DESIGN AND SIMULATION OF PARABOLIC DISH COLLECTOR FOR HOT WATER GENERATION

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Abstract—The 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. In this paper, a parabolic dish collector is designed for generation of hot water which can be used for domestic applications. The simulation of dish collector is done in mat lab software.

Index Terms— aperture area, concentration ratio, , parabolic dish collector, thermal system

I. INTRODUCTION

The world energy requirement is increasing at a faster rate. Almost all the non-renewable energy sources will be depleted in the near future. These sources also cause environmental hazards. Thus the dependence on such sources has to be reduced. Thus the only viable option to meet the future energy requirement is to use the renewable energy sources. 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 utilisation. 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 45^0. [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 and cone shaped helical coil made of copper and is coated with nickel chrome is placed at its focal point. 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 ^{0}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 ^{0}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%). [5] In this paper a parabolic dish collector is designed and simulation of the dish collector is performed using mat lab software.

II. DESIGN CALCULATIONS

Design of Parabolic dish collector and Absorber tank

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 (l) 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, d_{abs}. By equating internal volume of the cylinder and the volume of water, V_w,

$$\frac{\Pi dabs^2}{4} = V_w \quad (1)$$

$$\frac{\Pi dabs^2}{4} = 0.001$$

Therefore, $d_{abs} = l = 0.1083$ m

Outside diameter of absorber, $D_{abs} = d_{abs} + 2 \times t$ (2)

$$Dabs = 0.1083 + 2 \times 0.002 = 0.1123m$$

Total area of the absorber is given by,

$$Aabs = \frac{\Pi Dabs^2}{4} + \Pi Dabs l = 0.045 m^2 \quad (3)$$

Area of parabolic dish, $A_p = \Pi r^2 = 0.6792 m^2$ (4)

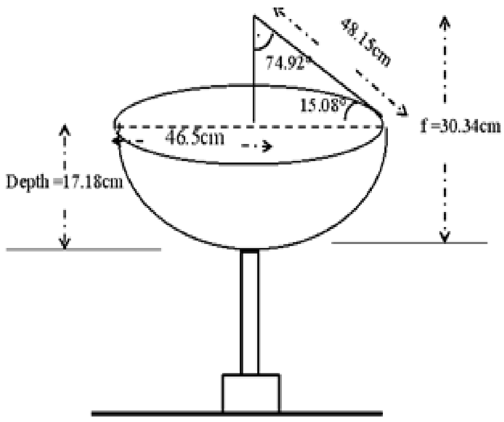

Fig.1. Schematic diagram of parabolic dish collector

Diameter	0.93 m
Aperture area	0.6792 m^2
Rim angle	74.92°
Focal length	0.3034 m
Depth	0.1781 m

Table. I. Parameters of parabolic dish collector

Concentration ratio, $C = \frac{A_p}{A_{abs}} = \frac{0.6792}{0.045} = 14.76$

(5)

$C = \frac{1}{\sin^2 \theta}, \theta = 15.08°$

(6)

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

(7)

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

(8)

Thus, $f = 0.93 * \frac{1 + \cos 74.92}{4 \sin 74.92} = 0.3034m$

Depth of the dish, $D = \frac{R^2}{4f} = 0.1781m$

(9)

The schematic diagram of the designed parabolic dish collector is shown in Fig.1 and table I specifies the parameters of parabolic dish collector.

B. Design of main storage tank

The main storage tank 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 tank (d_t) and length (l_t) are equal. The thickness of tank is assumed to be 2mm. By equating internal volume of the cylinder and the volume of water, V_w,

$\frac{\pi d_t^{\,2}}{4} l_t = V_w$.

(10)

$\frac{\pi d_t^{\,3}}{4} = 0.005$

(11)

Therefore, $d_t = l_t = 0.1853m$

Outside diameter of storage tank is given by

$D = d_t + 2 * l_t$

(12)

$D = 0.1853 + 2 * 0.002 = 0.1893m$

III. SYSTEM DESCRIPTION

The schematic diagram of the proposed system is shown in Fig.2. The main components are parabolic dish collector, cylindrical absorber tank, main storage tank, copper tubes, flexible pipe and a vertical stand. The cold water which is stored in the main storage tank is made to flow through flexible pipe and it will reach the cylindrical absorber tank. The absorber tank is kept at the focal point of the parabolic dish collector. Thus the water gets heated up because of concentration of solar radiation at the focus of the concentrating collector. The hot water is then allowed to flow through the copper tube and move to the top of the storage tank from where it can be taken out for different purposes.

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 II 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.

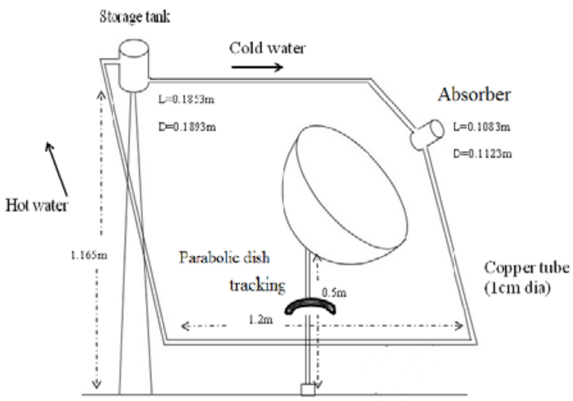

Fig.2. Schematic diagram of proposed model

Table. II. Reflectivity of high reflective surfaces

Material	Reflectivity
Aluminium	80-98%
Copper	75%
Silver	93-96%
Stainless Steel	62-63%

IV. SIMULATION OF PARABOLIC DISH COLLECTOR

The simulation of dish collector was done in Mat lab version 7.12.0 (R2011a). The useful heat gain rate obtained is given by the following equation.

$$Q_u = m * C_p * (T_w - T_a) = \eta * I_b * A_a \quad (13)$$

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, η is the efficiency, T_w and T_a are the outlet water temperature and ambient temperature respectively. Equation (13) shows that as solar radiation is increased, the outlet water temperature will be increased. The mass flow rate is assumed to be 0.002kg/s and efficiency as 50%. Fig.3 shows the simulation circuit of parabolic dish collector. From figure 3, it can be observed that when solar radiation was 1000W/m^2, the outlet water temperature was 70.56°C. A graph of outlet water temperature versus solar radiation was obtained by simulation of parabolic dish collector. Fig 4 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 900W/m^2, 800W/m^2, 700W/m^2, 600W/m^2, 500W/m^2, 400W/m^2, 300W/m^2 and 200W/m^2, the water temperature was also reduced to 66.51°C, 62.45°C, 58.39°C, 54.34°C, 50.28°C, 46.23°C, 42.17°C and 38.11°C respectively.

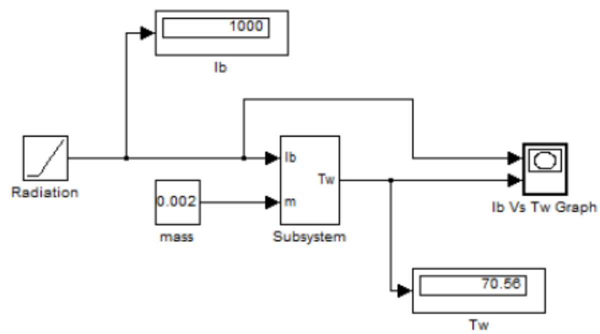

Fig.3. Simulation circuit of parabolic dish collector

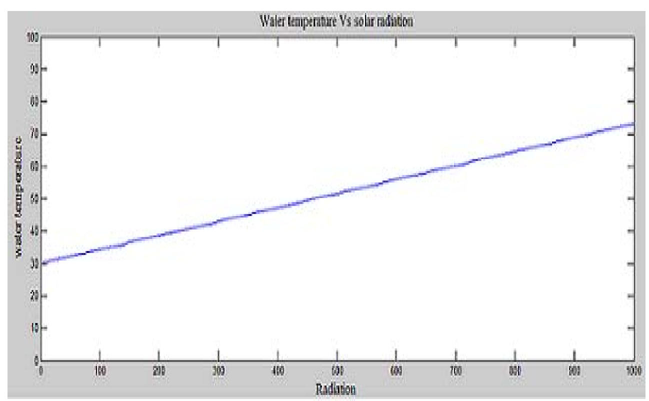

Fig.4. Variation of outlet water temperature with solar radiation

V. CONCLUSION

The designing and simulation 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 manual tracking method for the dish collector, the total cost of the system can be reduced.

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