Experimental study of Parabolic Trough Collector (PTC) and compare with ANSYS model

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Abstract - *This paper is concerned with an experimental study of a simple parabolic trough solar collector tested under the climatic condition present in a NAGPUR on dated 5-March-2015 to 11-March-2015. The study is based on the compression of experimental model with analytical model. Analysis is carried out with the help of ANSYS software. Analysis* ***is done on the collectors' performance, temperature*** *effective length of the concentrator and different velocities. A small scale parabolic trough was fabricated with the local available materials using stainless steel sheets as parabolic reflector and galvanized steel pipe as the receiver. The collector is designed with simple parabolic equations. It was out door tested at the Nagpur having latitude 21.1500° N, longitude 79.0900° E and 67m elevation. The heat transfer fluid (water) was force circulated from a header tank. The water was continuously circulated from same header tank. From the test result and the* ***collectors' performance, the model is seen fairly*** *acceptable for thermal processes.*

Key Words: Parabolic trough collector, solar collector, PCT.

Introduction

This project researched the viability of producing high temperature industrial process heat from the sun's energy. The research was performed through the design, construction, operation, and analysis of a high temperature solar thermal system. The solar thermal system is intended to improve plant efficiency with minimal impact on day-to-day production operations. Process steam in the plant is used for cooking, which includes heating edible oil for frying, and heating baking equipment. Steam is also converted into hot water for cleaning and sterilization processes. Accordingly solar thermal systems became one of the most attractive solutions for these problems. Parabolic trough collectors (PTCs) are currently the most proven solar thermal technology for solar steam generation since high temperature can be obtained without any serious degradation of the collector efficiency. Researchers and engineers tried to optimize the solar energy utilization based on the solar energy parameters. The paper focuses on the effective length of the PTC as one of these parameters depends on the mass flow rate. Since collectors' efficiency depends on the solar insolation and ambient weather condition, the collector performance depending on these parameters is investigated. From the results of this parameter, other similar system can be optimized. A simple parabolic trough collector is designed, fabricated and tested.

Parabolic trough collector

Parabolic trough is a device in a parabolic shape, having small focal length of. Experiment was conducted on PTC (Parabolic trough collector) of length 1 m and of having area is 1×0.6 m^2. The dimensions of PTC are shown in Table 1. Fig. 6shows the experiment setup of PTC. The PTC having single axis tracking system, from East-West and it positioned in a South–North direction. Water is chosen as a heat transfer fluid. The thermal conductivity of water is 2.18 W/(m. K) at 0 °C, and initial or inlet temperature of water is considered as 300^{0}K. The hot water is used for domestic application. It can be seen from Fig. 1 that the PTC is consists of a receiver and a reflector. The reflector curved surface concentrate the sun rays in one axis (Focal point). Stainless steel used as a reflective material, having a length of 68.875 cm. The receiver consists of absorber tube placed at a centre of copper plate shown in Fig. 2. Copper plate is used to increase the heat transfer area. The absorber tube is plated with a selective coating, in which the coating is designed to allow pipes to absorb high levels of the solar radiation while emitting very little infrared radiation. The receivers are coated with high temperature PU-MATT black paint (α= 0.94 and ε = 0.9) to absorb the maximum solar radiation.

Construction

Parabolic trough collector is fabricated in different levels like parabolic trough collector, tracking system, steam drum and foundation. Parabolic trough collector concentrate solar radiation on copper tube placed at a focal point of parabolic trough collector. Fig. 1 shows the path of light concentrating on tube through which water is flowing. Dimensions and material of components used are shown in Table 1

Table 1
Dimensions of PTC

Focal length	0.15m
Aperture width	0.6m
Rim angle	90^0
Concentration ratio	12
Mirror reflectivity	90%
Material of the absorber pipe	Copper
Absorber inner diameter	11mm
Absorber outer diameter	12mm
Coating absorbance	0.94
Coating emissivity	0.9

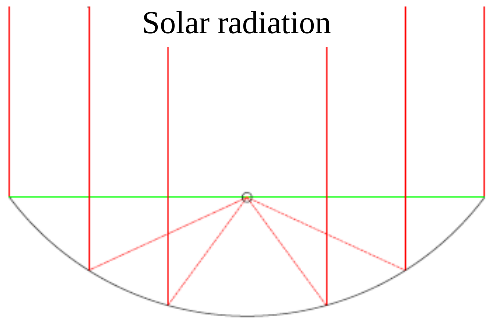

Fig. 1 Path of radiation

Light is concentrating on copper tube after getting reflected from collector. Fig 3 is a drawing prepared in CATIA V5 showing the view of parabolic trough collector with copper tube.

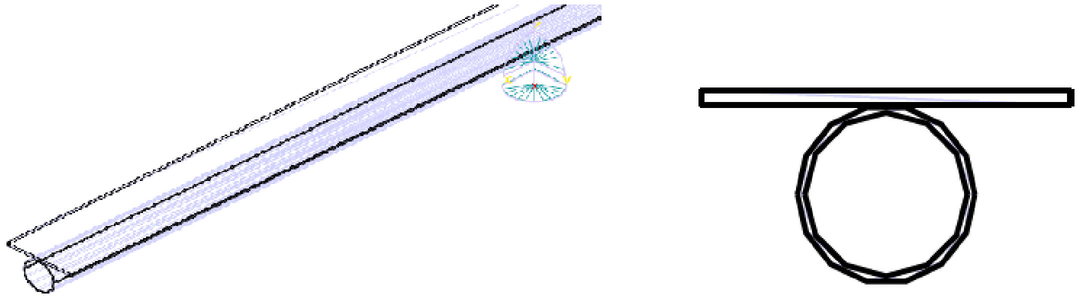

Fig. 2 Receiver

1.1 The receiver

The receiver pipe is selected from the available local pipes. Although the copper is relatively low absorptivity, it is selected as the collector absorber as only available pipe at moment of design and test. A pipe of 1.1 cm inner diameter and 1.2 cm outer diameters is connected to a copper plate of 2.5cm width is used. It is acceptable according to the aperture width to give geometrical concentration ratio of 12, according to the limitation of the collectors' parameters and common practice such as piping, fluid velocity, fabrication and heat loss. It needs daily adjusting the sun motion. The absorber is coated with black color.

1.2 The reflecting surface

The collectors reflecting surface of stainless steel is curved in a parabolic shape that linearly extended into trough shape to form curve area of 2.88m^{2}and aperture area of 2.4 m^2.

Trough design

Stainless steel sheet 2.4m ×1m was chosen as reflecting surface. The collector is designed with simple parabolic equations. From geometrical relations of the parabolic section, equations (1), the cross section for the parabolic trough was traced as shown by Fig 4. The sheet was curved to form a parabolic trough module of 2.4m length which was calculated from equation (4) and 1m aperture width with effective aperture area of 2.4 m^2. Simple parabolic equation in Cartesian coordinates is,

$$x^2 = 4fy \qquad (1)$$

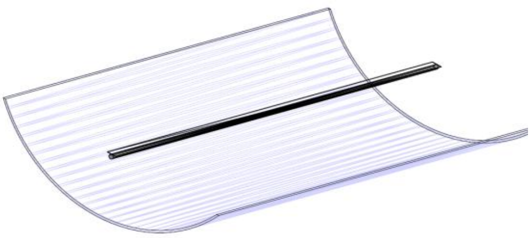

Fig. 3 Drawing of concentrator and receiver in CATIA V5.

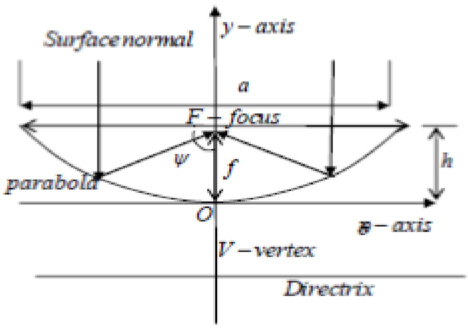

Fig. 4 Cross sectional view of parabola

From equation (1), the height of the parabola in terms of the focal length and aperture diameter is:

$$\left(\frac{a}{2}\right)^2 = 4fh \qquad (2)$$

$$h = \frac{a^2}{16f} \qquad (3)$$

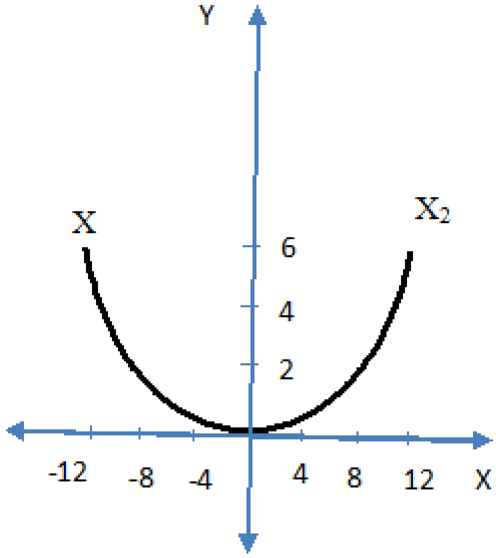

Fig. 5 Parabola

Length of parabola from X to X_2 ie "S" shown in Fig. 5.

$$S = \left[\left(\frac{pq}{t} + t\ln\left(\frac{p+q}{t}\right)\right)\right] \qquad (4)$$

p = 30 cm

t = 2(15) = 30 cm

$q = \sqrt{t^2 + p^2}$ = 42.425 cm

S = 68.875 cm

Experimental setup

The experimental setup for testing the collector consists of the constructed collector, 96liters storage tank, and throttling valve. The storage tank is fixed at one side of the collector. Pump is connected to the inlet pipe with valve, for controlling the flow rate and the velocity of water flowing through tube. The storage tank is filled from main water supply and flow is done in an open system. The water inlet and outlet temperature of the absorber tube, the water flow rate and the solar radiation intensity are continually measured during the experiment. The test was carried outdoor during 5-March-2015 to 11-March-2015.

Fig. 6 Experimental setup

Analysis

Analysis is done using ANSYS software with different concentration ratio and different velocity of fluid. Analysis and experiment is conducted on application basis. In household application like BATH, maximum temperature of water required of 70^0-80^0C. So, by considering output temp and input temperature of water constant the other parameter was designed. Fig. 7 shows the result of temperature of water at outlet in ANSYS model.

Result

Analysis is done with different velocities like 0.01m/s, 0.025m/s, 0.05m/s, 0.1m/s and 0.15 m/s. With velocity 0.05m/s, the result was optimum which is shown in the Fig. 9, 10, 11 and 12 considering the outlet temperature of water 89^0C. And Fig. 8 shows the increase in the velocity of flow across the flow and change in velocity to the perpendicular direction of flow.

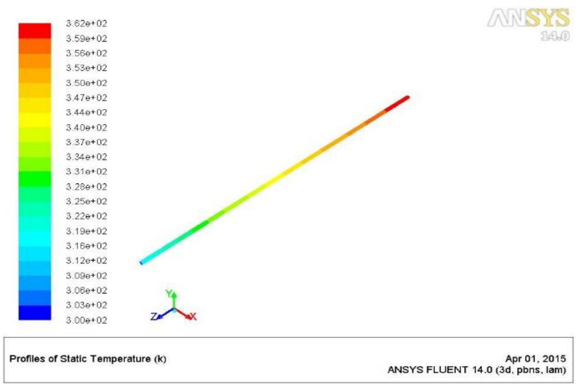

Fig. 7 ANSYS result (Temperature of water at outlet)

Outle Inlet

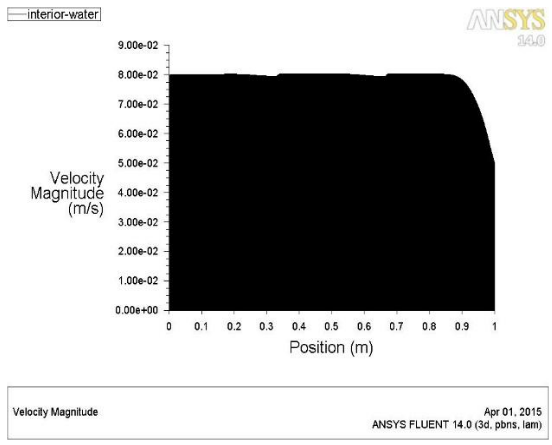

Fig. 8 ANSYS result (change in velocity in direction of flow)

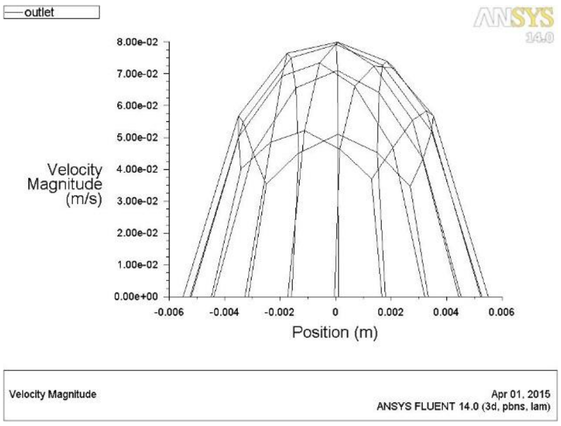

Fig. 9 ANSYS result (change in velocity in direction of perpendicular to flow at outlet)

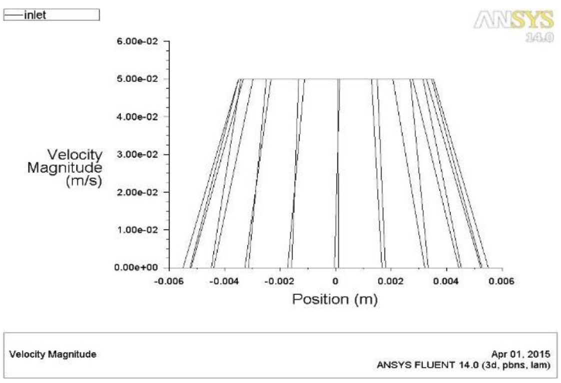

Fig. 10 ANSYS result (change in velocity in direction of perpendicular to flow at inlet)

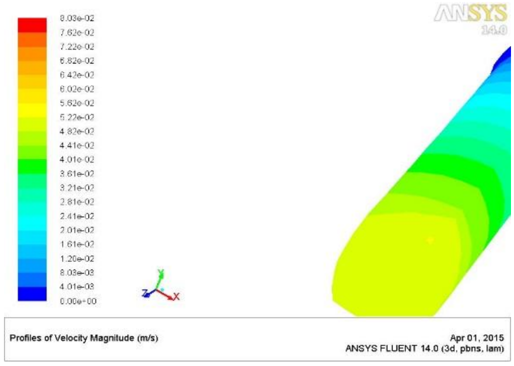

Fig. 11 ANSYS result (velocity at inlet)

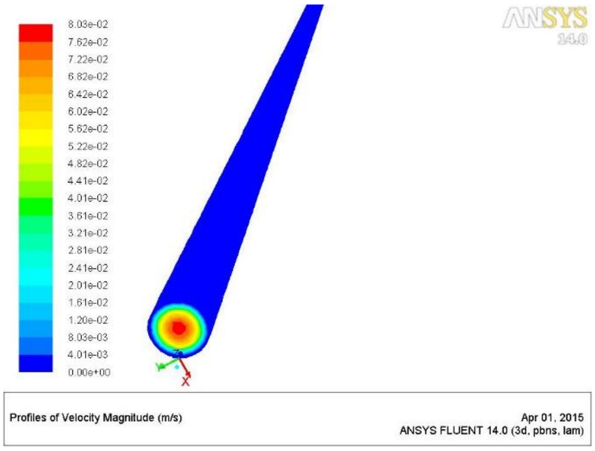

Fig. 12 ANSYS result (change in velocity in direction of flow)

Table showing the experimental result conducted during 5-March-2015 to 11-March-2015.

Conclusion

From the test results, the collector and the receiver can be optimized to the required length for selected temperature required. Since the concentration ratio is one of the parameters affect the collector's performance, and the experiment is carried on one concentration ratio. The configuration of the collector is N-S orientation. This will allow operation with tracking system in such a way that most of the concentrated rays are intercepted by the receiver and the performance probably changed. The experimental result is shown in Table 2. Experiment result is compared with ANSYS result, the average collector efficiency getting is about 36.5%.

The results achieved using this miniature parabolic trough solar concentrator did not quite match up to the results expected based on the initial ANSYS modeling. The ANSYS model initially proposed considered perfect conditions and a perfect parabolic trough concentrator. Thermal losses can occur through heat transfer by conduction through the surface of the parabolic trough and into the frame. Heat loss due to convection can also be a major issue on the receiver pipe surface .Fluctuation in wind speed throughout testing likely caused more heat loss than expected. Better insulation of the back of the reflecting surface would also help with the heat lost due to conduction. The shape of the parabola may also not have been perfect due to issues during construction. These could all affect the amount of incident radiation on the copper receiver tube and thus the amount of heat transferred to the concentrator fluid. Therefore the temperature gain received in testing was significantly lower than predicted with the ANSYS model.

References

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Table 2

Sr. No	Time	Ambient temperature	Initial water temperature	Final water temperature
1	8:00	24	19	25
2	8:30	26	20	27
3	9:00	29	22	28
4	9:30	30	23	31
5	10:00	32	25	34
6	10:30	34	25	36
7	11:00	35	27	40
8	11:30	38	27	40

Experimental result

BIOGRAPHIES

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