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Experimental Study of Parabolic through Collector with Glass Enveloped Copper Receiver Tube Filled with SS Sponge Material

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Abstract

In the present study, an acrylic glass enveloped copper tube receiver filled with stainless steel (SS) sponge material has been designed and tested in the local climatic conditions of Coimbatore, Tamilnadu, India. The SS sponge serves as the resistant medium to maintain the optimum flow rate for the heat transfer fluid to absorb large amount of solar energy for the best performance of the proposed system. To elucidate the significance of the new receiver, receiver of same dimension and material has been tested with the parabolic trough collector. Results for both the receivers have been used to evaluate the instantaneous efficiency of the system and it is found that, the receiver with SS sponge material has shown an instantaneous efficiency of 54.42% and 40.22% for the receiver without SS sponge material.

Key Words: Metal tubular, stainless steel sponge, compact parabolic trough collector.

1. Introduction

A number of researchers have made sincere efforts to design, construct and analyse the parabolic trough collector with receivers made of altered metal tubular structures and found that the receivers play an important role for the performance of the thermal module. However the parabolic thermal collectors are far and wide being used from last (decade) a period of ten years in solar thermal power plant.

Yadav et al. [1] have examined the reflectors of the concentrator that influences the efficiency of concentrator and suggested that aluminium sheets are good reflector than that of stainless sheets. Dabra et al. [2] have studied the influence of inclination angle of the collectors for the efficiency of the parabolic trough collector system and found that steeper inclination can be used for vacuum tubular receiver. Wang et al. [3] suggested that the U-shaped tubular receiver performed with compound parabolic concentrator can produce moderate temperature of 200◦C suitable for commercial application. Brooks et al. [4] have verified different absorber tubular in (PTC) parabolic trough collector shielded with and without glass cover.

Results of the study revealed that the shielded evacuated absorber tubular has given maximum efficiency. Leonard et al. [5] designed a prototype parabolic trough concentrator consisting of UV stable thermo plastic mirror sheet parabolic frame with absorber tube receiver provided with and without insulation. Results of the study revealed that the system with and without insulated tubular receiver has given a power of 91.5 W and 51.3W. Pradeep kumar et al. [6] has designed and analysed the performance of the parabolic trough collector with different reflectors i.e., Aluminium and mirror. The result of the study revealed that the system with mirror reflector has shown better performance than the system with aluminium. V.C. Gunge et al.[7] has designed a receiver tube with variable diameter (OD) dimensions viz., 1.6, 1.4 and 1.2 cm and found that the efficiency of the receiver with varying diameter is better than the ordinary receiver. Reddy et al. [8] has studied a 15 m2 parabolic trough collector through porous disc receiver.

It has been observed that the parabolic trough collector with porous disc receiver has shown significant performance for heat applications process. Reddy et al. [9] developed 3-D numerical model to predict the behaviour of finned receiver in order to progress its heat transfer to the working fluid. Around 13.8% enhancement in heat transfer is obtained with finned receiver at 6.4 kg/s mass flow rate of working fluid. Jaramillo et al. [10] has estimated the performance of five parabolic trough collectors for the cause of generating warm water and steam with low enthalpy with 45° and 90° rim angled collectors. Highest thermal efficiency of 35% and 67% was attained for the collector with rim angle of 45° and 90° respectively.

In the present study, an attempt has been made to design, fabricate and study the acrylic glass enveloped copper tube receiver filled with stainless steel (SS) to be used in the parabolic trough collector system. Experiments have been carried out with the system in local climatic conditions of Coimbatore, Tamilnadu, India. Comparison has been made with the receiver without SS sponge material.

2. Experimental Setup

The experimental setup consist of a parabolic trough Collector accompanied with tracking mechanism which has an aperture area of 0.9 m^2 and focal length of the proposed system is 0.13 m. The tracking mechanism has been designed using equal arm balance method to track the system towards the motion of the sun throughout the day.

Fig .1 shows the photograph of the proposed compact parabolic trough system and its receiver is depicted in Fig.2 (a) and Fig.2 (b) Table.1 represents the specification of proposed compact parabolic trough system with receiver. Reflector reflects the sun rays towards the receiver which is enveloped by glass to reduce the convection of heat from the receiver to the surroundings.

Experiments have been carried out in the month of May 2017 and observations on one of the typical days for both glass enveloped receiver with and without SS Sponge is shown in the Fig. 3.

The mass flow rate of heat transfer fluid has been maintained as 0.0023 kg/s. Table 2 represents the instruments, measure parameters and model used during the experiment.

Table 1: Specification of Compact Parabolic Trough Collector

Parameter	Specification
Rim angle	90°
Focal length(F)	13
Aperture width (W_a)	0.52 m
Diameter of the receiver tube(D_o) with and without SS Sponge	0.02m
Length of the trough and receiver (L) with and without SS Sponge	1.8m
Aperture area	0.9m^2
Concentration ratio (C)	7.96
Reflectivity of the collector(γ)	0.8
Tracker	Semi-automatic

Table 2: Specification of Measuring Devices

Device	Measure	Parameter	Model
Pyranometer	Solar radiation	Global radiation	LP-silicon- PYRA 04
Thermal sensor	Temperature	Inlet, outlet fluid	LM 35
Water flow sensor	Flow rate	Inlet fluid flow rate	DN25
Digital Thermometer	Temperature	Ambient	BFHTC-1

Figure 1: Photograph of the Compact Parabolic Trough Collector

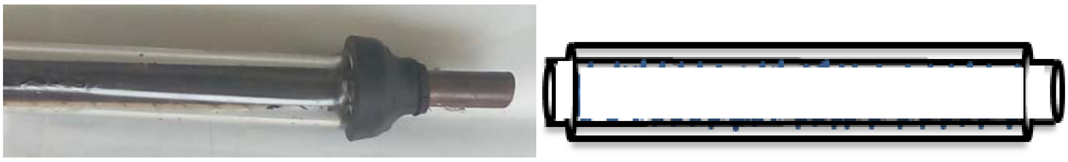

Figure 2(a): Photograph and Schematic of the Proposed Receiver without SS Sponge

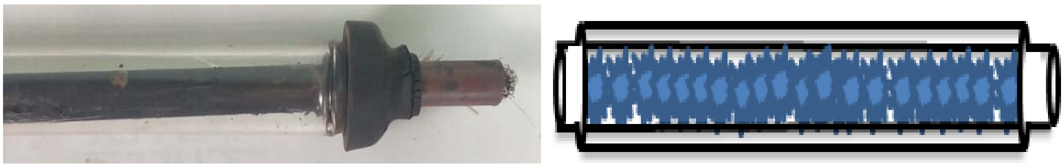

Figure 2(b): Photograph and Schematic of Proposed Receiver with SS Sponge

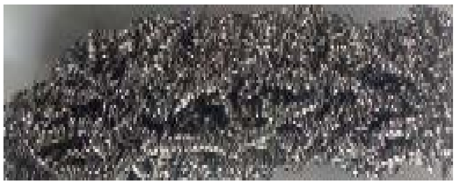

Figure 3: Photograph of the Stainless steel Sponge Shape

Efficiency of the system has been calculated by following eqn.

$$\eta = \frac{Heat\ transfered\ to\ the\ fluid}{Total\ Solar\ Radiation} = \frac{m \times C_p (T_{out} - T_{in})}{A_p \times I_b}$$

m	=	Mass flow rate , kg/s
C_p	=	Heat capacity of the fluid, J/kg K
T_{out}	=	Outlet temperature of the fluid, °C
T_{in}	=	Inlet temperature of the fluid, °C
A_p	=	Area of aperture, m^2
I_b	=	Global Solar intensity, W/m^2

3. Results and Discussion

Experiments have been conducted with the proposed parabolic trough system provided with the glass enveloped receiver with SS Sponge and temperature of the heat transfer liquid is measured at regular intervals throughout the working hours of the day.

Also the inlet and outlet temperature of the heat transfer liquid has also been measured. Fig.4 shows the variation of inlet, outlet temperature and temperature difference between the inlet and outlet temperature of the heat transfer fluid (water). From the figure, it is found that the outlet temperature gradually increases during the morning hours and reached a maximum of 74°C at13:00 hours. The outlet temperature increases with the increase of intensity of the solar radiation.

Fig.5 shows the efficiency of the system with glass enveloped receiver with SS sponge and it has been found that the system efficiency increased gradually upto 15:00 hours. This is due to the thermal energy storage within the SS sponge and the glass envelop diminishes the convection heat transfer from the receiver tube to the surroundings.

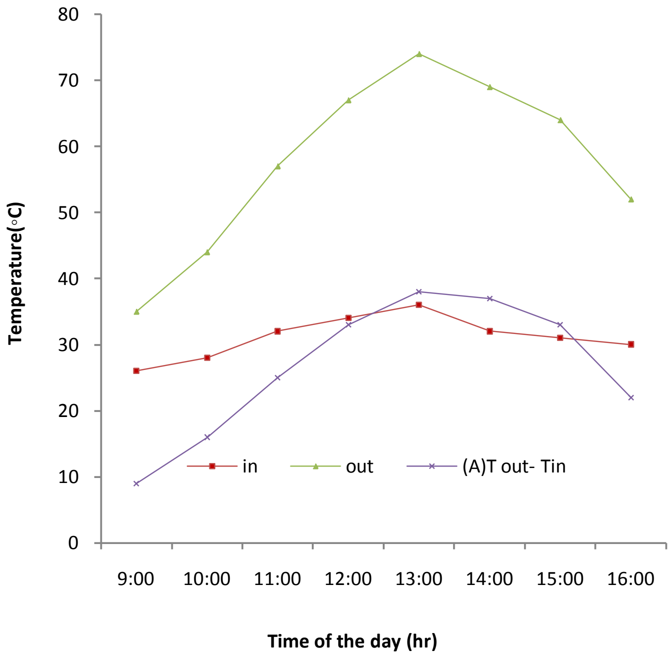

Figure 4: Variation of the Heat Transfer Fluid Temperature, Inlet, Outlet and Temperature Difference Between the Inlet and Outlet Fluid Temperature Throughout the Day for Envelop with SS Sponge Receiver

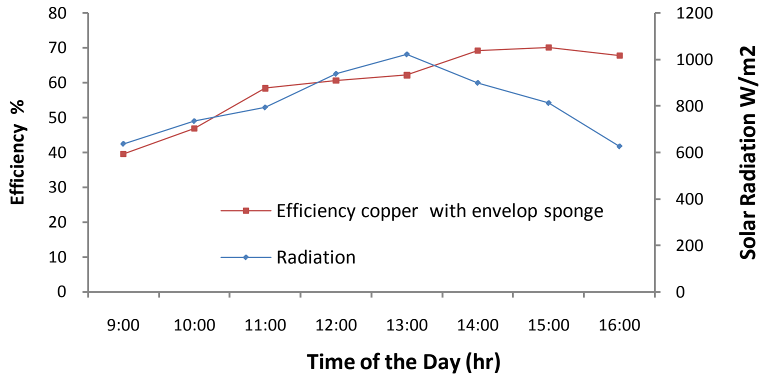

Figure 5: Variation of Solar Radiation and Efficiency Throughout the Day with SS Sponge Receiver

Fig.6. shows the variation of temperature of inlet, outlet heat transfer fluid (Water) temperature and temperature difference between the inlet and outlet of heat transfer fluid for the system with the glass envelop receiver without SS sponge material. From the figure, it is found that the outlet fluid temperature gradually increases up to noon and reached its maximum of 66◦C at 13:00 hours for the inlet heat transfer fluid temperature of 34◦C. The outlet temperature decrease gradually in the evening hours. Fig.7. shows the efficiency of the system without SS sponge within the glass envelope receiver tube and it has been seen that the efficiency is influenced by the intensity of solar radiation. It has also seen that the efficiency increases to only 6% during 11:00 to 13:00 hours and started gradually decreasing during the afternoon hours.

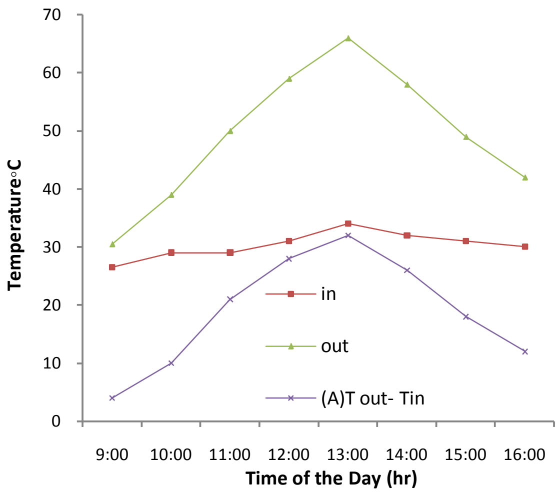

Figure 6: Variation of Average Heat Transfer Fluid Temperature, Inlet, Outlet and Temperature Difference Between the Inlet and Outlet Fluid Temperature Throughout the Day for Envelop without SS Sponge Receiver

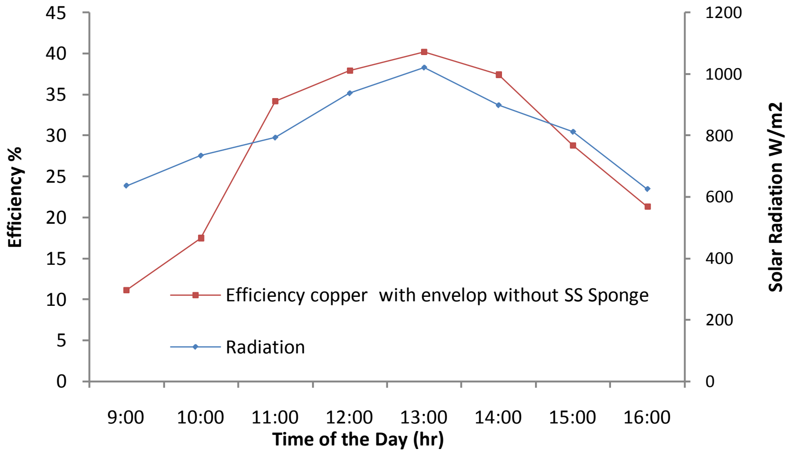

Figure 7: Variation of Solar Radiation and Efficiency Throughout the Day for without SS Sponge Receiver

Fig 8 shows the variation of instantaneous efficiency of the proposed system with the glass envelop receiver tube with and without SS sponge. It has been observed that, the efficiency of the system with the glass envelop copper tube receiver with SS sponge is pronounced throughout the working hours of the day compared to the experimental observation for the system without SS sponge. It is understood that, the sponge material in the receiver tube served as a thermal storage material as well as automatic water flow control for the heat transfer fluid. Due to the optimum flow rate of heat transfer fluid, the fluid i.e., water absorbs the large amount of thermal energy and the outlet water temperature reaches its maximum.

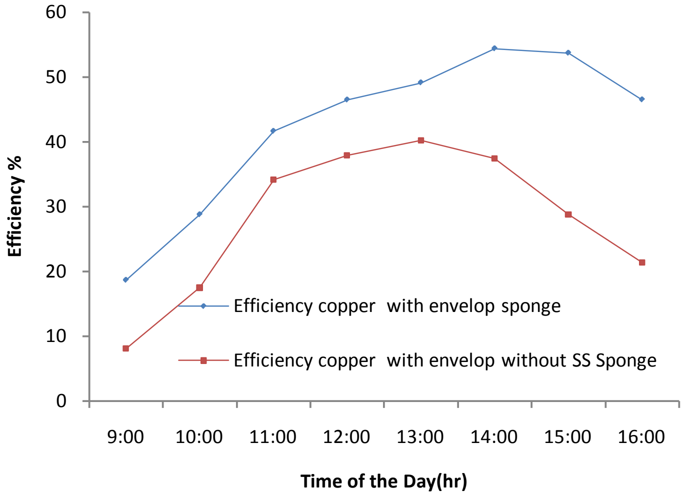

Figure 8: Variation of Instantaneous Efficiency of Time with SS Sponge and without SS Sponge Receiver

4. Conclusion

The following conclusions have been drawn, they are:

(i) The proposed system provided with the glass enveloped copper tube receiver with SS sponge automatically optimized the flow rate of heat transfer fluid to absorb a large amount of thermal energy.

(ii) The SS sponge material inside the receiver tube serve as a diaphragm for the heat transfer fluid and never obstructed the flow of the fluid during the working hours of the day.

(iii) The heat energy extracted prolonged upto 15:00 hrs from the morning hours and led to the increase of efficiency of the system.

(iv) The proposed system efficiency was influenced by the solar radiation and the efficiency had the same trend as that of the solar radiation intensity.

(v) The convective heat transfer from the receiver tube to the surrounding ambient had been reduced and thereby led to the enhancement of efficiency of the system.

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