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SOLAR THERMAL POWER GENERATION USING CYLINDRICAL PARABOLIC COLLECTOR

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ABSTRACT

The solar thermal power station based on parabolic concentrating collector gained momentum with the active involvement of the government and the private sector in different countries. This movement can potentially help in diversifying the country's energy options besides relying on fossil fuel. This paper, presenting the design of cylindrical parabolic concentrating solar collector for producing superheated steam at 126℃ under 2 bar pressure by heating water from 30℃. which can drive a small steam turbine for generating electricity. An experimental study has been conducted to determine the performance of the collector. The design of the so-called collector is discussed in brief. The collector is efficient enough to collect the solar thermal energy for producing superheated steam. A schematic diagram of the collector has also been given in this paper.

Keywords: *Rim angle, Aperture area, Radiation Intensity.*

1. INTRODUCTION

In recent years the world is concerned about end lasting energy supply problem. If the world goes on using the traditional fuels only. It is most likely that the world will have to halt its all development activities and the human civilization will come to a stagnant position after some days. Under such circum stances, solar thermal technology can make a major contribution towards the replacement of fossil fuels with renewable, leading to a suitable energy system.

Several improvement of the solar thermal power generation have been made in last few years by the following Industries: KJC Operating Company (USA), Solel Solar System (Israel), Plataforma Solar De Almeria, Laboratories: Sandia Lab, National Renewable energy Lab, Others: World Bank, California Energy Commission etc. In Bangladesh, Prof. H. Iqbal (1999) designed a solar steam boiler system.

Concentrating solar thermal technology uses large sun tracking mirror to concentrate solar radiation for producing steam. This steam can be used for rotating the turbine blade to generate electricity. There are different concentrating solar thermal technologies such as parabolic dish, power tower, cylindrical parabolic. Among them parabolic technology is the best for its low cost even in the small power generation. This technology uses parabolic shaped reflector that the sun direct beam radiation on a linear receiver located at the focus of the parabola.

In the design of the collector, the receiver tube is divided into three chambers; water is used instead of heat transfer fluid. Water is converted into saturated steam by absorbing solar thermal energy in the first chamber of the collector. This saturated steam will naturally fill the rest two chambers, where it becomes superheated by absorbing solar thermal energy. This superheated steam will finally come out of the tube under certain pressure.

2. NOMENCLATURES

The following symbols are used in this paper:

A_p	= Aperture Area (m^2)	h_{fg}	= Enthalpy of evaporation (KJ/Kg)
2b	= Aperture (m)	$\eta_{overall}$	= Overall efficiency
$D_{o,g}$	= Glass envelop outside dia (m)	I_{DN}	= Direct solar radiation Intensity(W/m^2)
L	= Length of absorber tube (m)	W	= Solar image size (m)
m_s	= Mass flow rate of water (Kg/sec)	ϕ	= Rim angle (^{0})
C_{pw}	= Specific heat of water (KJ/Kg/^{0}K	r_{max}	= Maximum mirror radius (m)
t_{sat}	= Saturation temperature of the steam (^{0}C)	F	= Focal length of the collector (m)
t_w	= Temperature of the water (^{0}C)		

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3. DESIGN OF COLLECTOR COMPONENTS

A cylindrical parabolic collector mainly consists of following components which are given bellow.

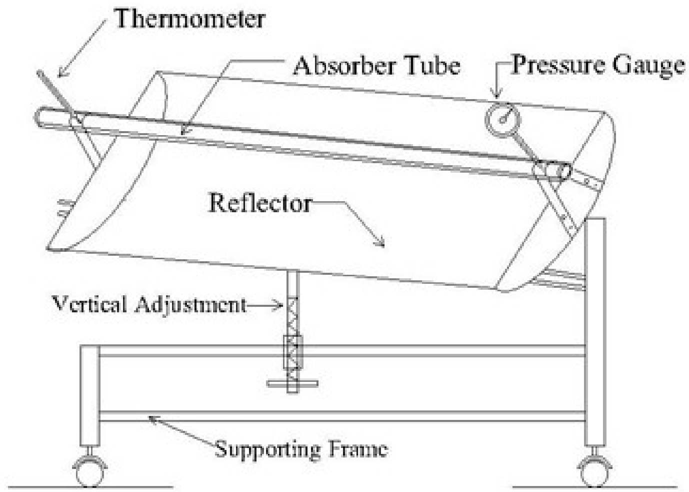


Figure 1: Schematic diagram of the parabolic solar concentrator.

3.1 Reflector Design

The reflector is 3.08 m in length and 1.5 m in width, it is tilted with an angle when facing south. It is mounted on the base constructed with steel bars. It can be rotated about its center to track the sun's motion manually. It is made of normal aluminium sheet. The solar concentrator is designed on the basis of the following assumptions.

a) The reflecting surface is continuous and perfect parabola.
b) Specular flections exist all over the reflector.
c) Uniform radiations intensity all over the concentrator.

The aperture area of the concentrator can be calculated by the following equation

$$A_p = \left(2b - D_{o,g}\right) \times L = (1.5 - 0.055) \times 3.08 = 4.45m^2 \quad (1)$$

3.1.1 Absorber Tube Design

The absorber tube is made of copper tube and surrounding by glass cover. The inside and outside diameter of the absorber tube is 0.024 m and 0.029 m respectively. It is designed on the basis of following assumptions:

a) All the energy reflected from the parabolic concentrator is to be collected.
b) Placement of the tube will ensure the smallest distance from parabola to focus.

3.1.2 Focal Length of the Reflector Design

For 1.5 m aperture area and 0.029 m solar image width (i.e., outside diameter of the absorber tube), the best rim angle ϕ_{max} can be calculated as

$$\phi_{max} = \frac{\sin \quad max}{4\tan \quad '} \quad (2)$$

$$\frac{0.75}{0.029} = \frac{\sin 2\phi_{max}}{4\tan 16'} \therefore \phi_{max} = 75.61^{\circ}$$

Again, minimum mirror radius

$$r_{max} = \frac{b}{\sin \quad max} = \frac{0.75}{\sin 75.61} = 0.77\ m \quad (3)$$

Focal length of the concentrator can be calculated as

$$2f = (1 + \cos\phi_{max}) \times r_{max} \quad (4)$$

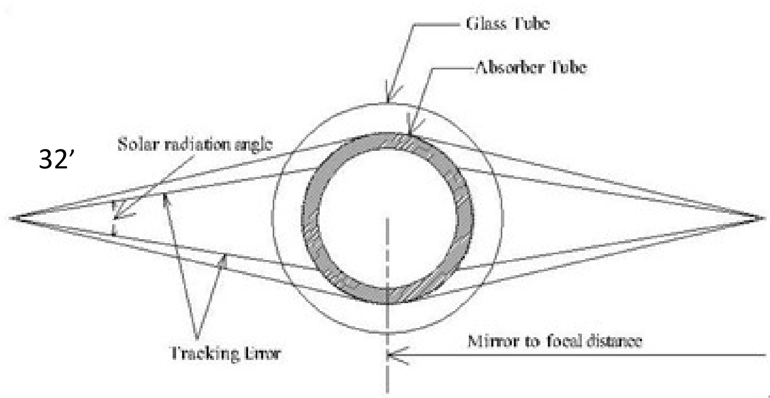


Figure 2: Solar radiation angle

3.2 Mass Flow Rate of Steam per Module

As mass flow rate is continuous throughout the system, the flow rate can be calculated as

$$A_p = \frac{m_s\left[C_{pw}(t_{sat}-t_w)+h_{fg}\right]}{\eta_{overall}\times I_{DN}} \quad (5)$$

$$2.25 = \frac{m_s[4.2(120-30)+220\ \ .9]}{0.2\times 2160}$$

$$\therefore m_s = 0.3768\ kg/hr$$

3.3 Force Required to Maintain Constant Pressure

Two bar pressure is to be maintained at the outlet of the tube, required dead weight can be calculated as

$$\text{Force,F} = (2\times 10^5)\times\frac{\pi}{4}\times(3\times 10^{-3})^2 = 1.41\ \text{Newton} \quad (6)$$

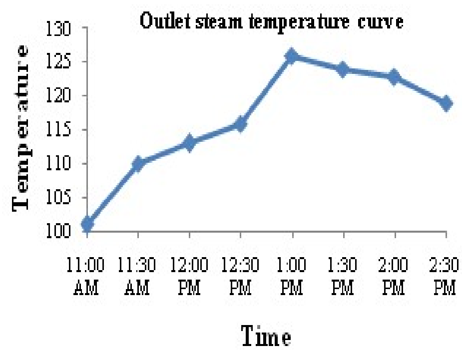
$$\therefore \text{Dead Weight} = \frac{F}{g} = 0.144\ kg \quad (7)$$

4. PERFORMANCE ANALYSIS

Performance test of the designed collector was carried out and evaluated. The experiment was performed over several days during the month of June. The collector was placed in the sunny area. A blacken absorber tube containing water, was placed on the focal point. The light from the sun falling on the collector was reflected through the focus. The arrangement was set accordingly to the position of the sun by tracking. After absorbing solar thermal energy water became saturated steam and then finally saturated steam is produced. This superheated steam finally came out of the tube under certain pressure. All the temperature was measured by thermometer, pressure by pressure gauge and flow rate by flow meter.

Table 1: Performance test of the designed parabolic solar collector was conducted at ambient temperature $30℃$ and pressure 1 bar (on 8 June, 2011)

No of observation	Time	Outlet steam temp. (℃)	Outlet steam pressure (bar)	Steam flow rate (kg/hr)
1	11.00AM	101	1.0	0.320
2	11.30AM	110	1.1	0.331
3	12.00PM	113	1.3	0.342
4	12.30PM	116	1.6	0.356
5	01.00PM	126	2.0	0.375
6	01.30PM	124	1.9	0.373
7	02.00PM	123	1.8	0.365
8	02.30PM	119	1.5	0.350



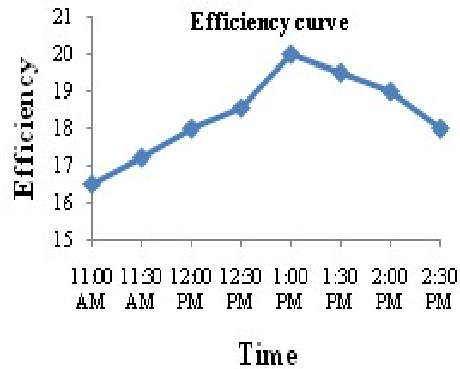
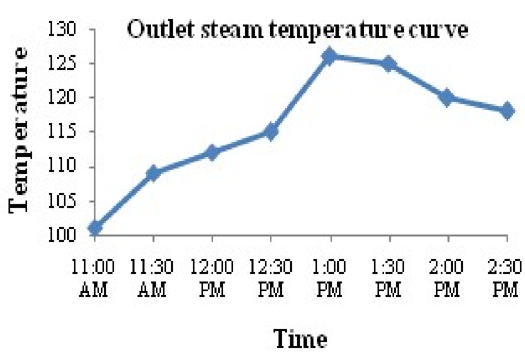


Figure 3: Variation of steam outlet temp with time **Figure 4:** Variation of efficiency with time

Table 2: Performance test of the designed parabolic solar collector was conducted at ambient temperature 30℃ and pressure 1 bar (on 9 June, 2011)

No of observation	Time	Outlet steam temp. (℃)	Outlet steam pressure (bar)	Steam flow rate (kg/hr)
1	11.00AM	101	1.0	0.316
2	11.30AM	109	1.0	0.325
3	12.00PM	112	1.2	0.337
4	12.30PM	115	1.5	0.350
5	01.00PM	126	2.0	0.375
6	01.30PM	125	1.9	0.373
7	02.00PM	120	1.8	0.366
8	02.30PM	118	1.6	0.355



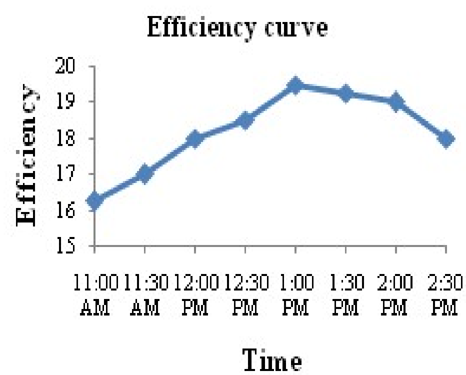


Figure 5: Variation of steam outlet temp with time **Figure 6:** Variation of efficiency with time

The collector efficiency is calculated as follows,

$$\eta_{overall} = \frac{m_s\left[C_{pw}(t_{sat}-t_w)+h_{fg}\right]}{A_p \times I_{DN}} \tag{8}$$

Two days performance of the collector is included here

5. RESULTS AND DISCUSSIONS

In this experiment, maximum temperature of the steam was found 126℃ under 2 bar pressure at a flow rate of 0.375Kg/hr. If the outlet steam temperature is investigated in the Mollier Diagram corresponding to the outlet steam pressure, it is seen that steam at outlet is a superheated steam. So, it is possible to produce superheated steam by this collector for driving small steam turbine to generate power.

It is seen form the Fig. 3 that, temperature increases to a point with time then decreases. This is due to the fact the direct normal solar radiation is not constant throughout the day. It increases up to the solar noon, then decreases. At noon the direct normal radiation is maximum. The available beam radiation received by the collector during the noon period on both days was about 2160 KJ/hr-m^2. From the Fig. 4 type equation here, it is seen that, the efficiency (based on the beam component only) drops at the higher outlet steam temperature. So, this concentrator is best efficient at noon.

It is possible to increase the operating temperature by using selective surface which have high remittance .The rate of flow of steam can be increased by reducing heat loss. This can be done by using anti-reflecting coating and maintaining vacuum between the glass cover and absorber tube. The above things were not used in this concentrator to make it cheap. So, future research can be conducted on cost benefit aspect.

6. CONCLUSIONS

At present, in most of the cases fossil fuel are use to produce superheated steam, but solar energy can be a great source of heat in this purpose. No Collector has been design yet to produce superheat steam from water of ambient temperature. But this concentrator is capable of producing superheated steam from water of ambient temperature at a flow rate of 0.375Kg/hr under 2 bar pressure and 126℃. A series of parabolic collector can be used to produce sufficient amount of superheated steam that can drive a small stream turbine for power generation. This collector also facilitated with the pressure flexibility. Besides these, to keep the construction cost low, the cylindrical solar collector is constructed using locally available materials.

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