Peltier Effect Based Circuit Box for Precise Temperature Control in Medical Applications

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Abstract

It is an innovative concept, in which semiconductor element is used for heating and cooling process. The semiconductor element is made up of bismuth and tellurium. This process is carried on the principle of reverse process of Seebeck effect. In this paper, the wall is constructed of using two semiconductor metal junctions. This wall automatically adopted with atmosphere based on the signal from temperature sensor. The heating and cooling process is achieved by changing the current direction of power source. High power DC source is used to supply the power to versatile wall. In this paper the temperature range is maintained between 18^{o}C to 45^{o}C. This temperature control system consist of mode selection button, microcontroller, Optocoupler with relay, high amps DC source and Semiconductor element wall. By pressing mode button we can choose the required mode and that information is taken to microcontroller through port 1. The 12 V relay is connected in port 2 through Optocoupler in order to provide isolation between control and power side. There are two more relays we can change the current direction to bimetal semiconductor elements. For forward direction of current flow heating process is carried on. In same way cooling process is also carried on by changing the current in reverse direction. The bimetal semiconductors get power from external high amps power source.

Keywords: Reverse Seebeck effect, DC source, Microcontroller, Optocoupler, Temperature Sensor.

1 INTRODUCTION

The heating and cooling process are very important process in domestic and industrial application [2]. Both process are entirely different and opposite process. For heating (or) cooling we need heater (or) cooler respectively. The modern refrigeration system consists of parts like evaporator, condenser tubes, compressor, and throttle valve. The product to be cooled is placed inside the evaporator and it is cooled by the heat exchange between the product and the coolant fluid flowing inside the condenser tubes. This results in the emission of greenhouse gases such Freon and chloro-fluro carbons which in turn causes a drastic increase in the global temperature [4]. Moreover the entire refrigeration system becomes bulky due the presence of the compressor and also the working of compressor causes noise and it is undesirable. In case of transportation of organs such as heart, kidneys, eyes, etc. is done today using just an ice box. Sterilization for these organs will be difficult in ice boxes. Transportation of medicines and surgical instruments that need proper maintenance of temperature is also difficult. Certain testing requires maintenance of a particular temperature over a small area. To overcome the above difficulties and implement a portable, noise free, eco-friendly transportation equipment for safe transport of organs and other medical equipment's and to make a box with proper temperature maintenance we develop a test circuit box with precise temperature control. It is achieved by employing the principle of reverse seebeck or Peltier effect. Figure 1 shows the block diagram for the temperature control system.

The principle of operation involved here is the reverse seebeck effect or the Peltier effect. According to the Peltier effect, whenever there is flow of current between a dissimilar metal junctions one junction gets hot and the other junction gets cooled. We trap the heat or chillness from the corresponding junction and produce the desired temperature maintenance. We make use of doped semiconductor material for producing the dissimilar junction. The semiconductor material used here is doped bismuth telluride. This semiconductor is made available into modules. By passing current between this semiconductor junction heat and cold surfaces are formed. By adjusting the voltage supply given to these modules the desired temperature maintenance can be achieved [1]. But here we develop a system to do both operations in one base. In this system Peltier effect (principle) based semiconductor element is used to carry on both operations. By changing the current direction in the bimetal junction we can change the effect in the metal surface. In future this technique will dominate the domestic (or) industries heat (or) cooling process. In this system controlling operation is carried on using microcontroller AT89S52. The thermocouple is used to sense the current temperature of the Test circuit box and give the corresponding voltage as its output [5]. An Analog to Digital Convertor converts the analog voltage corresponding to the temperature into a digital one and stores it in the microcontroller. In the microcontroller certain mathematical calculations are performed and the temperature corresponding to the digital voltage value from the thermocouple is displayed in an LCD display interfaced with the microcontroller.

The major advantages of the test circuit box are the following,

- Test circuit box is a compact warmer and cooler with an exact temperature control system without the use of any compressor, condenser and uses thermoelectric cooling modules.
- It is eco-friendly without the emission of greenhouse gases.
- The operation of this box is noiseless and maintenance free.

The applications of the test circuit box are the following,

- Used for organ transplanting in ambulances in case of emergency.
- Can be used in cryogenic and satellite applications where maintaining of temperature is necessary where the size of the cooling box must be compact and small.
- Can be used in fields of Biotechnology for bacteria growth. The bacteria normally grows at a very low

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temperature below 0'C. This can be achieved by this test circuit box.

- Can be used in artificial DNA synthesis in polymerase chain reaction. Polymerase chain reaction is the process of duplicating the strands of DNA with the available DNA segment. The polymerase chain reaction requires the maintenance of five different temperatures at five different stages of its reaction for a particular period of time.

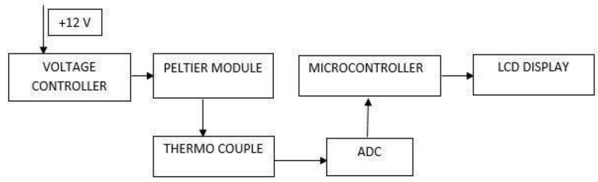

Fig. 1. System block diagram

2 PELTIER MODULE

2.1 Peltier Effect

Peltier found there was an opposite phenomenon to the Seebeck Effect, whereby thermal energy could be absorbed at one dissimilar metal junction and discharged at the other junction when an electric current flowed within the closed circuit. The thermocouple circuit is modified to obtain a different configuration that illustrates the Peltier Effect, a phenomenon opposite that of the Seebeck Effect [3]. If a voltage (Ein) is applied to terminals T1 and T2, an electrical current (I) will flow in the circuit. As a result of the current flow, a slight cooling effect (QC) will occur at thermocouple junction A (where heat is absorbed), and a heating effect (QH) will occur at junction B (where heat is expelled). Note that this effect may be reversed whereby a change in the direction of electric current flow will reverse the direction of heat flow. Joule heating, having a magnitude of I^2 x R (where R is the electrical resistance), also occurs in the conductors as a result of current flow. This Joule heating effect acts in opposition to the Peltier Effect and causes a net reduction of the available cooling [6]. The Peltier effect can be expressed mathematically as

$$QC \text{ or } QH = \beta \times I = (\alpha T) \times I \quad (1)$$

Where:

β is the differential Peltier coefficient between the two materials A and B in volts.

I is the electric current flow in amperes.

QC and QH are the rates of cooling and heating, respectively, in watts.

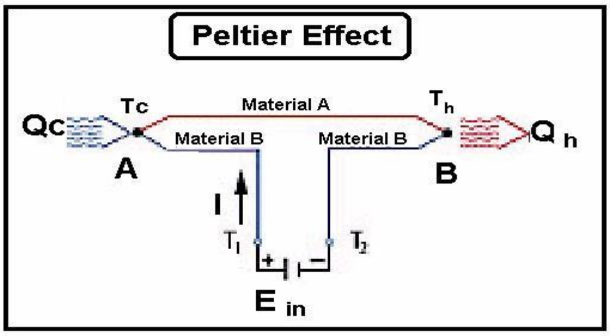

Fig. 2. Peltier effect in dissimilar metal junction

Peltier coefficient β has important effect on Thermoelectric cooling as following:

a) β <0 ; Negative Peltier coefficient

High energy electrons move from right to left. Thermal current and electric current flow in opposite directions.

b) β >0 ; Positive Peltier coefficient

High energy holes move from left to right. Thermal current and electric current flow in same direction.

2.2 Thermoelectric principle of operation

The typical thermoelectric module is manufactured using two thin ceramic wafers with a series of P and N doped bismuth-telluride semiconductor material sandwiched between. The ceramic material on both sides of the thermoelectric adds rigidity and the necessary electrical insulation. The N type material has an excess of electrons, while the P type material has a deficit of electrons. One P and one N make up a couple. The thermoelectric couples are electrically in series and thermally in parallel. A thermoelectric module can contain one to several hundred couples. As the electrons move from the P type material to the N type material through an electrical connector, the electrons jump to a higher energy state absorbing thermal energy (cold side).Continuing through the lattice of material; the electrons flow from the N type material to the P type material through an electrical connector dropping to a lower energy state and releasing energy as heat to the heat sink (hot side). Thermoelectric can be used to heat and to cool, depending on the direction of the current [7]. In an application requiring both heating and cooling, the design should focus on the cooling mode. Using a thermoelectric in the heating mode is very efficient because all the internal heating (Joulian heat) and the load from the cold side is pumped to the hot side. This reduces the power needed to achieve the desired heating.

2.3 Thermal analysis

The appropriate thermoelectric for an application, depends on at least three parameters [7]. These parameters are the hot surface temperature (Th), the cold surface temperature (Tc), and the heat load to be absorbed at the cold surface (QC).The hot side of the thermoelectric is the side where heat is released when DC power is applied. This side is attached to the heat sink. When using an air cooled heat sink (natural or forced convection) the hot side temperature and its heat transferred can be found by using following equation.

$$Th = Tamb + \theta\ Qh \qquad (2)$$

where:

Th = the hot side temperature (°C).

Tamb = the ambient temperature (°C).

θ = Thermal resistance of heat exchanger (°C/watt).

$$Qh = QC + Pin \qquad (3)$$

$$COP = QC / Pin \qquad (4)$$

Where

Qh = the heat released to the hot side of the thermoelectric (watts).

QC = the heat absorbed from the cold side (watts).

Pin = the electrical input power to the thermoelectric (watts).

COP = coefficient of performance of the thermoelectric device, typically is between 0.4 and 0.7 for single stage applications. Estimating QC, the heat load in watts absorbed from the cold side is difficult, because all thermal loads in the design must be considered. Among these thermal loads are:

- ACTIVE - I^2R heat load from the electronic devices. Any load generated by a chemical reaction.
- PASSIVE - Radiation (heat loss between two close objects with different temperatures).
- Convection (heat loss through the air, where the air has a different temperature than the object)
- Insulation losses
- Conduction losses (heat loss through leads, screws, etc.)
- Transient load (time required to change the temperature of an object).

By energy balance across the hot and cold junction it produces

$$Qh = (\alpha\ Th) \times I - C\ (Th - Tc) + I2\ R/2 \qquad (5)$$

$$QC = (\alpha\ Tc) \times I - C\ (Th - Tc) - I2\ R/2 \qquad (6)$$

$$R = RA + RB \qquad (7)$$

$$C = (kA + kB)\ (A/L) \qquad (8)$$

To get the max the heat absorbed from the cold side (QC); by differentiate the Qc to the electric current I,

$$d\ Qc / d\ I = 0 \qquad (9)$$

Then it produces

$$Iopt. = \alpha\ Tc / R \qquad (10)$$

Substitute for Iopt. To get the max the heat absorbed from the cold side

$$QC\ (max) = [(Z\ Tc2)/2 - (Th - Tc)]\ C \qquad (11)$$

Where:

Z = Figure of merit for the material A and B

$$Z = \alpha 2 / RC \qquad (12)$$

The cold side of the thermoelectric is the side that gets cold when DC power is applied. This side may need to be colder than the desired temperature of the cooled object. This is especially true when the cold side is not in direct contact with the object, such as when cooling an enclosure.

The temperature difference across the thermoelectric (ΔT) relates to Th and Tc according to

$$\Delta T = Th - Tc \qquad (13)$$

The thermoelectric performance curves show the relationship between ΔT and the other parameters.

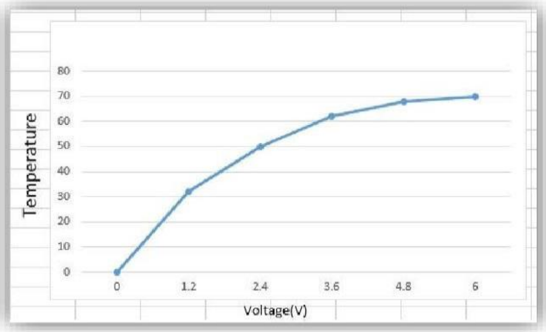

Fig. 3. Performance curve (ΔT vs. Voltage)

2.4 Comparison with conventional refrigeration

Because thermoelectric cooling is a form of solid-state refrigeration, it has the advantage of being compact and durable. A thermoelectric cooler uses no moving parts (except for some fans), and employs no fluids, eliminating the need for bulky piping and mechanical compressors used in vapor-cycle cooling systems. Such sturdiness allows thermoelectric cooling to be used where conventional refrigeration would fail. In a current application, a thermoelectric cold plate cools radio equipment mounted in a fighter jet wingtip. The exacting size and weight requirements, as well as the extreme forces in this unusual environment, rule out the use of conventional refrigeration. Thermoelectric devices also have the advantage of being able to maintain a much narrower temperature range than conventional refrigeration. They can maintain a target temperature to within ±1° or better, while conventional refrigeration varies over several degrees. Unfortunately, modules tend to be expensive, limiting their use in applications that call for more than 1 kW/h of cooling power. Owing to their small size, if nothing else, there are also limits to the maximum temperature differential that can be achieved between one side of a thermoelectric module and the other. However, in applications requiring a higher ΔT, modules can be cascaded by stacking one module on top of another. When one module's cold side is another's hot side, some unusually cold temperatures can be achieved.

2.5 Moisture and vibration effect

Moisture must not penetrate into the thermoelectric module area. The presence of moisture will cause an electro-corrosion that will degrade the thermoelectric material, conductors and solders. Moisture can also provide an electrical path to ground causing an electrical short or hot side to cold side thermal short. A proper sealing method or dry atmosphere can eliminate these problems. Thermoelectric modules in various types of assemblies have for years been used in different Military/Aerospace applications. Thermoelectric devices have been successfully subjected to shock and vibration requirements for aircraft, ordinance, space vehicles, shipboard use and most other such systems. While a thermoelectric device is quite strong in both tension and compression, it tends to be relatively weak in shear. When in a sever shock or vibration environment, care should be taken in the design of the assembly to insure "compressive loading" of thermoelectric devices.

3 MODELLING AND SIMULATION

3.1 Mathematical modelling

When current flows through a semiconductor there are two effects,

- Peltier effect
- Joule heating effect

According to Peltier effect whenever an electric current is passed through a dissimilar metal junction one junction gets hot and the other gets cold. According to Joule heating effect whenever electric current flows through a conductor heat energy is produced.

In a Peltier module according to Peltier effect we have

Qc or Qh = STI (14)

Where

Qc– heat capacity of the cold junction (watts),

Qh – heat capacity on the hot junction (watts),

S – Seebeck co-efficient,

T– Temperature of the hot or the cold junction,

I – input current that is passed in the module.

On cold side of the junction

Qc = STcI (15)

Where Tc - temperature of cold junction

Power developed due to joules heating effect = 1/2 I^2R

Losses due to thermal conductance = k ΔT

Therefore

Qc = STcI-1/2 I2R - k ΔT (16)

Here in the cold junction the Peltier and the Joule heating effect are opposing each other so we get a negative sign in between.

On heat side of the junction

Qh = SThI (17)

Power developed due to joules heating effect = 1/2 I2R

Losses due to thermal conductance = k ΔT

Therefore

Qh = SThI+1/2 I2R - k ΔT (18)

Here in the hot junction the Peltier and the Joule heating effect both result in heating so the on the whole we get the surface heated so a positive sign is in between.

3.2 Thermal to Electrical analogy

Table 1

Thermal to Electrical analogy

Thermal quantity	Analogous Electrical Quantity
Heat, q	Current, I
Temperature, T	Voltage, V
Heat Capacity, C	Capacitance, C
Absolute Zero temperature	Ground

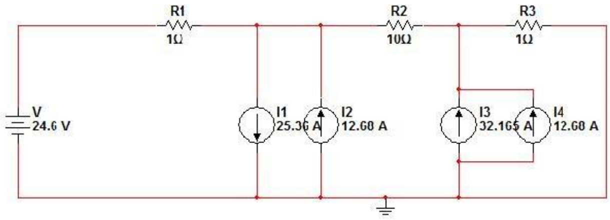

Fig. 4. Electrical equivalent of Peltier module

3.3 Calculation

Calculations are performed for the Peltier module rating of 24V and the cooling power that can be produced is calculated as follows,

Vm=24.6 VIm=7.9 A, Th=69

S = Vm/Th = 24.6/69 = 0.35652

Tc = (Im*R)/S = (7.9*10)/0.35652 = 221.58K

K = (Vm*Im) Th/ (2Th*ΔT) = (24.6*7.9*221.58)/ (2*(273+69)(273+68)) = 0.1846

Q c = STcI-1/2 i2R - k ΔT = 624.08-312.05-62.5528 = 249.47W

Thus for a voltage of 24.6V a cooling power of say 249.47W can be produced.

3.4 Simulation

From the mathematical model of the Peltier module developed the electrical equivalent circuit for the module is developed and that circuit is simulated using the Multisim software. The calculated values for the various current sources in the circuit are given, the supply voltage is varied using a potentiometer and the corresponding values of the cooling powers are noted.

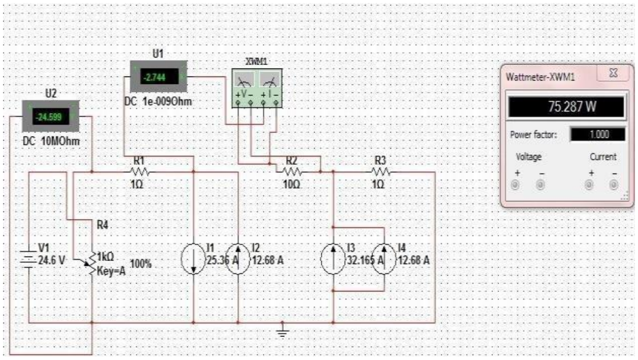

Fig. 5. Simulation of mathematical model of Peltier module in Multisim

3.5 Simulation result and waveform

Fig. 6. Simulation result of Peltier module

From the waveform of the simulation result we infer that the Peltier effect is predominant up to a particular value of voltage and when the voltage is increased beyond that threshold value Joule heating effect becomes predominant and as a net effect we get heating and not cooling power. The threshold value of voltage for the above simulation is 14.7V.

4 VOLTAGE CONTROLLER CIRCUIT

4.1 Chopper circuit

As stated earlier the power rating of the Peltier module will be high and it requires a large current to work at its full rating. The process of controlling or varying the voltage is very difficult. Let us consider that the module of rating 82W, 12V. The current rating of this module will be around 7A. This current is really a very big current. For a DC voltage source of 12V, 7A which is necessarily a car battery the controlling of voltage goes difficult. From the simulation result of the Peltier module we know that the module will work to its maximum efficiency only up to a particular threshold voltage. So we are in need to maintain that particular voltage from the input supply. Potentiometer for such a high current will again turn out to be bulky. Therefore a step down chopper circuit is designed to control the voltage from 0-12V and hence the necessary input voltage can be given to the module.

The step down chopper consists of an input power supply, a power MOSFET, an inductive filter and then to the Peltier module. The power MOSFET used here is IRFP450. The need for this particular MOSFET is that its switching losses is low and its current rating is 16A and will help to vary the input supply from the battery to the module. The voltage can be varied by varying the ON time and the OFF time of the pulse given to the gate of the power MOSFET. This can be easily done with the help of 555 timer IC but the disadvantage of using this one is that the voltage cannot be varied easily form 0-12V, instead it can be varied only form 6-12V which is completely undesirable. So we are going for another one TL494 IC which is a PWM control IC. We can vary the ON and OFF time of the gate pulse given to IRFP450 using this IC. The frequency of this TL494 PWM IC can be varied using the formula,

$$f = 1.1/RC \tag{19}$$

The frequency should be in the range of 44 kHz to avoid losses and get the desired voltage across the Peltier module. So the corresponding value values of R and C are chosen and the desired output voltage is got across the module. The necessity of the inductive filter is to prevent the ripples that are produced after chopping the input voltage. Since it is a high current devise we are going for an inductive filter. The optimum value of the inductance required for the filter is got by using the relation,

$$L = (1-k)\ R/2f \tag{20}$$

Where duty cycle $K=Ton/T$

$$C = (1-k)\ /\ 16\ Lf2 \tag{21}$$

50% of duty cycle:

$L= (1-0.5)1.2/2*44$ $L = 6.818mH$

40% of duty cycle:

L=8.181mH

30% of duty cycle:

L=9.54mH

20% of duty cycle:

L=10.9mH

Thus for various duty cycles the corresponding values of the inductance are calculated and the optimum value of inductor is chosen as 12.3mH for which the amount of ripples in all duty cycles is very low and also the losses across the inductor is also minimum. The chopper circuit is simulated using Multisim and the required value of inductor is chosen from the simulation result. The chopper circuit developed will be as follows,

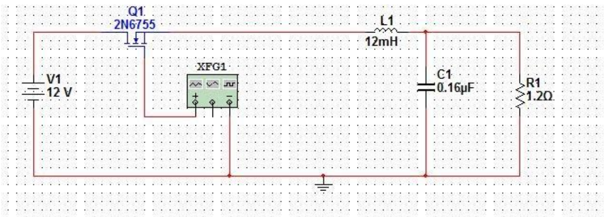

Fig. 7. Voltage controller circuit

4.2 Simulation of the chopper circuit

The simulations for various values of duty cycles are performed using Multisim software and the chopped output waveforms for these values are determined. In Multisim instead of TL494 IC we use a function generator. In hardware part the TL494 Pulse Width Modulation controller is developed for controlling the gate pulse of the power MOSFET. The simulation circuit and the waveform for the duty cycle of 40% is got in the waveform.

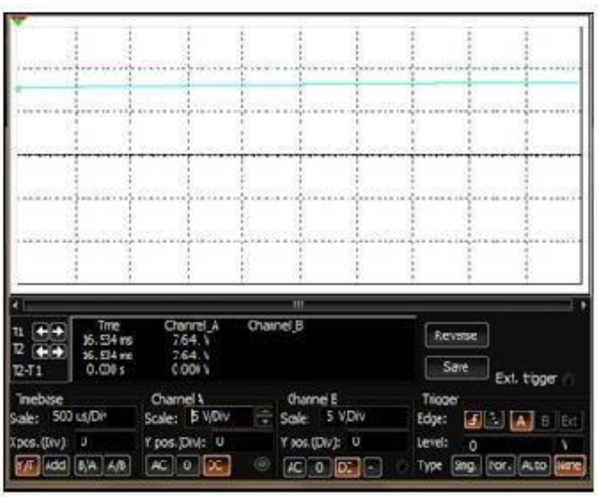

Fig. 8. Output waveform of the chopper circuit

4.3 Test circuit box calculation

Our Test circuit box is made up of copper (Cu) or aluminum (Al) plate. Here we are choose copper plate because copper has good thermal conductivity and mechanical strength. And main advantage of copper is it will instantly cooled and maintained for very long time. Foam Coating is done to prevent heat loss by convection. The advantages of using foam is it will not allow the cool junction to hot junction and hot junction to cold junction. It will act as insulator. On the Heat side we will place the heat sink with fan it will dissipate the heat from hot side. The Dimensions of the test circuit box is – 15cm×15cm×10cm.Outter surface of our box is laminated by Foam sheet. The Calculation made for designing the test circuit box was given below, Power of the module is given by

$$Q = q/A = CP\,(T1 - T2) + hfg + CP\,(T3 - T4) \qquad (22)$$

Where

q/A - the heat flux emitted

Hfg – latent heat of fusion of the material. CP - Specific heat capacity

T1 – room temperature. T2, T3 – freezing point of the material. T4 – required temperature that is needed.

For air Cp=1 hfg=58.68 T1=30 C T2, T3 = 0 C Q=82W

The maximum surface area that can transfer this heat is $0.755m^2$

Model Graph iss also shown below.

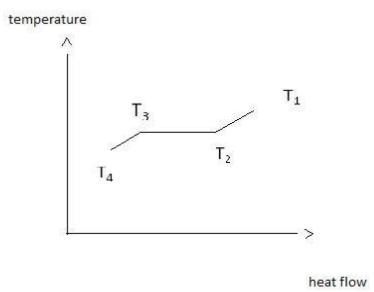

Fig. 9. Relationship between temperature and heat flow

In our Test circuit box how we place the Peltier module means first we place the hot side of the module must face the outside of the test circuit box and cold side must face the interior side of the box. Heat sink with Fan can place on the heat side of the module. It will prevent the heat and it will not allow the hot junction to cold junction.

4.4 Microcontroller interfacing

The temperature of the Peltier module and the box is measured using a thermocouple. The thermocouple is a temperature sensor and it converts the temperature into a corresponding voltage. This voltage is in analog form and it is converted into its corresponding digital form and it is stored in the microcontroller 89S52. The ADC IC used is ADC0804. The ADC is interfaced with the microcontroller through the ports 1 and 3. The digital voltage is used in the mathematical relationship between temperature and voltage in a thermocouple and the corresponding temperature is displayed by the LCD through the port2 of the microcontroller. The port 1 is interfaced with the 8 data lines of the 8 bit ADC. The analog voltage from the thermocouple is converted into an 8 bit digital output voltage. This digital value is fed into the microcontroller and it is stored in a memory location. The Read (RD), Write (WR), Interrupt (INTR) pins of the ADC are all active low signals and they are interfaced with the pins 2, 3 and 4 of the port 3. The chip select (CS) which is again an active low signal is interfaced with port 3.

4.5 Relationship between voltage and temperature

There is linear relationship between the analog output voltage and the temperature that is to be sensed. The values of temperature and the corresponding output voltage are got from the data sheet of the k type thermocouple. It can be seen from the table from below. When the values are plotted as a graph the plot obtained is a straight line. The equation of the straight line is obtained by using two point formula and this equation is fed into the microcontroller. When the voltage is got from the ADC it is applied in this equation and the corresponding temperature is displayed in the LCD.

Table 2

Thermal to Electrical analogy

Temperature(^{o}C)	Voltage(mV)
-40	-1.527
-30	-1.156
-20	-0.778
-10	-0.392
0	0
10	0.397
20	0.798
30	1.203
40	1.612

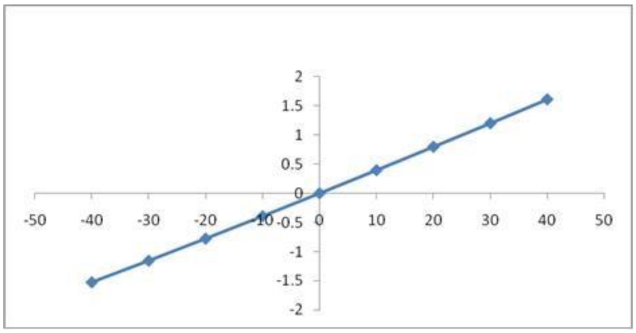

Fig. 13. Relationship between voltage and temperature in a thermocouple (k type)

5 CONCLUSION

The paper proposes hot and cool box with temperature control is very useful project for domestic (or) industrial application. All the block in this system is working very satisfactorily. The only problem is this paper is power consumption. It consumes lot of power for generating small amount of heat (or) cool. This problem will eliminate in future by changing the material combination. The R&D is going on recording this problem. The temperature we range also desired by material combination otherwise there is no problem in this paper and working very satisfactorily.

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