T.C
(MASTER THESIS)
YAŞAR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE

TEMPERATURE MEASUREMENT BY OPTICAL METHODS

Burak KATAGAL

Thesis Advisor: Prof. Dr. Coşkun İŞÇİ

Department of Electrical and Electronics Engineering

Bornova -İzmir
2015

YAŞAR UNIVERSITY

GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCE

(MASTER THESIS)

TEMPERATURE MEASUREMENT BY OPTICAL METHODS

Burak KATAGAL

Thesis Advisor: Prof. Dr. Coşkun İŞÇİ

Department of Electrical and Electronics Engineering

Bornova -İzmir

2015

APPROVAL PAGE

This study titled "TEMPERATURE MEASUREMENT BY OPTICAL METHODS" and presented as MSc Thesis by Burak KATAGAL has been evaluated in compliance with the relevant provision of Y.U Graduate Education and Training Regulations of Y.U institute of Science Education and Training Directions. The jury members below have decided for the defense of this thesis, and it has been declared by consensus/ majority of votes that the candidate has succeeded in his thesis defense. Examination dated..02/07/2015

Jury Members: **Signature:**

Head: Prof. Dr. Coşkun İŞCİ ....

Rapporteur Member: Prof. Dr. Mustafa GÜNDÜZALP ....

Member: Doç. Dr. Murat KÖMESLİ ....

Prof. Dr. Behzat Gürkan (Enst. Md.)

TEXT OF OATH

I declare and honestly confirm that my study titled "TEMPERATURE MEASUREMENT BY OPTICAL METHODS", and presented as Master's Thesis has been written without applying to any assistance inconsistent with scientific ethics and traditions, that all sources from which I have benefited listed in bibliography, and that I have benefited from these sources by means of making references.

d/m/2015 ……………………………….

Student Name & Signature

ÖZET

OPTİK METOTLARLA SICAKLIK ÖLÇÜMÜ

Burak KATAGAL

MSc in Electrical and Electronics Engineering
Supervisor: Prof. Dr. Coşkun İŞÇİ
May 2015

Sıcaklık günlük yaşantımızda sıkça karşılaştığımız bir terimdir. İnsanoğlu yüzyıllardır çeşitli yöntemlerle, sıcaklığı ölçecek bir takım cihazlar ve metodlar geliştirmiştir. Bu metodlar ışığında ölçülen sıcaklık değerleri birçok konuda hangi yolu izlemeleri gerektiği hususunda insanoğluna yol gösterici olmuştur.

Bu tez çalışmasında, sıcaklık ölçme yöntemlerinden birçoğu ele alınmış, fakat ağırlıklı olarak "Optik Metotlarla Sıcaklık Ölçümü" üzerinde durulmuştur. Bilindiği üzere optik methotlarla sıcaklık ölçmede kullanılan; kızılötesi termometre, optik pirometre ve termal kameralar gibi birçok cihaz mevcuttur.

Bu araştırma kapsamında, bu cihazların çalışma prensipleri, sıcaklık ölçüm aralıkları ve genel kullanım alanları üzerinde durulmuştur. Ayrıca birçok yerde bulabileceğimiz malzemelerle el yapımı bir optik pirometre yapılmış ve cihazla bir takım ölçümler yapılarak sonuçlar bilgisayar ortamına aktarılmış ve bazı çıkarımlar yapılmıştır.

Anahtar Kelimeler: Sıcaklık Ölçüm Cihazları, Optik Metotlar, Optik Pirometre Kalibrasyonu

ABSTRACT

TEMPERATURE MEASUREMENT BY OPTICAL METHODS

Burak KATAGAL

MSc in Electrical and Electronics Engineering
Supervisor: Prof. Dr. Coşkun İŞÇİ
May 2015

Temperature is a term frequently encountered in our daily lives. Humankind for centuries, have been developed various methods and devices for to measure temperature. In the light of these methods, measured temperature values have provided guidance to humankind, on many issues with regard to which way monitoring requirements.

In this thesis, we dealt with many of temperature measurement methods, but mostly "Temperature Measurement by Optical Methods" was emphasized. It is known that the optical method for measuring temperature; infrared thermometers, optical pyrometers and thermal cameras, as many equipment is available.

The scope of this research, focused on the working principle, temperature measurement range and general usage areas of this devices. In addition the material which will find in many places, handmade optical pyrometer was made, making some measurements with this device, the results were transferred to the computer environment, and some analysis were made.

Keywords: Temperature Measurement Devices, Optic Methods, Calibration of Optical Pyrometer

ACKNOWLEDGEMENTS

When making this thesis, I got help from a lot of people around me. Without their help, my work would not be understandable and effective.

Initially, I've had some difficulties in preparing this project, but my thesis advisor Prof. Dr. Coşkun İŞÇİ helped me about every subject and has enabled us to overcome the difficulties, so I would like to thank him.

In addition, for starters head of department Prof. Dr. Erol SEZER and all Yaşar University academic staff, I thank them all individually, because of the labor they gave me.

Also thank you "ŞAFAK" cast factory staff for providing the opportunity to make measurements with the optical pyrometer. Without their help, I would not see the performance of device at high temperatures.

Finally, I thank to my father Osman KATAGAL who is also electric technical teacher, for his useful advise and help. I also thank to my mother for her patience.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Cont'd)

Page

TABLE OF CONTENTS (Cont'd)

Page

INDEX OF FIGURES

FIGURE Page

INDEX OF FIGURES (Cont'd)

INDEX OF TABLES

CHAPTER ONE

INTRODUCTION

After the time, temperature is the most measured parameter in daily life. Temperature plays an important role, in demonstrating existing conditions in the production or quality control stages of a product or a device. Accurate measurement of the temperature is influenced positively the product quality and efficiency. At the same time, conditions in the developing world, in terms of speed temperature measuring devices which showing rapid reaction, are gaining importance.

Examples of these devices can be thought pyrometers and infrared thermometers. Pyrometer and infrared technology is not a new phenomenon, but together with the latest innovations in low-cost, more reliable and practical use thermometers has begun to take its place in the market.

One of the biggest advantages of these thermometers are remote measurement by means of a sensor can be done, without any contact with the product. Generally, if we list the advantages of this type of thermometers; making measurements in a short time and without contact with product, to measure temperatures up to 3000°C, not happen any interference during measurement, not a cause contamination in the substance to be measured, and makes it possible the measurement; physically impossible to reach, or harmful substances.

1.1 Heat and Temperature

A material according to some extent, showing quantity of coolness or warmth, is known as the temperature. Each molecule of a substance, has a different kinetic energy. The sum of all the kinetic energy of molecules, if divided by the total number of molecules, we find the average kinetic energy. This average kinetic energy is a measure of a temperature. If we compare the average kinetic energy of the two substances, substances with a high average kinetic energy is hotter than the average kinetic energy is low.

Which is proportional to the average kinetic energy of a substance in size is called the temperature. If changing the temperature of a substance, either giving around the heat, or receiving around the heat. Substances at different temperatures taken together, becomes exchanged the energy between them. Given or received energy is called heat energy [2,3].

To give basic information about heat and temperature;

- Heat and temperature are measurable,
- Heat is a kind of energy, but temperature is not,
- Heat units are calories or joules, the temperature unit is the only degree,
- Heat depends on the amount of substance, but temperature is not depend.

1.2 Optics

Optics examines the light's behavior, characteristics and interaction with matter. Generally optic examines the movement of visible, ultraviolet and infrared light. Because light is an electromagnetic wave and it is show same characteristics with the other types of electromagnetic waves (X-rays, microwaves, radio waves).

Optical science are associated with areas such as; astronomy, engineering types, photography, medicine (mainly Ophthalmology and Optometry) and cooperate with these areas.

In daily life there are lots of optical applications: mirrors, lenses, telescopes, microscopes, lasers, fiber optics, such as in articles that utilizes an optical scienes.

CHAPTER TWO

TEMPERATURE MEASUREMENT METHODS

Length, volume, pressure, electrical resistance, potential difference, color change and surface of the radiation intensity are thermometric properties. By using this thermometric properties, developed various temperature measurers.

Temperature measurement methods are divided into contact and non-contact;

Contact Thermometers

1- Expansion-type thermometers
   . Liquid Extensional Thermometers
   . Pressure Thermometers
   . Bimetallic Type Thermometers
   . Gas Thermometers
2- Thermistors
3- Resistance Thermometers (nickel, copper, (corrosion may suffer) platinum, tungsten)
4- Thermal Couples (Thermocouple)
5- Liquid Crystal Thermometers

Non-contact Thermometers

1- Optical Thermometers
2- Infrared Thermometers

2.1 CONTACT THERMOMETERS

2.1.1 Liquid extensional glass thermometers

Liquid extensional glass thermometers are the most widely used device in the temperature measurement, we can make measurement between -200 to +750°C with these devices. Basic working principle is, the liquid in the chamber expanding by the temperature rising in the capillary tube. In these glass thermometers; mercury, toluene, ethyl alcohol, kerosene, petroleum ether and pentane are used as the liquid. These fluids are used because of the volume expansion coefficient. Liquid mercury is the most commonly used [1-3].

Table 1. Liquids Used in Glass Thermometers

Liquid	Temperature Range(°C)
Mercury	-35 to +510
Alcohol	-80 to +70
Toluene	-80 to +100
Pentane	-200 to +30
Kerosene	-5 to +200

2.1.2 Pressure Thermometers

They have a similar structure to the ideal gas thermometer, but in the chamber placed other fluids, instead of the ideal gas. There are three types;

- Gas filled pressure thermometers
- Liquid-vapor filled pressure thermometers
- Liquid filled pressure thermometers

Such thermometer in practice called fluid expansion thermometer [1-3].

Figure 1. Pressure Thermometers

2.1.3 Bimetallic Type Thermometers

This type of thermometer is based on the extension of the principle to the temperature of solids. The two parts made of different materials are connected to each other by a method such as soldering or riveting. Each material represents a different elongation in a specific temperature difference. This type of thermometers measure between -50°C to + 400°C and accuracy is between ±%1-3 [1-3].

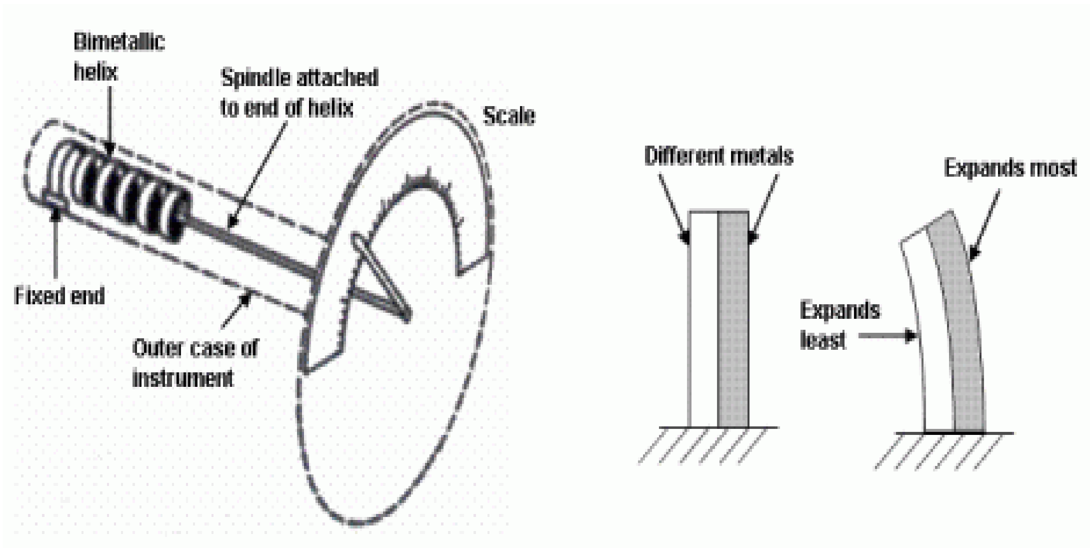

Figure 2. Bimetallic Type Thermometer

2.1.4 Ideal Gas Thermometer

The ideal gas thermometer is a device that measures temperature using the change of gas pressure in a constant volume. We can measure low temperature with a gas thermometer, like 1 Kelvin.

2.1.5 Thermistors

Thermistors are measure the change in resistance with temperature. Thermistors are very sensitive and can detect small temperature changes, it is ideal for precise temperature control [3].

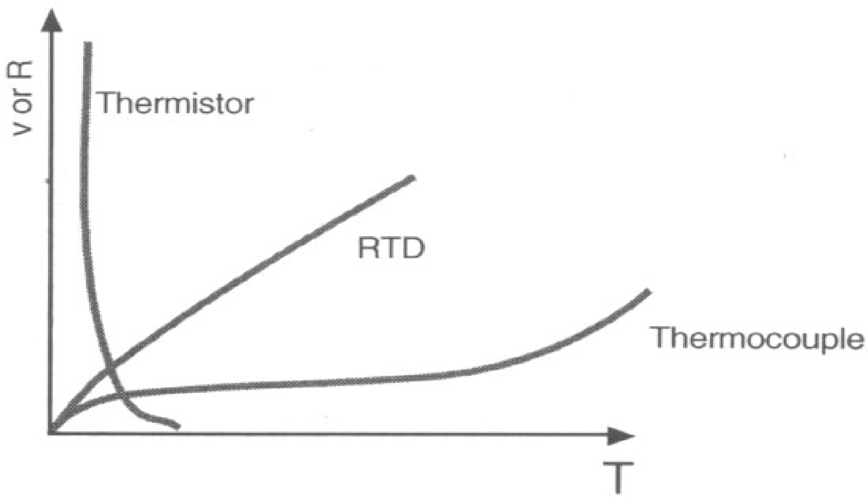

Figure 3. Non-Linear Behavior of the Thermistor

Electrical resistance of the thermistor is made from semiconductor material. Thermistor types;

2.1.6 PTC

. When the PTC resistors heat, resistance values increase, it is produced from barium titanate and tungsten. PTC's works in a stable manner, at temperatures ranging from -60 ºC to +150 ºC. Generally used in circuits designed to protect electric motors against overheating. Also can be used in all procedures, to keep the temperature level in a particular range.

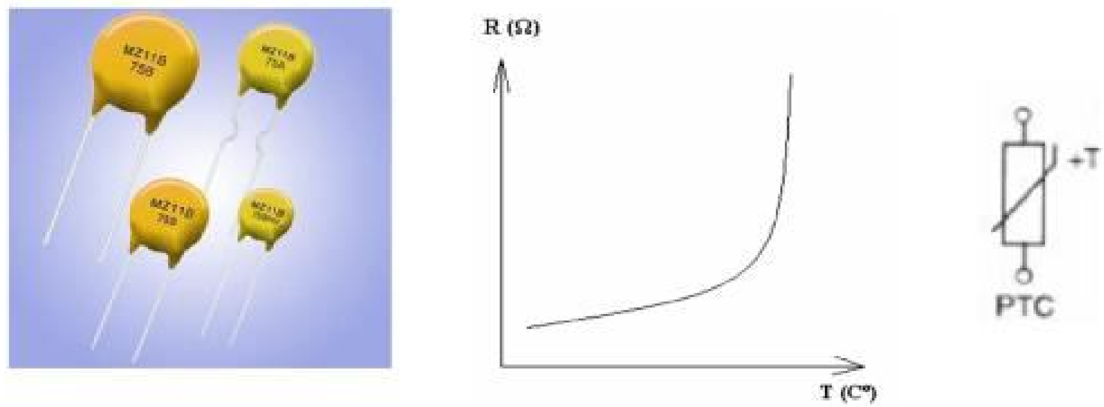

Figure 4. PTC Structure

2.1.7 NTC

When the NTC resistors heat, resistance values decrease, it is produced from substances such as germanium, silicon, and metal oxides. NTC's works in a stable manner, at temperatures ranging from -300 ºC to +50 ºC. Generally used in electronic thermometer, the radiator of a car, the output power of the amplifier floors, temperature controlled soldering iron. Usage areas are more than PTC.

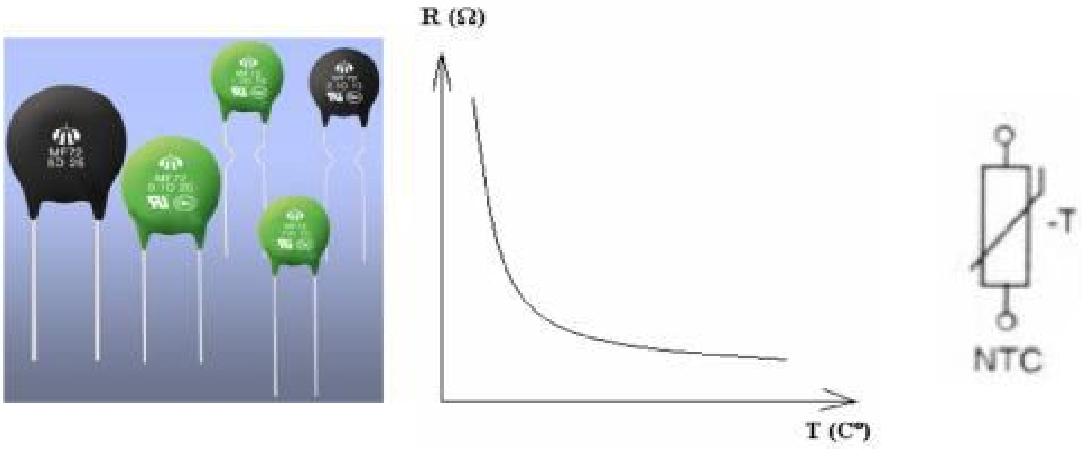

Figure 5. NTC Structure

2.1.8 Resistance Thermometers (RTD)

RTDs are made from such materials platinum, nickel, tungsten. They can measure the temperatures between -260 ºC to +950º C with sensitivity ± 0.01 ° C.

They give the best results at slowly changing temperature measurements. They are used where resistance thermometer; tanks, pipes and equipment bodies, gas and liquid medium (e.g., air, steam, gas, water, oil), low and high pressure applications, surface measurements. In the most widely used PT100 and NI100 resistance thermometers, resistance value at 0 ° C is standard 100 ohm. Platinum RTDs can be used up to -250 ° C to 950 ° C.

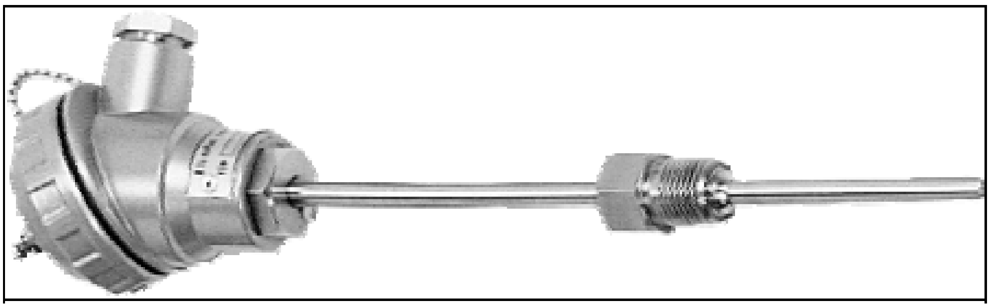

Figure 6. Platinum RTD (PT100)

RTDs are made of nickel wire, they are used at temperatures between -60 ° C to + 150 ° C. Application areas are generally air conditioning units. The difference is from PT100 's resistance change values and the operating range. Physical structures are the same as PT100 's [1-3].

2.1.9 Thermocouple

The most commonly used electrical temperature measurement method. We can measure temperature from -200 ° C to 2500 ° C with using thermocouples. When two different or unlike metals are joined together at two junctions, an electromotive force (emf) is generated at the two junctions. The amount of emf generated is different for different combinations of the metals. This is known as Seebeck effect.

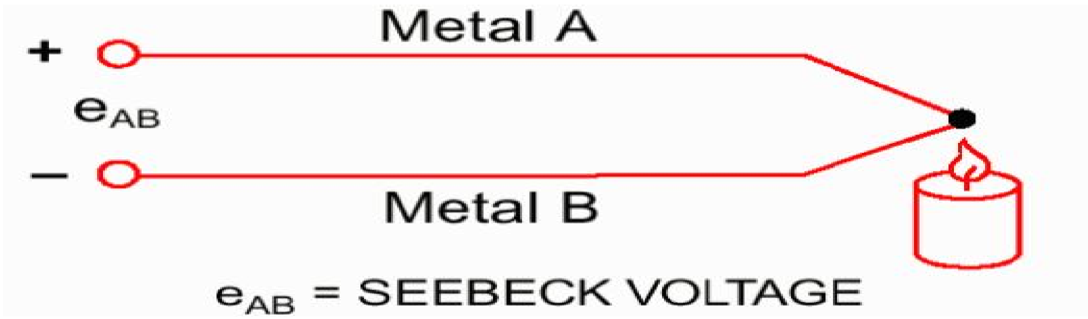

Figure 7. Seebeck Effect

There are at least two ends of a thermocouple circuit. One of the ends is used as the reference thermocouples; it is immersed in demineralised water at 0 ° C.

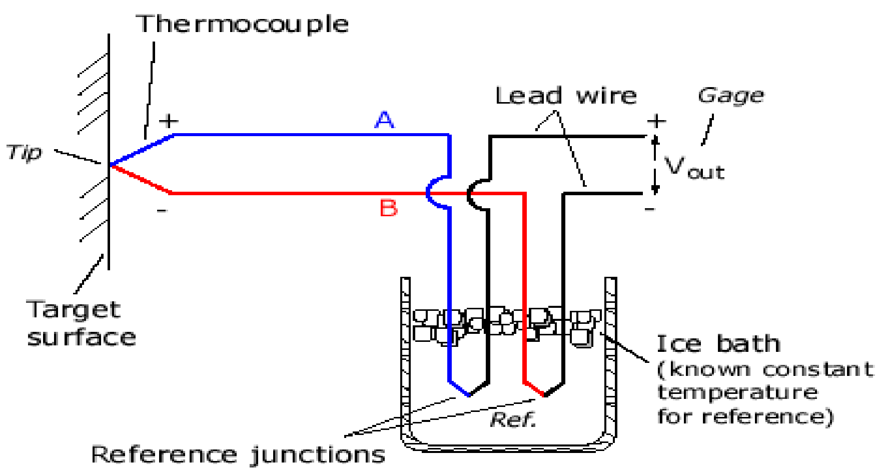

Figure 8. Termocouple Circuit

The resulting emf is measured by millivoltmeters galvanometer or potentiometer. These elements are electrically connected in series or parallel to increase the sensitivity of those thermocouples [1-3].

2.1.10 Liquid Crystal Thermometers

What is a liquid crystalline; in structure they carry solid features, but in appearance they are liquid. These structures are referred to as liquid crystals. They act according to aligned form of the molecules. These molecules are aligned in 3 different ways (Smetic, Nematic, Cholesteric)

Many commercial oils used in the industry, the protein in the animal body and oils, are in liquid crystal case. The colors of liquid crystals changes from red to purple. The color change with temperature is reversible process. Liquid crystals are used in the temperature measurement and image acquisition. Using liquid crystals, can be taken photograph of the object. In technical the liquid crystal is wipe on the object, and the temperature distribution on the object becomes visible. The top of the liquid crystal to protect from external influences is coated with polyvinyl alcohol.

Liquid crystals in the second type of temperature gauges, infrared rays emitted from the object, in contact with the liquid crystal and which absorbs infrared rays dropped onto the a sheet. With the observation of the liquid crystal portion, the temperature region is monitored freely [1-3].

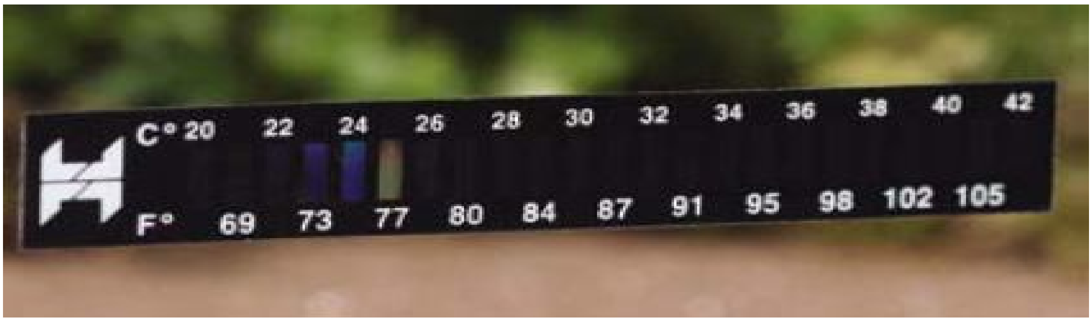

Figure 9. Liquid Crystal Thermometer

CHAPTER THREE

3.1 Non-contact Thermometers

For better understanding non-contact thermometer, primarily we need to know the following;

3.1.1 Some Basic Concepts

Emission (ε): Emission is the process by which a higher energy level of a particle becomes converted to a lower one through the emission of a photon, resulting in the production of light.

Reflection (ρ): Reflection is the change in direction of a wave front at an interface between two different media so that the wavefront returns into the medium from which it originated.

Wavelength (λ): Wavelength is the distance between repeating units of a wave pattern. ($\lambda = v / f$, v = wave velocity, f = frequency)

Black body: We can see the objects thanks to the light which they are reflected. If an object, completely absorbed and does not reflected the light which falling on their surface, we can not see the object. The body which absorbs all radiation energy falling on the surface, is called "black body" [6].

3.1.2 Black Body Radiation

- Black body: These are an ideal objects who completely absorbing all the electromagnetic radiation falling on it.
- Located on a small hole and emptied bodies behave as black bodies.
- Black body is the best thermal radiation emitter, because it absorbs all wavelengths of electromagnetic radiation falling on. [4,5].

3.1.3 Stefan Boltzmann Law

The Stefan–Boltzmann law, also known as Stefan's law, describes the power radiated from a black body in terms of its temperature. Specifically, the Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time (also known as the black-body *radiant exitance* or *emissive power*), E, is directly proportional to the fourth power of the black body's thermodynamic temperature *T* [7]:

$$\mathbf{E = \sigma\, T^4}$$

E = The Total Energy of the Emitted Unit Surface at Unit Time.
T = Absolute Temperature (K)

$$\boldsymbol{\sigma = \frac{2\pi^5\, k^4}{15c^2h^3} = 5.67 \times 10^{-8} W\, m^{-2}\, K^{-4}}$$

σ = Stefan Boltzmann Constant
h = Planck Constant
c = Velocity of Light

Stefan Boltzmann equation gives only the relationship between the emitted energy with temperature [4,8].

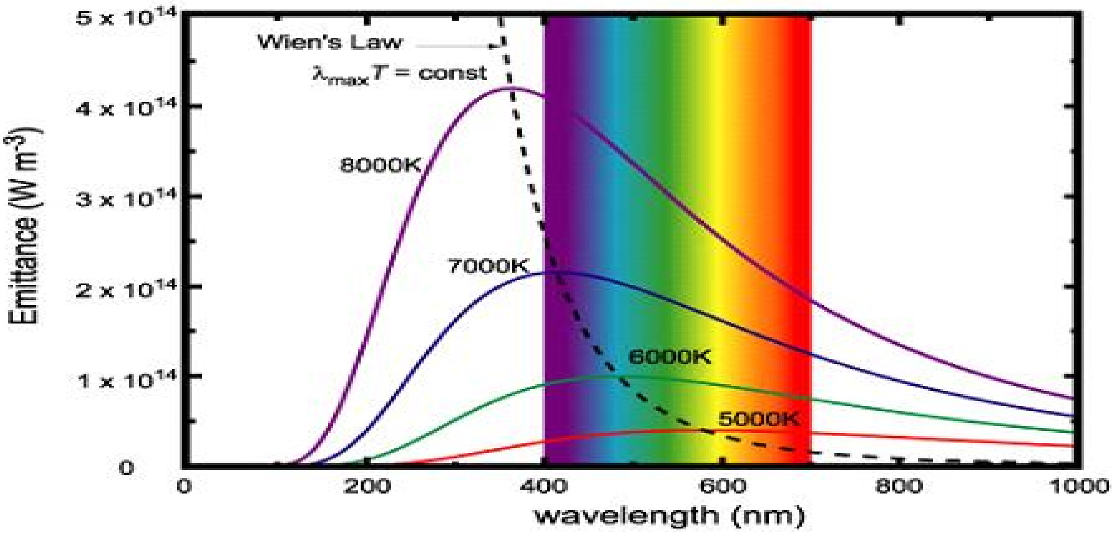

Figure 10. The Emitted Energy by the Black Body Change of According to Wavelength

(http://www.micro-epsilon.com/download/products/dat--infrared-basics--en-us.pdf)

- In constant temperature, while wavelength change, the radiation energy passes through a maximum.
- As temperature increases, wavelength decreases corresponding to the maximum.
- This has been poured into the equation by the German physicist W. Wien.

3.1.4 Wien Displacement Law

Black body and all other bodies, although at different rates, makes radiation at all wavelengths. According to "Wien law", there is a simple relationship between a black body temperature (T) and the maximum radiating wavelength;

$$\lambda max = \frac{b}{T}$$

T = Absolute Temperature (Kelvin)

b = Wiens Displacement Constant (2898μm K)

λmax = The Wavelength at Maximum Radiation (μm)

The wavelength of the maximum intensity point on a black body in the continuous spectrum is inversely proportional to absolute temperature. Hot objects can radiate energy in the short wavelength and cold objects can radiate energy at longer wavelengths [4,9,11].

3.2.1 Temperature Measurement with Radiation Method

When the objects are heated, they radiate electromagnetic energy. At low temperatures, this spread energy is felt. This radiation can be used to measure the temperature through intuition. Qualitatively that can be said; a glowing yellow color body is hotter than the dull red glowing object. Here pyrometer, take advantage of this radiation to measure the temperature.

Thanks to pyrometer, we can measure the temperature of an object which is in motion. Also thanks to its feature which make measurements without contact, we can make measurements safely at very high temperatures.

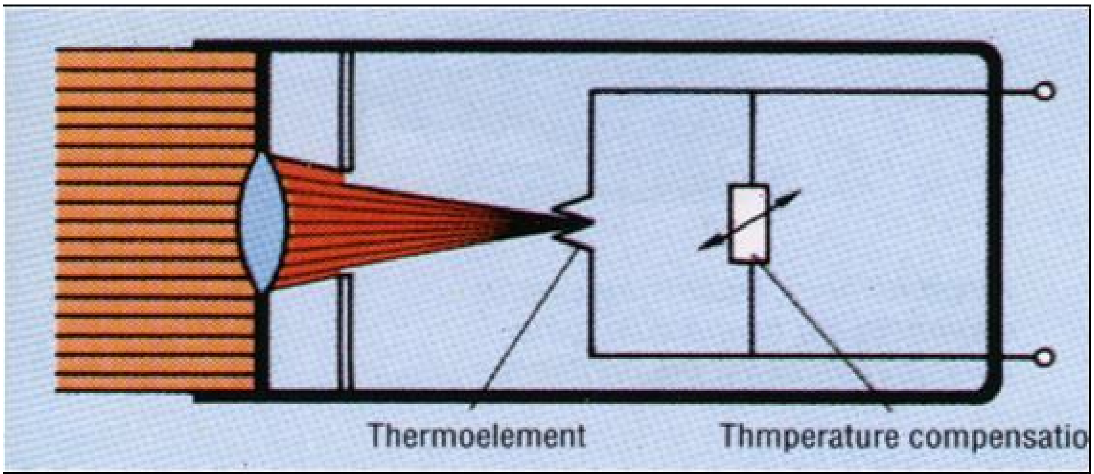

Figure 11. General Pyrometer Structure

Pyrometers, is a very simple device as shown in the figure, wherein emitted radiation of the object which temperature to be measure, is dropped onto thermocouple with help to lenses. Body temperature was obtained from the sensor and it is converted into electrical signals by clasical methods [2,3].

3.2.2 Total Radiation Pyrometer

Radiation from the hot surface, is dropped on temperature sensing surface (thermocouple, photoelectric element or resistance thermometer) with a collector lens or a mirror. This type of devices read the temperature from 400 °C to 3500 °C.

3.2.3 Optical Pyrometer

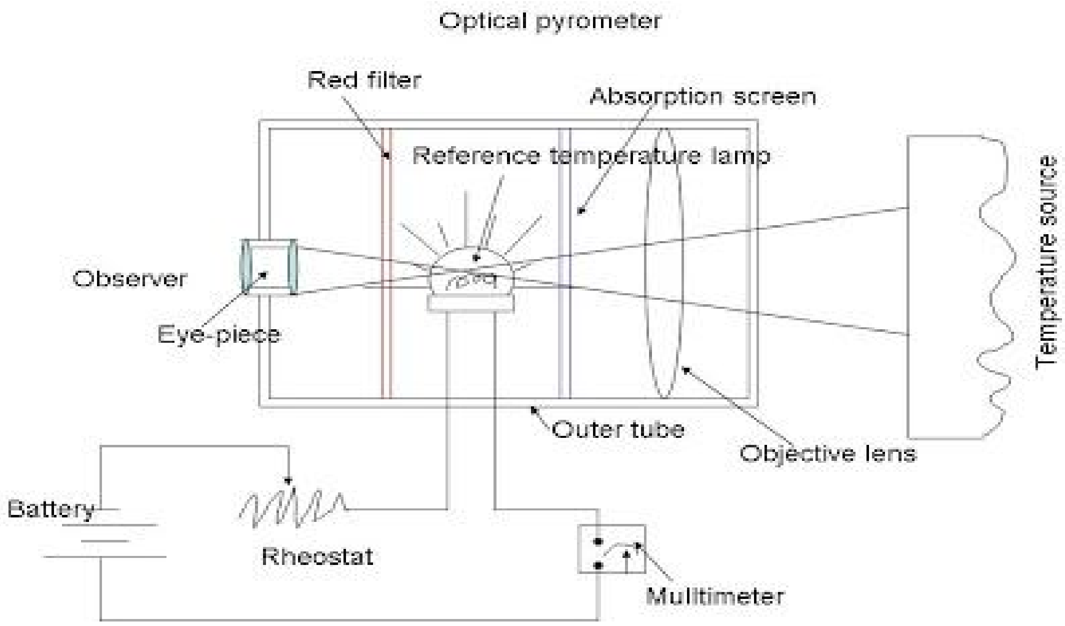

Figure 12. Optical Pyrometer Structure

In this type of pyrometer, thermocouple sensor is not used. According to the user's eye decision, simple measurements are made in the temperature range from 500° C to 3000° C. As can be seen from the figure (*figure12*), the user looks at the temperature source with the help of binoculars, and adjust the filament current.

When the filament color is same with temperature source color, filament becomes invisible, exactly at this moment read of value from scale gives the temperature of source [2,3,13].

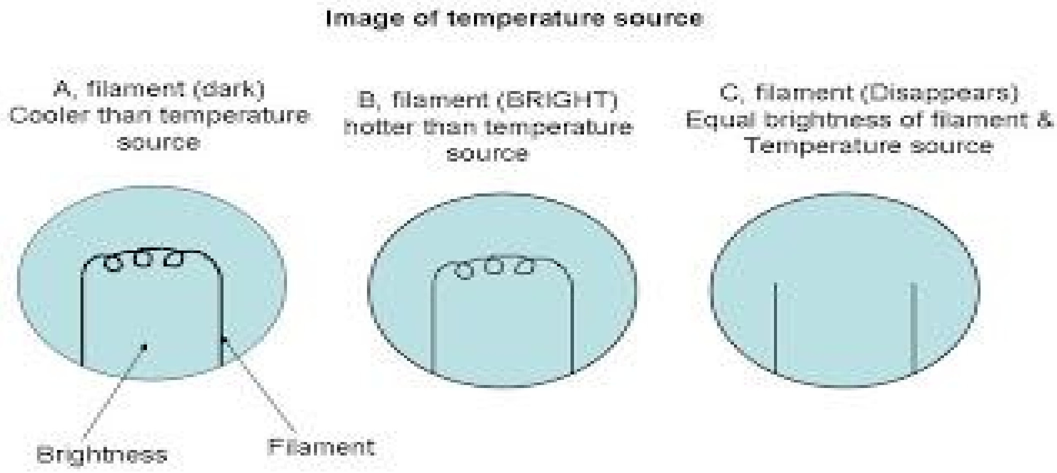

Figure 13. Filaments Appear Situations

3.2.4 Photoelectric Thermometers

In this type of pyrometer is used elements such as photodiode or phototransistor to detect radiation emitted by hot bodies. The following figure shows this arrangement. In the short wavelength applications, appropriate results are taken [3].

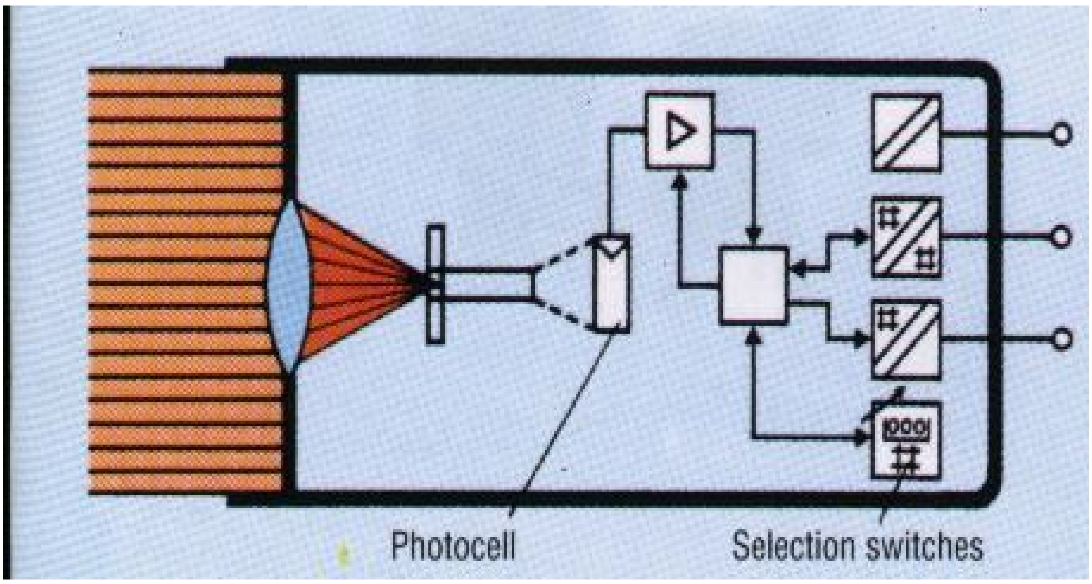

Figure 14. Photoelectric Thermometers Structure

3.2.5 Pyroelectric Techniques

Nowadays, thermopile is used extensively as termocouple in pyrometer. At the same time developing with CCD 'Charge Coupled Device' technology, trend has begun on this way. Especially infrared light-sensitive CCDs began to used in cameras and thermal imaging cameras have been created [3].

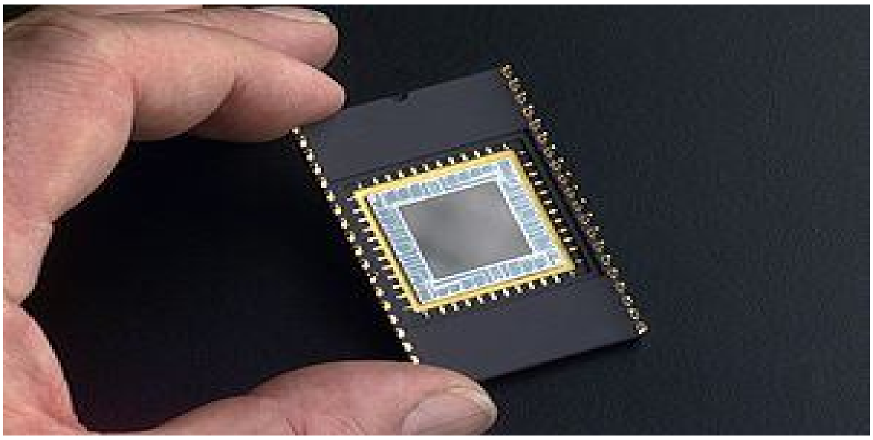

Figure 15. Charge Coupled Device

3.2.6 Infrared Thermometers

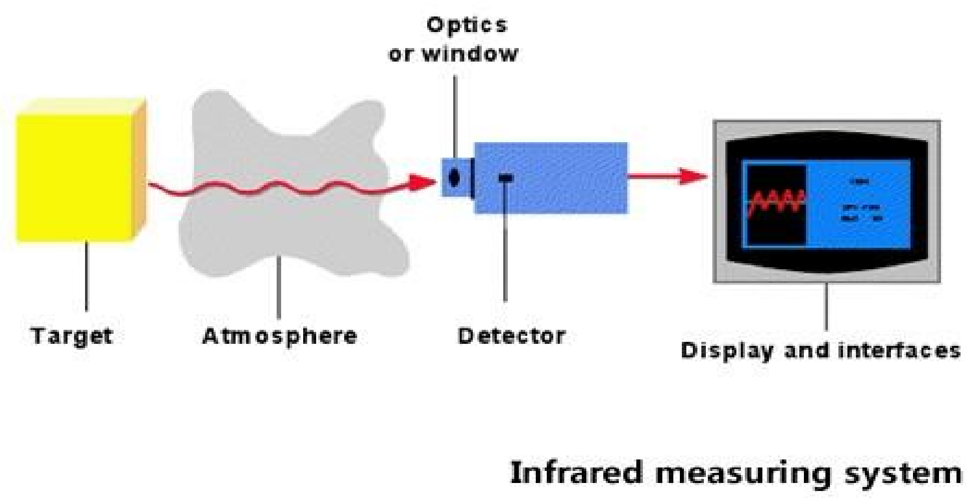

Figure 16. Infrared Measuring Structure

Infrared thermometers are devices, which used to measure temperature without contact.

Most of infrared thermometer having a pilot light beam for a better orientation. Infrared thermometers measure the surface temperature of only visible surfaces and does not perform measurement behind objects such as glass. Some of the infrared thermometer has adjustable K (emissivity value) value feature and in this way K value can be selected depending on the material (paper, wood, metallic surfaces ...). In addition, we can not to make the absolute temperature measurements on shiny surfaces with non-contact infrared thermometers [13,15-18].

3.2.7 What is the degree of emission on infrared thermometers?

Emittance radiation of an object with black body radiation emittance ratio is called emissivty. Emissivty value is between 0 to 1,0. For example, the degree of emission of a mirror is 0,1. This value is called "black shining". If the degree of emission on infrared thermometer is extremely high, the temperature of the object is found higher than the actual temperature. For example, if infrared thermometer set to 0.95 while emissions is 0,9, infrared thermometer displays a temperature above the actual temperature [17,18].

3.2.8 What should be taken into consideration when measuring the non-contact infrared thermometer?

The first thing to remember here the measured temperature is always the surface temperature. Measurements should be made in an open area, including the object to be measured with an infrared thermometer. Can not make measurement behind glass with non-contact infrared thermometer. Should not make measurements, in an environment with dust and moisture, between infrared thermometer and the object.

Infrared thermometer has a professional system for measurements the surface temperature. Some of these features are, targeting clarity thanks to laser, wide temperature range and adjustable degree of emission (material dependent). Thanks to the high optical resolution, objects can be measured easily from a distance. Measurement distance is associated with measurement point size. To make measurements from long distances, the area must be large.

However this situation sometimes may not be preferred. You can see how the device correctly use below the figure (*figure 17*).

Usage areas of the infrared thermometers are quite wide. These devices are useful for all industrial processes. Distribution network cabinets, maintenance of electrical units, temperature measurement of the machine parts, are just a few of them. You can see how the realization of temperature measurement using infrared thermometer in the photo below [17,18].

Figure 17. Temperature Measurement With Infrared Thermometers

Infrared thermometers a further application is the detection of SARS-infected patients. Febrile patients may infect this disease to other people.

3.3.1 Thermal Camera and Thermography

Is based on the principle of thermal radiation. The temperature distribution on the body surface can be measure contactless. Radiation spreading changes with temperature. According to the color change, temperature is determined.

In nature, every object radiates energy. Visible light is the best known form of electromagnetic energy. When looking at the objects, we see the changing of the color spectrum from red to purple. The main difference between these colors, is wavelength. All being which found in nature, emit electromagnetic energy at different wavelengths depending on their temperatures.

In the infrared band which starting just above at the red color, there are two wavelength range thermal. These are respectively "Medium Infrared" and "Far Infrared" bands.

All objects have a thermal radiation property. Furthermore objects has energy absorption abilty. To give an example; during the day bodies are heated by the sun, in this way they have a certain thermal energy, afterward they radiate thermal energy to the environment during the night. The wavelength of the emitted energy and amount of total emitted energy depends on the temperature of the object. The human body and a lot of objects which we encounter in our environment, has a temperature of around 30ºC. Significant portion of the emitted energy from these objects located in the far infrared band.

In general infrared cameras, can be used for security purposes, but also it is clear to use a wide variety of sectors. In particular, heat-guided missiles, night vision systems, and other military techniques has increased in importance with the development. In the electricity sector, it is used in the detection of electrical problems. Also in the energy sector, they are used for temperature analysis in installations and buildings. In the architectural field, it is used for the detection of fatigue in the steel structure, and also they are used for the detection of mold-moisture or crack under the plaster [12,13,15,20].

a) Emission, Reflection and Transmission

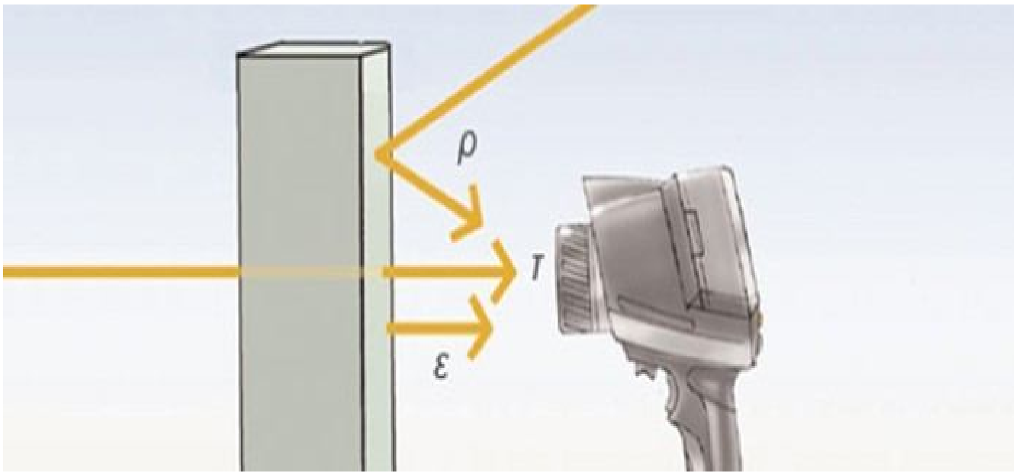

Figure 18. Emission, Reflection and Transmission

According to Kirchhoff's Law of Radiation Energy Conservation

Infrared radiation recorded by the thermal imager, include the following:

- emitted radiation by a measurement object;
- reflection of ambient radiation
- transmission of the measurement object radiation

Of their total are assumed to be always 1:

$$\varepsilon + \rho + \tau = 1$$

In practice rarely play a role in the transmission τ is negligible in the formula.

A simplified version of the formula:

$$\varepsilon + \rho = 1$$

This means that for thermography:

Less emissivity,

- the share of the reflected infrared radiation is higher,
- more difficult to get an accurate temperature measurement and
- also most importantly; reflected temperature is set correctly.

b) Relationship Between Emission and Reflection

1. A measurement object with high emissivity ($\varepsilon \geq 0,8$);
    - reflection (ρ) is low: $\rho = 1 - \varepsilon$
    - temperature can be easily measured with a thermal camera.
2. A measurement object with average emissivity ($0,6 < \varepsilon < 0,8$);
    - reflection (ρ) is the average: $\rho = 1 - \varepsilon$
    - temperature can be easily measured with a thermal camera.
3. A measurement object with low emissivity ($\varepsilon \leq 0,6$);
    - reflection (ρ) is high: $\rho = 1 - \varepsilon$
    - measuring the temperature with thermal cameras is possible, but you must interpret the results very carefully [4,12,20].

c) Emissivity Setting

If there is a big temperature difference between the measurement of the object and the measuring environment, the correct setting of the emissivity is particularly important.

When emissivity setting is made, should be considered in two important cases;

1. If the measured object temperature is higher than ambient temperature;
- As a result of extremely high emissivity setting, extremely low temperature measurement results occurs.
- As a result of extremely low emissivity setting, extremely high temperature measurement results occurs.

2. If the measured object temperature is lower than ambient temperature;
- As a result of extremely high emissivity setting, extremely high temperature measurement results occurs.
- As a result of extremely low emissivity setting, extremely low temperature measurement results occurs [12,20].

3.3.2 Sources of Error in Infrared Measurement

The following factors may distort the results of infrared measurement:

Table 2. Sources of Error in Infrared Measurement

Factors	**Error prevention**
Incorrect emissivity setting	Set the correct emissivity and adjust.
Incorrect RTC setting	Determine and set the reflected temperature.
Unclear thermal image	Focus on the thermal image in place, can not be changed after the image sharpness.
The measurement distance is too long or too short	Consider the minimum focusing distance of your thermal imaging camera while measuring.
Making measurements with an unsuitable lens	Make a right choice between a telephoto lens and wide-angle lens.
Measurement point is too large	Measurement while your thermal imaging camera, make sure the minimum focus distance. While a normal image, use the appropriate telephoto or wide-angle lens.When possible, choose a short measurement distance.
Transmission path errors (eg. Air pollution, cover, etc.)	Avoid making measurements under the influence of sources that may be causing the error.
Radiation effect of external sources (ie. Light bulbs, sun, heaters etc.)	If possible, put out the source of the disturbance effect or insulation or thermal image taken into consideration when assessing this impact.
Incorrect interpretation of the thermal image, depending on the reflection	Avoid measurements, where the source of interference. If possible, hide or disable these resources, if is not, consider the effect that when the analysis the thermal image.
Rapid changes in ambient temperature	If the ambient temperature is changed toward you warm in the cold, there is a risk of condensation on the lens. If possible, use thermal cameras with the stabilized temperature detectors.
Due to the lack of information about the design of the measurement object incorrect interpretation of the thermal image	The type and design of the measuring object should be known.While the İnterpreting of the thermal image if it possible, also use real image (photo).

3.3.3 Measurements in the Glass and Metal Surface

a) Measurements in the Glass Surface

The human eye can look through glass, but glass is infrared radiation-proof. Thermal cameras can measure the just surface temperature of the glass, does not measure the temperature of the materials behind. However, for short-wave radiation such as solar, glass is conductive. For this reason, rays of the sun can heat the measurement object passing through the window. Also glass is a reflective material. Therefore, when measuring the glass surface, pay attention to specular reflection [16, 20].

b) Measurements in the Metal Surface

Especially metals with shiny surface, are strong reflectors in terms of the long-wave infrared radiation, and they have extremely low emissivity.

To measure the temperature of the metal surface with a thermal camera can cause some problems. In this regard, it is important to make the correct emissivity and reflected temperature settings. Also it should be noted that the information provided about the specular reflection. Paint has a high emissivity, for this reason if metals are painted, does not occur any problem during the measurement. However, we still need to be wary of reflection that due to the radiation environment [16,20].

3.3.4 Emissivity Table

The following table is a guide in setting emission for infrared measurements. The table gives the emissivity ε values for some commonly used materials. Emissivity value changes according to the temperature of the body and surface structure [20,18].

Table 3. Emissivity Values of Commonly Used Material

Material (material temperature)	**Emissivity**
Aluminum, deeply oxidized (93 ° C)	0.2
Brass, oxidized (200 ° C)	0.61
Clay, burnt (70 ° C)	0.91
Concrete (25 ° C)	0.93
Copper, oxidized (130 ° C)	0.76
Mushrooms (20 ° C)	0.7
Cotton (20 ° C)	0.77
Granite (20 ° C)	0.45
Gypsum (20 ° C)	0.9
Ice smooth (0 ° C)	0.97
Lead (40 ° C)	0.43
Cast iron (100 ° C)	0.8
Marble, white (40 ° C)	0.95
Oil paint (all colors) (90 ° C)	0.92 to 0.96
Paper (20 ° C)	0.97
Plastic: PE, PP, PVC (20 ° C)	0.94
Porcelain (20 ° C)	0.92
Rubber, hard (23 ° C)	0.94
Sandstone (40 ° C)	0.67
Steel oxidized (200 ° C)	0.79
Wood (70 ° C)	0.94

3.4.1 High Temperature Measurement Devices Used in Industry

Many devices are used for measuring high temperatures in the industury. Some of these devices can measure with contact, such as dip-type thermocouples. This devices are generally used in casting factories. These thermocouples are dipped into molten iron crucible, after 5-6 seconds they removed from the crucible and temperature value is read [14].

(a)

(b)

(c)

Figure 19. a. Dip-type Thermocouple (*http://turkish.alibaba.com/product-gs/pt-rh-expendable-immersion-thermocouple-disposable-thermocouple-type-r-s-b--1572454498.html)*

b. Lc-600 Thermodetector *(http://turkish.alibaba.com/product-gs/lc-600-thermodetector-60082828911.html)*

c. Dip-type Thermocouple Usage *(http://tr.kaydoksan.com.tr/icerik/782/0/dokumhane.html)*

Otherwise, in some risky situations non-contact measurement devices are widely used (such as infrared thermometer, pyrometer). These devices are available on the market and they can measure temperatures up to 2500 °C. These devices generally use metal, glass and paper industry, and prices of these devices changes depends on the measurement range, accuracy, optical resolution and response time.

Figure 20. Optris CTlaser 1M / 2M Model IR Thermometer
(http://www.tuanamuhendislik.com/yuksek/cs1m2m.htm)

The device shown in the figure (*figure20*) has a wide temperature range (between 250 ° C to 2200 ° C). Optical resolution is 300: 1, thus we can measure the temperature of small objects from long distances. Also the measuring apparatus of this device withstands temperatures up to 100 ° C, in this way the device is not affected when measuring at very high temperature. Response time of device is only 1 ms, thanks to this feature, can be monitored rapid production processes. In addition, via the electronic box, can be taken different analog and digital outputs [19,24].

Figure 21. Extech 42570 Model Dual Laser Infrared Thermometer *(http://www.e-olcum.com/Extech-42570-Cift-Lazerli-Infrared-Termometre,PR-125.html)*

Another widely used device is *(shown in the figure21)* pistol type dual laser infrared thermometer. With this device can measure temperature with -50°C to + 2200 ° C. At the point where dual lasers combined, we can make precise and accurate measurements. Thanks to 50: 1 optical ratio, it makes the measurement in small diameter surface from long distances. With help to K-type thermocouple input and USB connection, data analysis can be done. Thanks to the fast response time (100 ms), we can measure sudden temperature changes. Also with help to brightness ratio which adjustable by users, makes precise measurements for different surfaces (polished aluminum, metal, glass, etc ...) [25].

CHAPTER FOUR

4.1.1 Optical Pyrometer Applications

Primarily, as mentioned detailed in the third unit, we will briefly explain the working principle of optical pyrometer again. Optical pyrometers principle is based on comparison with emitted radiation of objects and electrically heated lamp filament. By changing current severity of filaments, color of light emitted by the heated body, reach the same color with filament.

If the same color object with filament color, lamp filament not appear. In this case, we can easily say; the filament with measured object temperature is same. Current which passing through the filament is calibrated according to temperature [21].

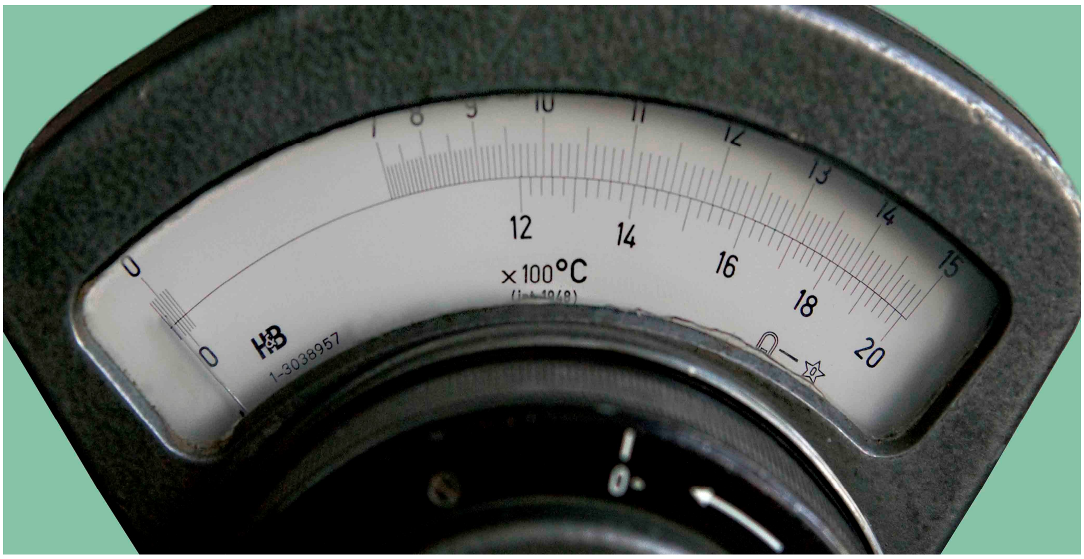

Figure 22. Optical Pyrometer Temperature Scale

4.1.2 Optical Pyrometer Construction

First of all suitable circuit elements was selected. In this study, filament lamp with power 4W, 1K ohm potentiometer, milliampermeter which can measure in the range of 0-500mA, and lastly 12V DC power supply were selected.

Based on our data, the maximum current of the circuit is calculated as follows:

P = 4W

V= 12V

R= 0 K ohm (for find Imax)

P= I x V → Imax=P/V → Imax=4W/12V → Imax= 334mA

4.1.3 Drawings Of The Circuit With Electronics Workbench

In this study, "Electronics Workbench" electronic circuit drawing program was used. With this program, many electronic circuits can be created, and we can also anticipate how the circuit works thanks to the simulation feature.

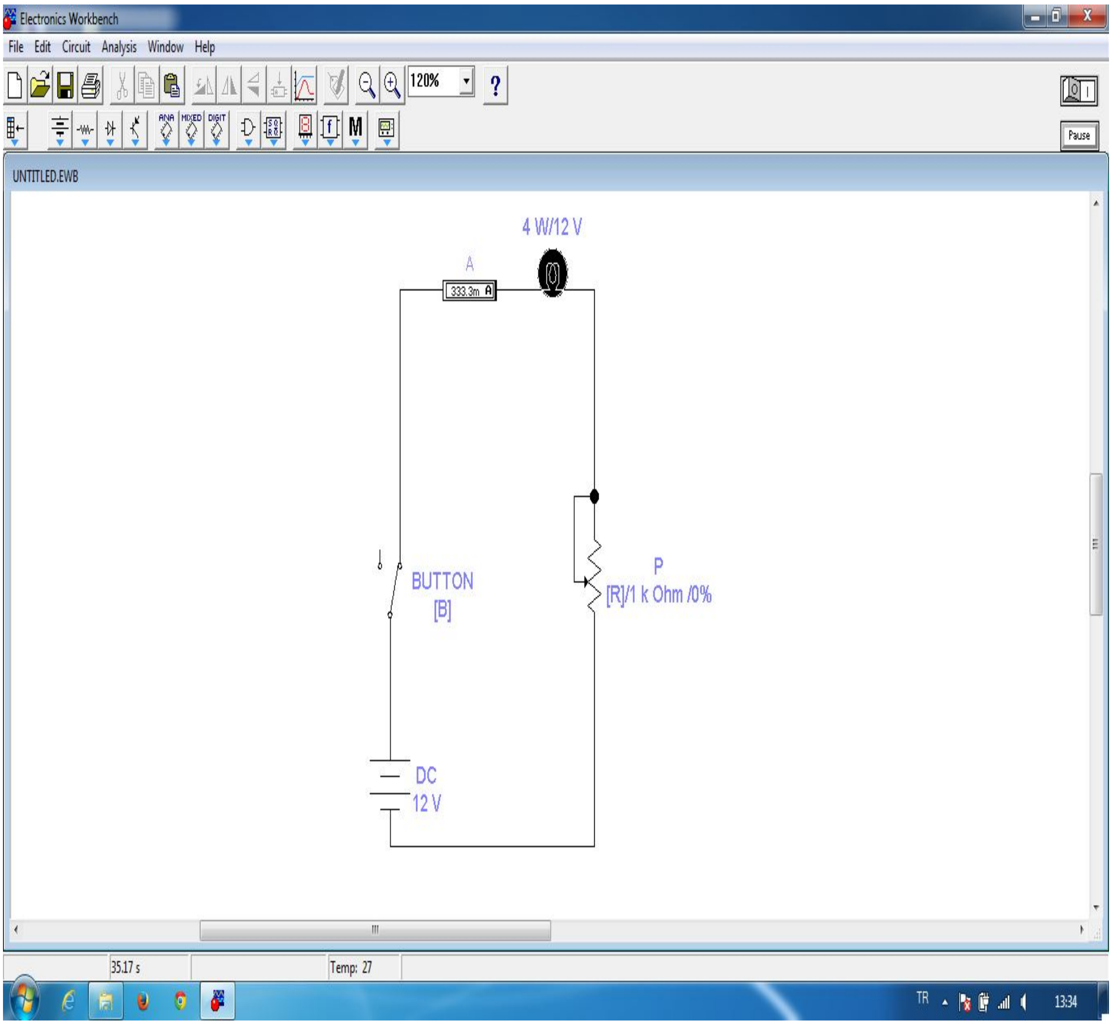

Figure 23. Drawing an Optical Pyrometer Circuit with "Electronic Workbench"

As seen in the figure *(figure23)*, we will run our circuit with pressing the 0-I button and we will see the current value in ampermeter (333.3mA). Also we can on-off the circuit, with the key button (*in figure23 as shown [B]*).

In addition, we can also easily make potentiometer setting, with the help to computer keyboard. If we press “P” and “↑” on keyboard, resistance of the potentiometer is increase, in the same way if we press “P” and “↓” resistance of the potentiometer is decrease. Finally, while setting potentiometer, we can easily follow the current value of the circuit with help to ampermeter.

4.1.4 Handmade Simple Optical Pyrometer Construction

The following elements were used in making handmade pyrometer;

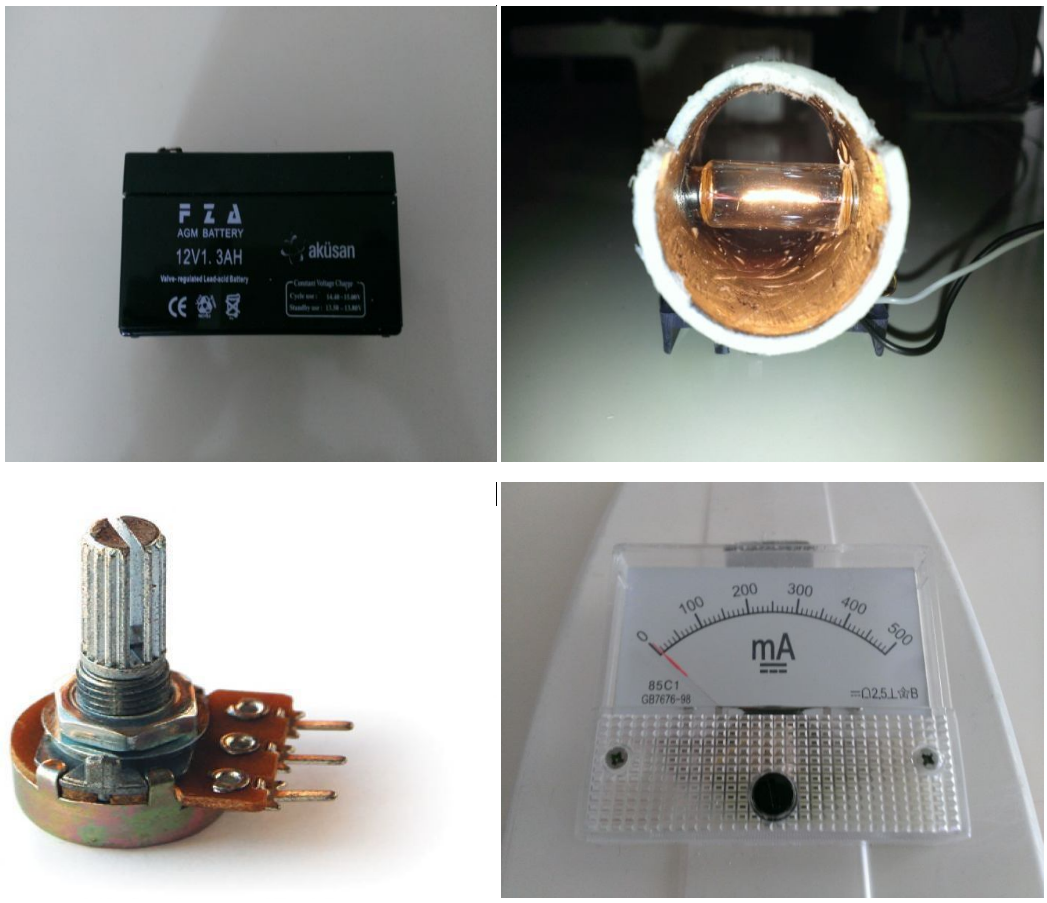

Figure 24. Circuit Elements Used in the Optical Pyrometer: DC Supply (12V), Filament Lamb (4W), Potentiometer (1K), Ampermeter (0-500mA range)

Circuit elements were soldered in series. Then these elements were placed in the handheld vacuum cleaner chassis.

Figure 25. Handmade Optical Pyrometer

As shown in figure (*figure25*), when we press and hold the button, current passes through our circuit and filament lamps lights up. Also with the help of the potentiometer, we set the current flowing through the circuit and therefore we are setting up the filament lamp light intensity.

4.1.5 Filament Structure

Incandescent lamp or with another name bulb is based on the principle, heating of the metal filament wire and making radiation as a result of this warming. Hot filament wire is taken a glass sphere (bulb). This sphere is filled with the inert gas, in this way the filament wire is isolated from the air. Bulb works with voltage which applied to the screw terminal sockets.

Incandescent lamps have a high color efficiency but their light efficiency is low. The reason for this their heat losses are high. Incandescent lamps, creates a continuous radiation. The average temperature of the filament wire is 1500 °C. Filament wire is made of tungsten. The melting point of tungsten is pretty high(3482 °C). Filament wire is placed onto the support wires. In this way, not affected by concussion during transportation and usage. Emitted light from the incandescent lamps changes directly proportional to voltage value. The increase in voltage applied to the lamp, will cause an increase in total luminous flux of the lamp. The resistance of the lamp filament varies depending on temperature. Cold filament resistance is less than the hot filament resistance (approximately 15 times) [22,23].

Advantages of Incandescent Lamps:

- Colour efficiency is high.
- Using dimmer circuits, lighting levels can be adjusted easily.
- Frequently opening and closing of the lamp will not affect the lamp life. For this reason, they use frequent switching places such as bathroom, toilet, warehouse.
- There is no need auxiliary elements, such as ballast.
- It is cheaper.
- Light spectra is continuous.

Disadvantages of Incandescent Lamps:

- Usage life is low (average 1000-2000 hours).
- Light efficiency is low (8-22 lm / W).
- While working, they emit very high temperatures (Approximately %90 of power is consumed as heat).
- They are much more negatively affected by voltage fluctuations in the grid and usage life is reduced.

4.1.6 Calibration Of The Optical Pyrometer

As mentioned before optical pyrometers are devices which based on the principle to compare color between the lamp filament and the object to be measured. In this case, we need to know object temperature which make comparison. For this reason temperatue measurement devices were used as shown below (*figure26,27*).

TECMAN TM550 model infrared thermometer and ST890C$^+$ model multimeter (which can measure temperatures thanks to the thermocouple), were used for calibration.

Figure 26. TECMAN TM550 Infrared Thermometer

Figure 27. ST890C$^+$ Multimeter

Specifications of the devices;

Table 4. TECMAN Model TM550 Infrared Thermometer Specification

SPECIFICATIONS		
Basic Parameters		
Model	TM350+	TM550
Temperature Range	-50℃~480℃	-50℃~550℃
	-58℉~896℉	-58℉~1022℉
Accuracy	±1.5℃ or 1.5%	±1.5℃ or 1.5%
Distance Spot Ratio	12:1	12:1
Emissivity	0.95	0.95
Repeatability	±0.5℃ or 1%	±0.5℃ or 1%
Response Time	500ms	500ms
Resolution	0.1℃ / 0.1℉	0.1℃ / 0.1℉
Wavelength	8μm~14μm	8μm~14μm
Special Function		
℃/℉ Selection	✓	✓
Laser Switch	✓	✓
Delay Display Time	8 Seconds	8 Seconds
Auto Power Off	✓	✓
Low Battery Indication	✓	✓
Backlight Display	✓	✓

ST890C^{+} Multimeter Specification:

Attention: Multimeter was used only temperature measurement, for this reason only related to temperature measurement features are given.

Table 5. ST890C^{+} Multimeter Specification

Features	**Measurement Range**	**Accuracy**
Temperature	-40 ~ 1000 °C	±2°C or 1.0%

Generally, optical pyrometers are used to measure temperatures from 500°C to 2000°C. For this reason, to make measurements at higher temperatures, the casting factory was visited. As seen in the photo below, the calibration of the device was made up to 1520°C with dip-type thermocouple which used in the factory for measure high temperature.

Figure 28. Calibration With Dip-type Thermocouple at "Şafak" Casting Factory

4.1.7 Measurements and Results

Primarily, measurements were performed up to 1000°C, with the devices available in our hands. As the measurement object, coal fire and heated iron was used. These measurements were made between 470°C with 885°C.

Afterward, to make measurement at higher temperature, iron cast factory was visited. At this factory, some measurements were made (1120°C, 1330°C, 1490°C, and 1520°C). These measurements were performed, with help to the dip-type thermocouple which used in the casting factory.

Measurement values were transferred to the table, and also temperature-current graph was formed. This table and graph was created with "Microsoft Office Excel 2007" computer program.

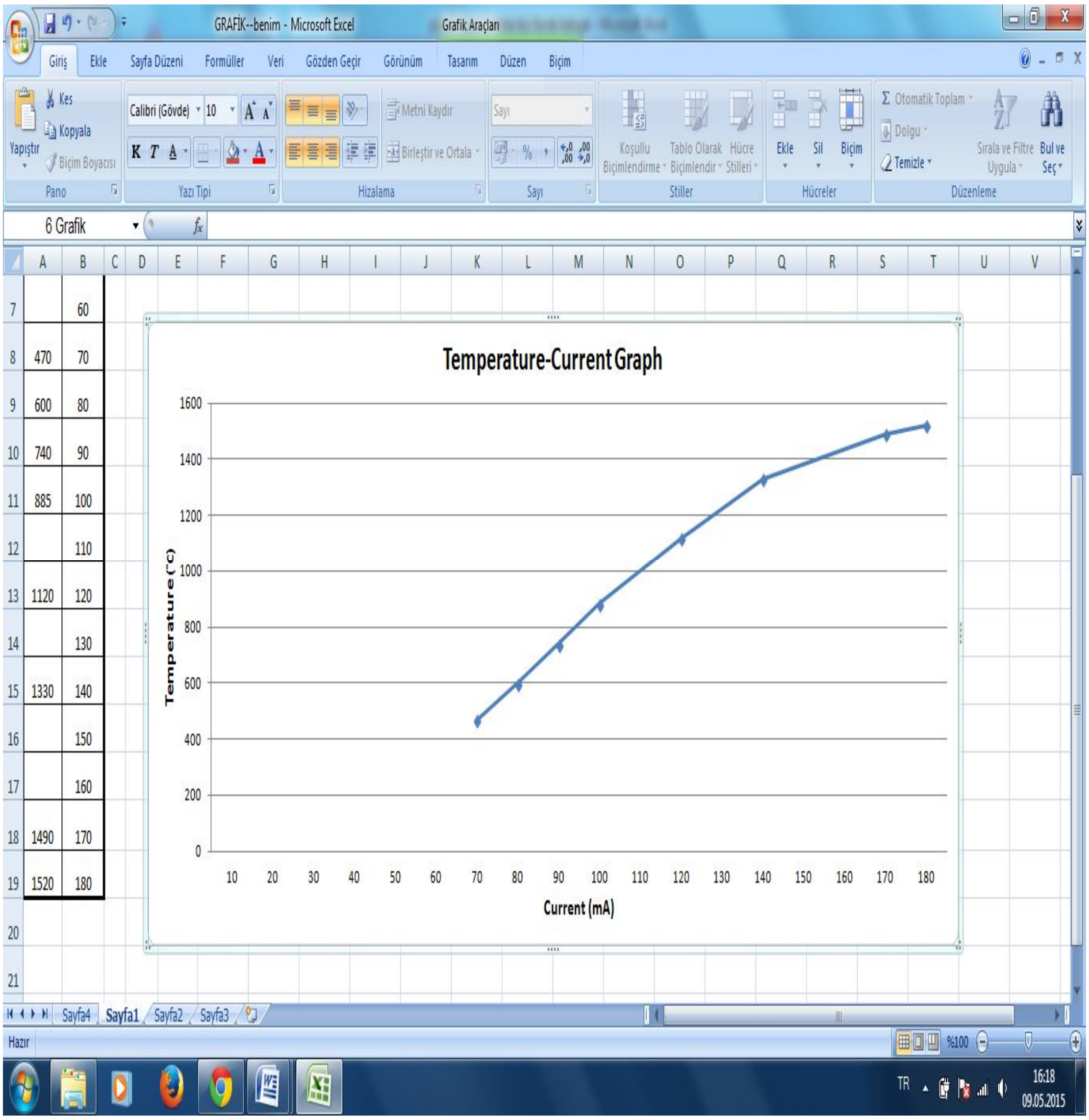

Figure 29. Temperature-Current Table and Graph in Excel

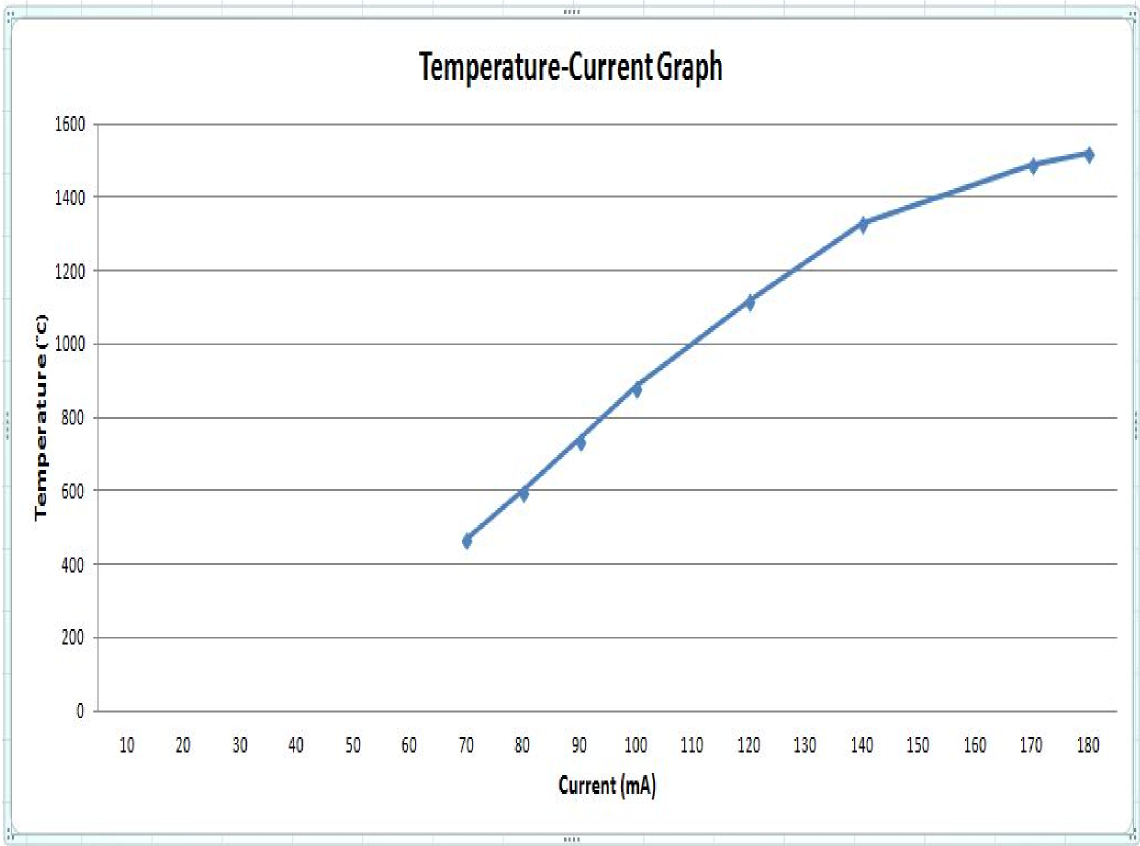

Figure 30. Temperature-Current Graph

Table 6. Measurement Result

mA	˚C
70	470
80	600
90	740
100	885
120	1120
140	1330
170	1490
180	1520

When the values examined carefully on the graph, at the beginning we can see that the temperature and current increased linearly, but when temperatures increased more, we can see that the slope of the temperature-current graph, going on a little to the horizontal axis.

CHAPTER FIVE

5.1 SUMMARY

After the time, temperature is the most measured parameter in daily life. Temperature plays an important role, in demonstrating existing conditions in the production or quality control stages of a product or a device. Accurate measurement of the temperature is influenced positively the product quality and efficiency. At the same time, conditions in the developing world, in terms of speed temperature measuring devices which showing rapid reaction, are gaining importance.

In this research, a lot temperature measurement method were examined. Also usage area, measurement range, adventages and disadventages of these devices were mentioned. But mainly focused on the method of non-contact temperature measurement. The most commonly used ones; infrared thermometer and pyrometer.

Also scope of this research, handmade optical pyrometer was made. The calibration of the device was made with help to Tecman model “TM550” infrared thermometer which has -50° C ~ 550° C measurement range and ST890C$^+$ model multimeter which can measure temperature thanks to the thermocouple, also this device has -40°C ~ 1000°C measurement range. For temperatures above 1000°C, dip-type thermocouple was used, this type of thermocouples are generally used in casting factories and they measure up to 1800°C.

Lastly, scope of this project some measurements were made with optical pyrometer. Afterwards these measurement values were transferred to tables and graphs with using Microsoft Office Excel 2007.

5.2 CONCLUSION

Scope of this research, the temperature was measured using a variety of devices, such as: optical pyrometer, infrared thermometer and thermocouple. In this way, the working principle, usage areas, advantages and disadvantages of these devices was understood better.

In this study, measurements were performed between 470°C with 1520°C. These temperature values, measured by the infrared thermometer and thermocouple. Also, using handmade optical pyrometer which made under this research, the current values was found corresponding to these temperatures. Then the current-temperature graph was created. If we carefully examine the graph, we can see the following; the temperature-current graph linearly increased until 885°C, but after 885°C, this linear increase is steadily decrease and graph is approaching horizontal axis. Here, although not a regular increase in temperature with current, we can say that, the increase is almost linear.

5.3 SUGGESTIONS

Emissivity value of the infrared thermometer which used in this study is 0.95. For this reason, to get the right results in the measurements with this device, objects were selected which have the emissivity value from 0.90 to 0.97. In some infrared thermometers has adjustable emissivity value feature. These devices are financially a little expensive, but they are quite useful for applications on the emissivity subject.

Scope of this research, measurements was made up to 1520°C. Also we can measure temperatures above 1520°C with using higher temperature measurement devices. In this way, measurements can be expanded more.

REFERENCES

[1] http://ocw.metu.edu.tr/pluginfile.php/1870/mod_resource/content/0/AE547/AE547_8_temperature.pdf (Accessed: 16 December 2014).

[2] http://www.baskent.edu.tr/~erol/courses/MAK%20401/Konu%206%20Sicaklik%20Olcumleri.pdf (Accessed: 16 December 2014).

[3] http://hbogm.meb.gov.tr/modulerprogramlar/kursprogramlari/endustriyel_otomasyon/moduller/SicaklikOlcumu.pdf (Accessed: 19 December 2014).

[4] Francis A. Jenkins & Harvey E.White (2001), "Fundamentals of Optics", Fourt Edition, McGraw-Hill Companies, 11,191p.

[5] http://www.engineeringtoolbox.com/radiation-heat-transfer-d_431.html (Accessed: 23 February 2015).

[6] http://en.wikipedia.org/wiki/Black-body_radiation (Accessed: 26 March 2015).

[7] http://en.wikipedia.org/wiki/Stefan%E2%80%93Boltzmann_law (Accessed: 26 March 2015).

[8] http://scienceworld.wolfram.com/physics/Stefan-BoltzmannConstant.html (Accessed: 26 March 2015).

[9] http://en.wikipedia.org/wiki/Wien%27s_displacement_law (Accessed: 26 March 2015).

[10] B. Stuart (2004), "Infrared Spectroscopy: Fundamentals and Applications", John Wiley & Sons, 3-6p.

[11] http://mintaka.sdsu.edu/faculty/wfw/CLASSES/ASTROBIO/LECTURES/wien_law.pdf (Accessed: 28 March 2015).

[12] Collective of authors, IMPAC Infrared GmbH, Pyrometer-Handbook, Copyright IMPAC Infrared GmbH 2004

[13] A. Rogalski*1 and K. Chrzanowski*2 , Infrared devices and techniques, 1*Institute of Applied Physics, 2*Institute of Optoelectronics Military University of Technology, 2 Kaliskiego Str., 00-908 Warsaw, Poland

[14] Otomasyon Dergisi (Şubat 2012), Termokupl Uygulamalarında Dış Koruyucu Kılıflar

[15] M. Schlessinger (1994), Infrared Technology Fundamentals, Marcel Dekker Inc. Second Edition

[16] http://support.fluke.com/raytek-sales/Download/Asset/IR_THEORY_ 55514_ ENG_REVB_LR.PDF (Accessed: 17 April 2015).

[17] http://www.scigiene.com/pdfs/Infrared%20Thermometers.pdf (Accessed: 17 April 2015).

[18] http://www.micro-epsilon.com/download/products/dat--infrared-basics--en-us.pdf (Accessed: 17 April 2015).

[19] Döküm Dergisi (17 Nisan, 2014), Hadde Sektörü İçin Temassız Sıcaklık Ölçüm Cihazları

[20] http://www.testo.com.tr/egitimler/termografi/ (Accessed: 19 April 2015).

[21] http://www.deprez.org/folio_0014_en.html (Accessed: 21 April 2015).

[22] http://www.fotonelektroteknik.com.tr/?ynt=solm&eyl=detay&id=6 (Accessed: 25 April 2015).

[23] http://www.elektrikport.com/teknik-kutuphane/akkor-flamanli-(enkandesan)-lambalar-3-bolum/4161#ad-image-0 (Accessed: 3 May 2015).

[24] http://tuanamuhendislik.com/yuksek/cs1m.htm (Accessed: 5 May 2015).

[25] http://www.pce-cihazlari.com.tr/oelcuem-teknolojisi/oelcuem-cihazlari/termometreler.htm?gclid=CJrY8vGmucUCFW7KtAodrjEAXw (Accessed: 5 May 2015).