

Experimental Investigation on cost effective concentrating collector for steam generation

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Abstract— Energy is the soul of the modern world. Fossil fuels are expected to get exterminated with the growing demand of human beings. As a solution to the twin problem of growing demand and limited fossil fuel, the state-of-the art technology is shifting towards renewable sources of energy. One of the renewable energy sources which have high potential to cater the energy need is solar energy. Solar energy has been already utilized in various applications like dryer, cooker, water heater, refrigeration, steam generators. In this paper, an experimental set up was prepared of solar assisted steam generator (coupled to concentrating collector) and analysis have been carried out of steam generating potential at different period of day and different dates of year which has an impact due to variation of solar insolation at different time and date of the year. Temperature variation between the fluid inside the steam generator cylinder and ambient temperature is checked and other parameters affecting the performance like wind velocity, motor speed are also noted down. Experimental results showed that the temperature produced by solar steam generator is satisfactorily high with economic and simple experimental set up.

Keywords:- Steam Generator, Solar Insolation, concentrating collector, Infrared Thermometer

I. INTRODUCTION

The World of today has been struggling hard to solve the dual problem related to the ever growing energy demand and growing environmental degradation [1]-[3]. Solar energy possesses huge potential to solve this problem due to its characteristics of highly abundant in nature and clean energy. In this paper, an alternative technique (using solar energy) to cater a portion of hot water and steam required by mankind has been suggested. Solar water heater and steam generator are gaining its proficient position in the modern green technology market because of its low cost and high efficiency [4]. In hot climates, solar power is abundantly available that is used to power solar steam generation [5]. Steam generators have got a wide application in hospitals, industries, cooking (which is also known as solar cookers), domestic applications in winter season. A large amount of electricity consumed in industries and hospitals is by the steam generator operational electricity consumption and the current demand may increase more with global warming and increase comfort expectations [6][12]. So, to save a considerable amount of electricity and its associated bills,

solar water heating techniques is a viable solution where the operational cost is meagre as compared to the conventional electrically-operated water heaters for steam generation purposes. So, this solar water heating technology must be adopted to improve the life standards of developing countries and to reduce the grid dependency in peak periods. Designing Solar Water Heaters are more suitable and economic for hot climates, and can be considered an appropriate technology for places with high solar insolation. The global solar thermal market is dominated by countries like China, Greece, Germany, Turkey Brazil, Europe, Japan and India. European Union (EU) has multi schemes for promoting solar operated systems [4][7][14]. It has been reported that about 20,000 SWH are installed every year in India [4]. Highly populated Countries like China, India need to move towards greener and cleaner technology for powering air conditioning where the cooling demand can be substantially high in the upcoming years Even Rajasthan Government has issued many subsidies for solar operated devices [5][16] and currently it has been toiling hard to satisfy energy demand of 24,000 MW from solar sources.

Studies by Islam *et al.* [4] revealed the long term proven technological feasibility and described the variance in the temperature attained by the SWH depending on the variance in constructional techniques. Voropoulos *et al.* [6] observed that solar still when coupled to a solar water heater performs better than when stand-alone solar still is installed. Odeh *et al.* [7] suggested that direct use of water as working fluid in solar parabolic collector is more feasible and showed better performance in terms of lower losses and higher efficiency as compared to Syltherm800 (synthetic fluid) when used as the working fluid and the heat from Syltherm800 was transferred to water for steam generation. Radosavljević *et al.* [8] studied the effect of local latitude, azimuth of the front of the object (ψ), angle of the slope of the receiving surface(s), coefficient of reflection from the surroundings, etc., and provided a mathematical model for calculating the solar intensity that reaches horizontal and vertical surfaces on Earth by the use of mathematical modeling a program in InSunZra. As when we make any study regarding solar power of any specific location, the need to know the solar intensity of that place based on its definite longitude and latitude is of huge importance. Huang *et al* [9] devised an analytical model for finding out the optical performance and developed a modified integration algorithm to simulate the performance of a parabolic trough collector along with vacuum tube receiver and deduced the parameters like receiver efficiency, cosine factor, heat loss and conversion

efficiency discarding the losses and considering optical error, tracking error, position error when the system is fully installed. **Liu et al [10]** suggested a procedure to develop a facet concentrator that runs on medium temperature thermal source for deploying and using in laboratory-scale researches. The authors approximated the concentrator to be an ideal truncated circular paraboloid having square flat facets resting on a parabolic frame and developed a procedure to design facet concentrator and optimized by Monte Carlo ray tracing analysis and extracted the collection efficiency, flux non uniformity and computed that a facet concentrator of 164 nos. corresponding to the facet size of 24.1cm with an error of 5mrad can deliver up to 8.15kW with an average CR of 108. **Li et al [11]** formulated an analytical function to predict the performance of a paraboloidal solar dish collector (having cavity or flat receiver) by the integration of optical efficiency of local points in the total reflecting space and also optimized the receiver size and dish's rim angle to enhance annual net thermal energy that is collected at different heat loss coefficients and at different optical errors. The study gave a clear delineation of preferring non-window and window cavity receiver based on the optical error. **Gudekar et al [12]** analyzed a Compound Parabolic Collector and developed a working model of it with an aperture area of 30m² for steam generation applications and devised a system which is easy to manufacture, lesser mirror area per unit aperture area and economically viable than other concentrating collectors and It has been observed that the efficiency of conversion of solar energy into heat energy reaches up to 71%, with low operating maintenance. **Chemisana et al [13]** devised methodology of reflective concentrating systems when the concentrator works at different inclination angle for tracking different Sun's positions and validated the results in a two-axis Fresnel reflective solar concentrator to obtain slope error maps of concentrating systems considering the overall effects of optical quality, geometrical concept of the vanishing point , the Sun shape over the absorber, devised a methodology to mechanically evaluate the structure performance at different inclinations, which is the major advantage of this procedure and after comparative analysis it has been observed the difference was up to only 5.38%.

Various techniques for capturing solar power have been devised and efficiency of the associated devices has also been enhanced with constant scientific researches [7]-[13]. Usage and acceptability of Solar powered devices like water heaters, cookers, power generation, air heaters and dryers have gained momentum in the past few years [6]. Although, solar water heater is a matured and accepted technology all over the world yet there is a need to further improve the system performance. The performed experiment is thrived for the better system performance and to analyze the potential of SWH in Rajasthan.

II. EXPERIMENTAL SET UP

An experimental set up has been prepared with a concentrating collector coupled to a Cu cylinder where steam is generated and was chosen for investigation. The technical

specifications of the experimental setup are given in table 1, and the experimental setup in shown in figure. 1.

Sl. no	Components	Specifications
1.	Concentrating collector	Parabolic(2a=50') Circumference:158' Focal point:6.0093'
2.	Cu cylinder	Useful volume: Water volume:2l
3.	Infrared thermometer	
4.	General thermometer(Hg)	
5.	Pressure gauge	
6.	Anemometer	
7.	Temperature sensor	Range:200°C
8.	Regulated DC power supply	

Table 1: Specifications of experimental set up

Concentrating collector collects solar energy and concentrates the solar energy into its focal point where the copper cylinder is fixed with an arrangement as shown in figure 1. The copper cylinder is painted black so that it can have maximum absorptivity as ideal black has absorptivity of 1. Infrared thermometer is used to measure Cu cylinder surface temperature and general thermometer is used to measure ambient temperature. Pressure gauge is also incorporated in the system to verify whether the pressure generated due to high temperature within the cylinder is in safe limits. Temperature sensor measures the inside temperature of copper cylinder where steam is generated by its sensor wires in the cylinder and display unit outside. DC power supply was provided to an automatic tilter who used to regulate the tilt axis according to the direction of solar radiation.



Figure 1: Experimental set up

This experimental set up as shown in figure 1. has been installed in Suresh Gyan Vihar college premises at Jaipur (Latitude:26.91°N, Longitude:75.78°E). The location of deploying any solar technology has a major role as the solar intensity varies drastically with location of a place.

III. OBSERVATIONS

Solar intensity at various days of a week and different period of the day has been noted down from 22nd Sept-27th Sept'14. A trend has been observed in all those readings that high solar intensity is observed during 11am to 2pm with its peak value in noon time.

Date	22 nd Sept	23 th Sept	24 th Sept	25 th Sept	26 th Sept	27 th Sept
Time (hrs)	W/m ²					
09:00	738	861	760	716	712	719
10:00	886	1217	938	904	900	815
11:00	393	1290	1105	1048	928	1066
12:00	595	1239	1128	1151	1190	1225
13:00	1140	1331	1012	1176	1108	1140
14:00	1046	1178	1007	1098	914	1075
15:00	877	946	897	916	885	925
16:00	813	825	622	697	630	734

Table 2: Solar radiation data

From this data table, we can see the variation in solar intensity at different dates of a year due to variation in declination angle which depends on the n, number of day of a year.

$$\delta = 23.45 \sin \left[\frac{360}{365} (284 + n) \right]$$

With high solar intensity values during 11am to 2pm, high cylinder surface temperature can be expected with steam generation potential. Data table for 22nd Sept'14 has been given in below and the following parameters like cylinder surface temperature, ambient temperature, reflector surface temperature and wind velocity are noted down and the potential for steam generation even with such a small concentrating collector of low aperture area has been investigated.

Time(min) Baseline: 11:20am	Temp (west,) (°C)	Temp (east) (°C)	Temp (Bottom) (°C)	Aver. temp
0	124	107	91	107
30	140	107	100	115.3
60	150	113	114	125.7
90	106	130	108	114.6
120	109	128	118	118.6
150	112	138	110	120

Table 3: Cylinder surface temperature of sideways and bottom surface

Cylinder surface temperature varies at sideways and bottom surface due to different solar irradiation at different parts of the cylinder. The bottom surface is having the least surface temperature as it does not get direct solar intensity. To compare the cylinder surface temperature with other temperatures, the average temperature of the surface is calculated to have a more realistic comparison. The cylinder surface temperature during the observed

period was above 100°C which gives a clear indication that steam generation is possible with the installed experimental set up as water boils at 100°C when the atmospheric pressure is 1 bar.

Time(min) Baseline: 11:20am	Temp at cylinder surface (°C)	Temp of environment (°C)	Difference (°C)
0	54	34	20
30	65	42	23
60	107.3	46	61.33
90	115.3	47	68.33
120	125.7	47	78.66
150	114.66	46	68.66

Table 4: Comparative analysis of cylinder surface temperature and environment temperature.

Temperature at cylinder surface is compared with ambient temperature and it has been found that a relatively high difference has been observed between these values implying the collector potential to collect the solar heat and successively raise the temperature to an extent to successfully generate steam.

Time (min) Baseline: 11:20am	Temp at reflector surface(°C)	Temp at surface of cylinder (°C)	Difference (°C)
0	50	54	4
30	52	65	13
60	72	107.33	35
90	82	115.33	33
120	94	125.66	31.66
150	90	114.66	24.66
180	88	118.66	30

Table 5: Comparative analysis of cylinder and reflector surface temperature.

Temperature between the reflector surface and cylinder surface are compared and it has been found that cylinder temperature is higher than reflector temperature as the cylinder is placed at its focal point of the concentrator accumulating all the solar radiations striking on the reflector surface.

Time(min) Baseline: 11:20am	Cyl. outside Temp (°C)	Cyl. inside Temp (°C)	Difference (°C)
0	54	45	9

30	85	72.5	12.5
60	107.33	92	15
90	115.33	104	11
120	125.66	115	10
150	114.66	112	2
180	118.66	114	4

Table 6: Comparative analysis of cylinder inside and outside surface temperature.

Cylinder outside and inside temperature has also been noted down and it has been found that there is a slight decrement in these two temperatures even though Copper has a high conductivity. Higher the conductivity of the cylinder material, lower will be the temperature drop between the cylinder inside and outside temperature. Ideally when the thermal conductivity approaches to infinity and the volume of the surface tends to zero, then the temperature drop seems to vanish, but in practical there will be temperature drop due to finite volume of the surface.

Time (min) Baseline:11:20am	Wind velocity(m/s)
0	1.41
30	5.8
60	3.4
90	3.1
120	3.9

Table 7: Wind velocity at different period of the day.

Wind velocity at different period of the solar peak period has been observed and it has been deduced although the wind velocity was present, which led to higher convective losses but the set up was successful enough in generating the required temperature to produce steam inside the Cu cylinder.

IV. CONCLUSION

From the above analysis it has been concluded that at favourable locations, it is possible to generate steam with a small aperture area and the system is highly economic requiring no electricity cost to run the system as compared to conventional steam generator. There also remains a huge scope to improve the system performance by incorporating transparent glass (single or multi-layer) as they have the ability to reduce convective losses and further improve the steam generation capacity of the installed system. However, solar steam generator has been regarded as a very promising application for solar thermal energy in countries with high insolation. A lot of research needs to be done on cost reduction, system quality improvement, energy performance enhancement, and better building and process integration to make it easily adoptable by common people [7]-[13]. North-western part like Rajasthan and Gujarat has high solar intensity that makes it worthy enough for solar powered devices and systems [13][15]. With these objectives in mind, R&D should aim at improving system performance, integration and reducing material costs of each component present in

solar steam generator. It has been believed that this experimental analysis would boost the commercial market to develop such technology commercially and this experimental set up was prepared at a very low cost.

Abbreviations

CPC	Concentrating Parabolic Collector
CR	Concentrating Ratio
n	no of days starting from Jan 1 st , $1 \leq n \leq 365$
SWH	Solar Water Heater

Greek symbols

δ	declination
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