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Effect of Innovative Glassy House and Secondary Reflectors Combination with Nanocoating on Fast and Slow Increase of Receiver Temperature in Parabolic Solar Collector

Mohammed Ajmi Abd[1], **Alaa Y. Ali**[2 3]

[1]Northern Technical University, Ministry of Higher Education, College of Health and Medical Techniques.

[2]Electrical Department, Engineering College Alshirqat, Tikrit University, Iraq.

[3]Natural Resources Research Center, Tikrit University, Iraq.

mohammed.aj@ntu.edu.iq, alaa.y.ali@tu.edu.iq, dr.alaayali@gmail.com

Abstract. The purpose of this work is to enhance the ability of the receiver for increasing in temperature absorbing, firstly achieving a rapid rise the temperature in a relatively short time through geometric variables, and secondly, achieving higher temperatures and maintaining them over time for long periods using nano-coatings.The present study related to the development of parabolic dish solar concentrator as a design by using the concept of a glass house with an attempt to invent and manufacture small-sized secondary reflectors to be placed inside the greenhouse which is placed on the side of the receiver at an angle of 45° to reflect the rays that may pass directly without passing through the receiver. The three primary modifications include, copper receiver, a glassy spherical cover, and secondary reflectors. A copper tube is made up of coil in spiral shape and it is fixed in the focus of dish to obtain maximum solar energy. The higher absorber temperature was 58°C with out any modification.The absorber temperature increased with first modification to(87°C,50%), by using second modification (a glassy spherical) it was found that the glass cover improved the rapid and greater temperature rise which increased to (132°C, 137%), Also by using of a glassy spherical cover with secondary reflectors (third modification), the increasing absorber temperature are raised to (162°C ,179%). The temperature of the receiver will be less lost with an increase in wind speed in the second and third modifications.Thirdly, a nanocoating was used for each of (CuO, TiO_2) to determine the extent to which it is possible to achieve an increase in the absorbed temperature for a relatively long time without any modification once which increased to (71°C,22.4% for CuO nanocoating) and decreased to (50C, -60% for TiO_2 nanocoating). Using the third modification with nanocoating and for a relatively long period time, this research found that the temperature increased (175°C,201 % for CuO nanocoating), and (115 C, 98% for TiO_2 nanocoating).This means that the nanocoating of (TiO_2) without an air-tight cover leads to a decrease in the absorption efficiency compared to the absorbing surface alone, but it increases with the use of the third modification, while the coating with (CuO) increases the absorbed temperature in both cases and is more efficient than titanium oxide, the higher temperature difference of the nanocoating is due to higher thermal conductivity of CuO nanoparticles.These results can enhance the improvement of designs used for the same purpose in the future.

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Keywords. Glassy house, Parabolic concentrator, sustainable development, nanocoating, secondary concentrators

I.Introduction

The recent researches are cared about on renewable energy and sustainable development. Solar energy is an important part of this technology..since different types of solar energy are used, the thermal energy is a promising renewable source with high efficiency [1,2]. The performance of the thermal collectors is sensitive to the optical and geometric factors. Numerical and experimental searches of optical (solar parabolic concentrator SPC) parameters that have been done to get the optimum thermal performance [3,4]. Reflecting Mirrors are used to concentrate solar power onto a small area where the solar energy can be converted into heat by concentrators (CSP) technologies. Heat energy can be used for generating electricity [5,6], distillation of water, water heating, etc. There are three important points related to thermal absorber, First, the ability to absorbing of solar radiant heat with minimum heat losses which is the characteristic of a receiver. Second, the optical features and the structural factors related to the absorber. Third, (the conductive and convective) as soon as radiation heat losses from both of receiver and concentrator system. There are many geometries of receivers, such as a spiral coil absorber, modified cavity monotube boiler, conical cavity spiral, cylindrical shape spiral coil, all-glass evacuated tube receiver, etc. [7]. Concentrator in parabolic dish system (PD) is used for collect and focus the Direct Normal Irradiance -DNI onto receiver. In general, there are three factors needs to analyzing the operation of the parabolic dish concentrator- (PDC), These factors are:the reflective materials, dish aperture area size, and the irradiance. The parabolic dish concentrators are consisting of a mirrors that arranged in parabolic shape. Meanwhile, the quality of a mirror is measured by its reflectance. The reflectance is a percentage of incident radiation that can be reflected from surface of the concentrator. Many materials can be employed as the reflective surface. However, aluminum sheets or silver are the diverse common materials used since centuries as a reflective mirror in PD system [8,9].

In this research, the effect of the greenhouse was used to store heat and reduce its loss due to wind problems, as well as the thermal difference of the recipient and the ambient temperature, where it is possible to store solar radiation coming from all directions in addition to the rays reflected from the reflective dish, and the glass house works to reduce heat loss by two methods of convection and conductive. Secondary dishes were also used to reflect the rays coming from the primary reflector and reflect it to the receiver in order to increase the heat absorbed by the receiver and improve its efficiency.

II.Theoretical detail

A.Thermal Performance indexes

The equations of energy balance and Parametric that used for developing of thermal absorber are discussed in this section: Concentration Ratio and Shape of Receiver. It is defined as the of solar radiant rays accumulated by a particular concentrator. There are two differently defined concentration ratios in use as follows:

1.Optical Solar Concentration Ratio

It is defined as the ratio of the incoming radiant energy on the reflective surface (Isur) to radiant energy that reaches the receiver (Irec) [10]:

$CR_{opts} = \frac{I_{sur}}{I_{rec}}$ … … … … 1

Geometric Concentration Ratio (CR)**:** The ratio between the effective concentrator aperture area (A_a) to the effective receiver area (A_{rec}) [11,7]:

$CR = \frac{A_a}{A_{rec}}$……………2

The absorption of solar radiation is depending on various factors such as the size of the concentrator, concentrator direction (angle) and weather conditions. The advantage energy that can be obtained through the concentrator are calculated by following energy balance equation (Pu).

$Pu = \eta_o I_c A_a - U_c (T_c - T_a) A_r$………3

where η_o represent the "optical efficiency", U_c refers to "collector heat-loss conductance", T_c is the temperature of the collector, T_a is ambient air temperature and I_c represent the insulation incident on the collector. Furthermore, "The instantaneous collector efficiency" η_c is given by the equation:

$\eta_c = \eta_o - \frac{U_c(T_c - T_a)}{I_c} \frac{1}{\gamma}$…………………..4

The "instantaneous efficiency" η_{inst} of the solar thermal collector can simplify by neglecting the optical efficiency [12,13]:

$\eta_{inst} = \frac{Q}{A_a I_c} = \frac{a}{I_c}$……………5

Where A_a represents the aperture surface area, the useful heat is depending on specific heat (Cp) at a constant pressure.

2. Optical Energy :

To find the trans heat and optical energy ($Qopt$) of the worker receiver; we are use this equation:

$Qopt = Aa\ ps.m\ .\ \tau g.\ ar.\ S.\ Ia$…………6

$ps.m$: " reflectance of concentrating pieces ."

τg: "Transmittance of a glass which covering the receiver."

Aa: "Aperture of the PD."

S: "receiver shading factor

Ia: "Insulation incident on the PD aperture."

ar: "Absorbance of the of the copper tupe receiver."

S, ar, $ps.m$, and τg are "constants". They are relating with a material that used and depending on the geometric accuracy of the PD system . These constants are nominally agglomerated with a constant term. $nopt$: "The optical efficiency of the concentrator " [14].

III.The experimental work

The using of closed a glass house, secondary reflector:

The glass house assumption was applied in this research due to many considerations. Research in the field of solar energy investments in this regard has used different types of heat receivers, and a glass cover is usually used on the receivers that made of other materials and in different shapes such as cylindrical or square, etc. Our current study dealt with, for the first time, and according to the references that were reviewed, the application of the idea of the glass house, in order to invest the solar radiation from all directions until it enters the glass place, in addition to the larger rays reflected from the parabolic dish. The spherical shape was used to ensure that the rays are not refracted or reflected to the outside, because they will fall vertically. Fig.1, shows the parabolic dish system that used in this research with its different parts.

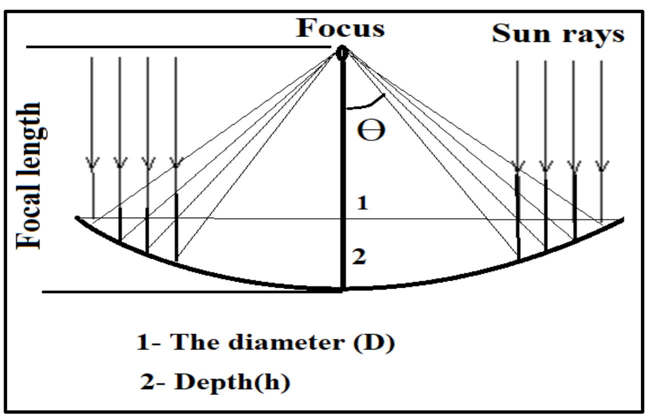
Figure1: Shows the parabolic dish concentrator with its parts: a- secondary parabolic concentrator inside of its,b-parabolic concentrator C-glass cover d- all of parts that used experimentally.

The scope for this study is conversion of solar energy to the heat energy transfer from the concentrator to the absorber in a parabolic dish system (PDS). The parabolic dish (PD) is made from galvanized- steel which covered by a flexible glass sheet mirror with a reflectivity of about (95%), these reflected mirrors are cut in to pieces and shapes and fixed on a concentrator. The geometrical dimensions of the designed (PD) are shown in Table 1.

Table 1:The geometrical dimensions of the designed (PD) .

Diameter of (PD) (d)	**1.12m**
Surface Collection of the parabola	**$0.98m^2$**
Focal distance (f)	**71cm**
Depth of parabola (h)	**11cm**
Rim angle	**43**
f/d	**0.63**

The geometric structure of the parabolic dish system is shown in Fig.2, it is showing the parabolic solar dish.



Figuer2.The parabolic dish concentrator

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V.Receiver fabrication

The experimental receiver (absorber) is made from copper as a tube. Copper is used for making a spiral coil tubular receiver. Thermal conductivity of copper is 385W/mK , so that it is a perfect absorber of heat and can be used for heating applications . It is localized at 66 cm from total focal length (71cm) to study the absorbing temperature of reciever with different conditions. The copper tubing is in the coil shape. The inlet diameter of tube was 15mm, and outlet diameter was18mm, and the total length was 1.5 m. The tube was wrapped as(PD) with a diameter (D) and the focal length (f), depth of the PD -(h).

a coil with a diameter 14cm consisting of (4 windings). Thermocouple with K-type was attached to measure the absorber temperature of coil. To obtain the perfect design of the receiver; the heat losses should be minimized from receiver, and heat transfer by convective and radiant from the receiver to the surrounding medium must be treated due to the difference in temperatures between them. The size of the absorber coil and its direction in (PDS) can affect on the heat losing. The heat loss in the case of the wind parallel to the plane of the opening are higher than to the case of the vertical wind, as found in research [14,15]. The measured readings and experimental factors were taken on 24, 25 February. The first modification was used secondary reflectors with coil. The second modification was a glassy spherical cover with 1.5mm thickness and 30cm radius which are covered the receiver. the principle of the glass house was used in this work, in order to allow the rays to enter also from the sun directly in addition to the rays reflected from the collector. The use of the principle of the glass house will work to compensate for the heat lost by conduction and convection, in addition to preventing the receiver from contacting with the surrounding air. This method will minimize losses by weather conditions (humidity and winds).

The third modification was used two secondary parabolic dish with 10cm diameter and 1.2cm depth inside the spherical glass house.

Table 2 :shows Specifications of second receiver design.

Diameter of (PD) (d)	**12cm**
Surface Collection of the parabola	**113cm^2**
Focal distance (f)	**9cm**
Depth of parabola (h)	**1cm**
f/d	**0.75**

D.Nanocoatings.

In order to study the effect of nanocoating on the absorbance temperature of the surface (copper tube), a black board paint purchased from the market consisting of (talc, acrylic, water, glycol, titanium dioxide, carbon black, opacifiers, silica, and esters in the appropriate proportions) was used. The other step of the work was to investigate how it is possible to achieve rapid temperature increase of the absorbing surface by adding nanomaterials of (nano copper oxide, nano titanium dioxide) to the black paint in the weight ratio (15% for each). The powders (nanoparticles) were purchased from Sigma-Aldrich company, and the particle size were (30-70 nm) for each of them .The nano paint was prepared using an ultrasonic device, a magnetic mixer and the ability to stir liquids of different

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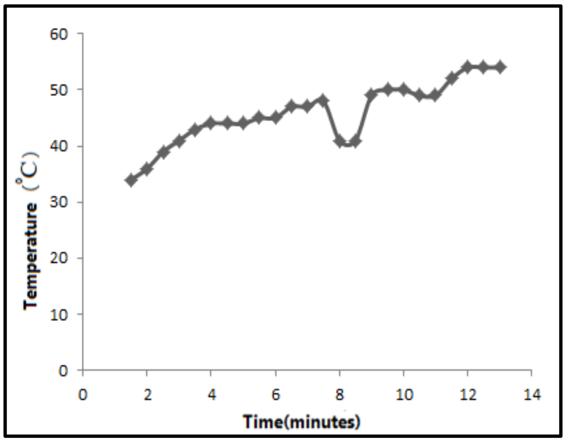
viscosities of the typeIII.in the first step, the nanocoating was tested in atmospheric air for both materials. The second step was tested with the use of internal secondary reflectors and the surrounding glass sphere (with the third condition).

IV.Results and discussion

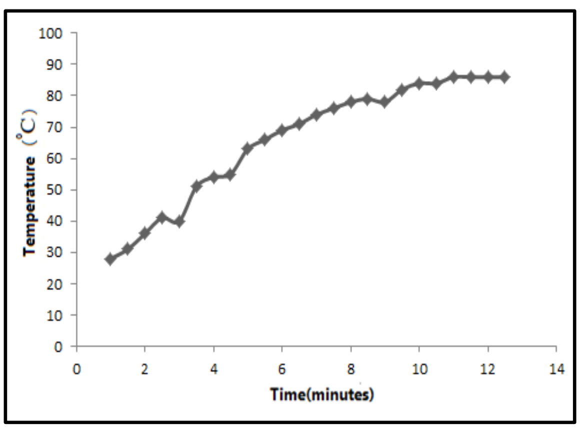
The variation of the receiver temperature as function of time without any modification are shown in Fig.3



Figuer3: Relation between fast temporary temperature increasing with time.

We note from the figure that the increasing of absorbed temperature by the receiver, which suffers changes due to the surrounding conditions (ambient temperature, humidity, wind speed). By using three modifications can be shown in next figures. These experiences are done in five days under comparative climatic conditions with ambient temperature are (24 ,25,23.24,22 $^{\circ}$C) respectively.

A.First modification:It was by using of two secondary reflector that localized in angle of 45° from back side of receiver, Fig. 4, shows the relation between increasing of receiving temperature as a function of time.



Figuer4: Relation between fast temporary temperature increasing with time at first condition.

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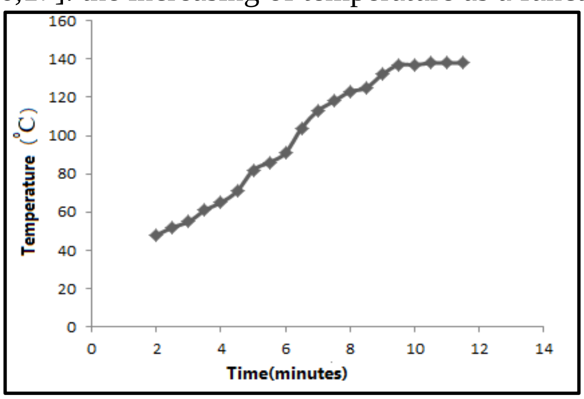
With the use of the second modification in designing the temperature of receiver by using two secondary reflectors, it works to reflect the penetrating rays from the primary reflector towards the inner surface of the coil, In addition to the rays coming directly from solar radiation. The temporary temperature distribution inside the spiral tube is presented. As can be observed in this figure, the mean value of the increasing temperature on the surface of the receiver (is around 87 °C) is high, and very different to the ambient temperature (24°C). The increasing of temperature are decreased with the increasing of wind speed, which will be in direct contact with the receiver, the receiver loses part of the heat absorbed by convection and conduction, and also by radiation according to relation of Stefan-Boltzmann in emissivity [12], so this study goes now towods the second modification of the receiver.

B.Second modification

because wind speeds lead to forced convection heat losses [7], the second modification can result in a glassy spherical surface as a covered, the losses resulting from convection and conduction can be reduced to a minimum by covering with glass. These conclusions are similar to what was stated by research [16,17]. the increasing of temperature as a function of time are shown in Fig.5.



Figuer5: Relation between fast temporary temperature increases with time at second modification .

The receiver covered with white glass is to separate the inside and outside spaces of the cavity and reduce convective losses from the receiver .The mean value of the increasing temperature on the surface of the receiver in side of a spherical a glassy cover (is around 138 °C). It is obvious that the temperature is increasing at this modification. It was found that by covering the receiver the average concentrating thermal efficiency increased,agree with [18].This is due to the reducing of an ambient air and temperature that touching of receiver and reducing the convection heat transfer from absorber tube to environment, agree with [19]. The increasing ratio as a comparison with first modification is (58%).

C.Third modification

The third modification was used a secondary parabolic reflector that placed inside of glass house and the process were done at the point (138 ºC, 15 min). Accordingly, the absorber temperature of receiver increased to 162ºC. Fig. (6) shows the relation between the temperature increasing as a function of time.

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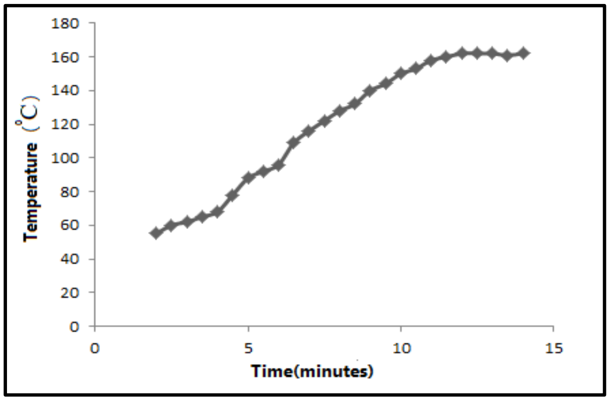

Figure 6: Relation between fast temporary temperature increasing with time at third modification.

The main aim of this modification is to study the use of a secondary parabolic reflector, and to increase concentration ratio [20]. The parabolic secondary dish was used to reflect the sun's rays reflected from the primary dish, as it is placed at a lateral angle of 45° with the axis of the receiver in order not to prevent the passage of rays to the primary parabolic dish, and also to reflect the largest amount of rays to receiver. The increasing ratio as a comparison with first modification were (86%), and (17.4%) with second modification.

The solar radiation was found at hours.This study mentioned the relation between solar radiation and time in (Salah Aldeen-baiji, Iraq) for latitude (35.018) and longitude (43.445) in five days at the end of February 2023. Fig. 7, shows the relation between solar radiation with time.

The solar radiation rises gradually from morning to noon and then decreases, so that the temperature at the focus reaches its maximum value and maintains its stability between 12 o'clock and 1 o'clock in the afternoon, agree with [21]. The solar radiation value reaches its maximum value, which is 740w/m^2 because the sun's intensity is at its peak. This was calculated on the first day of the experiment only, because the readings were close for the rest of the days.

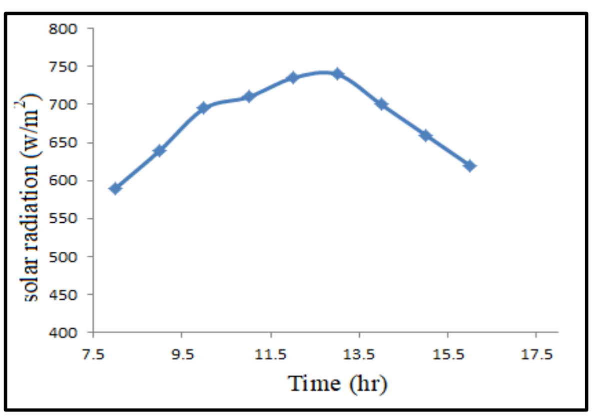

Figure 7: The relation between solar radiation and time.

Ambient temperature suffers a slight variation and the maximum temperature reached at 12 o'clock, while the average total wind speed was 1.32m/s and the maximum value is 2.2m/s. table 3 shows The experimental calculations of the Optical energy with maximum Solar radiation.

a_r	I (w/m^2)	A_a (m^2)	τg	$P_{S.m}$	Q opt.(W)
0.8	740	0.98	1	0.95	551.4

These effects have a significant impact on the heat loss of the system, Fig. 8, shows the relation between receiver temperature at third modification, ambient temperature, solar radiation with local time in hour.

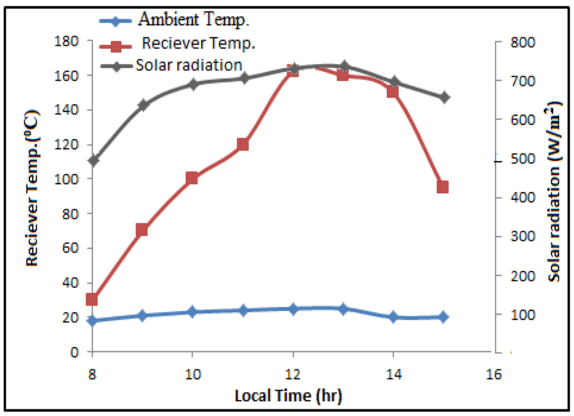

Figure 8: Relation between receiver and ambient temperature, solar radiation with local time in hour at third modification.

Wind speeds effect leads to forced convection and conductive heat losses, agree with [22,15], thus the temperature of receiver will decrease. Wind speed was observed in the range of 0.5-2,2 m/sec, Fig. (9) shows the relation between the receiver temperature and wind speed with the three modifications.

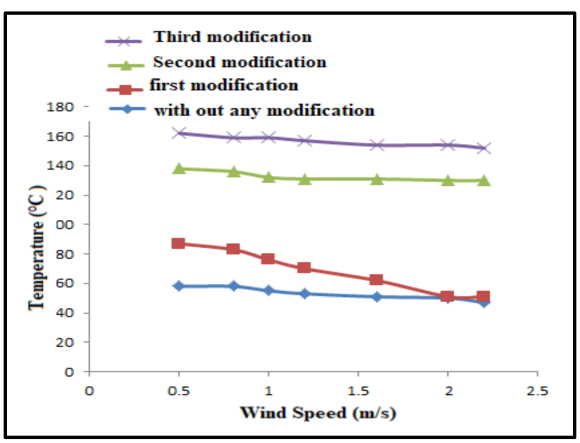

Figure 9: The relation between the receiver temperature and wind speed with the three modifications.

This study notes from Fig. 9, that the temperature of the receiver decreases more rapidly with the increasing of wind speed, due to the fact that the increase of wind speed will increase the heat loss of the receiver, which is in direct contact, agree with the results [22,19]. However, the temperature will be less lost with an increase in wind speed in the second modification.This includes putting the receiver in the glass sphere, and it will also be less lost in the third modification of the receiver.This includes adding secondary reflectors inside the glass sphere.

Table 4 represents the variation of absorbed temperature with the percentage increase at the three modifications.

Type of modification	**The highest absorbed temperature ºC**	**percentage increase baced to no modification (%)**
With out any modifications	58	-----------
First modification	87	50
Second modification	138	137
Third modification	162	179

D.Nanocoating:

The effect of adding nanomaterials as a heat absorbing coating and enhancing the heat absorption process was studied.

The heat transfer improvement of the nanocoating will improve of thermophysical properties such as (T.C thermal conductivity) and coefficient of heat transfer due to the adding of CuO nanoparticles to (paint/absorber surface). [23]. It is also a unique solar absorber with broadband absorption ranging from visible to near-infrared wavelengths with emission suppression at longer wavelengths [24,25].

The heat transfer was increased by adding a small amount of nanoparticles into the paint and mixing them well, which will eventually enhance the heat transfer. On the other hand, the large temperature difference of CuO coating compared with TiO_2 coating is due to the higher thermal conductivity of CuO nanoparticles [23,26].

Titanium dioxide has a high refractive index, and research found that using smaller particle size showed high near-infrared reflectivity, due to the area-to-volume ratio as well as the boundaries [27,28]. Figures 10 and 11 show the effect of nanocoating without and with the third modification, respectively.

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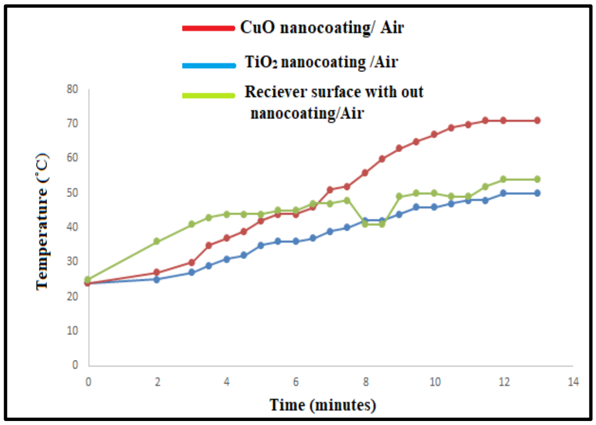

Figure 10: Comparison between the rapid increase in temperature of the receiving surface and time without any modification when using the nanocoating on the surface .

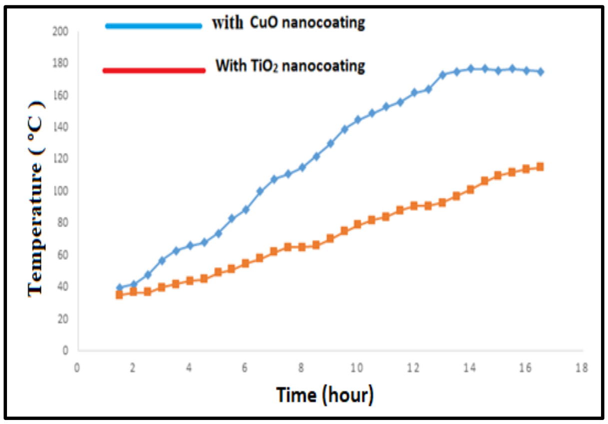

Figure11: Relationship between receiver temperature and time in hours when using nanocoating with third modification

Table 5 represent the variation of absorbed temperature with the percentage increase at nanocoatings.

Type of modification	**The highest absorbed temperature °C**	percentage increase with out any modification (58 **°C**)%
CuO nanocoating/ to Air	71	22.4
CuO nanocoating/Thir	175	201
TiO_2 nanocoating/to	50	-60
TiO_2 nanocoating/Third modification	115	98.2

VII.Conclusions

The experiments were carried out for three modifications along with nano coatings to study the performance of solar dish concentrator. These results are important for being advantageous in the future when designing similar concentrated systems. The designs were based on a parapolice dish concentrator and receiver that covered by a glassy house with secondary reflectors. To enhancing of temperature increasing of receiver and reducing the heat loss by conduction and convective, the modification by a glass cover and secondary reflector were used.The effect of wind speed on absorbed temperature was of a very small value with a glassy house or cover as a comparison with no a glass cover. Finally, the advantage that will be get according to this research are:

1 - Trapping the heat inside as much as possible, and reducing the heat loos by conductive, convective and radiation.

2- It achieves a rapid and temporary rise in the temperature of the receiver in a short time

3 - Reducing the effect weather conditions such as : (wind and humidity).

4-Adding copper oxide to the paint had been proven effective in absorbing heat when exposed to air and even more effective when used in a greenhouse, unlike titanium oxide, which is, when added to the paint results in negative results in absorbing heat.

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