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Study Work on Parabolic Solar through Water Heating system with Various Type of Coating on Reflectors with or without Glass

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Abstract: Solar energy serves as the wellspring of all forms of energy present on Earth, establishing its role as a significant contributor. The contemporary surge in global energy demand exerts pressure on traditional energy reservoirs, including coal, petroleum, natural gas, and fossil fuels. These resources, limited in nature, face potential depletion in the absence of recourse to alternative sources. Solar energy emerges as a viable substitute for diverse energy production processes due to its renewable attributes, devoid of any contribution to the emission of greenhouse gases or environmental contaminants. Furthermore, its enduring nature safeguards against imminent depletion. This study delves into the prospect of harnessing solar energy for hot water generation through a thermal system. The research involves the construction of a solar radiation tracking system operated manually. A comparative evaluation ensues, featuring parabolic trough solar water heaters utilizing distinct reflector materials, both with and without the incorporation of glass covers. The reflective component materializes as a stainless steel sheet-formed trough, skillfully cut and welded, integrated with aluminum foil and mirror strips for reflective enhancement. Functioning as the absorber, a copper tube boasting an 18mm diameter and 240mm focal length is adopted. The experimental protocol spans four phases, each involving varying reflector configurations, including instances with and without a glass cover affixed to the trough's surface to mitigate wind-induced losses below. Performance metrics are meticulously documented, subsequently subjected to comparison against three alternative scenarios. The experimentation transpired within the precincts of SRCEM College, Banmore, during the summer season of May 2023, situated in the region of Madhya Pradesh, India. The study's culmination sheds light on the potential of solar thermal systems for hot water generation. The insights gained from the comprehensive evaluation of parabolic trough solar water heaters, encompassing diverse reflector configurations and the influence of glass cover presence, lay the groundwork for a potential revolution in sustainable energy utilization. Amidst the contemporary energy conundrum, this research unveils innovative avenues that harness the abundant offerings of solar energy, promising a cleaner and enduring energy landscape.
Keywords: Parabolic Solar Collector, Black Carbon Foil, Absorber Tube, Glass Cover, Trough, Aluminium Foil.

I. INTRODUCTION

Manifesting as electromagnetic waves, the sun radiates energy uniformly in all directions. This celestial entity bestows the essential life-sustaining energy upon our solar system. A clean, inexhaustible, copious, and universally accessible renewable energy resource, it refrains from engendering the emission of greenhouse gases or other contaminants into the ambiance. Its sustainability thrives over the long term, a stark contrast to the finite temporal scope characterizing conventional oil, coal, and gas reserves. Nonetheless, solar energy is not without its limitations, predominantly as it manifests as a dispersed form of energy, intermittently and sporadically accessible, rather than perpetually and consistently. Notably, the sun generates a yearly energy yield of 2.81023 kw/year.[1]

A. Energy Consumption and Standard of Living

A nation's energy consumption is apportioned across distinct domains or sectors contingent on energy-centric activities. These sectors can be further disaggregated into subcategories:

1) Residential sector (comprising households and offices, inclusive of commercial edifices).
2) Transportation realm.
3) Agricultural domain.
4) Industrial sector.

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Heightened energy utilization within a country signifies the intensification of specific industries. This could entail enhanced household comforts engendered by multifarious appliances, improved transportation networks, and augmented agricultural and industrial output. Cumulatively, these dynamics culminate in an elevated standard of living. Consequently, a nation's per capita energy consumption mirrors its populace's quality of life or affluence (i.e., income). Table 1 presents outcomes, underscoring this concept, wherein comparative data pertaining to annual primary energy consumption across select nations is presented to accentuate the notion.[2]

Table 1 Primary Energy Consumption of Some Country

Country	Total annual energy consumption (in hexajoules, i.e., 10^6 joule)	Per capita annual energy consumption (in gigajoules i.e, 10^9 joules,)
USA	99.4	322
Japan	21.2	172
France	12.5	188
UK	9.8	167
China	62.5	49
India	23.6	25
Global average		70

The global annual energy consumption is currently estimated at 500 hexajoules. In the context of this energy distribution, the United States, representing approximately 6% of the world's population, accounts for 26% of the total energy consumption. Conversely, India, encompassing roughly 17% of the global population, contributes only 3.4 percent to the total energy usage. This disparity is mirrored in the discernible contrast in the quality of life experienced by the populace of these nations. Electricity assumes a pivotal role as a prerequisite for a nation's economic and societal advancement. In 2007, the per capita electrical energy consumption in the United States stood at 12,123 kWh, while India's corresponding figure was 702 kWh.[3]

B. Depletion of Solar Radiation

Various components compose Earth's atmosphere, including gaseous elements, suspended dust, and minute solid and liquid particles. Among these substances are air molecules, ozone, oxygen, nitrogen, carbon dioxide, carbon monoxide, water vapor, dust, and water droplets. Consequently, solar energy encounters hindrance as it navigates through the atmosphere. Notably, different molecules serve distinct functions, such as selectively absorbing specific wavelengths, resulting in an increase in the energy and temperature of the absorbing molecules:

1) Absorption

a) Different molecules selectively absorb specific wavelengths, elevating their temperatures due to absorbed radiation.
b) X-rays and strong ultraviolet light are absorbed by atmospheric gases like nitrogen and molecular oxygen.
c) Ozone effectively absorbs UV energy within the (2.3 μm) range.
d) Water vapor (H2O) and carbon dioxide predominantly absorb infrared light beyond the range (> 2.3 μm) while diminishing near-infrared energy within this range.
e) Dust particles and air molecules, regardless of wavelength, absorb a portion of solar radiation energy.[4]

2) Scattering

The dispersed incoming energy is redistributed by dust particles and air molecules of various sizes, resulting in a portion of radiation being lost to space and the remaining diffused and directed downwards to the Earth's surface from multiple angles. A significant portion of incoming solar radiation is reflected back into the atmosphere by clouds. Another portion is absorbed by clouds, while the remainder is scattered and transmitted downwards to the Earth's surface in cloudy conditions

3) Beam Radiation

Solar radiation that propagates in a straight line and reaches the Earth's surface without altering its course, aligned with the sun, is referred to as beam or direct radiation.

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4) Diffused Radiation

Solar radiation scattered by aerosols, dust, and molecules is categorized as diffused radiation, characterized by its lack of a singular direction.[4]

II. SOLAR TIME

Solar time is anchored to the instance when the sun crosses an observer's meridian, known as solar noon. At solar noon, the sun occupies its zenith position in the sky. The sun traverses each degree of longitude in 4 minutes. Standard time is adjusted to solar time through the following equation:Solar time =Standard time

$4(L_{ST} - L_{LOC}) + E \qquad (1.3)$

Here, Lst represents the standard longitude for measuring a country's standard time, and Lioc is the observer's location longitude. The (+) sign is used when the country's standard meridian lies in the western hemisphere relative to the prime meridian, and (-) if it resides in the eastern hemisphere. E denotes the equation of time, accounting for variations in the Earth's rotation and orbital revolution, resulting in discrepancies in the solar day's duration, which is not a constant 24 hours throughout the year.[5]

III. APPLICATION OF SOLAR ENERGY

1) *Power Plants:* Solar energy facilitates power generation through methods such as utilizing the sun's heat to boil water, generating steam for turbine rotation and electricity production. Solar panels, photovoltaic and thermoelectric technologies, among others, convert sunlight into usable power.
2) *Household:* Solar energy is increasingly integrated into households, powering residential appliances and solar heaters for hot water. Photovoltaic cells installed on rooftops capture and store energy in batteries, providing a sustainable energy source for various purposes.
3) *Commercial Use:* Solar panels, including glass PV modules, installed on building rooftops provide reliable electricity to businesses, offering an independent power source for diverse applications.
4) *Ventilation System:* Solar energy aids in ventilation, powering fans for moisture, odor, and heat regulation in structures.
5) *Power Pump:* Solar power supports water circulation within buildings, enhancing ventilation and distribution.
6) *Swimming Pools:* Solar blankets and solar hot water heating systems maintain pool water temperature during winter.
7) *Remote Applications:* Solar panels and batteries enable remote buildings like schools and clinics to generate and utilize electric power on the go.[6]

IV. SOLAR COLLECTOR

Solar electricity has relatively low density per unit area (ranging from 1 kW/m2 to 0.1 kW/m2), resulting in inefficiency. Solar thermal collectors encompass a substantial ground area to address this limitation. The fundamental element of a solar thermal system is the solar thermal collector, which adeptly captures solar energy as heat and transfers it to a heat transfer fluid. This fluid then conveys the heat to a thermal storage tank/boiler, ready for subsequent phases of the system.[7]

A. *Classification of Solar Collector*

Figure 1 provides an overview of solar collector classification, categorized by their manner of solar light capture. Non-concentrating collectors absorb radiation upon impact with their surfaces, while concentrating collectors elevate radiation concentration per unit area before absorption. Concentrating collectors are subdivided into focus and non-focus types based on their radiation concentration techniques. The focus type further delineates into line or point focus depending on the focusing mechanism.[7]

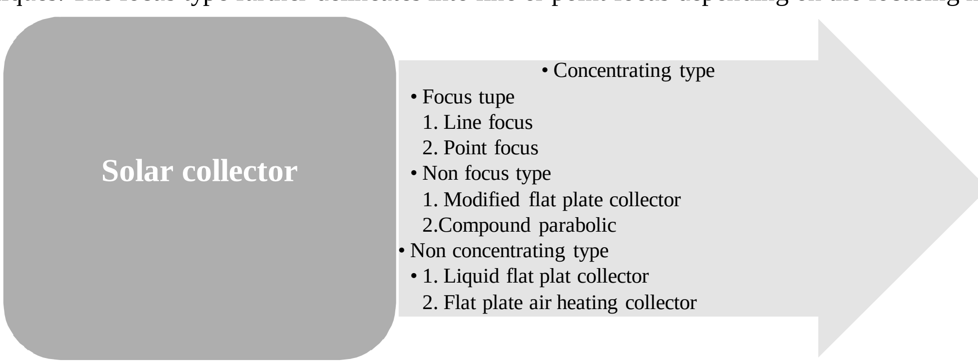

Figure 1 Hierarchy for types of solar collector

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V. EXPERIMENTAL SETUP

1) *Case 1:* Involved a setup with black carbon material foil without a glass cover on the parabolic trough.

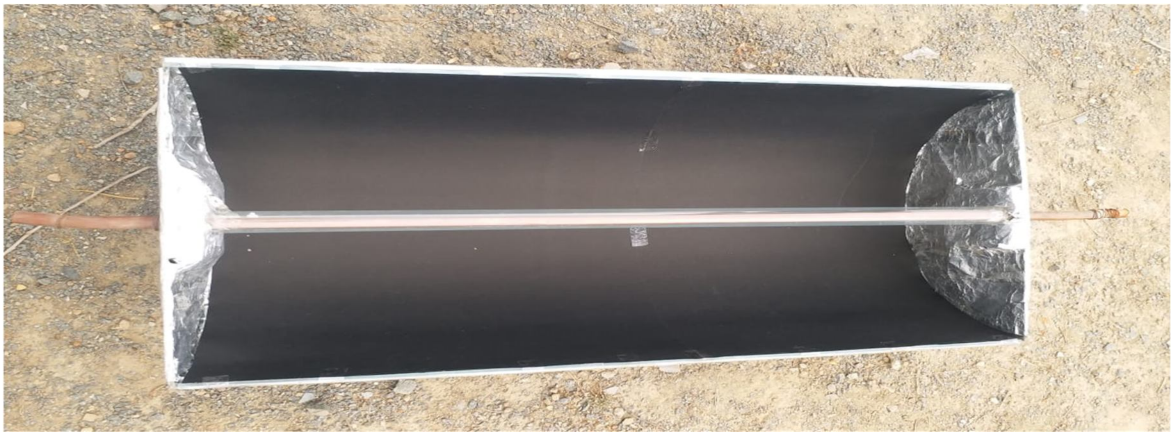

Figure 2 Parabolic trough has black carbon material foil.

2) *Case 2:* The setup incorporated black carbon material foil with a plane glass cover on the trough face.

Figure 3 Parabolic trough has black carbon material foil with plane glass cover

3) *Case 3:* Used an aluminum foil as a reflector without a plane glass cover on the trough face.

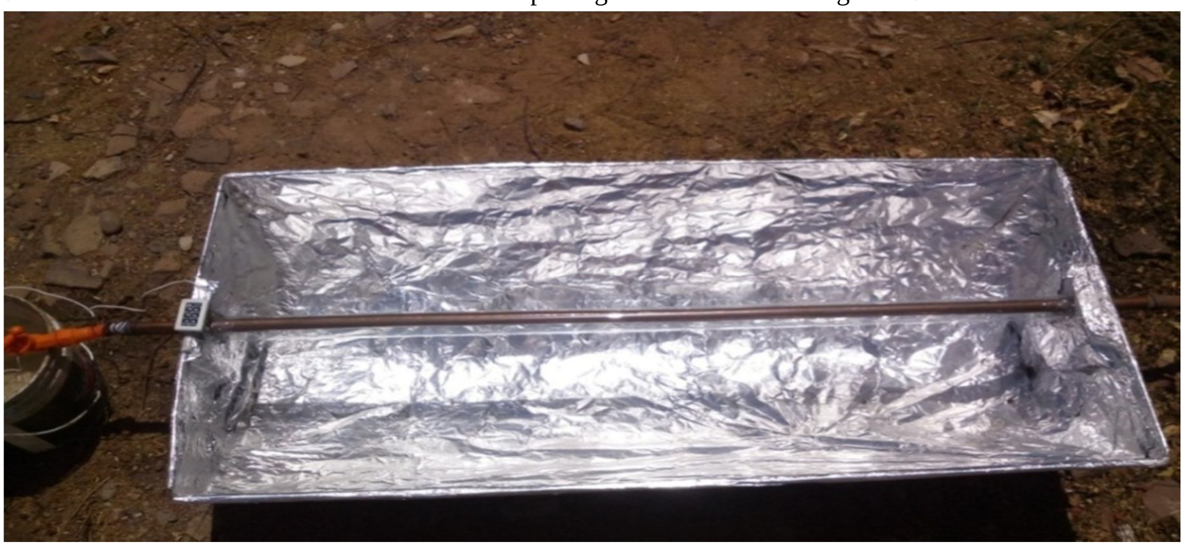

Figure 4 Parabolic trough collector developed has aluminum foil as reflector copper tube without plane glass cover

4) *Case 4:* utilized aluminum foil as a reflector with a plane glass cover on the trough face.

Figure 5 Parabolic trough collector developed has aluminum foil as reflector, copper tube with plane glass cover

5) *Case 5* - The setup incorporated rectangular mirror strips as a reflector without a plane glass cover.

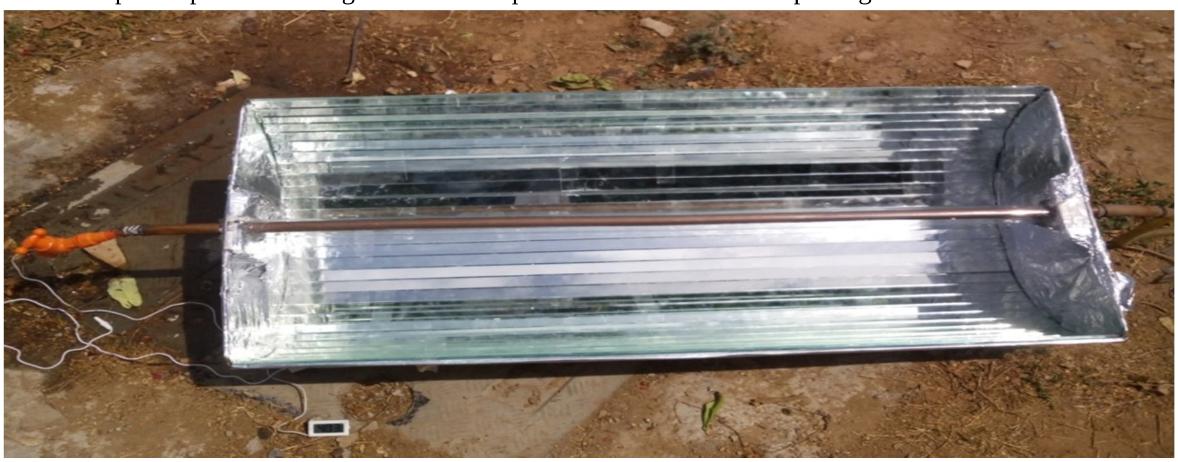

Figure 6 Parabolic trough collector has rectangular mirror strips, copper tube as reflector without plane glass cover

6) *Case 6* - The setup involved rectangular mirror strips as a reflector with a plane glass cover on the trough face.

Figure 7 Parabolic trough collector has rectangular mirror strips, copper tube as reflector with plane glass cover

The parabolic trough collector with rectangular mirror strips, a copper tube as a reflector, and a plane glass cover. These diagrams depict the experimental setup, which includes a stainless-steel parabolic trough, black carbon material foil, copper absorber tube, and a plane transparent glass cover. The experiment was conducted in four phases across these configurations, involving welding, cutting stainless steel sheets, and constructing different absorbent carbon materials. The upcoming section enumerates the components of the system.

VI. EQUIPMENT LIST FOR EXPERIMENTAL SETUPS

1) Stainless steel sheet parabolic trough
2) Black carbon material sheet foil as a single reflector
3) Copper absorber tube
4) Plane glass cover for the trough face
5) Digital thermometer for temperature measurements

VII. PARABOLIC TROUGH

Parabolic Trough The parabolic trough is constructed using stainless steel sheets due to their corrosion resistance, economic viability, and ease of molding into trough shapes. All dimensional specifications are detailed in Table 3.1.

Table 2 Specification of Parabolic trough

Trough sheet	S S Steel
Total area of aperture	0.8 m^2
Width of aperture	2 m
Length of aperture	0.8 m
Thickness of sheet	0.5 mm
Thermal Conductivity	386 W/mK
Focal length	241 mm
Absorber tube diameter	19 mm

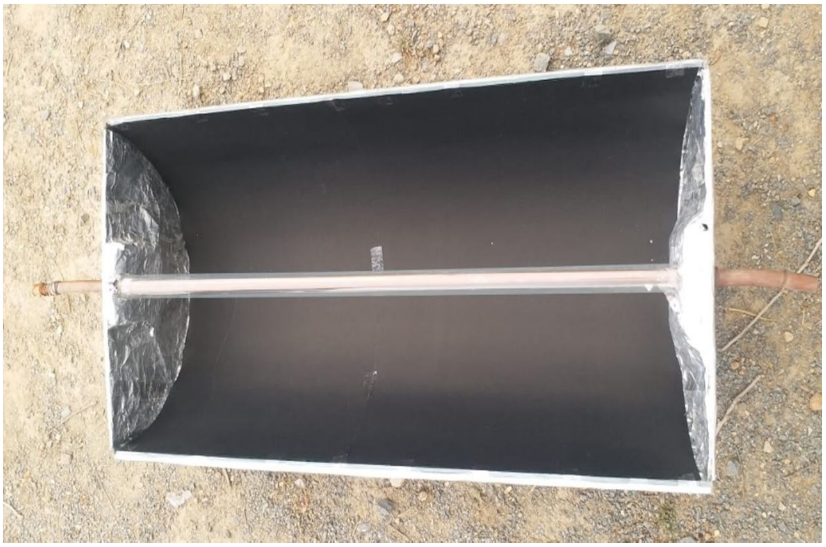

Figure 8 Top view of parabolic trough collector

Figure 9 Side view of parabolic trough collector

Figure 10 Front view of parabolic trough collecto

A. *Reflector*

Reflector Black carbon foil and glass cover are employed as reflectors, with black carbon absorbing 95% of energy and the plain sheet foil reflecting 1%.

B. *Absorber Tube*

Absorber Tube A high thermal conductive material, copper, is chosen for the absorber tube due to its high heat transfer rate. Copper tubes are utilized as absorbers, with detailed specifications outlined in Table 3.2.

Table 3 Specification of absorber tube

Material	Copper
Diameter of tube	20 mm
Thermal conductivity	386 W/m◦c
Emissivity	0.79

Figure 11 Absorber tube

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C. Plane Glass Cover

Plane Glass Cover A rectangular planar clear glass cover, equivalent in dimensions to the trough face, is used to shield the trough face from wind losses, enabling maximal heat transfer to the working fluid through the absorber tube.

D. Thermometer

Thermometer Digital thermometers are utilized to measure inlet and outlet water temperatures in the experiments.

Figure 12 Digital Thermometer

VIII. BASIC TERMINOLOGY USED

1) *Solar Concentration Ratio:* This refers to the quantity of solar light energy concentration obtained by a specific collector, calculated as the ratio of averaged radiant solar flux integrated across the receiver area to the flux incident on the collector aperture. It is directly proportional to reflector quality, with higher concentration ratios enabling higher operating temperatures with reduced thermal loss.
2) *Tilt Angle:* The angle between the focus line of the trough collector and the horizontal.
3) *Rim Angle (Ψ):* The angle subtended by the edges of the reflector at the focus.
4) *Collector Acceptance Angle:* The sensitivity of the solar parabolic trough collector to tracking misalignment.

IX. METHODOLOGY

A. Specification of Experimental Parameters

Table 4 Specification of Parameter	
Mass flow rate (m)	0.12kg/s
Specific heat of water(c_p)	4.21 kj/kg-k
Density of water(ρ)	1000kg/m^3
Inlet temperature(t_i)	26◦c=297k
Beam radiation(H_b)	500W/m^2
Tilt factor(R_B)	0.25
Collector area(A_c)	0.8 m^2
Outer diameter of absorber tube	18 mm
Black carbon foil reflectivity(ρ)	0.97
Mirror sheet reflectivity(ρ)	1
Absorber tube emissivity α	0.78

B. Collector Efficiency

$$\text{Collector efficiency} = \frac{Qu}{[Ac \times Hb \times Rb]} \quad (1)$$

Where
Q_u = heat gain by the fluid (Kw)
A_c = area of collector (m^2)
R_b = beam radiation (W/m^2)
H_b = tilt factor

And,

$$\mathbf{Q_u = mc_p\Delta t}$$

Where,

m= mass flow rate (kg/s)
c_p= specific heat of fluid (kg)
Δt = Temperature difference

C. Experimental Procedure

Growing demand for hot water in domestic, commercial, and industrial sectors has led to the consideration of solar parabolic water heaters as an economical and efficient option. Electric heaters, while available, come with higher costs and safety risks. Our study methodology consisted of four phases:

1) Initial setup alignment to optimize sun angle.
2) Testing different flow rates to determine maximum temperature.
3) Collecting six readings for each setup in one day.
4) Implementing various setups with and without glass covers to gather outlet temperature and ambient temperature data.

Figure 13 Experiment taken for black carbon foil as reflector with and without plane glass cover on face

Figure 14 Experiment taken for black carbon foil with plane glass cover on face

X. OBSERVATIONS

Observations Experiments were conducted in Gwalior (M.P.) at SRCEM College Banmore Gwalior in May 2023. Different reflector materials were utilized, and data was collected with and without plane glass covers on the trough face. Details and observations for each experiment are presented in Table 5.

Table 5 Detail of all Experiments	
Place of Experiment Performed	SRCEM College Banmore, Gwalior (M.P.)
Date of Experiments performed	10/05/2023,12/05/2023,13/05/2023 16/05/2023, 18/05/2023, 19/05/2023
Flow rate	0.12 kg/s
Season	Summer

1) *Experiment No.1*

The experiment was performed at 11:00 am to 4:00 pm, on date 10 May 2023. The configuration of setup was parabolic trough having black carbon material as observe without plane glass cover on trough face was considered. The following observations are obtained,

Table 6 observed data in Experiment no.1

S.N.	Time(Hour)	Ambient Temperature in ◦c(t_a)	Outlet Temperature in ◦c(t_o)	Inlet Temperature in ◦c (t_i)
1	11:00 am	35.9	31.1	26
2	12:00 am	36.2	33.3	26
3	01:00 pm	38.4	38.2	26
4	02:00 pm	39.7	37.1	26
5	03:00 pm	40.2	36.5	26
6	04:00 pm	40.7	35.7	26

2) *Experiment No.2*

The experiment was performed at 11:00 am to 4:00 pm, on date 12 May 2023. The configuration of setup was parabolic trough having black carbon material as observe with plane glass cover on trough face was considered.

Table 7 observed data in experiment no 2

S.N.	Time(Hour)	Ambient Temperature in ◦c(t_a)	Outlet Temperature in ◦c(t_o)	Inlet Temperature in ◦c (t_i)
1	11:00 am	36.1	37.3	26
2	12:00 am	38.9	37.2	26
3	01:00 pm	40.6	40.5	26
4	02:00 pm	40.8	39.2	26
5	03:00 pm	41.1	39.6	26
6	04:00 pm	41.7	37.5	26

3) Experiment No.3

The experiment was performed at 11:00 am to 4:00 pm, on date 13 May 2023. The configuration of setup was parabolic trough having aluminum foil without plane glass cover on trough face was considered.

Table 8 observed data in experiment no 3

S.N.	Time(Hour)	Ambient Temperature in ◦c(t_a)	Outlet Temperature in ◦c(t_o)	Inlet Temperature in ◦c (t_i)
1	11:00 am	37.2	38.2	26
2	12:00 am	38.5	38.7	26
3	01:00 pm	39.3	40.3	26
4	02:00 pm	40.9	40.6	26
5	03:00 pm	41.5	41.4	26
6	04:00 pm	41.9	39.3	26

4) Experiment No.4

The experiment was performed at 11:00 am to 4:00 pm, on date 16 May 2023. The configuration of setup was parabolic trough having mirror protected copper tube and aluminum foil with plane glass cover on trough face was considered.

Table 9 observed data in experiment no 4

S.N.	Time(Hour)	Ambient Temperature in ◦c(t_a)	Outlet Temperature in ◦c(t_o)	Inlet Temperature in ◦c (t_i)
1	11:00 am	38.2	45.4	26
2	12:00 am	39.8	46.7	26
3	01:00 pm	40.7	51.6	26
4	02:00 pm	41.2	47.1	26
5	03:00 pm	41.5	46.5	26
6	04:00 pm	41.8	46.2	26

5) Experiment No.5

The experiment was performed at 11:00 am to 4:00 pm, on date 18 May 2023. The configuration of setup was parabolic trough having mirror protected copper tube and rectangular mirror strips with plane glass cover on trough face was considered

Table 10 observed data in experiment no 5

S.N.	Time(Hour)	Ambient Temperature in ◦c(t_a)	Outlet Temperature in ◦c(t_o)	Inlet Temperature in ◦c (t_i)
1	11:00 am	39.3	45.7	26
2	12:00 am	39.8	47.4	26
3	01:00 pm	40.9	51.3	26
4	02:00 pm	41.7	51.7	26
5	03:00 pm	43.3	48.4	26
6	04:00 pm	44.4	46.5	26

6) Experiment No.6

The experiment was performed at 11:00 am to 4:00 pm, on date 19 May 2023. The configuration of setup was parabolic trough having mirror protected copper tube and rectangular mirror strips with plane glass cover on trough face was considered.

Observed data in experiment no 6				
S.N.	Time(Hour)	Ambient Temperature in ◦c(t_a)	Outlet Temperature in ◦c(t_o)	Inlet Temperature in ◦c (t_i)
1	11:00 am	41.3	47.1	26
2	12:00 am	42.8	48.5	26
3	01:00 pm	45.7	51.2	26
4	02:00 pm	47.3	51.9	26
5	03:00 pm	47.9	49.4	26
6	04:00 pm	47.3	48.6	26

XI. CONCLUSION

1) The highest working fluid outlet temperature, reaching 51.9°C, was achieved in the fourth experiment. This specific setup employed a mirror as a reflector and featured a plane glass cover over the trough face. Notably, this temperature is twice the inlet water temperature, which was 26°C. Correspondingly, the first, second, and third arrangements yielded maximum temperatures of 40.6°C, 50.4°C, and 51.7°C, respectively, around 2.00 p.m.
2) The greatest efficiency was observed in the second experiment, utilizing aluminum foil as a reflector with a plane glass cover, registering an efficiency of 52.03%. This marked a 68.70% improvement compared to the first experiment's maximum efficiency, which used aluminum as a reflector without a plane glass cover.
3) The third experiment, employing mirror strips as a reflector without a plane glass cover, demonstrated an efficiency of 77.80%, indicating a 15% increase over the second experiment's trough efficiency.
4) Ultimately, the fourth experiment achieved the highest efficiency of approximately 13.287%. This experiment employed mirror strips as a reflector with a plane glass cover and outperformed the third experiment's efficiency by about 42%. Remarkably, this fourth experiment's efficiency was about 82% higher than that of the first experiment. Given these outcomes, we conclude that, for troughs of the same specifications, the most efficient and cost-effective configuration involves using a mirror as a reflector along with a glass cover on the trough face.

XII. FUTURE SCOPE

1) Exploring the use of air as the working fluid, which could serve winter home heating and grain drying purposes.
2) Investigating the application of a single highly reflective mirror sheet for enhanced reflection, as opposed to mirror fragments.
3) Exploring the feasibility of using nickel coating as an alternative reflector material.
4) Experimenting with solar cells to generate electricity instead of utilizing the absorber tube, potentially storing energy in a battery. Enhancing heat absorption through Teflon or black paint coating on the absorber pipe could also be explored.
5) Incorporating automated sun tracking with LEDs into the collector's support structure.
6) Considering absorber tube coiling to further enhance efficiency.
7) Evaluating more efficient absorber materials to replace the copper tube.
8) Factoring in wind losses and efficiency calculations by employing a glass cover, which would account for real-world conditions.
9) Scaling up the trough size to impact its effectiveness and potentially integrating it into larger areas such as building roofs.

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