Design and Thermal Performance of a Solar Oven

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July 2010
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Date of Examination: 24 / 7 /2010
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Dedication

This work is dedicated with gratitude

To

My..
Father
Mother
Brothers
Sisters
And Friends
Acknowledgements

I would like to express my sincere appreciation to my supervisor Dr Abdalla M.A.Suliman for his magnificent assistance and guidance during the stages of this study, to my colleagues and friends for their encouragement.

Special thanks are sent to Miss Zeinap Haron who typed this dissertation.
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ABSTRACT

Solar energy is one of renewable energy sources, it is clear, environmentally friendly, abundant and free source of power. This study deals with the design and applications of a solar oven (parabolic trough type). The study was subjected to design parabolic trough solar concentrator collector, and then to use it as a solar oven. Thermal performance of the above unit was carried out. The solar oven was designed and built on the yard of the Faculty of Engineering and Technology, University of Gezira, Wad Medani (φ = 15°), Sudan. The specification of the unit can be summarized as the Diameter of the oven (D) = 2.01 m, Focal length (f) = 0.43 m, Height (h) = 0.60 m, Length (L) = 2.40 m. From the result it was recorded that, the maximum plate temperature of the solar oven was 121°C at the mid day time hours and was found that the maximum absorbed heat is 269.7W/m² and the maximum amount of the heat lost is 822W/m². The study recommends that the unit can be used for baking foods and other thermal domestic purposes.
التصميم و السلوك الحراري لفرن شمسي

إعداد:
إبراهيم محمد حسين الشايقي
ماجستير الهندسة الكيميائية (2010)
قسم الكيمياء التطبيقية و تكنولوجيا الكيمياء
كلية الهندسة والتكنولوجيا
جامعة الجزيرة

ملخص الأطروحة

الطاقة الشمسية أحد مصادر الطاقة المتجددة وهي مصدر طاقة نظيف و صديق للبيئة و متوفرة وحرة. تختص هذه الدراسة بتصميم وتطبيقات الفرن الشمسي. قامت الدراسة بتصميم المجمع الشمسي واستخدامه كفن شمسي وتحديد السلوك الحراري. صمم الفرن الشمسي ويني في فناء كلية الهندسة والتكنولوجيا - جامعة الجزيرة - ودمدني (خط عرض01 درجة)، السودان. من مواصفات هذا الفرن انه مصنوع من الحديد والزجاج، أبعاده هي: القطر (د) = 0.2 متر، ارتفاع البؤرة (ه) = 2.0 متر، الارتفاع (ه) = 0.5 متر، الطول (ل) = 0.4 متر من النتائج التي حصلت عليها الدراسة أن أقصى درجة حرارة لسطح الفرن الشمسي كانت 121 درجة مئوية في ساعات الظهيرة ووجد أيضاً أن أقصى حرارة ممددة هي 269.7 واط/م² وأقصى حرارة مفقودة هي 200 واط/م². من الممكن استخدام هذا الفرن في صنع الأطعمة وأي أغراض حرارية محلية أخرى.
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CHAPTER ONE

1. INTRODUCTION

1.1. Energy :

Energy can be defined as ability to do work i.e. (motion, growth, heat light …etc). It is needed for all life activities that help to survive.

1.1.1. Energy types:

1) Stored energy is called potential energy.

2) moving energy is called kinetic energy

1.1.2. Forms of energy:

1) Chemical energy,

2) Electrical energy.

3) Thermal energy (heat).

4) Radiation energy (light).

5) Mechanical energy.

6) Nuclear energy.

1.2. Renewable energy:

Before the industrial revolution renewable energy was largely the only energy source used by humanity. Solid befouls like wood is still the main power source for many poor people in developing countries.
Renewable energy sources include:

1) Solar energy, which comes from the sun and can be turned into electricity and heat.

2) Wind energy.

3) Geothermal energy from inside the earth.

4) Biomass from plants.

5) Hydropower from water.

1.3. Solar energy:

1.3.1. Advantages:

All chemical and radioactive polluting byproducts of the thermonuclear reactions remain behind on the sun, while only pure radiant energy reaches the Earth.

Solar energy is clean and environmentally friendly source of power, and abundant and free or (cheap) source of power. Because it is by now clear that, the fossil fuels era of non-renewable source of energy is gradually coming to end i.e. (oil and natural gas will be depleted first, followed eventually by coal).

Energy reaching the earth is incredible. By one calculation, 30 days of sunshine striking the Earth have the energy equivalent of the total of all the planet’s fossil fuels, both used and unused!!.
Decrease our dependence on fossil fuels.

Mitigates the effects of acid rain, carbon dioxide, and other impacts of burning coal and counters risks associated with nuclear energy. Pollution free, indefinitely sustainable. Solar energy appears as solving source.

1.3.2. Disadvantages of solar energy:

The energy from the sun can be captured and put to work directly or Indirectly. Solar energy is the diffuse source. To harness it, we must concentrate it into an amount and form that we can use, such as heat and electricity.

Unfortunately, solar energy is not always available on demand, Sun does not shine constantly. It is unobtainable under heavy clouds or at night.

Solar radiation arrives at low intensity, and must be concentrated for high temperature(over250º F[120º C] ) application.

The variation in availability of solar radiation occurs daily, according to Location, changes in solar angle every day, climate variation during seasons.

1.4. Objectives:

The study was subjected to achieve the following objectives:-
1. To design a parabolic trough solar concentrator collector.

2. To apply the above collector as a solar oven.

3. To achieve the thermal performance of the above unit.
2.1 Solar energy fundamentals:

2.1.1 The sun:

The sun is one of about 1- billion stars in our galaxy, the milky way. The sun is by far the largest object in the solar system. It contain more than 99.8% of the total mass of the solar system. The light takes 8 minutes and 20 seconds to travel from the sun to the earth (Solcomhouse, 2003).

Stine, and Geyer, (2001) reported that; “apparent surface temperature of the sun is around 6000K (10340⁰F) and energy is released at the rate of 3.83 x 10²⁶ J/S”.

Sukhatme, (1996), stated that “the sun is a large sphere of very hot gases, the heat being generated by various kinds of fusion reactions, its diameter is 1.39 x 10⁶ km while that of the earth is 1.27 x 10⁴ km. The mean distance between the two is 1.496 x 10⁸ km. although the sun is large, its subtends an angle of only 32 minutes at the earth surface. Thus, the beam radiation received from the sun on the earth is almost parallel”.

Mazria, (1979), reported that “the total mass of the sun is about 2.2 x 10²⁷ tons, and losses only 2 x 10⁻²²⁰% of it’s mass each second”.

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2.1.2 Solar radiation:

“All objects having a temperature above the absolute zero (-273.16°C), radiate energy to their surrounding (Pidwirny, 2003).

The thermonuclear fusions at the core of the sun release energy in the form of high frequency electromagnetic radiation.

“Most of the electromagnetic radiation reaching the earth emanates from a spherical outer shell of hot dense gas called the photosphere (Stine, and Geyer, 2001).

“Solar radiation is the heat, light and other radioactive energy that is emitted from the sun” (Focus, 2002).

2.1.2.1 Solar constant:

Duffie, and Bechmann, (1980), defined the solar constant (I_{sc}) as, “the energy from the sun, per unit time, received on a unit area of surface perpendicular to the earth’s mean distance from the sun outside of the atmosphere. The standard value that was accepted by the “American society for testing material (ASTM), and by NASA, (1971) is 1353 w/m².

Stine, and Geyer, (2001) state that “the radiant energy falling on 1m² of the surface area is reduced to 1367W.”
Sukhatme, (1996), reported that “radiation coming from the sun is essentially equivalent to a blackbody radiation. Using Stefan Boltzmann law, the equivalent blackbody temperature can be shown to be as 5762 K for a solar constant value:

\[ I_{sc} = 1367 \text{ w/m}^2 \]  

(2-1)

**2.1.2.2 Beam radiation (I_b):**

It is the solar radiation received from the sun without being scattered by the atmosphere.

**2.1.2.3 Diffuse radiation (I_d):**

It is the solar radiation received from the sun after it’s direction has been changed by scattering by the atmosphere.

**2.1.2.4 Total solar radiation (I):**

It is the sum of the beam and diffuse radiation on a horizontal surface (often referred to as global radiation), i.e.

\[ I_b + I_d = I \]  

(2-2)

**2.1.2.5 Solar radiation measuring instruments:**

There are two main types of instruments:

1. **Pyranometer:**

Measuring the total radiation (I), at normal incidence on a horizontal surface.
2. Pyrheliometer:

Measuring the intensity of beam solar radiation ($I_b$) at normal incidence on a horizontal surface.

“In addition the terms solarimeter and actinometer are referred to pyranometer and pyrheliometer respectively” (Duffie, and Bechmann, 1980).

2.1.2.6 Solar time:

“Time based on the apparent angular motion of the sun across the sky, with solar noon, the time, the sun crosses the meridian of the observer. Solar time is the time specified in all of the sun angles relationships, it does coincide with local clock time. It is necessary to convert standard time to solar time by applying two corrections. First, there is a constant correction for the difference in longitude between the observer meridian location and the meridian on which the local standard time is based. The sun takes four minutes to transverse $1^0$ of longitude. The second correction is from the equation of time which takes into account the perturbations in the earth’s rate of rotation which affective time the sun crosses the observer’s meridian, (Duffie and Bechmann, 1980).
2.1.2.7 Absorbed solar radiation (S):

The solar radiation incident on a tilted surface \( I_b \), This incident radiation has three different distributions: beam radiation, diffuse sky radiation, and diffuse ground – reflected radiation and each must be treated separately when transmitted, absorbed by black plate surface inside the collector. On an hourly basis, an equation for the absorbed radiation \( S \) by the black surface through the cover \( (s) \) (tilted surface), can be represented as follows:

\[
S = I_b \cdot R_b \cdot (\tau\alpha)_b \left( \frac{1 + \cos \beta}{2} \right) + P_s (I_b + I_d)(\tau\alpha)_g \left( \frac{1 - \cos \beta}{2} \right)
\]  

(2.3)


\( S = \) Absorbed solar radiation \( (\text{w/m}^2) \).

\( (\tau\alpha)_b \) = Transmittance – absorbance product of beam radiation.

\( (\tau\alpha)_d \) = Transmittance – absorbance product of diffuse ground sky radiation.

\( (\tau\alpha)_g \) = Transmittance – absorbance product of diffuse ground reflected radiation.

\( \rho_g \) = Diffuse ground reflectance  = 0.2 for snow less ground (dry land) 0.7 for snow ground.

\( \beta \) = Tilted angle (degrees).
For practical solar collector, a reasonable approximation, has been reported by [Stine, and Geyer, (2001), Sukhatme, (1996), Duffie, and Bechmann, (1980)] as:

\[
(\tau\alpha) = 1.01\tau(\theta)\alpha
\]  \hspace{1cm} (2.4)

\(\theta\) : The incident angle of the radiation (\(\theta\)) (degree).

\(\alpha\) : The absorbance of a black painted plate is (\(\alpha = 0.95\)). [Independent of direction].


\[
I_{\beta} - \text{W/m}^2 \hspace{1cm} S - \text{W/m}^2
\]

\[
S = (\tau\alpha) I_{\beta} \text{ [Suliman, Oct. (2004)]}
\]

\[
S = 1.01 \, \tau(\theta) \, \alpha \, I_{\beta}
\]

\(\alpha = 0.95\)

\[
SA = Q_a
\]

\(A = \text{The area of the black painted plate in m}^2\).

\(Q_a = \text{The amount of energy absorbed.}\)

2.1.3 Solar thermal collectors:

Solar energy conversion is divided into natural (indirect) and technological (direct) collection systems.

The technological collection system are divided into thermal conversion or photovoltaic conversion.
The indirect conversion method of solar energy into, wind, geothermal, and wave energy.

Solar thermal conversion. It is a technological scheme that utilizes a familiar phenomenon. When a dark (or black) surface is placed in sunshine, it absorbs solar energy and heats up. Solar energy collectors working in this principle, consists of a surface facing the sun which transfers part of the energy it absorbs to a working air in contact with it.

To reduce the heat losses to the atmosphere, one or two sheets of glass are usually placed over the absorber surface to improve it’s efficiency. The use of selective surfaces (excellent absorber plates), special kinds of glass and good reflecting surfaces will improve the collector efficiency.

Thermal solar conversion collectors can be classified into:

1) Flat plate collectors.

2) Concentrating collectors.

3) Evacuated tubes collectors.

These types of thermal collectors suffer from heat losses due to radiation and convection which increase rapidly as the temperature of the working air or fluid increases (Suliman, 2004).
2.1.3.1 Concentration collectors:

Concentrating collectors are of various types and can be classified in many ways. They may be of the reflecting type utilizing mirrors or of the refracting type utilizing fresnel – lenses. The reflecting surfaces used may be parabolic, spherical or flat. They may be continuous or segmented. The goal of using large reflectors to concentrate the incident solar energy on to a smaller receiver, to increase the temperature of the heat collected from the sun “[Stine and Geyer, (2001)] Suliman, (2004).

Concentrating collectors also achieve temperatures, but unlike evacuated tube collectors, they can do so only when direct sun light is available NREL, (2000) Suliman (2004).

A solar collector uses reflective surfaces to concentrate sunlight onto a small area, where it is absorbed and converted to heat or, in the case of solar photovoltaic (PV) devices, into electricity. Concentrators can increase the power flux of sunlight hundreds of times. This class of collector is used for high-temperature applications such as steam production for the generation of electricity and thermal detoxification. Concentrating collectors are best suited to climates that have a high percentage of clear sky days.
2.1.3.2 The main types of concentrating collectors are:

- parabolic dish collectors.
- parabolic trough collectors.
- power tower.
- stationary concentrating collector (From Wikipedia, the free encyclopedia).

2.1.3.3 Concentration Ratio (C):

The term concentration ratio is used to describe the amount of light energy concentration achieved by a given collector.

The degree of concentration is a critical factor in solar collector design. Stine and Geyer (2001), defined the concentration ratio (C) in general, as the area of the collector aperture (Aₐ) divided by the surface area of the receiver (Aᵣ):

\[ C = \frac{A_a}{A_r} \quad \text{(2.5)} \]

Rapp. (1981) defined the theoretical concentration (Cₜ) as “the ratio of the entrance aperture of the area and exit aperture containing the refracted or reflected rays”, and he defined the effective concentration (Cₑ) as:

“The ratio of the entrance aperture area to the area of the receiver that is not well insulated”.
In different text books, the theoretical and effective concentration of solar collectors are based on the assumption of 100% transmission by lens 100% reflections by reflectors and 100% absorption by receiving surfaces.

The useful concentration $C_u$, was defined by Rapp (1981) as, “the product of effective concentration ($C_e$) times the overall optical efficiency $\eta_{opt}$. The overall optical efficiency is the product of transmissivities, refractivity and absorptivities for light interacting with all surfaces between the entrance aperture and receiver”. To illustrate these definitions, consider the following examples:-

For flat plate collectors $C_t = C_e = 1$, since the bottom of the collector plate is heavily insulated, but if the underside of collector was not insulated, $C_e = 0.5$ (because both the bottom and the top surfaces of the receiver plate would lose heat, although $C_t$ would remain equal unity.

**2.1.4 Parabolic trough collector:**

1. This type of collector is generally used in solar power plants. A trough-shaped parabolic reflector is used to concentrate sunlight on an insulated tube (Dewar tube) or heat pipe, placed at the focal point, containing coolant which transfers heat from the collectors to the boilers in the power station. Parabolic trough solar technology is the most proven and lowest cost large-scale solar power technology available today, primarily because of the nine large commercial-scale solar power plants that are operating in the California Mojave Desert.
These plants, developed by Luz International Limited and referred to as Solar Electric Generating Systems (SEGS), range in size from 14–80 MW and represent 354 MW of installed electric generating capacity. More than 2,000,000 m² of parabolic trough collector technology has been operating daily for up to 18 years, and as the year 2001 ended, these plants had accumulated 127 years of operational experience. The Luz collector technology has demonstrated its ability to operate in a commercial power plant environment like no other solar technology in the world. Although no new plants have been built since 1990, significant advancements in collector and plant design have been made possible by the efforts of the SEGS plants operators, the parabolic trough industry, and solar research laboratories around the world. This reviews the current state of the art of parabolic trough solar power technology and describes the R&D efforts that are in progress to enhance this technology. Also shows how the economics of future parabolic trough solar power plants are expected to improve.

Wikipedia, the free encyclopedia[www.parabolic trough]- (time:10:30pm date 6/6/2010)

2.1.4.1 History:

Organized, large-scale development of solar collectors began in the U.S. in the mid-1970 under the Energy Research and Development Administration (ERDA) and continued with the establishment of the U.S. Department of Energy (DOE) in 1978. Parabolic trough collectors capable of generating temperatures greater than 500ºC (932ºF) were initially developed
for industrial process heat (IPH) applications. Much of the early development was conducted by or sponsored through Sandia National Laboratories in Albuquerque, New Mexico. Numerous process heat applications, ranging in size from a few hundreds to about 5000 m\(^2\) of collector area, were put into service. Acurex, SunTec, and Solar Kinetics were the key parabolic trough manufacturers in the United States during this period.

Parabolic trough development was also taking place in Europe and culminated with the construction of the IEA Small Solar Power Systems Project/Distributed Collector System (SSPS/DCS) in Tabernas, Spain, in 1981. This facility consisted of two parabolic trough solar fields with a total mirror aperture area of 7602 m\(^2\). The fields used the single axis tracking Acurex collectors and the double-axis tracking parabolic trough collectors developed by M.A.N. of Munich, Germany. In 1982, Luz International Limited (Luz) developed a parabolic trough collector for IPH applications that was based largely on the experience that had been gained by DOE/Sandia and the SSPS projects.

Wikipedia, the free encyclopedia ( www. solar thermal energy time10:00pm Date 6/6/2010 )
2.1.4.2 Parabolic trough designs

Main article: Parabolic trough Sketch of a parabolic trough design. A change of position of the sun parallel to the receiver does not require adjustment of the mirrors. Parabolic trough power plants use a curved, mirrored trough which reflects the direct solar radiation onto a glass tube containing a fluid (also called a receiver, absorber or collector) running the length of the trough, positioned at the focal point of the reflectors. The trough is parabolic along one axis and linear in the orthogonal axis. For change of the daily position of the sun perpendicular to the receiver, the trough tilts east to west so that the direct radiation remains focused on the receiver. However, seasonal changes in the angle of sunlight parallel to the trough does not require adjustment of the mirrors, since the light is simply concentrated elsewhere on the receiver.

Thus the trough design does not require tracking on a second axis. The receiver may be enclosed in a glass vacuum chamber. The vacuum significantly reduces convective heat loss.

(http://en.wikipedia.org/wiki/solar thermal energy)
2.1.4.3 Advantages

- Very high temperatures are reached. High temperatures are suitable for electricity generation using conventional methods like steam turbine or some direct high temperature chemical reaction.
- Good efficiency. By concentrating sunlight current systems can get better efficiency than simple solar cells.
- A larger area can be covered by using relatively inexpensive mirrors rather than using expensive solar cells.
- Concentrated light can be redirected to a suitable location via optical fiber cable. For example illuminating buildings.
- Heat storage for power production during cloudy and overnight conditions can be accomplished, often by underground tank storage of heated fluids. Molten salts have been used to good effect.

2.4.1.4 Disadvantages

- Concentrating systems require sun tracking to maintain Sunlight focus at the collector.
- Inability to provide power in diffused light conditions. Solar Cells are able to provide some output even if the sky becomes a little bit cloudy, but power output from concentrating systems drop drastically
in cloudy conditions as diffused light cannot be concentrated passively.

2.4.1.5 Thermal Performance of Parabolic Trough Concentrator:

Calculation of the performance of concentrators follows the same general outlines as for flat plate collectors. The absorbed radiation per unit area of aperture ($S$), must be estimated from the optical properties of the aperture and receiver. Since

$$Q_u = Q_a - Q_1$$  \hspace{1cm} (2.6)

Is the energy balance equation, the parabolic concentrator heat balance equation is:

$$Q_u = A_a S - A_r U_1 (T_r - T_a)$$ \hspace{1cm} (2.7)

Where $Q_u$ = useful energy (W)

$S$ = absorbed solar $A_a$ = unshaped area of the aperture ($m^2$) radiation per unit of aperture area ($W/m^2$)

$A_r$ = area of the receiver ($m^2$).

$U_1$ = over all heat transfer coefficient($W/m^2 \cdot ^\circ C$)

$T_r$ = temperature of the receiver ($^\circ C$).
\( T_a = \) Ambient temperature (°C).

Rapp, Donald (1981), reported out,

An equation for calculation of \( S \):

\[
S = I_b \, C_e \, \eta_{opt}
\]  

(2.8)

\( I_b = \) Beam radiation (W/m\(^2\))

\( C_e = \) effective concentration

\( \eta_{opt} = \) optical efficiency of the reflecting surface.

(Rapp, (1981), stted that “a reasonable practical value of \( \eta_{opt} \) is 0.70”)

CHAPTER THREE

3. MATERIAL AND METHODS

3.1 Solar Oven Design:

3.1.1 Aperture Design:

Using the main equations dealing with parabolic trough concentrator geometry, the following design procedure was made:

- The parabolic trough concentrator diameter (D), and height (h), were chosen as:
  - D = 2.01m
  - h = 0.60m

So, the focal length (f) = 0.43m

[According the parabolic trough geometry (since h = d* 2/16f)], then

- The parabola curve was drawn, according to the following equation:

\[ y^2 = 4fx \]  
[Stine & Geyer (2001)]

<table>
<thead>
<tr>
<th>x</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>0</td>
<td>+1.31</td>
<td>+2.27</td>
<td>+2.93</td>
<td>+4.15</td>
<td>+5.87</td>
<td>+7.18</td>
<td>+8.29</td>
<td>+9.27</td>
<td>+10.16</td>
</tr>
</tbody>
</table>
Fig. (3.1): Parabolic Trough Geometry
Fig. (3.2): Parabolic Trough.
3.1.2 Specification:

* The designed parabolic concentrator has the following specifications;

3.1.2.1 Aperture

- The arc length \( S \) = 2.17m.

- The reflecting surface was made of glass mirrors.

- The outer frame made of iron sheets.

- The length of the reflector is 0.5m length were applied to increase the reflecting surface area [as mentioned in fig. (3.5)].
Fig. (3.3) Aperture Design
3.1.2.2 Receiver Design:

It was made of a black painted metal sheet (iron), having the following specifications:

- The shape is cylindrical (d = 0.3m, L = 2.5m)
- Plate thickness = 2 mm.
- Plate absorbtivity (α) = 0.95.
- Thermal conductivity (k) = 211 W/m°C.
- The receiver or cylinder cavity that act as an oven (0.3m × 2.5m)

Fig. (3.4): Receiver
3.1.2.3 Addition reflecting mirrors:

Have the following dimensions.

Length = 2.40m

Width = 1m

Thickness = 0.005m

Fig(3.5) Addition reflecting mirrors
3.2 Measuring elements:

1) Thermometer: To record the ambient temperature.

2) Digital thermometer: To record absorber plate temperature.

3) Pyranometer: To measure solar radiation.

Fig. (3.6): Thermometer
Fig. (3.7): high degree recording of digital thermometer
Fig. (3.8): Pyranometer
3.3 Method:

The following method was carried out.

1) The unit was open to focus the solar radiation after the dust removal.

2) The measuring elements were introduced.

3) The Ambient temperature (°C) $T_a$, the mean absorber plate temperature (°C). $T_p$, and = beam radiation(I) were recorded every half hour on the following days.

13/5/2010

14/5/2010

15/5/2010

16/5/2010

4) Calculation were made as in chapter four
CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Data sheet:

The following tables (4.1), (4.2), (4.3) and (4.4) represent the data sheet which were collected from the unit described in chapter three within the period of 13.5.2010 to 16.5.2010.

Data sheet (1), (2), (3) and (4) explain the relation between time every half an hour with $T_a$ ambient temperature and $T_p$ the mean absorber plate temperature.

Data sheet (5) represents the variation of measured solar radiation with time every half an hour.

Data sheet (6) Shows thermal performance of solar oven.
The following data were collected every half hour.

**Date**: 13.5.2010

\( \varphi = 15 \)

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>( T_p ) (( ^\circ \text{C} ))</th>
<th>( T_a ) (( ^\circ \text{C} ))</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>58</td>
<td>33</td>
</tr>
<tr>
<td>9:30</td>
<td>72.5</td>
<td>36</td>
</tr>
<tr>
<td>10:00</td>
<td>80</td>
<td>38</td>
</tr>
<tr>
<td>10:30</td>
<td>86</td>
<td>40</td>
</tr>
<tr>
<td>11:00</td>
<td>92</td>
<td>41</td>
</tr>
<tr>
<td>11:30</td>
<td>94</td>
<td>42</td>
</tr>
<tr>
<td>12:00</td>
<td>96.5</td>
<td>43</td>
</tr>
<tr>
<td>12:30</td>
<td>97.5</td>
<td>43</td>
</tr>
<tr>
<td>1:00</td>
<td>95</td>
<td>42</td>
</tr>
<tr>
<td>1:30</td>
<td>94.5</td>
<td>43</td>
</tr>
<tr>
<td>2:00</td>
<td>103</td>
<td>44</td>
</tr>
<tr>
<td>2:30</td>
<td>108</td>
<td>44</td>
</tr>
<tr>
<td>3:00</td>
<td>93</td>
<td>43</td>
</tr>
<tr>
<td>3:30</td>
<td>94</td>
<td>44</td>
</tr>
<tr>
<td>4:00</td>
<td>81.5</td>
<td>43</td>
</tr>
<tr>
<td>4:30</td>
<td>77.6</td>
<td>43</td>
</tr>
<tr>
<td>5:00</td>
<td>73.0</td>
<td>41</td>
</tr>
</tbody>
</table>

\( T_a \): Ambient temperature (\( ^\circ \text{C} \)).

\( T_p \): the mean absorber plate temperature (\( ^\circ \text{C} \)).
**Table (4.2): Data sheet (2)**

The following data were subjected to carry out every half hour.

**Date: 14.5.2010**

φ = 15

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Tp (°C)</th>
<th>Ta (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>58</td>
<td>34</td>
</tr>
<tr>
<td>9:30</td>
<td>73</td>
<td>37</td>
</tr>
<tr>
<td>10:00</td>
<td>80</td>
<td>39</td>
</tr>
<tr>
<td>10:30</td>
<td>85</td>
<td>40</td>
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<td>41</td>
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<tr>
<td>11:30</td>
<td>112</td>
<td>42</td>
</tr>
<tr>
<td>12:00</td>
<td>118</td>
<td>44</td>
</tr>
<tr>
<td>12:30</td>
<td>115</td>
<td>43</td>
</tr>
<tr>
<td>1:00</td>
<td>113</td>
<td>42</td>
</tr>
<tr>
<td>1:30</td>
<td>116</td>
<td>44</td>
</tr>
<tr>
<td>2:00</td>
<td>110</td>
<td>42</td>
</tr>
<tr>
<td>2:30</td>
<td>109</td>
<td>43</td>
</tr>
<tr>
<td>3:00</td>
<td>99</td>
<td>44</td>
</tr>
<tr>
<td>3:30</td>
<td>95</td>
<td>43</td>
</tr>
<tr>
<td>4:00</td>
<td>90</td>
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</tr>
<tr>
<td>4:30</td>
<td>80</td>
<td>43</td>
</tr>
<tr>
<td>5:00</td>
<td>76</td>
<td>40</td>
</tr>
</tbody>
</table>

**Ta:** Ambient temperature (°C).

**Tp:** the mean absorber plate temperature (°C).
Table (4.3) : Data sheet (3)

The following data were subjected to carry out every half hour

Date : 15.5.2010

φ = 15

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Tp (°C)</th>
<th>Ta (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>65</td>
<td>36</td>
</tr>
<tr>
<td>9:30</td>
<td>75.5</td>
<td>37</td>
</tr>
<tr>
<td>10:00</td>
<td>79</td>
<td>38</td>
</tr>
<tr>
<td>10:30</td>
<td>86</td>
<td>40</td>
</tr>
<tr>
<td>11:00</td>
<td>98</td>
<td>42</td>
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<tr>
<td>11:30</td>
<td>110</td>
<td>44</td>
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<tr>
<td>12:00</td>
<td>114</td>
<td>44</td>
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<tr>
<td>12:30</td>
<td>117</td>
<td>45</td>
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<td>1:00</td>
<td>115</td>
<td>45</td>
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<tr>
<td>1:30</td>
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<tr>
<td>2:00</td>
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<td>43</td>
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<tr>
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<td>75</td>
<td>39</td>
</tr>
<tr>
<td>4:30</td>
<td>64</td>
<td>30</td>
</tr>
<tr>
<td>5:00</td>
<td>80</td>
<td>38</td>
</tr>
</tbody>
</table>

Table (4.3)

Ta: Ambient temperature(°C).

Tp: the mean absorber plate temperature(°C).
Table (4.4) : Data sheet (4)

The following data were subjected to carry out every half hour

Date : 16.5.2010

φ = 15

<table>
<thead>
<tr>
<th>Time (hr)</th>
<th>Tp (°C)</th>
<th>Ta (°C) Ambient tmp</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:00</td>
<td>60</td>
<td>35</td>
</tr>
<tr>
<td>9:30</td>
<td>73</td>
<td>39</td>
</tr>
<tr>
<td>10:00</td>
<td>83.0</td>
<td>40</td>
</tr>
<tr>
<td>10:30</td>
<td>91</td>
<td>40</td>
</tr>
<tr>
<td>11:00</td>
<td>107</td>
<td>40</td>
</tr>
<tr>
<td>11:30</td>
<td>95</td>
<td>39</td>
</tr>
<tr>
<td>12:00</td>
<td>86</td>
<td>40</td>
</tr>
<tr>
<td>12:30</td>
<td>100.0</td>
<td>41</td>
</tr>
<tr>
<td>1:00</td>
<td>116.0</td>
<td>42</td>
</tr>
<tr>
<td>1:30</td>
<td>121.5</td>
<td>43</td>
</tr>
<tr>
<td>2:00</td>
<td>121.3</td>
<td>43</td>
</tr>
<tr>
<td>2:30</td>
<td>115</td>
<td>43</td>
</tr>
<tr>
<td>3:00</td>
<td>100</td>
<td>43</td>
</tr>
<tr>
<td>3:30</td>
<td>96</td>
<td>44</td>
</tr>
<tr>
<td>4:00</td>
<td>86</td>
<td>44</td>
</tr>
<tr>
<td>4:30</td>
<td>78</td>
<td>43</td>
</tr>
</tbody>
</table>

Ta: Ambient temperature(°C).

Tp: the mean absorber plate temperature(°C).
Table(4.5) : Data sheet (5)

The measured Solar Radiation Data.

16.10.2010

<table>
<thead>
<tr>
<th>Time Hr</th>
<th>$I_{w/m^2}$</th>
<th>$I_{d_{w/m^2}}$</th>
<th>$I_{b_{w/m^2}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:30</td>
<td>760</td>
<td>152</td>
<td>608</td>
</tr>
<tr>
<td>10:00</td>
<td>833</td>
<td>166.6</td>
<td>666</td>
</tr>
<tr>
<td>10:30</td>
<td>855</td>
<td>171</td>
<td>684</td>
</tr>
<tr>
<td>11:00</td>
<td>880</td>
<td>176</td>
<td>704</td>
</tr>
<tr>
<td>11:30</td>
<td>886</td>
<td>177.2</td>
<td>708</td>
</tr>
<tr>
<td>12:00</td>
<td>861</td>
<td>172.2</td>
<td>688</td>
</tr>
<tr>
<td>12:30</td>
<td>881</td>
<td>176.2</td>
<td>704</td>
</tr>
<tr>
<td>1:00</td>
<td>788</td>
<td>157.6</td>
<td>630</td>
</tr>
<tr>
<td>1:30</td>
<td>800</td>
<td>160</td>
<td>640</td>
</tr>
<tr>
<td>2:00</td>
<td>680</td>
<td>136</td>
<td>544</td>
</tr>
<tr>
<td>2:30</td>
<td>540</td>
<td>108</td>
<td>432</td>
</tr>
<tr>
<td>3:00</td>
<td>450</td>
<td>90</td>
<td>360</td>
</tr>
</tbody>
</table>

$I = \text{total radiation}$

$I_d = \text{diffuse radiation}$

$I_b = \text{beam radiation}$. 
4.2 Sample of calculation

Table (4.6) Data sheet (6) thermal performance of the solar oven explain the absorbed heat, lost heat and useful heat.

At solar time: 12:00

Ce = 27, Aa = 1.269841m², 7 η_{opt} = 0.7. Ib = 688w/m²

\[ Q_u = Q_a - Q_l \]
\[ Q_u = A_a S - A_r U_1 (T_r - T_a) \]
\[ Q_a = A_a S \]
\[ = S = Ib Ce \eta_{opt} \]
\[ S = 688 \times 27 \times 0.7 = 13003.2 \text{ w/m}^2 \]
\[ Q_a = 13003.2 \times 1.269841 = 16512 \text{ w} \]
\[ Q_L = A_r U_1 (T_r - T_a) \]
\[ = Ar = 0.063 \text{ m}^2 \]
\[ U_1 = 211 \text{ W/m}^2 \text{.C} \]
\[ T_r = T_p = 86 \text{ C}^\circ \]
\[ T_a = 40 \text{ C}^\circ \]
\[ = 0.063 \times 211 (86 - 40) \]
\[ Q_L = 611 \text{ w} \]
\[ Q_u = Q_a - Q_L \]
\[ = 16512 - 611 = 15901 \text{ w} \]

Maximum absorbed heat = \[ \frac{16992}{0.063} \text{ Maximum degree} = 269.7 \text{ w/m}^2 \]

Maximum heat lost

\[ \frac{1044}{1.269841} \text{ Maximum degree} = 822 \text{ w/m}^2 \]
4.3 Thermal performance of the Solar Oven:

Table (4.6) Data sheet (6)

The following data were collected from experiments which had been done at Wad Medani, 16.5.2010 using the designed solar oven.

<table>
<thead>
<tr>
<th>Time</th>
<th>$T_p({}^\circ\text{C})$</th>
<th>$T_a({}^\circ\text{C})$</th>
<th>$I_b\text{w/m}^2$</th>
<th>$Q_a\text{w}$</th>
<th>$Q_l\text{w}$</th>
<th>$Q_u\text{w}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>9:30</td>
<td>35</td>
<td>73</td>
<td>608</td>
<td>14597</td>
<td>505</td>
</tr>
<tr>
<td>2</td>
<td>10:00</td>
<td>40</td>
<td>83</td>
<td>606</td>
<td>15984</td>
<td>572</td>
</tr>
<tr>
<td>3</td>
<td>10:30</td>
<td>40</td>
<td>91</td>
<td>684</td>
<td>16416</td>
<td>678</td>
</tr>
<tr>
<td>4</td>
<td>11:00</td>
<td>40</td>
<td>107</td>
<td>704</td>
<td>16896</td>
<td>891</td>
</tr>
<tr>
<td>5</td>
<td>11:30</td>
<td>39</td>
<td>95</td>
<td>708</td>
<td>16992</td>
<td>744</td>
</tr>
<tr>
<td>6</td>
<td>12:00</td>
<td>40</td>
<td>86</td>
<td>688</td>
<td>16512</td>
<td>611</td>
</tr>
<tr>
<td>7</td>
<td>12:30</td>
<td>41</td>
<td>100</td>
<td>704</td>
<td>16896</td>
<td>784</td>
</tr>
<tr>
<td>8</td>
<td>1:00</td>
<td>42</td>
<td>116</td>
<td>630</td>
<td>15120</td>
<td>984</td>
</tr>
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<td>9</td>
<td>1:30</td>
<td>43</td>
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<td>630</td>
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<td>121.3</td>
<td>544</td>
<td>13056</td>
<td>1041</td>
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<td>115</td>
<td>432</td>
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<td>957</td>
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<td>12</td>
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<td>43</td>
<td>100</td>
<td>360</td>
<td>8640</td>
<td>758</td>
</tr>
</tbody>
</table>

Table (4.6)

$T_p$ = the absorber plate temperature (${}^\circ\text{C}$).

$T_a$ = Ambient temperature (${}^\circ\text{C}$).

$I_b$ = beam radiation

$Q_a$ = absorbed heat.

$Q_L$ = lost heat.

$Q_u$ = useful heat
4.4 Data Analysis:

From plotted graph the following points can be considered:

Ambient temperature $Ta$ and the absorber plate temperature $Tp$ vs the day time hour fig(4.1) 13.5.2010.

Ambient temperature $Ta$ and the absorber plate temperature $Tp$ vs the day time hour fig(4.2) 14.5.2010.

Ambient temperature $Ta$ and the absorber plate temperature $Tp$ vs the day time hour fig(4.3) 15.5.2010.

Ambient temperature $Ta$ and the absorber plate temperature $Tp$ vs the day time hour fig(4.4) 16.5.2010.

_ From all days above it is clear that $Tp$ increases sharply until it reaches 100$C^o$ at mid days and decreases at sun set.

_ Also it is clear that $Tp$ decreases gradually of any cloud motion under the sun.

$I_b$ vs the day time hour fig (4.5) 16.5.2010.

$Q_a, Q_l$ and $Q_u$ vs the time hour fig (4.6).

_ It is clear that $Q_a$ and $Q_u$ increase together from morning to mid day and decreases in the after noon.

_ $Q_l$ remain with very little changes
Fig. (4.1) Ambient temperature\(\text{(C}^\circ\text{o)}\)\(\text{(Ta)}\) and absorber plate temperature \(\text{(C}^\circ\text{o)}\).

Tp vs the day time hour  13.5.2010.

Fig. (4.2): Ambient temperature\(\text{(C}^\circ\text{o)}\) Ta and absorber plate temperature \(\text{(C}^\circ\text{o)}\).

Tp vs the day time hour  14.5.2010.
Fig. (4.3): Ambient temperature ($^\circ$C) $T_a$ and absorber plate temperature ($^\circ$C) $T_p$ vs the day time hour 15.5.2010.

Fig. (4.4): Ambient temperature ($^\circ$C) $T_a$ and absorber plate temperature ($^\circ$C) $T_p$ vs the day time hour 16.5.2010.
Fig. (4.5): Beam radiation. $I_b$ vs the day time hour 16.5.2010.
Fig. (4.6): Absorbed heat (Qa), lost heat (Ql) and useful heat Qu vs the time hour
4.5 Conclusion:

From data calculation sheets explained before and from the data analysis, the following points can be considered:

1. It is clear that the plate temp. (Tp) increases sharply in the morning and reach above 100°C for more (peak 120°C) for more than (5) hours and then decreases gradually for the rest the day.
2. The ambient temp. (Ta) increases gradually from the morning (about 30°C) up to 45°C.
3. It is clear that when skies are clean the beam radiation increases sharply but decreases in the same manner if any cloud covered the sun.

4.6 Recommendation:

1. The unit can be used for baking foods and other thermal domestic purposes (egg, bread, and burger).
2. Scaling up of the unit can be considered.
3. Selection of economical of construction.
4. Carry the knowledge of renewable energy utilization to community.
References


7. Wikipedia, the free encyclopedia ( www. solar thermal energy time10:00pm Date 6/6/2010 )

8. Wikipedia, the free encyclopedia[www.parabolic trough]-(time10:30pm date 6/6/2010)


11. suliman, A. M.A, Design and Application of asolar solvent extraction unit( Oct. 2004)