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Design of Concentrating Parabolic Reflector System to Generate Energy

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ABSTRACT

The paper contains the design, construction and testing of a parabolic reflector system. Using concentrating collector, the rays from sun is concentrated at the focus point of the reflector in which different experiments are carried out to estimate the temperatures at the focal point. It also describes the sun tracking system unit by keeping the whole arrangement mounted on a hinged frame supported with a slotted lever for tilting the parabolic dish reflector to different angles so that the sun is always directed to the collector at different period of the day.

Keywords: Concentrating, Energy, Parabolic Disc, Sun, Solar

INTRODUCTION

World population is expected to double by the middle of the 21st century (Global Energy,1998). This will consequently result in a 3-5-fold increase in world economic output by the year 2050, and a 10-15-fold increase by the year 2100. Consequently, Primary energy requirements are expected to increase by approximately three folds by the year 2050 and five folds by the year 2100. This is expected to exert tremendous pressure on primary energy supplier. Energy has an established positive correlation with economic growth. Providing adequate, affordable and clean energy is a prerequisite for eradicating poverty and improving productivity? The inevitable increase in the use of fossil fuels alongside a country's economic growth presents associated side effects of threat to the nation's energy security, as well as environmental degradation through climate change. A feasible alternative to the indiscriminate burning of fossil fuels lies in the accelerated use of renewable energy [1-2].

The prime objective of this paper is to design and fabricate a parabolic reflector system to minimize heat loses on the reflectors and thereby improving high temperature concentration at the focal point. The performance analysis of a parabolic reflector system to heat various materials and the water passing through the focal point of the concentrator is also discussed.

IMPORTANCE OF THE STUDY

Using a Renewable Source of Energy - The primary source of energy is the sun. The radiant energy incident on the reflector surface is utilized in heating purposes.

The Assembly of the Heating System is Simple - The solar rays are converged to the focal point of the parabolic dish where various materials are heated along with the absorber where water is heated.

Cost of Generation is Low - The primary resource, solar radiation and the secondary resource, water is available in plenty are utilized in the assembly to generate power and so the resources spent in providing the energy are relatively reduced.

Eco- Friendly and Non-Polluting - As there is no emission of gases which may be harmful, like carbon monoxide, nitrogen, etc. into the atmosphere, it serves as effective method against environmental hazards like global warming, pollution, etc.

Position can be Changed According to the Conditions - The existence of the wheels in its supporting frame will allow the users the facility to place the system where the incident radiation is maximum.

DETAILS OF THE DESIGN

Solar energy should be concentrated optically before being transformed into heat so as to increase the thermal effect of the device concentration. It is obtained by reflection or refraction of solar radiation by the use of mirrors or lens. The reflected or refracted light is concentrated in the focal zone, thus increasing the energy flux in the receiving target. The parabolic reflector will reflect all the radiation falling on it to its focal point. So as the area of parabolic collector increases it can harness more solar radiation [1-2]. The basic principle adopted in the construction of the parabolic reflector system is that when parallel rays of light from the sun close to and parallel to the principal axis are incident on a concave or parabolic shaped mirror, they converge or come together after reflection to a point on the principal axis called the principal focus [1-2].

PHASES OF THE DESIGN

Parabolic Reflector System

In this phase we design the reflector system by fixing reflecting material over the parabolic dish and then we fix the dish over the supporting frame.

Setting up the Absorber at the Focal Point

Once the reflector assembly is constructed, the focal point is located and the absorber is fixed at the focal point for heating purposes.

Parabolic Reflector System

Among the different types of collectors, the parabolic collector is taken into consideration as the image is formed on the focal axes of the parabola and so it is an imaging type. A parabolic mirror reflects solar radiation which is parallel to its axis, to its focus. The developed model is shown in the Fig. 1.

The parabolic dish of the required diameter is selected and then the reflector material is fixed upon it. The parabolic dish is shown in the Fig. 2. The parabolic dish is then fixed with the reflector material, which is glass in the project due to its high emissivity. Following table gives the emissivity of various material surfaces. As glass has high emissivity, so small parts of cut glass with the width of 1 cm are placed uniformly over the parabolic dish as shown in Fig. 3. Once the reflector material is placed on the parabolic dish, the frame to support the dish is made. The focal point keeps on changing with the orientation of sun and as such dish alignment mechanism is fitted at the bottom of the parabolic dish. Wheels are provided at the base of the supporting frame for the mobility of the parabolic reflector system. The final arrangement for the parabolic reflector system is shown in Fig. 4.

Table – 1 The Parabolic Reflector Arrangement

Part Name	Part No
parabolic dish	1
dish holder	2
roots connecting dish holder and main frame	3
dish alignment mechanism	4
supporting frame for rods	5
main supporting frame	6
wheels for movement	7

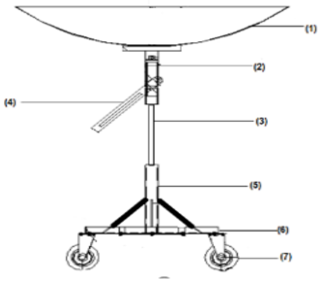

Fig. 1 The parabolic reflector system

Fig. 2 The parabolic dish

Fig. 3 The reflector material

Fig. 4 Parabolic Reflector System

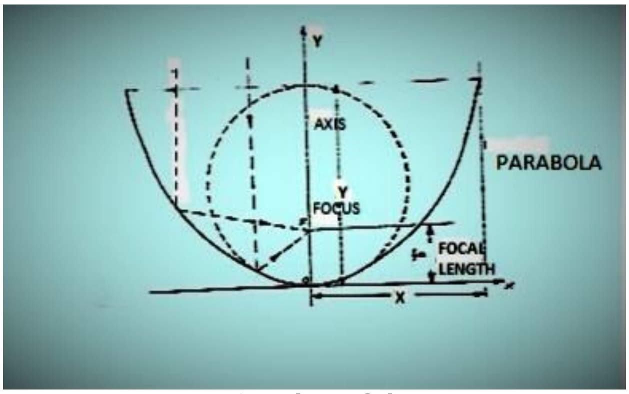

Fig. 5 The parabola

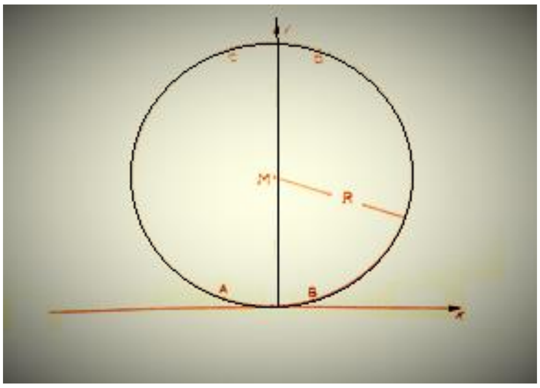

Fig. 6 Arc which is a part of circle of radius R

Setting up the Absorber at the Focal Point

The property of a parabolic mirror to converge the rays at its focal point is used in the construction of concentrating collectors in the form of a parabola with the absorber placed at its focal point.

Fig. 1 shows a parabola which is described by the equation

$$\boldsymbol{y = x^2 / 4f} \tag{1}$$

The distance of the focal point from the vertex is known as the focal length f. A parabola can be assumed to be made up of a small arc. Such an arc is shown in Fig. 6. The arc is a part of the circle with radius R.

The equation of the arc follows the equation of a circle i.e.

$$\boldsymbol{X^2 + (Y - R)^2 = R^2} \tag{2}$$

$$\boldsymbol{\Rightarrow Y = +R\,(1 - X^2/R^2)^{1/2} + R}$$

For segments with a very small surface area i.e. $X^2/R^2 < 1$, one can write the following expression i.e.

$$\boldsymbol{(1 - X^2/R^2)^{1/2} = 1 - X^2/2R^2} \tag{3}$$

and hence,
$$\boldsymbol{Y = +(R - X^2/2R^2) + R} \tag{4}$$

The equation mentioned holds good for both the arc segments AB and CD. Considering only the lower arc segment AB, one gets
$$\boldsymbol{Y = X^2/2R^2} \tag{5}$$

Comparing eq (5) with eq (1), it is clear that eq (5) also describes a parabola with **f= R/2.** This shows that a mirror segment, which satisfies the condition X2/R2 < 1, can be used to make a parabolic concentrator. This result is advantageous for the fabrication of collectors, because a circular shape is easier to fabricate than a parabolic one. The preceding considerations are also rated for a rationally symmetric form meaning that a paraboloid can be approximated by a spherical segment.

For this work, we have $\boldsymbol{y = 4ft = 1.22m}$; $\boldsymbol{x = 8ft = 2.44m}$;
Therefore using Eqn (1) focal length = $\boldsymbol{4ft = 1.22\ m}$

System Arrangement

The parabolic reflector system considered in this design is made up of the following main parts: The figure of the final arrangement is shown in Fig. 7.

Tank- The storage tank is made of plastic and mounted on a stand higher than the parabolic dish stand for storing cold water.

Flexible Pipe - A flexible pipe is fitted which carries cold water from the storage tank to the absorber.

Parabolic Dish- This is the concave dish made of plastic. The reflector plain mirror is cut into small pieces and glued uniformly over the dish serve as the reflecting surface of the parabolic dish that converges heat to the base of the absorber.

Absorber - It is a capillary tube made of aluminium that carries water, painted black and located at the focal point of the parabolic dish. When the sunlight rays are incident on the reflective surfaces of the parabolic dish, they are reflected and converged to the base of the absorber located at the focal point to heat up the water in it.

Adjustable Mechanism - Parabolic dish adjustable mechanism is made of an arrangement to support the weight of parabolic dish and absorber and help in its orientation. The main function is to allow the parabolic dish to align at various angles to capture the sunlight rays depending on the movement and position of the sun.

Outlet Hose - This is a pipe made of galvanized steel and it is fixed at the top of the absorber. It serves as the outlet for the heated water to flow from the exit of the capillary tube.

Fig. 7 Parabolic reflector arrangement

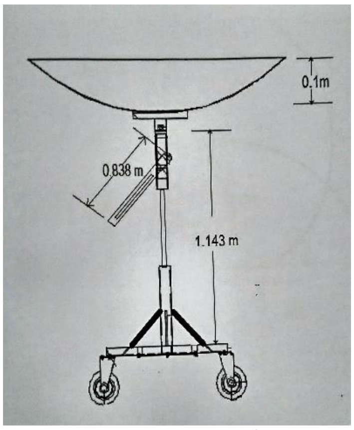

Fig. 8(a) Dimensions of the parabolic reflector assembly

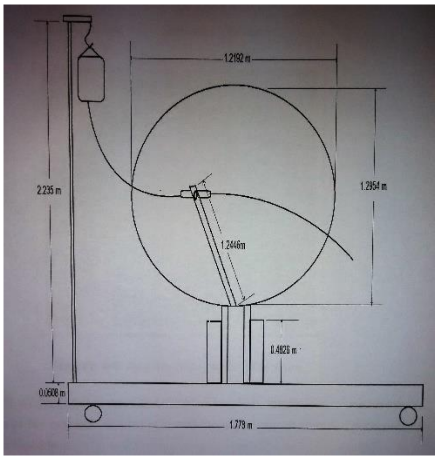

Fig. 8(b) Dimensions of the parabolic reflector assembly

Fig. 9 Dish alignment mechanism

Fig. 10 Capillary tube

FIGURES AND DIMENSIONS

Parabolic Reflector System

A prototype was selected with minimum dimensions but as it was not able to generate sufficient amount of energy, so the dimensions were changed. The dimensions of the proposed model of the parabolic reflector system are shown in fig.8(b)

Intermediate Supporting Frame

The supporting frame is used as an intermediate support between the parabolic dish and the supporting frame.

Dish Alignment Mechanism

The dish alignment mechanism consists of the rear hub of a bicycle and the adjusting mechanism with nut and bolt fitted to it.

The Capillary Tube and the Focal Position Adjusting Mechanism

The capillary tube is fitted to the focal point as the absorber and as the focal point keeps on shifting with the orientation of sun, a focal position adjusting mechanism is fitted to place the absorber or capillary tube at the focal point.

Dimension of the capillary tube: Length: 15 cm Diameter: 2.28 cm

RESULTS AND DISCUSSION

Results taken on 20th June from 11am to 2pm. On June 20, N=171, where N= Number of Days.

Dibrugarh (India) is $(27.5°N, 94.35°E)$

Declination angle, $(\delta) = 23.45 \sin\left[{}^{360}/_{365}\{284 + N\}\right] = 23.45 \sin\left[{}^{360}/_{365}\{284 + 171\}\right] = 23.38°$

Hour angle,

Therefore $w_s = \cos^{-1}[-\tan(27.5°)\tan(23.38°)] = 102.94 = 1.796\, rad$

Day length $= 2w_s = 2 \times 102.94 = 205.88 = 12.72\, hours.$

Now, monthly average of the daily global radiation on a horizontal surface at the same location on a clear day, $H_0\ (KJ/m^2\ day)$

$H_0 = {}^{24}/_{\pi} \times I_{sc}\left[1 + 0.033\cos({}^{360N}/_{365})\right]w_s \sin(\phi)\sin(\delta) + \cos(\phi)\cos(\delta)\sin w_s$ Where, I_{sc}= Solar Constant $= 1353\ W/m^2$

$H0 = 24/\pi\ x\ 1.353 \times 3600\ (1 + 0.033\ cos\ (360x171)/365)[1.428\ sin27.5°\ (sin23.38°) + cos\ (27.5°)\ cos\ (23.38°)\ sin\ (102.94°)]$

$= 37066.70\ KJ/m^2\ day.$

Now, monthly average of the daily global radiation on a horizontal surface at the location,

By Angstrom Equation, $H_g = H_0\ [a + b\ (S\ /\ S_{max})]$

Where, S = monthly average of the sunshine hours per day at the location and a, b = constants obtained by fitting data.

Therefore, $H_g = 37067\ [0.22 + 0.57\ (4.86/12.76)] = 16183.45\ LJ/m^2\ day$

By Liu and Jordan's equation,

$H_d/\ H_g = 1.390 - 4.027(H_g/H_0) + 5.531(H_g/H_0)^2 - 3.108(H_g/H_0)^3$

$= 1.390 - 4.027(16183.45/37067) + 5.531(16183.45/37067)^2 - 3.108(16183.45/37067)^3$

$H_d/H_g = 0.434$

Therefore,

Average daily diffuse radiation, $H_d = 16183.45\ x\ 0.434 = 7023.61\ KJ/m^2\ day$

Now, $I_g = I_b + I_d$

I_g = hourly global radiation = $16183.45/24 = 674.31\ KJ/m^2\ day$

I_b = hourly beam radiation

I_d = hourly diffuse radiation = $7024/24 = 292.6\ KJ/m^2$

Now, $I_h = I_g - I_d = 674.31 - 292.6 = 381.7\ kJ\ /\ m^2\ hr$

Tilt factor for beam radiation,

$R_b = cos\ (\theta)/cos\ (\theta_Z)$

$Cos\ (\theta) = sin^2\ (\delta) + cos^2\ (\delta)\ cos\ w$

$= sin^2\ (23.38°) + cos^2\ (23.38°)\ cos\ (17.25°) = 0.9522$

Where, $w = 15(t_s - 12) = 15\ (13.15 - 12) = 17.25°$

At 13:15 P.M.

$Cos\ (\theta_Z) = sin\ (\phi)\ sin\ (\delta) + cos\ (\phi)\ cos\ (\delta)\ cosw$

$= sin\ (27.5°)\ sin\ (23.38°) + cos\ (27.5°)\ cos\ (23.38°)\ cos\ (17.25°) = 0.96$

$R_b = cos\ (\theta)\ /\ cos\ (\theta_Z) = 0.9522\ /\ 0.96 = 0.99$

The absorbed solar energy, $S = I_b\ R_b\ p\ r\ (\tau\alpha)_b$

$= 381.7 \times 0.99 \times 0.9\ x\ 0.8 \times 0.7563 = 205.77\ KJ\ /\ m^2\ hr$

A_u= Area of the concentrator surface

$A_u = 2 \times \pi \times 2.28 \times 15 = 214.884\ cm^2$

Therefore, $Q_u = mc_p(T_{f0} - T_{fi}) = 51 \times 4.42 \times (38 - 25) = 2930.46\ KJ$

where, m = flow rate =51 Kg/hr, C_p= specific heat of water= 4.42 KJ/Kg^0K

T_{fi}= Fluid temperature entering the absorber, T_{f0}=Temperature of fluid coming out of the absorber.

Now, efficiency of collection

$\eta_{collection} = Q_u/\ A_u \times I_bR_b = [2930.46\ /(214.884 \times 381.7 \times 0.99)] \times 100 = 36\ \%$

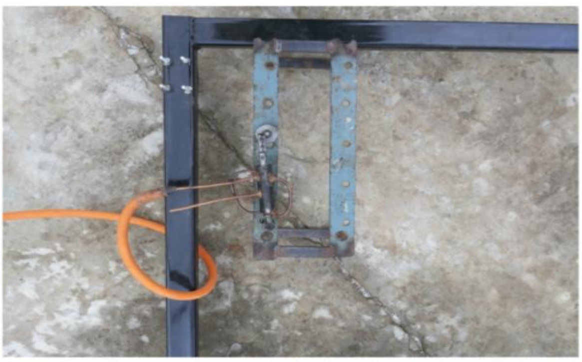

Fig. 11 Piston assembly running at 8-10psi

Fig. 12 Compressor running at 28 psi

WORKING AND RESULT

For the research and development, we developed a piston assembly working at around 8-10 psi and reciprocating compressor running at around 28psi and then fitted the parabolic reflector assembly for research purposes.

The intake gas enters the suction manifold, then flows into the compression cylinder where it gets compressed by a piston driven in a reciprocating motion via a crankshaft, and is then discharged. Steam from the outlet enters the *steam chest* and is admitted to the front end of the cylinder. The high pressure steam presses the piston backward, driving the flywheel around one half turn. At the end of the piston stroke, the valve shifts, allowing the remaining steam pressure to escape through the exhaust port underneath. The pressure escapes in a quick burst at the same time, the valve slide begins admitting high pressure steam to the back end of the cylinder. This presses the piston forward, pulling the flywheel around another half turn. At the end of the second stroke, the steam is released from the rear portion of the cylinder. The steam coming out of the outlet pipe was only pressurized to 5-8 psi and more pressure was required to be developed to run the piston assembly and the compressor smoothly.

CONCLUSION

The rising demands of the resources that are abundant and inexhaustible are proving to be a big challenge for the scientists and technicians in developing new methods and techniques in harnessing power from these inexhaustible resources and utilising it in meeting the demands. As such technologies related to solar energy has been advancing gradually and new, high-tech systems are working efficiently to harness the power of the sun and drastically reducing the harmful carbon dioxide emissions from the burning of fossil fuels. The availability of solar radiation on the earth's surface is a function of geographical zone. With about 300 clear, sunny days in a year, India's theoretical solar power reception, on only its land area, is about 5000 Petawatt-hours per year (PWh/yr) (5000 trillion kWh /yr or about 600 TW). The daily average solar energy incident over India varies from 4 to 7 kWh/m2 with about 1500–2000 sunshine hours per year (depending upon location), which is far more than current total energy consumption. Thus with the help of the parabolic solar reflector system, the amount of solar radiation incident on earth's surface can be utilised to derive mechanical power, which will lead to working of various machineries present.

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