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EFFECT OF TOP GLASS COVER ON THERMAL PERFORMANCE OF CYLINDRICAL PARABOLIC COLLECTOR

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Abstract- ***Sun has been identified as one of the most promising clean and renewable source of energy. Solar energy can be used directly or indirectly for electricity generation and solar thermal application. Concentric solar energy collectors can collect large amounts of heat from solar radiation to produce steam which is further fed to turbine for power production. Present work deals with design and fabrication of prototype cylindrical parabolic collector for hot water generation. Experimentation has done by using top glass cover and without top glass cover to study its effect on output characteristics of system. Thermal performance and efficiency of open and closed cylindrical parabolic collector is evaluated as per ASHRAE Standard 93, 1986. Comparative heat transfer analysis of both open and closed cylindrical parabolic collector system shows that top glass cover improves the instantaneous efficiency from 45.56 % to 62.60 % and Overall efficiency by 10%. This low cost prototype cylindrical parabolic collector can deliver 80 liters of hot water within temperature range of 58 ⁰C to 69⁰C throughout a day and can be used for industrial process heat or domestic application.***

Key Words: *Concentrated solar power, cylindrical parabolic collector, solar energy, solar thermal application, hot water generation, industrial process heat application.*

1. Introduction

Growing population, industrialization and increased electrification rate in India demands large amount energy in the form of electricity. India's electricity consumption rate is supposed to increase from 2280 BkWh by 2021-22 to 4500 BkWh by 2031-32 [1]. Expected rise in sector wise energy demand from 2009 to 2035 is as shown in figure1.

There are two scenarios of World energy outlook 2011 called new energy policy scenario (NPS) which shows India's commitment on energy security, climate change, energy related challenges and 450 scenario set the path way to meet 50% of its energy goals by limiting the increase of global temperature to 2^0C compared with present industrial levels.

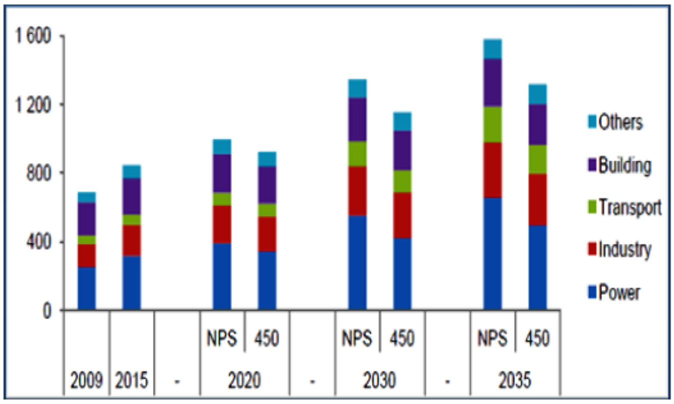

Fig-1: Sector wise electricity demand in India (MToe) [2]

From figure1.it is observed that power sector is the most dominant in energy consumption. Conventional energy sources like coal, crude oil used for electricity generation causes global warming, pollution, depletion of ozone layer etc. and are going to deplete soon. To overcome above mentioned problems, there is need to utilize nonconventional or renewable energy sources which can satisfy current energy demand and are nonpolluting. Renewable energy sources like solar, wind, biomass, ocean etc. are needed to be considered to power production. India has a vast potential of renewable energy sources. Sun generates energy in the form of radiation at the rate of 3.8 x 10^{23} kW but a very small fraction of this energy i.e. 1.8 x 10^{14} is intercepted by Earth surface which is thousands times larger than current energy consumption rate [3]. Solar power technology used for electricity generation and solar thermal application can reduce the dependency and burden on fossil fuel.

Solar energy technologies consist of solar photovoltaic cells, solar flat plate and concentric collectors, solar towers etc. out of which concentrating solar power collectors such as cylindrical parabolic collectors (CPC) are capable of producing hot water; steam can be further used for industrial process heat and power production.

H. Price et al. have reviewed the advances in parabolic trough collector technology and its suitability in commercial power plants. It was observed that about one third of total installation cost is required for solar collectors, so it is very important to reduce cost of solar collectors by research and development activity. A detail survey has done about the efforts taken by various international organizations to make this technology economically viable. Advancement in various parts of parabolic collector technology such as support structure, reflector, receiver etc. has discussed and how it contributes to improving overall of efficiency is mentioned in detail [4].

Ahmed S. Hegazy et al. have tested solar parabolic trough collector for salt-water desalination in arid areas of Saudi Arabia. Design and analysis was done using finite element analysis to study the load bearing capacity of support structure. Automatic tracking system was design and implemented for solar parabolic collectors. It was observed that major heat loss was occurred from receiver tube as it was not covered with glass and efficiency of collectors was found to be 40%, but performance can be further improved to utilize it for commercial water desalination application [5].

An experimental study has done by A. Nasir to evaluate the performance of parabolic cylindrical trough for air heating application. Solar air heater consist of two flat plates, square galvanized pipes and centrifugal fan for maintaining constant air flow inside trough. Maximum temperature attained by air was 97^{0}C with efficiency of 65% [6].

Kawira M. et al. has fabricated and characterized the parabolic trough collector for steam generation. Parabolic trough was manufacture with material available in local market and tested at various inlet temperatures. Thermal performance is evaluated for both open and close collector with different reflector material. It was observed that close system has 20% more efficiency than open parabolic trough system [7].

A.V. Arasu et al. presented a parabolic trough collector for hot water generation. Water is circulated back into storage tank and no heat is withdrawal through system. Storage tank water temperature was increased from 35^{0}C to 73.84^{0}C throughout a day. It was observed that all performance characteristics of trough are dependent on solar beam radiations and maximum efficiency was obtained during noon as radiations are higher at that time [8].

Parabolic collectors consume about half of the total cost of power plant. To reduce the cost of installation and maintenance, parabolic trough parameters such as concentration ratio,mass flow rate of heat transfer fluid, length of collector,rim angle, etc. areneed to be optimized. A MATLAB code was designed to predict the economic performance of collector. Study shows that performance and economy of plant depends on input parameters and by controlling these parameters, collector yields best thermal performance. The same code can be used to forecast the performance of commercial power plant [9].

From above literature review it was observed that high initial cost and lower efficiency are the major drawbacks of using of cylindrical parabolic collector technology. Thermal performance and conversion efficiency of collectors get reduced due to higher wind speed, dust and harsh environmental conditions. To make concentrating collector technology economically viable, an attempt has made in this work to design a prototype cylindrical parabolic trough collector with top glass cover and fabricated with low cost locally available material. Top glass cover avoids the entry and deposition of dust, soil over reflector and also reduces convective heat losses due to higher wind speed.

2. Design and Material selection

Concentration ratio is an important design parameter in CPC which gives the amount of solar energy is converted in to useful form out of total solar radiation fall on it. Concentration ratio can be calculated by

$$Cr = \frac{\textit{Area of Aperture}}{\textit{Area of Absorber tube}}$$

Or

$$Cr = \frac{W - D_o}{\pi * D_o}$$

$$Cr = \frac{1030 - 19}{\pi * 19}$$

$$\underline{Cr = 16.94 \sim 17}$$

Solar radiations falls on Earth surface are either beam or diffused form. CPC absorbs only beam radiations and focus all these rays to focal point or line. Theabsorber tube is placed concentrically along this focal line, as its axis. Following equation shows the important relationship between the width and depth of CPC and used to calculate the focal point,

$$f = \frac{w^2}{16d}$$

$$f = \frac{1030^2}{16 * 300} = 221.02\ mm$$

CPC consist of curved mild steel reflector coated with silver foil of reflectivity 0.85, copper tube used as absorber tube coated with black zinc having absorptivity

0.90, support structure made of steel can give strong mechanical support. Manual tracking system is adopted to reduce initial project cost. A well-insulated storage tank of 100 liters capacity used to store hot water. Top glass cover of thickness 3 mm having transmissivity 0.9 is used to cover whole aperture area of CPC.

.**Table-1:** Specifications of CPC

Parameters	Values
Collector Width	1030 mm
Collector length	1082 mm
Depth of Collector	300 mm
Focal distance	221 mm
Receiver inner diameter	17 mm
Receiver outer diameter	19 mm
Concentration ratio	17
Storage tank capacity (hot and cold water)	100 liters
Tank insulation material	Asbestos
Glass cover thickness	3 mm
Rim angle	134.52^o
Mass flow rate of water	10 liters/hr

3. Experimental setup and Test procedure

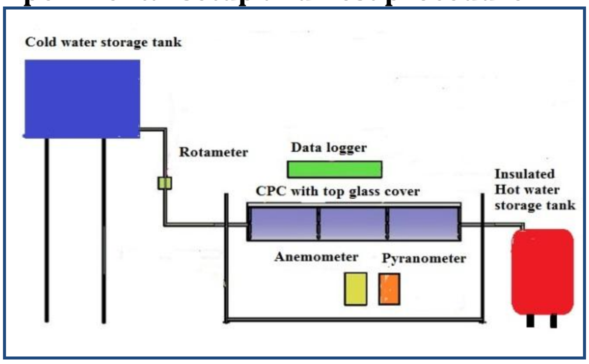

Fig-2: Experimental setup for testing of CPC

Experimental consist of cold and hot water storage tank of 100 liters capacity. Cold water storage tank kept at 5 feet above from ground to facilitate easy flow of water into CPC. Hot water storage tank is kept on ground and well insulated with asbestos to avoid heat flow from hot water to atmosphere. Rotameter is used to measure water flow rate and attached before CPC as shown in figure2. Anemometer measures wind speed and Pyranometer is used to read global radiation. As CPC absorbs only beam radiation its value calculated manually. Data logger consists of k type thermocouple measures temperature of water at various locations such as inlet and outlet of CPC, temperature of absorber tube etc.

Cylindrical parabolic collector is tested according to ASHRAE Standard 93, 1986 [10] and Thermal performance is evaluated as per the procedure given in reference book [11]. Test is carried out with and without top glass cover to study effect of top glass cover on thermal performance. Experimental data is collected after each half an hour from morning 10AM to 4PM in the month of May at ShivajiUniversity Kolhapur (M.S) India (Latitude: 16.42° N, Longitude: 74.13°W).

4. Results and Discussion

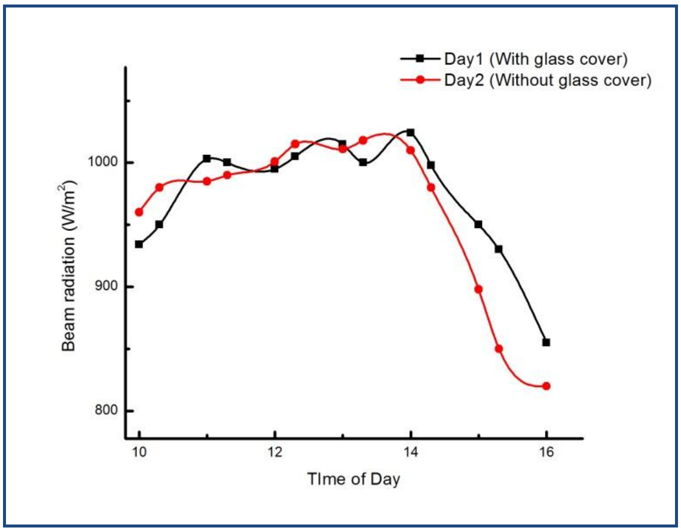

Fig-3: Beam radiation available during day 1 and 2 over time of day

Figure3.shows the availability of beam radiation over time of day for both days, it is observed that beam radiation increases slowly from morning up to noon and decreases in the evening. During summer sky is clear so beam radiations are available in large quantity. Both days show similar pattern of radiations in the range of 810 W/m^2 to 1050 W/m^2.

Variation of mean absorber tube temperature over period of day is shown in figure4. During day 1 whole CPC is covered with glass and no air is allowed to enter in to CPC so mean absorber tube temperature is higher than that of day 2. When CPC is open more convective heat losses are observed. During day 1 mean absorber tube temperature was in between 60^0C to 86^0C and for day 2 it is 35^0C to 55^0C.

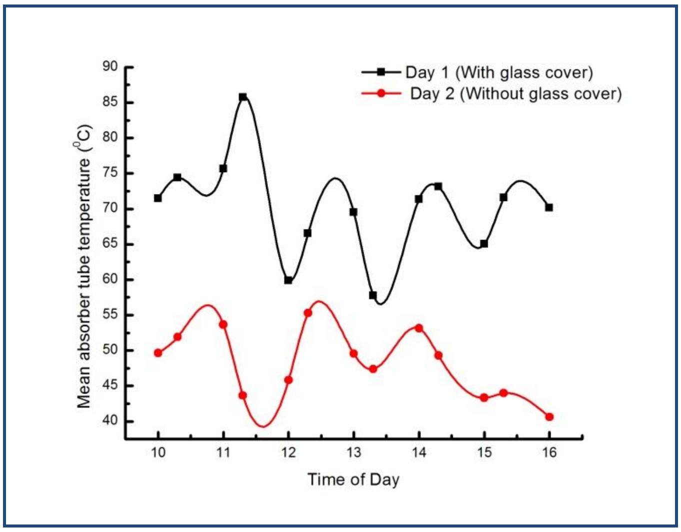

Fig-4: Mean absorber tube temperature for day 1 and 2 Over time of day

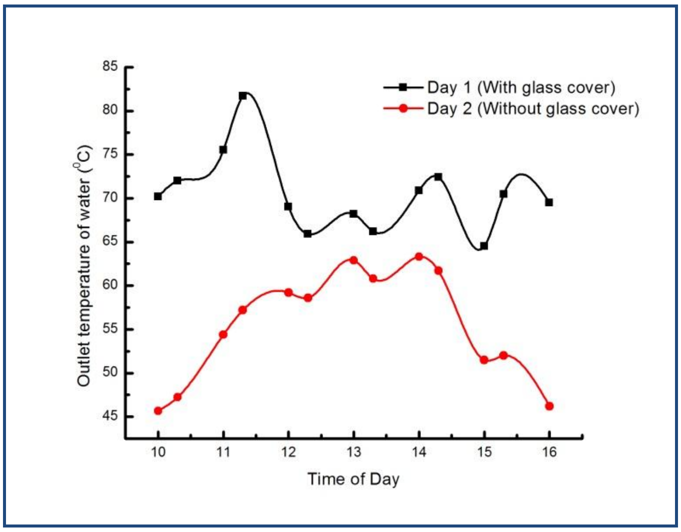

Fig-5: Outlet temperature of water for day 1 and 2 over time of day

Outlet temperature of water through CPC for day 1 is higher than day 2. Maximum temperature achieved by open CPC is 63^0C and closed CPC is 82^0C as shown in figure5. It means more heat is transferred by closed CPC to water and less heat losses as compared to open CPC. There is 19^0C temperature difference observed between maximum temperatures observed by both systems.

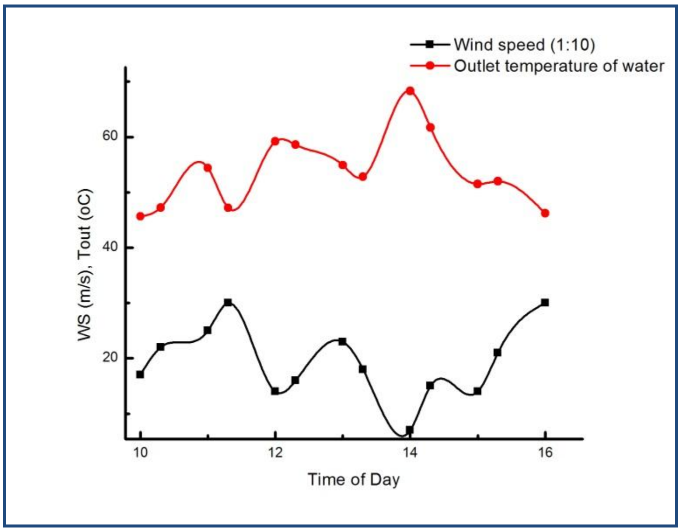

Fig-6: Effect of wind speed on outlet temperature of water for day 2 over time of day

Figure6.shows effect of wind speed on outlet temperature of water, as wind speed increases there is more heat loss by convection and reduces outlet temperature of water. Wind speed in scaled to 1:10 ratio to observe the relation between them. At 11AM wind speed increase to 3 m/s cause fall in outlet temperature of water from 59^0C to 48^0C. After 2 PM wind speed increases and outlet temperature falls linearly.

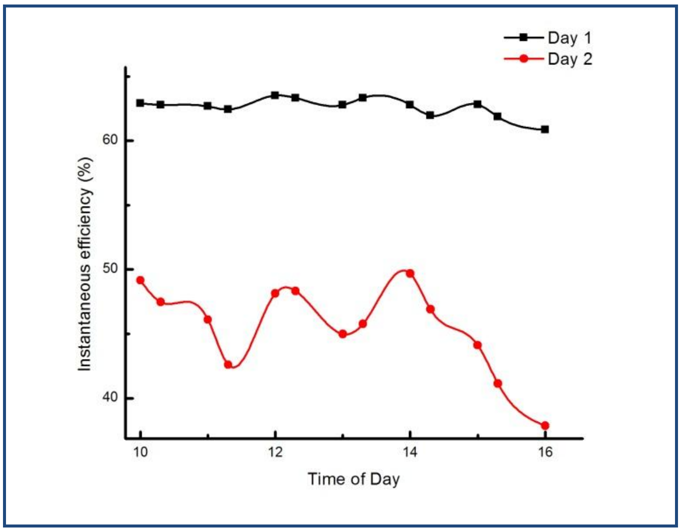

Fig-7: Comparison of instantaneous efficiency of CPC with top glass cover for day 1 and without glass cover for day 2 Over time of day

Instantaneous efficiency of closed CPC has nearly constant value over time of day and varies 62 to 63% but the efficiency of open CPC shows variation due to change in wind speed. Instantaneous efficiency of open CPC varies in between 35 to 50%.

5. CONCLUSIONS

A cylindrical parabolic collector was designed and fabricated with low cost material for hot water generation. Thermal performance of both open and closed CPC was compared to study the effect of top glass cover. It was observed that, glass cover reduces the convective heat loss through system and improves the heat transfer from absorber tube to working fluid. Maximum outlet temperature obtained by closed CPC is 82^0C which is 19^0C more than open CPC. Overall efficiency of closed CPC is 10% more than open CPC system. It was also observed that glass cover doesn't allow soil and dust particle to get deposited over reflector and absorber tube which enhances the overall performance of CPC as well as reduces the cleaning problems. This system can be commercialized by varying design specifications as per requirement to produce hot water at desired temperature to satisfy industrial and domestic demands.

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NOMENCLATURE

BkWh- Billon kilowatts
CPC- Cylindrical parabolic trough
Cr- Concentration ratio
w- Aperture Width
f- Focus of CPC
d- Depth of CPC
Do- Outer diameter of absorber tube
Ws- Wind speed
Tout- Outlet temperature of water

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BIOGRAPHY

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