Experimental Evaluation of Solar Water Heater Using Solar Reflector with Secondary Booster

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ABSTRACT

The solar concentrating technology is highly recommended in the current scenario of fossil fuel crises; it is important to develop conventional devices like the solar water heater. The objective of this work is the analysis of secondary booster in parabolic trough collector (PTC) of a solar water heater. A secondary reflector is located at the end of PTC with different shape and angles to enhance the performance of the solar collector at an optimum level. This extra booster increases the reflecting surface area as well as reduces the end optical losses by reflecting it to the receiver. The optimum inclination angle of this booster is found by ANSYS software and experimental analysis. Cost-effective Secondary reflector of parabolic shape and 90o inclined recover most radiation loss and give higher efficiency than conventional PTC in the morning. 30o inclined Secondary reflector gives an overall greater performance.

Keywords
Parabolic trough collector, Booster reflector, Optical end loss

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Introduction

This Presently, most of the countries are facing two main problems: (i) meeting the basic energy demand and (ii) reducing the environmental pollution. Developing countries like India faced these problems at more extreme levels because of an explosion in population increment and industrial developments. To meet the energy demand more and more fossil fuels are burned, the results increase in pollution and global warming. Also, these fuels are limited quantities and take millions of years to make a theme. As time increases the price of these fuels are also increasing and buying them to meet current energy demand makes a problem for the economic growth of the country. It produces need to find a source to meet the increasing energy demand, safe for the environment and easily available. Solar energy is one of the best sources to meet energy demand. India is just above the equator line, so it receives more solar radiation around 4-7 kWh/m2/day. India also has 250-300 clear, sunny days in a year in most of the regions of the country make around 5000 trillion kWh of solar energy per year.

Paresh et al. [1] Show that Heating/Cooling accessories are most power-consuming (30% -40%) devices among all of the commercial devices. P. Veeraboina et al. [2] Also estimate the increase in solar water heating market size in future and also showed that 80% of solar heaters are used for residential purposes. Solar collectors are used for concentrating solar radiation in a specific spot so that, high temperature can be achieved at that spot for heating. Solar concentrating devices can be used in a various range of areas like power generation, heating-cooling, desalination etc. There are some solar collectors which are used in high demands are parabolic trough collector (PTC), Linear Fresnel reflector (LFR), solar tower and dish concentrator. PTC is mostly used for the starting of solar concentrator generation because of its feasibility and efficiency.

Among all solar collectors, parabolic trough and flat plat collectors are mostly used for water heating applications in residential purpose. Flat plate collectors have higher quantity output but it requires a storage tank and also flat collector are larger. In the other hand, PTC is more efficient but the output is less in quantity. For instant water heating and less volume requirement, PTC is suitable. It can operate in less radiation in the early morning and does not require high maintenance. It is more cost-effective and easily installable.

Literature Review

Reflector surface is not smooth as it looks, Roughed surface change the direction of reflected sunray [3]. Due to surrounding wind and cloudy weather and other natural conditions, sun rays can be deflected and we can't get the proper concentration to a receiver. This phenomenon is called optical losses.

Changing working fluid gives higher heat transmission but it only uses the radiation received and does not consider lost radiation. Receiver tubes surfaces are also optimized but it makes its manufacturing more complex. Lots of other research is going on solar water heating, but it may increase the cost of PTC which also uneconomic for the rural communities.

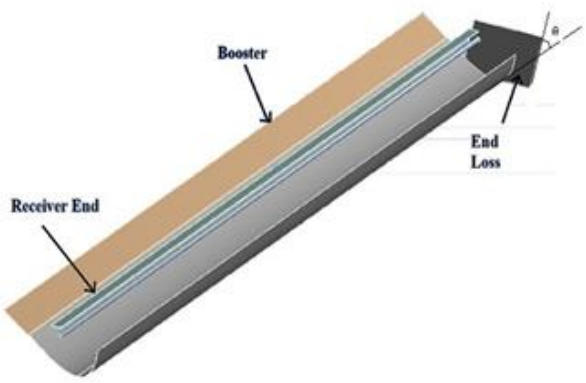

Fig. 1. Location-based Secondary Reflector (SR)

A simple and effective solution is the use of an extra reflector to concentrate these loosed called secondary reflector (SR) or booster reflector. The inclination angle of SR is also affecting the performance of the collector as it directs lost sun rays properly and gets a more reflecting surface. A literature review is made based on the location of secondary booster PTC.

A. Literature review based on Secondary reflector used at the receiver end

The David Rodriguez-Sanchez, Gary Rosengarten [4] uses a flat strip of a mirror and get concentration ratio increased up to 80%. Hongbo Liang et al. [5] Designed cavity shaped reflector and get maximum efficiency of the system is found 85.03%. Piotr Felinski, Robert Sekret [6] use a cheap aluminium reflector and get a temperature of Phase Changing Material (PCM) rise from 60.18 oC to 68.43 oC. Qiliang Wang
[7] and Mahmoud Abdelhamid [8] uses secondary reflector inside the receiver tube to improve efficiency. Alexandros Vouros [9] design optimal shape by simulation and get concentration ratio up to 95%. Alberto Sanchez-Gonzalez, Jesús Gomez-Hernandez [10], Should Jiang et al [11] and Irfan Ullah, Seoyong Shin [12] uses a downstream reflector to concentrate rays at bottom-placed receiver.

B. Literature review based on Secondary reflector as Booster

Hiroshi Tanaka [13] uses flat reflector at different inclination angle for flat plate collector to find optimum inclination angle for different length of reflector and collector ratio. Naveed ur Rehman [14] optimize the performance of wall connected flat plat collector with booster reflector. Jee Joe Michael [15] gets more uniform output of PV module using single and double booster with ideal inclination. Ljiljana T. Kosti´c, Zoran T. Pavlovi´ [16] optimize Inclined PV/T collector with double side booster and get 35.7% increment in energy output. Lianwei Qin et al. [17] purify water by UV light and generate power also, by using double booster power output doubled than the non-concentrated collector. J.T. Mahdi, B.E. Smith [18] and K.K. Chong et al [19] uses double booster called V-trough collector to get water temperature of 85.9oC. Chunliu Mao et al. [20] uses bottom mirror reflectors to increase the efficiency of horizontal all-glass evacuated tubes.

C. Secondary reflector used to reduce end optical loss

Evangelos Bellos et al. [21] investigates secondary reflector and get 21.7% optical enhancement. Evangelos Bellos et al. [22] also extend the length of receiver and displaces receiver such that lost radiation can be utilized.

Methodology

Eexperimental work is carried out to understand the effect of SR with different inclination on Thermal efficiency and Simulation in ANSYS is used to find the optical performance of PTC.

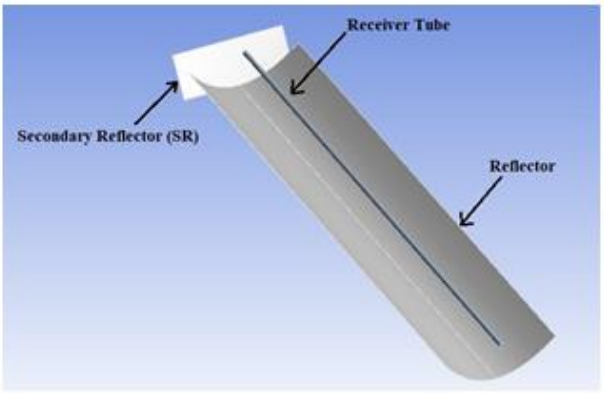

Fig. 2. PTC with inclined SR

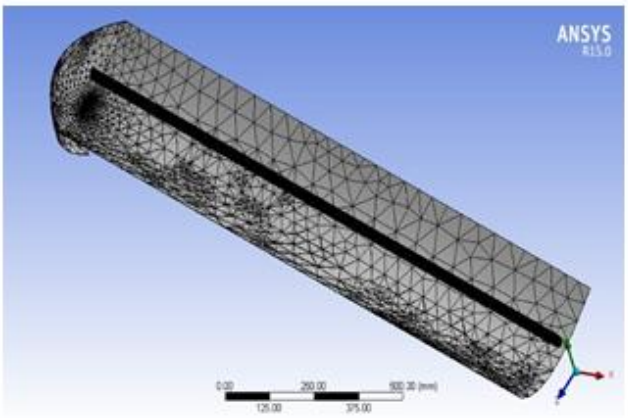

Fig. 3. PTC with Parabolic Secondary Reflector

The solar collector is a test based on thermal and optical performance. PTC has 1.5m length,0.4m width positioned in East-West direction at 23.5o South facing. Copper receiver tube has 15mm diameter and 1.5m length. Mass flow rate(m) is 0.05 kg/s, C is Specific heat of water = 4.186 Kj/Kg ^{o}C and Means PTC with no SR

A. Thermal Performance

Thermal performance is compared with thermal efficiency ( ). The experiment is carried out for 1st and 2nd week of March 2020. Reading of outlet temperature (Tout), inlet temperature (Tin) and solar irradiance(G) is taken at every 2- hour time from 7:00 to 13:00.
Heat absorbed by water
$Q_a = m \cdot C \cdot (T_{out} - T_{in})$ (1)
Total available solar energy
Qs = A.G (2)
A = Aperture area(m2), G = Solar irradiance(W/m2)
Thermal efficiency:

$$\eta_{th} = \frac{Q_a}{Q_s} \quad (3)$$

B. Optical Performance

Optical performance is measured by Incident angle modifier (IAM or K).1st March and 1st April is selected for simulation with ray-tracing in ANSYS Fluent.

$$K = \frac{\eta_{opt(\theta 1)}}{\eta_{opt(\theta i = 0^{0})}} \quad (4)$$

Optical efficiency at an incident angle is found by

$$\eta_{opt}(\theta i) = \frac{Q_{abs}}{O_r} \quad (5)$$

Qabs =Heat received at the receiver, measured by simulation software.

Result And Discussion

A. Thermal Performance

The graph shows that thermal efficiency is greater for PTC with SR than PTC without SR in the morning times. But as the time increaser the sun is moving beside the SR, it causes the shadow effect of SR in the PTC and the efficiency is reduced. In those situations, thermal efficiency is less in PTC with SR than PTC without SR. 30o and 45o inclined SR still gives more efficient performance because it reflects more sun rays as the sun moves towards the west direction.

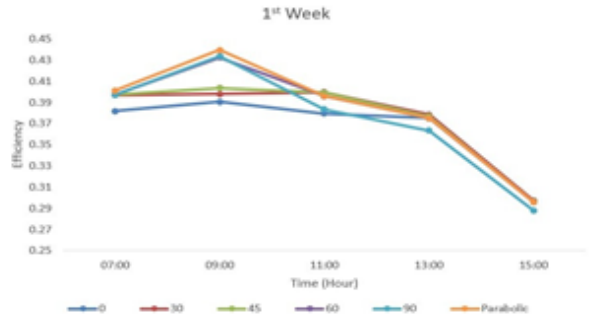

Fig. 4. Thermal Efficiency Comparison on 1st week of March

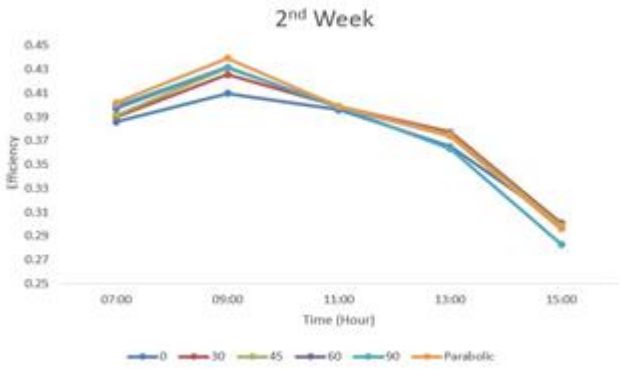

Fig. 5. Thermal Efficiency Comparison on 2nd week of March

Till mid-day SR of parabolic shape and 90o inclined gives 3-5% higher efficiency than conventional PTC as it recovers almost all lost radiation. After this both parabolic and 90o inclined SR not allowed the sun rays passing through them and causes shadow which tends to reduce the efficiency of PTC. As the inclination of SR reduces it allows more sun rays to pass and gives higher performance. 30o inclined giver optimum performance among all of them.

B. Optical Performance

For optical performance, the same happened as thermal performance. PTC with parabolic shape SR gives the highest optical performance in the morning.

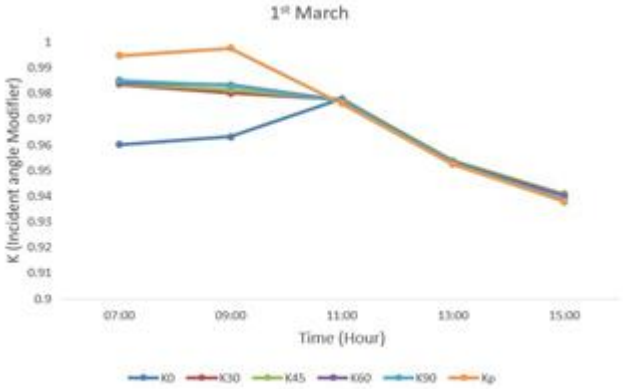

Fig. 6. Incident angle modifier comparison on March

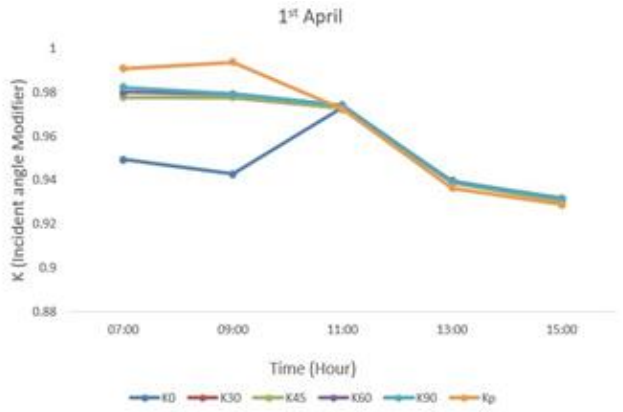

Fig. 7. Incident angle modifier comparison on April

Validation of Experiment with Numerical simulation

Numerical simulation is done for 1st week of march at 9:00 time for SR at all angles and Parabolic shaped SR. outlet temperature (Tout) is found by simulation and thermal efficiency is found by it.

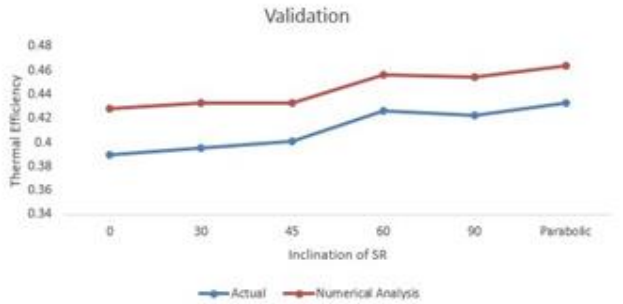

Fig. 8. Validation between Actual and Numerical simulation

The graph shows that numerical analysis gives higher thermal efficiency around 3-5 % greater than actual thermal efficiency. Heat loss by air convection, Conduction loss in the reflector, Glass tube, cloudy weather and copper tube and other natural losses are not considered in simulation gives higher performance.

Uncertainty Analysis

It is essential to investigate this deviation which might occur due to carelessness or due to the environmental factors during experimentation. Uncertainty analysis provides the maximum possible error in numerical digits. It is based on random sampling during the experimentation. The uncertainty analysis tells us to approximate expected accuracy, not the exact accuracy of the system and equipment. To evaluate uncertainty involved in this experiment the method suggested by Kline and McClintock is used. If the data of any parameter is calculated using certain measured quantities then an error in measurement of "y" (parameter) is given as follows.

$$\frac{\delta y}{y} = \sqrt{\left(\frac{\delta y}{\delta x_1}\delta x_1\right)^2 + \left(\frac{\delta y}{\delta x_2}\delta x_2\right)^2 + \left(\frac{\delta y}{\delta x_3}\delta x_3\right)^2 + \cdots} \qquad (6)$$

Table I. Uncertainty Analysis Of An Experiment

Uncertainty of Experiment		
Factor	***Notation***	***Uncertainty***
Area of PTC reflector	A	± 0.00026
Cross Section Area of Receiver Tube	A_c	± 0.00942
Mass inside receiver tube	m	± 0.009451
Available Heat	Qs	± 0.00025
Absorbed Heat	Qa	± 0.01773
Thermal efficiency	η_{th}	± 0.01773

Conclusion

Radiation loss is a big problem for all solar collectors and for this, many kinds of research are going on. Use of secondary reflector gives good result in almost all solar collector and it is also not affecting the current design of collector. Cheaper SR helps to concentrate lost radiation.

In terms of instant water heating applications, parabolic SR and 90o inclined SR gives less heat loss. Especially in parabolic SR, because it reflects more lost rays towards the receiver compare to flat SR and gives 3-5% more efficiency. 30o inclined SR gives the overall highest performance among all of these cases.

Future Scope

The current setup has a length to width (L/W) is 15: 4, which has less end radiation loss. As the width to length ratio is an increase, end radiation loss also increases and SR gives a more impactful performance.

Rim angle (ψ) is taken as 90o for this experiment if the rim angle is decrease means focal length is increased. As the focal length increases radiation loss is also increases and the size of SR also increase to recover these lost rays. Height should be smaller than the focal length. SR gives greater performance for decreased rim angles.

The only disadvantage of parabolic SR is that after mid-day it causes a shadow effect for PTC reflector which gives less thermal efficiency as well as optical efficiency. If the PTC uses continuous tracking mechanism than it will overcome this problem.

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