# Experimental Analysis of Thermal Performance Characteristics for Aluminium & Copper Absorber Tubes Employed in PTSC-water Heating System

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**Abstract—***In solar thermal processes, the way in which the assessment of heat transfer takes place amongst different key elements of solar hot water system essentially requires system design and performance predictions. Many factors affect the head loss in pipes, the viscosity of the fluid being handled, the size of the pipes, the roughness of the internal surface of the pipes, the changes in elevations within the system and the length of travel of the fluid. This paper is mainly emphasized on the selection of the optimize parameters (like flow management, thermal expansion, economization through selection of absorber material, reflective surface material, material emissivity properties etc.) for the efficient solar thermal conversion through for a water heating process in order to reduce the loss of heat through conduction, convection and radiation and make a system economic. For this purpose, experimental results have been obtained for different types of absorber tube.*

## 1. INTRODUCTION

Solar water heating system comprises of several innovations and many mature renewable energy technologies, which have been accepted in most countries over the world for many years. Nowadays, the world's energy demand has been increased tremendously, and it is the natural, safe and costless process to collect the hot water by solar radiations. Energy as an essential factor for the socio-economic development of the societies, play an important role. In future, the present work could be extended to validate the model development and its economic and environmental impacts on the respective sectors of implementation.

## 2. SWH THERMAL ENERGY ANALYSIS

The exchange of energy between two bodies of different temperatures is called heat transfer. This mechanism or modes of transformation of energy generally occurs via three different ways:

- Conduction
- Convection
- Radiation

Conduction heat transfer mode of energy transformation occurs in a body when a temperature gradient exists, where the heat travelling to the lower temperature region. The heat transfer rate is directly proportional to the temperature gradient multiplied with the area through which heat transfer takes place. Convection heat transfer mode of energy transformation occurs when the working fluid comes into contact with solid objects. In this case, the heat transfer is directly proportional to the temperature difference between the fluid and the object's surface area in contact with the working fluid. Radiation heat transfer mode of energy transformation occurs through electromagnetic radiation emission and absorption between bodies of different temperature and is known as thermal radiation. This mode does not require any solid medium to propagate.

## 3. RESISTANCE TO FLOW IN A PIPE

When a fluid flows through a pipe the internal roughness of the pipe wall can create local eddy currents within the fluid adding a resistance to flow of the fluid. Pipes with smooth walls such as glass, copper, brass and polyethylene have only a small effect on the frictional resistance. Pipes with less smooth walls such as concrete, cast iron and steel will create larger eddy currents which will sometimes have a significant effect on the frictional resistance. The velocity profile in a pipe will show that the fluid at the center of the stream will move more quickly than the fluid towards the edge of the stream. Therefore friction will occur between layers within the fluid. Fluids with a high viscosity will flow more slowly and will generally not support eddy currents and therefore the internal roughness of the pipe will have no effect on the frictional resistance. This condition is known as laminar flow.

The flow of liquid through a pipe is resisted by viscous shear stresses within the liquid and the turbulence that occurs along the internal walls of the pipe, created by the roughness of the pipe material. This resistance is usually known as pipe friction and is measured is feet or meters head of the fluid, thus the term head loss is also used to express the resistance to flow. The resistance through various valves and fittings will also contribute to the overall head loss. In a well-designed system the resistance through valves and fittings will be of minor significance to the overall head loss, many designers choose to ignore the head loss for valves and fittings at least in the initial stages of a design. Much research has been carried out over many years and various formulae to calculate head loss have been developed based on experimental data. Among these is the Chézy formula which dealt with water flow in open channels.

Thermal energy gained or lost by a body during the process of heat transfer can be expressed in terms of the temperature change undergone by the body itself, the mass of body and the capacity. For analytical calculation, in order to use constant values for emissivity following assumptions are made:

- Radiation properties are independent of wavelength
- Surfaces are diffuse equally
- Surface temperature is uniformly distributed
- Incident energy is uniformly distributed over the surface

## 4. PTSC WATER HEATING SYSTEM:DESIGN & FABRICATION

The prototype models used for SWH system is an active system. The first prototype model of PTSC water heating system consists of a ½" copper pipe which is selected as receiver and is sprayed with black resistant paint in order to maximize the energy absorption by the copper pipe. Various paints were chosen to increase the absorptivity of the copper pipe.The design parameters of parabolic trough collector can be classified into two categories:

1. Geometric
2. Functional

The geometric parameters of a PTSC systems includes its aperture width and length, rim angle, focal length, diameter of the glass envelope (if required) and the concentration ratio, while the functional parameters includes optical efficiency, instantaneous and overall thermal efficiency and receiver thermal losses. In this section an analysis of the geometrical characteristics of the mini parabolic solar collectors is made. The data of the mini parabolic system used for study are provided. The length, l =1066mm (approx. 42"), is big enough to avoid end effects, as the image from the end of the trough is formed beyond the end of the receiver.

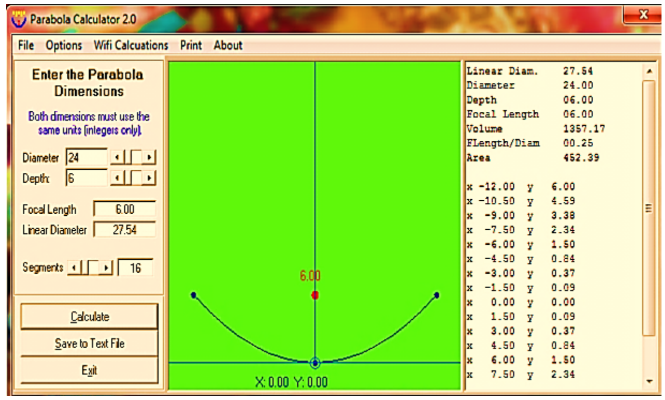


**Fig. 1: Designing of parabola concentrator using Parabola Calculator 2.0 version**

**Table1: Different parameters with their design values**

| Parameter | Design value |
|---|---|
| Linear Diameter | 27.54" |
| Volume | 1357.17 cubic inch |
| Area | 452.39 inch² |
| Depth | 6" |
| Diameter (D) | 24.00" |
| Focal Length (f) | 6" |
| Rim Angle | 90° |
| f/D | 0.25 |
| Concentration height | 9" |

After finalizing the design considerations of the ,the main task is to fabricate the concentrator with the use of different easy available and more economic materials. The main accent is on reduction of the cost of the PTSC system, by using different alternate materials without compromising on the quality and performance of the system. The fabrication of PTSC system is shown in below figure2:

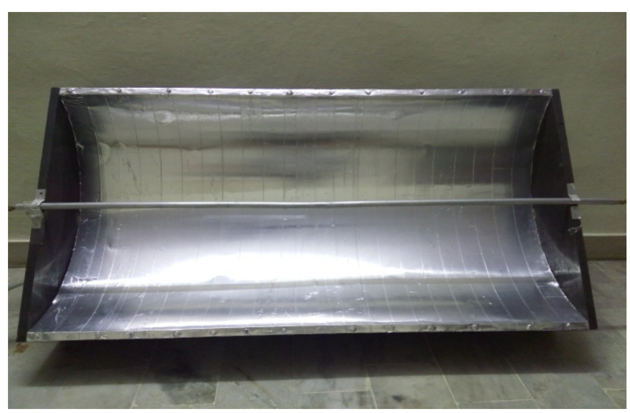

**Fig. 2: Reflector with Al absorber tube**

## 5. WORKING PRINCIPLE OF SHW SYSTEM

**Fig.** 3, shows the basic schematic arrangement for water flow through the receiver Copper pipe. The storage tank is of 15 liters capacity and is filled with the water, used as a working fluid. Water is circulated to the absorber tube with the help of a water pump which is located inside the storage tank. The mass flow rate of water through the absorber tube is 0.1344kg/sec.

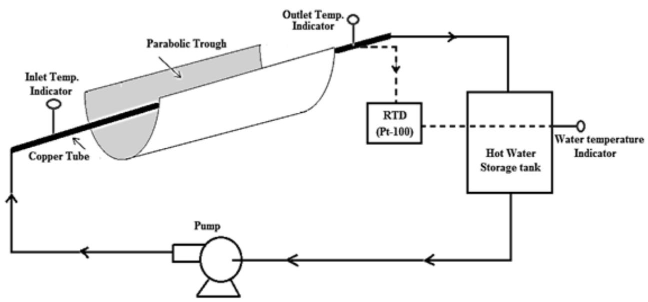


**Fig. 3: Proposed Scheme**

During circular transmission, fluid gains heat in the absorber tube and comes back in the storage tank. The water is then re-circulated again and again through the absorber tube throughout the whole day.

Two insulated pipes one from storage tank to the inlet of the absorber tube and other from the outlet of the absorber tube to the storage tank are used to carry the water from storage tank to the absorber tube. It is noted that in the experimental set up the peak temperature of the water is obtained at 01:00 PM and after that the temperature started decreasing due to the thermal losses from the absorber tube. The temperature, of the water in the storage tank, inlet and outlet to the absorber tube is measured by a conventional laboratory purpose thermometer and is indicated by RTD (Pt-100).

**Heat Transportation**

The collector performance is a function of the temperature of the fluid entering the collector and this temperature is the same as the temperature in the exit portion of the storage unit. On ignoring the heat losses from the connecting pipes, the outlet temperature from the collector becomes the inlet temperature to the storage unit.The model for SHWS is composed of three sections:

- Heat collection elements
  - Concentrating collector panel
  - Absorber Copper boiler tubearray where the heat transportation or phase change takes place.
- Reservoir (15Litre) that supplies water to the absorber tube.
- Conveyance system (tubes, valve and pipes)

## 6. MATHEMATICAL APPROACH

Area Concentration ratio (C) is given by:

$$C= A_a/A_r = (42'' \times 24'')/(\pi/4 \times (5/8)^2 \times 42'')=78.2\%$$

Let the average day insolation be 6.79 $Kw/m^2$.

Thus, $q_S'' = C \times I \times \rho \times K$

where; C = Concentration ratio (78.2%)

I = Insolation (833 w/m2)

$\rho$ = Reflectivity of concentrator (0.95)

K = Correction Factor (For this 0.7)

$$q_S'' = 78.2 \times 833 \times 0.95 \times 0.7 = 43318.5 \text{ w/m}^2$$

Now assume that heating conditions are constant on whole surface of the Copper tube with working fluid as water, than mass flow rate ($\dot{M}$) is given by:

$$\dot{M}= 3.55 \times 10^{-2} \text{ gal/sec} \times 3.7854 \times \text{Kg/gal}$$

$$\dot{M} = 0.1344 \text{ Kg/sec}$$

Now assume that steady state condition is obtained with incompressible constant properties, thin wall tube etc. From introducing the water to inlet to heat transfer:

$$A_S= \pi DL= (\dot{M} C_P (T_{m,o})-T_{m,i}))/(q_S'') \text{ or } T_{(m,o)}= (\pi DLq_S'')/(\dot{M}C_P) + T_{(m,i)} = 28.47°C$$

**Comparison of test results to mathematical model**

After building and testing, the length of the concentrator is reduced to 40" from 42". Thus:

$$C= A_a/A_r = (40'' \times 24'')/(\pi/4 \times (5/8)^2 \times 40'')=78.2\%$$

For I = 8.96KW/m solar insolation,

$$q_s'' = 78.2 \times 896 \times 0.95 \times 0.7 = 46594.6 \text{ w/m2}$$

On still assuming the constant heating conditions on tube with the same working fluid and same tube diameter:

$$\dot{M}_{measured} = 0.144 \text{ Kg/sec}$$

For the measured mass flow rate of 0.114 Kg/sec,

$$T_{(m,o)}= (\pi DLq_s'')/(\dot{M}C_P) + T_{(m,i)} = 29.15°C$$

Thus,

Measured $T_{(m,o)}$ = 28.47°C

Calculated $T_{(m,o)}$= 29.15°C

Thus with the above results obtained in respect of the outlet working fluid temperature, an error occurs (0.68°C). Thus due to effects of various environmental parameters, the results suffers the error.

## 7. RESULTS & DISCUSSION

The fabricated PTSC has different components e.g reflector, absorber tube, support structure, instrumentation and measurement etc. The research work is mainly concentrated on the experimental investigation and comparison of ½" (half-inch) diameter absorber tubes made up of Aluminium and Copper.

Firstly Aluminium tube of ½" in diameter is used as an absorber tube material for the performance evaluation of the fabricated PTSC system.The stepwise experimental procedure which is followed during the experiment is as follows:

Step 1: Cleaning of the reflector surface with a lubricant polish and absorber tube with a blower in order to remove dust particles. The fresh water is filled in the storage tank. The collector is exposed to the sun at least 30 min before start of the experiment.

Step 2: Setting and tracking of the reflector towards the sun. The pump is started at 7:30 A.M.

Step 3: In each experiment, for 30 min duration, the water flow rate passing through the absorber was maintained constant rate

Step 4: Start taking readings inlet and outlet temperatures of the working fluid from 8:00 A.M onwards. A direct contact point method is also adopted to measure the temperature along the absorber tube by placing the conventional laboratory purpose thermometer at any point on tube.

Step 5: The readings shown in below table(s) are taken after every hour up to 5:00 P.M.

Step 6: The pump is switched off and the whole set up is covered up. This procedure is repeated again for the next readings.

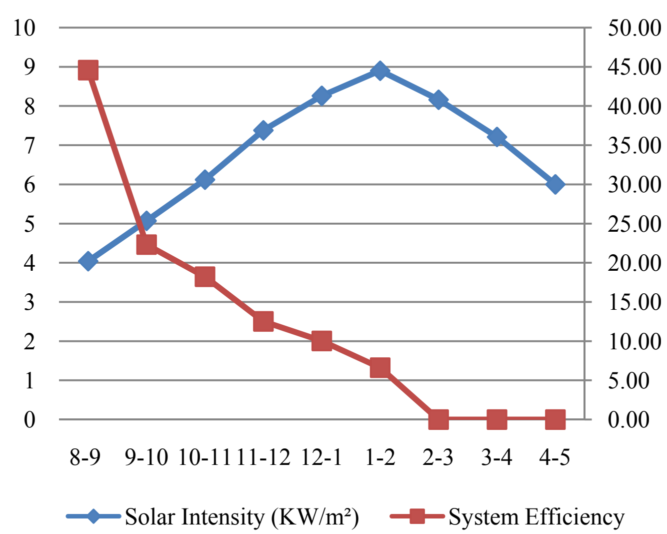


**Fig. 4: Time and Intensity variation with Instant. Efficiency (%) for Aluminium tube**

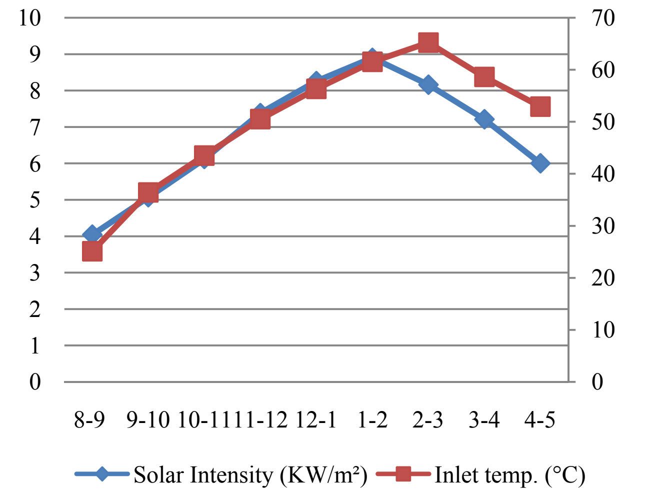


**Fig. 5: Time and Intensity variation with Inlet fluid temperature for Aluminium tube**

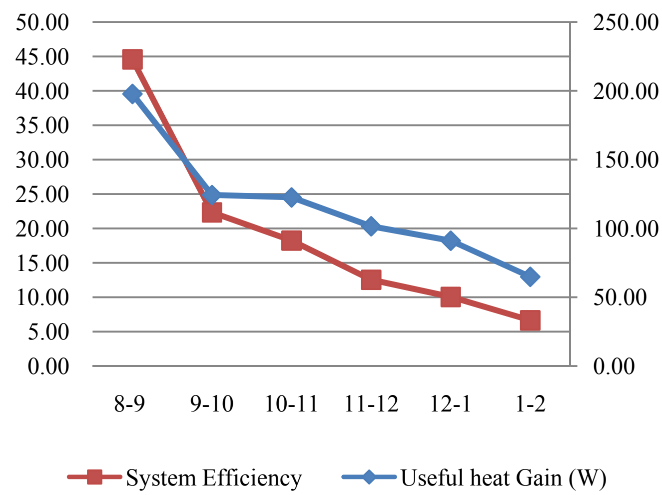


**Fig. 6: Time and Heat Gain variation with Instant. Efficiency (%) for Aluminium tube**

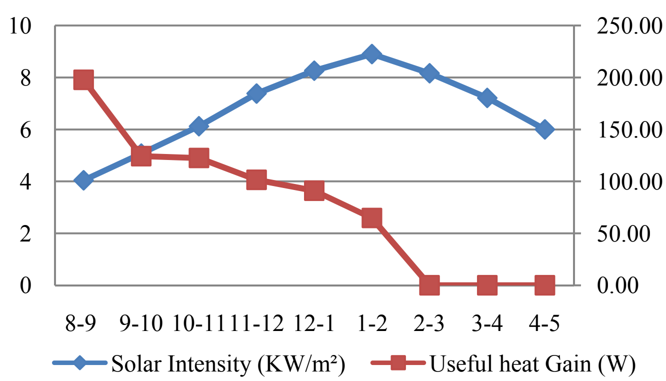


**Fig. 7: Time and Intensity Variation with Useful heat gain for Aluminium tube**

Now instead of Aluminium, an absorber tube made up of Copper, with diameter of ½" is used and the same readings are performed as in the case of Aluminium tube. The table below gives the measured values of the inlet and outlet temperature of water, intensity of solar radiations, with respect to the time, for recirculated water system.

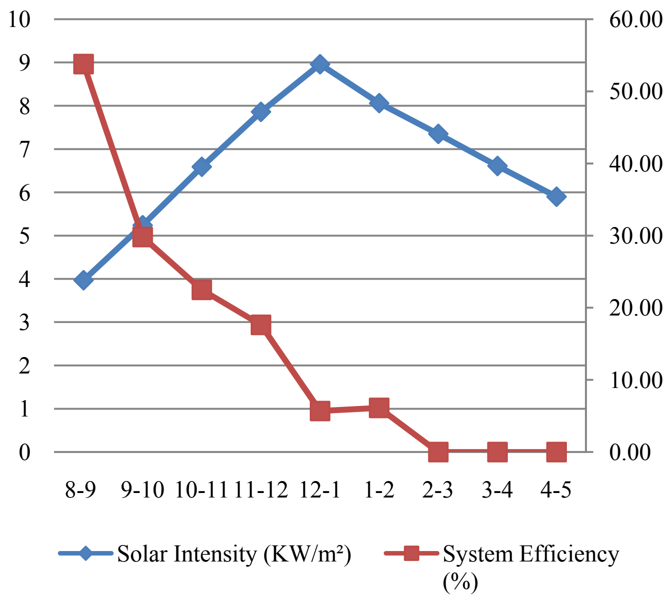


**Fig. 8: Time and Intensity variation with Instant. Efficiency (%) for Copper tube**

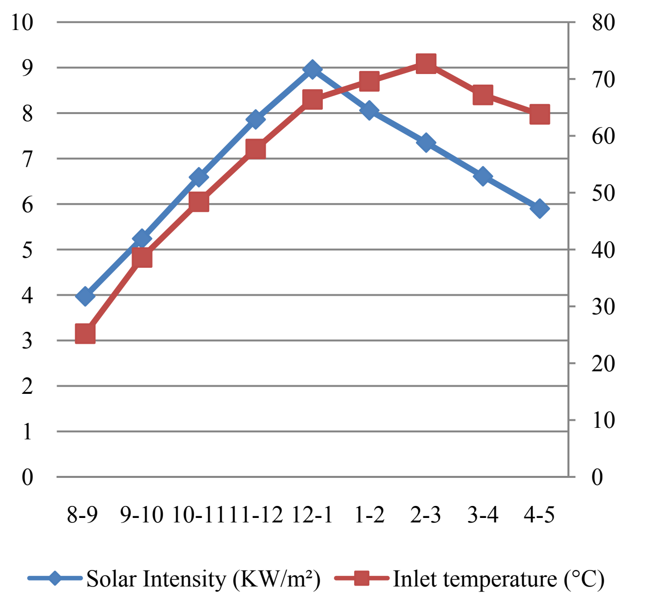


**Fig. 8: Time and Intensity variation with Inlet fluid temperature for Copper tube**

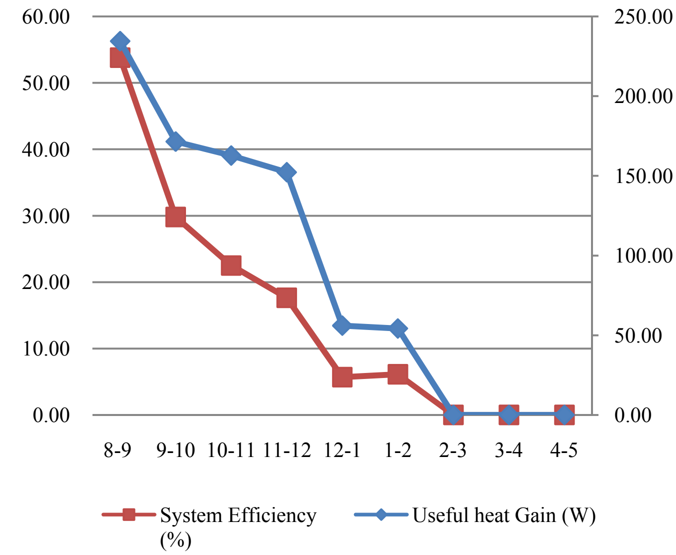


**Fig. 9: Time and Heat Gain variation with Instant. Efficiency (%) for Copper tube**

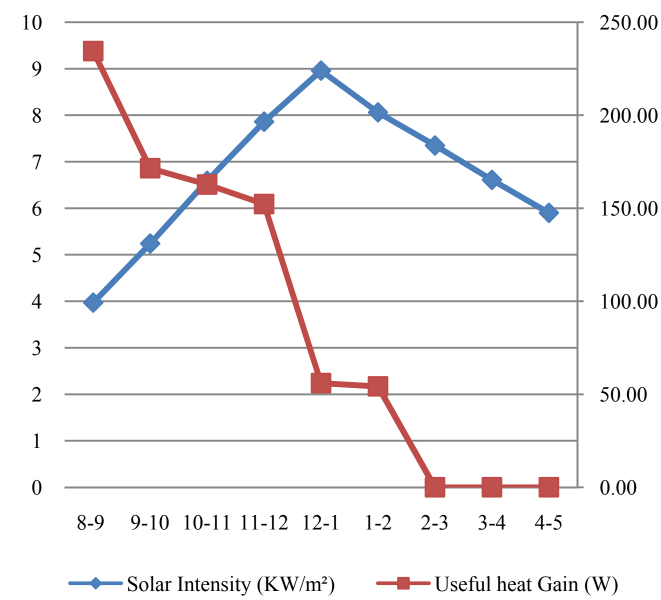


**Fig. 10: Time and Intensity Variation with Useful heat gain for Copper tube**

## 8. DISCUSSION

From the graphical representations above, it is observed that, for time axis (X-axis):

a) For Aluminium absorber tube, as the time accumulates the temperature of the water increases from 25.1 °C at 8:00

A.M to the peak temperature of 61.5 ºC at 2:00 P.M and for Copper absorber tube, the storage tank water temperature increases steadily from an initial temperature of 25.2 ºC at 8:00 A.M to a peak temperature of 72.7 ºC at 1:00 P.M, as no energy is withdrawn from the storage tank during the collection period and after that it decreases to 67.2 ºC due to thermal losses.

b) For Aluminium absorber tube, due to increase in thermal losses the temperature of water decreases after 2:00 P.M and the solar intensity also decreases with the increase in time. The temperature of water decreases more rapidly than the solar intensity and for Copper absorber tube, the solar intensity also increases with time to a maximum value of 8.96 KW/m2 at 12 Noon after which it decreases. Further it is observed that the useful heat gain is maximum between 8:00 A.M to 9:00 A.M and it then decreases with the increase in time and solar intensity. The instantaneous efficiency decreases with the increase in time and solar intensity.

c) For Aluminium absorber tube, the maximum increase in temperature of water is between 8:00 A.M to 9:00 A.M and the minimum increase is between 1:00 P.M to 2:00 P.M. Further, as the time and solar intensity increases the system downturn to the peak temperature. Both the efficiencies are at their maximum values between 8:00 A.M-9:00 A.M. The useful heat gain also decreases with an increase in time. For Copper absorber tube, the maximum value of system efficiency is between 8:00 A.M-9:00 A.M. It firstly decreases to a large amount and then slowly to the lowest value at 5:00 P.M.

## 9. CONCLUSION

From the graphically interpretations, when the results obtained with Copper tube as an absorber are compared with that of an Aluminium absorber tube it is observed that the maximum temperature of water in the storage tank is higher when Copper tube is used.

The hourly system efficiencies and the useful heat gain taken hourly are higher in discrimination to the Aluminium tube. As the thermal conductivity of Copper is higher than Aluminium therefore the peak temperature of the water in the storage tank is attained at 1:00 P.M which is earlier than that in case of Aluminium tube. So the use of Copper tube gives the better performance and results as compared to Aluminium tube.

Despite the thermal losses experienced the solar concentrator did heat the water fairly consistently throughout testing. The project was a general success through the processes of designing, building, and testing. When the experimental results of bare Aluminium absorber tube and bare Copper absorber tube with same outer and inner diameter of 0.5" and 0.43" are compared then the Copper tube showed the better results. The maximum temperature of water in the storage tank is 72.7ºC in case of Copper absorber tube and 65.2ºC in case of Aluminium absorber tube.

## 10. FUTURE SCOPE

The possibility of future scope is to overcome all the possible remittances of the system and make the system optimize in working in all the possible conditions, either favorable or non-favorable. For my research work, there is a lot of scope of future investigation as well which is as follows:

i. The sensitivity analysis can be done on a single or multiple number of attributes e.g. thickness of the absorber tube to make it different and better than the other competitive products present in the global market.
ii. The comparison and evaluation of different PTSC designs on the basis of some other attributes like quality, reliability etc. as the permanent function is formed by the structural constituents and their interactions.
iii. This fabricated PTSC system can be used for steam generation if length of the collector and the effective aperture area is increased.
iv. We can do further work on the tracking mechanism of the parabolic solar collector by the use of automatic tracking (gears, motors) with the help of sensors or relays.
v. Experimental investigation can be done by considering the different materials for the reflector and with that the performance of parabolic trough solar collector system is evaluated.

## REFERENCES


[1] Amirtham Valan Arasu and Samuel Thambu Sornakumar, “Performance Characteristics of the Solar Parabolic Trough Collector with Hot Water Generation System”, BIBLID: 0354-9836, 10 (2006), 2, 167-174.

[2] M J Brooks, I Mills, T M Harms, “Performance of a parabolic trough solar collector”, Journal of Energy in South Africa Vol. 17 No 3 August 2006.

[3] Ming Qu, David H. Archer, Sophie V. Masson, “A Linear Parabolic Trough Solar Collector Performance Model”, Renewable Energy Resources and a Greener Future Vol.VII-3-3, 2006, ESL-IC-06-11-267.

[4] R. T. Durai Prabhakaran, B. J. C. Babu & V. P. Agrawal (2006): “Optimum Selection of a Composite Product System Using MADM Approach, Materials and Manufacturing Processes”, 21:8, 883-891

[5] N. Naeeni, M. Yaghoubi, “Analysis of wind flow around a parabolic collector heat transfer from receiver tube”, Renewable Energy 32 (2007) 1259–1272.

[6] Scrivani, T. El Asmar, U. Bardi “Solar trough concentration for fresh water production and waste water treatment”, Desalination 206 (2007) 485-493.

[7] Ari Rabl, “Comparison of Solar Concentrators Solar Energy”, vol.18. Pp.93-111, pregamon press 1976.

[8] Jaideep Ahluwalia, Sumit Kumar Gupta and V.P. Agrawal, “Computer-aided optimum selection of roller bearings”, Computer-Aided Design 25 (1993) 493-499.

[9] A. Thomas and H. M. Guven, “Parabolic Trough Concentrators---Design, Construction and Evaluation”, Energy Convers, Mgmt Vol. 34, No. 5, pp. 401-416, 1993.

[10] Soteris Kalogirou, Polyvic Efeftheriou, Stephen Llyod And John Ward, “Low Cost High Accuracy Parabolic Troughs Construction and Evaluation”, Renewable Energy, Vol. 5,Part 1,Pp, 384-386,1994.