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Absorber Tube with Internal Hinged Blades for Solar Parabolic Trough Collector

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Abstract

Solar parabolic collectors exploit solar energy for both thermal and power generation applications. But, they demand long arrays of reflective concentrating surfaces with receiver tube throughout the length of axis of the concentrators. For one and half meter long parabolic trough with aluminium sheet as reflective surface, experimental analysis was done attempting to increase the energy transfer rate and reduce the length of arrays. Two absorber tubes were fabricated and distilled water was used as the working fluid in the tubes. The modified absorber tube with hinged blades delivered an average efficiency of 69.33% compared to 60.82% obtained for simple conventional absorber tube. Plots for performance results of the tubes with varying direct normal irradiance and mass flow rates were obtained. Slope and intercept values of 70.887 and -0.419 respectively were obtained for the collector equation of absorber tubes hinged blades compared to slope and intercept values of 61.571 and -0.401 respectively. The present work delivers better performance compared to earlier works Thus, the proposal present its scope for both domestic and industrial applications.

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Keywords: absorber tube; parabolic trough; aluminium reflective sheet; hinged blades; solar thermal

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1. Introduction

Solar energy presents itself as a highly potential source of energy for sustainable progress. But, high investment, requirement of large area for installation of solar energy devices and wavering availability of radiations has restrained its development. Solar parabolic trough collector (SPTC) provides an effective way to harness solar energy providing "one-axis concentration" such that distilled water flowing through the absorber tube, gains the concentrated energy and accomplish the work as per required application. Since years, researchers and scientists have been trying to optimize the performance of SPTC so that rapid heat transfer can take place and overall length of the trough collector can be reduced.

Tao et al. [1] introduced design method and working principle for new type of trough collector with efficient performance of SPTC by introducing widely opened concentrating collectors. However, increase in the width of concentrating apparatus may result to unbalanced design and higher probability of back reflection with spillage loses of the incident solar radiations. To avoid such hindrances, requirement of precise design and tracking will be needed, that adds some more minuses to the proposed design. Cobalt electrode position on absorber tubes by Barrera et al. [2] and effort on solar selective coatings by Farooq and Raja [3] resulted in enhancement of the efficiency for operation of solar apparatuses. But with increase in coating temperature, radiation thermal losses may increase, thus high thermal stresses may develop in the receiver tube.

The implementation and development of recirculation operation mode for SPTC by Valenzuela et al. [4] showed increase in output temperature and performance of the apparatus. But, the system possesses minor drawbacks concerning the use of steam at high pressures, risk for steam leakage and higher stresses on tube. An innovative numerical model evaluation of heat transfer characteristics for porous disc receiver by Ravi Kumar and Reddy [5] presents an efficient design of absorber tube, but flow across the tube is very high and also the system will require only pure fluid to avoid accumulation of particles on the tube walls and porous disc, than can be caused by highly interrupted flow through the receiver tube. Selectively coated receiver with U-tube was analyzed by Ma et al. [6] that demonstrated better performance, but with very mass flow rate of fluid flowing through the tube.

Although ample research and development have been done to improve performance efficiency of parabolic trough concentrators, the authors presents innovative design of absorber tube with internal hinged blades. The experimental analysis and fabrication procedure for the modifications done in the receiver tube are presented. The proposed absorber tube is well suitable for application in various solar energy devices, linear and line focus concentration systems with various advantages as well. Experimentation was performed at VIT University, Vellore (12.92 °N, 79.13 °E) twice, once on October 24th, 2014 and on October 26th, 2014, to verify the consistency of the obtained results.

2. Materials and Methods

Copper tubes with 1 mm thickness and 1.5 cm outer diameter were used to fabricate the absorber tubes. The specifications of cylindrical axis trough collector, absorber tubes and the apparatus are given in Table 1. All the tubes were made of 1.5 m long copper tubes. Parabolic trough with rim angle of 120° and focal length 26.25 cm, was used which has reflective surface of aluminium alloy and reflectivity of about 85%. Details for fabrication processes of the tubes have been included.

The enclosed volume in the glass tube was evacuated to develop a low pressure vacuum, thus reducing the heat transfer losses. Absorber tube with internal hinged blades had 2 mm drill holes along a straight line with pitch distance of 50 mm. Galvanized iron sheets of 49 mm^2 (7 mm * 7 mm) were made to hinge internally from the drilled holes, such that the blades don't make contact with tube's inner surface. This ensured the continuous flow of distilled water. The drill holes were welded using gas welding to make the tube leak proof. With flow of distilled water, the blades provide hindrance to flow along the tube, creating turbulence in the flow. Increase in turbulence increased the contact time between distilled water and absorber tube's inner surface, hence the heat transfer increased. The experimental setup and design of hinged blades is presented in Figure 1.

Initially, absorber tube was fixed on SPTC's axis and the trough was adjusted such that axis of focus and the absorber tube accords. Then the tube was connected to the pump through a hose and distilled water, used as working fluid, was collected in tank. The pump was switched on, leaving the system for 10 minutes with specified volume flow rate, controlled by valves. Parabolic trough collector was adjusted frequently to align the absorber tubes with focus of reflected radiations to maintain tilt factor with the value of 1.00 ± 2%. Pyrheliometer, with sensitivity of 4.95 mV/W/m^2, was used to measure the beam radiation. The performance parameters for each tube were obtained every 10 minutes and then the flow rate was altered. The experiment for each tube was conducted for a span of 50 minutes.

Table 1. Specifications of apparatus.

Sl. No.	Component	Dimension
1	Length of SPTC, *L*	1.5 m
2	Width of SPTC, *W*	0.91 m
3	Rim angle of SPTC, θ_r	120 degree
4	Focal length of SPTC, *f*	26.25 cm
5	Concentration ratio, *C*	19
6	Specific heat of distilled water, C_p	4182 J/kgK
7	Tilt factor for beam radiation, *R*	1.00 ± 2%
8	Inner diameter of glass tube	3.4 cm
9	Thickness of glass tube	4.5 mm
10	Vacuum pressure in glass tube	600 mm of Hg

A tank of 15 litres capacity was employed to store distilled water that was pumped across the tubes through a valve. Thus, volume flow rates could be varied and experimentation was done with varying mass flow rates. Digital thermocouples were used to measure the temperature values and stop watch for measuring time required to fill a litre capacity collecting jar, thus determining the volume flow rate.

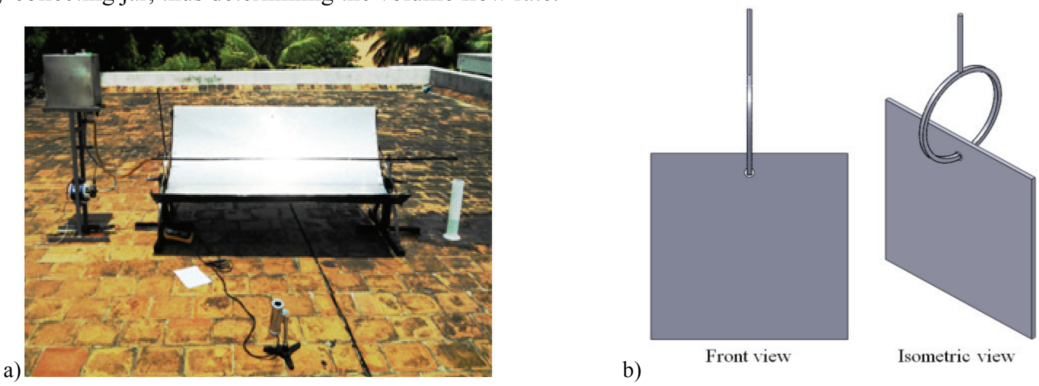

Fig. 1. (a) Experimental Set up (b) Design of blades

3. Results and Discussion

Experimental results and observations for the experimentation done by the authors are tabulated in Table 2. Based on these results, plots were obtained for instantaneous efficiency with varying volume flow rate (Figure 2), direct normal irradiance (Figure 3) and $(T_{in}-T_{amb})/I_b$ (Figure 4). Increased performance results were obtained for the absorber tube with internal hinged blades for almost same mass flow rates and solar beam flux. Ma et al. [6] maintained very low mass flow rates of 0.001 kg/s, 0.002 kg/s and 0.003 kg/s and obtained efficiency of about 35-40% with higher radiation densities of about 950 W/m^2. In the present work, better instantaneous efficiencies were obtained at a lower solar beam flux. Variation of temperature difference across the absorber tubes with varying DNI presents direct proportionality relation amongst the two parameters i.e. with increase in DNI, temperature difference for the distilled water also increments.

Table 2. Results and Observation

v (litre/min)	***I_b*** (W/m²)	***T_fi*** (°C)	***T_fo*** (°C)	***T_amb*** (°C)	***(T_fi – T_amb)/I_b*** (°C m²/W)	***η*** (%)
24-10-201, Simple absorber tube						
1.22	747.95	42.5	49.9	31.6	0.0146	61.70
1.08	818.52	48.5	57.6	31.7	0.0205	61.38
1.00	790.29	56.3	65.4	31.6	0.0313	58.77
0.97	776.18	63.9	73.4	31.5	0.0417	60.54
0.89	776.18	72.0	82.3	31.6	0.0520	60.07
24-10-2014, Absorber tube with hinged blades						
1.21	747.95	44.3	52.8	31.5	0.0171	70.22
1.05	797.59	50.8	61.1	31.4	0.0243	69.50
1.01	804.40	59.2	70.0	31.5	0.0344	69.28
0.96	762.07	67.9	78.7	31.6	0.0476	69.68
0.90	733.84	76.6	87.5	31.6	0.0613	67.97
26-10-2014, Simple absorber tube						
1.20	620.94	41.1	47.3	31.6	0.0153	61.42
1.07	677.39	46.0	53.4	31.7	0.0211	59.57
1.00	635.06	52.0	59.5	31.6	0.0321	60.40
0.97	663.28	58.2	66.2	31.5	0.0403	59.52
0.90	635.06	64.7	72.9	31.6	0.0521	59.45
26-10-2014, Absorber tube with hinged blades						
1.22	649.17	43.2	50.5	31.5	0.0180	69.77
1.05	592.72	48.4	56.2	31.4	0.0287	70.82
1.02	635.06	54.3	62.7	31.5	0.0359	68.84
0.95	649.17	60.8	70.0	31.6	0.0450	68.85
0.90	620.94	68.0	77.2	31.6	0.0586	68.39

The calculated instantaneous efficiency values are plotted against a parameter $(T_{in}$-$T_{amb})/I_b$ in Figure 4. Although the sets of results are scattered, they together yield a straight line with negative slope. This scattering of experimentally acquired points and deviation from the straight line can be determined by obtaining the best fit line using least square method. Equation 1 presents the equation for the collector with simple absorber tube while equation 2 gives collector equation for absorber tube with hinged blades.

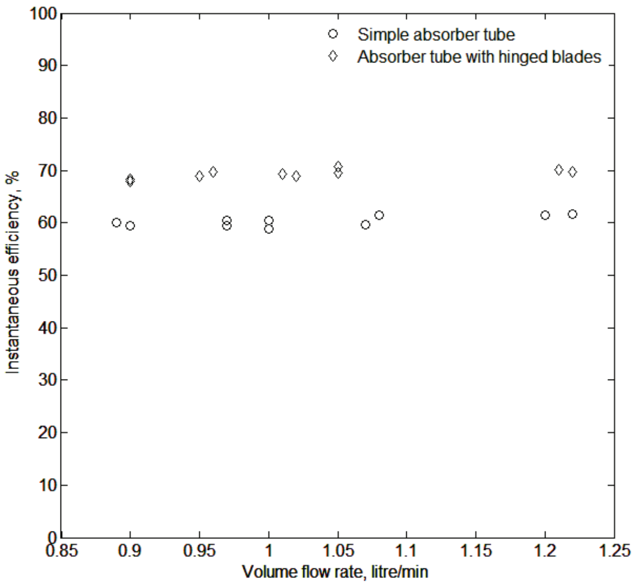

Fig. 2. Instantaneous efficiency vs. Volume flow rate.

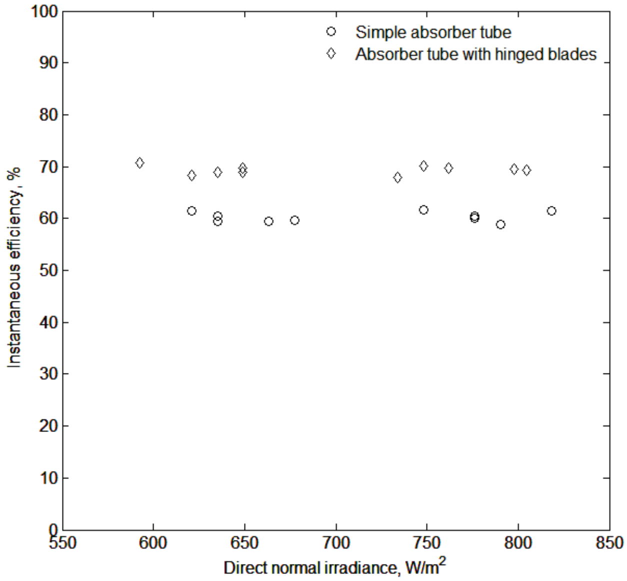

Fig. 3. Instantaneous efficiency vs. Direct normal irradiance.

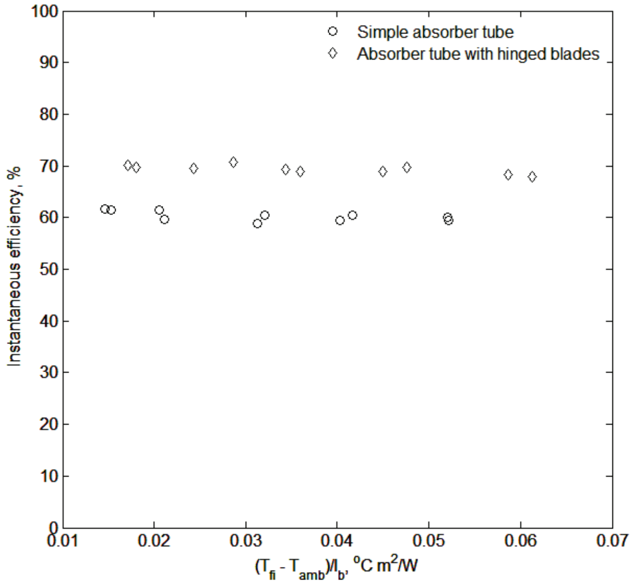

Fig. 4. Instantaneous efficiency vs. $(T_{in}-T_{amb})/I_b$.

Figure 5 presents the variation of total incident energy on the absorber tube with useful heat gain by the distilled water. The plot clearly indicates the increment in heat gain by the new absorber tube compared to simple conventional absorber tube, for almost equal values of total incident energy.

$$\eta = 61.571 - 0.401\left(\frac{T_{fi} - T_{amb}}{I_b}\right) \qquad (1)$$

$$\eta = 70.887 - 0.419\left(\frac{T_{fi} - T_{amb}}{I_b}\right) \quad (2)$$

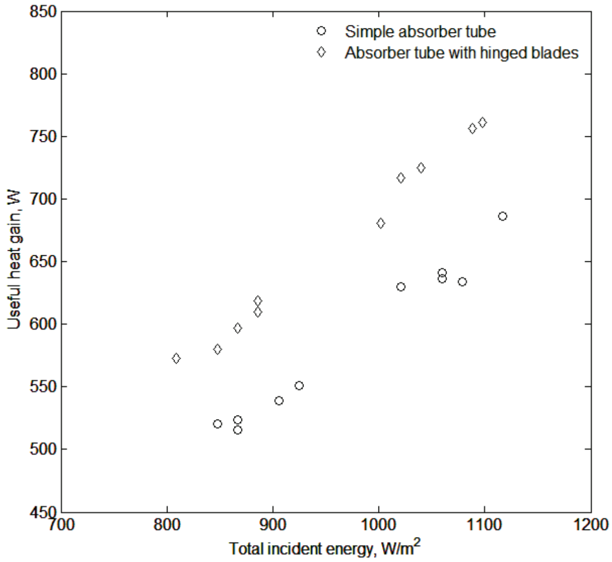

Fig. 5. Useful heat gain vs. Incident energy on absorber tubes.

Slope and intercept values for the collector equation of simple absorber tube were obtained more or less equal to the values obtained by Arasu and Sornakumar [7]. The proposed design appears to have substantial application in the developing fields as well. It can be used for thermal applications, involving heat transfer, organic rankine cycles and even in absorption power and cooling cycles, making performance of system efficient. The experimental investigation of a natural circulation heat pipe for steam generation by Zhang et al. [8] uses high pressure of 7.5 bar for steam generation securing nearly 38.52 % thermal efficiency which can be optimized to a great extent, if the proposed absorber tube with internally hinged blades is used.

4. Conclusion

Vellore is 216 m above sea level and receives two periods of monsoons mostly during June – August and October – December. As the experiments were conducted during the second phase of monsoon, intensified solar flux was not available compared to that obtained in summer season, slightly affecting the performance curves of the absorber tube. Increment in heat transfer rate required for harnessing of solar energy, especially for application of direct steam generation in solar thermal power plants, was the prime aim of this project. With the obtained results, it can be concluded that the modification of introducing hinged blades in the absorber tubes of solar parabolic concentrating collector can deliver highly efficient performance compared to that of traditional tubes. Average instantaneous thermal efficiency of 69.33% was obtained for internally hinged blades. Slope and intercept values of -0.419 and 70.887 respectively for the collector equation obtained of modified tube verifies the improved efficiency of the SPTC.

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