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# Developments in Parabolic Solar Dish Concentrator for Enhanced System Efficiency of Steam Generation

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## Abstract

In this paper, design and fabrication of the parabolic solar dish concentrator for the steam generation have been carried out. The experimental setup consists of the parabolic dish of solar concentrator system is fabricated with highly reflective mirror. The concentrated heat is absorbed by a copper tube which is made up of coil in a curved shape and it is fixed on solar trace path to obtain maximum solar energy. The black coating over the receiver surface to reduce the various losses it is located in the focal point on the solar ray's concentration and its core application in steam granulation coil receiver, heat transfer fluid as water and it is going through the system. The present study concerning the development and design of the parabolic dish solar concentrator indicates a diameter of 2.4 meters to obtain a concentration ratio of 91.16×. The outdoor experimental of a parabolic dish concentrator has been tested. The performance of parabolic dish concentrator studied for different experimental conditions. The outdoor experimental has also been carried out to estimate outlet temperature. The maximum temperature of 635 °C has been recorded, when the flow rate is 0.4 kg / min.

**Keywords:** *Solar Concentrator, Outdoor Testing, Coil Receiver, Dish Solar Concentrator.*

## 1. Introduction

Recent researches are concentrating on renewable energy technology; solar energy is a significant part of this technology. Where variety types of solar energy are used, thermal energy is a promising source with high efficiency. However, available heat flux per $m^2$ is not enough for large projects, which lead to concentrating sun rays on a small area. The concentration of the sun rays is not a new technology. Ali [1-4] describes non-imaging optics as an area dedicated to designing of optical concentrators, where, instead of the using imaging systems, light collecting systems are utilized. O'Gallagher [5] confirms this fact, by "non-imaging optics is a new approach to the collection, concentration, and transport of light developed by physicists from the University of Chicago over the past 35 years."

A concentrator, as described by Winston, Miñano and Benítez [6] is, therefore, used to amplify the power density to be absorbed to extremely high levels so as to be able to provide sufficient energy for large-scale uses or generation of electric or motive power. The notion of a Hyperboloid concentrator originated in geometric optics and was later adopted in solar thermal energy. Winston, Miñano and Benítez [6] inform that whether the use of geometrical optics is for image forming purposes or not, it has been the main instrument used in the design nearly all optical systems. Lovegrove, Luzzi et al demonstrated the solar driven closed-loop thermos chemical energy storage system using ammonia of 20 m2 dish solar concentrator [7]. They have shown that the ammonia dissociation receiver/reactors are well suited for high-quality superheated steam production. Based on catalyst material, cavity receiver of 20 reactor tubes filled with iron based catalyst material was used in the system. They investigated the maximizing potential for electrical power production from ammonia synthesis reactor. Mills presented the various solar thermo-electric technologies [8]. Kennedy provided the extensive status of the material for solar reflectors [9]. The development, performance and durability of the solar reflectors have been discussed. The glass with silvered polymer and front-surface mirrors has shown an excellent candidate for solar reflectors. Klaib and Palavras and Bakos dealt with the development and performance characteristics of a low-cost dish solar concentrator and its application in zeolite desorption [10, 11] Hassib discussed the geometric analysis of the compound conical concentrator with receivers of various geometries [12]. The shape of the receiver determines the profile the reflector. It was also shown that the resulting flux distribution determines the shape of the receiver and its position relative to the reflector. El-Refaie described the conical solar energy concentrator with tubular axial absorber [13].

The current study presents the design and experimental analysis of a parabolic solar dish concentrator and coil receiver for the steam generation have been designed, fabricated and the outdoor performance test was also carried out for dish solar concentrator system of 91.16 × concentration ratios. The tests were carried out at SIRTE, LIBYA to obtain the maximum outlet temperature and daily performance of the dish solar concentrator system. In the daily performance test, the maximum fluid temperature of 635°C was observed.

## 2. Design of the Solar Parabolic Dish Concentrator

### *2.1. Concentrator*

The equation for the parabolic dish in profile coordinates (x , y) is:

$$Y = \frac{x^2}{4f} \tag{1}$$

where f is the focal length of the parabolic solar concentrator. Figure 1 shows the diameter of the parabolic solar dish surface (D) and the focal length of the parabolic concentrator (f). The schematic diagram of geometrical parameters of solar dish concentrator system is shown in Figure 1.

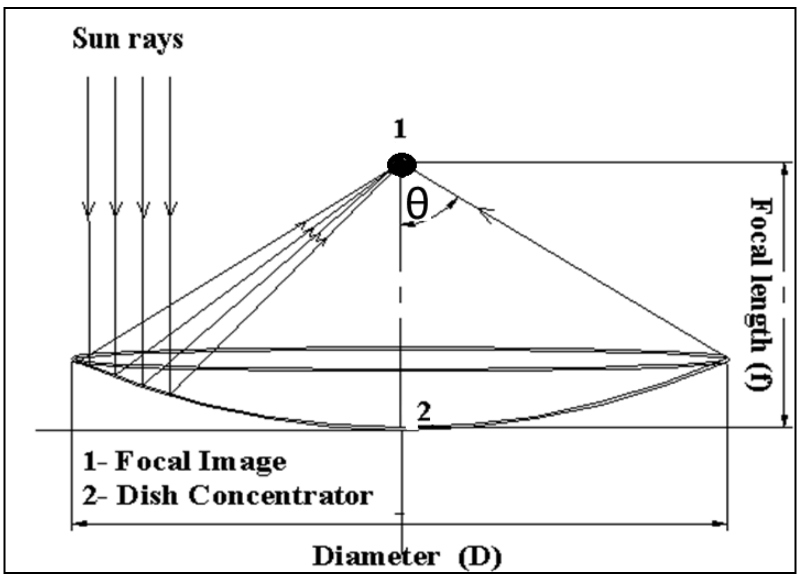


**Figure 1.** Schematic diagram of geometrical parameters of solar dish concentrator system

The aperture area of this parabola dish solar concentrator is given by equation (2) where receiver area given by equation (3)

$$Ap = \pi r_p^2 \tag{2}$$

$$Ar = \pi r_r^2 \tag{3}$$

where $Ap$ is the aperture area of dish solar concentrator and $Ar$ is the area of receiver.

The Geometric Concentrating Ratio is given by the Equation

$$CRg = \frac{Ap - Ar}{Ar} \qquad (4)$$

The focal length of the parabolic concentrator dish is

$$f = \sqrt{\frac{Ap \times (1 + \cos\emptyset)}{4 \times \pi \times (\sin\emptyset)}} \qquad (5)$$

### 2.2. Receiver

The receiver design is an integral part of any collector, the light concentrated by the dish solar concentrator must focus at the receiver were it will be absorbed as heat and transferred to the working fluid. The efficiency of the concentrating system is defined at the ratio between the useful energy delivered to the working fluid, Qu, to the energy incident on the concentrator's aperture, Qs;

$$\eta_c = \frac{Q_u}{Q_s} \qquad (6)$$

The efficiency of the system is largely determined by the amount of heat lost from the receiver to surrounding environment. This heat loss occurs through conduction, $Q_{lk}$, convection, $Q_{lc}$ and radiation, $Q_{lr}$. The total heat loss from the receiver is given by;

$$Q_l = Q_{lk} + Q_{lc} + Q_{lr} \qquad (7)$$

The receiver should be designed in order to reduce the heat loss; the design must take into account the shape of the receiver.

## 3. Optical Analysis of Parabolic Dish Concentrator

Based on ray trace technique, the parabolic dish geometry has been drawing using CAD software Solid Edge and Solid Works. The internal surface material was a mirror which reflectivity was 0.94. The solar radiation source has been made by Optics works, a ray tracing software, was used in order to determine the optimum dish and receiver dimensions for maximum optical efficiency, (Optics works Ltd, 2010). Defining a light source and reflective properties of the material shows angles at which light is reflected; from this the optical efficiency of the dish can be determined. A snapshot of the parabolic dish and receiver with the optical rays, can be seen in Figure 2.

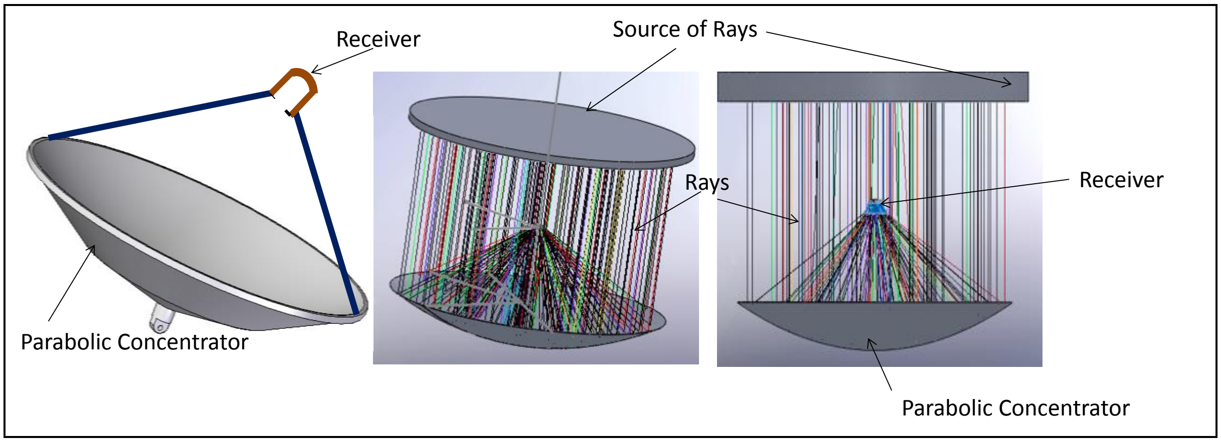


**Figure 2.** The ray tracing of Parabolic dish at (θ is 0º) incidence angle.

By placing a detector along the underside of the receiver, optics works can graphical demonstrate the distribution of light incident across its surface. This flux distribution, as seen in Figure 3, is highly concentrated at the centre of the receiver.

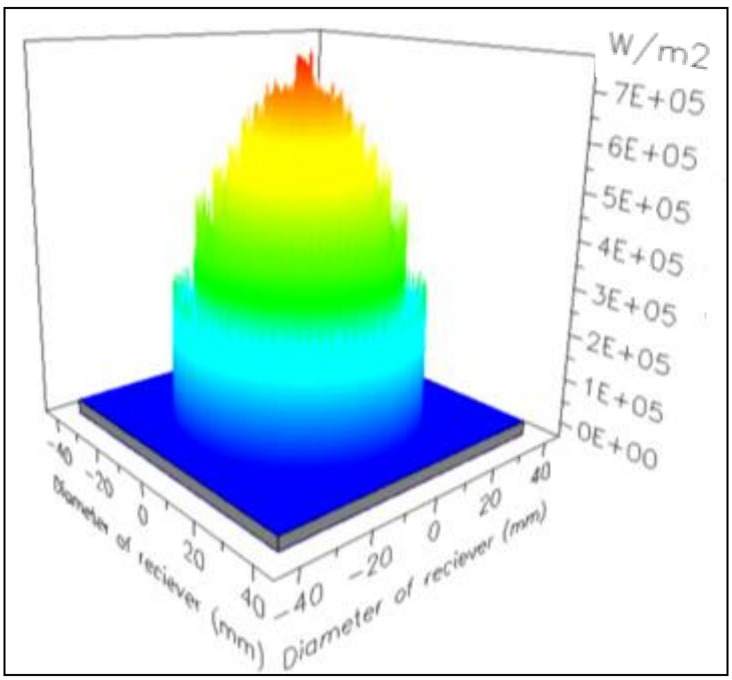


**Figure 3.** Flux distribution across the receiver of the 3-D parabolic dish

The detector is also use to determine the total amount of light incident on the receiver. A similar detector is then placed across the surface of the parabolic dish. The ratio between the total amount of light that is incident on the parabolic dish and the total amount of light that is concentrated on the receiver, gives the optical efficiency. The optimum receiver area for a 0.049063 $m^2$ dish is 4.524 $m^2$.

## 4. Fabrication of Parabolic Dish Solar Concentrator

The parabolic dish solar concentrator was constructed out of fiberglass, a concentration ratio of 91.16 $\times$ is large enough to give the required receiver temperature and assure that the irradiance of input radiation is large in comparison with thermal radiation out of the receiver. The entire concentrator system was limited in size by the parabolic dish solar concentrator. The largest diameter dish is 2.4 m. A focal length of 0.85 m was chosen to give the solar concentrator dish a rim angle of 39°. It was important to fabricate the solar concentrator system by hand using small sections of mirror were made and fitted together to form a continuous solar concentrator dish shape, The fabrication of the parabolic dish solar concentrator is carried out at Sirte University. The process of fabrication of the parabolic dish solar concentrator and the finished solar concentrator dish is shown in Figure 4. The geometrical specifications of solar parabolic dish concentrator are shown in Table 1.

**Table 1.** Geometrical specifications of solar parabolic dish concentrator

| Input Data | | |
|---|---|---|
| **Parameter** | **Value** | **Unit** |
| Reflectivity of the dish | 0.90 | - |
| R | 1.2 | m |
| Depth of the parabolic dish | 1.135 | m |
| Reflect surface | Mirror | - |
| Frame of the dish solar concentrator | Fiberglass | - |
| **Calculations** | | |
| Aperture area of the dish (Ap) | 4.524 | $m^2$ |
| R | 0.125 | m |
| Ar | 0.049063 | $m^2$ |
| Diameter of the dish (D) | 2.4 | m |
| Focal length of the dish (F) | 0.85 | m |
| Ratio (Focal length/Diameter of the dish) | 0.3541 | - |
| Rim angle of the dish (Φ) | 39.406 | ° |
| Geometric Concentration ratio (CR) | 91.16 | - |
| Number of Mirror | 2052 | - |

**Figure 4.** Fabrication process of the parabolic dish solar concentrator

## 5. Receiver Fabrication

The receiver is fabricated by bending and welding process, and formed a coil flat portion to capture the maximum incident solar radiation. The copper tubing of the apparatus consists of copper coils and the copper tubing of 8 mm copper pipe, which was carried water from main through a warm water bath. Thermocouple was attached to measure the inlet temperature, outlet temperature. The inlet diameter of the copper tube was 0.006 m and outlet diameter was 0.008 m total length was 5 m. The hardened copper tube with length of 5 m is connected with the small blocks by brazing process and this set up makes the counter flow arrangement to enhance more heat transfer. The receiver is fully coated by black paint with a high temperature resistant. The purpose of high absorptive and low reflective black paint was used to coat the receiver surface this paint is to absorb more radiation as shown in Figure 4a. The material of the receiver box is mild steel material. The receiver box is fabricated by bending and welding process as shown in Figure 4b. The entire receiver assembly is placed within a chamber and covered with glass wool insulation with thermal conductivity 0.037 W/mK to minimize losses as shown in Figure 4b. The measured reflective coefficient for the receiver with and without black paint is shown in Figure 5. It can be observed that the reflectivity of the black coated receiver is very low in the range of about 6% with maximum of 10%, while the reflectivity of the uncoated receiver increases sharply from about 15% at the wavelength of 250 nm to a maximum of 86% at the wavelength of 850 nm and remain constant. The receiver design specification has shown Table 2.

**Table 2.** Specifications of receiver design

| Parameter | Value | Unit |
|---|---|---|
| Length | 5 | m |
| Width of Receiver | 0.25 | m |
| $\pi$ | 3.14 | - |
| Aperture area of Receiver | | $m^2$ |
| Receiver Tube O.D. (Outlet Diameter) | 0.008 | m |
| Receiver Tube I.D. (Inlet Diameter) | 0.006 | m |
| Receiver surface | Copper | - |
| Receiver frame | Mild steel material | - |
| Insulation | Polyurethane foam | $m^2$ |
| Insulation K-factor | 0.0024 | W/m $^oC$ |
| Absorber | Black Coating | |

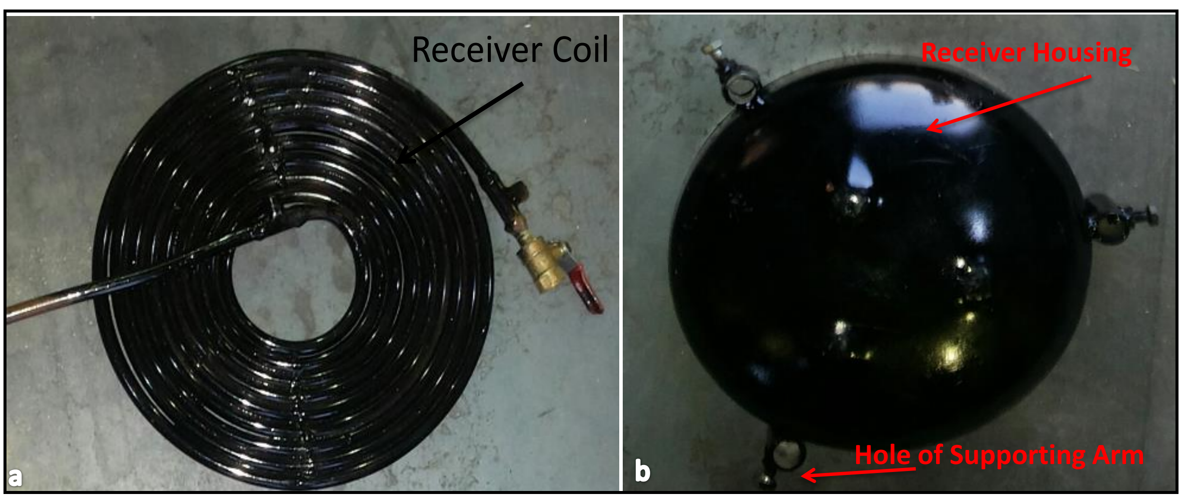


**Figure 4.** (a) Coil receiver with coated by black paint;
(b) chamber and covered with glass wool insulation

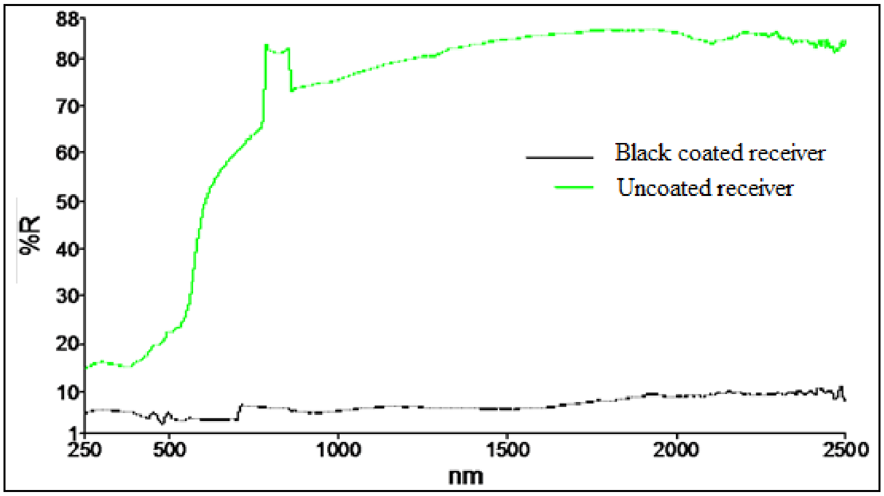


**Figure 5.** Measured reflective coefficient for coated and uncoated receiver [3]

## 6. Experimental Set-up and Parameters Measurements

### *6.1. Outdoor Experimental Set-up of Parabolic Dish Solar Concentrator*

This experimental work mainly studies the solar transformation energy into thermal energy by using a follower solar parabolic dish concentrator with using a manual tracking of the sun. In order to investigate the parabolic dish solar concentrator performance, an experimental unit has been designed, built and tested in Meteorological station. This station is located at Sirte University where Longitude is 16° 35´ 42´´E and Latitude is 31° 3´ 49´´N.

The experiment has been carried out on a parabolic dish concentrator of 4.524 $m^2$ and a copper receiver of 0.049063 $m^2$. The system efficiency depends on the heat input, which depends on the temperatures of the water at the inlet and outlet of the heat exchanger and the mass flow rate. The experimental cycle consists of the parabolic dish solar concentrator with copper coil receiver; one end of the receiver is connected to inlet tank and other end to the outlet of the tank. The Schematic of the outdoor open cycle of the dish solar concentrator experimental setup is shown in Figure 6. The inlet and outlet temperatures of water are measured. The flow rate of 0.4 kg/min is allowed to flow through the receiver.

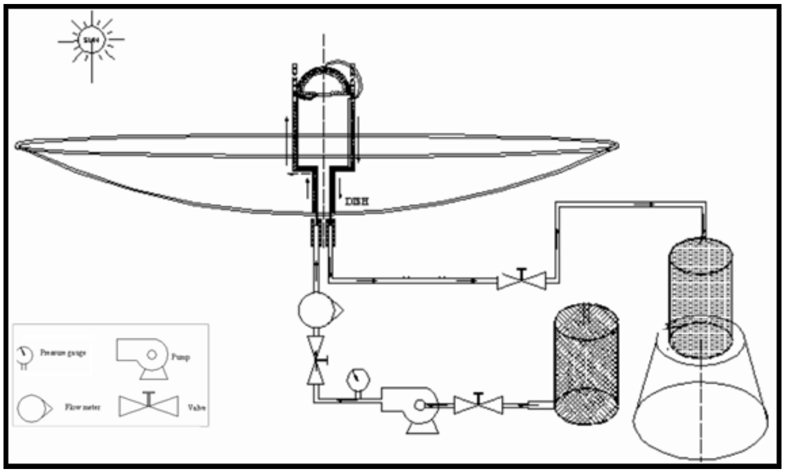


**Figure 6.** The Schematic of the outdoor open cycle of the dish solar concentrator experimental setup

The variation of inlet and outlet temperatures with time is shown in figure 6. The maximum outlet temperature of 610 °C is recorded for the solar radiation of 850 W/m$^2$. In the flow conditions, water is allowed to flow through the receiver and heated depends on the solar concentration level. The receiver is placed on the top of the solar concentrator and radiation from the solar radiation reached the receiver through reflections in the concentrator and finally absorbed by the receiver. However, the outlet temperature of the solar concentrator system is examined whether the outlet temperatures would be useful for a seawater desalination process. The dish solar concentrator is designed and constructed for experimental testing as shown in Figure 7. The working fluid flows from the inlet tank to the coil receivers and the hot water is collected in the collection tank. Each tank has capacity of 10 litters.

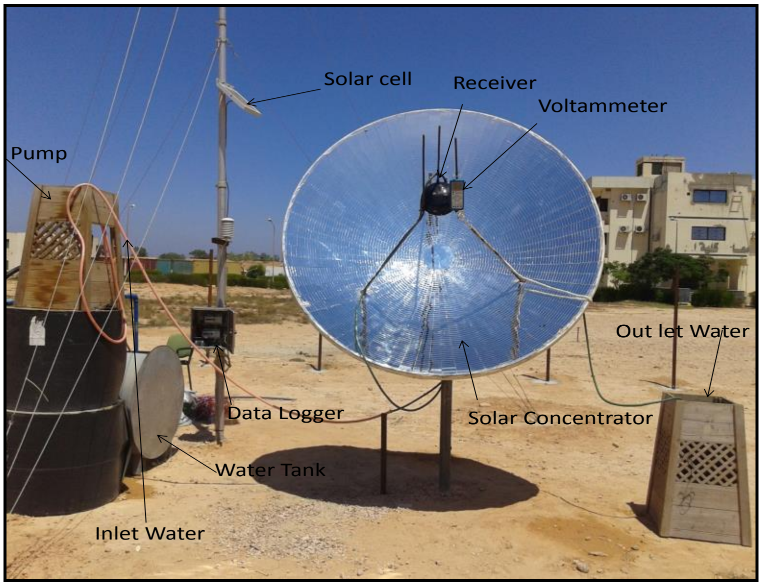


**Figure 7.** Experimental dish solar concentrator apparatus located at Sirte University-Libya

### *6.2. Parameters Measurements and Data Gathering*

In this work, difference measuring techniques is implemented. The temperature measurements of the collector system and ambient temperature have been obtained using type-k thermocouples. The wind speed and direction are detected using an in-situ anemometer as shown Figure 8. The global solar radiation flux on the parabolic dish solar concentrator and the solar flux on the horizontal plane are both measured using precision pyrometer sensors. Water mass flow measurement is performed using a conventional glass tube Rotameter. All measurements, including inlet temperature, outlet temperatures, and surface temperatures of the receivers, inlet and collection tank temperatures, and solar radiation data have been recorded using a data acquisition system and then all data is off-line analyzed. The various temperatures such as surface temperature of the receivers, inlet and outlet temperature of the receivers, inlet and collection tank temperatures are measured using K-type thermocouples, these whole measurements are shown on Figure 8.

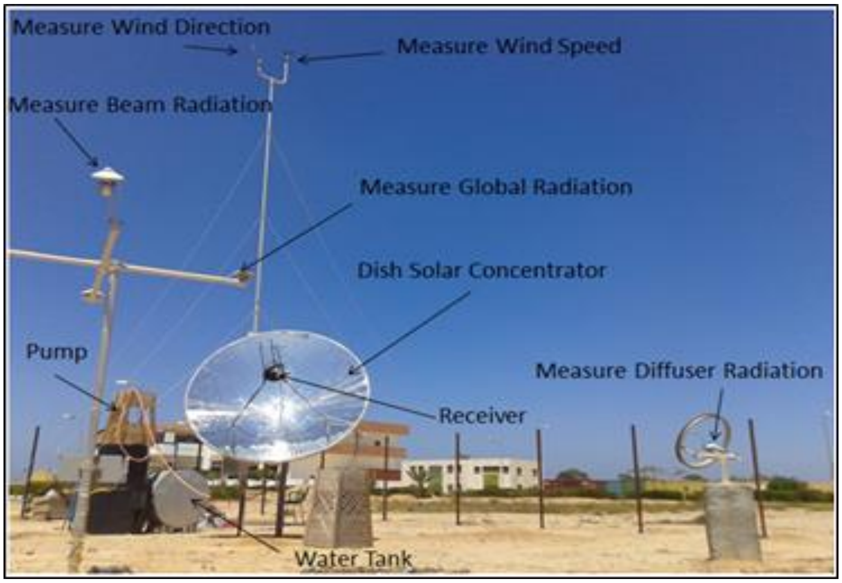


**Figure 8.** The solar radiation and wind speed measurements for dish collector (Meteorological station)

Figure 8 illustrates the test procedure which includes the measurements of climatic parameters such as global solar irradiance on the climatic system (solar radiation system), ambient temperature, wind direction and speed. Operational parameters such as initial inlet water temperature, outlet water temperature, and flow rate are continually observed. These parameters allow evaluating increase or decrease of water temperature and the available energy transferred to the water during the operation period.

## 7. 7. Results and Discussion

Experimental thermal performance analysis was carried out for flow rate of 0.4 kg/min. The working fluid enters from inlet tank to the first flow meter and passes to the receiver and goes to outlet tank. Figure 9 shows the outlet temperatures of the system on 13$^{th}$ of August 2014 for the flow rate is 0.4 kg/min. The temperatures increased when the hour angle increases up to 12:30 pm and then start to decrease. The maximum temperature recorded was approximately 610 °C and occurred between 12:00 to 13:30 hrs, when the average solar radiation was 871 W/m$^2$. When wind speed was 3 m/s, humidity was 65 % and ambient temperature was 26 °C. Figure 10 (a,b) represents wind speed and wind direction variation measured by the meteorological station during the period from 9:20 am  to 18 pm, the wind speed increase with time from morning to evening. The maximum hourly 17:30 reaching 4.5 m/s and minimum hourly 9:30 was 0.5 m/s. Based on the data from the Meteorological station in Sirte (Sirte University). Figure 11 shows the Photograph of the Voltammeter indicate to the temperature recorder was 610 °C.

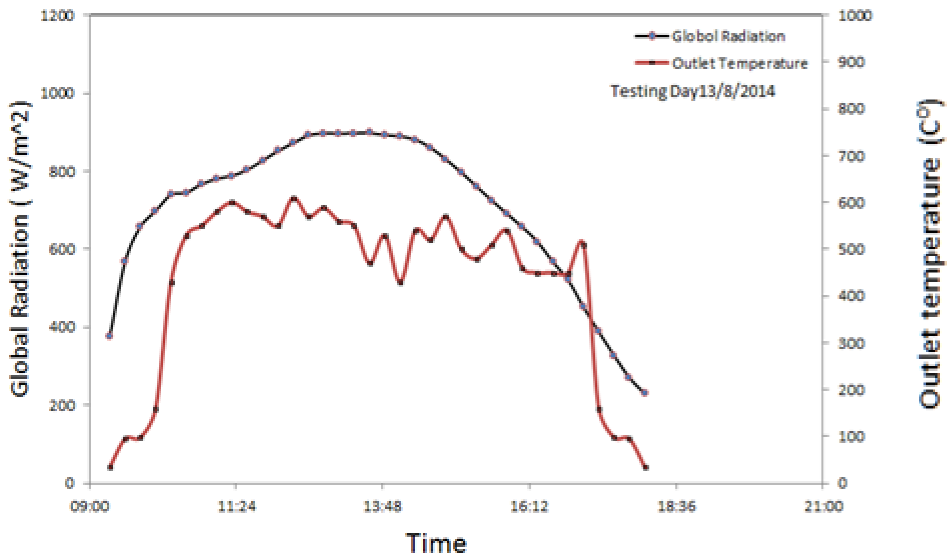


**Figure 9.** Diurnal variation of global radiation and outlet temperature with time when flow rate was 0.4 kg /min on 13$^{th}$ August 2014

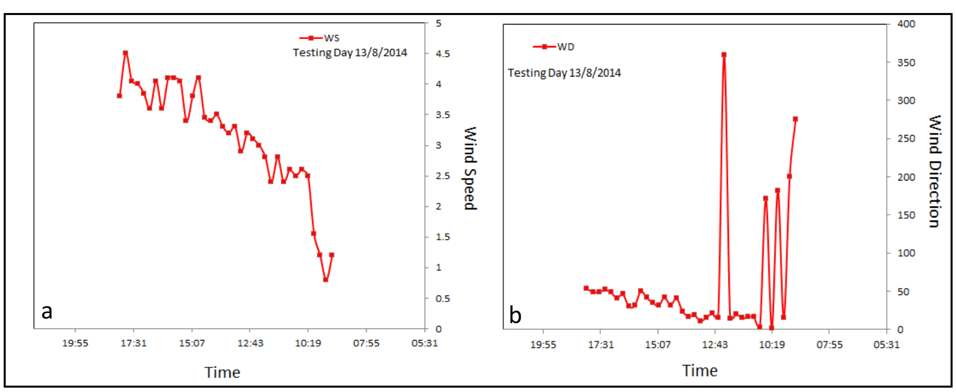


**Figure 10.** Diurnal variation of (a) wind speed and
(b) wind direction with time on 13$^{th}$ August 2014

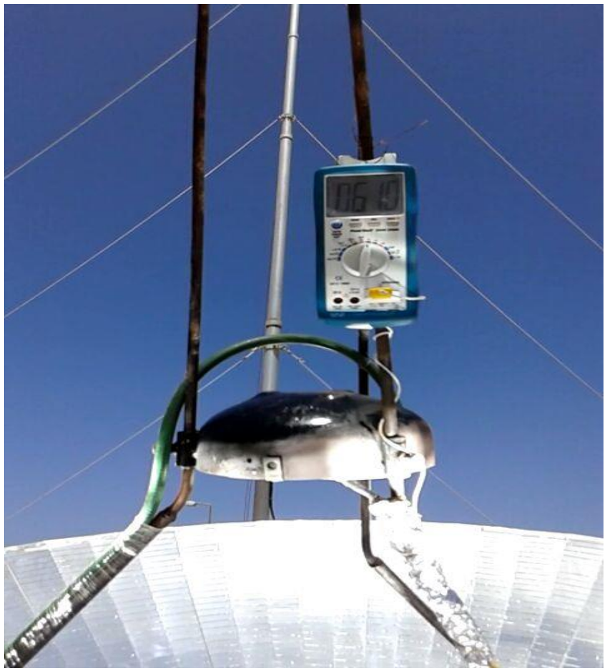

**Figure 11.** Photograph of the Voltammeter indicates to the temperature recorder.

Figure 12 shows the outlet temperature when the flow rate was 0.4 kg/min, the experiment was carried out from 9:30 to 17:30 hrs on 16th August 2014. Again the temperatures increased when the hour angle increased up to 13:00 hrs and decreased thereafter. The maximum temperature recorded was 635 °C; this was recorded between 11:00 to 13:00 hrs when the average solar radiation was 857 W/m$^2$. Where wind speed was 3.6 m/s, humidity was 59.6% and ambient temperature was 26 °C.

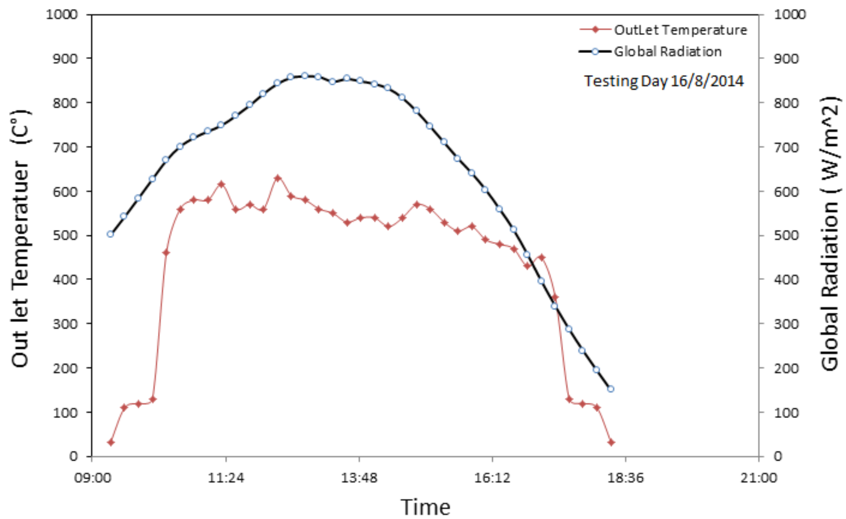


**Figure 12.** Diurnal variation of Global radiation and outlet temperature with time when flow rate was 0.4 kg/min on 16th August 2014

## 4. Conclusion

In this design, parabolic dish solar concentrator and coil absorber is placed at the foci point of the concentrator has been carried out. This design of imaging profile increases the solar concentration to produce high temperature with high optical efficiency and less heat losses in the absorber. This paper mainly presents an insight into the design, fabrication and outdoor testing of parabolic dish solar concentrator for high temperature applications.

The parabolic dish solar concentrator was fabricated in Sirte - Libya, at Sirte University. This parabolic dish solar concentrator was used for the outdoor testing in Sirte. The experiments were carried out for different conditions to study the performance of solar dish concentrator. The system efficiency depends on the heat input; temperatures of the water at the inlet and outlet of the receiver and the mass flow rate have been carried out. The maximum temperature of 635°C was reached when flow rate is 0.4 kg/min.


### Acknowledgment

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