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Performance Test of Standalone Parabolic Trough Solar Collector for Water Heating Application

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Abstract: *The tests were conducted to characterize performance of the system by measuring the flow rate, fluid inlet and outlet temperatures as well as ambient air temperature. This system involves reflector, absorber tube, supporting system and manual tracking mechanism. Experimental study is performed on small scale parabolic trough collector. In this system, the reflector is made of stainless steel (AISI 402) and the absorber tube material is copper, its thermal conductivity is quite high. The design parameters are concentrator aperture width, 0.9144 m, absorber length, 0.6096 m, concentration ratio, 15. The maximum available temperature rise is 10˚C between inlet and outlet. From this work, useful information is provided for designing and manufacturing of parabolic trough collector for water heating.*

Key Words: *Solar Energy, Parabolic Trough, Water outlet Temperature, Experiment.*

1. INTRODUCTION:

The role of renewable energy is becoming more and more important since many intensive researches have been done in the respective areas. Most of the renewable technologies such as solar thermal and power systems, wind turbines and hydraulic turbines have come to a mature stage in developed countries. A great number installation of hydraulic turbines and research works on hydraulic turbines has been done in Myanmar. However, very few installations of solar thermal and power plants have been done in Myanmar although there are many photovoltaic cells installed in rural areas and solar water heating systems in cities and towns. Research works on solar thermal and power plants have also been limited due to the lack of motivation, research facilities and equipment although there are some theoretical works done. Parabolic trough collector is renewable energy and it can produce required amount of energy without burning fuel. In our Myanmar, parabolic trough collector has not been reported because it is not available in local market, expensive to construct and sufficient knowledge has not been distributed. Therefore, the purpose of this study is to construct a standalone parabolic trough collector for water heating application. Parabolic collector with reflecting or concentrating mirror, receiver tube has been constructed stand alone without any integrated components except the inlet and outlet pipes, the insulation and the pump.

2. THEORY OF PARABOLIC TROUGH SOLAR COLLECTOR (PTSC)

PTSC can be divided into two parts. It is showed in figure 2.1. This frame made by wood and it can support this system. Reflector is made by bending a sheet of reflective material into a parabola shape and it is reflected sun rays on the absorber tube. Reflector material is made by polish steel. Copper tube is used for receiver tube since its thermal conductivity is higher than steel and it is available in local market and not expensive.

The working principle of parabolic trough collector is the sun rays hits the collector and it is reflected on the absorber tube. This tube absorbs rays and it can transfer heat. At this time, the cold water passing the tube and it is transferred heat send into the water. In this way, this system can produce required amount of water.

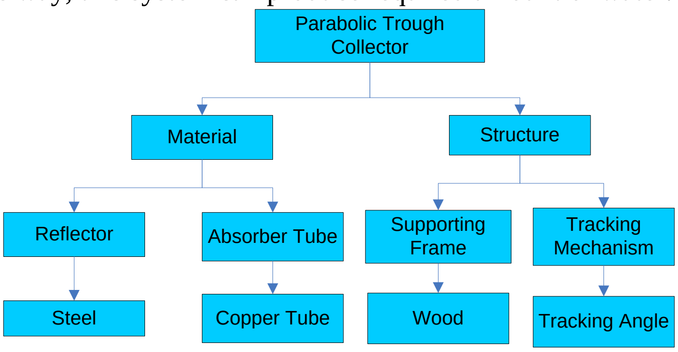

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Figure 2.1. Parts of Parabolic Trough Collector

3. BASIC EQUATION FOR WATER HEATING SYSTEM

In this system, the main equations have seven parts. They are following described.

(i) Affective Irradiance on Aperture

$$I = I_b \cos\theta \tag{1}$$

where, I – effective irradiance on aperture
I_b – beam radiation
θ – angle of incidence of the sun on the aperture

(ii) Beam Irradiance

$$I_b = I_{0,\,eff}\ [\ a_0 + a_1 \exp\ (\ -\frac{k}{\cos\theta_z}\ )\ ] \tag{2}$$

where,
I_b - beam irradiance,
$I_{0,\,eff}$ - effective solar constant,
θ_z - solar zenith angle

a_0, a_1 and k are coefficients of tropical climate type.

(iii) Effective Beam Irradiance

$$I_{0,\,eff} = I_0\left[1+0.033\cos\left(\frac{360n}{365.25}\right)\right] \tag{3}$$

where, n - the day of year after 1 January,
I_0 - the solar constant = 1367 W/m^2

(iv) Parabolic equation

$$y = \frac{x^2}{4f} \tag{4}$$

where, y – length of reflector
x – width of reflector
f – focal length

(v) Curvature equation

$$x^2 = 2Ry \tag{5}$$

$$R = \frac{x^2}{16f} \tag{6}$$

where, R – radius of curvature

(vi) Tracking Angle

$$\text{E/W track angle} = \tan^{-1}\left(\frac{\cos\omega}{\tan\delta}\right) \tag{7}$$

where, δ – declination angle
ω – hour angle

(vii) Water Outlet Temperature

$$\frac{T_{f_0} - T_{f_i}}{\left[\left(\frac{CS}{U_l}\right) + T_a\right] - T_{f_i}} = 1 - \exp\left(-\frac{F'\pi D_0 U_l L}{m^{\cdot} C_p}\right) \tag{8}$$

where,
T_{f0} - outlet temperature (K)
T_{fi} - inlet temperature (K)
F′ - collector efficiency factor
D_0 - outer diameter of tube (m)
U - overall heat coefficient (W/m^{2}K)
$m^{\cdot}$ - mass flow rate (kg/s)

C_p - specific heat of fluid (kJ/kgK)
C – concentrating ratio
S – absorption of heat flux on the absorber tube (W/m^2)
T_a – ambient air temperature (K)
L – length of the tube (m)
Velocity, v = 0.002 m/s

4. DESIGN DATA OF AVAILABLE ISOLATION

Mandalay, North latitude, λ=21.98°
East longitude, L= 96.1ºE
Elevation above sea level, H=74.676x10^{-3} km
Climate type, Tropical
Local standard time of meridian, L_{st}=97.5ºE

5. EXPERIMENTAL SET UP

(a) Reflector: A stainless steel sheet of dimensions (3ft x 2ft) is used to form the parabolic shape in prototype with the use of all the dimensions calculated from the software and theory.

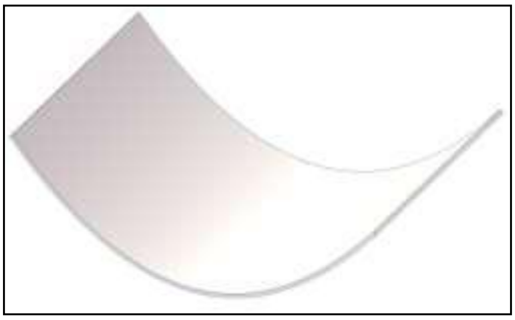

Figure 5.1. Steel Sheet Reflector

The stainless steel sheet is used to provide the mechanical strength to the parabolic trough. The value of reflector's reflectivity is 90%. It is shown in figure 5.1.

(b) A copper tube with the glass cover tube on it joined by the glass to metal seals on both sides of the copper tube is used as an absorber tube.

Figure 5.2. Absorber Tube

The glass cover tube is used so as to reduce the conductive, convective, and radiative losses from the copper tube. A copper tube with length 2ft and with inside and outside diameter of 17 mm and 19 mm are used. A copper tube with the glass cover tube over it is shown in figure 5.2.

(c) Support structure: The support structure for the PTSC is made up of wood. The selection of wood as a material for the support structure is because it is cheap, easy to maintain, lighter in weight and also it is very flexible to the changes if necessary. The support structure which is made up of wood is black painted. The support structure is fabricated in such a way that it could withstand wind loads, stress loads etc. It is also designed so that it could not affect the shape of the parabola and also to minimize the alignment errors. The provision of manual tracking is also there in the support structure. Figure 5.3 shows the support structure used in the experiment.

Figure 5.3. Wood Supporting Frame

6. CONSTRUCTED PARABOLIC TROUGH COLLECTOR

This collector is constructed in Mandalay Technological University at Mechanical Engineering Department. The purpose of this research is to construct a standalone parabolic trough collector for water heating application. Parabolic collector with reflecting or concentrating mirror, receiver tube has been constructed standalone without any integrated components except the inlet and outlet pipes, the insulation and the pump. The working fluid used water. Performance test were conducted to obtain the characterize performance of the system by measuring the flow rate, fluid inlet and outlet temperatures as well as ambient air temperature. The maximum available temperature rise is 10°C in December. The details specifications are shown in figure 6.1. The collector width is 0.9144 m and absorber tube length is 0.6096 m. Concentration ratio of this collector is 15 and the rim angle 79°. Glass is the highest reflectivity but it is not available in local market.

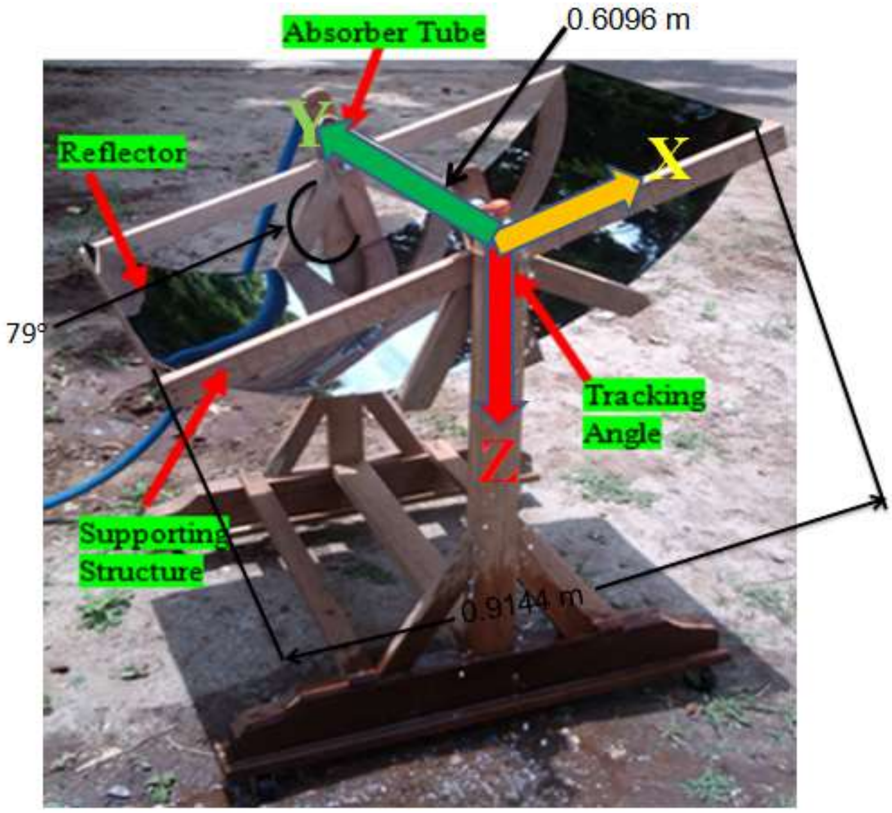

Figure 6.1. Parabolic Trough Collector

Polish steel is the second highest reflectivity and it was used for collector since it is also available in local market and not expensive. The total cost of this application is 150000 kyat. One limitation of this collector is that the tracking of the collector to follow the sun's motion was done manually.

7. EXPERIMENTAL RESULTS AND DISCUSSIONS

Experiment is tested on October 2013 to June 2014, September 2014 and December 2014. It is regularly recorded at the month of the first and last week and measured the ambient temperature, inlet and outlet water temperature. The working time is 9:30 am to 4:00 pm. In Figure 7.1 shows the monthly ambient temperature on October 2013 to September 2014.

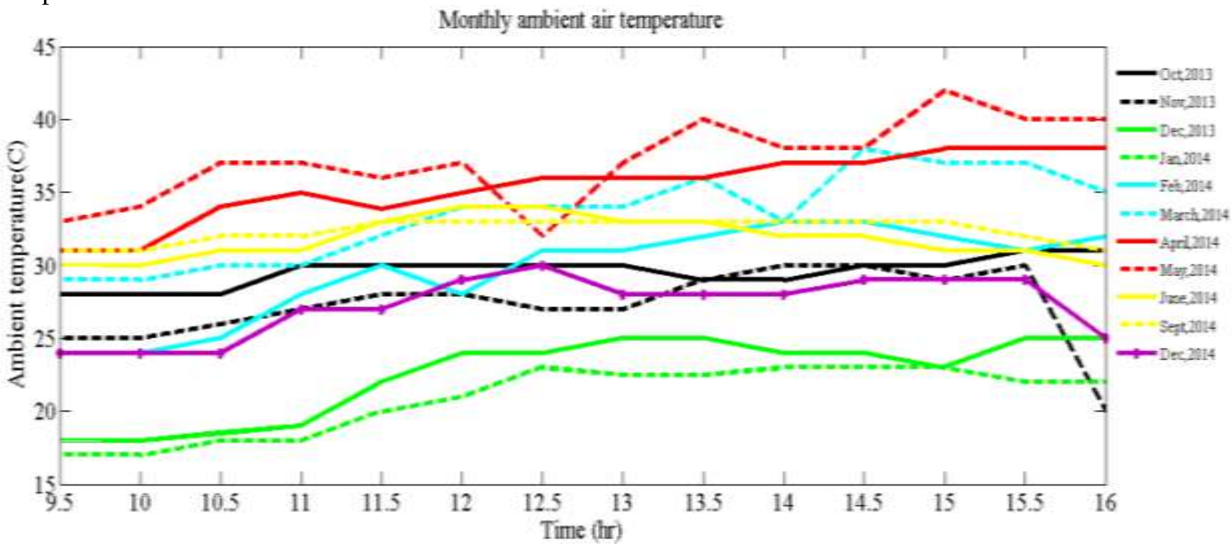

Figure 7.1. Monthly Ambient Temperature

Myanmar has three seasons. They are summer, rainy and winter. Summer is March to June and rainy is defined July to October. Winter is November to February. It can be seen in the figure that the x-axis is working time for this application and the y-axis is ambient temperature. May is the hottest moth in Mandalay and this temperature vary with time.

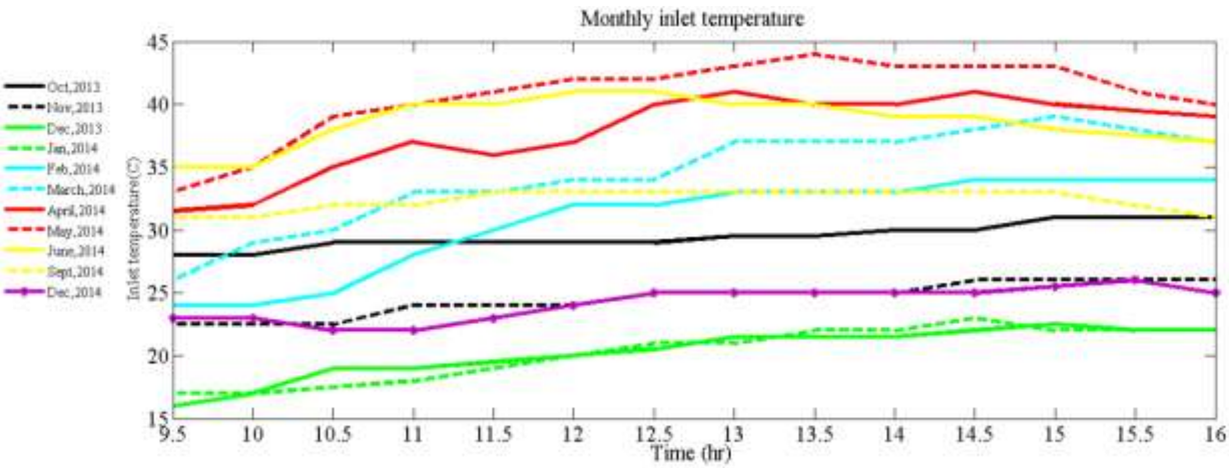

Figure 7.2. Monthly Water Inlet Temperature

The maximum temperature is 42°C.In Figure 7.2, x-axis represent working hour and y-axis is inlet water temperature for this application. Similarly, it can be seen that May is the highest and December is the lowest. This figure shows the ten months of water inlet temperature with vary time. In Figure 7.3 shows the experiment of water outlet temperature for ten months. X-axis represents working time (hr) and y-axis is water outlet temperature(C) with time. It can be clearly see that May is the highest and December is the lowest. Generally, the each month is occurred the maximum temperature at approximately 1 pm to 2pm. The water outlet temperature is depending on the ambient and inlet temperature. It is steadily increase until 2 pm and then it was decreased to 4 pm.

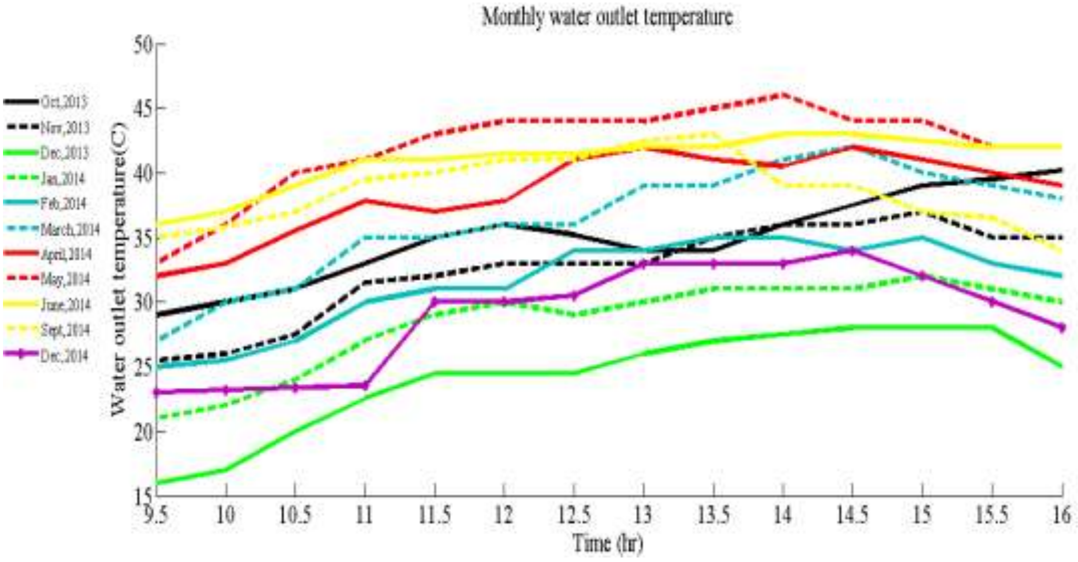

Figure 7.3. Monthly Water Outlet Temperature

7.1. Comparison between Theory and Experiment of Water Outlet Temperature

In Figure 7.4 shows the percentage deviation between theory and experiment of water outlet temperature on December 6th 2014. According to this figure, maximum and minimum outlet temperatures $(22^{\circ}C - 34^{\circ}C)$ for experiment and $(22^{\circ}C - 36^{\circ}C)$ for theory. Therefore, the deviation has 14% and it is shown in figure 7.5.

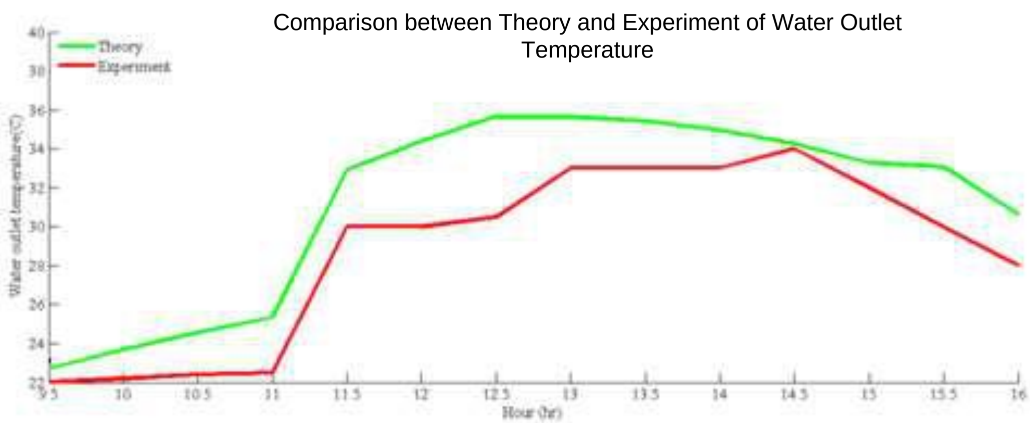

Figure 7.4. Comparison between theory and experiment of water outlet temperature on Dec 6th 2014

Between theoretical and experimental outlet temperatures results have 14%. Because tracking angle rotation, hourly clearness index, intercept factor, specular reflectivity and beam radiation and heat losses of absorber tube.

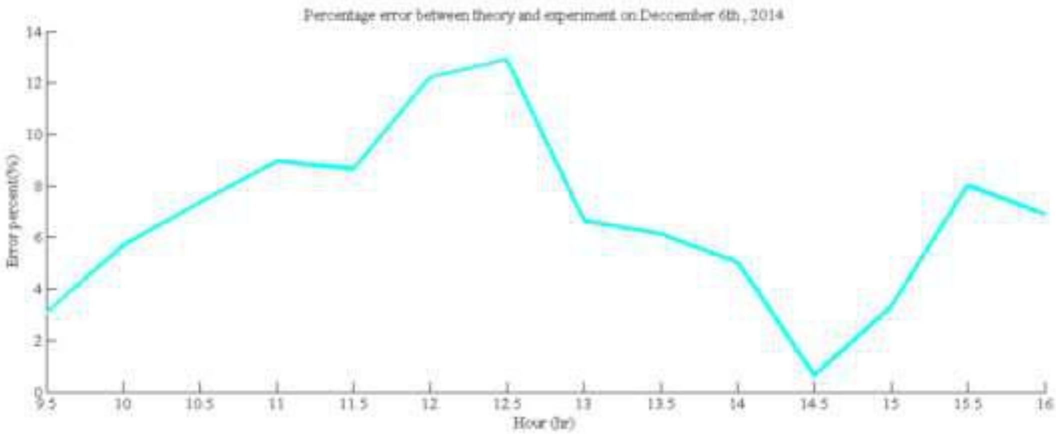

Figure 7.5. Deviation between theory and experiment of water outlet temperature

8. CONCLUSION:

In this study, the design of parabolic trough collector for water heating application has been mainly studied. The test was performed at Mechanical Engineering Department, Mandalay Technological University. Firstly, the systematic investigation was conducted into the operating principle and performance analysis of standalone parabolic trough collector by numerical and experimental methods. Based on the results, the optimum value of rim angle is 79°, concentration ratio is 15 and focal point is 0.227 m. According to the Department of Meteorology (Mandalay), the maximum value of radiation on December, 2013 is 800 W/m^2. In experiment, the maximum water outlet temperature is 32°C, the inlet temperature is 23ºC and the ambient air temperature is 24°C on December 2014. Water outlet temperature rise is 10ºC. According to the study on the effect of inlet velocity, the optimum inlet velocity is the mass flow rate is 0.08 kg/s.

9. RECOMMENDATIONS:

In this experiment, the parabolic unit is open loop. Therefore, it should be tested close loop to complete water heating system. Moreover, inlet velocity must be properly controlled with using pump. This system should be set up with automatically tracking system. It should be test with the various fluids to produce power.

10. ACKNOWLEDGMENT:

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