. These units first appeared, on a large scale, during the 19^{th} century (Andrew *et al.*, 1975).

Ice was first made artificially about 1820 as an experiment. Not until 1834 did artificial ice manufacturing became practical. Jacob Perkins, an American Engineer, invented the apparatus which was the forerunner of our modern vapour compression systems (Andrew *et al.*, 1975). In 1855 a German Engineer produced the first absorption type of refrigerating mechanism, although Michael Faraday had discovered the principles for it in 1824 (Andrew *et al.*, 1975). Little artificial ice was produced until shortly after 1890. During 1890, a warm winter resulted in a shortage of natural ice. This helped start the mechanical ice – making industry.

Mechanical domestic refrigeration first appeared about 1910. J.M Larsen produced a manually operated household machine in 1913 (Andrew *et al.*, 1975). By 1918, Kelvinator produced the first automatic refrigerator for the American market. The fist of the sealed or "hermetic" automatic refrigeration unit was introduced by General Electric in 1928 (Andrew *et al.*, 1975). It was named the **Monitor Top**. Beginning with 1920, domestic refrigeration, became one of the important industries. The Electrolux, which was an automatic domestic absorption unit, appeared in 1927. Automatic refrigeration units, for the comfort cooling part of air conditioning, appeared in 1927 (Andrew *et al.*, 1975).

Fast freezing to preserve food for extended periods was developed about 1923. This marked the beginning of the modern frozen foods industry (Andrew *et al.*, 1975). Mechanical refrigeration systems were first connected to heating plants to provide summer cooling in the late 1920's. By 1940, practically all domestic units were of the hermetic type. Commercial units had also been successfully made and used (Andrew *et al.*, 1975). These units were capable of refrigerating large commercial food storage systems, comfort cooling of large auditoriums, producing of low temperatures used in many commercial operations.

1.3 THERMOELECTRIC DEVICES

Thermoelectric devices operate on a phenomenon called **thermoelectric effect** which is the direct conversion of a temperature gradient across two dissimilar metals into electricity. This thermoelectric effect is also reversible directly converting electricity into, a temperature gradient. This thermoelectric effect is based on a combination of the **Seebeck effect** and **Peltier effect** (en.wikipedia.org/wiki/Thermoelectric_effect).German Physicist Thomas Seebeck accidentally discovered the Seebeck effect when he observed a voltage differential between the ends of a bar, composed of two dissimilar metals, when one end was heated and the opposite was cooled. Thirteen years later, John Peltier observed the reverse phenomenon which now referred to as the **Peltier effect** (en.wikipedia.org/wiki/Thermoelectric_effect). The Seebeck effect has been implemented for decades in thermocouples, but it was not until recent advances in semiconductor technology that the thermoelectric effect was applied to heating, cooling and power generation.

With the principles of operation in semiconductor technology and the thermoelectric effect, thermoelectric coolers or refrigerators are produced. These devices do not use refrigerants, compressors or any moving parts; hence they are lighter than other refrigerating devices.

1.4 RESEACH OBJECTIVES

The objectives of this research work are to:

i. design a thermoelectric refrigerator;

ii. construct the thermoelectric refrigerator designed; and

iii. evaluate the performance of the system.

1.5 PROJECT SIGNIFICANCE

The significance of this project is viewed from its relevance to:

i. The field of Engineering;

ii. Development of the Nation; and

iii. The Global concern.

1.5.1 Relevance to Engineering Field

This research work will make a further positive contribution to the impact the building service Engineering has been making on human thermal comfort. It will be useful in food storage and preservation as well as in cooling of beverages and other fruit drinks.

1.5.2 Relevance to National Development

The success of this project means a local substitute to other means of refrigeration and hence could be a source of another-local and indigenous industry. This will enhance technology development in our Nation and hence improving the economy of the Nation.

1.5.3 Global Relevance

It will bring a drastic reduction on the effect of Chloroflurocarbons (CFC's) refrigerants on the ozone layer, because this kind of refrigeration device does not use refrigerants.

1.6 Research Methodology

Extensive research was carried out on the required facts and procedures adopted in order to achieve the desired aims and objectives of this project. The tools used are: the library, computer centre, electrical electronics workshop and the air conditioning and refrigeration workshop at the Federal University of Technology, Akure.

In determining the methods, materials and procedures adopted, the following facts were taken into considerations:

i. The capacity of the system to be designed.

ii. The type of semi conductor (module) that is suitable for single stage thermoelectric refrigerator that can produce COP between 0.4 and 0.7.

iii. The appropriate thermoelectric circuit board (power supply section) that could take in 240 V and step-it-down to 12 V.

iv. The thermoelectric refrigerating cabinet and the size of suitable heat exchangers.

Then the following parameters were measured:

- The secondary current of the power supply; (I_s);
- The secondary voltage of the power supply; (V_s);
- The mass of each food item sampled, (m);
- The initial temperature before cooling (T_1);
- The final temperature of food items after cooling, (T_2); and
- The periodic time of cooling, (t).

Also, the following quantities were derived:

- The heat removed from the refrigerating cabinet; (Q)
- The electrical energy required to remove a particular quantity of heat from the refrigerating chamber, (VIt);
- Coefficient of performance (COP) using the heat pumped from the refrigerating chamber and the electrical energy supplied.

The developed prototype was tested using fruit for different periods of time, and the results of the tests were analyzed.

CHAPTER TWO

2.0 LITERATURE REVIEW

Refrigeration in engineering sense means, maintaining a system at a temperature less than the temperature of the surroundings. This will not occur naturally. So device must be developed to ensure this desired condition, hence the need for a refrigerator.

The purpose of a refrigerator is to transfer heat from a cold chamber which is at a lower temperature than that of its surroundings. Elementary refrigerators have been used which utilized the melting of ice or the sublimation of carbon dioxide at atmospheric pressure to provide cooling effect. The continuous consumption of the refrigerating substance with the means of replenishment required from another source of supply make these methods inconvenient.

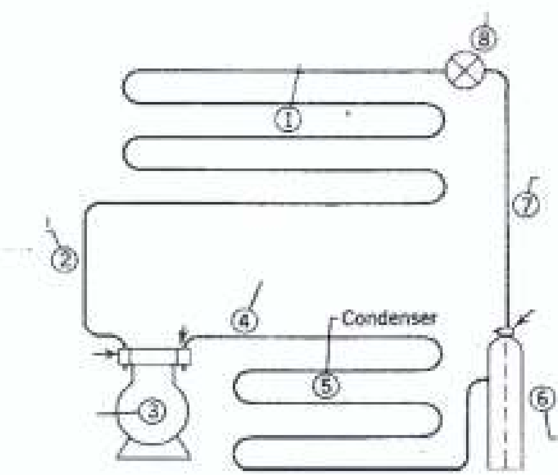
The nature of the problem suggests a means of refrigeration which consist of a cycle of processes with the same quality of working fluid called the refrigerant, in continuous circulation. If the refrigerant received energy in the cold chamber at a temperature below that of the surroundings, then this energy must be rejected before the refrigerant can return to the cold chamber in its initial state, this energy rejection must be carried out at a temperature above that of surroundings.

The energy at rejections is of high quality because of its higher temperature than that received in the cold chamber. This energy can be used for heating and refrigerating. Plants, designed entirely for these purpose are called heat pumps. There is no different between a refrigerator and a heat pump. The two systems require an input of energy. With the refrigerator, the important quantity is the energy removed from the cold chamber called refrigerating effect, and with the heat pump, it is the energy to be rejected by the refrigerant for heating purposes.

Refrigeration is the achievement of a temperature below that of the immediate surroundings. In any practical refrigeration system, the maintenance of low temperature requires the removal of heat from the product at low temperature and discharge of this heat at a higher temperature. The refrigerator is basic to the heating, ventilating and air conditioning industries. Applications vary from food processing, packaging, storing and transportation to environmental control and comfort.

2.1 VAPOUR COMPRESSION REFRIGERATION SYSTEM

Vapor compression system undergoes processes called a thermodynamic cycle. This cycle is shown in (a flow diagram) Fig. 2.1. The principal parts of the system are: an evaporator, whose function it is to provide heat transfer surface through which heat can pass from the refrigerated space or product into the vaporizing refrigerant; a suction line, which conveys the low pressure vapour from the evaporator to the suction inlet of the compressor; a compressor, whose function is to remove the vapour from the evaporator, and raise the temperature and pressure of the vapour to a point such that the vapour can be condensed with normally available condensing media; a discharge line which delivers the high - pressure, high - temperature vapour from the discharge of the compressor to the condenser; a condenser, whose purpose it is to provide a heat transfer surface through which heat passes from the hot refrigerant vapour to the surrounding; a receiver tank, which provides storage for the condensed liquid so that a constant supply of liquid is available to the evaporator as needed; a liquid line, which carries the liquid refrigerant from the receiver tank to the refrigerant flow control; and a refrigerant flow control, whose function it is to meter the proper amount of refrigerant to the evaporator and to reduce the pressure of the liquid entering the evaporator so that the liquid will vaporize in the evaporator at the desired low temperature (Dossat, 1979).



Legend

Number – Description
1. Evaporation
2. Suction line
3. Compressor
4. Discharge line
5. Condenser
6. Receiver tank
7. Liquid line
8. Refrigerator flow control

Fig. 2.1: A flow diagram of vapour compression refrigeration system (Dossat,1979)

2.2 VAPOUR ABSORPTION REFRIGERATION SYSTEM.

This refrigeration system is similar to the vapour- compression system in that it employs volatile refrigerant, usually vapourizes under low pressure in the evaporator by absorbing latent heat from the material being cooled and condenses under high pressure in the condenser by surrendering the latent heat to the condensing medium.

The principal difference in the absorption and Vapour compression system is the motivating force that circulates the refrigerant through the system and provides the necessary pressure differential between the vapourizing and condensing processes. In the absorption cycle, the vapour compressor employed in the vapour compression system is replaced by an absorber and generator, which perform all the functions performed by the-compressor in the Vapour - compression system. In addition, the energy input required by the vapour compression system is supplied by the mechanical work of the compressor; the energy input in the absorption cycle is in the form of heat supplied directly to the generator. The source of the heat supplied to the generator is usually low - pressure steam or hot water, although in smaller systems the heat usually supplied by combustion of an appropriate fuel, such as natural gas, propane, or kerosene, directly in the generator or by an electric resistance heater installed in the generator.

The system consists of four basic components: an evaporator and an absorber, which are located on the low - pressure side of the system, and a generator and a condenser, which are on the high pressure side of the system. Two working fluids are employed, a refrigerant and an absorbent. The flow cycle for the refrigerant is from the condenser to the evaporator to the absorber to the generator and back to the condenser, while the absorbent passes from the absorber to the generator and back to the absorber (Dossat, 1979).

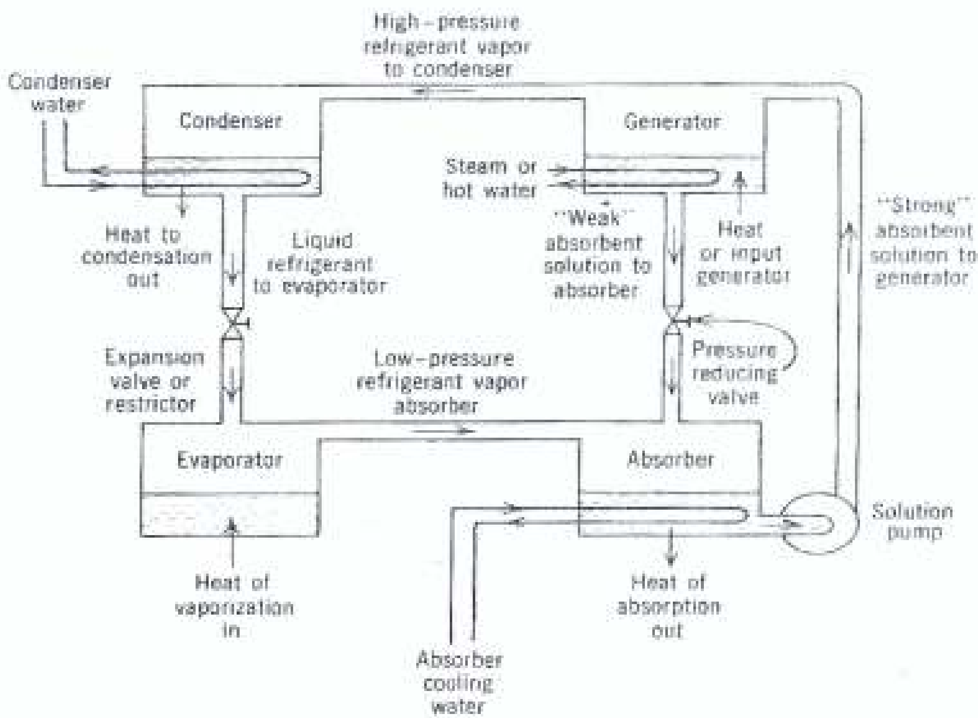


Fig 2.2 Basic absorption refrigeration cycle (Dossat, 1979.)

The operating sequence is as follows: The high - pressure liquid refrigerant from the condenser passes into the evaporator through an expansion device or restrictor that reduces the pressure of the refrigerant to the low pressure existing in the evaporator. The liquid refrigerant vaporize in the evaporator by absorbing latent heal from the material being cooled, and the resulting low pressure vapour then passes from the evaporator through an unrestricted passage to the absorber, where it is absorbed by, and goes into solution with, the absorbent.

The refrigerant flows from the evaporator to the absorber because the vapour pressure of the absorbent - refrigerant solution in the absorber is lower than the vapour pressure of the refrigerant in the evaporator. It is the vapour pressure of the absorbent - refrigerant solution in the absorber that determines the pressure on the low - pressure side of the system and, consequently, the vapourizing temperature of the refrigerant in the evaporator. In turn, the .vapour pressure of the absorbent - refrigerant solution depends on the nature of the absorbent, its temperature, and its concentration. The lower the temperature of the absorbent and the higher the concentration (the smaller the percentage of .refrigerant in the solution), the lower is the vapour pressure of the solution.

As the refrigerant vapour from the evaporator is dissolved into the absorbent solution, the volume of the refrigerant is decreased (compression occurs) and the heat of absorption is released. In order to maintain the absorbent solution at the required level, the heat released in the absorber, which is equal to the sum of the latent heat of condensation of the refrigerant vapour and the heat of dilution of the absorbent, must be discarded to the surroundings, usually to the same heat sink or condensing medium used for heat discard at the condenser.

In order to transfer heat from the absorber to the sink, the temperature of the absorber must be higher than that of the available sink. In as much as the efficiency of the absorber increases as the temperature of the absorbent solution is reduced, it follows that the efficiency of the absorber depends in part on the temperature of the available coolant.

Since the refrigerant vapour dissolving into the absorbent solution increases the strength (percentage refrigeration) and vapour pressure of the solution, it is necessary to continuously re-concentrate the solution in order to maintain the vapour pressure of the solution at a level low enough to provide the required low pressure and temperature in the evaporator. The re-concentration is accomplished by continuously removing the "strong" absorbent solution from the generator where most of the refrigerant vapour is "boiled off" by the application of heat and the resulting "weak" solution is returned to the absorber to absorb more refrigerant vapour from the evaporator.

Since the absorber is on the low - pressure side of the system and the generator is on the high - pressure side, the strong solution must be pumped from the absorber to the generator and the weak solution returned to the absorber through a pressure reducing valve.

In the generator, the refrigerant is separated from the absorbent by heating the solution and vapourizing the refrigerant. The resulting high - pressure refrigerant vapour then passes to the condenser, where it is condensed by giving up latent heat the condensing medium, after which it is ready for recirculation to the evaporator.

The weak absorbent solution left in the generator is returned to the absorber through the absorber return pipe as previously described. The relative strength of the weak solution is controlled by the amount of heat supplied to the generator.

To realize maximum system efficiency, the pressure differential between the low - pressure and high pressure sides of the system should be maintained as small as possible by keeping the low side pressure as high as possible consistent with the refrigeration requirement and the high side pressure as low as possible with the available condensing medium.

The efficiency system can be improved by providing a heat exchange between strong solution going to the generator and the high - temperature weak solution returning from the generator to, the absorber. Since the temperature of the strong solution going to the generator is increased, while the temperature of the weak solution going to the absorber is decreased, the heat exchange result in a reduction both the heat supplied to the generator and the cooling required by the absorber.

There are Ammoniua – water (HN_3 – H_2O) system's type and Water – Littium Bromide (H_2O – LiBr) system's type (i.e. there are both liquid and solid absorbent types). Absorption systems are further classified as: intermittent and continuous systems. When the absorption system provides refrigeration constantly it is called a **continuous absorption**, while the system that provides refrigeration at intermittent rate is an **intermittent absorption system.** These are possible through the use of automatic controls (Andrew et al., 1975).

2.3 ABSORPTION SYSTEMS COMPARED WITH COMPRESSION SYSTEMS.

The main parts in vapour compression system are: compressor, condenser, evaporator, refrigerant control devices while that of Absorption system are: generator, rectifier, analyzer, condenser, refrigerant control device, and evaporator. Generally, copper pipe is used to connect the parts in compression system, while steel pipe is used to connect absorption system.

Gas like Freon or ammonia or carbon dioxide is charged in compression system but in absorption system, mixture of gases like Ammonia – Water, Water – Lithium bromide are charged. In compression system Prime mover like diesel or petrol engine required to operate it while in absorption system heat energy like gas or steam, or kerosene flame or electric heater is required.

In compression system, the flow of gas depends upon compressor while the flow of gas in absorption depends upon the working of generator. Compression system is a noisy system but absorption is a quiet system. There are so many moving parts in the system, hence there is a lot of wear and tear. Absorption system has no moving parts and there is less possibility of wear and tear.

Vapour compression system is more costly than absorption system. It requires more servicing than absorption system; nevertheless vapour compression system is more efficient than vapour absorption system.

2.4 THERMOELECTRIC REFRIGERATION SYSTEM

Thermoelectric is a recent development in the field of refrigeration. The importance of thermoelectric refrigeration was realized much later compared with its merits. The development of semiconductor technology enhanced the feasibility of thermoelectric coolers to a great extent. If proper materials are found, it will possibly be a better field of refrigeration over the other methods even at present.

The thermoelectric process is a means of removing heat from one area and putting it in another area using electrical energy rather than refrigerant as heat "carrier". It has been used mainly in portable refrigerators and luxury type stationary domestic refrigerators, water cooler and for cooling the scientific apparatus used in space explorations and in aircraft.

Thermoelectric cooling requires none of the conventional equipment necessary in a vapour compression system. There is no compressor, evaporator, condenser or refrigerant. In fact, there are no moving parts; the unit is silent, compact and requires little service. In this system, the input of

240 V a-c current is stepped down in a transformer to 12 V d-c. This current is then passed through thermoelectric module so that the junction inside the refrigerator becomes cold and the junction outside the refrigerator is warmed.

Thermoelectric cooling units, when used in refrigeration, are called modules. A module consists of several cold and hot junctions in series. The diagram of such a module is shown in Figure 2.6. The letters P and N, used in thermoelectric application do not refer to current polarity, positive (+) and negative (-), P and N, in thermoelectric units, refer to the properties of semiconductor materials. The materials are also designated as positive or negative depending on how the semiconductor electrons behave under the influence of current flow.

The construction of a module attached to a refrigerator is shown schematically in Fig 2.6. The direction of the direct current flow into the modules determines whether the junction will be cooled or warmed. A reverse switch is usually provided as part of the electric circuit to determine the direction of the flow of the current. This makes it possible to cause the cabinet to either cool the food or warm it. This type of refrigerators which are operated from either 240 V household current or from a 12 V battery, has been fairly popular for picnics and camping use (Andrew et al., 1975).

.5 DEVELOPMENT OF THERMOELECTRIC PHYSICS

Before discussing principle covering the operation of thermoelectric refrigerator it is necessary lo review, the effect of the heat on certain metals and materials. According to Arora, 1997, seebeck (German Physicist) in 1821 observed that if a closed circuit was made of two dissimilar metals, an electrical current flowed in the circuit when the two junctions are maintained at different temperatures.

In 1834 Jean Peltier discovered that when a direct current is passed through a junction of two dissimilar metals, the junction became either hot or cold. Peltier, like Seebeck, failed to see the significance of this finding in relationship to thermo-electric cooling (Arora, 1997).

In 1838 Emil Lenz clearly showed the importance of both Peltier's and Seebeck's discovery by placing a drop of water on a junction of two dissimilar metals and passing a direct current through the circuit (Arora, 1997). When the current flowed in one direction, the water froze. When the flow of current reversed, the ice melted. However, Lenz, like his predecessors, failed to realize the significance of his findings and the knowledge of his findings and the knowledge remained dormant for over 100 years, mainly due to the unavailability of material (semi -conductors) which could produce wide temperature differences, it was not until 1930's that the available material (semi - conductors) were developed that made the application of Seebeck's and Peltier's discovery applicable to spot cooling.

In the period of 1 940's progress in thermoelectric refrigeration was limited mostly to the scientific laboratories in the early 1960's many companies began an intense desire to manufacture refrigeration equipment based on thermo — electric principle (Arora, 1997). The full size refrigerators, water coolers, portable coolers and spot appliance coolers for both domestic and industrial use are available in the market.

The third effect was pointed out by Thomson in 1851. He related the heat absorbed or evolved in a single conductor to the temperature gradient along it and current flowing through it. This is an effect which takes place in addition to the joule (I^2 R) heating (Arora, 1997).

2.6 BASIC THEORY

2.6.1 Thermoelectric Effect

The thermoelectric effect is the direct conversion of temperature difference to electric voltage and vice versa. On the measurement- scale of everyday life, a thermoelectric device creates a voltage when there is a different temperature on each side. Conversely (and, thermodynamically speaking, reversibly) when a voltage is applied to it, it creates temperature difference. On the scale of atoms (specially, charge carriers), an applied temperature difference causes charge carriers in the material, whether they are electrons or holes, to diffuse from the hot side to the cold side, similar to a classical gas that expands when heated; hence the thermally-induced current (en.wikipedia.org/wiki/Thermoelectric_effect, 2008).

This effect can be used to generate electricity, to measure temperature, to cool objects, or heat them or cook them, because the direction of heating and cooling is determined by the sign of the applied voltage; thermoelectric devices make very convenient temperature controllers. The term thermoelectric effect or thermoelectricity encompasses three separately identified effects; the **Seebeck effect,** the **Peltier effect, and the Thomson effect** (en.wikipedia.org/wiki/Thermoelectric_effect, 2008).

2.6.2 Seebeck Effect.

The seebeck effect shown in Fig. (2.3), is the conversion of temperature different directly into electricity. Seebeck discovered that a compass needle would be deflected when a closed loop was formed of two metals joined in two places with a temperature difference between the junctions. This is because the metal responds differently to the temperature difference, which creates a current loop, which produces a magnetic field. Seebeck, however at this time did not recognize there was an electric current involved, so he called the phenomenon the thermomagnetic effect, thinking that the two metals became magnetically polarized by the temperature gradient. The Danish physicist Hans' orsted played a vital role in explaining and conceiving the term "thermoelectricity" (en.wikipedia.org/wiki/Thermoelectric_effect, 2008).

The effect is that a voltage, the thermoelectric EMF, is created in the presence of a temperature difference between two different metals or semiconductors. This causes a continuous current in the conductors if they form a complete loop. The voltage created is of the order several microvolts per kelvin difference. One such combination, copper- constantan, has a seebeck coefficient of 41 microvolt per kelvin at room temperature.

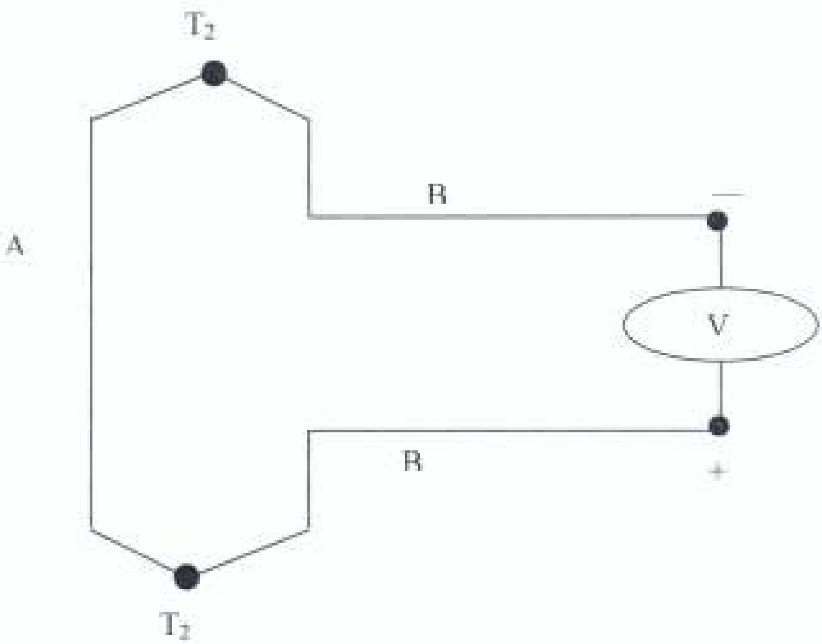


Fig. 2.3: The circuit demonstrating Seebeck effect (en.wikipedia.org/wiki/Thermoelectric_effect, 2008).

The voltage developed can be derived from S_A and S_B, where S_A and S_B are the seebeck coefficients (also called thermoelectric power or thermopower) of the metals A and B as a function of temperature, and T_1 and T_2 are the temperatures of two junctions. The seebeck coefficients are non-linear as a function of temperature, and depend on the conductors absolute temperature, material and molecular structure. If seebeck coefficients are effectively constant for the measured temperature range, then equation (1) for voltage in thermoelectricity can be written as thus:

$$V = (S_B - S_A)(T_2 - T_1) \tag{1}$$

The seebeck effect is commonly used in a device called thermocouple (because it is made from a coupling or junction of material, usually metals) to measure a temperature difference directly or to measure an absolute temperature by setting one end to a known temperature. Several thermocouples when connected in series are called a thermopile, which is sometimes constructed in order to increase the output voltage since the voltage induced over each individual couple is small. This is also the principle at work behind thermal diodes and thermoelectric generators (such as radioisotope thermoelectric generators or RTGS) which are used for creating power from heat differentials.

The seebeck effect is due to two effects: charge carrier diffusion and phonon drag. If both connections are held at the same temperature, but one connection is periodically opened and closed, and AC voltage is measured, which is also temperature dependent. This application of the Kelvin probe is sometimes used to argue that the underlying physics only needs one junction. This effect is still visible if the wires only come close, but do not touch, thus no diffusion is needed.

(en.wilipedia.org/wiki/thermoelectric_effect,'2008).

2.6.3 Thermopower

The thermopower, or thermoelectric power, or seebeck coefficient of a material measure the magnitude of an induced thermoelectric voltage in response to a temperature difference across that material. The power has units of (V/K), though in practice it is more common to use microvolt per kelvin. An applied temperature difference causes charge carriers in the materials, whether they are electrons or holes, to diffuse from the hot side to the cold side, similar to how gas expands when heated. Mobile charged carriers migrating; to the cold side leave behind their oppositely charged and immobile nuclei at the hot side thus giving rise to a thermoelectric, voltage. Since separation of charges creates an electric potential, the build-up of charged carriers into the cold side eventually ceases at some maximum value because there exists an equal amount of charge carriers drifting back to the hot side as a result of the electric field at equilibrium. Only an increase in the temperature difference can resume a build-up of more charge carriers on the cold side and thus lead to an increase in thermoelectric voltage.

The thermopower of a material, represented by **S**, depends on the materials temperature and crystal structure. Metals have small thermopowers because most have half-filled bands. Electrons (negative charges) and holes (positive charges) both contribute to the induced thermoelectric voltage thus canceling each other's contribution to that voltage and making it small. In contrast, semiconductor can be doped with an excess amount of electrons or holes and thus can have large positive or negative value of the thermopower depending on the charge of the excess carriers. The sign of the thermopower can determine which charged carriers dominate the electric transport in both metals and semiconductors.

If the temperature difference (ΔT) between the two ends of a material is small, then the thermopower of the material is defined as:

$$S = \frac{\Delta V}{\Delta T} \qquad (2)$$

And a thermoelectric voltage (ΔV) is seen at the terminals. This can also be written in relation to the electric field (E) and the temperature gradient ΔT, as in equation (3), (en.wilipedia.org/wiki/thermoelectric_effect).

$$S = \frac{E}{\Delta T} \qquad (3)$$

2.6.4 Charge — Carrier Diffusion

Charge - carrier in the material (electrons in metal, electrons and holes in semiconductors, ions in ionic conductors) will diffuse when one end of a conductor is at a different temperature from the other. Hot carriers, diffuse from the hot end to the cold end, since there is a lower density of hot carrier at the cold end of the conductor. Cold carriers diffuse from the cold end to the hot end for the same reason. If the conductor were left to reach thermodynamic equilibrium, this process would result in heat being distributed evenly throughout the conductor. The movement of heat (in the form of hot charge carries) from one end to the other is called a heat current. As charge carriers are moving, it is also an electric current.

In a system where both ends are kept at a constant temperature difference (a constant heat current from one end to the other), there is a constant diffusion of carriers. If the rate of diffusion of hot and cold carriers in opposite directions were equal, there would be no net change in charge. However, the diffusing charges are scattered by impurities, imperfections, and lattice vibration (phonons). If the scattering is energy dependent, the hot and cold carriers will diffuse at different rates. This creates a higher density of carriers at one end of the material, and the distance between the positive and negative charges produced a potential difference, an electrostatic voltage.

This electric field, however, opposes the uneven scattering of carriers, and equilibrium is related where the net number of carriers diffusing in one direction canceled by the net number of carriers moving in opposite direction from the electrostatic field. This means the thermopower of a material depends greatly on impurities, imperfection, and structural charges (which often vary themselves with temperature and electric field), and the thermopower of materials is a collection of many different effects.

Early thermocouples were metallic, but many more recently developed thermoelectric devices are made from alternating P-type and n-type semiconductor elements connected metallic interconnects as pictured in Fig. (2.5) semiconductor junctions are especially common in power generation devices, while metallic junctions are more common in temperature measurement. Charge flows through the n-type element, crosses a metallic interconnect and passes into the p-type element. If a power source is provided, the thermoelectric device may act as a cooler, as in figure (2.4). Element in the n-type element move opposite the direction of current and holes in the p-type element will move in the direction of current, both removing heat from one side of the device.

If a heat source is provided, the thermoelectric device may function as a power generator as in Fig. (2.5), the heat source will drive electrons in the n-type element toward the cooler region, thus creating a current through the circuit. Holes in the p-type element will then flow in the direction of the current. The current can then be used to power a load, converting the thermal energy into electrical energy.

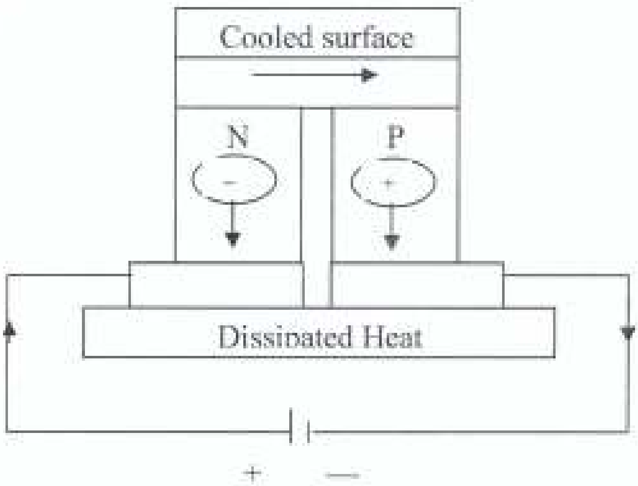


Fig 2.4: Thermoelectric module used in cooling system.

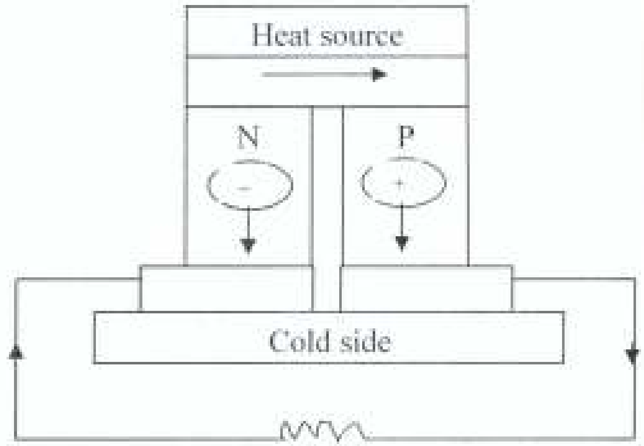


Fig 2.5: Thermoelectric module used in power generation system.

(en.wikipedia.org/wiki/Thermoelectric_effect, 2008).

2.6.5 Peltier Effect

This effect bears the name of Jean - Charles who discovered in 1834, the calorific effect of an electrical current at the junction of two different metals. When a current (I) is made to flow through the circuit, heat is evolved at the upper junction (at T_2), and absorbed at the lower junction (at T_1). The Peltier heat absorbed by the lower junction per unit time, Q is as shown in equation (4)

$$Q=\pi_{AB}I=(\pi_B-\pi_A)I \qquad (4)$$

where: $\Pi = ST$

Π is the Peltier coefficient, π_{AB} is for the entire thermocouple S is the seebeck coefficient, T is the absolute temperature, π_A and π_B are the coefficient of each material. P-type silicon has a positive Peltier coefficient (not above ~ 550 K); and n-type silicon is typically negative. The Peltier coefficient represent how much heat current is carried per unit charge through a given material. Since charge current must be continuous across a junction, the associated heat flow will develop a discontinuity if Π_A and Π_B are different. This causes a non-zero divergence at the junction and so heat must accumulate or deplete there, depending on the sign of the current. Another way to understand how this effect could cool a junction is to note that when electrons flow from a region of high density to a region of low density, they expand (as with an ideal gas) and cool.

The conductors are attempting to return to the electron equilibrium that existed before the current was applied by absorbing energy at one connector and releasing it at the other. The individual couples can be connected in series to enhance effect. An interesting consequence of this effect is that the direction of heat transfer is controlled by the polarity of the current; reversing the polarity will change the direction of transfer and thus the sign of the heat absorbed or evolved. A Peltier Cooler or heater or thermoelectric heat pump is a solid- state active heat pump which transfers heat from one side of the device to the other. Peltier cooling is also called thermo-electric cooling (TEC).

2.6.6 Thomson Effect

This effect was experimentally observed by William Thomson in 1851 (en.wikipedia.org/wiki/Thermoelectric_effect, 2008). It describes the cooling or heating of a current carrying conductor with a temperature gradient. It explains that any current- carrying conductor (except for a superconductor), with a temperature difference between two points will either absorb or emit heat, depending on the material.

In metals such as zinc and copper, which have a hotter end at a higher potential and a cooler end at a lower potential, when current moves from the hotter end to the colder end, it is moving from a high potential, to a low potential. So there is an evolution of heat. This is called the **positive Thomson effect.** In metals such as cobalt, nickel, and iron, which have a cooler end at a higher potential and a hotter end at a lower potential, when current moves from the hotter end to the colder end, it is moving from a low to a high potential, there is absorption of heat. This is called the **negative Thomson effect**

2.6.7 The Thomson Relationships

The seebeck effect is actually a combination of the Peltier and Thomson effects. In 1854, Thomson found two relationships, now called the Thomson or Kelvin relationships, between the corresponding coefficients. The absolute temperature **T**, the Peltier coefficient **Π** and seebeck coefficient **S** are related by the first Thomson relation in equation (5)

$$\Pi = S.T \quad (5)$$

This predicted the Thomson effect before it was actually formalized; also the Thomson coefficient μ by the second Thomson relation is given in equation (6)

$$\mu = T \frac{ds}{dT} \quad (6)$$

Thomson's theoretical treatment of thermoelectricity is remarkable in the fact that it is probably the first attempt to develop a reasonable theory of irreversible thermodynamics (non-equilibrium thermodynamics)

2.6.8 Figure of Merit

The figure of merit for thermoelectric devices is defined in equation (7)

$$Z = \frac{\sigma S^2}{\lambda} \quad (7)$$

Where σ is the electrical conductivity, λ is the thermal conductivity, and **S** is the seebeck coefficient or thermopower (conventionally in $^{\mu V}/_{k}$). This is more commonly expressed as the dimensionless figure of merit **ZT** by multiplying it with the average temperature $((T_2 + T_1)/2)$ (en.wilipedia.org/wiki/thermoelectric_effect 2008).

Thermoelectric power generation efficiency is determined by a non dimensional figure of merit, ZT in equation (8)

$$ZT = \frac{S^2 RT}{K} \qquad (8)$$

Where **S** is the seebeck coefficient, R is electrical conductivity, T is absolute temperature and K is thermal conductivity; the value of **ZT** is taken to be one (i.e ZT = 1)

(Documents and setting/jy/my documents/p07440-Home.htm, 2008)

2.7 PRINCIPLES OF OPERATION

The principles covering the operation of thermoelectric refrigerators according to Andrew et al; 1975 are based on the invention of solid state semiconductor as a replacement for vacuum tubes in the field of electronics. Electronics concerns electron flow through gases, vacuums and semiconductors. Electronics was first developed with the discovery of vacuum tubes and gas filled tubes. It was found that electrons would flow from a heated element in a tube to another element if a potential difference existed between the two elements.

The solid state parts (electronics) involved in these principles are the: Semiconductors, Inductors, Diodes, Rectifiers, Transistors, Capacitors. Presistors, Thermistor, Transformer.

Semiconductors: Semiconductors are intermediate materials that are in between conductors which can conduct heat and electricity readily and insulators which can conduct heat and electricity very poorly.

These materials are ordinarily insulators, but they can be made to conduct electricity easily under certain conditions. These materials (Semiconductors) form the basis of the present electronics industry. The term "solid state electronics" refers to electronics device which are made up of semiconductor elements.

Common devices which are semiconductors are transistors, diodes, and photocells. Many modern motor controls consist of Silicon controlled rectifier, which are semi-conductive switching devices.

The conductivity of a semiconductor can be controlled by an electrical signal, light intensity, pressure, temperature and other signal devices. Semiconductors can therefore serve as relays and switches (in modern electrical control system).

Semiconductors are of two general types: **(i). intrinsic (ii). Extrinsic semiconductor**

Intrinsic semiconductors: are pure substances like silicon and germanium or combined substances like lead sulfide. These are particularly useful as thermometers and as other temperature sensing devices.

Extrinsic semiconductors are combination of intrinsic semiconductors with very little "impurities". These materials are very sensitive to electrical forces and are the basic materials for electronic control use. This is the type that thermoelectric refrigerators use to produce cooling.

Inductors: Inductance may be defined as the property in an electric circuit which resists a change in current. This resistance to a change of current is the result of the energy stored within the magnetic field of a coil. Inductor is used to allow the passage of current, and as well remove a-c ripples.

Diodes: A solid state diode is a two materials, solid material wafer or capsule which allows electrons to flow through it in one direction only. The diode acts as an electron flow check valve.

Rectifiers: Rectifier is an electronic valve which permits flow of electrons through them in one direction only. This device changes alternating current to an output of direct current. The process of changing an alternating current to a pulsating direct current is called rectification.

Transistors: A transistor is a three layer sandwich of different components which consist chiefly of germanium semiconductor material. The materials are labeled for their properties. **P** is for positive, meaning a lack of electrons (it has "holes" ready to receive electrons). **N** is for negative, meaning the material has a surplus of electrons. The type used in thermoelectric cooler is "field effect transistor" this semiconductor allows the supply of voltage across transformer.

Capacitors: Capacitance in a circuit may be defined as the property which opposes any change in voltage. Compare this to inductance, which is the property that opposes a change in current. Capacitance gives the amount of charge that must be given to a conductor in order to raise its potential difference by one volt.

A capacitor is a simple electronic component, and may be described as two plates of conductive material separated by insulation, which is called the dielectric. These plates are connected to a dc source of voltage. A capacitor will block a direct current.

However, one plate became negatively charged, the other positively charged, and a strong electric field exists between them. Capacitor provides some filtering action to a pulsating current.

Resistors: Resistance is the only component of a circuit that uses power, most of the useful effects and labour saving devices provided by electrical power use some form of resistance. Resistance may purposely be introduced into a circuit to reduce voltages and limit current flow in electronics devices.

Thermistors: A thermistor is a solid state semiconductor which allows fewer electrons to flow through it as the material's temperature increases. Most thermistor is made of Lithium Chloride or doped Barium Titanate.

The resistance changes about six percent for each degree Celsius. The thermistor must be kept free from moisture. It can be used in place of a bimetallic strip or in place of a temperature sensitive power element. This is used in three ways: Temperature - operated electric circuit control, To measure temperatures. To step the electric power flow to a motor if the motor windings' temperature increases to the danger point.

Transformer: Several types of transformers are used by electrical utilities to transform voltage to electrical power satisfactory to the user. A transformer can be defined as a device used to transfer energy from one circuit to another by electromagnetic induction. Basically a transformer consists of two or more coils of wire around a common laminated iron core, so that coupling between the coils approaches unity.

It has no moving parts and requires little care. The first winding or input winding is called the **primary** and this winding receives the energy from the source. The second winding or output winding is called the **secondary** and the output load is attached to this winding. The energy in the secondary is the result of the mutual induction between the secondary and the primary windings. Transformer as a device operates on an alternating current or a pulsating direct current.

2.7.1 Thermoelectric module

Thermoelectric cooling units, when used refrigeration, are called modules. A module consists of several cold and hot junctions in series, as shown in Fig (2.6). Most commercially available modules consist of an array of either Lead Telluride or Bismuth Telluride semi conductor pellets. Some specialized power generation modules may also use Silicon Germanium.

Lead Telluride molecules are generally used for power generation applications due to their ability to operate near combustion gas temperature of 500°C while Bismuth Telluride modules are most often used for heating and cooling applications for temperatures less than 200°C. Thermoelectric module size is limited due to thermal material expansion between hot and cold sides.

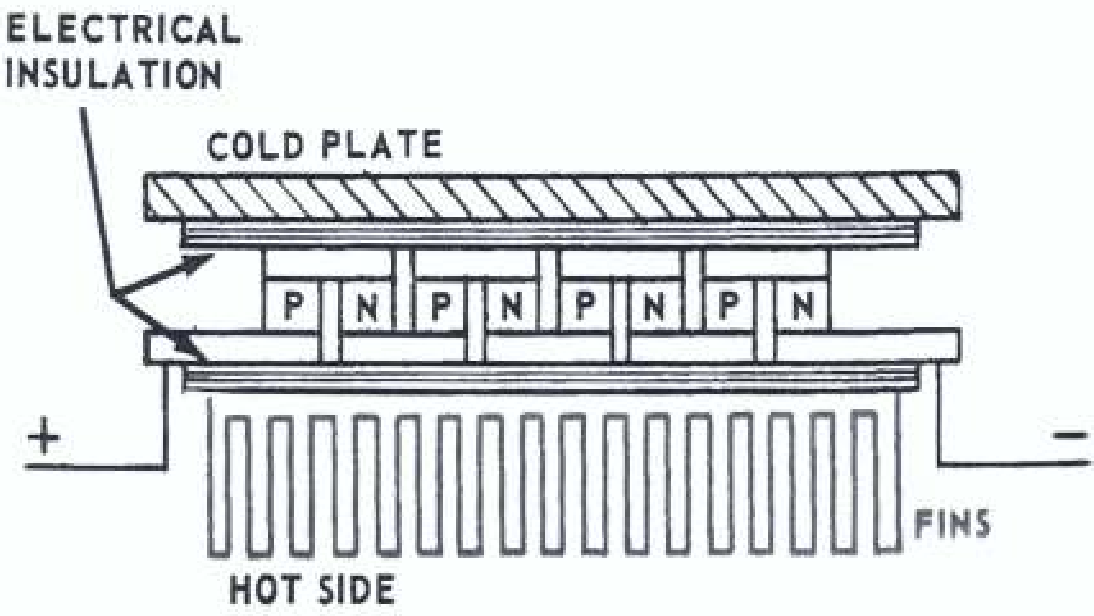


Fig. 2.6: Assembled thermoelectric module. (Andrew *et al.*, 1975)

2.7.2 Thermoelectric couple,

As shown in Fig. (2.7), the couple moves heat from the inside of an insulated space to a heat exchanger on the outside. Electrons, rather than refrigerant carry away the heat. The thermoelectric couple works because of the difference in the energy level of the two semiconductors (metallic alloys and oxides) P and N. The P and N refer to the two different semiconductors used. These materials are made quite large in cross - section to reduce the electrical resistance, the large size also means less heat is generated by the current flow through them; not much heat can be transferred by single couple. To increase the cooling effect, several couples may be connected in series. This group of couples is called a module. The group of modules may be connected together in parallel, to increase the capacity.

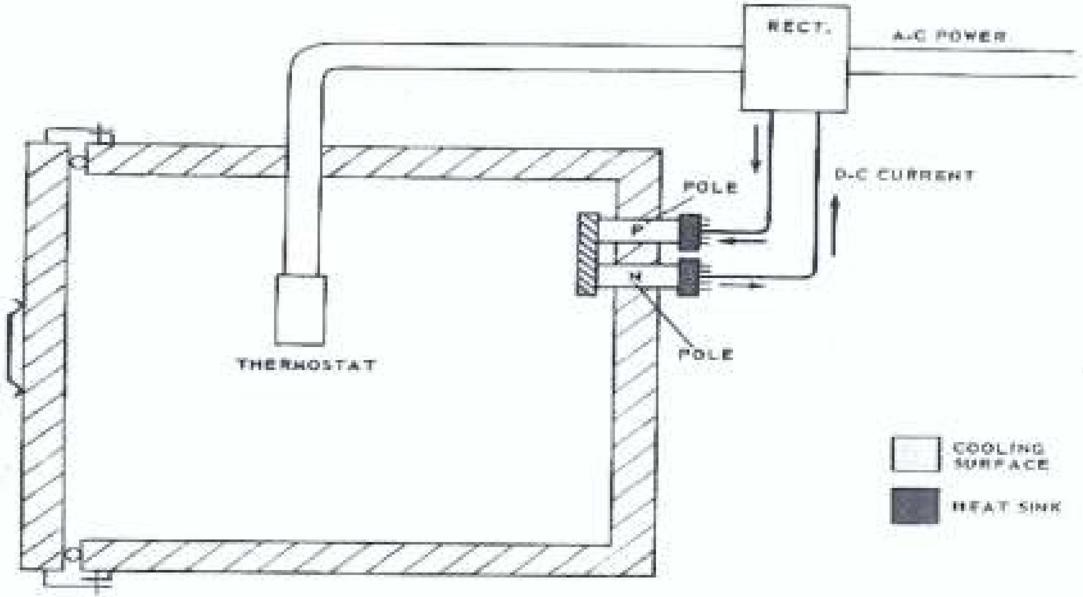


Fig. 2.7: Thermoelectric couple. (Andrew *et al.*, 1975)

2.7.3 How thermoelectric coolers (TECs) work

Thermoelectric coolers as simply demonstrated in Fig. (2.8) are solid state heat pumps that operate on the Peltier effect, the theory that there is a heating or cooling effect when electric current passes through two conductors, is shown in Fig. (2.9) using N – type semiconductor; when a voltage applied to the free ends of two dissimilar materials creates a temperature difference. With this temperature difference, Peltier cooling will cause heat to move from one end to the other (Andrew *et al.*, 1975). A typical thermoelectric cooler will consist of an array of P - and n- type semiconductor elements that act as the two dissimilar conductors. The array of elements is soldered between two ceramic plates, electrically in series and thermally in parallel as a dc current passes through one or more pairs of elements from n - to p -, there is a decrease in temperature at the junction ("cold side") resulting in the absorption of heat from the environment. The heat is carried through the cooler by electron transport and released on the opposite ("hot") side as the electrons move from a high to low energy state. The heat pumping capacity of a cooler is proportional to the current and the number of pairs of n- and p- type elements (or couples). N and P type semiconductors (usually Bismuth Telluride) are the preferred materials used to achieve the Peltier effect because they can be easily optimized for pumping heat and due to the ability to control the type of charge carrier within the conductor.

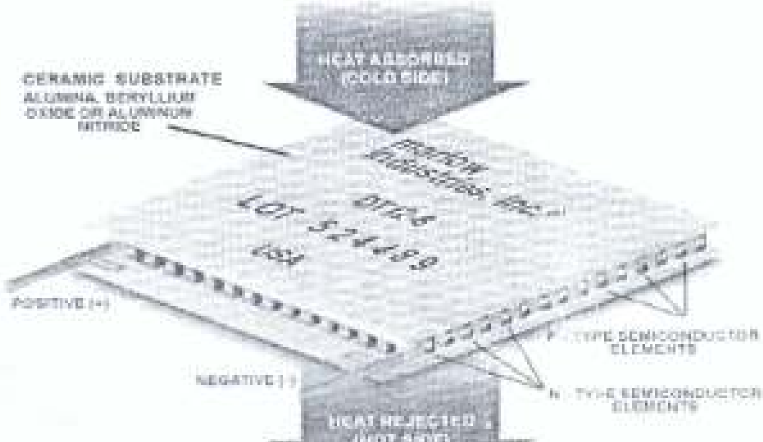


Figure 2.8: Diagram of typical thermoelectric cooler (www.marlow.com/TechnicalInfo/frequently_asked_questions_faqs.htm).

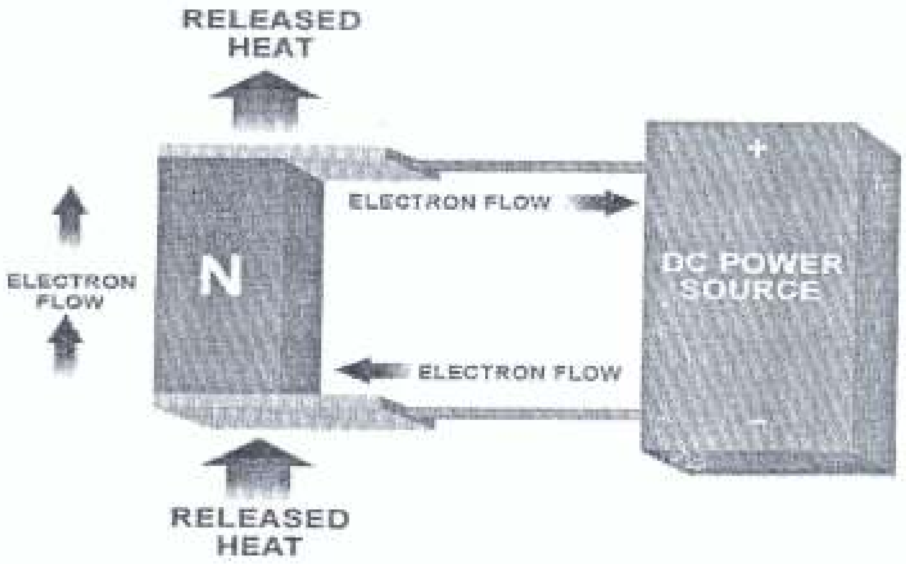


Figure 2.9: Peltier effect using "N-type" semiconductor (www.marlow.com/TechnicalInfo/frequently_asked_questions_fags.htm).

This illustrates an "N-type" semiconductor element utilized to facilitate the Peltier effect. In this example, negatively charged electron repelled by the negative pole and attracted to the positive pole of the DC power source. This forces electron flow in a clockwise direction through the "N-type" material. Heat is absorbed at the bottom junction and actively transferred to the top junction by the electrons as they flow through the semiconductor element. This is known as electron transport.

2.8 Coefficient of Performance (COP)

In refrigeration process coefficient of performance (COP) can be defined as the ratio of output to input energy. The output is the amount of heat absorbed by the system, while the input is the amount of energy required to produce the refrigerating effect (Arora, 1979).

Coefficient of performance is related to an efficiency of a machine, that is the amount of energy one gets out of a machine versus how much energy is input into it. In heat pumping applications, this term is rarely used because the energy taken in is very different from the service provided. When electrical energy is supplied to a thermometric cooler, we get heat pumping, in thermoelectric coolers, it is standard to use "coefficient of performance" not efficiency.

Coefficient of performance (COP) in thermoelectric refrigerator is the amount of heat pumping divided by the amount of supplied electric power. In other words, COP tells us how many units of heat pumping we can get for each units of electrical power supplied. It is possible in special situations, to pump more watts of heat than the watts of electrical power input. COP depends on the applications, heat pumped, and temperature differential required. Typically, the coefficient of performance for thermoelectric refrigerator is heat pumped divided by input power; for a single-stage application COP is between 0.4 and 0.7 (www.marlow.com/technicalinfo/frequently_asked_question_fags.htm).
COP of a heat pump is the ratio of the change in heat at the "output" (the heat reservoir of interest) to the supplied work. This is represented mathematically in equation (9).

$$COP = \frac{|\Delta Q|}{\Delta W} \quad (9)$$

Where:

$|\Delta Q|$ is the change in heat at the reservoir of interest, and ΔW is the work consumed by the heat pump.

The COP for heating and cooling are different, because the heat reservoir of interest differs. When the interest is in how well the refrigerator cools, the COP is the ratio of the heat removed from the cold reservoir to input work. However, for heating, the COP is the ratio of the heat removed from the cold reservoir plus the heat added to the hot reservoir by the input work to input work. These are given in equations (10) and (11) respectively.

$$COP_{heating} = \frac{|\Delta Q_{cold}| + \Delta W}{\Delta W} \quad (10)$$

$$\therefore COP_{cooling} = \frac{|\Delta Q_{cold}|}{\Delta W} \quad (11)$$

According to the first law of thermodynamics in a reversible system we can show in equation (12) that;

$$Q_{hot} = Q_{cold} + W \text{ and } W = Q_{hot} - Q_{cold} \quad (12)$$

Where:

Q_{hot} is the heat given off by the hot heat reservoir and Q_{cold} is the heat taken in by the cold heat reservoir.

Therefore, by substituting for W, in equation (10), equation (13) is obtained

$$COP_{heating} = \frac{Q_{hot}}{Q_{hot} - Q_{cold}} \tag{13}$$

For a heat pump operating at maximum theoretical efficiency (i.e. Carnot efficiency); it can be shown in equation (14) and (15)

$$\frac{Q_{hot}}{T_{hot}} = \frac{Q_{cold}}{T_{cold}} \tag{14}$$

and

$$Q_{cold} = \frac{Q_{hot}T_{cold}}{T_{hot}} \tag{15}$$

Where T_{hot} and T_{cold} are the temperatures of the hot and cold heat reservoirs respectively.

Hence, at maximum theoretical efficiency,

$$COP_{heating} = \frac{T_{hot}}{T_{hot} - T_{cold}} \tag{16}$$

Similarly, coefficient of performance cooling:

$$COP_{cooling} = \frac{T_{cold}}{T_{hot} - T_{cold}} \tag{17}$$

It can also be shown that:

$$COP_{cooling} = COP_{heating} - 1 \tag{18}$$

(en.wikipedia.org/wiki/coefficient_of_perfomance)

2.8.1 Heat Gain from Products:

The heat emitted from the products to be refrigerated is very important in case of cold storages. The loads to be considered in cold storages are divided into the following groups:

Chilling load above freezing; freezing load, and cooling load below freezing point (Dossat, 1979). The one to be considered for the scope of this work is "cooling above freezing".

In considering this cooling, it depends upon the mass of the product (m), mean specific heat of the product (C'_{cm})actual storage temperature of the product (T'_1)desired cooling temperature of the product $(T'_2)$and the cooling time (t_c). Mathematically, cooling load above freezing is expressed as shown in equation (19) (Khurmi and Gupta, 1978).

$$Q_c' = \frac{MC'_{cm}(T'_1 - T_2')}{t_c} \qquad (19)$$

Therefore the heat required to be removed from the product in order to bring it to the cooling temperature (T'_2) by the refrigerator is the Q'_c

2.8.2 Advantage of a Thermoelectric System over Others

Thermoelectric coolers are solid state heat pumps which have no moving parts and do not require the use of harmful CFCs. Since it has no moving parts they are inherently reliable and required little or no maintenance.

They are ideal for cooling devices that may be sensitive to mechanical vibration. Their compact size makes them well suited for application that are space or weight limited such as portable or airborne equipment. Thermoelectric coolers can be used for cooling and when the current is reversed it can also be used for warming. Thermoelectric coolers required less number of parts, and it has much more flexible units than conventional units.

The control is easy as it is done merely by adjusting the current supply. It has no leakage problem, the use of ducts, pipes and refrigerants are not required. This system can completely rid off effects such as ozone depletion and green house effects caused by CFCs refrigerants.

CHAPTER THREE

3.0 DESIGN ANALYSIS

In designing the system, the following assumptions and facts were taken into consideration:

The capacity of the system is assumed to be 30 (W).

The required voltage should not be more than 12 V.

The following parameters were determined:

The current required to produce the heat pumping (I_s)

The transformation ratio needed in the windings of the transformer that will step down 240 V to 12 V (N_p: N_s).

The values of resistors required at the primary and secondary circuits of the power supply section. (R_p: R_s).

The appropriate module that will be able to use the determined current, to produce the designed capacity of 30 W.

The appropriate refrigerating cabinet of dimension 210 mm long, 148 mm wide and 135 mm high and heat exchangers that would be combined with the chosen module to produce 30 W

3.1 Design Calculation

The capacity of the system is 30 W and the voltage required is 12 V.

In order to determine the required current, equation (20) is adopted.

$$Q = W = VI \quad (20)$$

where:

W = Maximum heat to be pumped (J).

V = Voltage across the refrigerator to produce the desired capacity.

With V = 12 V and Q = 30 W

Hence I is calculated to be 2.5 A

Having known the current to be 2.5 A, the voltage 12 V and the rate of pumping heat to be 30W, the appropriate P-N module for the design as selected from the Appendix 2, is bismuth telluride (Bi_2 Te_3) module of type *inbc*l-127.04 because it has capacity to accept maximum current of 3.9 A, voltage of 15.4 V to produce 33.40W (WAT_{RONIX}.Inc, 2008).

3.2 DESIGN CALCULATION FOR POWER SUPPLY;

In order to determine the appropriate thermoelectric Circuit Board for this design, there is need to find out the ratio of transformation required in the transformer.

3.2.1 Ratio of transformation: In a transformer the primary winding is connected to the source of power supply. The circuit to which power is delivered is connected to the secondary winding of the transformer.

Recalling from equation (20) that, power is the product of current and voltage; therefore neglecting loses, equation (21) is obtained.

$$I_p V_p = I_s V_s \qquad (21)$$

The above relation may be expressed simply as follows:

$$\frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P} \tag{22}$$

Where:

N_P = Number of time in primary winding.

N_s = Number of turns in secondary winding.

V_P = Voltage induced in primary winding.

V_s = Voltage induced in secondary winding.

(Pasini and Anthony and; 1976)

3.3.3 Step down transformer-turn ratio winding design

Fig. 3.1: shows the step down transformer used in the system.

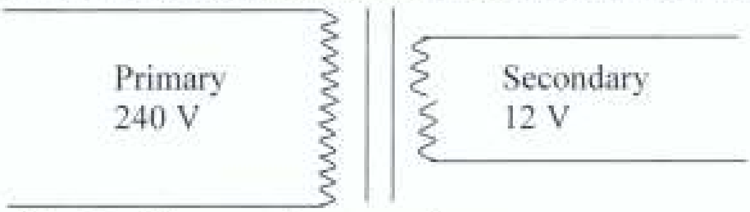


Fig. 3.1: The step down transformer.

The iron core of 60 mm by 38 mm iron frame, is used to design the transformer required as in figure (3.2)

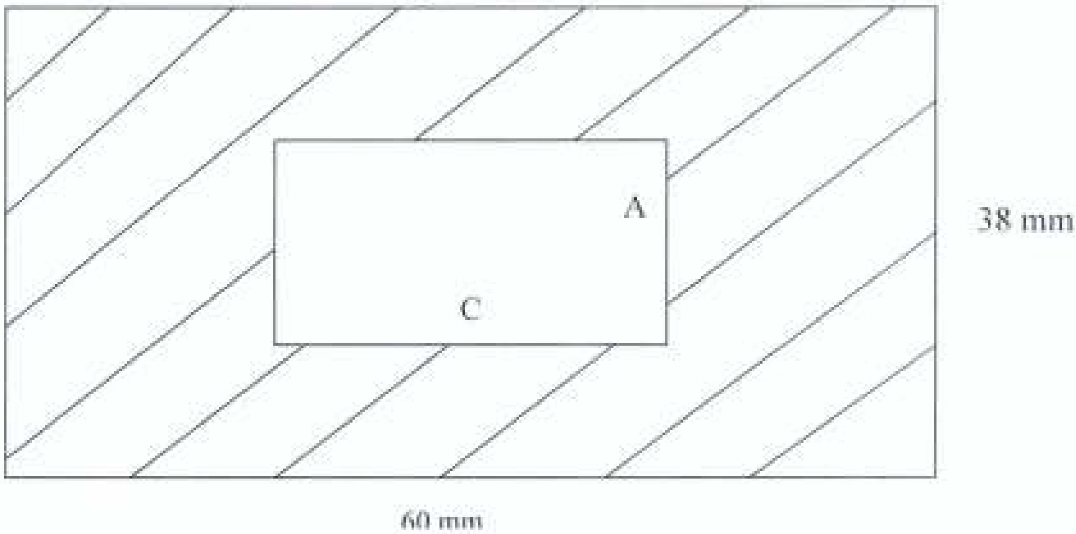


Fig.3.2: Iron frame used in the transformer.

From figure (3.2),

The Area of the core = AC as in equation (23)

Also $AC = K_T$ (Area of the iron frame) (23)

$= K_T$ (60x38) mm^2

$= 0.00228\ K_T\ m^2$

Where, K_T = 0.88, the voltage transformer ratio normally less than unity for step-down transformer (Anthony and Panshi, 1988)

Area of core (AC) = *K_T (Area of the frame)*

Hence,

$AC = 0.0020064\ m^2$

3.2.3 Primary winding

With primary voltage of 240 V, the primary winding (turn) is expressed as in equation (24)

$$N_p = \frac{V}{2\pi f.B.A.C} \qquad (24)$$

Where B = 1.4 (Afe; 2009) personal contact)

f = 50 Hz, AC. = 0.0020064,

V = 240V

Therefore from equation (24):

$N_p = 271.9$

The number of turns in primary winding N_P is 300 (rounded off to the nearest hundred)

Recalling from equation (22)

$$\frac{N_P}{N_S} = \frac{V_P}{V_S}$$

But V_P = 240V, V_S=12V

Hence, secondary winding (N_s) =15turns

Therefore the step-down transformer of N_p (300 turns) and N_s (15 turns) was adopted.

Since the design is to run 12 V, 30 W thermoelectric refrigerators from 240 V a - c mains; the desired voltage can be obtained by using a 20: 1 step down transformer.

Assuming no energy loss in the transformer; power input = power output Therefore recalling equation (21): I_p = 0.13A

Hence, it implies that the current taken from mains is 0.13A.

The value of the resistor required can be obtained from equation (25) (Abbot, 1977).

$$V = IR \tag{25}$$

Where R = Primary resistance in (ohms)

V = Primary voltage in (volts)

I = Primary current in (ampere)

.-. R_p= 1846 Ω

Also the transformer's secondary current using equation (21)

.-. I_s = 2.5A

Therefore the value of resistor required at the secondary part of the circuit;

Using equation (25) is

$R_s = 4.8\ \Omega$

Therefore from the design calculation to select the appropriate circuit Board for the power supply section that will meet the needed thermoelectric effect that can power successfully a refrigerator of 30 W, such Circuit Board's transformer must- have the following parameters:

i. 300 turns in its primary winding

ii. 15 turns in its secondary winding.

iii. Primary current (I_p) of 0.13 A

iv. Secondary current (I_s) of 2.5 A

v. Primary resistant (R_p) of 1846 Ω

vi. secondary resistant (R_s) of 4.8 Ω

The designed parameters are summarized in Table 3.1

Table 3.1: Summary of the parameters used in the design

S/N	Parameters	Designed value	Assumed value
1	Capacity		30 W
2	Primary voltage		240 V
3	Secondary voltage		12 V
4	Primary current	0.13 A	
5	Secondary current	2.5 A	
6	Primary resistant	1846 Ω	
7	Secondary resistant	4.8 Ω	
8	Frequency		50 Hz
9	Primary winding	300 turns	
10	Secondary winding	15 turns	

CHAPTER FOUR

4.0 CONSTRUCTION AND EXPERIMENTATION

4.1 Construction of Thermoelectric Refrigerator

The construction of thermo-electric refrigerator involves proper arrangement of the parts, contained in the three sections that made up the system. The sections involved are: the power supply, the thermoelectric couple and the refrigerating cabinet.

The power supply: in this section, the solid state (electronic) parts involved, are arranged in such a way that the power supplied from the mains is stepped down by the transformer of the Circuit Board to 12 V: the Circuit Board used is shown in plate (1), it would give an output voltage of 12 V and current of 2.5 A. A recitifier is incorporated to permit the flow of electrons through the circuit in one direction only. This also allows the use of direct current to power the system when the need be. Then the choke coil, is arranged next to the rectifier and the thermoelectric semiconductor (module) that uses the electric energy supplied to remove heat from the refrigerating cabinet. The electrical circuit showing the arrangement of the electronic parts involved in the power supply section is as shown in Fig (4.1), while Fig. (4.2), shows the assembled thermoelectric module with the hot and cold heat exchangers. The P – N junctions used in the module are four and they have the following rating: voltage 15.4 V, current 4.6 A, they can withstand temperature of $60^{O}C$ and can remove maximum heat of 41 W from a refrigerating space. But these P – N junctions are used to produce an output of 30 W only using voltage of 12 V and current of 2.5 A.

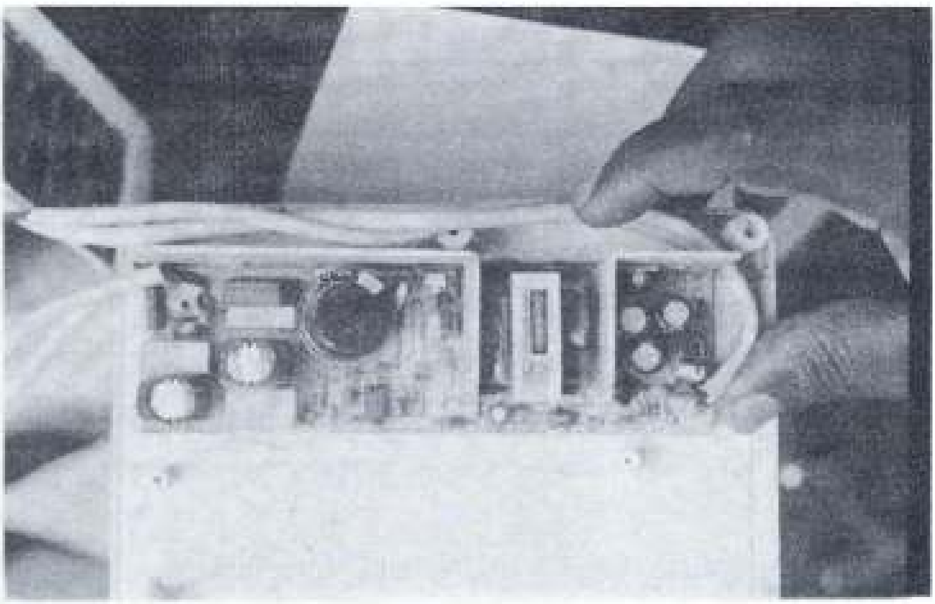


Plate 1: Thermoelectric Circuit board.

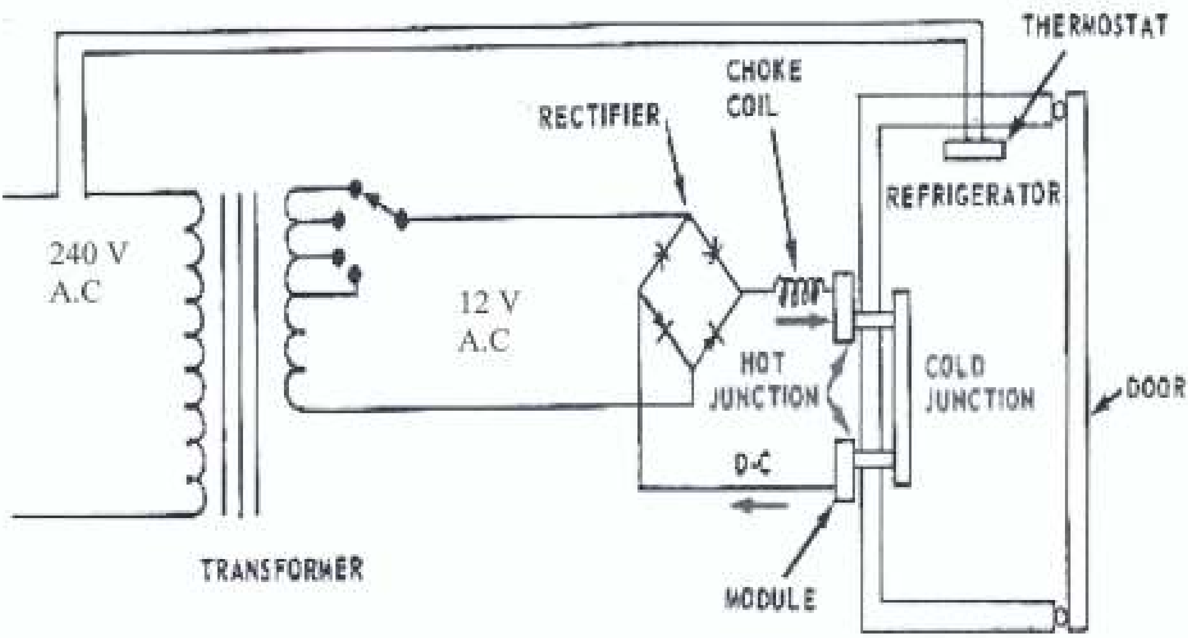


Fig 4.1: The simplified electrical circuit for thermoelectric refrigerator. (Andrew *et al.*, 1975)

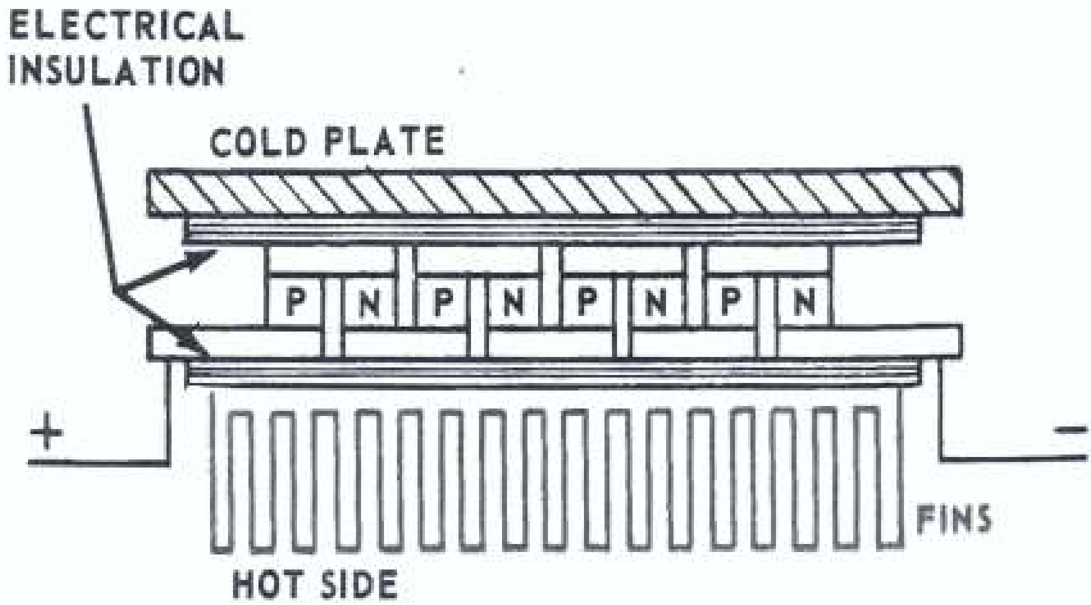


Fig 4.2: Assembled thermoelectric module. (Andrew *et al.*, 1975)

The thermoelectric couple: this section shown in Fig (4.3) consists of the hot heat reservoir, the module and the cold heat exchanger, the hot heat exchanger used is a finned rectangular Aluminum, alloy of size: 135 mm long, 120 mm wide, 15 mm high. Shown in plate (2) while the cold heat exchanger is a square block Aluminum alloy of size: 43 mm long, 43 mm wide and 25 mm high as shown in plate (3). The thermoelectric module used is a semiconductor made of Bismuth Telluride ($Bi_2 Te_3$) of type *inbc* 1-127.04 and size 40 mm by 40 mm by 4.7 mm; its assembly diagram is in Fig. (4.2)

The thermoelectric arrangement is such that, the cold heat exchanger is directly in contact with the outer surface of the wall of refrigerating cabinet, and the module is coupled between the cold and hot heat exchanger; the hot heat exchanger is at the extreme outer part of the refrigerating cabinet.

The refrigerating cabinet adopted, is a thermoelectric type of size 210 mm by 148 mm by 135 mm as in plate (4). The module positioned between the cold and hot heat exchangers is lagged that the cold heat exchanger does not interact with the hot heat exchanger; this module is electrically connected to the circuit board by soldering, at the secondary section of the power supply circuit.

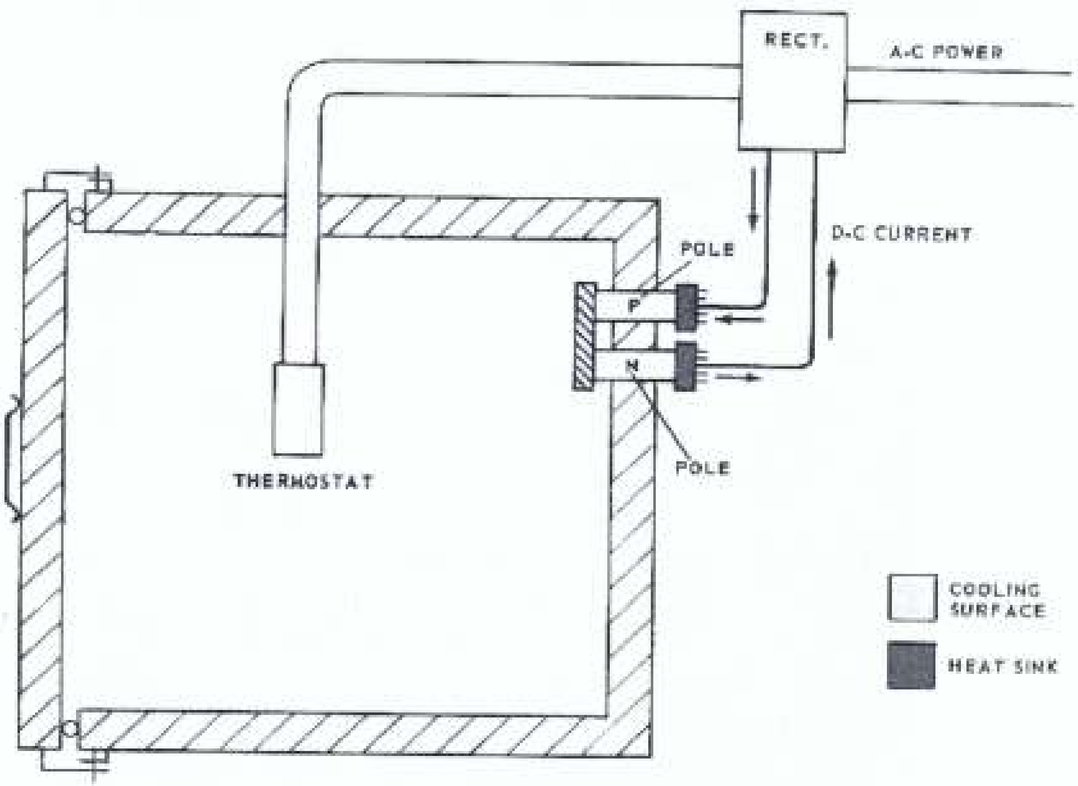


Fig. 4.3: Thermoelectric couple. (Andrew *et al.*, 1975)

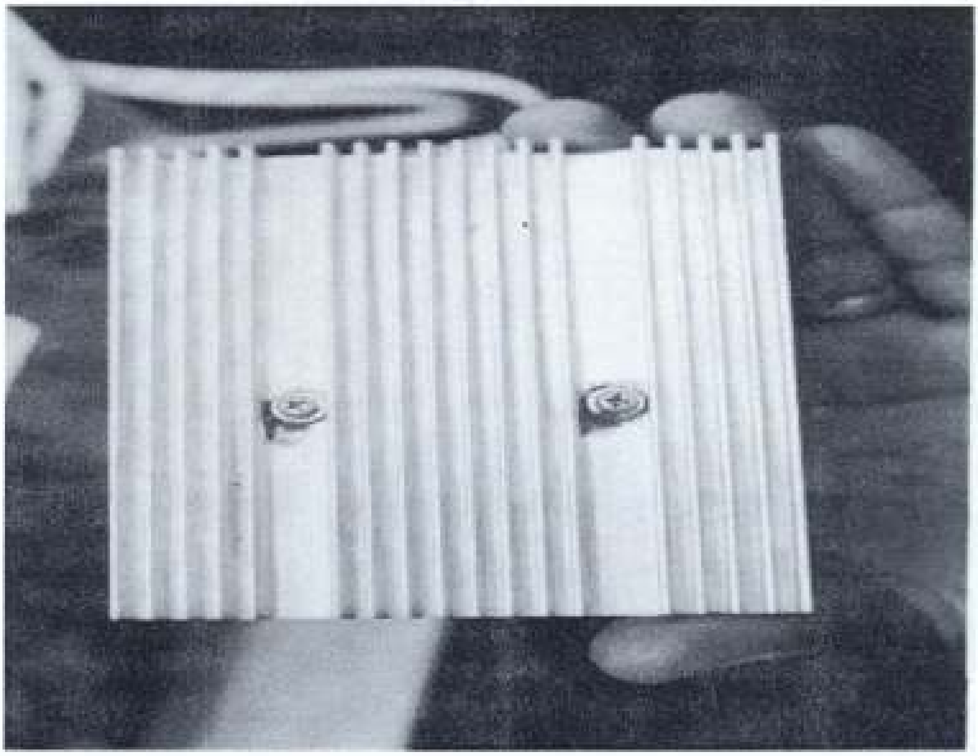


Plate 2: Hot heat exchanger

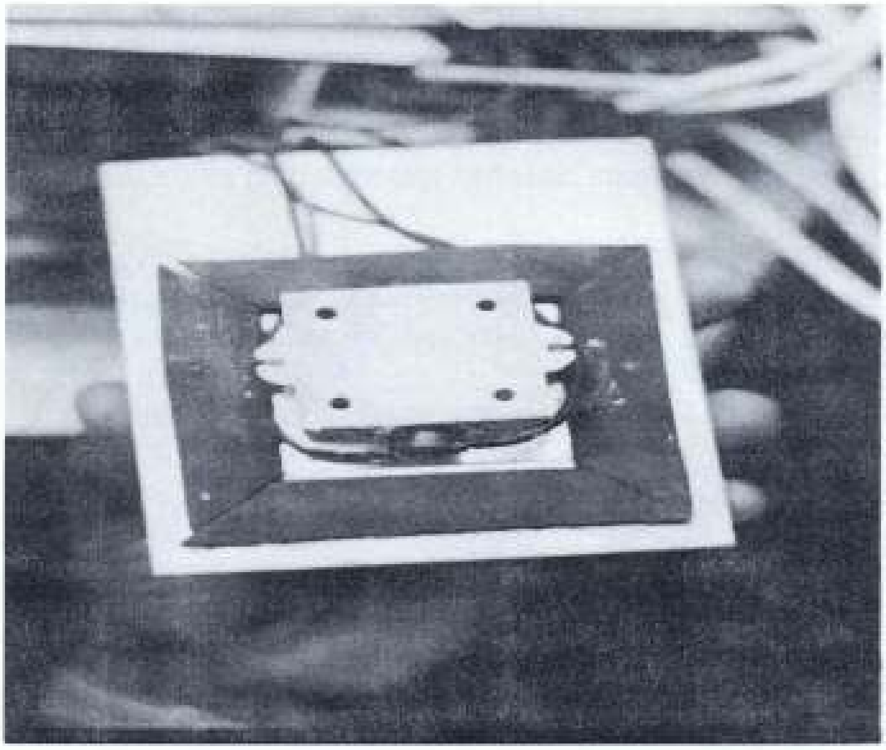


Plate 3: Cold heat exchanger.

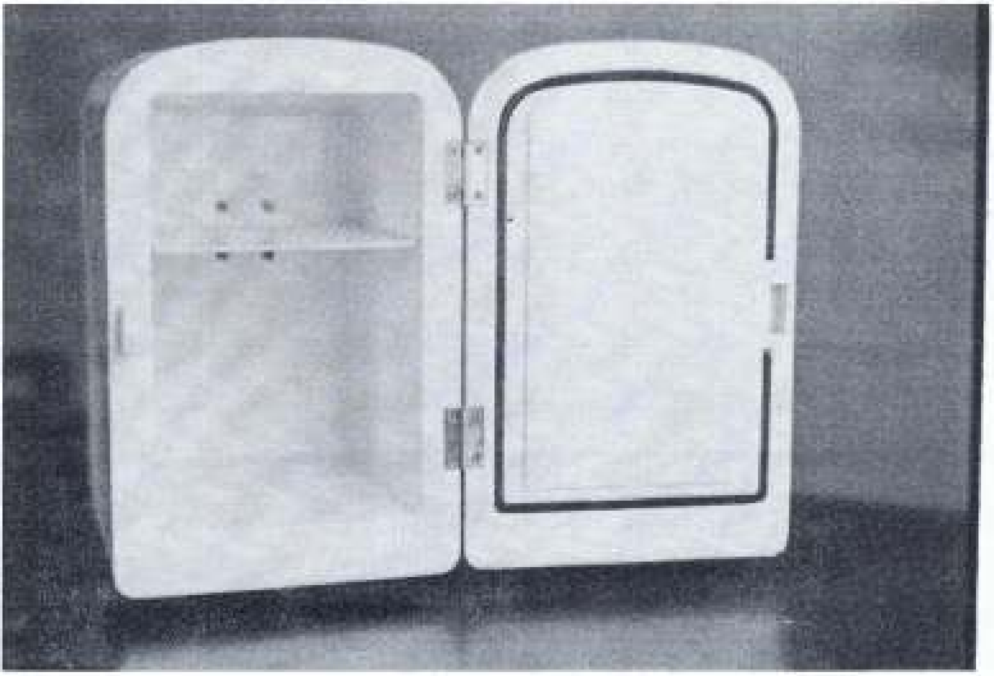


Plate 4: Thermoelectric refrigerating cabinet.

All the electrical joints and the wire connections were made by soldering; the A soldered joints were insulated with adhesive to prevent disconnection, partial contact and short circuiting.

Two power connection points were provided, one for a-c power source and the other for d-c power sources. These points make provision for the use of either of the power sources when it is desired. Ditto provision was made for two switches (reverse switches). One is to determine whether the inside of the refrigerating cabinet is to be kept cold or warm, this depends on the direction of flow of electrons, if the switch is kept on hot side the cabinet begins to warm when power supply is on; and if otherwise the cabinet begins to cool if power supply is on. The second reverse switch is to determine which power source is used; when the switch is on a-c supply side, the system has to be connected to a-c power source, if otherwise it has to be connected to d-c power source.

The simplified diagram of the assembled parts of this thermoelectric refrigerator is shown in Fig 4.4.

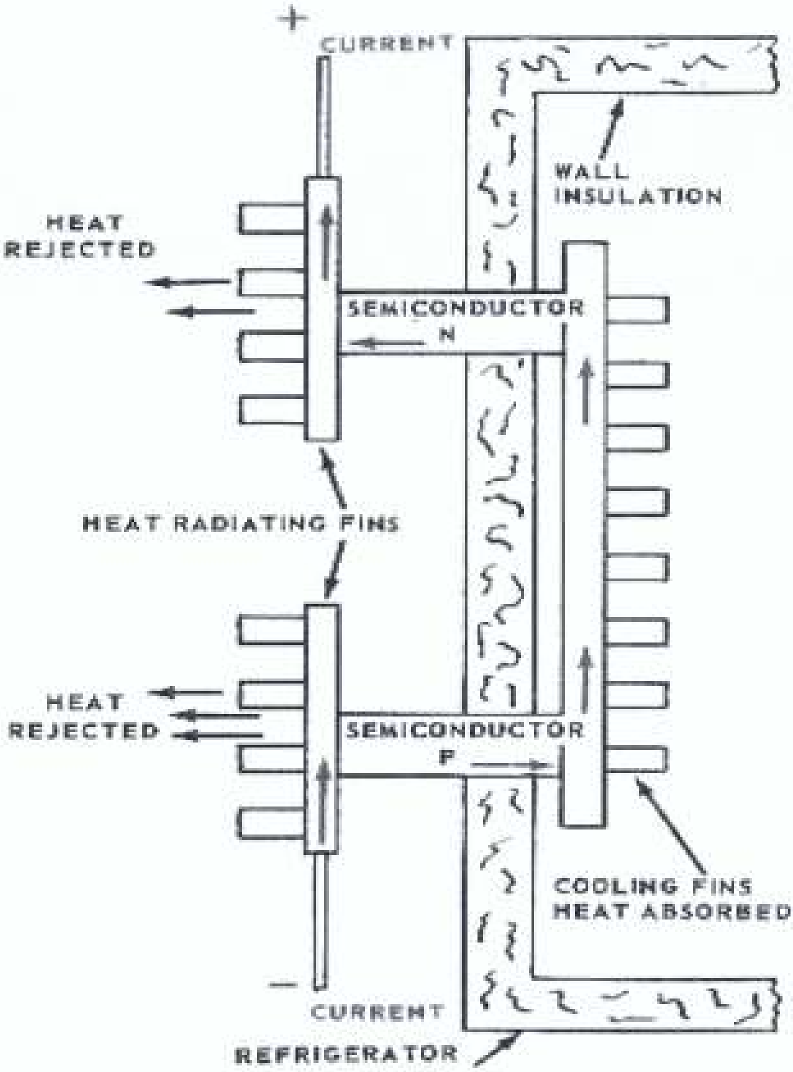


Fig. 4.4: The simplified diagram of thermoelectric system. (Andrew *et al.*, 1975)

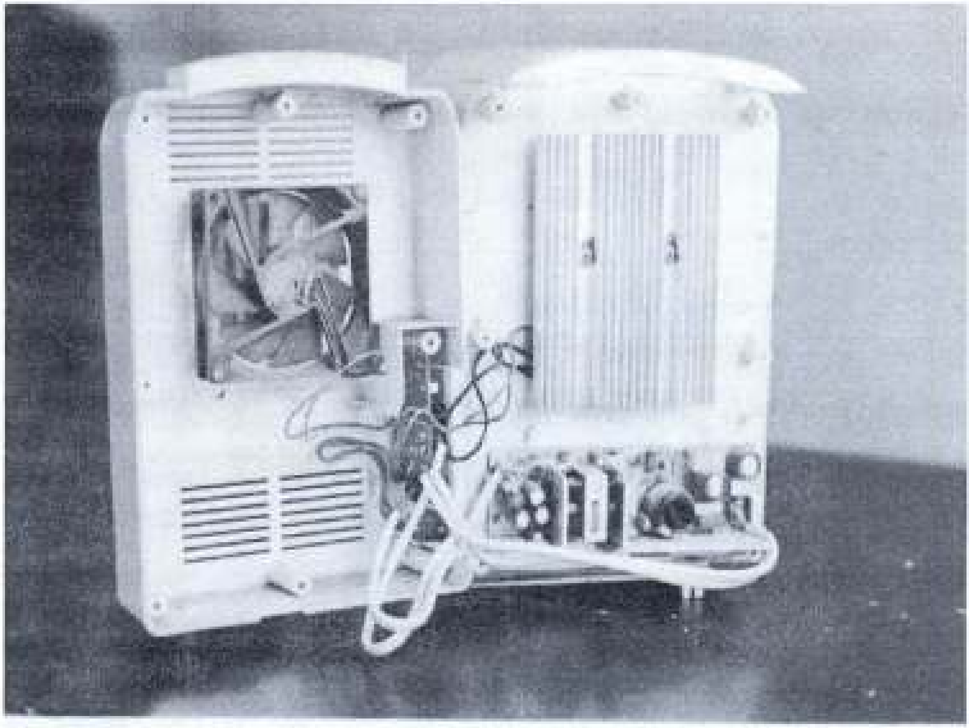


Plate 5: Assembly of the hot heat exchanger, electrical panel and the fan

4.2 Production Cost Estimate

The cost- effectiveness of a product or the production of a system depends on how readily available and affordable the parts involved are. Thermoelectric parts though are simple but are not readily available in the electronics market of Nigeria. Though the cold and the hot heat exchanger parts could be improvised, but the module really needs a specification; and are much more available in the electronics market of some countries where thermoelectric refrigerators are popular such as in France, India, America and London (Documents and Settings/jy/my documents/Po7440.Home.htm, 2008).

The parts used in the construction of this system are obtained from those dealing with imported electronics, in Lagos. (Alaba market).

Table (4.1): Production Cost Estimate

MATERIAL	TYPE DIMENSION (mm)	AMOUNT (₦)
Refrigerating cabinet	Thermoelectric (210 mm by 148 mm by 135 mm)	2500
Hot heat Exchanger	Rectangular finned Aluminum Alloy (135 mm by 102 mm by 15 mm)	2000
Cold Heat Exchanger	Block Aluminum Alloy (43 mm by 43 mm by 25 mm)	2000
Module	Bismuth Telluride *inbc*l-127.05 (40 mm by 40 mm by 4.0 mm)	2500
Printed Circuit Board	Thermoelectric type	2500
Transport		5,000
Information (cost)		3000
Workmanship		3000
TOTAL COST		22,500

The materials adopted in the construction, cost ₦11500; the workmanship of the electrical electronics technician that helped in achieving the correct arrangement of the electronics used, based on the electrical circuit given him is ₦3000, transportation cost to access information is ₦ 5000, while the access to information costs ₦3 000; thereby making the total financial implication of producing this refrigerator to be ₦ 22, 500 only. Nevertheless, if the materials involved are ordered for, in bulk and there is mass production, the cost of production of one unit will be less.

4.3 Experimentation

The scope of this study is limited to thermoelectric cooling; therefore the prototype develop is only experimented for cooling process, using few samples of food items that the capacity of the cabinet can accommodate.

The Experimental Procedure

The food items used were: lemon, apple, orange, grape, banana, water, carrot and tomato. The mass of each food items was taken with the aid of beam-balance and recorded in grammes. The specific heat capacity of these food items were adopted from ASHARAE (2002).

Then, each food item was pierced to accommodate the bulb of Celsius thermometer in order to take the temperature. The initial temperature of each food item before cooling was recorded.

The temperatures of the cold and hot heat exchanger were taken after each cooling process. Also, the final temperature of each food item after cooling was taken. Then the heat removed from each food item after each cooling period was calculated as:

$$Q = mc\theta \tag{26}$$

The work done to remove the heat is calculated as

$$W = VIt \tag{27}$$

The COP of each cooling process was calculated, and then the average COP for the whole system was determined.

4.4 Results and Discussions

In this section the result obtained from the cooling process experimentation using the thermoelectric refrigeration developed are presented in Table (4.2). The table shows the type of food items selected, mass of each, and their corresponding specific heat capacity obtained from ASHARAE (2002), temperature measured before and after cooling, as well as the duration of cooling.

Table (4:2): showing the mass, temperature, specific heat capacity and period of cooling each food item.

FOOD SAMPLE	MASS (g)	SPECIFIC HEAT CAPACITY (kJ/ kg. K)	INITIAL TEMP (°C)BEFORE COOLING	FINAL TEMP (°C) AFTER COOLING						
				½hr	1hr	2hrs	3hrs	4 hrs	5hrs	6hr
LEMON	372	3.81	26	19	17	13	9	8	8	8
APPLE	95	3.72	26	17	16	14	10	9	9	9
ORANGE	232	3.81	26	18	16	13	9	8	8	8
TOMATO	153	3.85	27	15	14	11	5	5	5	5
CARROT	82	3.89	26	15	14	9	8	6	6	6
WATER	693 (50cl)	4.20	25	16	15	12	11	8	8	8
GRAPE	352	3.96	26	19	17	14	10	9	9	9
BANANA	160	3.35	27	17	16	11	7	5	5	5

In Table 4.2 the temperatures before and after cooling were obtained, by piercing through the food items and taking temperatures using Celsius thermometer. The specific heat capacity of each food item is obtained from ASHARAE (2002), why the mass of food items were obtained by weighing each on beam balance.

From the experimental data in Table (4.2), one can infer that: the difference in the temperatures of food items measured under the same experimental environmental conditions and period of cooling; is a function of their masses and specific heat capacity. It can be observed also that temperature of food items after cooling for four hours (4 hrs) indicates negligible or no further reduction in temperature if cooling continues; that is after four hours (4 hrs) of cooling the temperatures of the fruits will be constant (no further chilling after four hours). The temperatures of the hot heat exchanger are:

$$\theta_{ho} = 28^{o}C,\ \ \theta_{h1} = 32^{o}C,\ \ \theta_{h2} = 30^{o}C,\ \ \theta_{h3} = 26^{o}C,\ \ \theta_{h4} = 26^{o}C$$

Where:

θ_{ho} = temperature of the hot heat exchanger before cooling process.

θ_{h1} = Temperature of hot heat exchanger after cooling for 1hour

θ_{h2} = Temperature of hot heat exchanger after cooling for 2 hours

θ_{h3} = Temperature of hot heat exchanger after cooling for 3 hours

θ_{h4} = Temperature of hot heat exchanger after cooling for 4 hours

Similarly, the temperatures of the cold heat exchanger are:

$$\theta_{Co} = 25^{0}C,\ \ \theta_{C1} = 21^{o}C,\ \ \theta_{C2} = 13^{o}C,\ \ \theta_{C3} = 10^{o}C$$

Where:

θ_{Co} = Temperature of cold heat exchanger before cooling process.

θ_{C1} = Temperature of cold heat exchanger after cooling for 1 hour

θ_{C2} = Temperature of cold heat exchanger after cooling for 2 hour

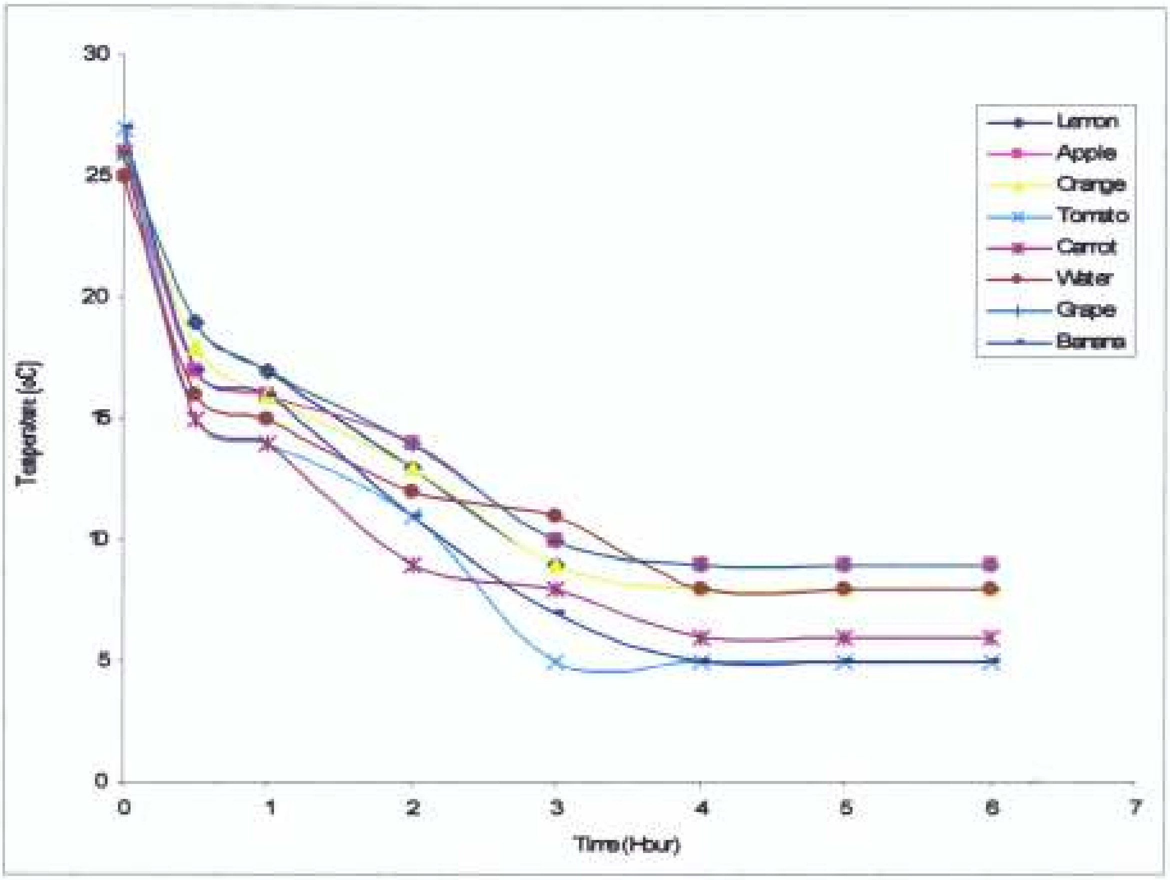


Fig 4.5: The graphical representation of how cooling (°C) varies with period (hour) in each food item

4.5 Coefficient of Performance (COP)

$$COP = \frac{|\Delta Q|}{\Delta W}$$

Where: | ΔQ | is the change in heat at the reservoir of interest, and ΔW is the work consumed by heat pump

$$\therefore COP_{cooling} = \frac{|\Delta Q_{cold}|}{\Delta W}$$

ΔQ_{cold} is the heat removed from the cold reservoir

But $Q = mc\theta$

(Abbot, 1977)

Where: m = mass (kg)

C = Specific heat capacity (kJ / kg. K)

θ = Change of temperature

$\theta = T_1 - T_2$

Calculating the heat removed from the food items after cooling for ½ hour

i. Lemon $Q = mc\theta$

$= 0.372x3.81x(26.19)$

$= 9.9212 \quad KJ$

i. Apple: (Q) $= 0.095 \; x3.72 \; x(26.17$

$= 3.1806 \quad KJ$

ii. Orange: (Q) $= 0.232x3.81x(26-18)$

$= 7.0741 \quad KJ$

iii. Tomato: (Q) $= 0.153x3.85x(27-15)$

$= 7.0686 \quad KJ$

iv. Carrot: (Q) $= 0.082x3.89x(26-15)$

$= 3.5088 \quad KJ$

v. Water: (Q) $= 0.693x4.20x(25-15)$

$= 26.195 \quad KJ$

vi. Grape: (Q) $= 0.352x3.96x(26-19)$

$= 9.7574$ KJ

vii. Banana: (Q) $= 0.160x3.35x(27-17)$

$= 5.3600$ KJ

The Total Heat Removed from the Food Items after Cooling for ½ hour

= (9.9212 + 3.1806 + 7.0714 + 7.0686 + 3.5088 + 26.1954 + 9.7574 + 5.3600) kJ

= 72.0634 KJ

$\therefore |\Delta Q_{cold}| = 72.0634$ KJ

But $\Delta W = VIt$

Where:

V = Voltage

I = Ampere.

t = Time

$\rightarrow \Delta W = 12x2.5x(30x60)$

$= 54000J$

$$\therefore COP_{cooling} = \frac{|\Delta Q_{cold}|}{\Delta W}$$

$$\frac{72063}{54000}$$

$= 1.3345$

Calculating the Heat Removed from the Food Items after Cooling for 1 Hour

i. Lemon (Q) $= 0.372x3.81x(26.17)$

$= 12.7559$ KJ

ii. Apple: (Q) = $0.095 \ x3.72 \ x(26.16)$

$= 3.5340$ KJ

iii. Orange: (Q) $= 0.232x3.81x(26 - 16)$

$= 8.8392$ KJ

iv. Tomato: (Q) $= 0.153x3.85x(27 - 14)$

$= 7.6577$ KJ

v. Carrot: (Q) $= 0.082x3.89x(26 - 14)$

$= 3.8278$ KJ

vi. Water: (Q) $= 0.693x4.20x(25 - 15)$

$= 29.1060$ KJ

vii. Grape: (Q) $= 0.352x3.96x(26 - 17)$

$= 12.5453$ KJ

viii. Banana: (Q) $= 0.160x3.35x(27 - 16)$

$= 5.8960$ KJ

The Total heat removed from the food items after cooling

= (12.7559 + 3. 5340 + 8.8392 + 7.6577 + 3.8278 + 29.1060 + 12.5453 + 5.8960) KJ

= 84.1619 KJ

But $\Delta W = VIt$

$= 12x2.5x(60x60)$

$$= 108000J$$

$$\therefore COP_{cooling} = \frac{|\Delta Q_{cold}|}{\Delta W} \text{ (After 1 hour)}$$

$$\frac{84162}{108000}$$

$$= 0.7793$$

Calculating the Heat Removed from the Food Items after Cooling for 2 Hours

i. Lemon (Q) $= 0.372x3.81x(26.13)$

$= 18.4252$ KJ

ii. Apple: (Q) $= 0.095\ x3.72\ x(26.14)$

$= 4.2408$ KJ

iii. Orange: (Q) $= 0.232x3.81x(26-13)$

$= 11.4910$ KJ

iv. Tomato: (Q) $= 0.153x3.85x(27-11)$

$= 9.4248$ KJ

v. Carrot: (Q) $= 0.082x3.89x(26-19)$

$= 5.4227$ KJ

vi. Water: (Q) $= 0.693x4.20x(25-12)$

$= 37.8378$ KJ

vii. Grape: (Q) $= 0.352x3.96x(26-14)$

$= 16.7270$ KJ

viii. Banana: (Q) $= 0.160x3.35x(27-11)$

$$=8.5760 \text{ KJ}$$

The Total heat removed from the food items after cooling

= (18.4252 + 4. 2408+ 11.4910 + 9.4248+5.4227 + 37.8378.+ 16.7270 + 8.5760) kJ

$$=112.1453 \text{ KJ}$$

But $\Delta W = VIt$

$$=12x2.5x(2x60x60)$$

$$=216000J$$

$$\therefore COP_{cooling} = \frac{|\Delta Q_{cold}|}{\Delta W}$$

$$\frac{112145}{216000}$$

$$=0.5191$$

Calculating the Heat Removed from the Food Items after Cooling for 3 Hours

i. Lemon (Q) $=0.372x3.81x(26.19)$

$$=24.0944 \text{ KJ}$$

ii. Apple: (Q) $= 0.095 \ x3.72 \ x(26.10)$

$$=5.6544 \text{ KJ}$$

iii. Orange: (Q) $=0.232x3.81x(26-9)$

$$=15.0266 \text{ KJ}$$

iv. Tomato: (Q) $=0.153x3.85x(27-5)$

$$=12.9591 \text{ KJ}$$

v. Carrot: (Q) $= 0.082x3.89x(26-8)$

$= 5.7416$ KJ

vi. Water: (Q) $= 0.693x4.20x(25-11)$

$= 40.7884$ KJ

vii. Grape: (Q) $= 0.352x3.96x(26-10)$

$= 22.3027$ KJ

viii. Banana: (Q) $= 0.160x3.35x(27-7)$

$= 10.72$ KJ

The Total heat removed from the food items after cooling

= (24.0944 + 5. 6544 + 15.0266 + 12.9591 + 5.7416 + 40.7484 + 22.3027 + 10.72) kJ

$= 137.2472 kJ$

But $\Delta W = VIt$

$= 12x2.5x(3x60x60)$

$= 324000 J$

$\therefore COP_{cooling} = \frac{137247}{324000}$

$= 0.4236$

Calculating the Heat Removed from the Food Items after Cooling for 4 Hours

i. Lemon (Q) $= 0.372x3.81x(26.8)$

$= 25.5118$ KJ

ii. Apple: (Q) $= 0.095\ x3.72\ x(26.9)$

$= 6.0078 \text{ KJ}$

iii. Orange: (Q) $= 0.232x3.81x(26-8)$

$= 15.9106 \text{ KJ}$

iv. Tomato: (Q) $= 0.153x3.85x(27-5)$

$= 12.9591 \text{ KJ}$

v. Carrot: (Q) $= 0.082x3.89x(26-6)$

$= 6.3796 \text{ KJ}$

vi. Water: (Q) $= 0.693x4.20x(25-8)$

$= 49.4802 \text{ KJ}$

vii. Grape: (Q) $= 0.352x3.96x(26-9)$

$= 23.6966 \text{ KJ}$

viii. Banana: (Q) $= 0.160x3.35x(27-5)$

$= 11.792 \text{ KJ}$ kJ

The Total heat removed from the food items after cooling

= (25.5118+ 6.0078 + 15.9106 +12.9591 +6.3796 + 49.4802 +23.6966 + 11.792) kJ

$= 146.43 \text{ KJ}$

But $\Delta W = VIt$

$= 12x2.5x(4x60x60)$

$= 432000J$

$$\therefore COP_{cooling} = \frac{146430}{432000}$$

$= 0.3389$

In order to get the average $COP_{cooling}$ of the system, the average COP for ½ hr, Ihr, 2hrs and 3hrs required, for this is the period where there are distinct temperature differences in the cooling processes

$$\text{Average } COP_{cooling} = \frac{1.33 + 0.78 + 0.52 + 0.42}{4}$$

$$= 0.76$$

Coefficient of performance (heating)

$$COP_{heating} = \frac{|\Delta Q_{cold}| + \Delta W}{\Delta W}$$

$$\underset{(after\ ½\ hour)}{COP_{heating}} = \frac{72063 + 54000}{54000}$$

$$= 2.3345$$

$$\underset{(after\ 1\ hour)}{COP_{heating}} = \frac{84162 + 108000}{108000}$$

$$= 1.7793$$

$$\underset{(after\ 2\ hours)}{COP_{heating}} = \frac{112145 + 216000}{216000}$$

$$= 1.5192$$

$$\underset{(after\ 3\ hours)}{COP_{heating}} = \frac{137247 + 324000}{324000}$$

$$= 1.4236$$

Average $COP_{heating}$ of the thermoelectric refrigerator

$$= \frac{2.3345 + 1.7793 + 1.5192 + 1.4236}{4}$$

$$= 1.76$$

$$= COP_{cooling} + 1$$

At maximum theoretical efficiency,

$$COP_{cooling} \frac{T_{cold}}{T_{hot} - T_{cold}}$$

while,

$$COP_{heating} \frac{T_{hot}}{T_{hot} - T_{cold}}$$

It has been stated earlier that after 1 hour of cooling. The temperature at hot heat exchanger is 32°C, and at cold heat exchanger is 21°C. Also a hot heat exchanger after 2 hours, the temperature is 30°C while at cold heat exchanger, it is 13°C.

Therefore, theoretical $COP_{cooling}$ (after 1 hour)

$$\frac{= 21}{32 - 21}$$

$$= 1.91$$

Theoretical $COP_{cooling}$ after 2 hours

$$\frac{= 13}{30 - 13}$$

$$= 0.7647$$

The average theoretical $COP_{cooling}$

$$=\frac{1.91+0.76}{2}$$

$$=1.34$$

Theoretical $COP_{heating} = \frac{T_{hot}}{T_{hot} - T_{cold}}$

$COP_{heating}$ $\frac{=32}{32-21}$ $=2.91$

(after 1 hour)

$COP_{heating}$ $\frac{=30}{30-13}$

(after 2 hours)

$$=1.76$$

The average theoretical $COP_{heating}$

$$=\frac{2.91+1.76}{2}$$

$$=2.3$$

Comparing the practical COP to the theoretical COP

The average practical $COP_{cooling}$ is 0.76 while,

The theoretical $COP_{cooling}$ is 1.34

$$\frac{0.76}{1.34}x100 = 57$$

Also,

The average practical $COP_{heating}$ is 1.76

While,

The average theoretical $COP_{heating}$ is 2.34.

$$\frac{1.76}{2.34}x100 = 75$$

Therefore, it is observed that thermoelectric refrigerators agree with the carrot efficiency as in the refrigerators that are using refrigerants, which states that theoretical efficiency cannot be achieved.

The heat removed from each food item during cooling processes are given in table (4.3)

Table (4.3) The Heat Removed from the Food After Cooling.

FOOD SAMPLE	HEAT REMOVED (kJ)					
	½ hour	1 hour	2 hours	3 hours	4 hours	5 hours
LEMON	9.92	12.76	18.43	24.09	25.51	25.51
APPLE	3.18	3.53	4.24	5.65	6.01	6.01
ORANGE	7.07	8.84	11.49	15.03	15.91	15.91
TOMATO	7.06	7.66	9.42	12.96	12.96	12.96
CARROT	3.51	3.83	5.42	5.74	6.38	6.38
WATER	26.20	29.11	37.84	40.75	49.48	49.48
GRAPE	9.76	12.55	16.73	22.30	23.70	23.70
BANANA	5.36	5.90	8.58	10.72	11.79	11.79

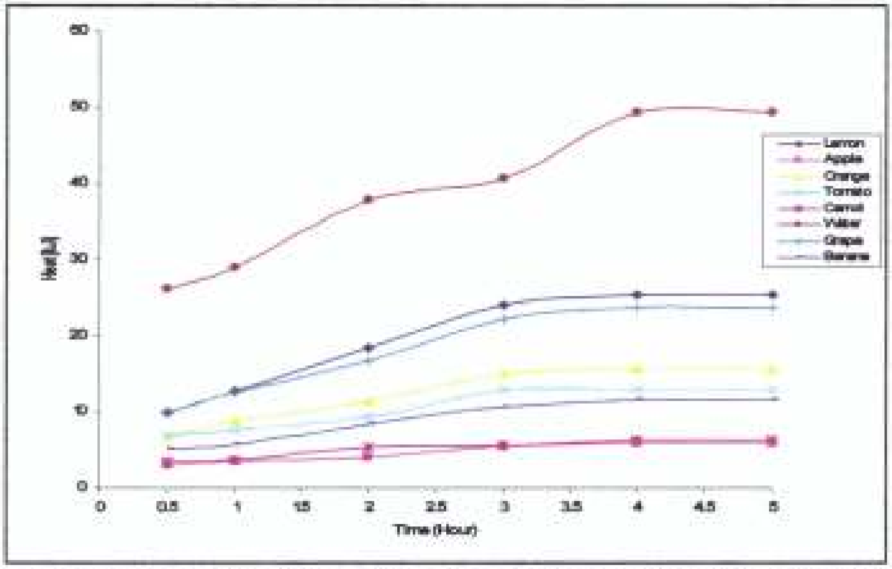


Fig. 4.6: graphical representation of how the heat removed from food item varies with the period of cooling

Thermoelectric properties

Using N-type buismuth telluride having a seeback coefficient (voltage per unit temperature difference) of -287 µV/K at 54 Celsius, its thermoelectric utility is also assisted by the combination of the high electrical conductivity of 1.1×10^5 siemens per meter with its very low latticthermal conductivity of 1.20 W/(m.k).

This implies that: $S = 287x10^{-6} V/K$

$T = 45^{\circ}C, \sigma = 1.1x10^5$ siemens per meter, $\lambda = 1.20$ W/$(m.k)$

Recalling from equation (5), the peltier coefficient,

$$\Pi = S.T$$

$$= (-287x10^{-6})(54) \text{ V}$$

$$= 0.015498 \text{ V}$$

$\therefore$ Its peltier coefficient (Π) =0.15498 V

Using equation (7), the figure of merit, $Z = \frac{\sigma S^2}{\lambda}$

$$= \frac{(1.1x10^5)(287x10^{-6})}{1.20}\left(\frac{siemens}{m} x \frac{v^2}{k^2} x \frac{mk}{w}\right)$$

$$= \frac{(1.1x10^5)(8.2369x10^{-8})}{1.2}\left(\frac{siemens(v^2)}{k(vI)}\right)$$

$$= 7.5505x10^{-3} siemens.\Omega/\text{k}$$

$\therefore$ Its figure of merit, $Z = 0.00755 siemens$ Ω/k

But dimensionless figure of merit ZT is given to be 1 (en.wikipedia.org/wiki/Thermoelectriceffect, 2008).

The calculated $Z = 0.00755$ at 54K

$$\Rightarrow Z = 0.01 \text{(by approximation)}$$

Therefore, to determine Z from ZT=1

$$\Rightarrow ZT = 1$$
$$\therefore Z = \frac{1}{54}$$
$$= 0.018$$

Calculated $Z = 0.01$ and theoretical

$$Z = 0.018$$

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The thermoelectric refrigerator developed was tested and its performance evaluated. The system was designed for a capacity of 30 W, using voltage of 12 V and current of 2.5 A. The transformer was designed to have 300 turns and 15 turns in the primary and secondary windings respectively. Resistors of 1846 Ω and 4.8 Ω were used at the primary and secondary sections of the circuit respectively. The transformer is capable of stepping down 240 V a-c supply to 12 V.

The semiconductor (module) used is made of Bismuth Telluride and of type *inbc* 1 – 127.05, which could withstand the maximum current of 4.6 A, maximum voltage of 15.4 V and can produce maximum capacity of 41 W. The system was experimented for Grape, Orange, Carrot, Banana, Lemon and Water (50 cl). It was observed that cooling the food samples for a half an hour and taking the amount of heat removed from Apple, Lemon and Water into consideration, 3.18 kJ of heat is removed from Apple, 9.92 kJ from Lemon and 26.20 kJ from Water. After cooling for two hours, 4.24 kJ of heat from Apple, 18.46 kJ of heat from Lemon and 37.84 kJ of heat from Water. When the food samples were cooled for four hours, 6.01 kJ of heat was removed from Apple, 25.51 kJ of heat from Lemon and 23.70 kJ of heat from water (the heat removed per unit mass of samples are: 47.12

kJ/kg, 48.35 kJ/kg and 65.80 kJ/kg for Apple, Lemon and Water respectively). In each of the cooling processes, Lemon always have the minimum heat removed from it, followed by Apple and Water always have the maximum heat removed form it when compared to the quantity of heat removed from other samples. It was also observed that further cooling after four hours, did not result to further temperature change in the samples during the experiment; therefore it is concluded that the system attains it maximum cooling capacity after four hours of cooling and hence the temperature remains constant.

When the refrigerator was charged with all the samples, it was observed that the cabinet is able to accommodate 2.14 kg (2.14 kg comprises of 0.372 kg of Lemon, 0.095 kg of Apple, 0.232 kg of Orange, 0.153 kg of Tomato, 0.082 kg of Carrot, 0.693 kg of Water, 0.352 kg of Grape and 0.160 kg of Banana) as its full charge. Having determined the quantity of heat removed from each fruit during the experiment, the Coefficient of Performance (COP) of the system is calculated to be 0.76. Most single stage thermoelectric refrigerator has COP of between 0.4 to 0.7; but this system has it COP higher than the existing ones with 0.06 because a larger module and a lower current were used.

This system is encouraged to be used for both domestic and industrial purposes; they are ideal for cooling devices that may be sensitive to mechanical vibration. Their compact size makes them well suited for application that are space or weight limited such as portable or airborne equipment. It requires little or no maintenance, because it has no moving parts and the control is easy as it is done merely by adjusting the current supply.

5.2 Recommendations

Based on the research carried out on this project work, the following are hereby recommend.

i. A thermoelectric refrigerator of a better coefficient of performance (COP) near that of vapour compression can be achieved by using multiple modules connected in series.

ii. The COP of a single stage thermoelectric refrigerator can be improved by reducing the current to the barest amperage, for this will reduce the energy impute required .to remove heat from the refrigerating chamber.

iii. The efficiency of the refrigerator can be improved on if a better module of Bismuth fellinde, type and of a larger area is used.

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APPENDIX 1

WATRONIX, Inc.

Low Cost Thermometric Modules

Type	Test: thot =27°C Air				Dimension (mm)		
#	Imax (A)	DTmax	Vmax	Qmax	L	W	H
*inb*S1-017-008	0.8	65	2.06	0.92	5.0	5.0	2.4
*inb*S1-031-008	0.8	65	3.75	1.67	6.6	6.6	2.4
*inb*S1-0.17.012	1.2	65	2.06	1.38	6.2	6.2	2.7
*inb*S1-0.31.012	1.2	65	3.75	2.51	8.3	8.3	2.7
*inb*S1-0.17.015	1.5	65	2.06	1.72	6.2	6.2	2.4
*inb*S1-0.31.015	1.5	65	3.75	3.15	8.3	8.3	2.4
*inb*S1-0.17.020	2.0	65	2.06	2.30	6.2	6.2	2.2
*inb*S1-0.31.020	2.0	65	3.75	4.20	8.3	8.3	2.2
*inb*S1-0.17.021	2.1	65	2.06	2.40	9	9	3.4
*inb*S1-0.31.021	2.1	65	3.75	4.40	12	12	3.4
*inb*S1-0.63.021	2.1	65	7.60	9.10	25	12	3.4
*inb*S1-0.17.021	2.1	65	8.60	10.00	18	18	3.4
*inb*S1-.127.021	2.1	65	15.40	18.20	25	25	3.4
*inb*S1-0.17.025	2.5	65	2.06	2.90	12	12	4.0
*inb*S1-0.31.025	2.5	65	3.75	5.30	15	15	4.0
*inb*S1-0.63.025	2.5	65	7.60	10.60	30	15	4.0
*inb*S1-0.71.025	2.5	65	8.60	2.00	23	23	4.0
*inb*S1-0.17.025	2.5	65	15.40	21.50	30	30	4.0
*inb*S1-0.17.030	3.0	65	2.06	3.40	12	12	3.6
*inb*S1-0.31.030	3.0	65	3.75	6.30	15	15	3.6
*inb*S1-0.63.030	3.0	65	7.60	12.30	30	15	3.6
*inb*S1-0.71.030	3.0	65	8.60	14.40	23	23	3.6
*inb*S1-.127.030	3.9	65	15.40	25.80	30	30	3.6
*inb*S1-.017.039	3.9	65	2.06	4.50	12.	12	3.2

APPENDIX 2

WA$_{\text{TRONIX}}$. Inc. **Low Cost Thermometric Modules**

Type	**Test: thot =27°C Air**				**Dimension (mm)**		
#	Imax (A)	DTmax	Vmax	Qmax	L	W	H
*inb*C1-017.03	3.0	65	2.0	3.90	15	15	4.9
*inb*C1-031.03	3.0	65	3.7	7.20	20	20	4.9
*inb*C1-035.03	3.0	65	4.2	8.15	30	15	4.9
*inb*C1-049.03	3.0	65	5.6	11.30	25	25	4.9
*inb*C1-063.03	3.0	65	7.6	14.50	40	20	4.9
*inb*C1-071.03	3.0	65	8.5	16.40	30	30	4.9
*inb*C1-127.03	3.0	65	15.4	29.30	40	40	4.9
*inb*C1-017.04	3.9	65	2.0	4.50	15	15	4.7
*inb*C1-031.04	3.9	65	3.7	8.20	20	20	4.7
*inb*C1-035.04	3.9	65	4.2	9.20	30	15	4.7
*inb*C1-049.04	3.9	65	5.6	12.90	25	25	4.7
*inb*C1-063.04	3.9	65	7.6	16.50	40	20	4.7
*inb*C1-071.04	3.9	65	8.5	18.70	30	30	4.7
*inb*C1-127.04	3.9	65	15.4	33.40	40	40	4.7
*inb*C1-127.05	4.6	65	15.4	41.00	40	40	4.0
*inb*C1-071.06	6.0	65	2.0	6.90	15	15	3.8
*inb*C1-031.06	6.0	65	3.7	12.50	20	20	3.8
*inb*C1-035.06	6.0	65	4.2	14.20	30	15	3.8
*inb*C1-049.06	6.0	65	5.6	20.00	25	20	3.8
*inb*C1-063.06	6.0	65	7.6	25.50	40	15	3.8
*inb*C1-071.06	6.0	65	8.5	28.70	30	20	3.8
*inb*C1-127.06	6.0	65	15.4	51.40	40	15	3.8
*inb*C1-017.08	8.5	65	2.0	9.20	15	20	3.3
*inb*C1-031.08	8.5	65	3.7	16.80	20	30	3.3
*inb*C1-035.08	8.5	65	4.2	19.00	30	25	3.3
*inb*C1-049.08	8.5	65	5.6	26.50	25	40	3.3

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