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EXPERIMENTAL INVESTIGATION TO DETERMINE INCREASE IN TEMPERATURE WITH GLASS COVER IN SOLAR WATER HEATER

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ABSTRACT

Availability of fossil fuels is a serious threat to the development of mankind as humans became completely dependent on energy for their sustenance with the growing technological innovations. This led to the search of newer and alternative sources of energy which are clean and available in abundance with nature. Such a promising alternative source of energy is solar energy which has huge potential to solve the twin problem of growing demand and limited fossil fuel. Solar energy has already gained its popularity and utilized in various systems as solar dryer, solar cooker, solar water heater, solar refrigeration, and solar steam generators. In this paper, an experimental set up was developed of solar assisted steam generator coupled to parabolic concentrating collector and performance analysis of steam generating potential with and without glass cover has been determined and the increase in efficiency of steam generator with the former case has been verified. Temperature variation of the fluid inside the cylinder and ambient temperature has been noted down and increase in temperature of water as compared to ambient temperature has been also observed. Experimental results deduced showed that the temperature generated by solar steam generator is satisfactorily high and the increase in efficiency with installation of glass cover is remarkable.

Index Terms— Solar Steam Generator, parabolic concentrating collector, Infrared Thermometer

1. INTRODUCTION

With highly growing environmental concerns, sustainability that can be done with the utilization of alternative energy sources is of prime concern. The environmental norms across the globe has emancipated the need to find an energy source that can cater insatiable energy need of human beings, solve energy related problems, such as, energy supply, energy security, emission control, energy conservation without affecting environment and the energy conservation methodologies. [1]-[3] A substantial amount of electricity consumed in industries, hospitals residential sectors, commercial and institutional facilities is due to the incorporation of steam generator and the electricity consumption may further increase in the coming days [6][12]. However, present source of electricity is mainly grid-dependent and the cost per unit increases during peak load consumption duration. So, to save a considerable amount of electricity bills, SWH is a viable solution where the operational cost is low as compared to the electrically-operated conventional water heaters for steam generation purposes. This led the researchers to search for some efficient substitutes, which promises harmonious correlation with sustainable development, management, energy conservation, and environmental preservation. Considering the environmental protection and in the context of sustainable utilization of energy sources, solar energy has massive potential to provide a feasible solution to the crisis for its characteristics of clean energy and highly abundant in nature but the problem that solar energy has comparatively lower efficiency is creating hindrance for successful deployment of solar systems. In this paper, a solar steam generator system (using concentrating parabolic collector) has been analyzed and ways to improve its efficiency has been suggested along with improvement in efficiency with glass cover has been observed. Solar operated steam generator is gaining its proficiency in the green technology market because of its low cost and higher efficiency as compared to other solar assisted devices like solar Photovoltaic cell, solar air conditioners [4]. In hot climates, solar power is abundantly available that can be used to power solar operated water heaters (SWHs) or steam generators [5]. The steam generated from Steam generators have various application in industries, hospitals, cooking (in form of solar cookers), domestic applications. This technology can be considered an appropriate technology to improve the life standards of developing countries and places where solar insolation is very high which will lead to faster payback period. SWH is already adopted by both developed as well as developing countries like China, Germany, Brazil, Europe, Turkey, Japan and India. European Union (EU) has launched multiple schemes for promoting solar operated systems [4][7]. It has been reported that about 20,000 SWH are installed every year in India [4]. So, even a slight increase in efficiency will save a considerable amount of electricity. Highly populated Countries like China, India need to move towards greener and cleaner technology for catering needs of hot water where the domestic needs can be substantially high in the upcoming years. Even Indian states like Gujarat and Rajasthan have made it mandatory to deploy solar water heaters in commercial buildings. State Government of Rajasthan has issued many schemes and subsidies for popularising solar operated devices among public [5][16] and currently it has been toiling hard to satisfy energy demand of 24,000 MW from solar sources (Source: Times

of India). Adopting SWHs can also put a check in the emission of greenhouse gases, countries across the globe are trying to achieve their intended goal of cutting down their emission, US-China recent deal to reduce emission by 26-28% by 2025 is also pressurising other countries (Source: Times of India, 13th Nov'14) and Solar devices can assist countries in this .

Variation in constructional techniques is found to vary the highest temperature attained by the SWH due to lower heat loss, higher efficiency and improved technological feasibility **Islam *et al.*** [4]. Using water directly as working fluid reduces the transmission loss and showed better performance as that from incorporating other fluid as the working fluid as investigated by **Odeh *et al.*** [7] using Syltherm800 (synthetic fluid). It has also been found by **Voropoulos *et al.*** [6] that coupling SWH with solar still also helps in improving the performance of solar still with respect to that of stand-alone solar still, thus, adding up to one more benefit of SWHs.

Solar power received (solar intensity) by any specific location is largely dependent on its location i.e., longitude and latitude. **Radosavljević *et al.* [8]** studied the effect of coefficient of reflection from the surroundings, azimuth of the front of the object (ψ), local latitude, angle of the slope of the receiving surface(s), 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 of a program in InSunZra. Analytical model of modified integration algorithm were devised by **Huang *et al.*** (2011) for finding the optical performance of a simulated parabolic trough collector along with vacuum tube receiver and deduced parameters like receiver efficiency, annual average efficiency, heat loss, cosine factor and conversion efficiency considering optical error, tracking error, position error [9]. A facet concentrator was developed by **Liu *et al.*** (2012) operating on medium temperature thermal source for using in laboratory-scale researches and computed that a concentrator of 164 nos. of the facet size of 24.1 cm with an error of 5mrad can deliver heat upto 8.15 kW, with an average CR of 108 [10].

Li *et al.* (2013) also formulated an analytical function to determine the optical efficiency in the total reflecting space of a paraboloidal solar dish collector (having cavity/ flat receiver) system by integrating optical efficiency of local points considering directional effects by the angular dependent model optimizing the receiver size and dish's rim angle to enhance annual net thermal energy at different heat loss coefficients. The study showed the performance of the paraboloidal dish with a windowed-cavity receiver or flat receiver as the optimal rim angle decreases when the effects of incidence angle are considered [11].

Gudekar *et al* (2013) analyzed the present CPC limitations and problems and developed a model of a Compound Parabolic Collector (CPC), aperture area of 30m^2 for steam generation applications, the system devised is easy to manufacture, have less mirror area per unit aperture area and economical than other concentrating and the conversion efficiency of solar energy to heat energy is attained up to 71%, requires single tilt adjustment daily for operation period of 6hrs with relatively low operating maintenance and concluded that more modifications in design will enhance system performance that will generate steam (at high temperature) at which subsequent amount of process heat can be utilized usefully [12].

Chemisana *et al.* (2013), focused on designing and testing of optical quality of solar concentrators using absorber reflection method (ARM), devised methodology of concentrating when it works at varied inclination angle for tracking different Sun's positions, validated the results obtained from simulated system (ray tracing and sum of squares) in a two-axis Fresnel reflective solar concentrator considering overall effects of optical quality, the Sun's shape over the absorber and deduced from their observation that mechanical stress on the structural system, where mirrors are fixed, largely dominates optical quality. Although they advised from their study that the system needs to be precise and strong to minimize the deformation of the concentrator during its movement while solar tracking, yet light enough to prevent overloads, the suggested methodology is simple and suitable to mechanically evaluate the structure performance at various inclination angles, the major advantage of this procedure is the results obtained can be verified with the experimental results of concentrated flux distribution profile [13].

2. SOLAR ENERGY AND ITS COLLECTION

Sun is a fusion reactor which produces total energy output of 3.8X 10^{20} MW but Earth receives a small fraction of it, nearly about 1.74X 10^{11} MW. For determining the feasibility for installation of any solar technology, we need to find out few parameters, like, location (latitude and longitude of the place) [3], solar insolation of the place [10].

Solar energy can be collected in many forms, by converting it into thermal energy sources as in solar thermal collectors, by converting it into electricity as in PVs[11] or in some chemical forms as in PCMs (which are growing popularity as thermal latent energy storage devices) [3][12]. The most popular among this are STCs like Flat Plate Collectors (FPCs), parabolic dish collectors (concentrators). Depending on the temperature requirement of the working fluid, various types of solar collectors can be installed which are broadly classified as concentrating and non-concentrating collectors [13]. The latter STC are more efficient with high conversion but costlier than the former.

Multiple ways to enhance performance of SWHs and their relevant studies for determining performance has been evaluated [7]-[13]. Although, solar water heater (SWH) is a matured and accepted technology all over the world yet there are many alternatives to further improve the system performance which can be a blessing to mankind. The performed experiment is also meant to thrive for attaining system with improved performance and higher efficiency at a place like Rajasthan, India where use of SWH is mandatory for all commercial buildings.

3. EXPERIMENTAL SET UP

An experimental set up has been deployed at SGVU, Jaipur (Latitude:26.91^{0}N, Longitude:75.78^{0}E) with a parabolic concentrating collector coupled to a Cu cylinder inside a glass box 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.

Table 1: Specifications of Experimental set up at SGVU, Jaipur

Sl. no	Components	Specifications
1.	Parabolic Concentrating collector	Major axis (2a=50") Circumference:158" Focal point:6.0093"
2.	Cu cylinder	Useful volume:5l Water volume:3l
3.	Infrared thermometer	
4.	General thermometer(Hg)	
5.	Pressure gauge	
6.	Regulated DC power supply	
7.	Thermocouple	Range:200^{0}C
8.	Glass box cover	Length: 15" Breadth: 12" Height: 15" Glass thickness: 3"

Parabolic Concentrating collector collects solar energy and concentrates solar energy incident on its plate at its focal point, the heat produced at the focal point is transmitted to the copper cylinder as shown in Figure 1. The copper cylinder is painted black so that it can absorb maximum solar radiations for its maximum absorptivity property as ideal black body has absorptivity of 1. Infrared thermometer is used to measure Copper cylinder surface temperature, while Mercury thermometer is used to measure ambient temperature. Pressure gauge is also installed in the set-up to check the pressure generated within the cylinder is in safe limits due to high temperature generated at its focal point. Thermocouple measures the inner temperature of copper cylinder by its sensor wires, put inside the cylinder and display unit outside to display the inner Cylinder temperature. DC power supply is also supplied to an automatic tilter which regulates the tilt axis according to the direction of solar radiation, the inclination angle is fixed at one side at 10^0. Glass box cover reduces heat loss by minimizing convective heat losses from the Copper cylinder body which may arise due to wind velocity as shown in **Figure 2.**

Figure 1: Experimental set up at SGVU, Jaipur

4. OBSERVATIONS

Solar intensity at various days of November month is collected where ambient temperature drops down and the need of hot water arises for domestic utilization purposes. The performance of SWHs in hot days i.e., from March-Oct'14 is commendable when the hot water is utilized in hospitals and for many industrial applications. So, the observations have been noted down in November to validate the effectiveness of SWH. Temperature inside and outside cylinder at various period of day (during 10am to 1pm) has been noted down from 15th-22nd Nov'14 to determine the trend of effectiveness of solar water heater after how many hours observed with its peak value observed in noon time. The location of deploying any solar technology and date when observation readings are taken has a key role in determining the effectiveness of solar water heater (SWH) as the solar intensity varies drastically with location of a place as well as at different dates of a year (for variation in declination angle which depends on '*n*', number of day of a year.

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

Due to different solar insolation at different surfaces, the temperature is different at sideways and bottom surface of the copper cylinder. As the bottom surface is having least direct irradiation so it is having the least surface temperature. To compare the cylinder surface temperature with inner cylinder temperature, the average temperature of the surface is calculated to have accurate comparison.

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 hot water.

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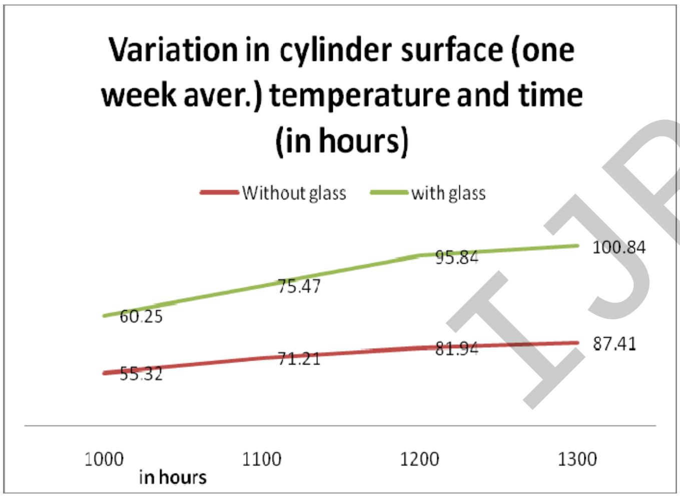
Figure 2: Cu cylinder inside glass box cover coupled to Experimental set up at SGVU, Jaipur

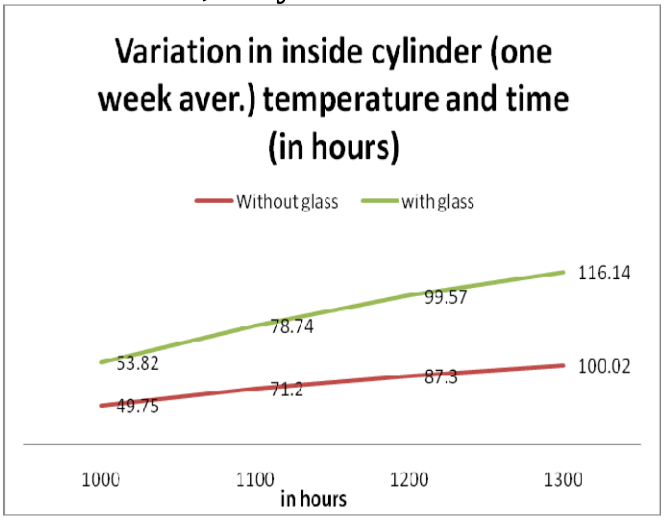
Outside average surface and inside temperature of cylinder has also been noted down and the consequent graphs are plotted.



Graph 1: Variation in cylinder surface temperature and time (in hours)

[Temperature indicated at the nodes of the graph are in ^0C]

The outside surface temperature of cylinder is calculated considering the temperature of sideways and bottom surface due to different solar irradiation at different parts of the cylinder. The bottom surface is having least surface temperature as it does not get direct solar intensity. To compare the cylinder surface temperature with time duration (in hours), the average cylinder temperature of the surface is calculated to have a more realistic comparison.



Graph 2: Variation in inner cylinder temperature and time (in hours)

[Temperature indicated at the nodes of the graph are in ^0C]

It has been observed that with use of glass, the inside cylinder temperature as well as cylinder surface temperature increases significantly as that of temperature attained in cylinder without glass as the glass reduces the convective heat losses. The subsequent increase in duration of operation the temperature of cylinder both inside and outside increases.

The average of ambient temperature noted in 15^{th}-22^{nd} sept'14 was 43.71^0C respectively and the readings are compared and it has been observed that the temperature increase is high enough such that the temperature generated in the cylinder is sufficient enough so that it can be utilized for water heating applications for domestic purposes as it becomes an essential part in winter season. The useful water volume inside the cylinder is low but it can be circulated in the tank for mass water heating purposes.

5. CONCLUSION

From the above analysis it has been concluded that at favourable location, it is possible to generate hot water with a small aperture area and the system is highly economic (costing Rs. 15,000 approx.) requiring no operating cost for electricity cost to run the system is zero as compared to conventional SWH. The meager electricity cost may add up to the system if a pump is coupled to circulate water in water tank. The glass cover box reduces the convective heat losses which make it more viable for producing hot water and the cost incurred for the glass cover box is just Rs.600 which is very low. Thus the experimental set up deployed at SGVU, Jaipur proves the effectiveness and satisfactory performance of SWH, which proves that it can be deployed in houses and the performance expected to achieve will be satisfactory and sufficient enough to content users' requirement. There also remains a wide scope to improve system performance by incorporating glass of multi-layer as they have the ability to further reduce convective losses and improve the water heating capacity of the installed system. Further research needs to be done on cost reduction, energy performance enhancement, system quality improvement, and better 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 worth enough for installing solar powered systems [13][15]. With these objectives in mind, R&D should aim at improving system performance of solar powered devices, and reducing material costs of each component present in water heater. It has been believed that this experimental analysis would boost the commercial market to develop such technology commercially as this experimental set up proved the sufficiency at a relatively low cost.

ABBREVIATIONS

ARM- Absorber Reflection Method

CFC- Chloro Fluoro Carbon

CPC- Compound Parabolic Collector

CR- Concentrating Ratio

DC- Direct Current

EU- European Union

n- No. of days starting from Jan 1st , 1≤n≤365

SWH- Solar Water Heater

Greek symbols

∂ Declination

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