MENG 411 CAPSTONE TEAM PROJECT

Eastern Mediterranean University

Faculty of Engineering

Department of Mechanical Engineering

Construction of Solar Furnace

Course Coordinator

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Capstone Team Project Spring 2014-2015

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Submitted to Assist. Prof. Dr. Mostafa Ranjbar in partial fufillment of the requirements for Capstone Team Project MENG411

Gazimagusa TRNC, 10th June 2015.

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Abstract

This project is about the design and construction of a concentrated solar furnace. The basic aim of the report is to provide information about the design and working principles of a solar furnace. The project utilized a parabolic concentrator and we designed the furnace in a cylindrical shape with steel for its body and an outer copper lid. To improve the efficiency of the furnace in this project, copper fins were attached inside to enhance heat transfer within the furnace. After manufacturing and assembly, we tested the furnace with and without fins and there was a difference noticed after recordings done at 20 minutes interval. The inner air temperatures recorded after 20 minutes was 55℃ without fins and 65℃ with fins. During the testing, the maximum temperature recorded inside the furnace was around 173 ℃ (air temperature) and 238℃ (fin tip temperature); these temperatures are high enough to be used in various domestic applications such as cooking.

CHAPTER 1

INTRODUCTION

1.1 Background

Solar energy is undoubtedly the oldest source of energy. It is basically the radiant light and heat from the sun. We can however trace all other forms of energy used on earth back to the sun. Harnessing the solar energy has been the aim of various researches for many years. We believe that resources for fossil based fuels such as oil and coal are limited and soon they will vanish. Many scientists are working to use solar energy for different purposes.The history of solar energy is as old as mankind and over the past two centuries this energy has become increasingly used either directly to produce electricity or in applications to satisfy different needs of mankind. One of such applications is in the production of solar furnaces which could be used for many purposes.

A solar furnace is a structure that uses concentrated solar power to produce high temperatures, usually for industry. Parabolic mirrors or heliostats concentrate light onto a focal point. The temperature at the focal point may reach very high temperatures, and this heat can be used to generate electricity, melt steel, and make hydrogen fuel or nano-materials. A solar furnace uses reflectors to channel and concentrate solar energy thus producing heat. The sizes of solar furnaces could range from small to large depending on the desired heat needs. In the past, around the 7th century, people used magnifying glasses in simple form to generate concentrated light from the sun and use this domestically in making wood to catch fire for cooking. However over the years, modifications and improvements in the field of technology have led to the production of more sophisticated solar furnaces.The largest solar furnace is at Odeillo in the Pyrenees-Orientales in France, opened in 1970 [1].

1.2 Objectives

The main aim of this project is to design and construct a working solar furnace. The major objective of the solar furnace design will be to generate heat from solar radiation as a high intensity energy source for high temperature processes. In this project the aim is to produce temperatures high enough to be used in cooking applications whether for domestic or industrial uses.

1.3 Limitations and Scope

A viable option for this technology is that which this project will be limited to; producing temperatures high enough to cause combustion of wood (carbonization) and also efficient enough to aid cooking in homes. The constituents of a solar furnace will be well documented as the economic benefits of solar furnaces are huge. Nevertheless one constraint to its production is high initial start-up costs but conversely once started there is only little operational costs needed to continue. By replacing conventional furnaces, like electric arc and blast furnaces, with a solar furnace operating at high temperatures, carbon dioxide (CO_2) emissions and energy consumption will be reduced greatly, which will better our society immensely.

This project will discuss the topic of solar furnace in details by first giving details of other research work done on the subject- literature review, then enumerating the methodology, design and calculations of this project and then ends with a conclusion and discussion part.

CHAPTER 2

LITERATURE REVIEW

2.1 A Brief History Of Solar furnace

A solar furnace is not actually a furnace but only implies an optical system which has solar radiation been received from a collector and concentrates it into a small area. In a case where this highly concentrated radiant energy is channeled into a cavity, high temperatures are obtained due to the heat generated. Actually, it is this cavity that is the furnace and it represents a small part of the entire system, hence it is not out of place, to call solar furnaces: - solar energy concentrators.
The idea of using solar energy to produce high temperatures is not new. In 212 B.C. Archimedes presumably set fire to the Roman fleet by concentrating the sun's rays on the ships by means of several hundred plane mirrors. In the 17th and 18th centuries both mirrors and lenses were used, and in 1772 Lavoisier built a furnace with a collecting lens having a diameter of about 5 feet, in which he almost reached the melting point of platinum (1773° C) [2]. After the work of Lavoisier, until the beginning of the twentieth century, solarfurnaces were completely ignored. However in 1921 Straubel andhis collaborators at the Zeiss Company in Germany constructed the first modern reflecting furnace. This was done with a glass parabolic mirror of about 6 feet diameter, and focal length of 2 feet; at the end temperatures above 3000°C were generated. This paved way for the use of different sizes of parabolic mirrors. Straubel had another collaborator in the person of W. Conn, he built a 10 foot furnace and this was installed at Rockhurst College in Kansas USA. This furnace is made of aluminum alloy sheet and is still operational at Convair in San Diego and is used for high temperature materials studies. More so, searchlight mirrors of around 5 feet diameter are good concentrators and are in operation in numerous laboratories in the United States.

The largest installation of solar furnaces of various sizes is located in Montlouis in the French Pyrenees. Professor FelixTrombe, head of the laboratory for the study of solar energy, hassix furnaces in operation and these are made of German parabolic searchlight mirrors. They are 6.5 feet in diameter and also there is one large furnace which is 35 feet in diameter. The large size reflector is made of 3500 smaller plane mirrors, attached to a steal frame which is parabolic in shape. To get a better focusing, each mirror used is bent mechanically and a curvature close to that of an ideal parabola is attained. Another larger furnace has been produced, this is more than 100 feet in diameter and after design its reflecting components have been tested. The power of this large installation is about 1000kW. Furthermore, Professor Guillemonat adopted W. Conn's design and built a 27 feet diameter furnace in Algiers New Orleans. The parabola for this furnace was made of 144 panels of electro polished aluminum formed to the required curvature. Other notable works in this field includes that of the old soviet Russia, in which a large solar energy research laboratory was installed near Tachkent; however these were low temperature furnaces and no report has exists about solar furnaces designed especially for high temperatures. Lavoisier's furnace was not the only one built to concentrate the sun's energy by means of a lens. Between 1930 and 1932 the California institute of technology (Caltech) built a lens furnace and this was spear-headed by George Ellery Hale and its purpose was to achieve high temperatures for spectroscopic studies[3] .This furnace is now positioned on the roof of the Caltech astrophysics department, and it is currently used for high temperature materials research.

Furthermore, anyone conversant with the field of high temperatures will find out that, the performances of already existing solar furnaces is not spectacular. It is possible to generate temperatures within the range of 3000° C through many different techniques: - these include, induction heating, melting in neutral atmosphere, electrical resistance heating, flames and so on. These techniques however have a limitation because they require a specific type of atmosphere around the specimen under study. Whereas for the solar furnaces, heat source is in form of a cone of radiation energy that can be termed as pure heat and this does not impose any restriction to the kind of atmosphere that surrounds the specimen. Another interesting feature of solar furnaces is that, the temperature obtainable at the focal areais concentrated and generates a high heat flux. Solar furnaces have the unique characteristic of being able to heat a body from inside to outside and this is useful in melting refractory substances which react very rapidly with crucible materials at high temperatures.

The Caltech furnace project makes use of the two outstanding features mentioned above. The first project is an investigation of highly refractory thorium oxide and zirconium oxide which have melting temperatures of 3200° C and 2700° C respectively. They melt these compositions in air at the focus of the furnace and assume oxidizing atmosphere around the melt. The second project is concerned with ceramic body structures and it is based on mixtures of titanium and zirconium dioxides, in which oxygen is usually lower than it should be. The California institute of technology (Caltech) solar furnace has nineteen lenses; they are each two feet in diameter, arranged hexagonally and pointed towards the sun. It also has secondary lenses 7.5 inches in diameter which are arranged on a hemisphere and are centered art the focal point. All the lenses deflect the rays before they reach the secondary lenses but with exception to the center one, this deflection is done by a series of eighteen plane mirrors. At the focus, the sun's image is one half inch in diameter. The entire optical system is mounted like a telescope on an equatorial axis and has a synchronous drive so that furnace stays pointed to the sun. On the frame, the lenses are bonded permanently, whereas the plane, mirrors are fixed in such a way so as to be adjusted for the best possible focusing. Figure 2.1 below shows the Caltech's furnace.

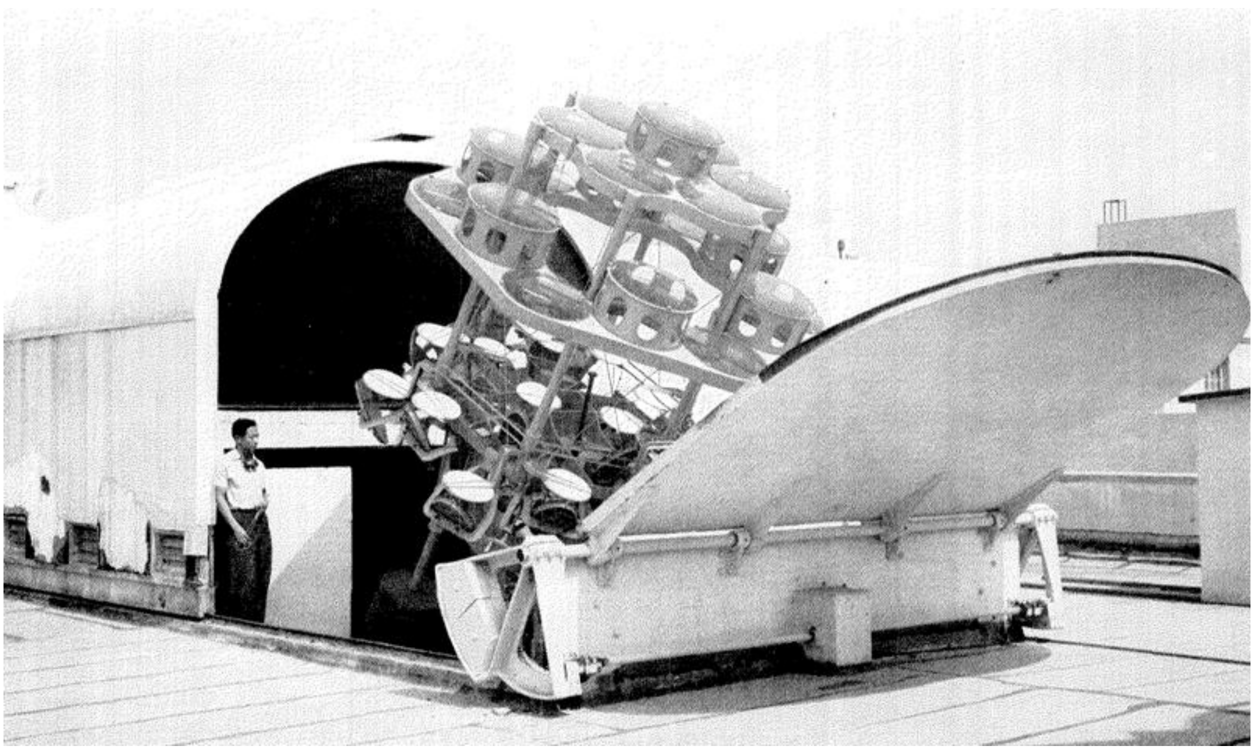

Figure 2.1. Caltech's Solar Furnace[2].

To make the adjustments more precisely, the full moon is used preferably and there is a negligible heat flux that enables observation of the moon's image on a ground glass and adjusting each plane mirror through centering them around the focus. After sometime, an analysis was made about the performances of the Caltech furnace and the findings showed that as regards to the maximum attainable temperature, the furnace lens is same as a parabolic reflector furnace that has ratio of focal length to diameter of 0.7. However, a maximum theoretical temperature can be calculated if the cavity of a black body that is perfectly insulated with a solar constant of 2 calories per minute and per square centimeter is used, thus eliminating atmospheric absorption. If for instance, there are no heat losses through this optical system, the maximum temperature attained is close to 4200° C. More real figures may be ascertained by taking 1.6 calories per min and per square centimeter (1.6cal/min/cm^2) for solar radiation and by estimating coefficients of absorption and reflection for the lenses and mirrors as 0.85. Under these above conditions,the maximum temperature gotten would be around 3400° C. Even though no accurate measurements have been made so far, temperatures as high as 3100 - 3200° C have been attained and this evident in the fact that, thorium whose melting point is 3200° C has been melted by this furnace.Figure 2.2 below shows the basic elements which the Caltech's furnace has.

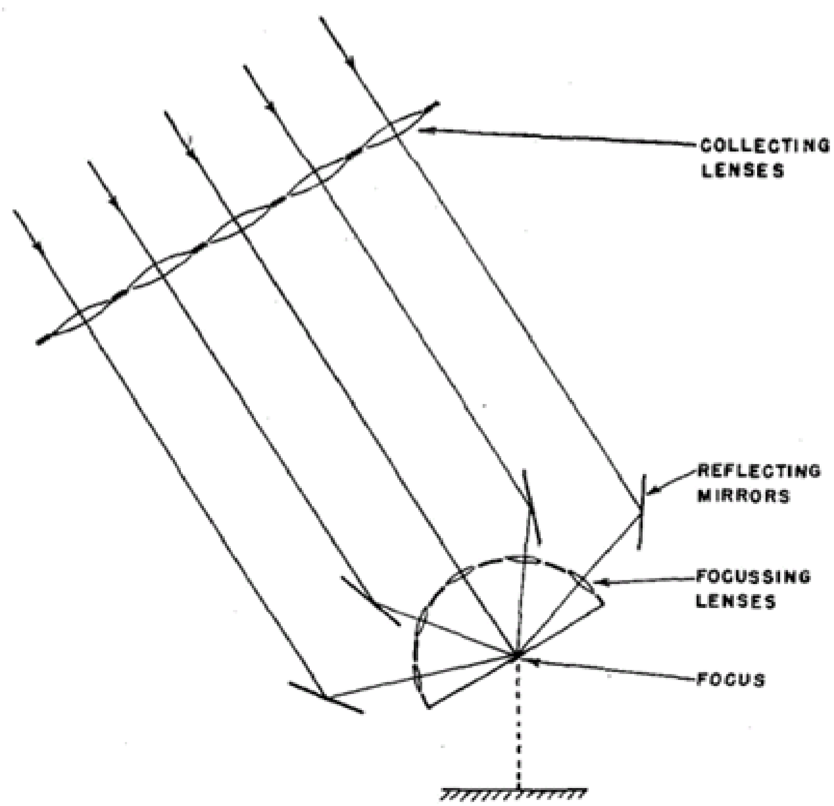

Figure 2.2 The basic elements of Caltech's lens furnace[2].

The Caltech furnace produced temperatures close to the maximum capability of a lens type solar furnace. In theory, the parabolic reflector furnace is capable of higher temperatures and with a parabolic reflector that has focal length to diameter ratio of 0.45, it is possible to reach temperatures of 4500° C. This amount of temperature was obtained by using a solar constant of 1.6 cal/cm^2/min and a coefficient of reflection of 0.85 for the mirror surface. The degree to which a parabolic reflector is optically perfect may be defined as the ratio of the actual heat flux received to the heat flux that should be received if the reflector were perfect[3]. This index of quality has a very large effect on the maximum temperature attainable. To show the relationship between temperature and perfection a parabolic reflector, figure 2.3 is given below.

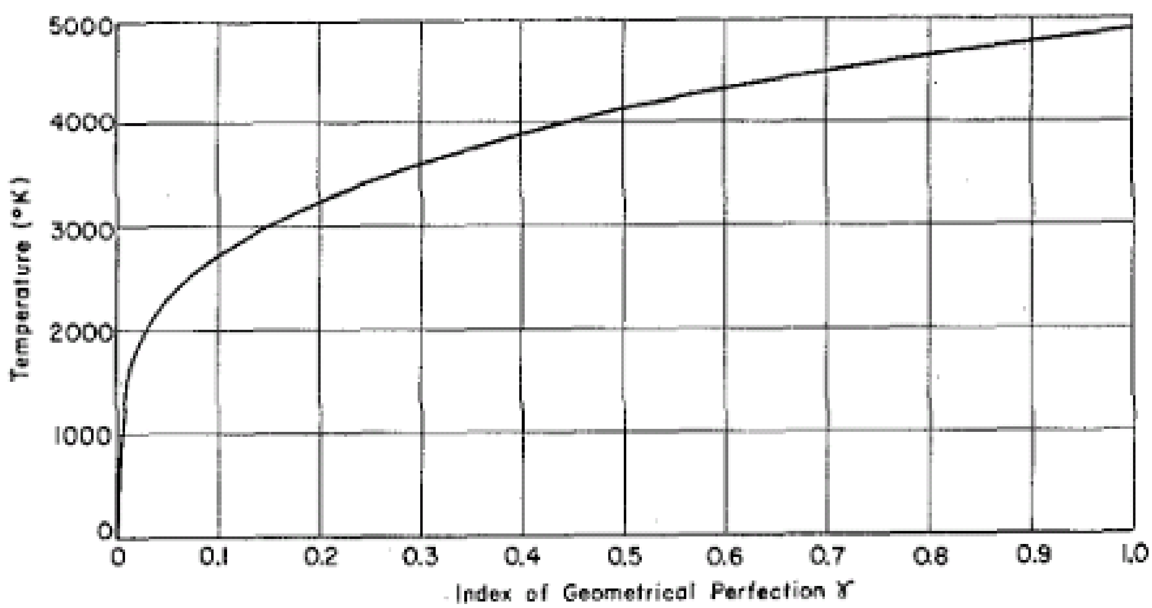

Figure 2.3 Temperature versus Index of Geometric perfection of parabolic reflector[3]

As shown in the above figure, a poor built reflector which has low index quality of 0.2 will only be capable of generating temperature of not more than 3000° C. This can be noticed in most of the existing parabolic furnaces which produce temperatures of not more than 3000° C, therefore they have quality index of about 0.2. Hence, to generate more temperatures as high as 3500 - 4500° C, it will be necessary to construct parabolic reflectors in which more than eighty (80) percent of the radiant light collected by the mirror would be concentrated within the sun's image area. The only obstacle to producing such high performance parabolic mirrors is very high cost.

2.2 Applications around the World

2.2.1 United States of America

Apart from the solar furnace produced by the California institute of technology (Caltech), there have been other attempts to develop these in the United States. This includes a solar furnace located at Sandia National laboratory in New Mexico, United States. The Sandia National laboratory whose mission is to maintain the reliability and surety of nuclear weapon systems, conduct research and development in arms control and nonproliferation technologies, and investigate methods for the disposal of the United States' nuclear weapons program'shazardous waste. Other missions include research and development in energy and environmental programs, as well as the surety of critical national infrastructures. In addition, Sandia is home to a wide variety of research including computational biology, materials science, alternative energy, psychology, MEMS, and cognitive science initiatives[4].

This solar furnace makes use of a heliostat, and by tracking the sun, this directs sunlight onto a mirrored parabolic reflector. The dish is easy to installexperiments; this is because its focal point does not move. The heliostat used in this solar furnace has an area of 95m^2, and it uses a parabolic reflector that has diameter of 6.7056 meters. After production, this solar furnace was capable of conducting high-temperature solar thermo chemical water-splitting experiments. It was able to generate 16 kW thermal power and its peak flux can be increased up to 500 W/cm^2. The solar furnace produced by Sandia Laboratory has many different functions, these includes: controlling power so as to be able to simulate nuclear and other forms of thermal transients. It can also be used in the investigation of thermo-physical material properties under concentrated sunlight; such properties include thermal conductivity, thermal diffusivity, thermal expansion, specific heat, mechanical properties, spectral emissivity and absorptivity. More so, this solar furnace is capable of detecting the level of performance and level of failure of high-temperature ceramic and refractory materials. It can also be used in simulating of thermal effects of nuclear explosions on materials and components. Figure 2.4 shows what the Sandia laboratory furnace in the USA looked liked.

Figure 2.4 The Sandia National Laboratories Solar Furnace in New Mexico, United States of America[4].

2.2.2 France

France boast of arguably the biggest solar furnace in the world, located at Odeillo in Pyrenees-Orientales in France and was commissioned in 1970. As opposed to the small one found in the United States, this is larger and employs an array of plane mirrors that aim to collect sunlight rays and reflect them on a mirror which is larger. These rays become focused onto an area that is approximately that of the size of a cooking pot and could generate temperatures as high as 3,000˚C. This furnace also makes use of a parabolic reflector that functions to focus solar radiation at a point and this aids generation of very high temperatures. The France solar has a composition of eight terraces, with sixty-three heliostats (flat mirrors) installed on them and these are mounted on an eight-story high parabolic reflector. Each of the flat mirrors are calculated in such a way that the reflected light is parallel to the symmetric axis of the parabolic dish. Figure 2.5 shows the world's largest furnace in Odeillo France.

Figure 2.5 View of the world's largest solar furnace at Odeillo in Pyrenees-Orientales France[1].

2.2.3 Spain

Solar furnaces have been produced across Europe over the years and Spain was not left out in producing its own. This solar furnace has a component that collects solar radiation and redirects it to a parabolic concentrator- this is termed the heliostat field. The reflective surface of these heliostats are made of flat non-concentrating faces that continuously track solar radiation, thus reflecting it as parallel horizontal beams onto the optical axis of the concentrator. This solar furnace is made up of four heliostats and these are arranged on two levels. The heliostats are primarily made of two mirrors that have a reflectivity of ninety percent (90%) and are supported or held in place by thirty suction cups. The solar furnace has its main component to be the concentrator disk, this helps to concentrate incident light from the heliostat and multiplies the radiant energy to the focal zone. It has good optical properties and this in turn affects the flux distribution at the focus. The concentrator disk of this solar furnace is composed of eighty-nine spherical facets, which have surface area to be totally- $98.5m^2$ and possesses 92% reflectivity. It also has a focal distance of 7.45m and the parabolic surface here tends to be spherical in shape with distribution been along five radii and whose curvatures are different and depends on their distance from the focus.

More so, this furnace functions with an attenuator which consists of horizontal glasses that tend to rotate on their axes and thus regulate the amount of sunlight that enter the concentrator. The total energy that enters the focus is directly proportional to the solar radiation that comes through the attenuator. The attenuator glasses in this furnace are twenty in number, and they are arranged in two columns as they form an angle of $55^{\circ}$to the horizontal but reaches $0^{\circ}$when open. Another component found here is the test table, which acts as a mobile support for the work pieces located under the focus of the concentrator. This table moves along the X, Y, and Z axis in a direction perpendicular to each other and in doing so keeps the test piece in position firmly in the focal area. This solar system however is different from the rest and aims at demonstrating how feasible solar thermal energy can be in supplying energy for many different industrial processes other than use in the generation of electricity and to also produce high process temperatures. The major processes which have utilized this technology are in manufacturing processes and also in solid waste treatment processes. Figure 2.5 shows the furnace developed in Spain.

Figure 2.6 Solar furnace in Almeria, Spain; with the Concentrator (left) and receiver (right)[4].

CHAPTER 3
DESIGN AND ANALYSIS

3.1 System Overview

To successfully design and produce the solar furnace, certain major components must be available and fully functional. A major component of this system is the concentrating collectors. This is basically used to concentrate solar energy optically before it is then transformed to heat and hence improves the thermal effect of the furnace. More so, in production of solar furnaces that operate at low temperatures, it is also necessary to have concentration of energy flux onto small areas so as to improve the performance of energy conversion. Concentration is earned either by the reflection or refraction of solar radiation using mirrors or lens. The focal zone functions to concentrate the reflected or refracted light and therefore increases the energy flux of the receiving target. The concentrating collector has an aperture area which it uses to intercept solar radiation and a receiver area which is the target receiver area. The ratio of the aperture area to that of the receiver area is known simply as the Concentration. By denoting the aperture area as A_a and the receiver area as A_r then, mathematically we can derive Concentration ratio C as;

$$C = A_a / A_r \qquad (3.1)$$

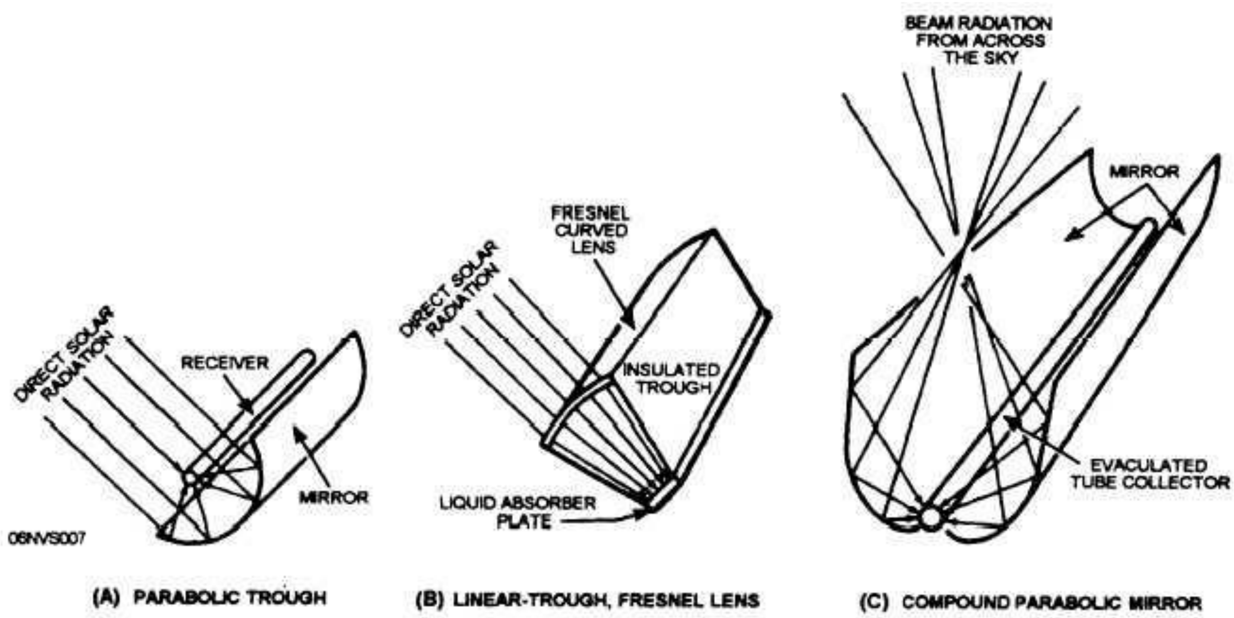

Figure 3.1 Schematic diagrams of Concentrating Collectors[5]

Considering a compound parabolic concentrator (CPC) of Winston design, it is a linear two-dimensional concentrator and it is made up of two different parabolas that have axes which are inclined at angles $\pm\theta_c$ and this is with respect to the optic axis of the collector. The total angle of $2\theta_c$ is referred to as acceptance angle of the CPC and the angle through which the light origin can be moved and still be able to converge at the receiver. This Winston collector works by approaching the higher limit allowed by the second law of thermodynamics. The cylindrical compound parabolic concentrator is a very efficient apparatus. If properly enhanced to track solar radiation in a better way, then an ideal CPC can attain a concentration ratio as expressed by $1/\sin\theta_c$ for a given acceptance half-angle θ_c. The efficiency of this device may however be decreased because of imperfect reflections and also because of tracking errors[5].

For design purposes, in other to form a reflector surface for a CPC, the normal to the reflector has to bisect the angle between a line from this surface and the incident ray at the surface with an angle θ_c between them, which is with respect to the collector axis. Each parabola extends till the point where the CPC axis becomes parallel with it. The reflecting parabolic reflectors work to make sure that solar radiation entering the aperture at angles $\pm\theta_c$ will be reflected to the receivers. Since the upper end of the ends of a receiver does only a minor job in contributing to the radiation that reaches the receiver, it can be cut off with a smaller CPC formed afterwards.

A cylindrical two-dimensional concentrator like the one used in this project can be positioned in such a way its long axis is along the north-south or along the east-west direction with its aperture tilted directly towards the equator. If it is oriented along the north-south direction, then the collector has to be able to track the sunlight continuously through turning about its axis. However when oriented east-west, a little adjustment in the tilt angle can enable the collector track the sun's light through its wide acceptance angle along the long axis.

3.1.1 Thermal Analysis of Concentrating Collectors

To be able define the amount of useful energy gained in flat-plate collectors as well as concentrators the Hottel-Whiller-Bliss equation is explored. This equation takes the form of:

$$Q_u = A_a F_R [H_a - \frac{Ar}{Aa} U_c(T_{f,in} - T_a)] \qquad (3.2)$$

Where $Q_{u;}$ represents useful energy

A_a = aperture area [m^2]

A_r = receiver area [m^2]

F_R = heat removal factor

H_a = absorbed radiation [W/m^2]

U_c = collector overall heat-loss coefficient from the absorber to ambience per unit absorber area.

$T_{f;in}$ = fluid inlet temperature [℃]

T_a = ambient temperature [℃]

To determine the overall heat-loss coefficient U_c is very important for the design of the solar collector which will be used. To do this, we have to put in consideration, the radiation, convection, and conduction losses of the collector setup. Because the collectors have differing configurations, it is important to do the analysis of each case specifically different. The heat-removal factor F_R is basically the ratio of the actual useful gain of energy of a collector to the useful energy gain of the whole absorber surface.

This collector efficiency is defined as the ratio of thermal resistance between the absorber and ambience and the thermal resistance between the fluid and ambience.

- For the concentrated collector used in this project, diameter of aperture D_a = 860mm
- This will yield A_a = 0.581m^2
- where ; $A = \pi d^2/4$
- diameter of receiver = 114mm
- This will yield area of receiver A_r = 0.0402m^2
- Therefore concentration ratio C,=A_a / A_r 0.581/0.0402 = 14.45

3.2 System Design

3.2.1 Furnace design

The choice of a cylinderical shape furnace was to enhance heat conduction and flow across the system. The rate of heat transfer through the cylinder can be modelled as steady. The cylinder has an inner radius of 53mm and an outer radius of 57mm. The outer body thickness therefore of the cylinder without the holes in the middle is 4mm. More so bearing the manufacturing processes in mind, cylindrical bodies are more readily rolled and formed as opposed to rectangular or square shaped metallic hence the choice of a cylinder furnace.

3.2.2 Solar Analysis of locality (Gazimagusa)

To effectively design our system to generate the desired temperatures for the furnace or the required output some basic factors have to be considered. These include the sunlight radiation intensity of our school locality Gazimagusa, Turkish Republic of Northern Cyprus, materials to be used and their properties, fins inside the furnace to enable better heat transfer; these will all be discussed in this sub-section.

Firstly,Gazimagusa is located at the latitude and longitude coordinates of 35.125 and 33.95.Famagusta has a typical Mediterraneanclimate- warm dry summers and mild winters.The typical Mediterranean climate has a temperature in excess of 22.0 °C average monthly to be the warmest period and an average in the coldest month between 18 to -3 °C. the earth's orbit around the sun is elliptical and has a mean center-to-center distance of about 1.5 x 10^8 km. Figure 3.3 below shows the how the earth orbits the sun, making the northern hemisphere tilt towards the sun in summer and away from the sun in winter and this phenomenon causes changes in season on earth.

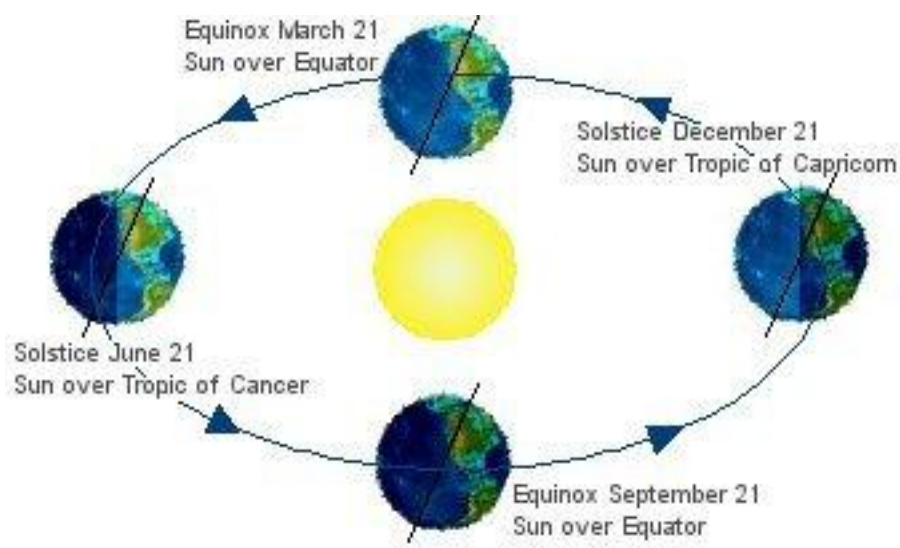

Figure 3.3 Motion of the earth about the sun[3].

Since the sun's radiation on earth is a function of the geometry of the receiving surface relative to the sun, it is important therefore to notice several geometric angles that show the sun-earth surface relations. Figure 3.4 shows the relationship between latitude, altitude and the sun's declination.

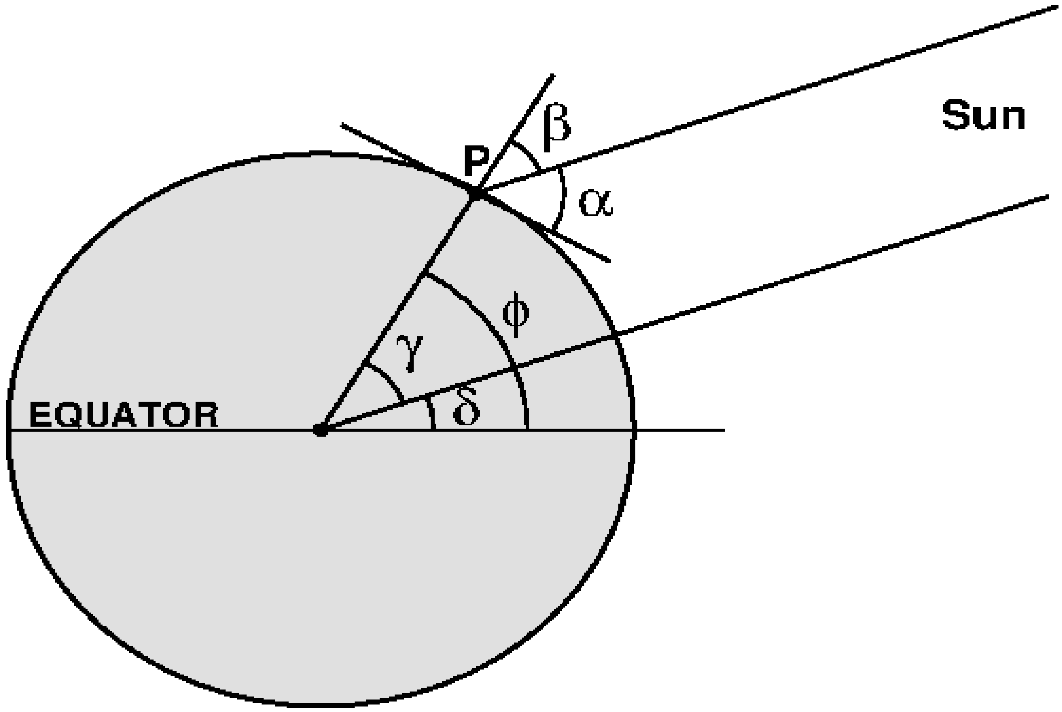

Figure 3.4 The sun's altitude, latitude and declination [4].

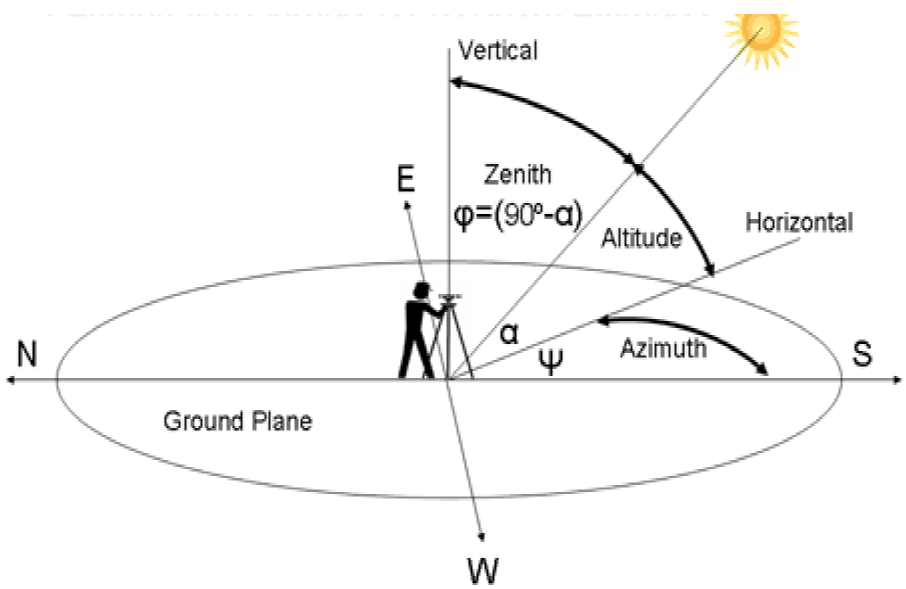

Figure 3.5 Solar path and solar zenith angle, altitude angle α, and azimuth angle Ψ[4].

3.2.3 Materials to be used

The solar furnace to be produced will basically be made of steel, with fins at the inner part to enable heat exchange throughout the entire system. Table 3.1 shows some basic properties of the cast irons.

Table 3.1 steel alloy and their properties [3]

Steel grade	Yield strength (Mpa)	Tensile strength (Mpa)	Tensile enlongation(%)
1015	306.8	413.7	37.5
1020	320.6	426.2	35.5
1022	340.1	435.8	34.0
1030	347.0	450.1	29.5
1040	359.2	468.9	28.0
1050	370.3	480.7	20.0
1060	382.0	495.1	18.0
1080	398.4	501.1	10.5

In the project, basically the 1030 steel grade will be used in the construction, however fins made of copper material will lie inside to enhance proper and better heat transfer by conduction to the outer surface of the iron core will be insulated to reduce the rate of heat loss.

3.2.4 Mathematical modelling

The **fin equation** for a volume element is:

(rate of heat conduction into the element at x) = (rate of heat conduction from the element at $x+\Delta x$) + (rate of heat convection from the element).

Mathematically, this is represented as : $\dot{Q}_{cond,x} = \dot{Q}_{cond,x+\Delta x} + \dot{Q}_{conv}$ (3.7)

Where; $\dot{Q}_{conv} = h(p\Delta x)(T-T_\infty)$ (3.8)

By dividing by Δx, we obtain

$$\frac{\dot{Q}_{cond,x+\Delta x} - \dot{Q}_{cond,x}}{\Delta x} + hp(T - T_\infty) = 0 \quad (3.9)$$

Taking limit as Δx→0 and using the definition of derivative gives

$$\frac{d\dot{Q}_{cond}}{dx} + hp(T - T_\infty) = 0 \quad (3.10)$$

From Fourier's law of heat conduction $\dot{Q}_{cond} = -kA_c\frac{dT}{dx}$ (3.11)

This finally yields $\frac{d}{dx}\left(kA_c\frac{dT}{dx}\right) - hp(T - T_\infty) = 0$ (3.12)

The fin efficiency however is defined through these equations:

$$\dot{Q}_{fin,max} = hA_{fin}(T_b - T_\infty) \quad (3.13)$$

Where h = convection heat transfer coefficient

T_b = base plate tempereture

T_∞ = ambient temperature

p = perimeter of fin

$$\eta_{fin} = \frac{\dot{Q}_{fin}}{\dot{Q}_{fin,max}} = \frac{actual\ heat\ tranfer\ rate\ from\ the\ fin}{ideal\ heat\ transfer\ rate\ from\ the\ fin} \quad (3.14)$$

$$\dot{Q}_{fin} = \eta_{fin}\,\dot{Q}_{fin,max} = \eta_{fin}\,hA_{fin}(T_b - T_\infty) \quad (3.15)$$

Where A_{fin} represents the total area of the fin.

- Energy balance for the entire system, modeled as a close system:
- $E_{in} - E_{out} = \Delta U = mC\,\Delta T$ ------ $Q = mC\,\Delta T$

- Where, ΔU is the internal energy of the system
- m= constant mass of the system
- C = heat capacity at constant volume
- ΔT = change in temperature of the system
- The net amount of heat transfer to the system considering the combined effect of convection and radiation = $Q = h_{combined} A_s (T_s - T_\infty)$

3.3 Cost Analysis

Our solar furnace is designed bearing in mind the feasibility of the project. Hence cost effective measures were taken when deciding the materials to be used. This is very noticeable from the aforementioned materials for the project. Steel is readily available in our locality at a very affordable price, the copper material used for the furnace lid and fins inside were ordered from Turkey at an affordable price and we could construct and use a parabolic concentrator as made readily available by our supervisor. The table below shows the various cost of the materials used in this project.

Table 3.2 Cost Analysis

	ITEMS	**AMOUNT**	**COST(TL)**
1	Cylindrical steel body	1	80
2	Screws	5	40
3	Copper lid	2	50
4	Copper fins	8	36
5	Transportation		100
	Total		**306**

Chapter 4

Manufacturing, Assembly and Testing

4.1 Manufacturing Procedure

A variety of different processes were used in the production of our project. These involved drilling, turning, shaping, milling, and tapping. Firstly, with hollow cylindrical body gotten, we machined its outer surface to create a smooth body surface. This was achieved by the help of filing and the shaping machine in the department workshop.Molten steel is made by melting iron ore and coke (a carbon-rich substance that results when coal is heated in the absence of air) in a furnace, then removing most of the carbon by blasting oxygen into the liquid. The molten steel is then poured into large, thick-walled iron molds, where it cools into the desired shape. However we were not involved in this as we already got our steel cylinder ready-made.

The next step taken in our manufacturing process was the sawing of the copper fins. We bought in a long form and they were already curling because of the high ductility of copper. Hence we ensured they were strengthened, and placed on a bench vise were we cut them into the required lengths for our project.

Furthermore, the end plate of the cylinder which was made of steel too was drilled and tapped for the handle used in opening and accessing the contents of the furnace. It was also drilled to provide the grip needed to fasten the screws on it. At the other end of the furnace there was a copper lid this was used to provide greater heat transfer rate from the incident solar radiation from the sun. A drilling was done on the body of the furnace to enable access to debris of the combustion inside and a handle created on the tail end of the furnace was to enable carriage and be able to access the furnace through opening and closing it and be able to put or remove anything from it. The handle was manufactured with a length difference so as not to be hurt by the increased temperatures created by the parabolic collector.

More so, the lathe machine in the workshop was used during our project; the lids were cut to the small thickness which we specified in our design by this process. The milling machine was also used to create the smoothened faces of the end edges of our furnace. These basic manufacturing processes constitute a majority of the ways through which our project was constructed.

4.2 Method of Assembly

The method of assembly used in this project was basically manual and conducted in the workshop of the mechanical engineering department. The basic process involved here was welding. This enabled the joining of different parts of the furnace such as the end plate enclosure to the body of the cylinder and as well in the manufacturing of the handle at the lid. The type of welding used was the stick welding, which uses an electrode that has flux. The electrode holder holds the electrode as it slowly melts away. Slag protects the weld puddle from atmospheric contamination.A filler material was added to the joint to form a pool of molten material that cools to form a joint that can be as strong as the base material.

Another method of assembly used was the screws used as fasteners on the cylinder head to enclose the furnace.

4.3 Testing

The testing of the furnace was done during the day at about mid day with high solar radiation at almost its peak and recordings and data was collected for two days in a row. These data and results are documented in the next chapter. To be able to make this testing, the furnace was mounted on a stance and the collector was faced toward so as to get the incident rays of the sun. This was done on the roof top of the department and we recorded the results.

Figure 4.1 Testing the furnace

Chapter 5

Results and discussion

5.1 Results

The furnace was tested in weather conditions favorable to produce increased heat radiations. With a solar radiation intensity of approximately 942W/m^2.

The local latitude of Gazimagusa is 35.15 and experiments were done on 15th and 16th June.

To calculate for the concentration ratio C, we need to calculate the area of the aperture of the collector A_a and area of the outer the lid surface of the furnace. To get these areas, we measured the diameters as diameter of aperture D_a = 860mm and diameter of receiver = 114mm

This will yield area of aperture A_a = 0.581m^2 and area of receiver = 0.0402m^2

Therefore concentration factor C, $= \frac{Aa}{Ar} = 14.45$

5.2 Thermocouples

The results measured in this project are measured by the k-type thermocouples. The temperstures important for the performance are the ambient temperature, the copper plate temperature and also the fin temperature. The k-type thermocouples were placed in several points within the system to obtain the necessary temperatures.

It has an accuracy of $\pm 0.5℃$, the data taken for the temperature using the k-type thermocouple was retrieved with two-channel digital thermometer (DM6802A series digital, VICHY). Figure 5.1 below shows the channel digital thermometer.

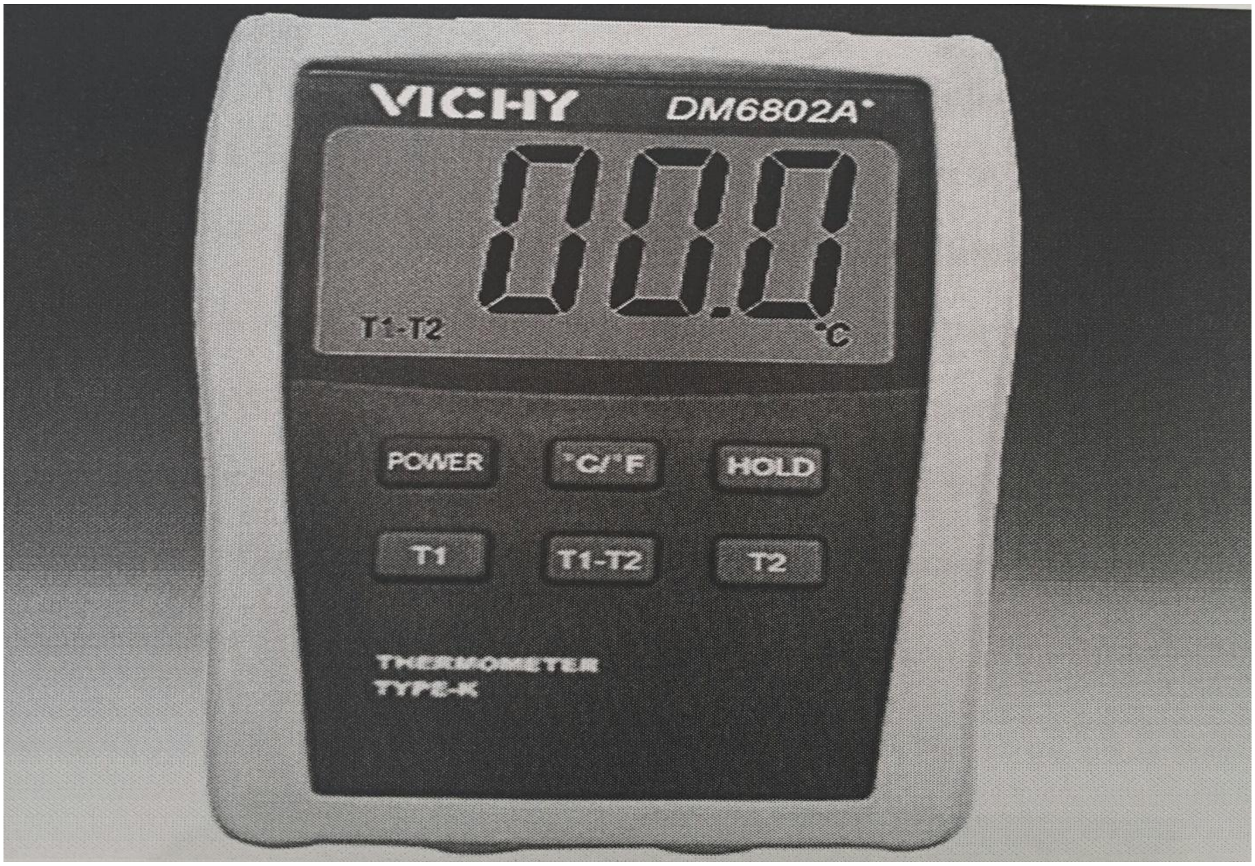

Figure 5.1 Two-channel digital thermometer (DM6802A series digital, VICHY).

The values gotten from the experiment results are tabulated below:

TABLE 5.1 Experimental work results

HOURS	INSIDE AIR TEMPERATURE (℃) [±0.5]	FIN TIP TEMPERATURE (at0cm) (℃) [±0.5]	Temperature at Middle of Fin (at 12.5cm) (℃) [±0.5]	TEMPERATURE AT FIN END (at 25cm) (℃) [±0.5]
10:30 AM	106	154	146	132
11:30 AM	134	178	169	157
12:30AM	168	205	198	188
13:30AM	173	238	233	227
14:30AM	169	219	210	201
15:30AM	150	210	199	187

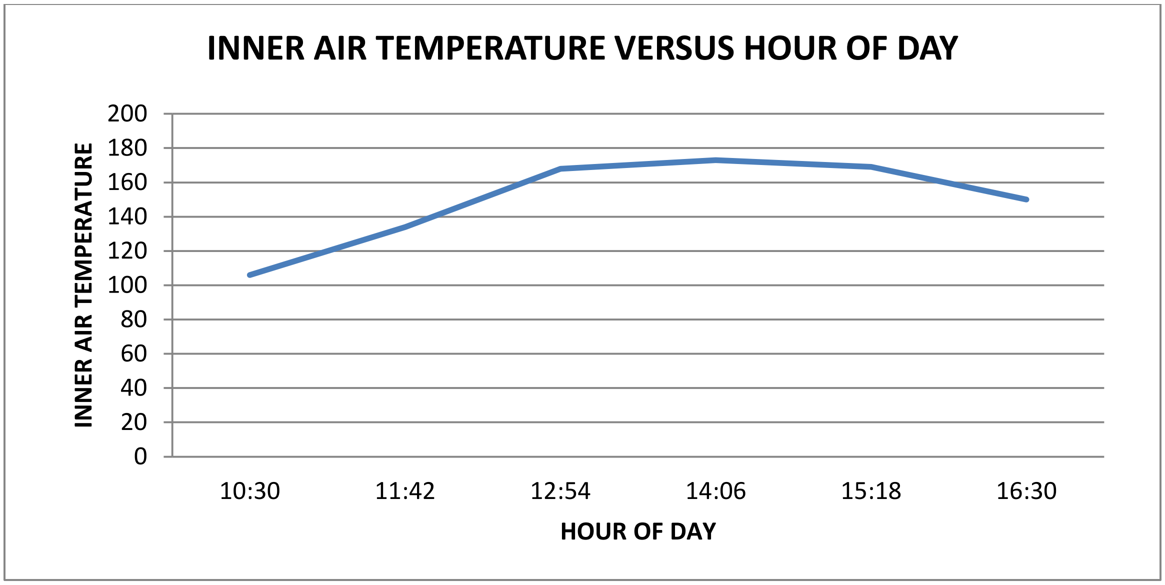

Figure 5.1 Graph of inner air temperature of the furnace against time of the day

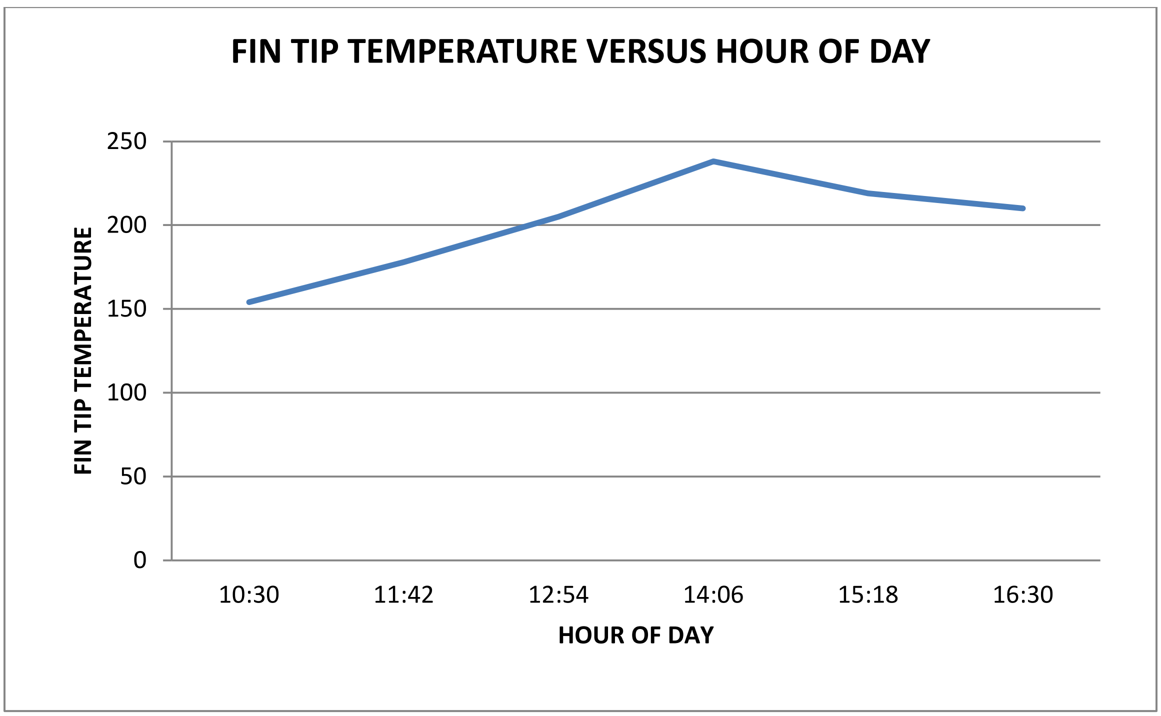

Figure 5.2 Graph of fin tip temperature against time of the day

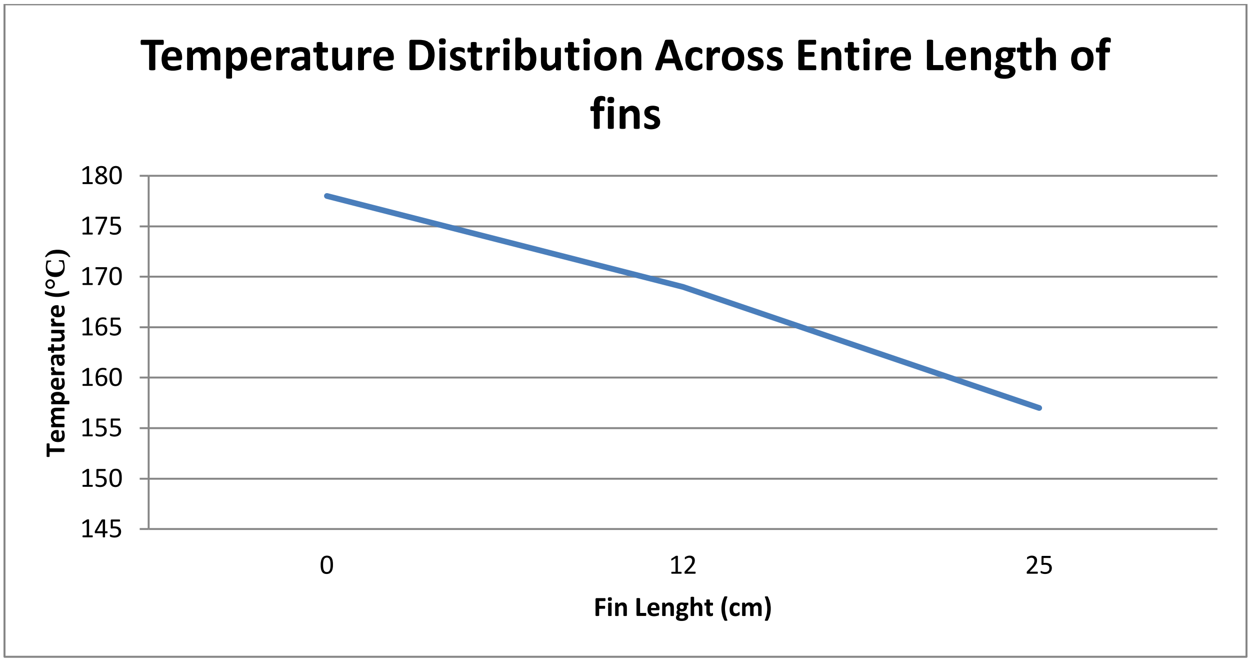

Figure 5.3 Graph of Temperature distribution across fin length with temperature values from row 1 of the table 5.1 above.

5.3 Discussion of results and Error analysis

From the results of our experiment one can see that the maximum temperature was recorded at about 1:30 pm launch time to be 173℃ for the inner air temperature of the furnace and 238℃ for the inner fin surface. These temperatures are high enough to boil water as well as burn other items after a period of time. However they might not have been as high enough to initiate carbonization as was intended initially. The results recorded above are not accurate because of the lack of a tracking mechanism for the system. The values will be different from what is obtainable in the ideal case. The collector was adjusted with change in the angle of the sun, hence there was errors recorded in taking the results.

5.4 Technical difficulties encountered

There were a few impediments to the effective conduct of the project, these included workshop machining and operations. Most times the workshop was not always available at our free periods but we managed to skip some classes and get the job done. Other difficulties includes the machining of the different work parts we had to work with, it was not so easy as we even got injured on some occasions but still the job had to be done. More so, during the testing/ experiment days we had difficulties in positioning the collector at the best possible point to maximize power radiation intensity. And because also this had to be done at the roof top of the department with no shades provided we were sun-burnt most times but we are happy to have gotten the job done.

Chapter 6
Conclusion and Future work

In conclusion, the project's main aim was to try to concentrate sun rays to a receiver focus point on our furnace. In order to achieve this, it was important to get a uniform concentration so as to get the desired inlet surface temperatures. Also contained in this project is the mathematical modeling of a solar furnace system as well as equations to help one understand how heat is created and dissipated across the system. Even though an obstacle was encountered during the testing as the parabolic reflector is not so hemispherical in shape, so the concentration was not so much at a point but we defeated this by trying to rotate the angles at which the collector was positioned so as to yield a more sharp and concentrated focus point.

This work however can be modified in the future by making some adjustments in the system, firstly, almost all the sunrays incident on the collector can becollected by making it be a more hemispherical one. More so, flat mirrors can be installed to be in front of the parabolic reflector and this orientation will help increase the concentration of sunrays at the focus point. This is because the reflected sun rays coming to the parabolic reflector are parallel to the principal axis. This type of model is called on-axis model. The advantage of this system is that the receiver of the system will not shade the parabolic reflector.

The solar furnace generated in this project produced temperatures high enough to be used in solar cooking applications. The collected heat can also be turned into electricity using the sterling engine. Since this is a moving trend around the globe in our today's world, and bearing in mind that Cyprus has a huge amount of sunlight radiation, these applications have to be reviewed in the nearest future to create a more renewable means of generating energy.

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APPENDICES

APPENDIX A

Log books

AMALAHA'S log book

Dates	**Details**
10-10-2014	Visited Prof Fuat in his office to let him know he was my supervisor
17-10-2014	Was with my team members and we pondered about a topic for the project
20-10-2014	We met with our supervisor and together we decided on the project---solar furnace
1-11-2014	Started to gather information about the chosen topic
3-11-2014	Was allocated the design and manufacturing aspect as well as calculations
20-11-2014	Stared to do the calculations with the relevant equattions
3-12-2014	Met with my team mates and we discussed how far everyone had gone in their own parts
20-12-2014	Chapter 3 which was done by me was completed
30-12-2014	We compiled the whole project and submitted to our supervisor to check
5-1-2014	After checking by the supervisor submitted the completed chapters 1-3 to Dr Neriman
3-3-2015	Started to order our materials from turkey
5-4-2015	After arrival of the parts we started machining in the workshop

6-5-2015	The project was almost done and we visited our supervisor to let him know our progress
20-5-2015	Final couplings and assembly in the workshop
15-6-2015	Testing the furnace at the rooftop of the department
22-6-2015	Submission of the completed capstone project report to Dr Ranjbar

ADEM's log book

Dates	Details
10-10-2014	Came to Prof Fuat in his office to let him know he was my supervisor
17-10-2014	We chose topic for the project
20-10-2014	We met with our supervisor and together we decided on the project---solar furnace
12-11-2014	Was in charge of introduction chapter
13-11-2014	Did research on internet about topic
20-12-2014	Submitted my finished chapter 1 to my group members
30-12-2014	We compiled the whole project and submitted to our supervisor to check
5-1-2014	After checking by the supervisor submitted the completed chapters 1-3 to Dr Neriman
3-3-2015	We ordered our materials from turkey
15-4-2015	Helped to do drilling in the workshop

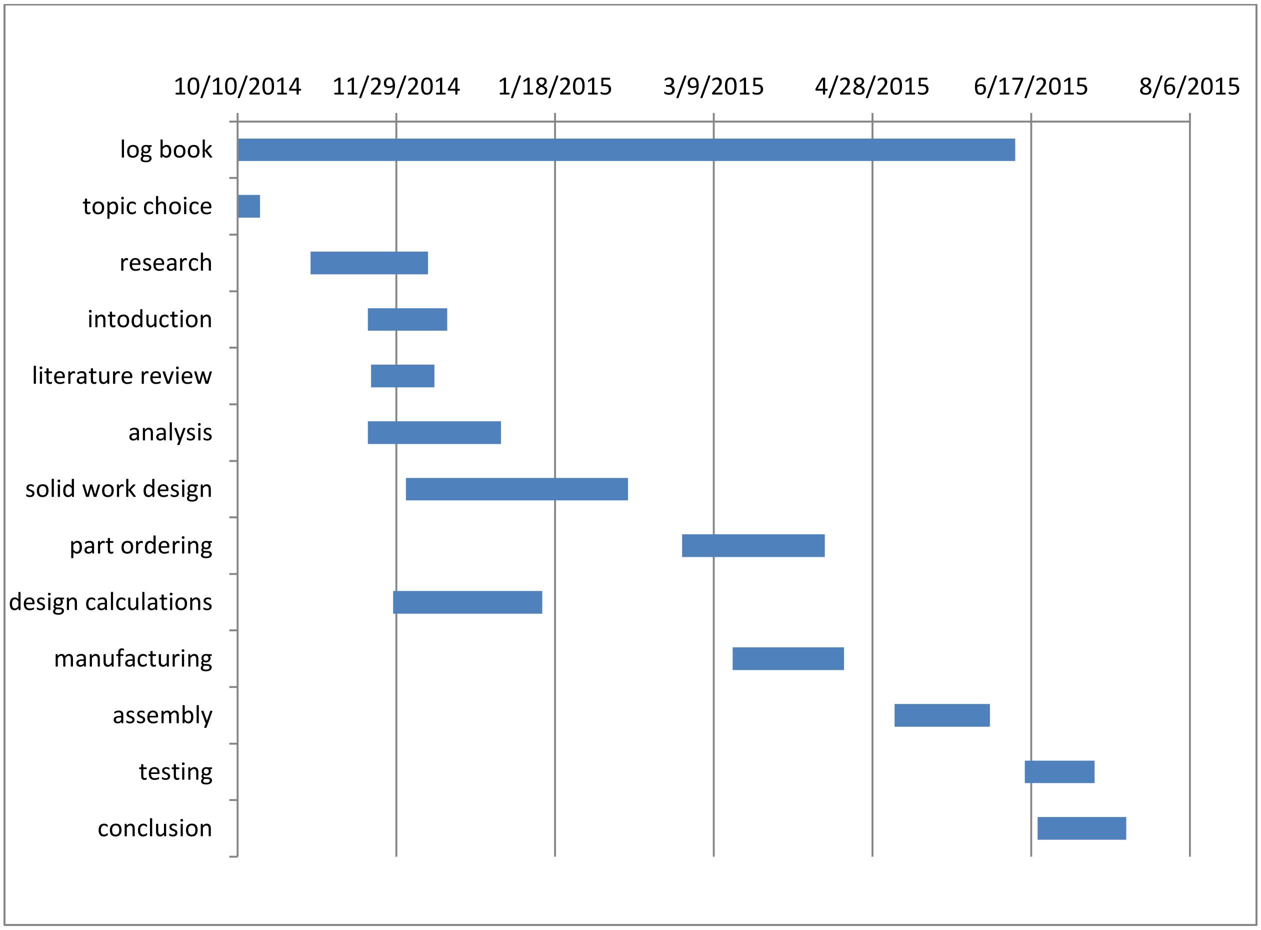
15-6-2015	Testing the furnace at the rooftop of the department
22-6-2015	Submission of the completed capstone project report to Dr Ranjbar

Diyar's log book

Dates	**Details**
10-10-2014	We visited Prof Fuat in his office to let him know he was our supervisor
17-10-2014	we decided about a topic for the project
21-11-2014	I was given chapter 2 by my teammates
3-12-2014	Started to gather information from the EMU for the literature review
1-1-2015	Finished my part and we met with our supervisor
3-3-2015	Started to order our materials from turkey
5-5-2015	Drilled and welded in the workshop
20-5-2015	Final couplings and assembly in the workshop
15-6-2015	Testing the furnace at the rooftop of the department
22-6-2015	Submission of the completed capstone project report to Dr Ranjbar

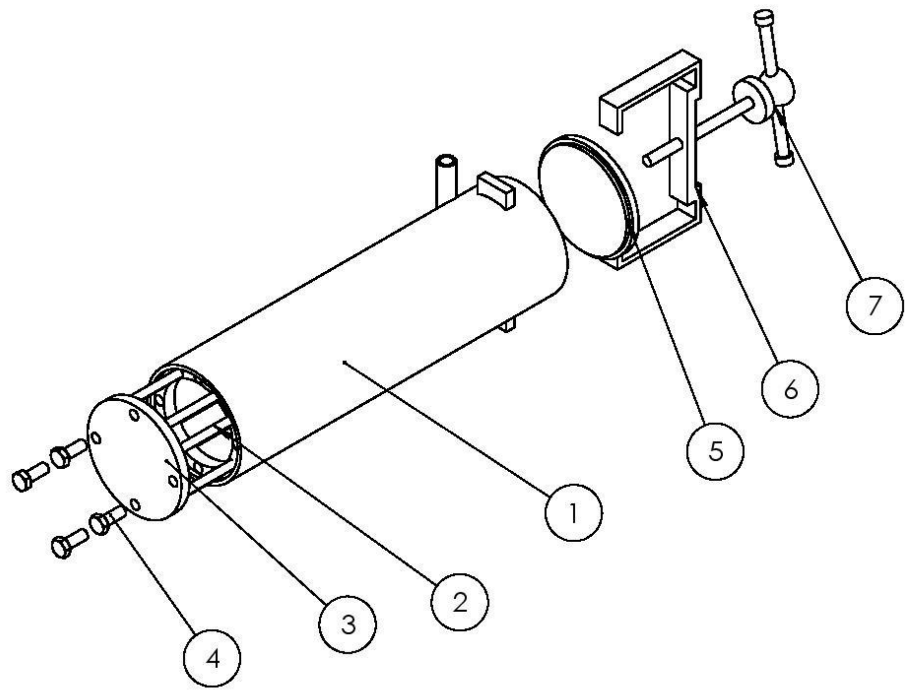
APPENDIX B

Gantt Chart



APPENDIX C

DRAWINGS



NO	NAME	AMT.	DESCRIPTION
7	HANDLE ADJUSTER	1	STEEL
6	HANDLE	1	STEEL
5	BACK LID	1	STEEL
4	BOLT	4	STEEL
3	FRONT LID	1	COPPER
2	FINS	8	COPPER
1	CYLINDRICAL BODY	1	STEEL

	NAME	DATE	SIGN
DRW.BY	118620	6/16/2015	
CHK.BY	C.K	6/16/2015	

SCALE		DRAWING NO.
1:5	ASSEMBLY OF SOLAR FURNACE	1

Appendix D

Engineering standards

Table 6.1 HCE Design and Parameter Study Summary

Design Option or Parameter	Purpose of Evaluation	Results and Comments
Absorber Pipe Base Material (Section 6.1)	To determine influence of less expensive materials (316L, B42 copper, and carbon steel) on the HCE performance	• Negligible, yet material selection is also driven by material strength, corrosion properties, installation ease, coating application, and cost considerations.
Selective Coating (Section 6.2)	To compare the differences on HCE performance between all the absorber coatings that have been used or have been proposed	• Chronologically, the improvements in coatings have improved HCE performance. • Solel's proposed UVAC Cermet with emittance of 0.07 @ 400°C gives the best HCE performance. • HCE performance would be sensitive to any variance in selective coating optical properties.
Annulus Gas Type (Section 6.3)	To evaluate the differences on HCE performance between vacuum, air, argon, and hydrogen in the HCE annulus	• Vacuum gives the best result. • Filling the annulus with an inert gas is better than air. • Hydrogen permeation can degrade HCE performance.
HCE Condition and Wind Speed (Section 6.4)	To evaluate the loss in HCE performance because of loss vacuum in annulus, or a broken glass envelope.	• A broken glass envelope on an HCE gives unacceptable performance results, especially with windy conditions. • The wind has little influence on HCE performance when the annulus vacuum is intact, but does when the vacuum is lost.
Annulus Gas Type (Section 6.3)	To evaluate the differences on HCE performance between vacuum, air, argon, and hydrogen in the HCE annulus	• Vacuum gives the best result. • Filling the annulus with an inert gas is better than air. • Hydrogen permeation can degrade HCE performance.
Annulus Pressure (Section 6.5)	To determine sensitivity of HCE performance to the vacuum level inside the HCE annulus	• Vacuum levels less than 0.1 torr show negligible improvements from the 0.0001 torr level. • HCE performance declines appreciably with pressures of 100 torr or greater in the annulus. • If hydrogen in present, the HCE performance is even more sensitive to annulus pressure.
Mirror Reflectance (Section 6.6)	To determine sensitivity of trough performance to the mirror reflectance.	• The trough performance drops appreciably with solar weighted reflectivity less than 0.9. • Keeping mirrors clean is very important to CSA performance.
Solar Incident Angle (Section 6.7)	Determine sensitivity of trough performance to solar incident angle.	• Trough performance is very sensitive to solar incident angle.

Engineering standards for heat collector elements (HCE)1

Table 6.1 (cont.)

Design Option or Parameter	Purpose of Evaluation	Results and Comments
Solar Insolation (Section 6.8)	Determine sensitivity of trough performance to solar insolation.	• Trough performance very sensitive to solar insolation. • Factors such as atmospheric pollutants and particu- lates should be considered when choosing a solar site.
HTF Flow Rate (Section 6.9)	Determine sensitivity of trough performance to HTF flow rate.	• HCE performance has weak dependency to HTF flow rate.
HTF Type (Section 6.10)	To determine sensitivity of HCE performance to the type of heat transfer fluid	• Trough performance has weak dependency to HTF type. • Operation of the HCE at higher temperatures decreases the HCE performance yet increases the power cycle efficiency.
Glass Envelope Diameter (Section 6.11)	Determine sensitivity of trough performance to glass envelope diameter.	• Appears to be an optimal diameter that minimizes the heat losses. • Influence of diameter on heat loss is more sensitive when the annulus is not under vacuum. • Clearance for absorber pipe bowing needs to be included.
Temperature and Heat Flux Variation along Receiver Length (Section 6.12)	Determine temperature and heat flux profiles along length of receiver.	• The temperatures along the length of the receiver increase in a slightly nonlinear fashion. • The temperature differences between the HTF and absorber (T_1 and T_2), between the inner and outer absorber pipe surfaces (T_2 and T_3), and between the inner and outer glass-envelope surfaces (T_4 and T_5) all remain constant. • The temperature difference between the absorber and glass-envelope (T_3 and T_4) changes in a slightly nonlinear fashion. • Radiation heat transfer fluxes increase nonlinearly. • Heat gain per receiver length decreases as the HTF temperature increases. • Heat loss per receiver length increases as the HCE cross-sectional temperatures increase. • Optical losses per unit receiver length remain constant.

Engineering standards for heat collector elements (HCE) 2

APPENDIX E

Poster and Website

http://student.emu.edu.tr/101165