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Experimental Investigation of Compound Parabolic Concentrator for Hot Water Generation

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ABSTRACT:
In previous studies we have found the importance and effectiveness of single trough collectors. The simulation results of compound parabolic collectors, which consist of multiple sets of trough collectors combined so that radiations released from one are collected by another and absorbed in the receiver, have previously been studied. The present project is an experimental study of the solar CPC system; a three-parabolides model for domestic and commercial water heating systems is developed and tested.
In the present work development and testing of compound parabolic trough collector is done based on simulation results of previous works. The present model is combination of three parabolides of different curvatures focusing each other and finally to the receiver part. The experiments were carried out in six separate events, and we have observed an average 55.02 degree centigrade rise in temperature of water.

KEYWORDS: Compound Parabolic Trough Collector, CPC, solar water heating, solar thermal energy.

I. INTRODUCTION

Energy is a crucial factor in the development of the economy and society. The role of energy has an immediate impact on corporate growth, which supports the expansion of the national economy. Energy that comes from the sun progresses as sunlight. Warmth and light are the two basic forms of solar energy. The climate transforms and uses daylight and warmth in a great variety of ways. Some of these changes result in the use of renewable energy sources including biomass, wind, and waves. The Gulf Stream, the fly stream, and the water level are all effects of the climate's absorption of solar energy.

Most of the energy that strikes the Earth's surface is absorbed; only a little amount is reflected. Together, the air and the Earth's surface absorb around 70% of the radiation that approaches, while about 30% is reflected back into space and does not warm the surface.

1.1 Energy Scenario

By 2050, the demand for energy is expected to have substantially increased and will have dramatically multiplied by the end of the century. Gradual improvements in the current energy organisations won't be sufficient to meet this need in a practical way. Finding sufficient sources of sustainable energy for the future is one of society's most daunting challenges.

According to their primary energy source, sunlight-based energy change frameworks can be divided into three categories: sun-based power, sun-based fills, and sun-oriented warm frameworks. Each of the three traditional methods for handling misuse of solar-powered equipment offers potential that has not yet been identified. The workshop participants considered the potential of each of the three approaches as well as the potential of half breed frameworks that combine important elements of distinct innovations into new, interdisciplinary ideal models.

1.2 Solar Energy

The most easily accessible source of energy is solar electricity. It is free because it belongs

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nowhere and has nowhere to go. Being the least filthy of the non-regular energy sources, it is also the most crucial because it lessens the impact on the nursery. Sun-oriented energy has been used since ancient times, but in a very primitive manner. Prior to 1970, some creative work was done in a few countries to better utilise solar energy, but the majority of this effort remained primarily scholastic. Following the shocking increase in oil prices in the 1970s, a few countries began to plan extensive, creative work programmers to exploit solar energy.

We use the energy of the sun when we hang our clothes outside to dry in the sun. Similar to this, solar-powered boards absorb the sun's energy to warm water and provide warmth for cooking. Such systems are readily available and in use in homes and manufacturing facilities. As seen by the patterns in the USA and Japan, it is expected that a significant portion of families worldwide will use solar energy within the next few years. The Ministry of Non-Conventional Electricity Sources and the Indian Renewable Energy Development Agency are developing a scheme to provide solar energy to more than 1,000,000 families in the coming few years. However, for a programme to be successful, the motivation of the participants is crucial. India is one of a very small number of countries that enjoys lengthy days and plenty of daylight, especially in the Thar Desert region. This area is suitable for outfitting sun-powered energy for a variety of purposes because it has abundant access to sun-based energy. Sun-based energy might be easily harnessed in areas with a comparable amount of solar radiation. India uses solar-powered nuclear energy to heat water for both contemporary and traditional uses. In Jodhpur, a 140 MW coordinated sun-oriented power plant is planned, however the overall cost is still exorbitant. We may also use energy from the sun to suit our energy needs. Sunlight-based radiation is directly converted into DC power using Solar Photovoltaic (SPV) cells. Either all things considered, this power can be used, or it can be stored in the battery. The electrical energy that has been stored can then be used in the evening. SPV can be used for a variety of purposes, including

(i) Lighting created at home
(ii) Illuminating streets
(iii) City jolt
(iv) Water siphoning
(v) Desalination of foul-smelling water

If a method for using sunlight-based energy could be developed, it would lessen our reliance on finite energy sources and improve the state of the environment in which we currently live.

1.3 Advantages of Solar Energy

(i) Solar Energy is Environmentally Friendly
(ii) Solar electricity facilitates off-grid living in homes
(iii) Solar battery storage systems can also be utilized to store electricity for nighttime and rainy days.
(iv) Solar energy causes fewer electricity losses.
(v) A Free Source of energy is Solar Power

1.4 Solar Concentrating Technology

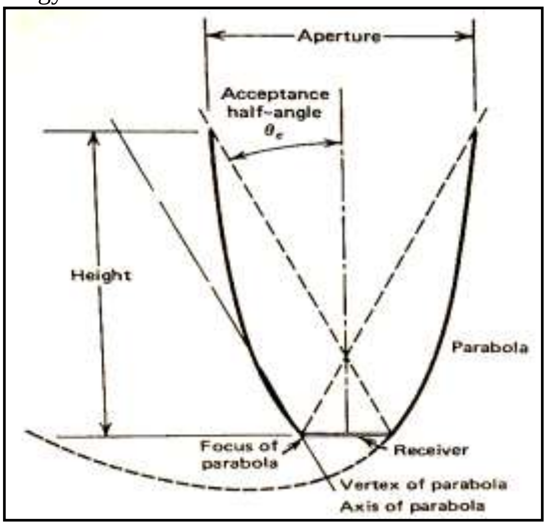
A solar concentrator is a device that allows sunlight to be concentrated on a smaller receiver or exit by collecting it from a wide area. Figure represents a conceptual design of a solar concentrator used to harness the power of the sun to generate power.

Solar concentrator can be categorized into two groups:
(i) Line Concentrating
(ii) Point Concentrating

1.5 Compound Parabolic Collector

Compound Parabolic Concentrator, or CPC for short, is a category of non-imaging concentrators. A non-imaging concentrator does not create an image of the source, but it does transmit radiation from the source to the receiver across a greater distance than imaging optics do.

The receiver, reflector, and cover are the three most crucial parts of a CPC. To collect as much solar light as possible, a receiver's high absorptance is important. A CPC consists of two parabolic reflectors, as shown in Figure. The maximum possible reflectivity should be used in solar concentrator reflectors. Its job is to direct solar energy in the form of a beam onto the receiver.



Typical profile of a Parabolic Concentrator Compound

1.6 Tilt Angle

A solar collector is required to collect solar energy and transmit it with the lowest amount of heat loss possible into a heat transfer fluid. It is important to quantify a collector's heat losses in addition to its capacity to absorb solar radiation in order to evaluate its performance. The optical and physical characteristics of a collector have an important impact in determining its capacity to absorb energy from the sun. The tilt angle of a solar collector with respect to the horizontal is one of the important variables affecting performance. This is because different tilt angles have different effects on the amount of solar energy hits the collector surface. Researchers have observed that varying the tilt angle four times a year according to the seasons would allow for very nearly optimal energy collection.

Optimal tilt angles by months:

January	February	March	April	May	June
39°	31°	23°	15°	7°	0°
July	**August**	**September**	**October**	**November**	**December**
7°	15°	23°	31°	39°	46°

Reference - https://www.shaktipumps.com/solar-calculator.php

II. OBJECTIVE OF STUDY

The Parabolic Trough Collectors (PTCs) are widely utilized in commercial solar thermal installations. Yet, due to their unique benefits, several alternative designs are also taken into consideration. For instance, a Compound Parabolic Collector (CPC) may focus the sun's rays on a flat receiver for the duration of an entire day without tracking. Since CPC does not need a complex tracking system like other solar concentrators, it has the benefit of being simple to use. As a result, during the past 30 years, efforts have been made to comprehend the distinctive qualities of CPC and to create a variety of its applications. Solar water heating systems may be the most appropriate application in this situation because they may be connected to nearby storage tanks and are built on unused roof space. CPC collectors were created and experimentally tried in earlier works to generate hot water for domestic usage.

In previous studies we have found single trough collectors significance and effectiveness. Previously we have studied the simulation results of compound parabolic collectors where more than one set of trough collectors are combined in a way that the radiations emitted from one are collected by another and collected in receiver. The present work is an experimental study of solar CPC System; a model consisting of three parabolides is developed and tested for house hold / industrial water heating system

III. LITRATURE REVIEW

1. **Vardan Singh et.al** have designed and analyzed compound parabolic collectors numerically on ANSYS software. They have analyzed three different geometries of CPC, in which two were designed in such a way that maximum concentration of radiations could provided to the receiver pipe. All the three models are further analyzed for three different tilt angles and results of temperature, velocity and motion of air are drawn.

2. As a demonstration prototype, **J.Macedo-Valencia etal** described the stages of design, modeling and assessment of a parabolic trough collector (PTC) for heating water. The parabolic aperture of 0.5 m wide by 0.95 m long was taken into account during the design process. Computer-aided design and manufacturing were used in the creation of the design. To determine the thermal performance of the parabolic trough collector, the results of the evaluation showed that at a flow rate of 0.200 L/min and a solar radiation of 783 W/m2, the maximum output temperature was 47.3 °C.

3. **SWH technologies developed by Chandrasekhar and Kandpal** could assist a large number of homes, according to their methodology. The methodology establishes a relationship between the seasonal and diurnal variations in ambient temperature at a place and the need of hot water for bathing. This has been used to estimate the expected capacity utilization of SWH for different locations in the country. The income levels of the households directly affect their capacity to purchase SWH. Using the income distribution of households in

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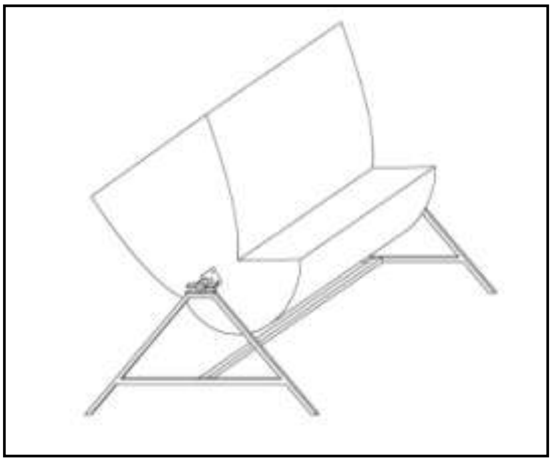
the country, the capital cost of typical SWH, and the rate of interest on the loans provided to the users to purchase SWH, the potential number of households who can use SWH have been estimated. In one of the examples presented in the paper, it is estimated that 45 million households in India can use SWH. This translates into a potential of 90 million m2 of SWH in the residential sector.

4. **To estimate the potential for SWH, Pillai and Banerjee** developed a model that takes into account adoption variables at the end-use level (microlevel factors) as well as market-wide effects (macro-level factors). The methodology can be used to estimate the potential for the individual sectors and also for the target area as a whole. In the paper, the methodology is illustrated for a synthetic area at Pune with an area of 2 sq. km and population of 10,000. The end use sectors considered are residential, hospitals, nursing homes and hotels. The estimated technical potential and market potential are 1700 m2 and 350 m2 of collector area, respectively.

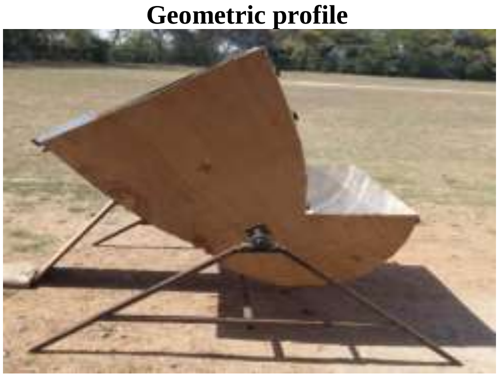
5. **Al Imam, M. F. I., R. A. Beg, M. S. Rahman and M. Z. H. Khan. (2016)** in this study, we analyse the photovoltaic thermal (PVT) collector system's conversion of solar radiation into thermal energy and its storage in phase change material (PCM). A compound parabolic concentrator (CPC) has been installed on the PVT collector in order to maximize solar radiation. When it comes to winter weather, clear and semi-cloudy days were used in this study to compare performance. Because of the simplicity of the arrangement for PCM storage within the same unit, the PVT solar collector with CPC acts as a solar collector, a PCM tank, and the CPC. There was no requirement for a connection pipe, which reduced the installation footprint and eliminated the necessity for continual tracking in order to improve the concentration ratio. Using updated equations generated for the energy storage system from the basic derivation of Hottel– Bliss–Whillier, we evaluated the collector's total heat loss, total useable energy, thermal efficiency, and overall efficiency as a function of various factors. According to the data, solar collectors' thermal efficiency is between 40% and 50% on a clear day; the figure drops to about 40% on a semi-cloudy day. The PVT collector's overall efficiency ranges between 55% and 63% on a clear day and 46%–55% on a partly cloudy day, with peak losses of roughly 3W/m2K on a clear day and 2.5W/m2K on a partly cloudy day. The plate temperature rose to roughly 3 meters from the entry, then stabilised. However, when the identical system was used without the PCM, the temperature rose dramatically.

IV. CONSTRUCTION OF MODEL



CAD Model of CPC

Geometric profile



Actual CPC Model

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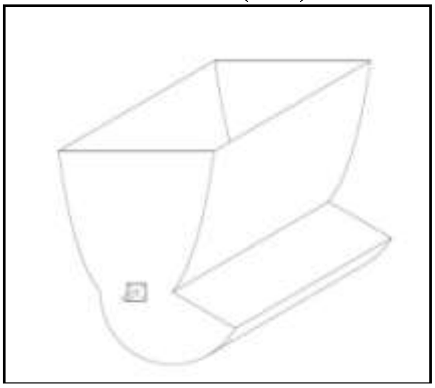
The construction is done in two parts (as shown)

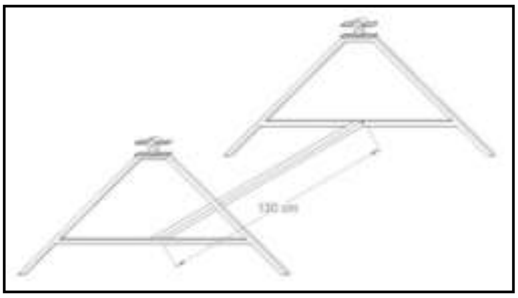
1. Solar Concentrator (CPC)



CAD Model of CPC

A geometric model is prepared on AutoCAD. A section as per drawing is cut on 12 mm thick plywood. After that all parts of CPC is assembled with the help of adhesive & nails.

2. Stand for Solar Concentrator



CAD Model of Stand

The stand is made by 1 inch square hollow pipe, welded on the structure firmly as shown in figure. This structure is attached with bearings to provide necessary angular moment. The whole structure is mounted on a triangular stand to give necessary height.

V. EXPERIMENTATION & OBSERVATION

The experimentation shall be done in six events.

Note: -

- All temperature readings are taken in degree Celsius.
- For this experiment the CPTC is fixed at angle of 32 degree and a submersible pump is put in tank of 10 L and water is circulated and readings are taken for half hour

Experimental Setup

Inlet Temp. of water

Outlet Temp. of water

EVENT – I
Obsevation Date – 13.03.2023

S. No.	Time (t)	Ambient Temp.	Temp. of Receiver	Inlet Temp.	Outlet Temp.	Temp. Difference
1.	11:00	31	49	22	31	9
2.	11:10	31.4	62	31	43	12
3.	11:20	31.8	76	43	55	12
4.	11:30	32	85	55	63	8
5.	11:40	32	98	63	74	11
6.	11:50	32.3	110	74	82	8

Table – 5.1

EVENT – II
Obsevation Date – 14.03.2023

S. No.	Time (t)	Ambient Temp.	Temp. of Receiver	Inlet Temp.	Outlet Temp.	Temp. Difference
1.	11:00	30	46	22	30	8
2.	11:10	30.5	61	30	41	11
3.	11:20	31	75	41	51	10
4.	11:30	32	84	51	60	9
5.	11:40	33	97	60	68	8
6.	11:50	33.5	108	68	78	10

Table – 5.2

EVENT – III
Obsevation Date – 15.03.2023

S. No.	Time (t)	Ambient Temp.	Temp. of Receiver	Inlet Temp.	Outlet Temp.	Temp. Difference
1.	11:00	32	48	22	30	8
2.	11:10	32.5	63	30	38	8
3.	11:20	33.6	74	38	48	10
4.	11:30	34	86	48	57	9
5.	11:40	34.3	96	57	65	8
6.	11:50	35	109	65	75	10

Table – 5.3

EVENT – IV
Obsevation Date – 16.03.2023

S. No.	Time (t)	Ambient Temp.	Temp. of Receiver	Inlet Temp.	Outlet Temp.	Temp. Difference
1.	11:00	31	47	22	29	7
2.	11:10	32	64	29	36	7
3.	11:20	32.5	75	36	45	9
4.	11:30	33.5	87	45	54	8
5.	11:40	34	98	54	65	11
6.	11:50	34.5	110	65	76	11

Table – 5.4

EVENT – V
Obsevation Date – 17.03.2023

S. No.	Time (t)	Ambient Temp.	Temp. of Receiver	Inlet Temp.	Outlet Temp.	Temp. Difference
1.	11:00	31	46	22	29	7
2.	11:10	31.6	65	29	37	8
3.	11:20	32	77	37	45	8
4.	11:30	32.3	89	45	55	10
5.	11:40	32.8	99	55	64	9
6.	11:50	33.8	107	64	75	11

Table – 5.5

EVENT – VI
Obsevation Date – 18.03.2023

S. No.	Time (t)	Ambient Temp.	Temp. of Receiver	Inlet Temp.	Outlet Temp.	Temp. Difference
1.	11:00	30.5	48	22	30	8
2.	11:10	31.2	66	30	37	7
3.	11:20	31.8	79	37	46	9
4.	11:30	32	91	46	57	11
5.	11:40	33	96	57	66	9
6.	11:50	33.5	108	66	77	11

Table – 5.6

Average Temperature found of all the six events is 77.166 °C

VI. CONCLUSIONS

In the present work development and testing of compound parabolic trough collector is done based on simulation results of previous works. The present model is combination of three parabolides of different curvatures focusing each other and finally to the receiver part.

The experiments were carried out in six separate events, from date 13.03.2023 to 18.03.2023, from 11 AM to 11:50 AM, readings are taken on each interval of 10 minutes. We have observed an average 55.02 degree centigrade rise in temperature of water when the receiver was placed at the compound parabolic trough collector's focal line and at tilt angle of 33 degrees.

The present setup can be viewed as a successful model of solar thermal system for house hold / industrial water heating.

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