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Design, fabrication and analysis of thermal storage solar parabola dish water heater prototype for use in Rajasthan, India

[1]MD. Zeyaul Mustafa Khan, [2]Hari Kumar Singh
Centre of Excellence-Renewable and Sustainable Energy Studies
[1, 2] Suresh Gyan Vihar University, Jaipur, Rajasthan, India

Abstract
This research increased dependence on conventional energy sources has led to depletion of such sources. Thus the most easily available energy source is solar energy which can be harnessed either by photovoltaic system or by thermal energy systems. The use of thermal systems is receiving more importance since they can achieve high concentration ratio and high temperature. Tapping the heat and infra-red rays from the sun using air and water as appropriate medium, separately and together as a whole is the most easiest and versatile way of energy capture. In order to tap this abundant energy we require an efficient design of a solar concentrator which heats up the ambient in the quickest pace. A cost effective solar concentrator is made with locally available raw materials which is efficient enough to make water reach steam point and air reach its hottest phase. In this paper, a parabolic dish collector is designed for generation of hot water which can be used for domestic applications.

Keywords: Parabolic Dish, Solar Concentrator, Tracker, Solar Water Heater, Solar Air Heater

1. Introduction

Solar incident rays or energy are more powerful and a renewable source of energy. It has obvious more advantageous over non-renewable energy sources such as: coal, oil & natural gas. It is safe, non-polluting, and reliable; work fast as due to increasing temperature. It is even more advantageous than other renewable energy sources, including wind and water power. It only has one drawback i.e., solar power energy can only be produce when the sun is shining. Solar concentrators are optical devices which increase the amount of incident energy on the absorber surface as compared to that on the concentrator aperture. Incident light is more absorbed at absorber by the use of reflecting or refracting surfaces. A solar parabolic disc collector mainly consists of (a) a focusing device (b) an absorber provided with a black paint (c) a tracking device. The selection of type of energy source depends on economic, environmental and safety considerations. Solar energy is considered to be more suitable on the basis of environmental and safety considerations.

Solar thermal systems are one of the main technologies for solar energy utilization. It can be used for generation of thermal energy such as air heating, hot water generation and in drying application. Solar collector is one of the main components in a solar thermal system. It absorbs the solar radiation as heat and transfers it to the heat transport fluid. The collected solar energy will be transferred either for hot water generation or space heating or to a thermal storage tank. Based on the way of solar collection, the solar collectors are classified into non concentrated and concentrated type. A non-concentrated solar collector has the same area for intercepting and absorbing solar radiation, while concentrated type will have a concave shaped reflective surface for intercepting radiation and it will be focused to a small area and thus increases radiation flux. Another advantage of concentrated collectors is that higher temperature can be achieved than that of non- concentrated collectors. The three main types of concentrated collectors are parabolic dish, parabolic trough and tower receiver. Among them, parabolic dish collector is one of the developing technologies. Since it has small absorber area, it has less radiation losses. B. Ricardo, V .Nicolas , E. C. Alma , S. Daniel and P. Guillermo (2012) developed a mathematical model of a system consisting of parabolic dish collector with cavity receiver and stirling engine at its focal point. A thermal model of the system was developed by considering the conduction, convection (natural and forced) and radiation losses that occurs from the dish and receiver. From the analysis of dish collector with Stirling engine, it was found that, high concentration can be achieved at receiver if rim angle is 450. [1] Atul (2012) had performed an experimental study of parabolic dish solar water heater with coated and non-coated receiver. The system consists of parabolic dish of 1.4m diameter with aluminium mirrors.

The experimental results showed that with the increase in mass flow rate, the total heat loss increased and thus the efficiency of the system also reduced. In this paper a parabolic dish collector system was designed for hot water generation and simulation of dish collector was also done. [2] M. L. Ibrahim (2012) designed and developed a parabolic dish solar water heater for domestic hot water applications. It was designed to provide 40 litres of hot water a day for a four member family and in one cycle it produces 10 litres of hot water thus the system may need 4 cycles to heat the total quantity of water. A proper methodology is used for sizing of the absorber and parabolic dish collector. An automatic electronic control circuit was used for tracking purpose for improved performance. This system was able to produce hot water of temperature near to 100 °C. [3] G. Shiva, G. Barat, H. T. Teymour and B. Ahmad (2013) calculated the thermal efficiency of a point focus parabolic dish steam generating system under varying climatic conditions. A parabolic dish collector with cylindrical receiver was used for steam or hot water generation. A performance analysis was done over an entire year and it was found that as the absorber temperature was increased from 150 to 200 °C, the convective heat loss coefficient was increased by about 25 to 41%. [4] M. R. A. Ghani, A. Rosnani, G. K. Chin, R.H. Siti and Z . Jano (2014) had done an analysis to determine about influence of material reflectivity and aperture size on the heat transfer rate from concentrator to receiver in parabolic dish systems. Among the different reflective materials, silver has highest reflectivity (96%) followed by aluminium (92%), iron sheet (87%) and stainless steel (67%).

2. Experimental SET-UP

Solar parabolic disc collector is constructed after study of different papers and measurement analysis. It mainly consists of frame of parabola, structure frame to support the parabola and tracker is fixed also at definite place to provide the proper movement to parabola, different fabrication and design also in consideration to study throughout the proper focal point and efficient performance. Instead of this, cylinder is used as boiler with two small pipe of bronze material of size 8mm is fixed with gas welding at two different ends. Two valves are used to control the pressure of water or steam and flow of water inside the cylinder.

SELECTION OF MATERIALS FOR THE CONSTRUCTION OF THE PARABOLA DISH

Material for the Body of the Dish:

Aluminium was selected over steel because of its lightness, lower cost, ease of fabrication and energy effectiveness in use of material. Its light weight reduces the overall weight of the Parabola dish, and also reduces the amount of work to be done by the Servo gear tracker in turning the dish from east to west and vice versa.

Material for the Reflecting Surface:

To reduce the overall weight of the solar water heater, a light glass mirror of 2mm thickness, of high surface quality and good specular reflectance with silver polished surface was selected. A glass mirror was selected over polished silver surface because its reflectivity of 96% is better than that of aluminium (85%). Also, glass surface is easier to clean than aluminium surface.

Material for the Absorber:

Copper was selected over aluminium and steel because of its high thermal absorptivity, ease of fabrication and energy effectiveness in use of material. Its light weight reduces the overall weight of the solar water heater and also reduces the amount of work to be done by the in turning the dish about its horizontal axis.

Material for the Absorber Surface Coating:

Black paint was selected for the absorber coating. It is selected over other coatings because of its higher absorptivity at angles other than normal incidence, adherence and durability when exposed to weathering, sunlight and high stagnation temperatures, cost effectiveness and protection to the absorber material.

Heat Transfer Fluid

Water was selected as the heat transfer fluid for the solar heater because of its stability at high temperatures, low material maintenance and transport costs, safe to use, and is the most commonly used fluid for domestic heating applications.

Material for the Vertical Support of the Dish:

A rectangular, hollow, steel bar was selected for the support of the dish and the Servo gear motor. This is because of its strength, rigidity, resistance to deflection by commonly encountered winds, and its ability to withstand transverse and cross-sectional loads of the entire heating portion.

Material for the Base of the Parabola Dish:

A combination of angle and flat, steel bars were chosen for the base which supports the whole solar water heater structure. Flat and angle bars were chosen to provide solid and rigid support for the rectangular, vertical axis steel bar which supports the parabolic dish.

Tracking Mechanism

A Servo gear tracker is single axis tracker which moves in the direction of east to west to track the maximum incident sunlight. The Servo gear gives a slow, steady motion to the parabolic dish as it turns on its axis from East to West. The hydraulic arm is controlled by a 6V-Motor fitted at one end of the jack. Solar energy radiation sensors fitted on the aperture of the dish send electric signals to the motor which, in turn, adjust the position of the dish until maximum solar radiation intensity is received at the aperture.

Valves are attached with M-seal at the bronze pipes. Inlet pipes plastic material of 10 m is used to pump the water inside the cylinder, pump used generally in the home cooler is taken into the use of small rating but it pump the water very fast. Supply to pump is given from the setup battery of 12v which is connected though manual switch. Outlet pipe is taken as steel pipe coated with the insulating form of air conditioner. Outlet pipe is placed inside the big bucket to take the heated water of setup and valve of outlet pipe is manually controlled. A schematic view of the constructed solar parabolic disc collector system is shown in the Fig respectively.

In this study of solar water heater were employed. The parabolic disc is having a size of 37.5 inches in diameter, the depth is given along the x axis with considering x= 1, 2, 3, & 4(inches). After this whole parabola is covered by the reflector sheet which is take as 4x8 m, which is further cut in the shape of leaf and circular in the bottom of rest. Leaf cut shape size is taken as 3.5x1ft and 24 pieces of leaf cut shape is attached on the above surface of the parabola frame. Two servo gear motor as tracker is attached to both the end of the frame to track the sun light at the proper focal point. Tracker is automatically running by the voltage control over supply to tracker. Voltage is controlled by the stabilizer which is fixed to 2v supply to tracker. Servo gear motor has very high rpm, so it needs the stabilizer to control the movement of tracker.

Instead of this, cylinder is taken as boiler of copper materials with black polished is taken into consideration. Cylinder of copper material is used for taking the reading, this cylinder if size 2 litres and having diameter 16 cm. Firstly, it is red colour on outside and reading is taken, after that black colour is coated outside to absorb the large amount of heat.. The alcohol thermometer is used to measure the environmental temperature. Digital solar power meter (TENMARS TM- 207) is measuring the horizontal altitude of the area is 26° angle, having the unit in w/m^2 solar flux. Digital anemometer (METRAVI AVM-05) is wind measuring device that is used here to measure the wind velocity of surrounding. Digital Multimeter (MASTEC S830) is used to measure the voltage change over the output power.

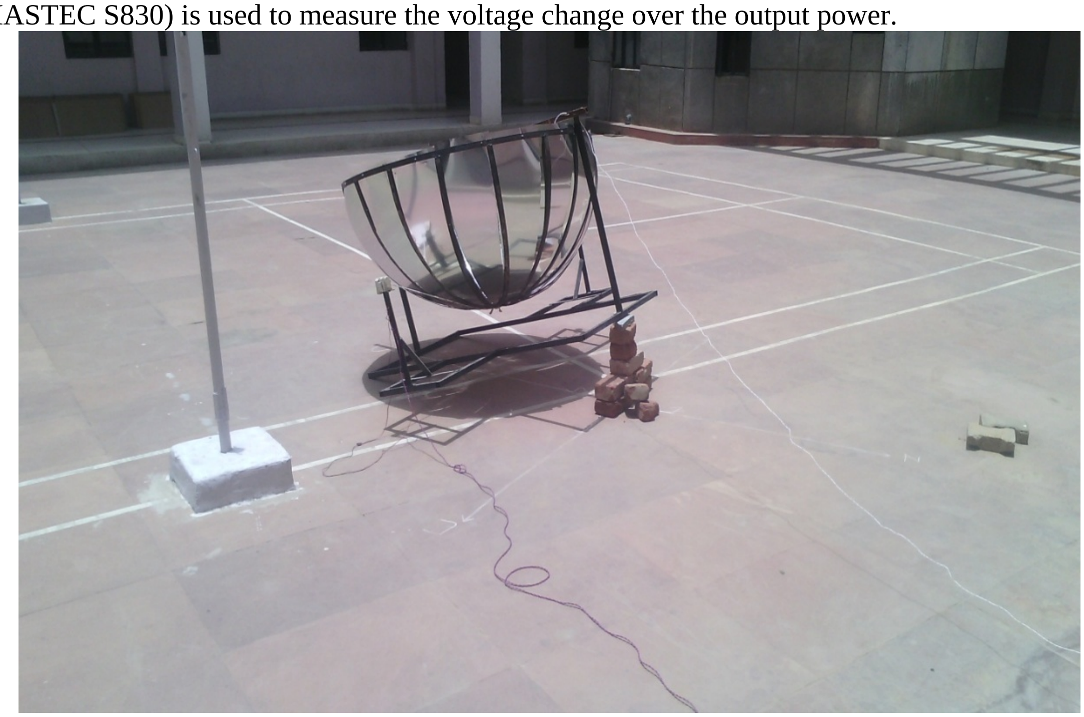

Figure 1: Solar parabolic dish collector experimental setup

One of the main factors that determine the reflection of maximum solar radiation to the receiver is the reflectance of the reflecting material used in the concentrator. The table I shows the reflectivity of some of the important reflective materials. Aluminium was selected as the reflective material due to low cost, high reflectivity and durability with the silver polished on the top of the surface as mirror for the high reflectivity and better performance of the system.

Table 1: Reflectivity of the reflective materials

MATERIAL	REFLECTIVITY
Aluminium	80-98%
Copper	75%
Silver	93-96%
Stainless Steel	62-63%

3. Design Calculation

Design of Parabolic Dish Collector and Absorber cylinder

The main parameters used for describing the concentrating collectors are given below.

1. Aperture area (A_a): The area of the collector at which solar radiation is intercepted.

2. Absorber area (A_{abs}): It is the area of the absorber where the entire radiation is concentrated after reflection or refraction from the optical concentrator.

3. Concentration Ratio(C): It is the ratio of total aperture area to the surface area of the absorber. It is also called as geometric concentration ratio. Its value varies from unity as in the case of at plate collector to few thousands for a parabolic dish collector. Let the diameter of the parabolic dish be 0.93 m.

Let the absorber tank placed at the focal point have outside diameter (D_{abs}), internal diameter (d_{abs}), height and thickness be 2mm. Let the volume of water to be heated be V_w =0.001 litres. For simple design, the height of the absorber is taken as same as that of internal diameter, abs d. By equating internal volume of the cylinder and the volume of water, V_w,

$\pi d_{abs2}/4= V_W$

$\pi d_{abs2}/4= 0.001$

Therefore, d_{abs} = l= 0.1083 m

Outside diameter of absorber,

$D_{abs} = d_{abs}+ 2 \times t$

$D_{abs} = 0.1083+ 2 \times 0.002 = 0.1123$ m

Total area of the absorber is given by,

$A_{abs}= {}_{\pi Dabs}{}^{2}/4+ {}_{\pi dabsl} = 0.045\ m^2$

Area of parabolic dish, $A_P = \pi\ r^2= 0.06792\ m^2$

Concentration ratio, $C = A_P/ A_{abs} = 14.76$

$C = 1/\sin^2\theta$, $\theta = 15.08^0$

Rim angle, $\Phi_{rim} = 90- \theta = 74.92$

Now, $f/ D_{ap} = 1 + \cos\Phi_{rim}/ 4 \sin\Phi_{rim} = 0.3034$ m

Depth of the dish, $D = R^2/4f = 0.1781$ m.

Table 2: Calculated Parameters of Solar Parabola

Diameter	0.93 m
Aperture Area	0.06792 m^2
Rim Angle	74.92
Focal Length	0.3034 m
Depth	0.1781 m

Design of main storage cylinder

The main storage cylinder is designed so as to hold 5 litres of water. It will be placed at a height above the focal point of the dish collector. A valve is provided to initially fill the tank with cold water. Another valve is used to collect the hot water. Assume that the diameter of the cylinder (d_c) and length (l_c) are equal. The thickness of cylinder is assumed to be 2mm. By equating internal volume of the cylinder and the volume of water, V_w,

$\pi d_c^2 \, l_c / 4 = V_w$

$\pi d_c^3 = 0.005$

So, $d_c = l_c = 0.1835$ m

Outside diameter of storage cylinder is given by,

$D = d_c + 2 \times l_c = 0.1893$ m.

4. Observation and Results

The useful heat gain rate obtained is given by the following equation.

$Q_U = mC_p\,(T_f - T_i) + m \times L = \eta \times I_b \times A_a$

Where m is the mass flow rate, C_p is the specific heat of water, I_b is the solar radiation, A_a is the aperture area, m is mass of water inside the cylinder, L is latent heat of water, η is the efficiency, T_f and T_i are the final outlet water temperature and intial ambient temperature of water respectively. Above equation shows that as solar radiation are increased, the outlet water temperature will be increased.

Input energy (Q_{in}) = solar flux * diameter of disc * time

Efficiency = $\frac{useful\ heat}{input\ energy} * 100$

Now, for copper cylinder:

Useful heat by water = 2* 4200 * (166 – 35) + 2 * 2275000 = 5614400 J

Q_{in} = 799 * 1.32 *5 * 3600 = 18984240 J

$\eta = \frac{5614400}{18984240} * 100 = 30\ \%$

The set up was tested with solar water heater and the highest temperature of water recorded was 170˚C and it was started to 24˚C during 10:00 hours as shown in below table. It has been found out that the time required for heating water is less than an hour during afternoon period. The temperature was not so enough to heat water during late evening but still it heats water very fast as recorded in sunny and cloudy days.

Table 3: Observed temperature of solar parabolic dish collector.

Day Time(min)	Wind velocity (m/s)	Temperature of focal point (°C)	Temperature inside cylinder (°C)	Temperature of environment (°C)	Solar flux at 26° (W/m^2)
10:00	2.5	30	24	32	538
10:30	3.9	38	40	32	686
11:00	3.3	53	69	34	703
11:30	4.1	91	90	35	795
12:00	3.5	110	115	36	840
12:30	4.9	142	148	37	946
13:00	4.5	165	162	38	957
13:30	4.6	173	170	40	993
14:00	3.4	169	169	39	702
14:30	4.0	155	161	38	685
15:00	3.1	145	156	35	669
15:30	3.4	140	140	34	620
AVG	**3.7**	**117.5**	**120.4**	**35.83**	**761.4**

The mass flow rate is assumed to be 0.002 kg/s and efficiency as 30%, it can be observed that when solar radiation was 1000 W/m^2, the outlet water temperature was 170.56 °C. A graph of outlet water temperature versus solar radiation was obtained by simulation of parabolic dish collector. Fig 1 shows the variation of outlet water temperature of parabolic dish collector with increase in radiation. The water temperature increases with increase in solar radiation. When solar radiation was reduced to 993W/m^2, 800W/m^2, 700W/m^2, 600W/m^2 and 500W/m^2, the water temperature was also reduced.

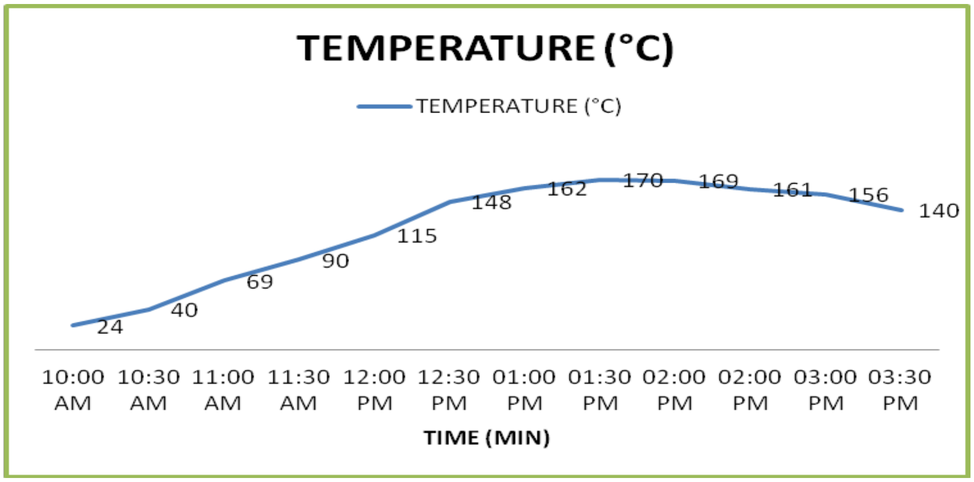

Figure 2 : Temperature graph recorded inside the cylinder for the time.

The temperature is sufficient to warm up the water. The inefficient nature of the system has been diagnosed as follows:

(i) The complete experimentation period was partially cloudy and sunny.
(ii) Since the evacuation process wasn't perfect, the accuracy of the parabola was not perfect due to that lots of incident light was reflected here and there than the focal point.
(iii) Since the cylinder size is bigger, the conduction heat loss from cylinder wall was considerable.
(iv) Heat loss from the outer surface of hose pipe and outer container as they weren't insulated.
(v) The system is designed to circulate the water from the one main tank to other insulated tank to store the heated water for long term storage use.

5. Conclusion

The designing of parabolic dish collector for hot water generation is presented in this paper. More research work has to be done for developing dish collectors for heating applications. The performance of such concentrating collectors can be improved by proper material selection for the reflecting surface and by reduction of manufacturing imperfections. By using single axis tracker the performance is increased for the dish collector and the total cost of the system can be reduced.
1. A Solar Parabola was fabricated in accordance to the details available in journals.
2. Temperature Profiling was carried out and graphically represented.
3. A parabolic concentrator was included with its base darkened for maximum absorption.
4. Temperature profiling was carried out with the parabolic concentrator and it was observed that the concentrator maximized the temperature yield of the internal of the cylinder.
5. Even though the initial investment is high, such systems can be encouraged due to its clean and green nature.

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