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## **Design and development of solar concentrator for Thermal applications**

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## **ABSTRACT**

Parabolic mirror surfaces are found wherever energy needs to be focused effectively and accurately. They are found built into car headlights, spotlights as well as astronomical telescopes. This research concerns the study of transformation of solar energy into thermal energy and focusing this energy at a point to heat water.

In this document the parabola was explored to design a simple, cheap and effective solar water heater. Local communities in Namibia can produce similar water heaters using available materials and the fuel; sunlight is abundant throughout the year in most areas.

The main part of the heater, the collector can have any shiny material as long as it refracts the sun's rays. In this project a parabolic solar concentrator was designed and constructed to heat water at the focal point, which is then stored in a tank for use.

## NOMENCLATURE

|                     |                               |
|---------------------|-------------------------------|
| $f_{\text{foc}}$    | Focal length                  |
| $F$                 | Focus point                   |
| $\psi$              | Angle of reflection           |
| $\rho_{\text{ang}}$ | Angle of incidence            |
| $h$                 | Parabola height               |
| $A_{\text{pd}}$     | Paraboloid surface area       |
| $A_{\text{ap}}$     | Aperture area                 |
| $\psi_{\text{rim}}$ | Rim angle                     |
| $d$                 | Aperture diameter             |
| $D$                 | Pipe diameter                 |
| $I_b$               | Beam normal insolation        |
| $\Phi$              | Total radiant flux            |
| $C_o$               | Optical concentration ratio   |
| $C_g$               | Geometric concentration ratio |
| $T$                 | Temperature of boiling water  |
| $T_o$               | Ambient temperature           |
| $Re$                | Reynolds number               |
| $\rho$              | Density of water              |
| $\dot{Q}$           | Heat energy                   |
| $A_\gamma$          | Absorber surface area         |
| $\nu$               | Kinematics viscosity          |
| $K$                 | Loss coefficient              |
| $V$                 | Fluid velocity                |

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## **1. INTRODUCTION**

### **1.1 Solar Heating**

In recent years, the general public has become aware that fossil and even nuclear energy sources are of limited availability. Consequently interest in the use of solar energy and other renewable sources has increased rapidly. The sun does not present the solution to all our energy problems but can, however, make a significant contribution to easing the world energy situation without creating additional environmental problems

The use of solar energy is centered at present on photovoltaic and thermal solar energy conversion systems. In the first-named, solar energy is converted into electricity directly by a photoelectric cell. The obtainable outputs are, however still limited. Higher outputs can be achieved by solar thermal conversion. In this process solar energy is received and transferred by a collector system to a working fluid.

The heated fluid is capable of supplying process heat or of doing work in a heat engine. In the low temperature range up to 100°C the plane collector is used (for heating water, for example). For temperatures above 100°C, the low radiation intensity makes it necessary for the collector to be designed as a concentrating element. In this case the sun's rays incident are first focused on a smaller surface.

This increases the energy flux and hence the temperature to which the working fluid can be heated. In the field of use of solar energy in plants, which collect this energy with concentrating collector systems and use it for water heating, the systems available for this application are, parabolic troughs, solar towers and parabolic solar dishes.

The primary objective of this project is to create a unit that concentrates the sun's energy using a reflective parabolic dish and an absorber to store and heat water at high temperature for domestic use.

### **1.2 Objectives**

This project involved the design and construction of a solar parabolic dish for domestic water heating. The following requirements were formulated for the design of the dish.

- The water is heated directly in the absorber and then transferred to a storage tank.
- The system has no sun tracking system it operates manually
- The dish is a kit that is easily assembled and does not need special installation
- The water heater is portable and is used on the ground
- The absorber is not fixed on the stand
- The heater has a capacity of 2liters of water
- The system has no pump
- Efficiency of the system is between 70-80%

## **2. LITERATURE REVIEW**

### **2.1 Solar Water Heating Systems**

Solar water heating systems (SWHS) can be either active or passive. An active system uses an electric pump to circulate the fluid through the collector; a passive system has no pump and relies on thermo-siphoning to circulate water. The amount of hot water a solar water heater produces depends on the type and size of the system, the amount of sun available at the site, installation angle and orientation.

SWHS are also characterized as open loop (also called "direct") or closed loop (also called "indirect"). An open-loop system circulates household (potable) water through the collector. A closed-loop system uses a heat-transfer fluid (water or diluted antifreeze) to collect heat and a heat exchanger to transfer the heat to the household water. A disadvantage of closed looped system is that efficiency is lost during the heat exchange process [7].

#### **2.1.1 Active Systems**

Active systems use electric pumps, valves, and controllers to circulate water or other heat-transfer fluids through the collectors. They are usually more expensive than passive systems but generally more efficient. Active systems are often easier to retrofit than passive systems because their storage tanks do not need to be installed above or close to the collectors. If installed using a PV panel to operate the pump, an active system can operate even during a power outage [9].

#### **2.1.2 Passive Systems**

Passive systems move household water or a heat-transfer fluid through the system without pumps. Passive systems have the advantage that electricity outage and electric pump breakdown are not issues. This makes passive systems generally more reliable, easier to maintain, and possibly longer lasting than active systems. Passive systems are often less expensive than active systems, but are also generally less efficient due to slower water flow rates through the system [7]

#### **2.1.2 Direct Systems**

These systems heat potable water directly in the collector.

#### **2.1.3 Indirect System**

The system heats propylene glycol or other heat transfer fluid in the collector and transfers heat to potable water via a heat exchanger. The disadvantage of this system is that efficiency is lost during the heat exchange process.

### **2.2 Thermal Solar Collectors**

There are basically three types of thermal solar collectors, flat plate, evacuated tube and concentrating.

#### **2.2.1 Flat Plate Solar Collectors**

The most basic and most common type of solar collector is the flat plate solar collector. At the heart of this collector you will find a sheet of thermally conductive dark material (usually metal) that absorbs as much sunlight as possible. Directly below this sheet a series of water conduits is found; the heat collected by the absorber is absorbed into the water and subsequently carried away by water flow. The collector is housed in an insulating box, with a glass plate on top to further insulate and heat the system [7].

### 2.2.2 Evacuated Tube Solar Collectors

Evacuated tube collectors consist of a parallel row of evacuated glass tubes. Within each tube, another glass tube is placed, which is covered in a strongly absorbing material. Since the evacuated space blocks both convection and conduction, the absorbed heat has little means of escape. The temperature within the tube itself can therefore reach extreme values, with temperatures of 170 °F to 350 °F commonly achieved [7].

### 2.2.3 Concentrating Solar Collectors

These use the reflective surfaces to concentrate sunlight onto a small area where it is absorbed and converted to heat. Due to their high heat coefficient, ordinary flat plates are not practical for elevated temperatures above 80°C. When higher temperatures are desired one needs to reduce the heat loss coefficient and this is accomplished by evacuation and concentration methods. The main types of concentrating collectors are, parabolic dish, parabolic trough, power tower and stationary concentrating collectors.

#### Parabolic dish

A concentrating solar collector, similar in appearance to a large satellite dish but has mirror-like reflectors and an absorber at the focal point. A parabolic dish system uses a computer and dual-axis tracking to follow the Sun across the sky and concentrate the Sun's rays onto the receiver located at the focal point in front of the dish. In some systems, a heat engine, such as a stirling engine, is linked to the receiver to generate electricity. Parabolic dish systems can reach 1000°C at the receiver, and achieve the highest efficiencies for converting solar energy to electricity in the small-power capacity range. **They can be used for heating water by reducing the temperature at the receiver.**

#### Parabolic trough

A type of concentrating solar collector that uses U-shaped troughs to concentrate sunlight onto a receiver tube, containing a working fluid such as water, which is positioned along the focal line of the trough. Sometimes a transparent glass tube envelops the receiver tube to reduce heat loss. Parabolic troughs often use single-axis or dual-axis tracking. In rare instances, they may be stationary. Temperatures at the receiver can reach 400°C. The heated working fluid may be used for medium temperature space or process heat, or to operate a steam turbine for power or electricity generation. Tracking is necessary on troughs because the rays need to be parallel to the axis. Usually troughs are mounted North-South and tracked East –West to always face the sun.



### Power solar towers

Also known as a *central receiver solar power plant*, a type of concentrating collector system that employs a field of large mirrors that follow the Sun's path across the sky. The mirrors concentrate sunlight onto a receiver on top of a high tower. A computer keeps the mirrors aligned so the reflected rays of the Sun are always aimed at the receiver, where temperatures well above 1000°C can be reached. High-pressure steam is generated to produce electricity.

### Stationary solar concentrating collector

A type of concentrating collector that uses compound parabolic reflectors and flat reflectors for directing solar energy to an accompanying absorber or aperture through a wide acceptance angle. The wide acceptance angle for these reflectors eliminates the need for a sun tracker. This class of collector includes parabolic trough flat-plate collectors, flat-plate collectors with parabolic boosting reflectors, and solar cookers. Development of the first two collectors has been done in Sweden. Solar cookers are used throughout the world, especially in the developing countries.

## **2.3 Material Selection for Solar Collector**

The golden rule is anything that reflects can be used as a concentrator. Factors affecting material selection in this project are:

- a) Reflectivity  
This is the most important factor as this is the sole purpose of the concentrator. It must be able to reflect sufficient light.
- b) Durability  
The material should not degrade under UV light, rain, wind etc. it should be durable and easy to maintain.
- c) Cost  
Material should not be expensive otherwise the purpose of using solar will be compromised if it becomes expensive.
- d) Other  
Availability, suitability and ease of integration are a few more factors that play a role in material selection.  
Thus based on the above factors, the materials that can be used are as shown in table 1.  
(See appendix)

The material used to make the solar dish in this project is mirror vinyl. It is highly reflective and durable. It is not available in Namibia so this makes it expensive because it has to be imported. Though is being imported, it is still cheaper than stainless steel which is locally available. Aluminum foil is also available locally but loses heat quickly making it less effective.

### 3. DESIGN CALCULATIONS AND ANALYSIS

The equations in the calculations below were used in the design of this project.

#### 3.1 Parabolic Geometry

##### 3.1.1 The Parabola

If the origin is taken at the vertex  $V$ , fig 2 and the  $x$ -axis along the axis of the parabola, the equation of the parabola, according to [2] is:

$$y^2 = 4fx \quad [1]$$

When the origin is shifted to the focus  $F$  as is often done in optical studies, with the vertex to the left of the origin, the equation of a parabola becomes:

$$y^2 = 4x(x+f) \quad [2]$$

In polar coordinates, using the usual definition of  $r$  as the distance from the origin and  $\theta$  the angle from the  $x$ -axis to  $r$ , a parabola with its vertex at the origin and symmetrical about the  $x$ -axis is given by:

$$\frac{\sin 2\theta}{\cos \theta} = \frac{4f}{r} \quad [3]$$

Often in solar studies, it is more useful to define the parabolic curve with the origin at  $F$  and in terms of the angle in polar coordinates with the origin at  $F$ . The angle is measured from the line  $VF$  and the parabolic radius  $p$ , is the distance from the focus  $F$  to the curve. Shifting the origin to the focus  $F$ , we have:

$$p = \frac{2f}{1 + \cos \psi} \quad [4]$$

The parabolic shape is widely used as the reflecting surface for concentrating solar collectors because it has the property that, for any line parallel to the axis of the parabola, the angle  $\rho$  between it and the surface normal is equal to the angle between the normal and a line to the focal point. Since solar radiation arrives at the earth in essentially parallel rays and by Snell's law the angle of reflection equals the angle of incidence, all radiation parallel to the axis of the parabola will be reflected to a single point  $F$ , which is the focus. Careful inspection of the geometry described in Figure 1 will show that the following is true: [2]

$$\psi = 2\rho \quad [5]$$

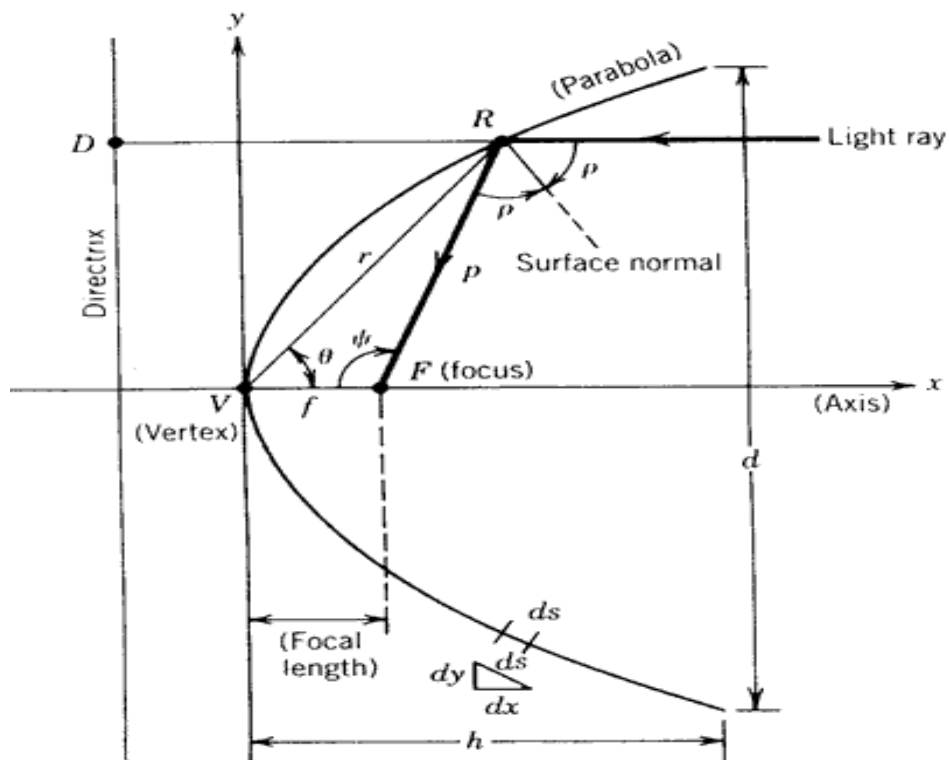


Fig 1. The Parabola

Solar concentrators use a truncated portion of this curve. The extent of this truncation is usually defined in terms of the rim angle or the ratio of the focal length to the aperture diameter  $f/d$ . the scale (size) of the curve is then specified in terms of a linear dimension such as the aperture diameter  $d$  or the focal length  $f$ . this is readily apparent in fig 2, which shows the various finite parabola having a common focus and the same aperture diameter.

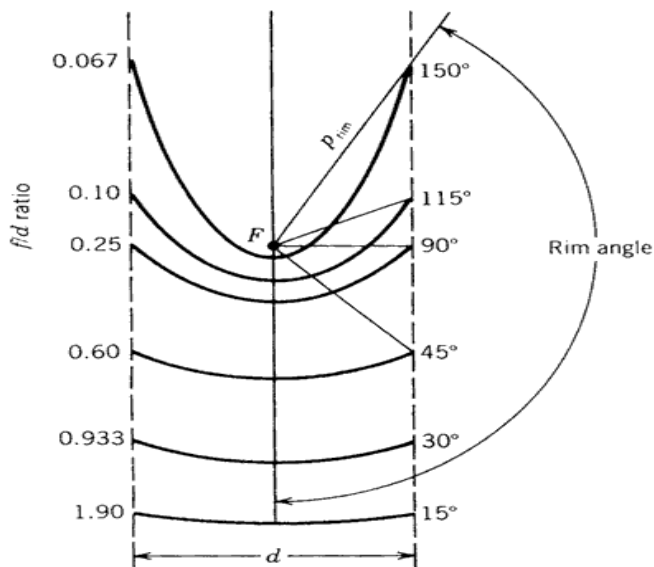


Fig 2. Segments of a parabola having a common focus  $F$  and the same aperture diameter.

It can be seen that a parabola with a small rim angle is relatively flat and the focal length is long compared to its aperture diameter. Once a specific portion of the parabolic curve has been selected, the height of the curve,  $h$  may be defined as the maximum distance from the vertex to a line drawn across the aperture of the parabola. In terms of focal length and aperture diameter, the height of the parabola is

$$\boxed{h = \frac{d^2}{16f}} \quad [6]$$

In a like manner, the rim angle  $\psi_{rim}$  may be found in terms of the parabola dimensions

$$\boxed{\psi_{rim} = 90^\circ + \tan^{-1} \left[ \frac{h-f}{\frac{d}{2}} \right]} \quad [7]$$

Another property of the parabola that may be of use in understanding solar concentrator design is the arc length  $s$ . This may be found for a particular parabola from Equation 7 by integrating a differential segment of this curve and applying the limits  $x = h$  and  $y = d/2$  as pictured in Figure2. The result is:

$$\boxed{s = \left[ \frac{d}{2} \sqrt{\left( \frac{4h}{d} \right)^2 + 1} \right] + 2f \ln \left[ \frac{4h}{d} + \sqrt{\left( \frac{4h}{d} \right)^2 + 1} \right]}$$

Where:  $d$  = distance across the aperture (or opening) of the parabola

$h$  = distance from the vertex to the aperture.

### 3.1.2 Paraboloid

The surface that is formed by rotating a parabolic curve about its axis is called a parabolic of revolution. Solar concentrators having a reflective surface in this shape are often called parabolic dish concentrators. The equation of the paraboloid of revolution as shown in fig 3, in rectangular coordinates with the  $z$ -axis as the axis of symmetry, is: [2]

$$\boxed{x^2 + y^2 = 4fz} \quad [8]$$

Where, the distance  $f$  is the focal length VF. In cylindrical coordinates, where  $a$  is the distance from the  $z$ -axis, this becomes:

$$\boxed{z = h = \frac{a^2}{4f}} \quad [9]$$

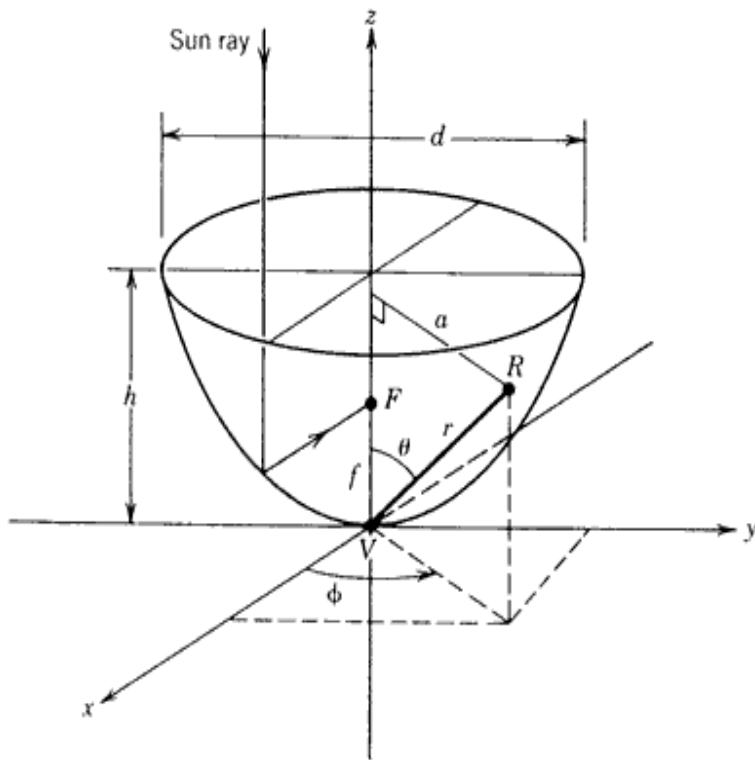


Fig 3. Paraboloid of revolution

A circular differential area strip on a paraboloid can be defined as shown in figure 3 by the equation:

$$dA_s = 2\pi a \sqrt{dz^2 + da^2}$$

[10]

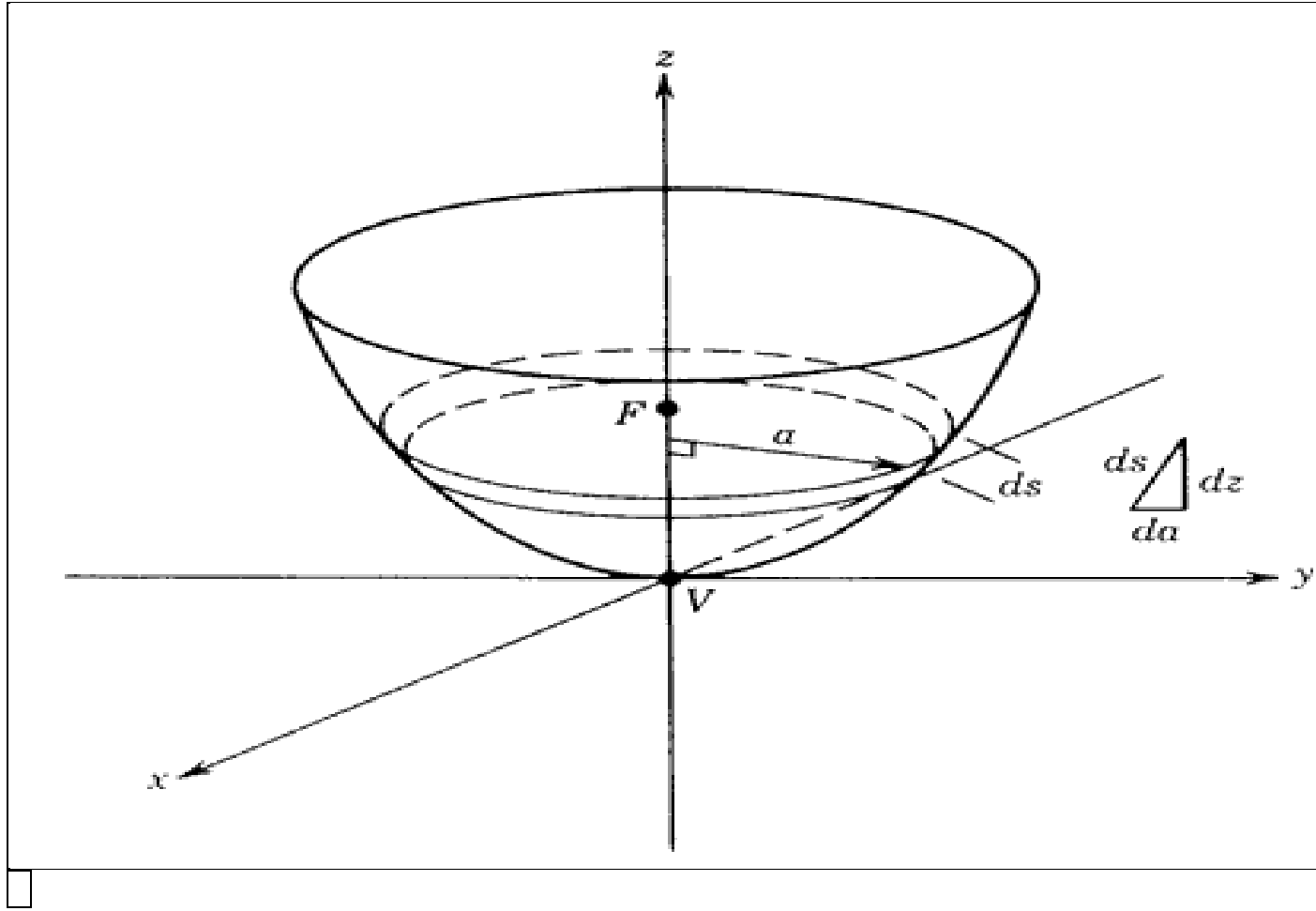


Fig 4. Parameters defining a circular strip of differential area

The differential element of arc  $ds$  is cast in terms of the height  $dz$  and radial distance  $da$ . Finding the derivative of  $z$  with respect to  $a$  using equation 3 gives:

$$dz = \left( \frac{2a}{4f} \right) da \quad [11]$$

Squaring both sides of equation 5 yields:

$$dz^2 = \left( \frac{a}{2f} \right)^2 da^2 \quad [12]$$

Substituting eq.6 into eq.4 gives:

$$dA_{pd} = 2\pi a \sqrt{\left( \frac{a}{2f} \right)^2 da^2 + da^2} \quad [13]$$

Simplifying eq.7 gives:

$$dA_{pd} = 2\pi a \sqrt{\left[\left(\frac{a}{2f}\right)^2 + 1\right]} da^2 \quad [14]$$

Simplifying eq.8 further gives:

$$dA_{pd} = 2\pi a \sqrt{\left[\left(\frac{a}{2f}\right)^2 + 1\right]} da \quad [15]$$

The full surface area  $A$ , of paraboloid having a focal length  $f$  and an aperture diameter  $d$  is found by integrating equation 9, thus:

$$A_{pd} = \int_0^d \sqrt{\left[\left(\frac{a}{2f}\right)^2 + 1\right]} da \quad [16]$$

The result is:

$$A_{pd} = \frac{8\pi f^2}{3} \left\{ \left[ \left( \frac{d}{4f} \right)^2 + 1 \right]^{\frac{3}{2}} - 1 \right\} \quad [17]$$

Let  $h = \left( \frac{d}{4f} \right)^2$  and substituting in eq.11:

$$A_{pd} = \frac{8\pi f^2}{3} h + 1 - 1 \quad [18]$$

The concentrator aperture area, of most importance for predicting the solar concentrator performance is simply the circular area defined by the aperture diameter  $d$  and is given by:

$$A_{ap} = \frac{\pi d^2}{4} \quad [19]$$

An equation for the aperture area may also be cast in terms of the focal length and the rim angle. Using Equation (8.6), which is the polar form of the equation of a parabola, we have

$$A_{ap} = \frac{\pi}{4} 2p \sin^2 \psi_{rim} \quad [20]$$

$$\text{But: } p = \frac{2f}{1 + \cos \psi} \quad [21]$$

### 3.1.3 Aperture Irradiance

Consider the parabolic mirror illustrated in Figure 5. A ray of light, with intensity of  $I_b$  incident parallel to the axis of the parabola, will be, as shown, reflected to the focus F of the parabola. Consider a differential area  $dA_s$  that can, in turn, be integrated over the entire surface of the mirror if desired. The differential surface area, [2],  $dA_s$  is defined as:

$$dA_s = l ds \quad [22]$$

Where:  $ds$  = differential arc length of the parabola shown in Figure 5

$l$  = either length of a differential strip on the surface of a parabolic trough along the direction of the focal line, or circumference of the differential ring on the surface of a parabolic dish.

An expanded view of Figure 5a shows the angles associated with  $ds$ .

$$ds = \frac{p \sin d\psi}{\cos\left(\frac{\psi}{2}\right)} \quad [23]$$

Since the angle  $d\psi$  is small Equation reduces to

$$ds = \frac{p d\psi}{\cos\left(\frac{\psi}{2}\right)} \quad [24]$$

Substituting eq.24 into eq.22 the differential area becomes:

$$dA_s = \frac{lp d\psi}{\cos\left(\frac{\psi}{2}\right)} \quad [25]$$

The total radiant flux  $d\Phi$ , reflected from this differential area (assuming no reflectance loss) to the point of focus is

$$\begin{aligned} d\Phi &= dA_s I_b \cos\left(\frac{\psi}{2}\right) \\ &= lp I_b d\psi \end{aligned} \quad [26]$$

Equation is the general form of the equation and holds for both parabolic troughs and dishes. However, for a parabolic dish we can substitute for  $l$  in Equation introducing the subscripts  $PT$  and  $PD$  to signify parabolic trough and parabolic dish, respectively, we can rewrite Equation as



$$d\Phi = \frac{8\pi I_b f^2 \sin \psi d\psi}{1 + \cos \psi^2} \quad [27]$$

The total radiant flux  $\Phi$  (watts) is the integral of eq 27. And is given by:

$$\Phi = 2 \int_0^{\psi_{rim}} \frac{8\pi I_b f^2 \sin \psi d\psi}{1 + \cos \psi^2} \quad [28]$$

Simplifying the equations becomes;

$$\Phi = 16\pi I_{bn} f^2 \int_0^{\psi_{rim}} \frac{\sin \psi d\psi}{1 + \cos \psi^2} \quad [29]$$

Let  $(1 + \cos \psi) = t$ ,  $-\sin \psi d\psi = dt$  and substituting in equation 29 gives:

$$\int_0^{\psi_{rim}} \frac{\sin \psi d\psi}{1 + \cos \psi} = \int_0^{\psi_{rim}} \frac{-dt}{t} = -\left[ \frac{-1}{t} \right]_0^{\psi_{rim}} = \left[ \frac{1}{t} \right]_0^{\psi_{rim}} = \left[ \frac{1}{1 + \cos \psi} \right]_0^{\psi_{rim}} \quad [30]$$

Equation 30 into eq.29:

$$\Phi = 16\pi I_b f^2 \left[ \frac{1}{1 + \cos \psi} \right]_0^{\psi_{rim}} = 16\pi I_b f^2 \left[ \frac{1}{1 + \cos \psi_{rim}} - \frac{1}{2} \right] \quad [31]$$

Where:  $I_b$  = beam normal irradiance.

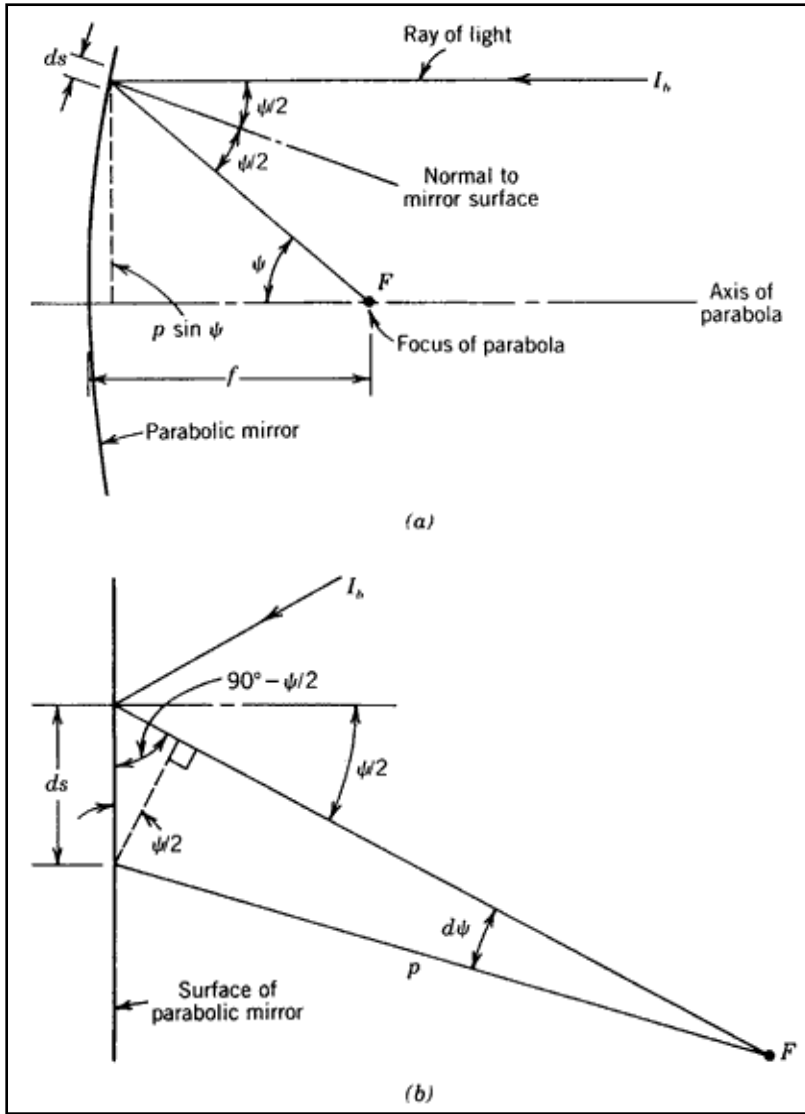


Fig 5. Reflection of a light ray from a parabolic mirror

### 3.2 Thermal Collector Capture and Loss Mechanisms

#### 3.2.1 Thermal Energy Balance

The energy balance on a solar collector receiver [2], can be written as:

$$\dot{Q}_{\text{useful}} = \dot{E}_{\text{opt}} - \dot{Q}_{\text{loss}} \quad [31]$$

where:  $\dot{Q}_{\text{useful}}$  = rate of useful energy leaving the collector

$\dot{E}_{\text{opt}}$  = rate of optical radiation incident on receiver

$\dot{Q}_{\text{loss}}$  = rate of thermal energy loss from the receiver

The useful energy for a solar thermal collector is the rate of thermal energy leaving the collector, usually described in terms of the rate of energy being added to a heat transfer fluid passing through the receiver, i.e.

$$\dot{Q}_{useful} = \dot{m} c_p (T_{out} - T_{in}) \quad [32]$$

where:  $\dot{m}$  = mass flow rate of heat transfer fluid  
 $c_p$  = specific heat capacity of heat transfer fluid  
 $T_{out}$  = temperature of heat transfer fluid leaving the absorber  
 $T_{in}$  = temperature of heat transfer fluid entering the receiver

The rate of optical radiation incident on an absorber/receiver is the direct solar irradiance for a concentrating collector. Since the capture area of the collector may not be aimed directly at the sun, this resource must be reduced to account for the angle of incidence. The incident solar resource then is:

$$\dot{E}_{inc} = I_a A_a \quad [33]$$

where:  $I_a$  = beam normal insolation  
 $A_a$  = aperture area of the collector

The solar resource is reduced by a number of losses as it passes through the aperture of the collector to the absorber. The rate of optical energy is therefore the product of incoming solar resource multiplied by a number of factors, ie.

$$\dot{E}_{opt} = \Gamma \rho \tau \sigma I_a A_a \quad [34]$$

where:  $\Gamma$  = capture fraction (fraction of reflected energy entering the receiver)  
 $\rho$  = reflective of any intermediate reflecting surfaces  
 $\tau$  = transmittance of any glass or plastic cover sheets or windows  
 $\sigma$  = absorptance of absorber or receiver surface

The first two are applicable to concentrating collectors.

### 3.2.2 Heat loss Mechanisms

Once the solar energy resource has made its way down the surface of the receiver of the collector, it raises the temperature of the receiver above the ambient temperature. This in turn starts a process of heat loss from the receiver. These heat loss mechanisms are convection, radiation and conduction. Therefore:

$$Q_{loss} = Q_{loss,convection} + Q_{loss,radiation} + Q_{loss,conduction} \quad [35]$$

#### Convection loss

Convection loss is proportional to the surface area of the receiver and the difference in the temperature between the receiver surface and the surrounding air ie.

$$Q_{loss,convection} = k A_r (T_r - T_a) \quad [36]$$

Where:  $K$  = average overall convective heat transfer coefficient

$A_r$  = surface area of the receiver  
 $T_r$  = average temperature of receiver  
 $T_a$  = ambient temperature

### Radiation loss

The rate of radiation heat loss is directly proportional to the emittance of the surface and the difference in temperature to the fourth power, i.e.

$$\dot{Q}_{loss} = \xi \sigma A_r T_r^4 - T_{sky}^4 \quad [37]$$

where:  $\xi$  = emittance of the absorber surface  
 $\sigma$  = the Stefan-Boltzmann constant  
 $T_{sky}$  = the equivalent black body temperature of the sky

### Conduction loss

This is described in terms of a material constant, the thickness of the material and its cross section area, i.e.

$$\dot{Q}_{loss,conduction} = \bar{K} \Delta \bar{x} A_r T_r - T_a \quad [38]$$

where:  $\bar{K}$  = equivalent average conductance (W/mK)

$\Delta \bar{x}$  = the average thickness of insulating material

The overall energy balance equation can be written as:

$$\dot{Q}_{useful} = \dot{m} c_p T_{out} - T_{in} = \Gamma \rho I_a A_a - A_r \left[ K' T_r - T_a + \xi \sigma T_r^4 - T_{sky}^4 \right] \quad [39]$$

where:  $K'$  = combined conduction and convection coefficient

### **3.2.3 Collector Efficiency**

The solar energy collection efficiency,  $\eta_{col}$  of thermal collectors is defined as the ratio of the useful energy leaving the collector to the usable solar irradiance falling on the aperture [2].

$$\eta_{col} = \frac{\dot{Q}_{useful}}{A_a I_a} \quad [40]$$

where:  $\dot{Q}_{useful}$  = rate of energy output  
 $A_a$  = aperture area of collector  
 $I_a$  = solar irradiance falling on the aperture

### 3.3 Concentration Ratio

The term "*concentration ratio*" is used to describe the amount of light energy concentration achieved by a given collector[2].

*Optical Concentration Ratio* ( $CR_o$ ). The averaged irradiance (radiant flux) ( $\Phi$ ) integrated over the receiver area ( $A_r$ ), divided by the insolation incident on the collector aperture.

$$CR_o = \frac{\frac{1}{A_r} \int I_\gamma dA_\gamma}{I_a} \quad [41]$$

*Geometric Concentration Ratio* ( $CR_g$ ). The area of the collector aperture  $A_a$  divided by the surface area of the receiver  $A_r$ .

$$CR_g = \frac{A_a}{A_r} \quad [42]$$

### 3.4 Energy Equation

#### 3.4.1 Bernoulli's Equation

Bernoulli's principle states that, in a steady flow, the sum of all forms of mechanical energy in a fluid along a streamline is the same at all points on that streamline [8].

Bernoulli's equation for incompressible steady flow between any two points on a stream line is:

$$\frac{P_i}{\rho_i g} + \frac{V_i^2}{2g} + z_i = \frac{P_j}{\rho_j g} + \frac{V_j^2}{2g} + z_j + \sum h_{Lmin,i-j} + \sum h_{Lfric,i-j} \quad [43]$$

where: P = pressure at a point

V = fluid flow velocity

$\rho$  = the density of the fluid at all points

g = gravitational acceleration

$h_{Lmin}$  = minor losses

$h_{Lfric}$  = friction losses

z = the elevation

### 3.4.2 Darcy Fluid Friction Equation (Major losses)

The Darcy equation relates pressure loss due to friction along a given length of pipe to the average velocity of the fluid flow.

$$h_{Loss, fric} = f \cdot \frac{L}{D} \cdot \frac{V^2}{2g} \quad [44]$$

where: L = length of pipe

D = diameter of pipe

V = velocity of fluid flow

F = Darcy friction constant

The friction constant f, is a function of the Reynolds number (Re), and the pipe roughness. i.e. The friction factor plot is usually referred to as the *Moody Diagram*, see appendix.

$$f = \frac{0.079}{\sqrt[4]{Re}} \quad [45]$$

The Reynolds number is the measure of the ratio of inertia forces to viscous forces.

$$Re = \frac{VD}{\nu}$$

where: V = average velocity of fluid

D = diameter of pipe

$\nu$  = kinematic viscosity of fluid (kg/m.s)

### 3.4.3 Minor losses

The minor head losses which for some cases, such as short pipes with multiple fittings, are actually a large percentage of the total head loss can be expressed as:

$$h_{min} = K \cdot \frac{V^2}{2} \quad [46]$$

where: K is the *Loss Coefficient*.

## **4. CONSTRUCTION**

### **4.1 Dish and Stand**

The dish has an aperture diameter of 1m , focal point at 0.2m and a height of 0.31m as shown in the excel spread sheet. The reflective material on the dish is Mirror which is a highly reflective aluminium and durable. It is not available in Namibia so this makes it expensive because it has to be imported.

Though it is being imported, it is still cheaper than stainless still which is locally available. Aluminium foil is also available locally but losses heat quickly making it less effective. The dish itself was manufactured in South Africa by a company called Sunfire productions.

The specifications that were provided to them were, the arpeture diameter, focus and the height. They supplied the dish as a kit which the student assembled herself by following the picture manual. Both the dish and the stand are made in such a way that they are easily assembled and disassembled.

### **4.2 Absorber and Tank**

The absorber can be a direct water heater as is the case with this design. As the absorber is heated by radiation focussed thereon the heat is directly transferred to the water. The metal for the absorber must have good absobtance and low heat emittance qualities.. In this project zinc sheet metal was used because of availability but was painted black to improve absopbtance. Black absorbs and emits heat faster. The absorber is a cylinder, 0.1m in diameter and a height of 0.3m.

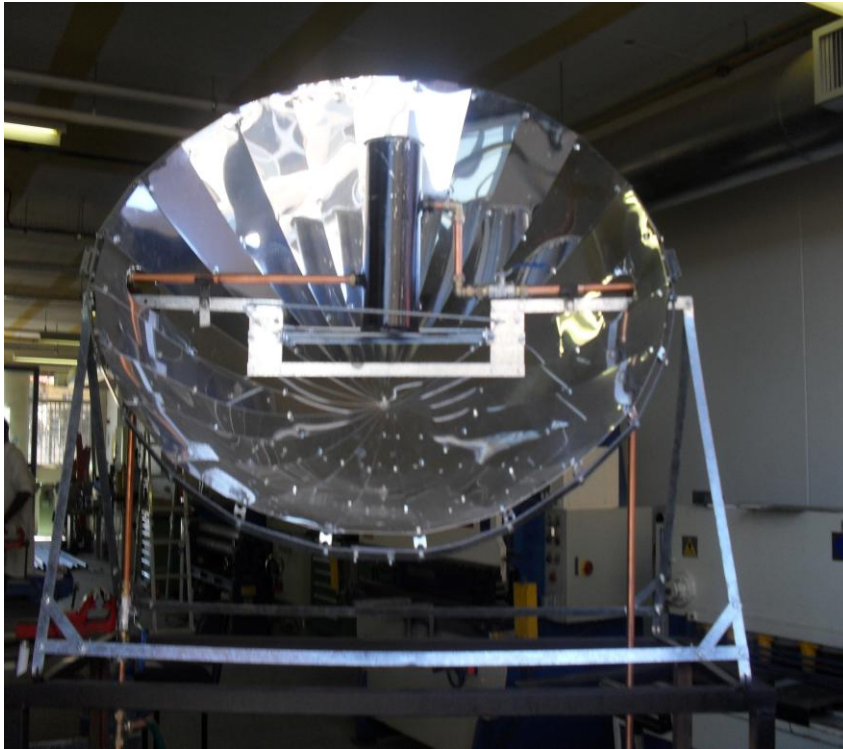
It has diameter 0.15m copper pipes on either sides, one for bringing cold water into the absorber and the other for carrying hot water to the storage tank. The absorber was manufactured at a back yard workshop in kleine kuppe as well as the tank. The tank has a 20litre capacity and is made from sheet metal. It is 300mm in diameter and 400mm high.

### **4.3 Plumbing**

All the plumbing and assembly were done in the Mechanical Department workshop. Diameter 15mm copper pipes were used and this and all the valves and fittings were purchased from local hardware stores.

### **4.4 Table**

The table is 1200mm high, 400mm wide and 1200mm long. The table was manufactured in the mechanical workshop at the Polytechnic of Namibia. The material used for the table is tubular square steel bar, 30mm x 30mm.



## 5.0 TESTING AND ANALYSIS

### 5.1 Determining the solar Energy in Windhoek Namibia

The solar intensity in Windhoek was measured using a pyranometer, the set up is as shown in the picture below. The energy was read off as voltage on the multimeter which was converted to  $\text{W/m}^2$  by multiplying by 107.9mV, the output of the pyranometer.

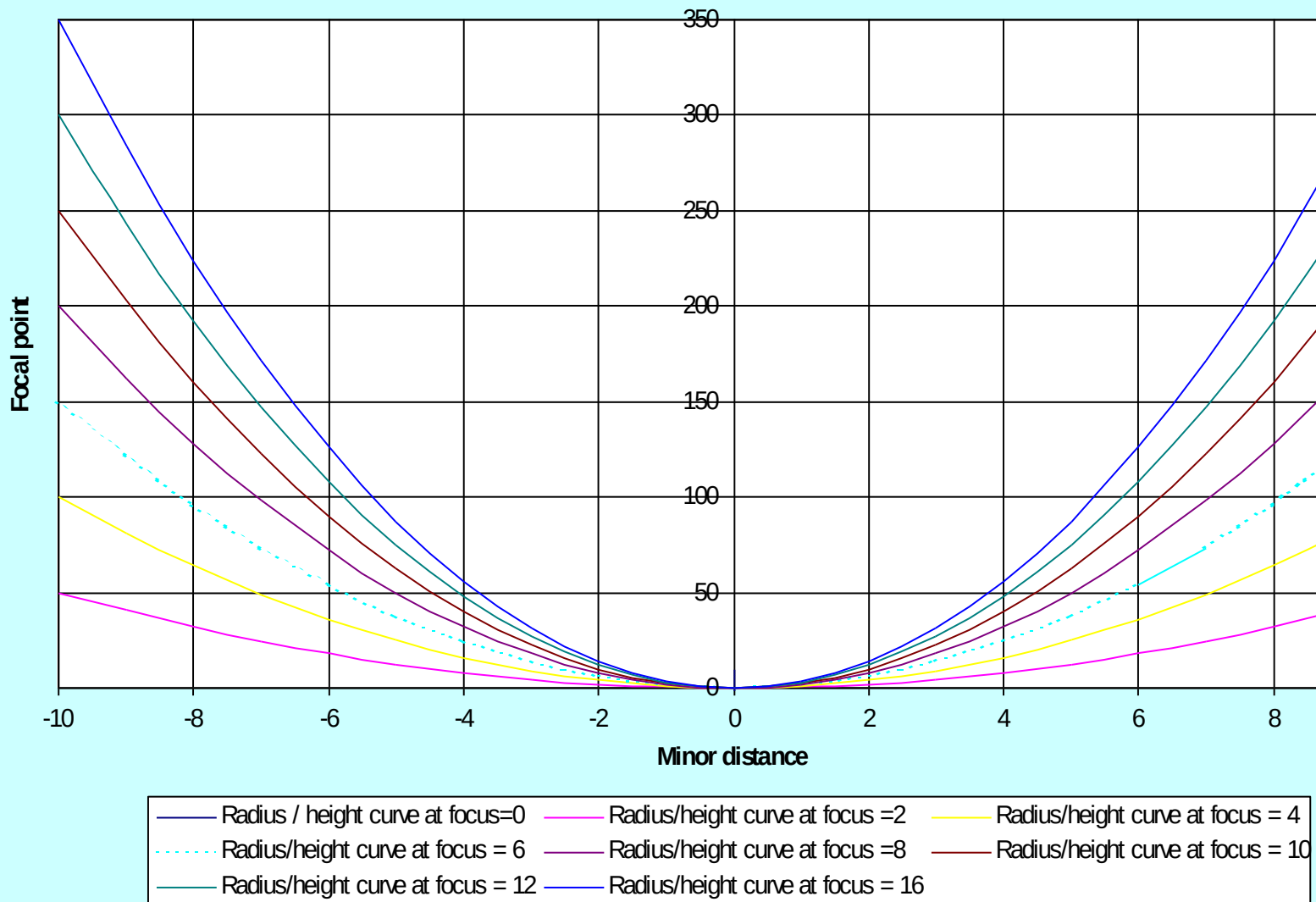
Readings were taken for two days, one in winter and the other one in summer. The readings were taken from 08.00am up to 12.30noon and the table of results and the graphs of these readings are as shown in table 1 and fig 6 respectively. The maximum beam normal insolation was experienced at 11.30 in winter, 12.30 in summer. In this project beam normal insolation is only used to determine the temperature since there is no tracking system.

**Table.1 Solar energy in Windhoek**

| Time of the day | Voltage (V) | Solar intensity ( $\text{W/m}^2$ ) |            |
|-----------------|-------------|------------------------------------|------------|
|                 |             | 14/07/2009                         | 08/10/2009 |
| 8.30am          | 0.038       | 351.85                             | 448        |
| 9.30am          | 0.062       | 574.07                             | 693        |
| 10.30am         | 0.076       | 703.70                             | 854        |
| 11.30am         | 0.084       | 777.78                             | 977        |
| 12.30pm         | 0.083       | 768.52                             | 1032       |
| 13.30pm         | 0.072       | 666.67                             | 1056       |
| 14.30pm         | 0.059       | 546.30                             | 836        |
| 15.30pm         | 0.037       | 342.59                             | 236        |
|                 |             |                                    |            |
|                 |             |                                    |            |



## Focal point vs minor distance



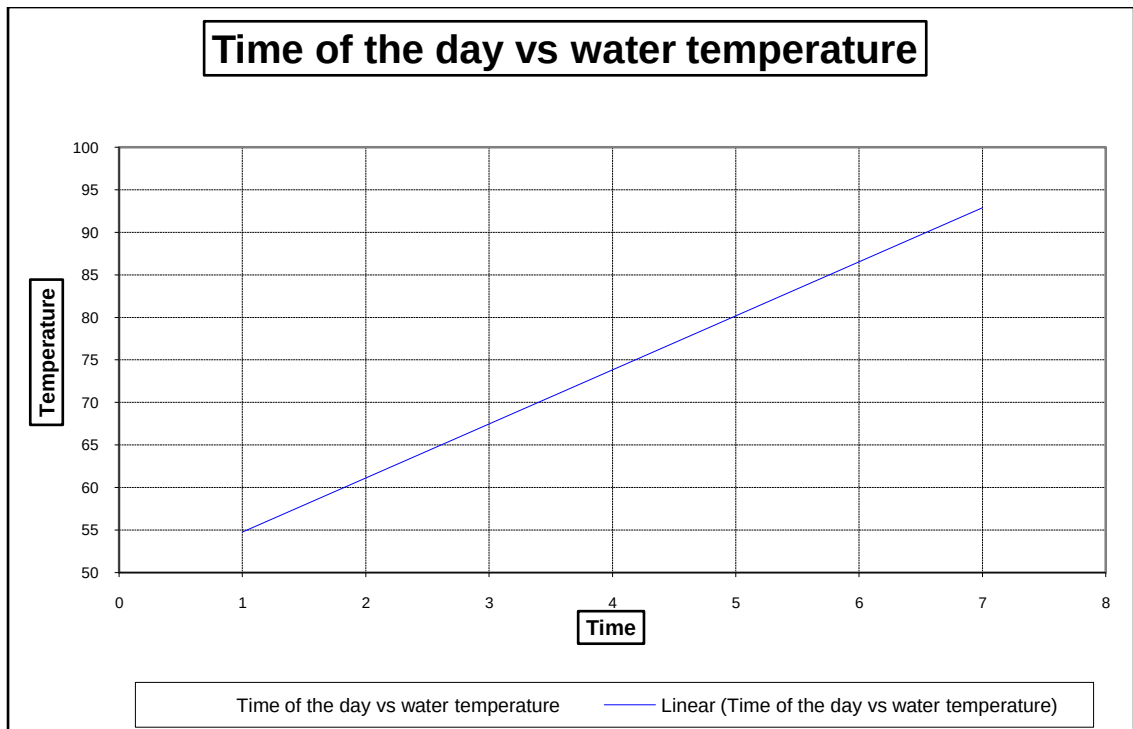
**Graph 1. Solar energy in Windhoek**

### 5.2.Determining the receiver water temperature

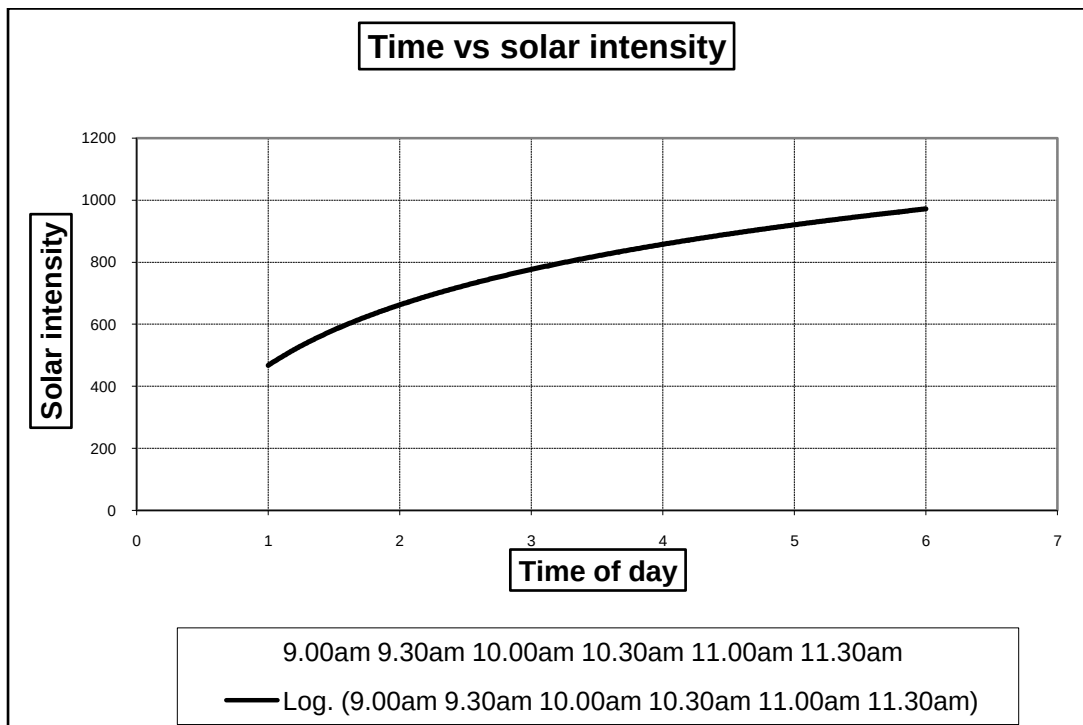
A temperature sensor measured the water temperature in the receiver with the output read off from the junction box. The temperature was recorded for different times of the day and the graphs below show some of the results obtained

**Table 2. Water temperature and solar energy at different times**

| Time of the day | Water Temperature (deg) | Solar intensity (W/m <sup>2</sup> ) |
|-----------------|-------------------------|-------------------------------------|
| 9.00am          | 52.1                    | 448                                 |
| .30am           | 62.1                    | 693                                 |
| 10.00am         | 70.5                    | 787                                 |
| 10.30am         | 73                      | 854                                 |
| 11.00am         | 80.4                    | 897                                 |
| 11.30am         | 87.8                    | 977                                 |
| 12.00am         | 91                      |                                     |



**Graph 2. Relationship between temperature and time**



**Graph 3. Relationship of solar energy and time**

### 5.3. Determining the flow rate

The flow rate of the water from the tap was determined using a bucket and timer method where the time it took to fill the 2 liter bucket was recorded.

## **6. CONCLUSION AND RECOMMENDATIONS**

The design and construction of a parabolic solar water heater has been presented in this project.

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